GMG Market Assessment Methodology

Green Mini-Grids Market Development Program

SEforALL Africa Hub

African Development Bank

Part 1: Evaluation of Methodologies and Best Practices Available to assess GMG Potential

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Prepared by

PREFACE

This paper, and subsequent papers in the Green Mini-Grid Market Development Programme (GMG MDP) document series, is a market assessment for green mini-grids for rural electrification in Mozambique. These are mini-grids powered by renewable energy resources – solar radiation, wind, hydropower or biomass – either exclusively or in combination with diesel generation.

Mini-grids are not a new phenomenon in Africa. Almost all national utilities own and operate diesel-powered generating facilities not connected to the main grid, which supply electricity to secondary towns and larger villages. This solution to rural electrification inevitably results in significant financial losses for the utility, as it is required to sell power at prices much below the cost of production and delivery. Moreover, it leaves the most remote towns and villages unelectrified. The latest Sustainable Energy for All (SE4ALL) Global Tracking Framework estimates that the urban-rural divide in access to electricity in Africa is as high as 450 percent (69 urban compared to 15 percent rural access).

There are three principal options for providing new connections to currently unserved populations in Africa, namely i) extension of the national grid, ii) installation of separate "mini" grids to operate independently from the main grid, and iii) stand-alone generating systems that supply individual consumers. The most cost-effective approach for powering mini-grids is to use renewable energy sources, which are widely available across Africa. However, the development of GMGs is not without challenges. Barriers to the growth of private sector mini-grids in Africa include gaps in the policy and regulatory framework, the lack of proven business models, the lack of market data and linkages, the lack of capacity of key stakeholders, and the lack of access to finance.

In response to these challenges, the SE4ALL Africa Hub at the African Development Bank (AfDB)[1] designed and launched Phase 1 of the GMG MDP in 2015, with grant funding from the AfDB's Sustainable Energy Fund for Africa (SEFA). The GMG MDP is a pan-African platform that addresses the technical, policy, financial and market barriers confronting the emerging GMG sector. It is part of a larger DFID-funded GMG Africa Programme, which also includes GMG initiatives in Kenya and Tanzania; country-specific GMG policy development through SEFA; and an Action Learning and Exchange component being implemented by the Energy Sector Management Assistance Program (ESMAP) at the World Bank.

The International Energy Agency (IEA) has predicted (in *Africa Energy Outlook 2014*) that by 2040, 70 percent of new rural electricity supply in Africa will be from stand-alone systems and mini-grids. The GMG MDP, SE4ALL, SEFA, ESMAP and similar programmes, which are contributing to falling costs, technological advancements and more efficiencies in GMG development, will help to ensure that up to two thirds of this supply will be powered by renewables.

The goals of the green mini-grids programme, in all its aspects, are central to AfDB's mission of spurring sustainable economic development, social progress and poverty reduction in its regional member countries (RMCs). Indeed, off-grid and mini-grid solutions are a key component of the AfDB's New Deal on Energy for Africa, launched by the Bank's president in January 2016. The New Deal is a transformative, partnership-driven effort with an aspirational goal of achieving universal access to energy in Africa by 2025.

This report was prepared by the Carbon Trust, UNEP and ECREEE at the request of the AfDB. It was written by Marco Sampablo and Luke Walley of the Carbon Trust and Dean Cooper and Eugene Ochieng of UNEP. The Carbon Trust is a mission-driven organization helping businesses, governments and the public sector to accelerate the move to a low carbon economy. The United Nations Environment Programme (UNEP) is a leading global environmental authority.

The content of this report was reviewed by Jeff Felten of the AfDB's GMG team and cleared by Dr. Daniel-Alexander Schroth, SE4All Africa Hub Coordinator at the AfDB. The report was edited by Kimberlee Brown.

1 The SE4All Africa Hub partnership includes the African Union Commission, the New Partnership for Africa's Development (NEPAD), the United Nations Development Programme (UNDP), and the Regional Economic Communities (RECs), which are represented on a rotating basis. http://www.se4all-africa.org

List of Acronyms

ADB	Asian Development Bank
ATP	Ability to Pay
BNEF	Bloomberg News Energy Finance
CDM	Clean Development Mechanism
CEIMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnologicas
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
ESG	Environmental, Social and Governance Database
EUEI	European Union Energy Initiative
EU-JRC	European Union Joint Research Centre
FAO	Food and Agriculture Organisation
GHG	Greenhouse Gases
GIS	geographic information system
GRI	Global Reporting Initiative
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IRRI	International Rice Research Institute
JAFTA	Japan Forest Technology Association
JICA	Japan International Cooperation Agency
LCOE	Levelised Cost of Electricity
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)
MDP	Market Development Program
NIS	Network Information Service
NREL	National Renewable Energy Laboratory
PAGE	Potential Area of Grid Extension
REE	Red Electrica de Espana
SDG	Sustainable Development Goal
SEFA	Sustainable Energy Fund for Africa
SE4ALL	Sustainable Energy for All
SHS	Solar Home System
UN-DESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
WEO	World Economic Outlook

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EXECUTIVE SUMMARY

The African Development Bank has engaged the services of the Carbon Trust, UNEP and ECREEE to assess the potential for green mini-grids in five African countries. The engagement requirements included the definition of a methodology to assess the potential for green mini-grids, with that methodology to be subsequently used to produce reports analysing the mini-grid potential in the five countries. Those reports will focus on the physical potential for green mini-grids in each country, and provide important information to local policymakers and to potential local and international investors in the Green Mini-Grid sector.

The first phase of the engagement, covered by this report, consisted of the identification and analysis of existing tools and/or research methodologies being used to evaluate, promote and support RE in Africa. The need to promote and support RE has gained significant attention over the last decade, and has resulted in the development of multiple tools by a wide range of actors, including governments, development institutions, research centres and corporations.

To identify and assess these tools, this report relies on experts' knowledge, interviews with policymakers and investors, reviews of academic journals, and other desk-based research:

- ***Expert knowledge.*** The Carbon Trust, UNEP and ECREEE and the experts working on this assignment have considerable experience in promoting and assessing renewable energies and electrification globally, especially in developing regions. UNEP, for instance, has developed the SWERA (Solar and Wind Energy Resource Assessment) initiative, while supporting mini-grid development in Africa as a senior partner of the Sustainable Energy for All (SE4ALL) initiative. ECREEE has developed the ECOWREX (ECOWAS Observatory for Renewable Energy and Energy Efficiency) platform to map renewable energy resources, projects and stakeholders, while continuing to drive data collection in the ECOWAS region. Through our professional network of experts, we have identified several existing tools and methodologies.
- ***Literature review and desk-based research.*** An extensive review of academic journals and other knowledge was conducted through ProQuest, Google Scholar, and other sources, to identify a broad number of tools that had been applied in Africa and other parts of the world.

The analysis identified a number of important tools that are currently being used to promote RE in Africa. Many are *decision-support tools*, developed by different stakeholders that are useful for practitioners during the planning and implementation of mini-grid projects. These include tools for resource assessment, technical design and analysis, and financial modelling. Other tools are, strictly speaking, not tools but methodologies, as they involve conducting opportunity assessments and other analytical work aimed at answering the question, "*Given the current conditions, how much of the prospective electrification can rely on off-grid solutions, notably green mini grids?*"

This paper focuses on these opportunity assessment methodologies, since they are more directly relevant than the decision-support tools for assessing the potential for green mini-grids. The analysis identified a total of twelve methodologies that are being used to promote RE, and classifies them into three broad groups (Table 1). The first two types are based on some type of geographic information system (GIS), which is used to conduct spatial analysis to estimate the cost of electrification through alternative solutions; i.e., grid extension, mini-grid and individual home systems. Ten of the twelve methodologies are based on GIS. The two methodologies in the third category are not based on GIS.

GIS-based methodologies are either supply-led or demand-led:

- **Supply-led methodologies** assess the suitability of mini-grids through a direct measure of the techno-economic competitiveness of each option, usually based on the levelised cost of energy for each technology. Examples include those developed by the EC Joint Research Commission and the KTH Royal Institute of Technology in Stockholm. The latter was utilised in the newly published UN-DESA electricity access tool.
- **Demand-led methodologies** focus on the level of energy consumption required by each settlement, taking into account the needs of service facilities such as hospitals and schools to prioritise settlements for electrification. Examples include those developed by Innovation Energie Developpement and applied to numerous African countries; and by the Japan International Cooperation Agency and applied in Cambodia.

Non-GIS based methodologies rank countries based on their suitability for renewable energies and for rural and off-grid electrification. Such methodologies have been developed by BNEF, with funding from DFID and USAID; and by the Reiner Lemoine Institute of Germany. The objective of the BNEF methodology is to compare the status of energy potential and country policies in order to promote the adoption of global best practices. The objective of the Reiner methodology is to conduct a preliminary filtering of countries to identify priority countries on which to focus its research.

Table ES1. List of methodologies examined

	Name	Author(s)
GIS supported, supply-led methodologies		
A	GIS-based cost comparison of solar PV, mini-hydro, diesel and grid extension for Africa	EC Joint Research Commission, Szabo S. et al.
B	GIS-based comparison of solar, wind, domestic and centralised diesel and grid extension in the municipality of Lorca, Spain	Centre for Energy, Environment and Technology and Polytechnic University of Madrid, J. Amador, J. Dominguez
C	GIS-based lowest cost assessment of solar, wind, mini-hydro, biogas and diesel technologies against grid extension, considering large mineral industry demand	KTH Royal Institute of Technology, D. Mentis, F. F. Nerini et al.
D	GIS-based planning tool using the Network Planner tool	Columbia University, Nkrumah University of Science and Technology, Kumasi Energy Centre. F. Kemausuor et al.
E	GIS-based comparison of solar, wind and grid extension for Vietnam	Hanoi Institute of Energy, K. Q. Nguyen
F	ECOWREX Mapping Tool and IntiGIS Planning Tool	ECOWAS Observatory for Renewable Energy and Energy Efficiency, CIEMAT
GIS supported, demand-led methodologies		
G	GIS-based integrated rural electrification planning considering grid extension, small hydro and biomass	Innovation Energie Developpement (IED)
H	The Master Plan Study on Rural Electrification by Renewable Energy in the Kingdom of Cambodia	Japan International Cooperation Agency
GIS supported, demand-led, grid-extension focused methodologies		
K	GIS-based, Demand-Led Rural Electricity Planning Tool for Uganda	IT Power, E. Kaijuka
L	GIS-based Electrification Planning Decision Support Tool for South Africa	Rural Area Power Solutions et al., D. I. Banks et al.

	Name	Author(s)
Non-GIS methodologies		
I	ClimateScope - Global Clean Energy Country Competitiveness Index	Multilateral Investment Fund, UK Department for International Development, Power Africa and Bloomberg New Energy Finance
J	Global Country Ranking Based on Suitability for Rural Electrification	Reiner Lemoine Institut gGmbH, Ann-Katrin Gerlach et al.

The analysis considered a range of input parameters to identify the common factors utilised by most methodologies. These parameters were categorised into five groups: Renewable, Network and Energy, Demographic, Policy/Political and Financial/ Economic.

- **For renewable energy data,** solar irradiation was most commonly used, owing to the accuracy and abundance of global satellite data. Wind speed was utilised by five methodologies, through satellite data or existing studies such as SWERA[2]. Only two methodologies used river flow rates to estimate mini-hydro potential; one was very high level (that is to say that it did not measure hydro resources at specific sites) and the other was only possible through a two-year field study as part of the development of an electrification master plan. Biomass was considered by five methodologies, but the identification of potential was limited.
- **For network and energy data,** there was limited availability of actionable data, and many methodologies relied on out-of-date sources such as the Africa Infrastructure Knowledge Program[3] (AfDB, 2011) and its predecessor, the Africa Infrastructure Country Diagnostic[4] (World Bank, 2008).
- **Policy/political and financial/economic factors—**i.e., non-physical factors—were used primarily by the non-GIS methodologies to rank countries on suitability for RE and mini-grid development. However, two supply-led GIS methodologies also used interest and inflation rates in the projection of scenarios over project periods.

The analysis found no real convergence on the approaches of these opportunity assessment methodologies. A wide variation was found in the approach and quality of the methodologies examined, with different approaches and considerations being trialled or demonstrated. For example, four main methods were used to mitigate the key issue of data paucity: (a) designing the methodology around available data sources; (b) using older data sources; (c) estimating or extrapolating data from other countries/studies or theoretical values; and (d) stakeholder consultations. Most common was to use approximate values such as cost estimates, sometimes utilising stakeholder consultations; or to use old data for datasets; or to design around these sources (i.e. conduct the assessment without the particular data). Another method, utilised by the Hanoi Institute of Energy, was to use missing grid infrastructure and population data parameters as variables. The levelised costs of energy of the different electrification options were then shown over a selected range of population density and distance to the grid values. This allowed the costs to be found despite the lack of data, although the missing spatial inputs meant that the mapping of the output was not possible.

The second deliverable of this project is the "creation or choice of an opportunity assessment methodology in order to generate comparable data across countries". The second phase will build heavily on the findings of this report. The analysis indicates that there is clear scope for combining various aspects of the methodologies examined to develop a template methodology that can be used to assess the potential of mini-grids in rural areas across Africa.

2 The Solar and Wind Assessment Tool developed by UNEP, hosted on OpenEI and maintained by NRE.

3 http://infrastructureafrica.opendataforafrica.org/

4 http://data.worldbank.org/data-catalog/africa-infrastructure

1. INTRODUCTION TO THE GREEN MINI GRID MARKET DEVELOPMENT PROGRAMME

1.1 PROJECT CONTEXT

The African Development Bank's Green Mini-Grids Market Development Programme (GMG MDP) aims to foster access to electricity across Africa by promoting the development of green mini-grids (GMGs) where they are technically and economically a better option than extension of the main grid.

To assess the potential for green mini-grids in five African countries, the Bank has engaged the services of the Carbon Trust, UNEP and ECREEE to (a) develop, based on best practices, a methodology to assess the physical potential for GMGs at the country level that can be applied across Africa; and (b) apply the methodology in five pilot countries, leading to the production of five country-level reports analysing the physical potential for green mini-grids in each country. The analytical work and pilots focus only on the physical potential for GMGs, and exclude other factors such as the regulatory and financial environments, which are equally important in determining the ultimate feasibility of mini-grids.

The immediate beneficiary of these market assessments will be the African Development Bank, which will have a tool to assess GMG potential across Africa, and allow it to compare and prioritize countries and interventions in this sector across the continent. In addition, the project will provide national governments and utilities with an enhanced methodology to assess the potential for mini-grid technologies in their countries, and inform their planning process and electrification strategies. The project will also benefit project developers and investors by providing them with relevant information on energy supply potential and consumption centres and markets. In the long term, the project will benefit the peoples of Africa, who will gain access to electricity—and the associated health, education and productivity benefits—through the development of green mini-grids.

This report constitutes the first deliverable of the project. It identifies and evaluates the methodologies currently being used to make rural electrification planning decisions. An understanding of these methodologies will allow the full contextualisation of the project, and facilitate the establishment of a best-practice, Africa-centric methodology.

1.2 GMG AND AFRICA CONTEXT

The Sustainable Development Goals mandate universal access to affordable, reliable and modern energy services by 2030 (SDG 7). However, around 600 million people in Africa do not have access to electricity (International Energy Agency estimate for 2011), and without a significant increase in investment, this number is expected to increase to almost 650 million by 2030. Connection to mini-grids is likely to be the most effective option for up to 40 percent of those people currently without any connection (World Economic Outlook, 2011).[5]

The electrification of isolated communities can have broad impacts on quality of life, bringing widespread social benefits and opportunities for economic development. Lighting can bring health, education and safety benefits, allowing people to study at night, reducing complications from childbirth at home in the dark, and illuminating public spaces and paths in the community. TV allows access to information as well as entertainment after work, often helping to reduce crime in rural areas (since potential criminals are otherwise occupied).

Moreover, the electrification of rural households usually reduces the indoor burning of kerosene and wood, which can cause respiratory disease. The World Bank has shown that the positive impact of greater renewable energy use on indoor air quality, health, knowledge, and fertility reduction is quantifiable and significant. Off-grid renewable energy solutions have demonstrable environmental benefits and can have a long-term advantage for home businesses.

5 World Energy Outlook 2011, Organisation for Economic Co-operation and Development (OECD) / International Energy Agency (IEA), 2011

Due to these benefits, the willingness of potential customers in isolated areas to pay for access to electricity is usually high, allowing financiers to charge rates that can provide a return on investment, even if these tariffs are above those levied by the national grid.

These benefits from rural electrification (RE) show that efforts to determine appropriate opportunities are well placed. There is a clear demand from currently unserved communities. The challenge for policymakers, service providers and potential financiers is to identify which electrification option will be most effective in each location; and determine which methodology should be used to assess the full potential of the local resources available.

1.3 RURAL ELECTRIFICATION PLANNING

African countries understand the importance of access to electricity in rural areas, and are putting together action plans for rural electrification. Many countries have set their own ambitious targets, alongside the SDG 7 and Sustainable Energy for All (SE4ALL) targets of 100 percent electrification by 2030. The 15 Member States of ECOWAS, for instance, adopted the ECOWAS Renewable Energy Policy in July 2013, which includes the following targets:

- Installation of 60,000 mini-grids between 2014 and 2020, for a total capacity of 3,600 MW, in order to serve 71.4 million people (total investment of €13.2 billion over six years).
- Distribution of 2.6 million stand-alone appliances by 2020, in order to serve 21 million people (total investment of €390 million over six years).

Yet despite these polices and targets, the high costs of RE and the lack of National and state-level planning and support have left hundreds of thousands of communities unelectrified. To address these challenges, some countries are developing rural electrification visions and master plans. Countries such as Kenya, Senegal and Mali have also created dedicated rural electrification agencies and regulators, and are introducing tax relief, tariffs and incentive schemes relating to decentralised energy.

1.4 ELECTRIFICATION OPTIONS

Provision of the most cost-effective supply of electricity to remote areas depends on a comparative assessment of the three main electricity supply options: extension of the national grid, mini-grids, and stand-alone systems. Each has its advantages, depending on local conditions. The best option will depend on the needs of the customers to be connected. The potential market demand must be a key driver in determining the means of electrification.

One of the most significant factors is affordability—will the tariffs charged match the disposable income of the customers? Another factor is the quality of service required; for a currently unelectrified community, a constant 24/7 supply may not be essential. The likely demand for power, at the time of connection and in the future, will depend on the type of consumers—will the connections go only to households, or will there be larger demand from schools, hospitals, government buildings or commercial activities? Another critical factor is the distribution of the population. Grid extension and mini-grids both require a concentration of users to justify the structural network costs. Dedicated infrastructure is unlikely to be the best alternative for remote, low-demand individual users in remote areas.

Selecting the most appropriate electrification option should not, however, be limited to a purely economic assessment. The significant social benefits associated with energy access make it a basic public service, even a public good; and this can justify tariff and connection subsidies to make this access affordable. The availability of public funding, whether through government or international donors, is therefore another factor in determining the most appropriate electrification option for remote areas.

In addition to the economic and social costs and benefits, electrification will also depend on the policy environment that governs the operation of electricity providers, from the national utility to mini-grid operators. The ability of suppliers to charge cost-reflective tariffs, and the potential impact of any incentives or regulatory restrictions, must be given careful consideration.

GRID EXTENSION

Extending the national grid involves increasing the coverage of the existing electricity network to supply currently unelectrified settlements. Grid extension can be categorised into the two components: transmission and distribution.

- **Transmission refers to long-distance, high-voltage lines** that carry electricity from large centralised power stations to a significant population centre or commercial operation. The high-voltage lines go to local transformer stations, where the voltage is lowered and then carried by a distribution network to end-users.
- **Grid extension to rural populations is usually focused on distribution network extensions,** involving medium-voltage lines. These are very expensive to construct and operate, and will normally be economically viable only if there is constant and high demand.

Areas with low population density or low demand will most likely be best served by a mini-grid or stand-alone systems. Geographic factors affecting the technical feasibility of extending the grid may also cause a reliance on non-grid solutions for rural populations.

MINI-GRIDS

A mini-grid is a relatively small, decentralised grid built to supply a group of end-users in a remote or isolated location (such an island or mountain community). Mini-grids can have a capacity ranging from a few kW to several MW, although there is currently no universally recognised definition of scale for a mini-grid. Smaller applications (less than about 10kW) are generally referred to as micro- or pico-grids.

Mini-grids can be built using renewable energy sources (hydro, solar, biomass, geothermal or wind), or diesel generators, or be a hybrid of these options. For grids without diesel generators, a battery system will typically be included to store energy for times when the renewable energy source (typically solar) is not available. However, batteries increase the cost of a mini-grid significantly, so the need for them must be weighed against their affordability for the target customers. The design of a mini-grid can vary considerably, depending on the sources of energy available and the level of demand.

Mini-grids can provide a supply of electricity to remote communities that allows the operation of most household appliances, and can offer sufficient capacity to power small companies, thereby enabling the growth of productive activity. The operation of a mini-grid usually involves support services such as maintenance and customer account management, which can create local jobs. There may also be health, education and safety benefits from electricity supplied to hospitals (including vaccine refrigeration), to schools (including computers), and for lighting public areas and roads.

There are, however, several barriers to the wider installation of mini-grids. The supply may not be as stable as that of the national grid, with more frequent power outages or surges that can damage appliances. In addition, there is a high initial capital cost, and potential developers may have difficultly accessing credit from regular banks. The lack of early finance and associated long-term repayment arrangements are often key concerns that prevent investors from supporting the take-up of mini-grids in Africa. Some institutions, such as the UN and the EU recognize the importance of this issue and have established grant programs to cover most or all of the initial investment cost.

Another barrier is that in most African countries, there is a commitment to the expansion of the national grid. This raises the question for potential investors and operators of what will happen if/when the main grid arrives. The connection of mini-grids to the national grid may be possible, through arrangements that, for example, allow the sale of additional generation using feed-in-tariffs already established for the main grid, or supplementing generation shortfalls when required. However, such a combined grid can bring new economic and contractual challenges. The Government of Cape Verde is currently discussing this issue, as the national grid has reached a settlement powered by a solar

mini-grid. It will be interesting to see how this potential conflict is resolved, and how other African countries can learn from the experience. The possibility of future connection to the national grid should be a priority consideration for the development of mini-grids in areas that are likely to be connected to the national grid in the foreseeable future.

STAND-ALONE SYSTEMS

Although definitions vary slightly, stand-alone systems usually refer to the localised use of a generation source for a single building or a small group of buildings. Examples of stand-alone applications include a PV system installed on the roof of a building, a diesel generator, or a pico-hydro turbine fed from a diverted stream flow. These are usually installed at the end-user's premises and so incur no network or distribution costs. There is also great value from the direct ownership of a stand-alone system, since the customer pays for the system directly and has responsibility for its operation and maintenance.

A key limitation of stand-alone systems is their low capacity, which allows for only limited use of household appliances and little scope for any commercial or productive use. The lack of a service provider also means that customers may be unaware of the system's operation/ maintenance requirements or the best way to use of the system to limit degradation (particularly of battery life, if battery is included). Another barrier for such stand-alone systems is the capital cost, which is typically borne in full by the user as an upfront purchase. There may be some local credit arrangements available from local vendors, but these are usually associated with very high interest rates, which undermine the cost-effectiveness of the system. Some grants are also available to lessen the initial cost barrier.

Despite these barriers and limitations, the immediacy of the benefits from electricity access makes this approach attractive in Africa. Consumer awareness of the benefits of such systems is increasing as greater numbers come into operation, many with the support of international donor programmes. Particularly for areas with very low consumer densities where any type of grid system will not be affordable, stand-alone systems are the best electrification alternative.

2. METHODOLOGIES

2.1 IDENTIFICATION OF METHODOLOGIES

A wide range of methodologies and planning tools have been developed for various aspects of electrification and green mini-grids. This report is concerned only with those methodologies that assess the *opportunity for mini-grid development,* and are available and applicable in an African context.

Methodology is defined in the report as a process through which an opportunity assessment of the potential for mini-grids is carried out. Methodologies are to be distinguished from "tools", which address other aspects of electrification planning such as mapping, system design and optimisation, and financial support tools. A methodology may consist of several pieces of work or reports, providing the underlying framework is the same.

The 12 methodologies selected for the analysis are shown in Table 1 and discussed in the following section. Each represents a different approach to identifying mini-grid opportunities, and provides useful insights for the development of template methodology. These methodologies were identified from 23 individual projects or reports, and were selected for their relevance and contrast.

Table 2: Summary of Methodologies Examined

	Name	Author(s)	Rationale
A	GIS-based cost comparison of solar PV, mini-hydro, diesel and grid extension for Africa	EC Joint Research Commission, Szabo S. et al.	Developed to identify the potential of different renewable options using remote input data
B	GIS-based comparison of solar, wind, domestic and centralised diesel and grid extension in the municipality of Lorca, Spain	Centre for Energy, Environment and Technology and Polytechnic University of Madrid, J. Amador, J. Dominguez	Developed to validate the use of GIS to identify the appropriate conventional or renewable technologies for electrification
C	GIS-based lowest cost assessment of solar, wind, mini-hydro, biogas and diesel technologies against grid extension, considering large mineral industry demand	KTH Royal Institute of Technology, D. Mentis, F. F. Nerini et al.	Developed to address the perceived need for a standardised framework toolkit
D	GIS-based planning tool using the Network Planner tool	Columbia University, Nkrumah University of Science and Technology, Kumasi Energy Centre. F. Kemausuor et al.	Developed to validate the Network Planner Tool for the electrification of communities in Ghana
E	GIS-based comparison of solar, wind and grid extension for Vietnam	Hanoi Institute of Energy, K. Q. Nguyen	An initial examination of the economic viability of alternatives to grid extension in rural communities.
F	ECOWREX Mapping Tool and IntiGIS Planning Tool	ECOWAS Observatory for Renewable Energy and Energy Efficiency, CIEMAT	Developed to provide accurate knowledge on existing and planned resources and renewable activities in the ECOWAS region

	Name	Author(s)	Rationale
G	GIS-based integrated rural electrification planning considering grid extension, small hydro and biomass	Innovation Energie Developpement (IED)	Part of the development of an Electrification Master Plan for Tanzania, utilising IED-developed integrated planning tools
H	The Master Plan Study on Rural Electrification by Renewable Energy in the Kingdom of Cambodia	Japan International Cooperation Agency	Part of the development of an Electrification Master Plan for Cambodia
I	ClimateScope - Global Clean Energy Country Competitiveness Index	Multilateral Investment Fund, UK Department for International Development, Power Africa and Bloomberg New Energy Finance	Measuring the strength of the renewable energy investment, policy development and generation instalment of 55 countries globally, as well as the strength of the enabling environment for renewable development
J	Global Country Ranking Based on Suitability for Rural Electrification	Reiner Lemoine Institut gGmbH, Ann-Katrin Gerlach et al.	Gives an indication of countries' applicability for the development of renewable mini-grids to aid the development of sustainable business models in these countries
K	GIS-based, Demand-Led Rural Electricity Planning Tool for Uganda	IT Power, E. Kaijuka	Aiming to stimulate rural development in Uganda, providing a simple framework for prioritisation of electrification of communities
L	GIS-based Electrification Planning Decision Support Tool for South Africa	Rural Area Power Solutions et al., D. I. Banks et al.	To aid the development of off-grid planning for more remote communities currently out of the focus of the national utility, ESKOM.

2.2 METHODOLOGY TYPES

The advance of spatial mapping has meant that, over the last two decades, a large number of such methodologies have utilised geographical information system (GIS) datasets at the input, calculation and output stages. This allows for relatively simple yet detailed design and mapping solutions, as well as for hosting of such maps on online platforms. GIS is used in 10 of the methodologies, and the remaining 2 are based on approaches that do not include GIS.

GIS-BASED

For GIS-based methodologies, a key distinction is made between demand-and supply-led approaches. Supply-led approaches assess the suitability of mini-grids through a measure of the techno-economic competitiveness of each option, usually based on the levelised cost of energy for each technology. This produces a least-cost solution, which can be a useful headline measure, but which can lack robustness, since there is little or no consideration given to the demand side. For example, a remote settlement may be assessed as most suitable for stand-alone systems based on population density, but the presence of strong road infrastructure and a local hospital may mean that the electricity demand will far exceed such a low-capacity system. These additional factors are critical and may not be accounted for in a least-cost solution.

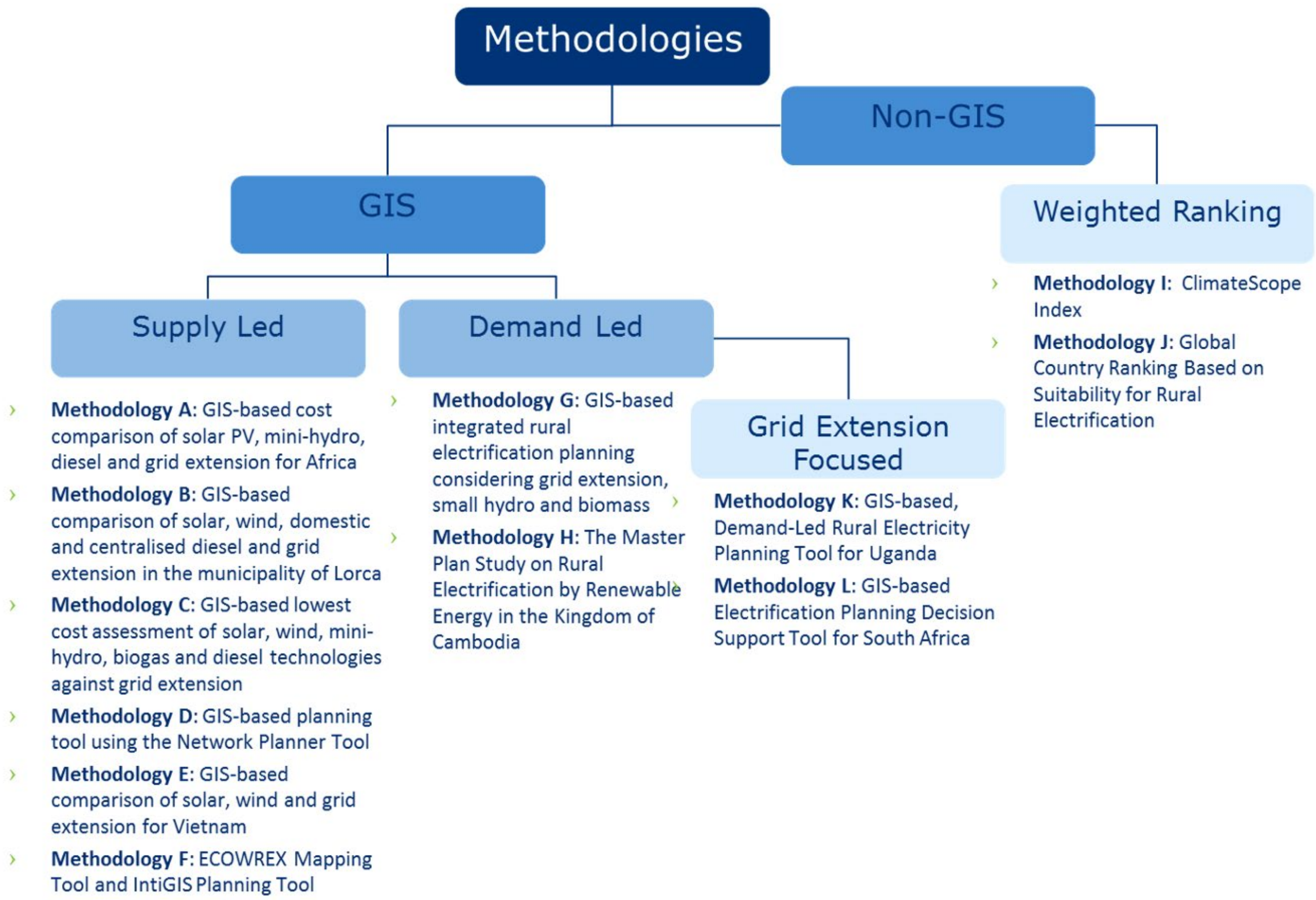
Demand-led approaches try to address this concern by focusing first on the level of energy consumption required by each settlement, taking into account the needs of service facilities such as hospitals or schools to identify priority settlements to target for electrification. This approach leads to a valid case for grid extension to these settlements to ensure that enough capacity is available. Settlements that remain non-electrified under this grid plan are then allocated stand-alone or mini-grid solutions, depending on resource availability and other factors. This approach can result in bias towards grid extension over decentralised renewable energy systems, as well as increasing the cost of the overall project. Remote settlements may also be grid connected, but only after a very long period involving multiple stages of infrastructure construction, whereas stand-alone systems could provide quick access to basic energy needs.

Included are two GIS-based methodologies that do not give consideration to renewable resource availability, and focus almost entirely on grid extension. These have been considered because of their relevance and potential for integration into a broader methodology. These grid-extension focused methodologies are included in Figure 1, along with the other categories and their associated methodologies.

NON-GIS BASED

Although the majority of methodologies fall into the GIS category, another approach is to create a weighted ranking, using a variety of indicators to determine the countries or regions that are most suitable for renewable-based rural electrification. The two examples studied in this report are the influential Climatescope Global Competitiveness Index run by Bloomberg New Energy Finance (BNEF), and the Global Country Ranking Based on Suitability for Rural Electrification, by Ann-Katrin Gerlach of the Reiner Lemoine Institute. These methodologies vary vastly in scope and scale, and the Climatescope index also considers a host of non-physical indicators. These two approaches have extensive outreach and therefore are familiar to a wide range of stakeholders. For this reason, they have been given specific attention in the methodologies reviewed.

Figure 1: Diagram of methodologies by type



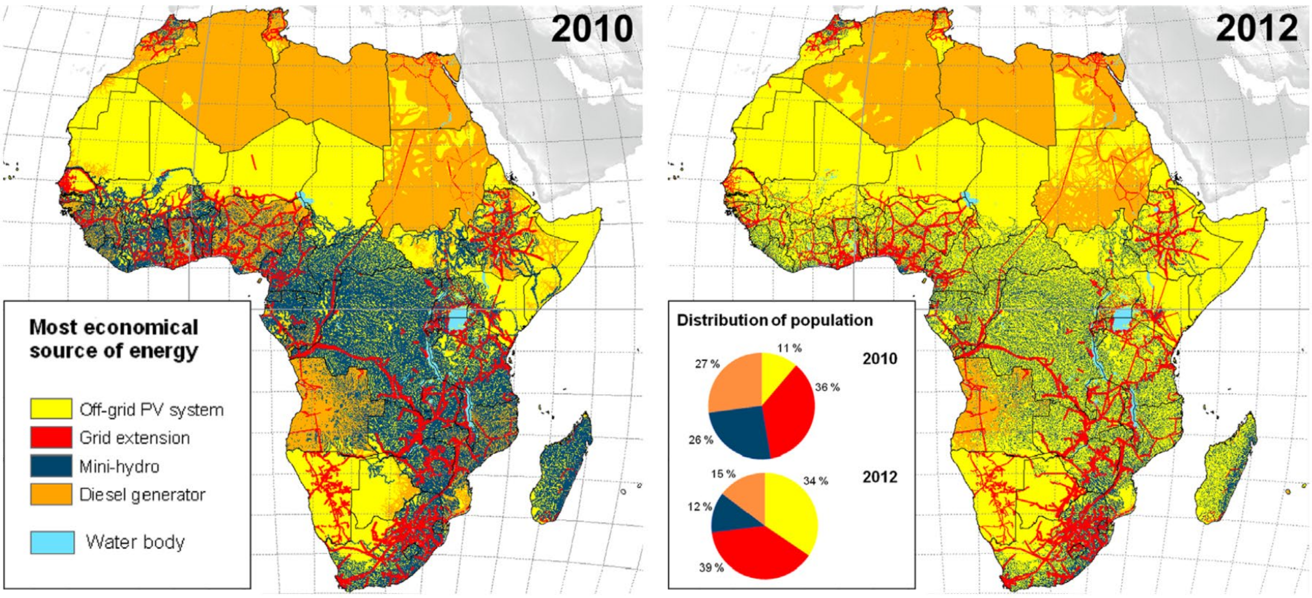
2.3 METHODOLOGY SUMMARIES

METHODOLOGY A: GIS-BASED COST COMPARISON OF SOLAR PV, MINI-HYDRO, DIESEL AND GRID EXTENSION FOR AFRICA (EC JOINT RESEARCH COMMISSION, SZABO S. ET AL.)

This methodology was developed by the Joint Research Commission in a series of analyses, from 2011 to 2013, to identify the potential of different renewable options. Of specific consideration was the variance in diesel costs between rural and urban communities, and circumnavigating the lack of comprehensive country-level data.

Methodology A compares the levelised costs of solar PV, mini-hydro and diesel generation, with grid extension considered viable within a fixed distance of the existing grid network. Later studies for the same project incorporated fixed grid extension costs and the assessment of mini-hydro potential. The cost estimates are considered against two ability-to-pay (ATP) scenarios, and spatial mapping is used to show differently coloured regions across Africa where each option is the lowest-cost solution (or where no options are viable within the ATP scenario). This is combined with a population density map to indicate the percentage of the population best served by each electrification solution (Figures 2 and 3).

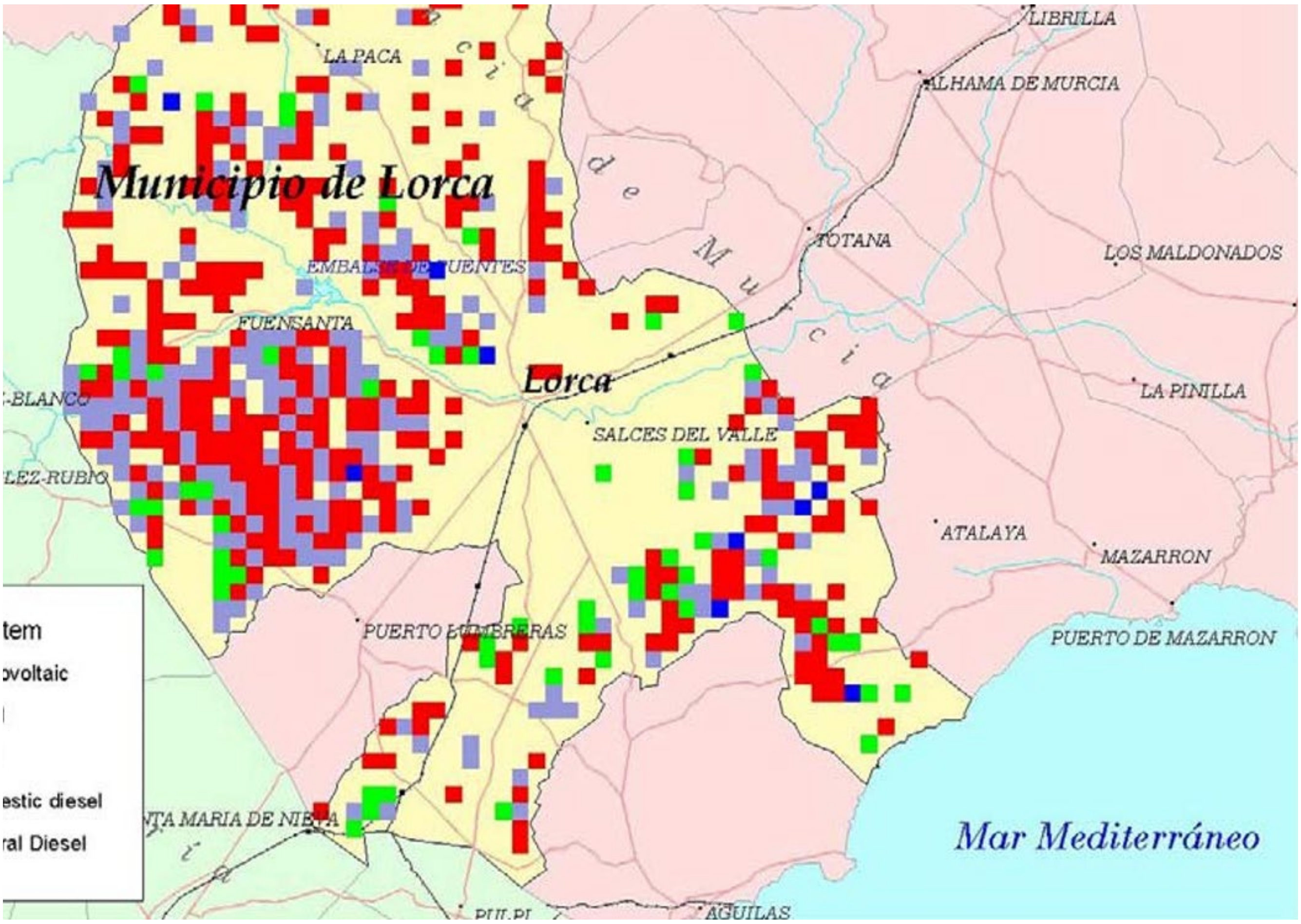
Figure 2: Comparing the lowest cost options between the original methodology (including mini-hydro) and the updated methodology and costs in the Sustainable Energy Planning report



METHODOLOGY B: GIS-BASED COMPARISON OF SOLAR, WIND, DOMESTIC AND CENTRALISED DIESEL AND GRID EXTENSION IN THE MUNICIPALITY OF LORCA (CENTRE FOR ENERGY, ENVIRONMENT AND TECHNOLOGY AND POLYTECHNIC UNIVERSITY OF MADRID, J. AMADOR, J. DOMINGUEZ)

This methodology was developed by researchers at CEIMAT and EUTI UMP to validate the use of GIS to identify the appropriate conventional or renewable technologies for electrification in Lorca, Spain. Comparing solar, wind, diesel and grid extension, a 1 km^2 resolution grid with least-cost technology options is modelled using demand estimation and population density to determine the local load

Figure 3: The final lowest cost model output

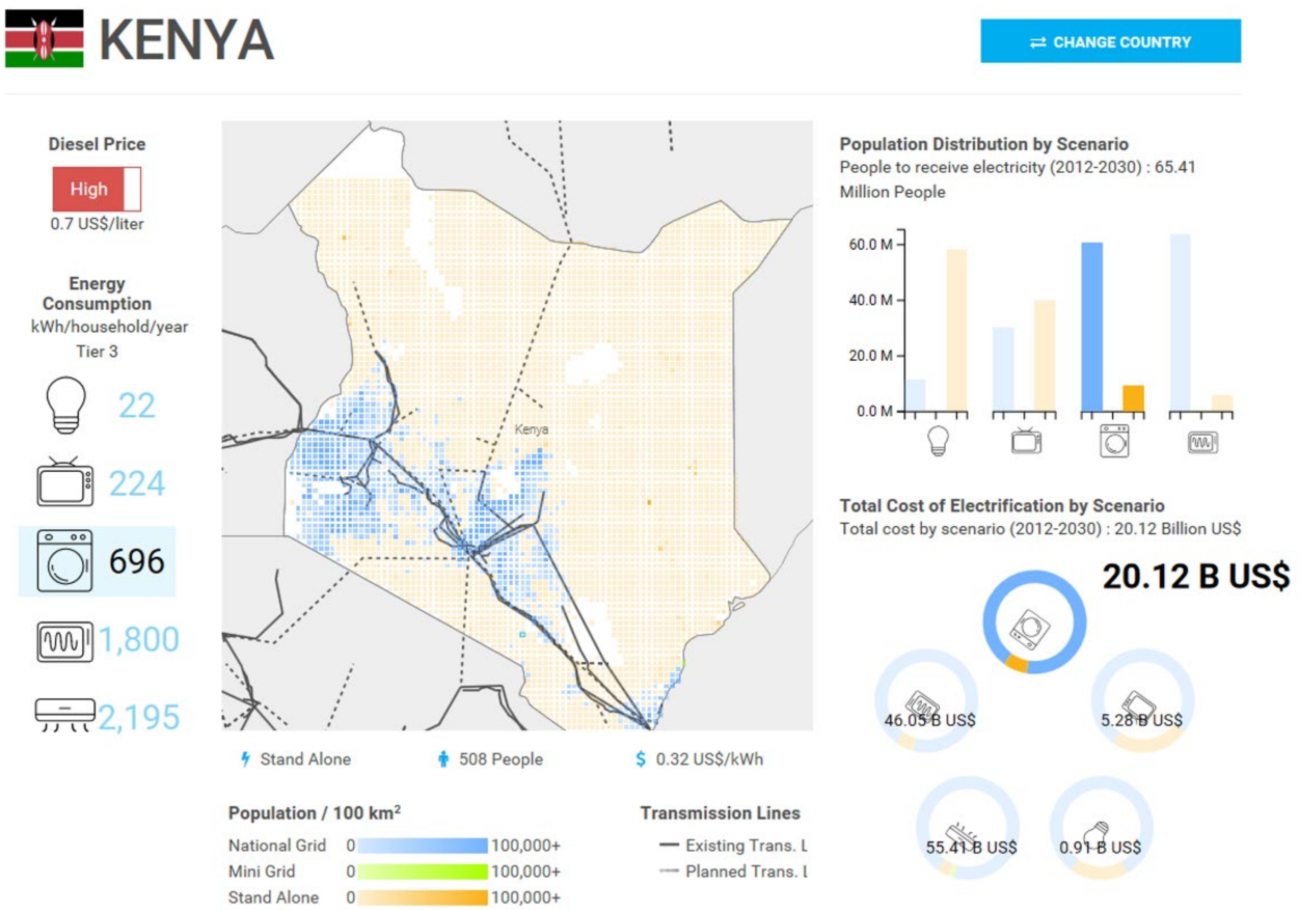


METHODOLOGY C: GIS-BASED LOWEST-COST ASSESSMENT OF SOLAR, WIND, MINI-HYDRO, BIOGAS AND DIESEL TECHNOLOGIES AGAINST GRID EXTENSION, CONSIDERING LARGE MINERAL INDUSTRY DEMAND (KTH ROYAL INSTITUTE OF TECHNOLOGY, D. MENTIS, F. F. NERINI ET AL.)

This methodology was developed primarily by the KTH Royal Institute of Technology to address the perceived need for a standardised framework that could provide the foundation on which to build locally appropriate toolkits. The framework has led to the development of the Unite UN-DESA open source electrification tool, which gives a country-wide electrification solution that considers the least cost of energy for each pixel, depending on the parameters of diesel price and energy consumption tier. The total estimated cost of electrification is then given.

The results of the methodology and framework papers were included in the IEA World Energy Outlook 2014.

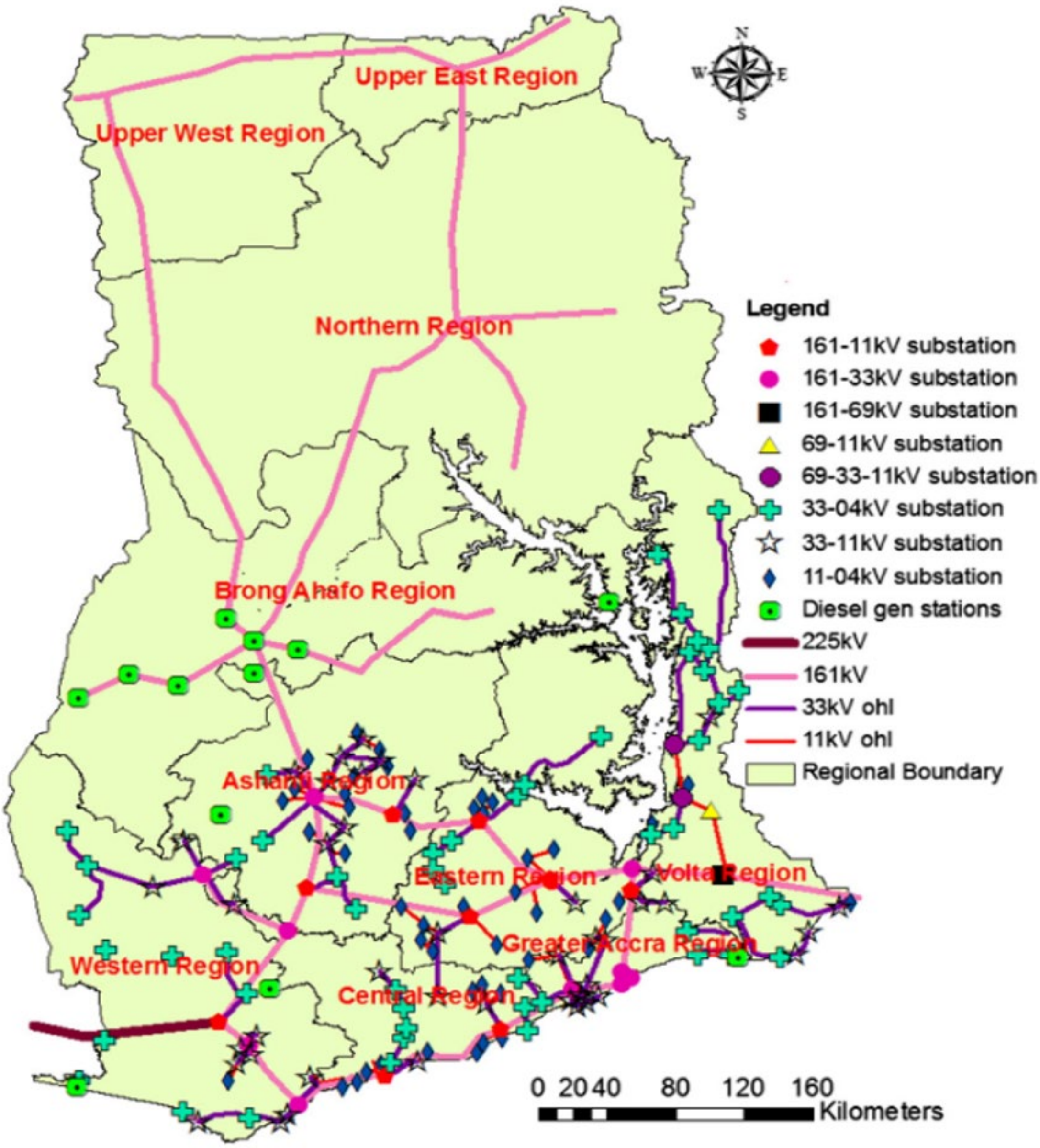
Figure 4: Screenshot of the electrification option outputted by the model for tier 3 access with high diesel prices. UN-DESA electricity access tool.



METHODOLOGY D: GIS-BASED PLANNING TOOL USING THE NETWORK PLANNER TOOL (COLUMBIA UNIVERSITY, NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI ENERGY CENTRE, F. KEMAUSUOR ET AL.)

With a planning period of 10 years, the Network Planner Tool was applied to 2,600 unelectrified communities in Ghana to predict the cost of different generation options (solar PV, diesel, grid extension) for each community. The total cost of electrification was given for each option/mix of options, and a sensitivity analysis was carried out to ensure the robustness of conclusions. The methodology relies on remote datasets to avoid incompleteness; therefore, wind, mini-hydro and biomass are not considered.

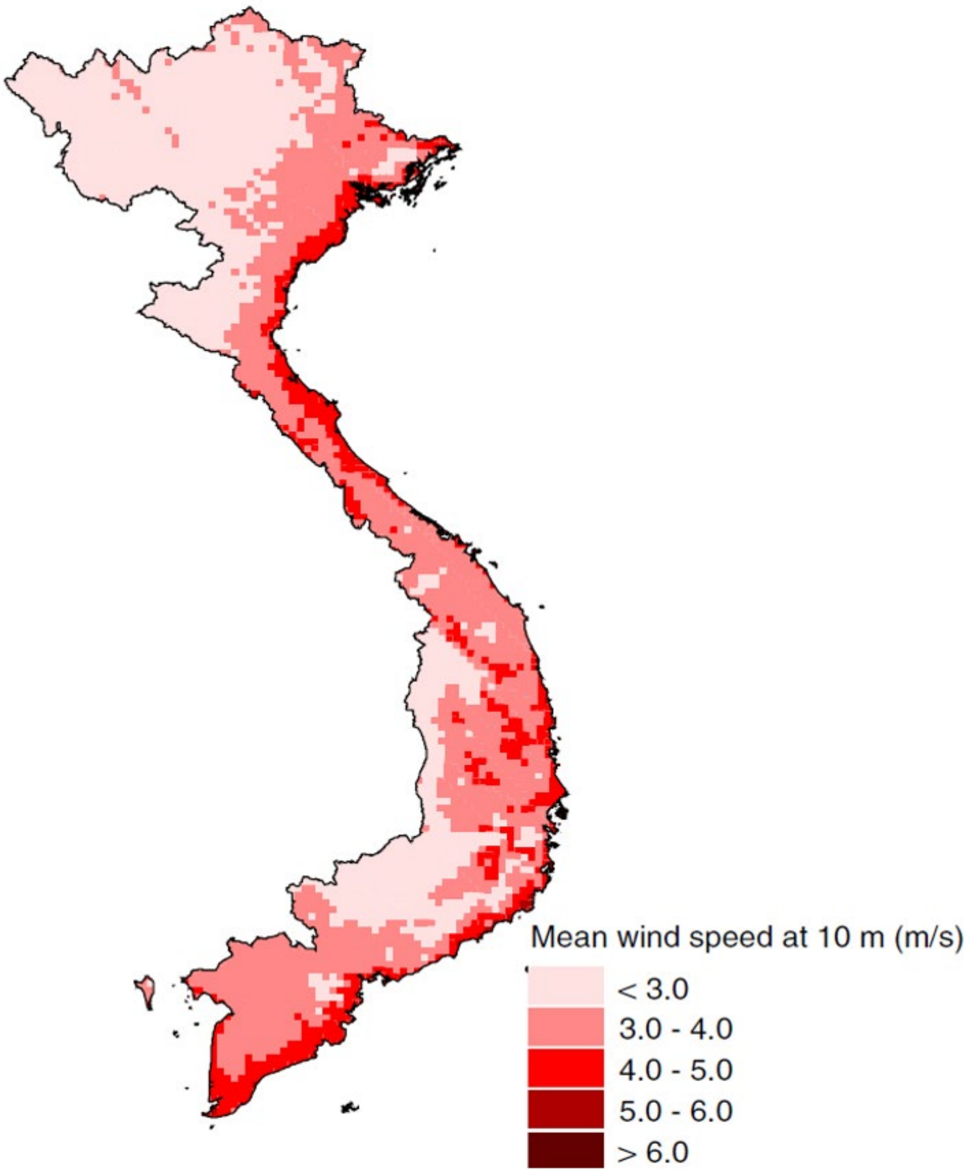
Figure 5: Grid infrastructure of Ghana, 2011.



METHODOLOGY E: GIS-BASED COMPARISON OF SOLAR, WIND AND GRID EXTENSION FOR VIETNAM (HANOI INSTITUTE OF ENERGY, K. Q. NGUYEN)

This methodology did not aim at identifying the lowest-cost option for rural electrification in Vietnam. Instead, it was utilised to produce a preliminary study of the competitiveness of solar, wind and decentralised diesel generation against grid extension. Due to lack of available data on non-electrified communities and grid infrastructure in Vietnam, settlement-specific data were not considered. Instead, the indicative costs of each option were compared for different distances to the grid and household densities. The parameters were considered over reasonable value ranges to indicate which settlements could be best electrified through the different options considered.

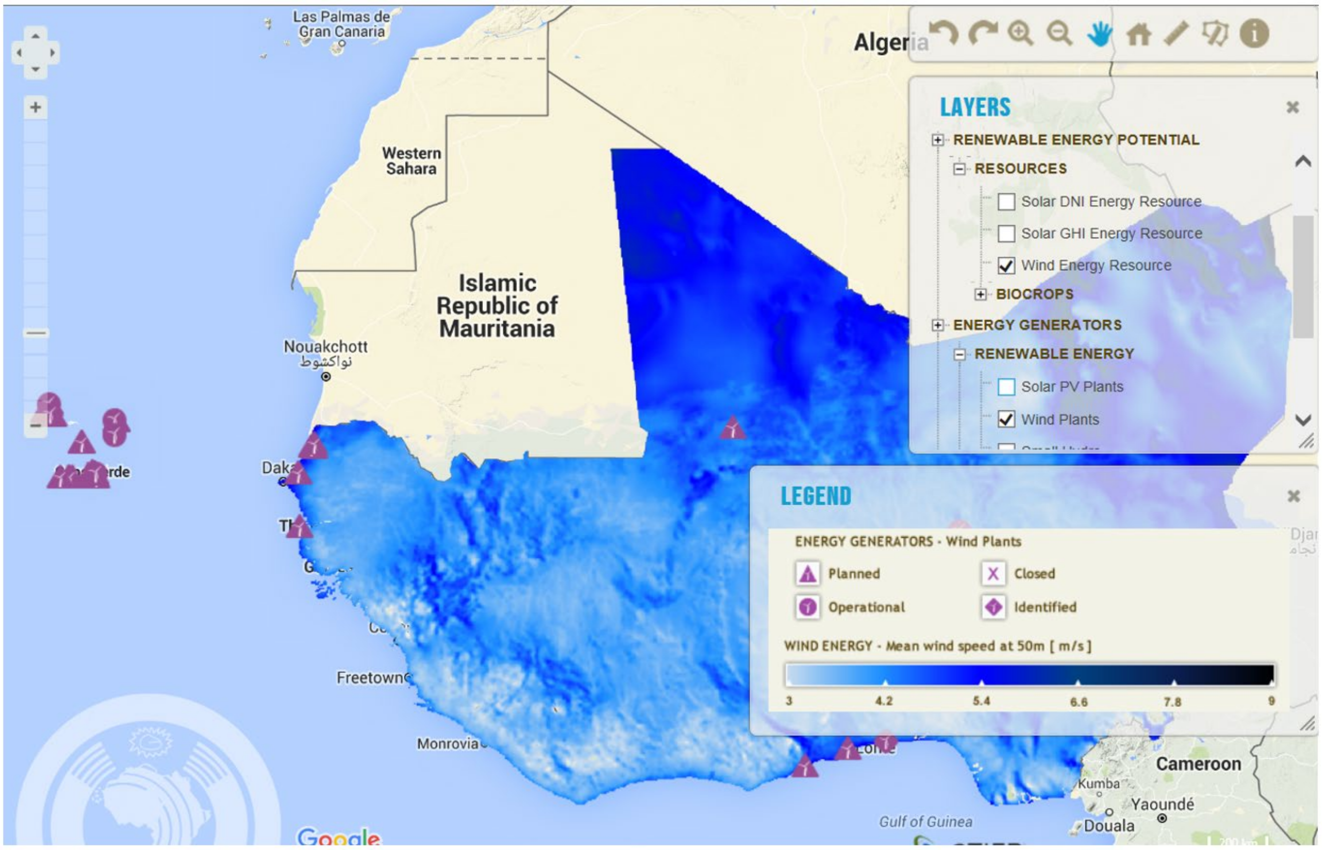
Figure 6: Mean wind speed at 10m height



METHODOLOGY F: ECOWREX MAPPING TOOL AND INTIGIS PLANNING TOOL– (ECOWAS OBSERVATORY FOR RENEWABLE ENERGY AND ENERGY EFFICIENCY, CIEMAT)

The ECOWREX mapping methodology was developed to provide accurate knowledge of existing and planned resources and renewable activities in the ECOWAS region, including solar, wind, biomass, hydro and wave projects. The IntiGIS tool was developed to compare the levelised costs of different decentralised technologies; and the second version, IntiGIS 2, will be integrated into ECOWREX to allow for technology comparisons within the ECOWAS region and for utilisation of the significant data available through ECOWREX for decentralised planning processes.

Figure 7: Screenshot of the existing and planned wind plants with mean wind speed at 50m for the ECOWAS region.

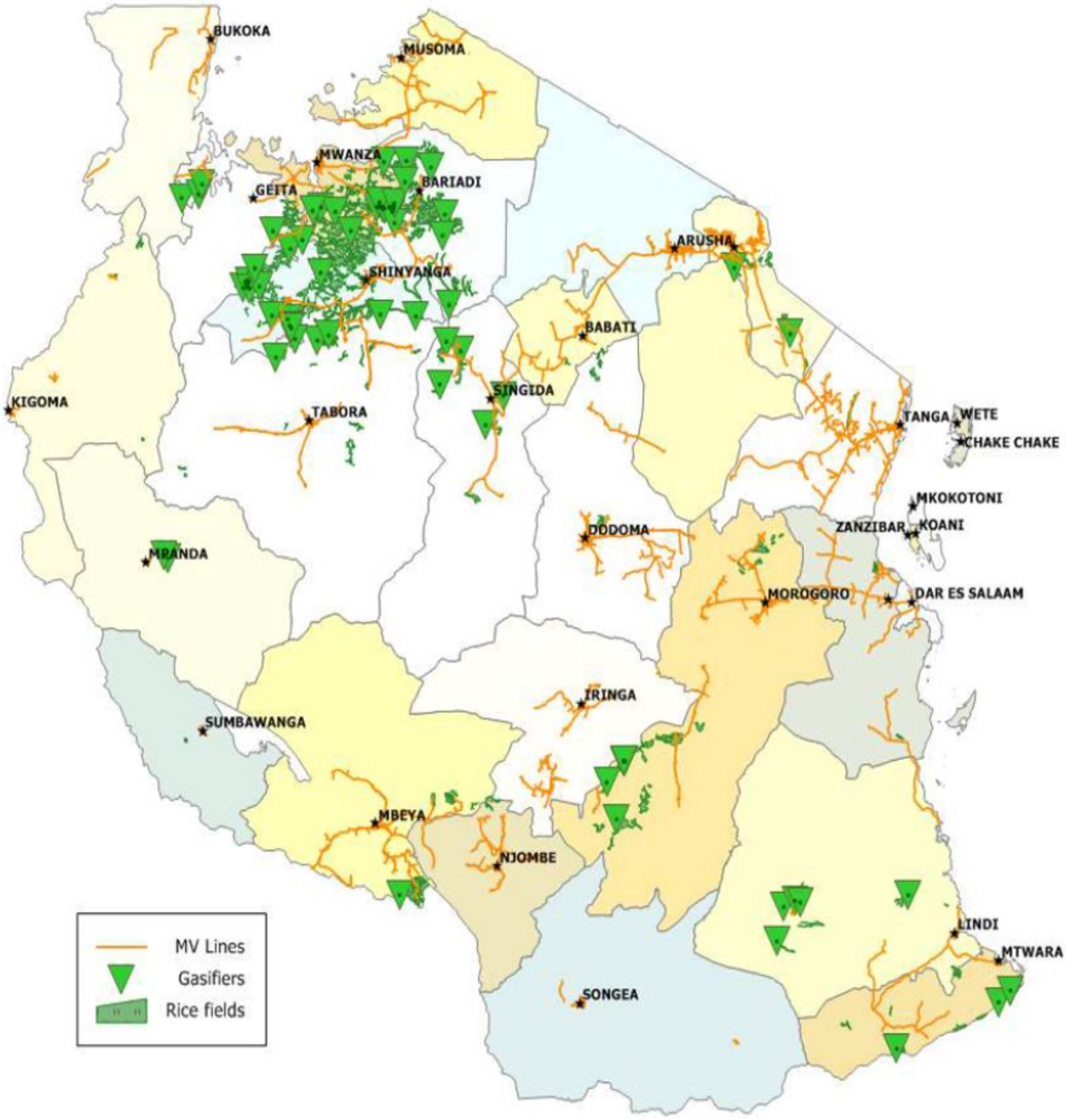


METHODOLOGY G: GIS-BASED INTEGRATED RURAL ELECTRIFICATION PLANNING CONSIDERING GRID EXTENSION, SMALL HYDRO AND BIOMASS (INNOVATION ENERGIE DEVELOPPEMENT)

This methodology has been implemented in multiple countries, and the case study of Tanzania is used here due to its inclusion of renewable source data, which is covered in more depth than in other projects. Tanzania's National Electrification Program Prospectus was used to develop an Electrification Master Plan that considers grid extension and small hydro, biomass or diesel mini-grids.

There have been several tools developed by IED that integrate this methodology, and these tools are utilised in IED's country-level work. These include GEOSIM, a GIS-based rural electrification planning tool, which is used to design and cost different decentralised options; and three other tools covering online GIS interfacing (GIMSYS), demand analysis and grid design/optimisation (GISELEC). GIMSYS, in particular, has been utilised in many countries to host an online GIS platform, although many websites show only the grid infrastructure and population centres.

Figure 8: Identified potential small biomass sites

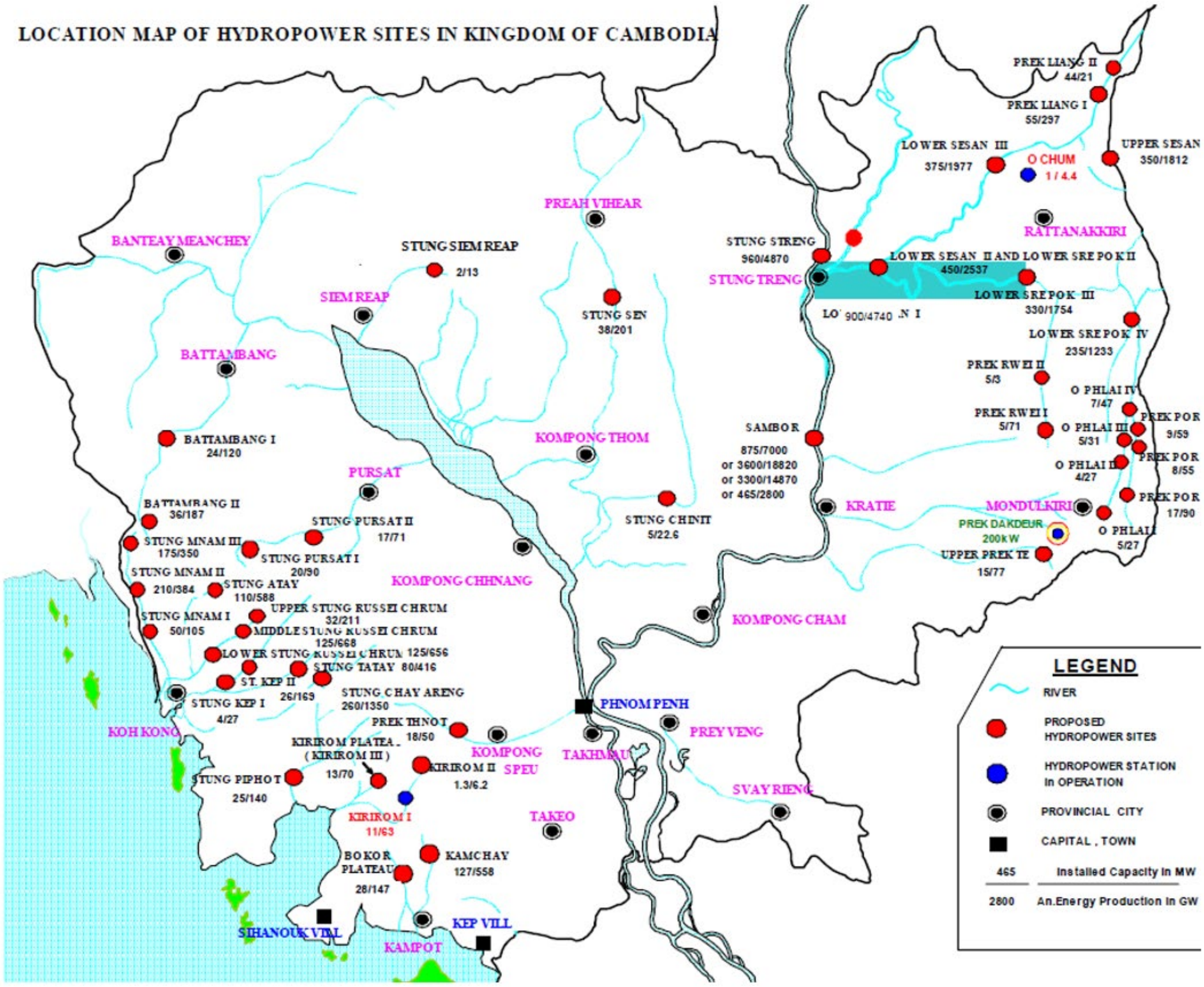


METHODOLOGY H: THE MASTER PLAN STUDY ON RURAL ELECTRIFICATION BY RENEWABLE ENERGY IN THE KINGDOM OF CAMBODIA (JAPAN INTERNATIONAL COOPERATION AGENCY)

This methodology was utilized by the Japan International Cooperation Agency (JICA) to prepare a Rural Electrification Master Plan for Cambodia. It consisted of two years of analytical work, including onsite data collection, community consultations, desk-based research and engagement with the Ministry of Industry, Mines and Energy and other relevant ministries. The methodology considered micro-hydro, solar, biomass, wind and diesel for mini-grids.

Due to the extensive nature of the study and the master plan, only the relevant aspects were assessed for this project.

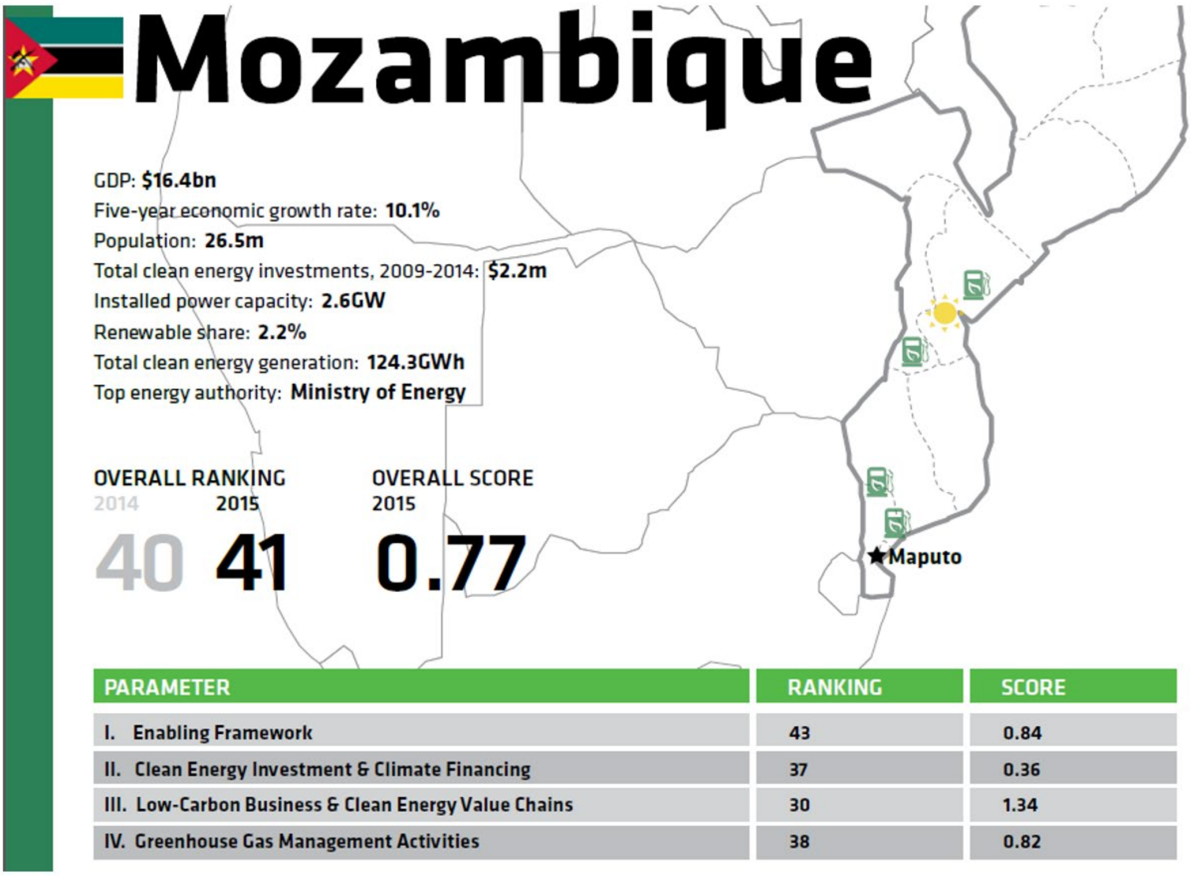
Figure 9: Identified and Currently Operating Hydropower Projects. Cambodia Ministry of Industry, Mines and Energy.



METHODOLOGY I: CLIMATESCOPE - GLOBAL CLEAN ENERGY COUNTRY COMPETITIVENESS INDEX (MULTILATERAL INVESTMENT FUND, UK DEPARTMENT FOR INTERNATIONAL DEVELOPMENT, POWER AFRICA AND BLOOMBERG NEW ENERGY FINANCE)

This methodology, the ClimateScope Clean Energy Country Competitiveness Index, measures the renewable-related energy investment, policy development and installed RE capacity (wind, solar, geothermal, biomass, small hydro and biofuel technologies) of 55 countries globally. Further, the index indicates the strength of the enabling environment for the development of clean energy and technologies in these countries. Of the 55 countries, 23 are evaluated using an augmented 'off-grid' methodology, which assesses a country's competitiveness relative to other countries for specific off-grid renewable technologies.

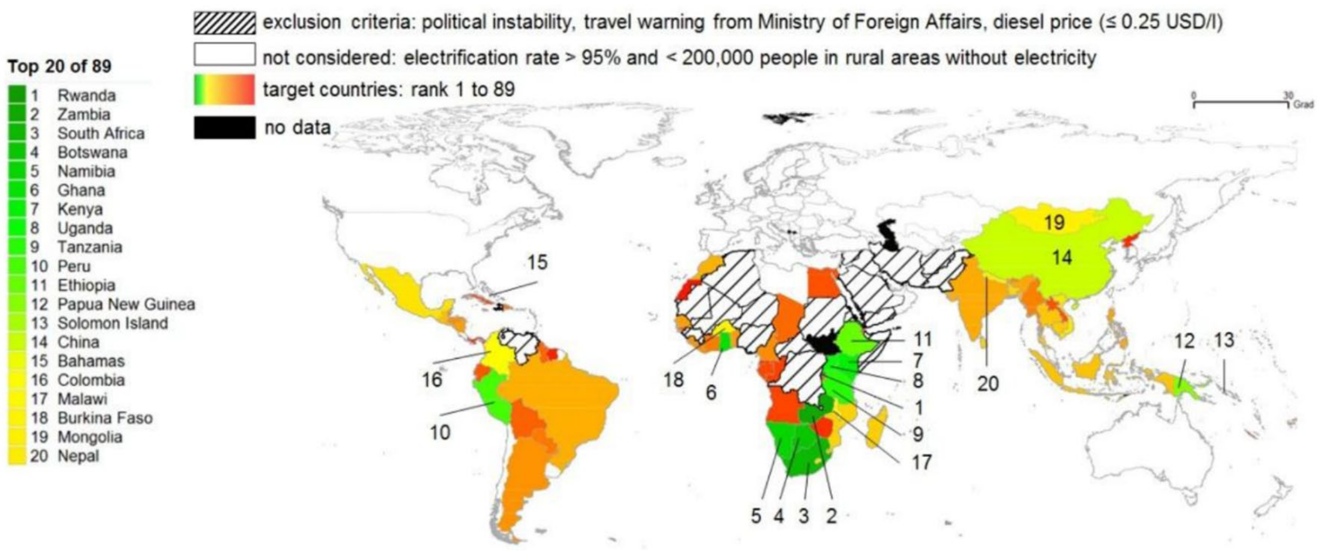
Figure 10: Example of ClimateScope country summary sheet – Mozambique.



METHODOLOGY J: GLOBAL COUNTRY RANKING BASED ON SUITABILITY FOR RURAL ELECTRIFICATION (REINER LEMOINE INSTITUT GGMBH, ANN-KATRIN GERLACH ET AL.)

This methodology is a simple worldwide country ranking that gives an indication of countries' suitability for the development of renewable mini-grids, to aid in the development of sustainable business models in these countries. The weighted ranking uses remote indicators (e.g., electrification rate, Corruption Perceptions Index) to assess the market potential and political and financial environment for mini-grids in each country.

Figure 11: Top 20 from 89 non-excluded countries, based on market potential and political and financial enabling environment



METHODOLOGY K: GIS-BASED, DEMAND-LED RURAL ELECTRICITY PLANNING TOOL FOR UGANDA (IT POWER, E. KAIJUKA)

This methodology identifies patterns of demand and priority areas for investment, with the aim of increasing the rate of rural electrification without having to develop a comprehensive electrification plan. The methodology provides investors with a demand-led prioritisation of target areas, from which supply-side system designs can be developed.

The methodology prioritises health centres, schools, households, and local government headquarters, in that order. A weighted benefit points score is awarded for each demand sector, including households, and the sub-counties are given a cumulative score based on the sectors within their boundaries.

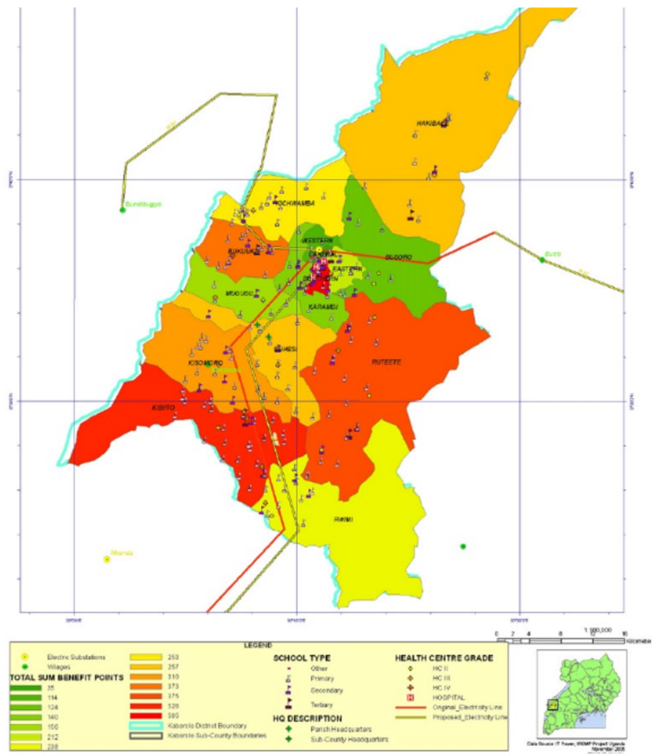


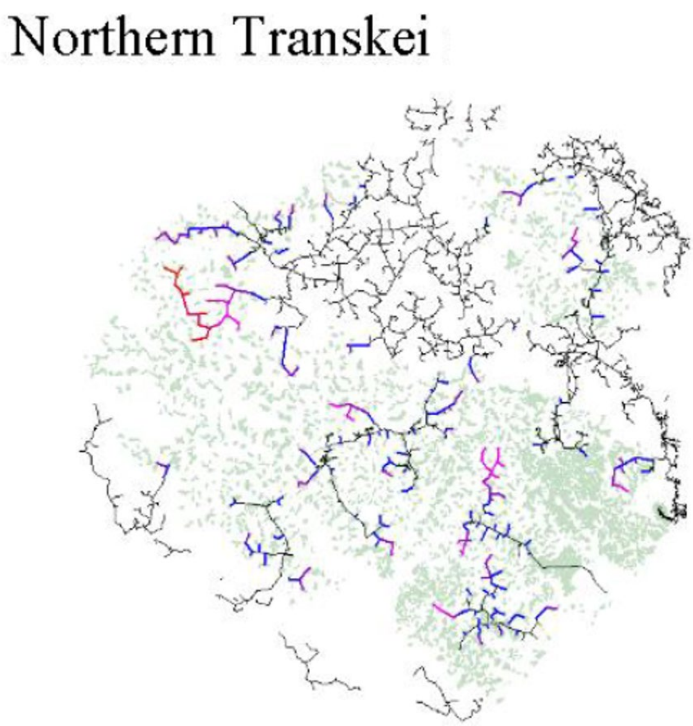
Figure 12 (right): Kabarole district benefit point allocation by sub-county. Red indicates higher priority and greater benefits; green indicates lower priority and lower benefits.

METHODOLOGY L: GIS-BASED ELECTRIFICATION PLANNING DECISION SUPPORT TOOL FOR SOUTH AFRICA (RURAL AREA POWER SOLUTIONS ET AL., D. I. BANKS ET AL.)

This methodology was developed to aid in planning rural electrification in South Africa, in order to address the wide disparities between electrified and unelectrified settlements. Grid-connected settlements have seen significant development benefits from the heavy tariff subsidies (up to R5000 per household), connection fees of only R100 (approximately US$6.70) as well as no minimum monthly charges, and connection fees of only R100 (approx. US$6.70). However, these subsidies have been burdensome for the national utility, Eskom, and have contributed to it operating at a loss. The methodology contributed to more effective decision-making for RE, specifically concerning off-grid connections for remote communities, to enable these communities to have the benefits of electricity without impacting the national budget.

The methodology is based on the principle of maximising the development impact of electrification for each un-electrified settlement, and using the potential development impact to prioritise electrification. The methodology recognises that a direct cost comparison of grid and off-grid solutions will not provide a robust solution without a high level of analysis, due to the different levels of service offered by the two types of solutions and high dependence on input parameters.

Figure 13: Electrification solution possible with maximum cost per point of R3500 (approx. US$235). Points are awarded based on electrification benefit, such as a hospital receiving 15 points or a household 1 point.



2.4 OTHER DECISION SUPPORT TOOLS

In addition to the specific methodologies discussed above, which are geared toward assessing the opportunity for green mini-grids under different local conditions, a range of decision support tools have been developed by different stakeholders. These tools are intended to be useful for practitioners during the planning and implementation of mini-grid projects. There are many such tools available, including software programmes, cloud-based services, checklists and templates that can be used for various aspects related to the planning, design and operation of mini-grids.

As part of the UN SE4All Clean Energy Mini-Grids initiative, an overview of "Tools for Mini-Grid Practitioners" has been produced by GIZ, which briefly describes more than 50 tools in the following areas:

- ***General tools*** for rural electrification planning and mapping include general web mapping services such as Bing Maps and Google Maps; as well as more dedicated software applications that provide support to rural electrification decision makers as they explore electrification options for rural communities.
- ***Tools for resource assessment*** provide data and resource analysis at selected locations for focus technologies such as solar PV and wind generators. International organisations such as UNEP, the International Renewable Energy Agency (IRENA) and the EU Joint Research Centre (EU-JRC) have provided support for such tools.
- ***Tools for technical design and analysis*** have been prepared by a range of project developers including SMA, Homer Energy and GIZ to plan rural electrification, with a focus on mini-grids. These tools are used to estimate the likely power demand from specific locations and optimize the required equipment.
- ***Tools for financing planning and business model development,*** including RETScreen, IRENA Project Navigator, and National Renewable Energy Laboratory's (NREL's) Crest were developed to support project developers in assessing the costs and likely returns from mini-grid implementation, including cash flows, fixed and variable costs, and required tariffs for users.
- ***Tools for operators and managers*** include systems from implementers with mini-grid experience including Sparkmeter and Lumter, with applications that cover supplier selection, integrating productive uses, payment management, monitoring and control systems, and troubleshooting.
- ***Other tools:*** from a range of organisations including the World Bank, McKinsey & Co, UNFCCC and GIZ that provide additional support including access to technical reference documents, analysis of supply quality, assistance tor co-operatives, legal templates and the calculation of CO_2 emissions.

One of more of these support tools may be useful to policymakers and investors for assessing the mini-grid potential of an identified location. The effective identification of locations, however, will depend on the development of the template methodology that is the objective of this analysis.

3. METHODOLOGY ANALYSIS

3.1 ASSESSMENT CRITERIA

The objective of this report is to identify and evaluate the existing methodologies that (a) are used to assess the potential for electrification through mini-grids; and (b) could help inform the development of the overall template methodology. The usefulness of each methodology to a project developer or other stakeholder will on its quality, applicability and practicality, as determined by the following key factors specified by the African Development Bank, are:

- Relevance to stakeholders
- Relevance and quality of outputs
- Data requirements
- Handling of data paucity
- Software requirements
- Robustness
- Openness and ease of use
- Interoperability with other planning tools
- Cost and level of training required.

The full assessments of the twelve methodologies can be found in Annex I. The indicative scoring of each methodology by factor is shown in Table 3.

Table 3: Scores out of five, by methodology and criteria

Methodology	A	B	C	D	E	F	G	H	I	J	K	L
Relevance to stakeholders	2	4	5	4	2	4	5	5	2	1	2	3
Relevance and quality of outputs	2	3	4	3	2	4	4	5	1	1	2	3
Data requirements	2	4	3	4	4	4	4	5	N/A	3	3	Not Known
Handling of data paucity	3	5	4	3	4	3	5	N/A	5	5	5	Not Known
Software requirements	3	3	3	5	3	3	4	3	5	5	3	3
Robustness	4	5	3	4	4	Not Known	3	5	3	3	4	3
Openness and ease of Use	4	2	5	5	3	4	1	2	2	5	5	2
Interoperability with other planning tools	5	3	5	3	5	5	5	N/A	5	5	5	5
Cost and level of training required	3	3	3	5	4	4	2	1	1	5	3	2

3.2 RELEVANCE TO STAKEHOLDERS

This section considers the overall usefulness of each methodology for determining the potential for a mini-grid. This section looks at whether a methodology considers all relevant resources or input factors, whether its mechanics and/or assumptions are applicable in practice, and whether its outputs provide information at the required scale. The quality of these inputs and outputs are also considered.

The analysis found that while the methodologies differ widely in their approach, they all provide actionable information that can be useful to policymakers and investors. The IntiGIS tool, for example, provides indications of mini-grid potential through the levelised cost of energy under different options. Other methodologies, such as Network Planner, use the cost of energy to suggest an electrification infrastructure. Lack of data was the limiting factor for many methodologies examined, with Methodology K – a GIS rural electricity planning tool for Uganda – only able to provide a recommendation based on demand. This is a severe limitation on its relevance for a developer looking to estimate overall potential, and it would need to be used in combination with other methodologies and tools.

Table 4: Relevance to stakeholders

Method	Relevance to Stakeholders	Score (1-5)
A	This is a high-level methodology that gives a clear, if only indicative, least-cost solution for energy across Africa. This is very useful as a first approach to identifying the region in Africa best suited for a specific development, but the lack of country-level data and resolution limits the impact of any conclusions drawn.	2
B	For the region in which this methodology was applied – Lorca, Spain – a clear prescription for the least-cost electrification system was identified. The scope of the methodology is very narrow. However, due to the small area assessed, the solution allowed for useful stakeholder decision-making.	4
C	This methodology gives a clear indication of the regions within a country that are best suited to different electrification options, with grid infrastructure and colour-coded pixels on a settlement scale. A developer could easily provide a very specific target region in which to perform a more detailed demand analysis and system design.	5
D	This methodology uses Network Planner, which develops a full solution for the electrification of a target region, giving total electrification costs and costs for each community or region. The methodology also considers demand from houses and services, as well as projected growth rates. The key limitation for developers is its dependence on remote data sets, which allows for application across Africa. However, since only solar data are available, that means that only the solar resource can be considered, and then only for a stand-alone (household or small facility) system. Mini-grids are assumed to use diesel generation.	4
E	Due to the lack of available data, this methodology does not give levelised cost of energy estimates for specific locations, but looks at the relative competitiveness of solar, wind and diesel solutions against grid extension for Vietnam. Therefore, it is useful to developers only as a base for building a more detailed opportunity assessment methodology.	2

Method	Relevance to Stakeholders	Score (1-5)
F	This methodology is applicable only to the ECOWAS region. The ECREEE mandate has resulted in significant data collection and other activities in the region, and these have informed the development of the methodology so that it meets the needs of developers and stakeholders. The integration of IntiGIS with the ECOWREX platform will create a powerful opportunity assessment tool.	4
G	Tanzania's National Electrification Prospectus provides a clear plan for stakeholders and developers about which regions to electrify and by which method. The settlements to be electrified by mini-grids and those that will later be connected to the national grid are both	5
H	Cambodia's Master Plan for Rural Electrification is useful because it outlines the role of all stakeholders, including private investors, in the development of green mini-grids.	5
I	This methodology collates information on current and planned projects, levels of investment, and the policy environment from multiple country-level sources to provide an overview of the electrification needs in the country. However, there are no indicators on a sub-country level on resource potentials, population distributions or other key factors.	2
J	This methodology can help developers prioritise countries for mini-grid development. However, a full decision would require much more detailed investigation of the technical, demographic, infrastructural and policy factors.	1
K	This methodology prioritises the electrification of sub-regions based on demand, which is relevant for both national planners and private mini-grid developers seeking to reduce the commercial risk of development. However, the lack of consideration of any other key factors limits its usefulness.	2
L	This methodology prioritises grid extension and does not consider renewable potential. However, it does specify within the modelled region which settlements can be electrified through mini-grids and which ones need stand-alone systems.	3

3.3 RELEVANCE AND QUALITY OF OUTPUTS

This section concerns the relevance and quality of outputs provided by each methodology; for example, whether the lowest cost of an energy technology option is shown for each area, or just an indication of the level of benefit that would be gained. Also of consideration is resolution or detail of results; for example, whether the opportunity level is given on a country, regional or sub-regional level.

Clarity of output was a key difference among the assessed methodologies. Methodologies like one developed by the KTH Royal Institute of Technology (Methodology C) achieved clarity through the spatial mapping of the lowest levelised cost of each energy option for the target region. The use of GIS software and databases is now common, and allows for clear visual representation of the outputs and easy drawing of conclusions.

The lower-scoring methodologies lost points mainly due to a lack of available data, resulting in either a reduction in scope, increase in the number of necessary estimations and theoretical models, or a lack of appropriate granularity. For example, remote data were utilised exclusively in methodologies A, I and J, with Methodology A utilising theoretical techniques to estimate resource potentials and methodologies I and J providing only countrywide indications.

Table 5: Relevance and quality of outputs assessment

Method	Relevance and Quality of Outputs	Score (1-5)
A	The output of this methodology was Africa-wide mapping of the relative economy (costs and savings) of mini-hydro, off-grid PV, grid extension and diesel generation. The conclusions were high level due to the resolution of input data, but did not reflect key factors such as population density or demand.	2
B	The output was a lowest-cost recommendation for every km^2, with a sensitivity analysis applied to show the dependence on every variable. The recommendation was clear with regard to demand estimation but not to the methodology applied. This limited the applicability of this methodology.	3
C	The output was a clear, countrywide electrification solution that shows the least-cost options for specific areas. A framework methodology is given local variable estimates to find a specific solution, including a small sensitivity analysis about the rural and urban energy consumption levels. Solutions were given for each pixel of 2.5kmx2.5km. The UN-DESA online electrification tool can deliver this methodology for all countries in Africa.	4
D	The output was a full electrification infrastructure that gave the investment costs required for different penetration rates, different electrification options, and region or settlement. The focus was on the overall cost of stand-alone, mini-grid and grid extension rather than on the relative opportunity of different renewable options, so the cost of energy was not given.	3
E	The output was the relative costs of different technologies for varying household densities and distances to the grid. Only estimates for the proportion of the population best served by each option were given, as there were no settlement or grid location data. Therefore, no site- specific recommendations were made.	2
F	The lack of completion of IntiGIS means the details of the methodology and outputs are not confirmed. However, the outputs will include a levelised cost of energy calculation for all of the technology options, and will cover the entire ECOWAS region with a good resolution (based on the resolution of current ECOWREX input data).	4
G	The output was a clearly identified electrification option for each settlement, including implementation timeframes, penetration rates, and identified hydro and biomass sites. The number of settlements in each region receiving each electrification option was listed, and total investment costs were given for each electrification option. However, the levelised cost of energy for each settlement was not given.	4

Method	Relevance and Quality of Outputs	Score (1-5)
H	The output was a complete Master Plan on Rural Electrification for Cambodia, which detailed in full the associated technical, economic, and policy aspects. The scope of the work included a consideration of all communities, providing a strong information base for any future stakeholder.	5
I	The output was a country ranking, with summary country profiles that indicated the policy environment for mini-grids.	1
J	The output was a country ranking that gave a country-level indication for the suitability for mini-grid development.	1
K	The output was a benefit points score that gave a clear ranking to each sub-region in the country. The grid and road infrastructure were mapped, but the output depended only on the population size and demand centres, so the result gave no indication as to the resources available near the demand centres.	2
L	The output was a proposal for a full electrification structure, which included the full financial costs of grid connection and the proportion of households connected to the grid, to a mini-grid, or with a stand-alone system. However, there was no technology assessment of the cost of energy for the proposed off-grid solutions.	3

3.4 DATA REQUIREMENTS

This section assesses the inputs utilised by the twelve methodologies and the quality of their underlying data sources. The assessment looks at whether the data were remotely assessed or collected via country field studies, the level of paucity, whether the source was up-to-date, and data accuracy. A high score represents a methodology that used a full range of up-to-date, accurate and relevant sources.

A checklist summary of the input parameters used to assess the methodologies is shown in figures 14a and 14b. The figures indicate the wide variety of inputs considered. As data were scarce, out-of-date, or unavailable for some of these inputs, most of the methodologies were designed, to some extent, around the availability of up-to-date inputs. For example, Methodology B, a GIS-based electrification tool in Lorca, Spain, used entirely Spain-specific sources. The source for wind speed was focused only on the Murcia region, of which Lorca is a municipality.

Within Africa, the limiting factor of data availability has led to various compensatory approaches, explained separately below. Sources that can be utilised tend to be at least 2-4 years old, often more than 6 years old, including international reports such as the Human Development Report, which are not necessarily updated annually. Resource potentials were assessed primarily through satellite data for solar and wind, with biomass and small hydro assessed through sites pre-identified by previous projects or by the government. An exception was Methodology A, which used elevation datasets and select gauge stations across Africa to estimate the annual flow rates of rivers.

Only two of the methodologies examined, G and H, relied on own fieldwork and data collection as part of the methodology, and these two methodologies also utilised government sources and statistics more than other methodologies. This suggests a lack of easy access to such sources (or more interest in data), perhaps requiring established working relationships or protracted communications with those possessing the data (i.e. government).

Figure 14.a: Summary checklist of methodology input parameters

Methodology	A	B	C	D	E	F	G	H	I	J	K	L
	Methodology A: GIS-based cost comparison of solar PV, mini-hydro, diesel and grid extension for Africa	Methodology B: GIS-based comparison of solar, wind, domestic and centralised diesel and grid extension in the municipality of Lorca	Methodology C: GIS-based lowest cost assessment of solar, wind, mini-hydro, biogas and diesel technologies against grid extension	Methodology D: GIS-based planning tool using the Network Planner Tool	Methodology E: GIS-based comparison of solar, wind and grid extension for Vietnam	Methodology F: ECOWREX Mapping Tool and IntiGIS Planning Tool	Methodology G: GIS-based integrated rural electrification planning considering grid extension, small hydro and biomass	Methodology H: The Master Plan Study on Rural Electrification by Renewable Energy in the Kingdom of Cambodia	Methodology I: ClimateScope Index	Methodology J: Global Country Ranking Based on Suitability for Rural Electrification	Methodology K: GIS-based, Demand-Led Rural Electricity Planning Tool for Uganda	Methodology L: GIS-based Electrification Planning Decision Support Tool for South Africa
Coverage	Africa	Lorca (Spain)	Nigeria, Ethiopia	Ghana	Vietnam	ECOWAS region	Tanzania	Cambodia	Global	Global	Uganda	South Africa
Methodology Type	Supply -Led	Supply -Led	Supply -Led	Supply -Led	Supply -Led	Supply -Led	Demand -Led	Demand -Led	Weighted Ranking	Weighted Ranking	Demand -Led Grid Extension	Demand -Led Grid Extension
GIS/Spatial Mapping	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Input Parameters Used												
Renewable												
PV – Solar Irradiation	Yes	Yes	Yes	Yes	Yes	Yes		Yes				
PV – Existing Solar Farms						Yes			Yes			
Hydro – River Annual Flowrate	Yes					(Coming Soon)		Yes				
Hydro – Existing Mini-Hydro Sites			Yes			Yes	Yes	Yes	Yes			
Hydro – Potential Mini-Hydro Sites			Yes				Yes	Yes				
Wind – Average Wind Speed		Yes	Yes		Yes	Yes		Yes				
Wind – Existing Wind Sites						Yes		Yes	Yes			
Biomass – Existing Biomass Sites						Yes		Yes	Yes			
Biomass – Agriculture Industry Locations							Yes					
Biomass – Potential Biomas Sites			Yes			Yes	Yes	Yes				
Network and Energy												
Network – Existing Grid Network	Yes	Yes	Yes	Yes		Yes	Yes	Yes			Yes	Yes
Network – Planned Grid Network			Yes			Yes	Yes	Yes				
Network – Grid Extension Cost	Yes				Yes			Yes				Yes
Network – Grid Network Charges					Yes			Yes	Yes			
Network – Grid Performance								Yes				
Network – Generator Licence Information (Service areas, licensee performance)								Yes				
Diesel – National Diesel Prices	Yes		Yes	Yes				Yes	Yes	Yes		
Diesel – Accessibility / Travel Time	Yes											
Diesel – Transportation Costs	Yes							Yes				
Diesel – Planned Large Industry Demand			Yes			Yes						

Figure 14.b: Summary checklist of methodology input parameters

Methodology A: GIS-based cost comparison of solar PV, mini-hydro, diesel and grid extension for Africa	Methodology B: GIS-based comparison of solar, wind, domestic and centralised diesel and grid extension in the municipality of Lorca	Methodology C: GIS-based lowest cost assessment of solar, wind, mini-hydro, biogas and diesel technologies against grid extension	Methodology D: GIS-based planning tool using the Network Planner Tool	Methodology E: GIS-based comparison of solar, wind and grid extension for Vietnam	Methodology F: ECOWREX Mapping Tool and IntiGIS Planning Tool	Methodology G: GIS-based integrated rural electrification planning considering grid extension, small hydro and biomass	Methodology H: The Master Plan Study on Rural Electrification by Renewable Energy in the Kingdom of Cambodia	Methodology I: ClimateScope Index	Methodology J: Global Country Ranking Based on Suitability for Rural Electrification	Methodology K: GIS-based, Demand-Led Rural Electricity Planning Tool for Uganda	Methodology L: GIS-based Electrification Planning Decision Support Tool for South Africa		
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	Methodology	
Africa	Lorca (Spain)	Nigeria, Ethiopia	Ghana	Vietnam	ECOWAS region	Tanzania	Cambodia	Global	Global	Uganda	South Africa	Coverage	
Supply -Led	Supply -Led	Supply -Led	Supply -Led	Supply -Led	Supply -Led	Demand -Led	Demand -Led	Weighted Ranking	Weighted Ranking	Demand -Led Grid Extension	Demand -Led Grid Extension	Methodology Type	
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	GIS/Spatial Mapping	
												Input Parameters Used	
												Demographic	
			Yes		Yes	Yes	Yes		Yes	Yes		Population Size	Population
	Yes	Yes			Yes		Yes				Yes	Population Density	Population
			Yes									Population Growth Rate	Population
			Yes			Yes	Yes					Settlement Locations	Population
		Yes					Yes	Yes	Yes			Electrification Level (National, Regional or Settlement)	Population
	Yes	Yes	Yes	Yes	Yes	Yes	Yes					User Demand Level(s) / Load Profile	Population
							Yes				Yes	Household Income	Population
			Yes					Yes				Electrictricity Demand Growth	Population
							Yes					Land Use / Land Cover	Population
								Yes				Cook Stove Use Level	Population
						Yes	Yes			Yes	Yes	Service Locations/Demand	Service
					Yes	Yes	Yes			Yes		Other Infrastructure	Service
												Policy/Political	
								Yes				Rural Electrification/Mini-Grid Policies	Policy
								Yes	Yes			Political Risk / Stability	Policy
								Yes				Distributed Energy Regulatory Framework	Policy
								Yes				Policy / Trade Barriers	Policy
									Yes			Corruption	Policy
												Financial / Economic	
			Yes	Yes								Interest / Discount Rate	Financial / Economic
				Yes					Yes			Inflation	Financial / Economic
			Yes					Yes				Economic Growth Rate	Financial / Economic
								Yes				Clean Energy Investment and Investment Growth Rate	Financial / Economic
								Yes				Loans, Grants and Grant Program Comittments	Financial / Economic
								Yes				Green Finance and Microfinance Institutions	Financial / Economic
								Yes				Sector Value Chains	Financial / Economic
								Yes				CDM	Financial / Economic
								Yes				GHG Emissions and Reporting	Financial / Economic
									Yes			Ease of Doing Business	Financial / Economic

Table 6: Data requirements assessment

Method	Data Requirements	Score (1-5)
A	Performance and cost assumptions used fixed values across Africa, with only diesel prices being country specific. Population factors were not considered in the cost of energy calculations, but were used to give the final proportion of the continent best served by each option. Data were sourced from 1997 to 2011, with only remote data used. Mini-hydro was assessed at a high level (macro) using a satellite global elevation map and data from select gauge stations across Africa. The grid and road infrastructure data were from 2008.	2
B	Data were collected under specific projects, such as the INDEL project REE Atlas on electricity demand in Spain, and through research such as Ramırez et al. (1999) on renewable energy resources in the Murcia Region. The data were from 2004/5. Given the free choice of a test region, however, it is reasonable to assume that the availability of even out-of-date data was a guiding factor in this choice, and that the availability of data in a randomly chosen region would have been much worse.	4
C	Recently identified mini-hydro sites were included, and solar and wind data were satellite based and recent. Infrastructure and grid network data were the same data from 2008 used in Methodology A. Population data were taken from a 2005 EU initiative. It is unknown whether updated sources were used in the UN-DESA tool released in March 2016.	3
D	Most data sources, including grid infrastructure, demographic data, interest and growth rates, were from local sources such as the Bank of Ghana and the Ministry of Energy. These data, from 2010 and 2011, were recent as of publication in 2013, and would be relatively easy to update. The solar irradiation data were taken from the SWERA National Renewable Energy Report for Ghana from 2011. Only the lack of other considered data sources limited the score of this methodology.	4
E	The renewable energy resource, economic and technical estimates were 4-6 years old at the point of publication, and utilising satellite data, a wind modelling project, and other publications specific to Vietnam. Reports by the Vietnamese Institute of Energy in 2000, 2005 and 2006 provided detailed estimates for demographic, network and economic factors. These country-level sources were relatively up-to-date at the time, and provided a suitable level of resolution and accuracy for this methodology. The wind data were extrapolated to 10m height by a theoretically derived equation, and the solar resolution was very low.	4

Method	Data Requirements	Score (1-5)
F	ECREEE have an ongoing programme to provide up-to-date information, but it is limited to data collected by public and private sources and data from the ministries of member states. The hydro-power resource is currently being assessed, and will be added to the available solar and wind data, which are based on existing studies that cannot be regularly updated. Biomass sites were identified, but biomass potential was indicated only through precipitation and temperature. Some data, such as from power stations in member states, are being collected annually, but this was not the case for most sources. However, the mandate of ECREEE means they are as up-to-date as possible.	4
G	Hydro and biomass potential sites were gathered from pre-existing work by the national utility TANESCO, the Minister for Industry, and GLOBCOVER. Stand-alone systems were indicated only, and solar irradiation was not considered. The age of data was not clear, but the cooperation of TANESCO and various ministries means the data were most likely up-to-date.	4
H	This best practice methodology utilised existing studies, ground-based data collection, ministry information and primary research. The Seila Commune Database, used extensively for demographic data, was three years old at publication, thus one of the oldest sources used. Small hydro and biomass were considered extensively using existing studies and hired locals to collect two years of site data across many pre-identified sites. Satellite data were used to gather solar irradiation and mean wind speeds. Extensive consideration was also given to grid infrastructure, performance and costs through collaboration with Ministry of Mines and Energy.	5
I	Data for the indicators used in the ranking were taken from Bloomberg New Energy Finance. Their sources are not clearly referenced apart from a few online global databases such as the Global Reporting Initiative and the World Bank's Worldwide Governance Indicators Index.	N/A
J	The data were from global datasets and sources, the oldest of which was the UNDP Human Development Report 2007/08. Some of these global datasets are annually updated, others less regularly.	3
K	The data were obtained from the Uganda Bureau of Statistics and through a workshop discussing the applicable weighting of different demand centres. Both sources appear to be from the year of publication, 2006. Only infrastructure, population and demand centres were considered.	3
L	The input parameters used in this methodology referenced sources that could not be found, so it could not be assessed for validity, age or relevance. The publication examined showed proof of concept, and therefore the mechanics rather than source quality is prioritised. The methodology considered grid infrastructure and demographic sources, with a focus on demand centres such as schools, clinics and police stations.	Not known

3.5 HANDLING OF DATA PAUCITY

This section concerns the approaches taken to perform a complete analysis using potentially incomplete data sets. Such approaches could include extrapolation from older datasets, consultation with local experts, drawing parallels with similar work in other countries, or theoretically modelling data. A high score reflects a methodology in which the approach applied meant that data paucity had little or no effect on the validity of the output.

The most comprehensive methodologies - the Electrification Master Plan in Cambodia and the National Electrification Prospectus in Tanzania – had the time and resources to conduct field studies as well as engage ministries and other stakeholders to ensure the collection of the most relevant data available for each parameter. Other methodologies had to address data paucity issues, and four primary methods were seen:

- Design the methodology around the available data sources
- Use older data sources if up-to-date data were not available
- Estimate or extrapolate data from similar countries or theoretical formulas
- Stakeholder consultations.

A good example was seen in Methodology E, by the Hanoi Institute of Energy. The lack of data in Vietnam on population centres and the grid network would have been a critical limitation on a methodology assessing the levelised cost of energy of different technologies. This was dealt with effectively by treating the missing parameters as variables, with the levelised cost of energy of different electrification options shown against a range of variable values. Therefore, the relative cost of energies of different options could be compared easily in a table for multiple household densities, to still arrive at a reasonably useful conclusion as to the most competitive option.

Table 7: Data paucity assessments

Method	Handling of Data Paucity	Score (1-5)
A	Local diesel costs were remotely estimated using the JRC Accessibility map of the travel time from the nearest major city. The hydro resource was remotely assessed using estimates for river flow rate based on a global elevation dataset and select gauge stations. Population data paucity was circumnavigated by using a fixed design of solar PV system, varied with solar irradiation to achieve a fixed peak power rating.	3
B	The test region had a full set of pre-existing studies, so paucity was not an issue. The exception was the grid extension costs, for which a non-linear equation was calculated from relevant studies/data. This approximation was more accurate than the fixed cost/km normally used.	5
C	Diesel costs were remotely estimated as in Methodology A. Grid extension plans were taken to be entirely those planned by the African Development Bank. Demand was remotely assessed using the national targets for energy access for rural and urban areas, and then used as a parameter in a sensitivity analysis.	4
D	Some consultation was used to address data paucity, including specific cost estimates of each technology, referenced against market prices. Local diesel prices and demand were agreed on through consultation.	3

Method	Handling of Data Paucity	Score (1-5)
E	The missing variables were not estimated but used as parameters. The output levelised cost of energy estimations were given in tables, with a variety of values applied to those parameters. This was a robust approach, but the critical nature of the missing population statistics meant only limited the outputs and conclusions could be drawn.	4
F	The ECOWREX platform mapped existing datasets, which will be updated if/when more up-to-date information becomes available. Aside from updated data, the methodology will not require further changes.	3
G	The paucity of data provided by TANESCO and the Tanzanian ministries was acknowledged in the National Electrification Program Prospectus report. It was noted that TANESCO is the main but not the only electricity supplier, and that the utilities' datasets have inaccuracies due, for example, to more than one household being connected to a single meter.	5
H	Extensive data collection and research were conducted as the baseline for the development of the Rural Electrification Master Plan.	N/A
I	The issue of data paucity was avoided by using remote data sources for the target locations.	5
J	The issue of data paucity was avoided by using remote data sources for the target locations.	5
K	The small number of inputs required came from available sources. The adequacy of data from those sources is not clear, but the GIS maps in the report appear comprehensive.	5
L	This cannot be assessed due to the unavailability of the listed sources.	Not Known

3.6 SOFTWARE REQUIREMENTS

Most of the methodologies utilised geographic information systems (GIS), which were run on a computer or laptop. This analysis is primarily concerned with the types of software requirements; i.e., whether specific software was required or the tool was hosted on an online platform. The report does not consider the specific processing constraints of the methodologies, as most could be applied using a variety of tools, and most did not specify which GIS software was used.

For reference, one of the most commonly used GIS software packages, ArcGIS, has software requirements that can be met by a standard-range computer[6]:

- CPU Speed – 2.2 GHz
- Platform – Windows 7 or higher (x64)
- Memory/RAM – 2 GB minimum
- Disk Space – 2.4 GB
- Graphics Adapter - 64MB RAM minimum, 256 MB RAM or higher recommended

6 http://www.esri.com/software/arcgis/arcgis-for-desktop/system-requirements

Therefore, the primary limitations in the delivery of a GIS-based tool was the training required or, in some cases, the cost of software and licensing.

For this category, a higher score denotes lower software requirements, with a score of 5 for no requirements at all.

Table 8: Software requirements assessment

Method	Software Requirements	Score (1-5)
A	Unspecified GIS software was utilised. Therefore, standard software requirements are assumed.	3
B	Unspecified GIS software was utilised. Therefore, standard software requirements are assumed.	3
C	The original methodology used an unspecified GIS tool, most likely one such as ArcGIS. The online tools using this methodology required only an internet connection. Reasonable download speeds may be required to use freely.	3
D	The Network Planner is online and can be run on a standard computer or laptop.	5
E	Unspecified GIS software was utilised. Therefore, standard software requirements assumed.	3
F	IntiGIS uses ArcGIS.	3
G	The GEOSIM software developed and used by IED is GIS based, and has minimal software requirements.*	4
H	Unspecified GIS software was utilised. Therefore, standard software requirements are assumed.	3
I	No software requirements.	5
J	No software requirements.	5
K	Unspecified GIS software was utilised. Therefore, standard software requirements are assumed.	3
L	Unspecified GIS software was utilised. Therefore, standard software requirements are assumed.	3

* http://www.geosim.fr/uploads/GEOSIM-EN.pdf

3.7 ROBUSTNESS

Robustness refers to the ability of a methodology or tool to deal with errors. A non-robust methodology is highly sensitive to errors, so the result would be highly variable when inputs are changed only slightly. This is of crucial importance for rural electrification, where the inherent uncertainty in measuring and forecasting demand and other population-dependent factors means a non-robust methodology would be likely to present a non-optimal solution.

The key issue concerning robustness is the risk of relying on inaccurate or out-of-date sources for parameters on which the output is highly dependent. Various sensitivity studies examined as part of the methodologies found that the sensitivity on parameters such as demand level, distance to the grid and local diesel prices have a significant impact on, for example, whether it is most economic to electrify via grid extension, mini-grid or stand-alone systems. For methodologies employing a weighting of factors, such as for demand-led prioritisation of settlements for electrification, the choice of weightings is significant. These methodologies tended to use stakeholder consultation to agree on the appropriate relative weightings.

Table 9: Robustness assessment

Method	Robustness	Score (1-5)
A	The methodology, as applied, was robust due being continent wide and not reliant on country-level data sources. The crucial exceptions were the grid and road infrastructure, which were already slightly out-dated when applied, and would need updating for any future projects.	4
B	A full spatial sensitivity analysis was done manually, with single variable parameterisation and simultaneous parameter variation (random changes in multiple variables), which demonstrated explicitly the dependence of the model outputs on input parameters such as demand. This enabled a fully robust conclusion to be drawn.	5
C	The methodology was based on country-level and remote data, with a robust framework methodology and few broad assumptions. The resource data were taken from sources such as IRENA and UNIDO, which have a high potential for updated source data. The infrastructure data were as given in Methodology A and were out-dated, as were the population data.	3
D	A sensitivity analysis was performed by varying certain parameters and measuring the effect on the final result. The high dependence on certain parameters such as demand and diesel price was therefore accounted for. However, the forecasting and projections used in the model, while creating a more precise solution, also introduced a greater potential for compounding errors and thus reduced robustness.	4
E	This methodology was robust due to parameterising variables for which there were no available data. Although this affected the conclusions drawn, it limited approximation and extrapolation. The broad nature of the final estimate for the proportion of population best served by each option was naturally robust.	4
F	It has not been possible to examine the robustness of the IntiGIS tool.	Not Known

Method	Robustness	Score (1-5)
G	This demand-led methodology measured development potential for different electrification solutions through existing social structures. Therefore, its robustness depended on the weighting criteria used to define the boundary of potential required for a settlement to be a 'development centre.' This distinction was crucial to the electrification options explored, and may well change with political and other factors. The National Electrification Program Prospectus is the foundation on which a National Electrification Master Plan will be developed, and part of the development of this plan would be a sensitivity analysis of the robustness of the scenario presented in the Prospectus.	3
H	The level of data collection ensured a robustness of input data. The main source of potential fragility was in the cut-off thresholds used to differentiate the levels of electrification provided to villages, which were based on criteria such as the level of electrification (excluding battery) and TV diffusion.	5
I	Less applicable as the purpose of a weighted ranking is to give an indicative list based on an assessment of the relevant choice and weighting of available indicators. This final ranking is highly dependent on the choice of indicators and weightings.	3
J	Less applicable as the purpose of a weighted ranking is to give an indicative list based on an assessment of the relevant choice and weighting of available of indicators. This final ranking is highly dependent on the choice of indicators and weightings.	3
K	The benefit ranking was dependent on the weightings given for each demand centre, especially with regard to the relative benefit assumed for household vs. service centres. These weightings were chosen in consultation with stakeholders. It could also be assumed that some level of correlation would exist between settlement size and service levels, which may mean a lower sensitivity on the relative weightings.	4
L	This methodology specifically avoided utilising a supply-led approach in order to prevent a perceived lack of robustness of outputs. This approach was taken due to the high sensitivity of the values found or chosen for certain input variables. The weighting values appear to have been chosen by the authors.	3

3.8 OPENNESS AND EASE OF USE

This section examines the ease with which the methodologies can be accessed and utilised. For example, an online platform might be freely available, while software developed internally at a national utility might not be available externally. For non-tool-based methodologies, the ease with which the methodology could be replicated by an external team is also considered.

The methodologies varied considerably in their openness and ease of use. Those with low scores lacked clarity concerning the mechanics used or the chosen data sources. Others, such as the Electrification Master Plan of Cambodia, were well presented given their scale and scope, but were by their nature too in-depth and involved to be easy to interpret and build upon.

At the technical level, none of the methodologies had a significant problem, as most were well presented and detailed. However, attempted replications of the methodologies were limited by GIS skills and software.

Utilising online tools such as Network Planner, for example, allowed users to circumnavigate the more technical aspects of the planning methodologies. However, some methodologies, such as the Joint Research Centre's assessment of Africa's renewable potential in Methodology A, utilised very technical academic work or publications that would be difficult to replicate as required.

Table 10: Openness and ease of use assessment

Method	Openness and Ease of Use	Score (1-5)
A	The outputs were presented as clear and understandable graphics. The methodology used to calculate hydro potential, taken from a previous research paper, was very complex and scientific, and therefore only usable as given. All of the other calculations were easily replicable.	4
B	There was a lack of clarity in some of the assumptions and model mechanics, which would hinder easy replication of this methodology, especially when considering the specificity of the data sources.	2
C	The UN-DESA tool was visually clear and easy to navigate, although it sometimes took a long time to load. Energy consumption and diesel price levels could be changed to compare electrification scenarios. To allow for replication, the underlying methodology was clearly presented and detailed, with equations and value choices outlined.	5
D	The Network Planner is freely available and usable online.	5
E	The methodology was clearly outlined to allow for replication, depending on data availability.	3
F	The IntiGIS software can be downloaded from the CIEMAT website, although replication would require the purchase of the commercial ArcGIS website. The ECOWREX platform and the soon-to-be integrated IntiGIS 2 are free of charge and easy to find online.	4
G	GEOSIM and the other complementary IED tools are commercial. Only the IED mapping platforms are available free of charge. The internal mechanisms of the GEOSIM software, which were used to calculate the electrification plan from the stated inputs, were not published. Therefore, replicability without purchasing the software would not be possible. Usability was low, as a 10-day training course was required prior to use.	1
H	The full Electrification Master Plan is available online, but is not easy to find and, due to its size and scope, is resource consuming to interpret.	2
I	The index and its methodology are freely available online. However, the sources used for each indicator were not given clearly.	2

Method	Openness and Ease of Use	Score (1-5)
J	This methodology is freely available online and is very simple replicate. The list of remote indicators and their weightings were clearly given.	5
K	The methodology is freely available online and the sources, inputs and mechanics were well explained. Replication would be very possible.	5
L	The methodology relies on a network optimisation algorithm that requires some technical understanding. The lack of clarity of sources limits openness and ease of use.	2

3.9 INTEROPERABILITY WITH OTHER PLANNING METHODOLOGIES OR TOOLS

This section examines the ease with which the inputs and outputs of the methodology can be integrated with other development tools. For example, a methodology's mapping tool may qualitatively give a regional indication of the solar resource, which would guide the application of a resource opportunity assessment of that region against other resources. The result –commonly a levelised cost of energy estimate for each resource throughout the region – could then potentially be fed into a system design and optimisation tool such as HOMER.

This assessment has found that the majority of the methodologies provide only an indication of the relative competitiveness of different electrification options at a settlement, sub-regional or regional level. Therefore, given the nature of opportunity assessment tools – i.e., providing indications of potential rather than a detailed system design or technical and economic assessment – there is naturally a strong fit with system design tools and further ground studies that would be utilised once a priority site had been identified.

Table 11: Interoperability assessments

Method	Interoperability with Other Planning Methodologies or Tools	Score (1-5)
A	This is a high level methodology that aims to provide an indicative assessment of the potential in a region. Therefore, it will be utilised prior to, and is completely compatible with, the development of more detailed scenarios.	5
B	The interoperability of this methodology is relatively low due to its aim of validating the use of GIS for electrification planning, rather than to facilitate, and form part of, a planning process. However, the outputs could theoretically be used to feed into a system design tool.	3
C	This methodology was designed purely as an opportunity assessment methodology, and therefore the output gives a strong indication as to the relative costs of different electrification options in a set location. A system design tool would then be utilised for a specified region to progress the planning process.	5

Method	Interoperability with Other Planning Methodologies or Tools	Score (1-5)
D	The Network Planner is not purely an opportunity assessment methodology, as it creates a full (but simplified) system design in order to calculate the least-cost option. Therefore, the output overlaps with some system design tools, although these could still easily be used to perform the detailed technical assessment required to progress to later planning stages.	3
E	The output of this methodology is not site specific, but provides indicative levelised cost of energy estimates for the entire country. Its utilisation will precede and be completely compatible with the development of more detailed scenarios.	5
F	The cost estimate for different technologies produced by IntiGIS are indicators for stakeholders and investors to use in developing more detailed studies. This methodology does not try to link directly with any other tools.	5
G	IED have developed four compatible tools covering the rural electrification planning process; design and costing (GEOSIM), demand analysis (DEMAND ANALYST), GIS interfacing (GIMSYS) and grid design/optimisation (GISELEC).	5
H	The Electrification Master Plan does not require the application of further tools. All factors, including necessary policy reforms and the establishment of institutions, are considered.	N/A
I	The index of country rankings indicating opportunities for the development of renewable mini-grids is directly compatible with any tool used to further explore the potential within a country selected from the ranking.	5
J	The index of country rankings indicating opportunities for the development of renewable mini-grids is directly compatible with any tool used to further explore the potential within a country selected from the ranking.	5
K	The aim of this methodology is to guide the planning process through the prioritisation of areas for electrification. Further tools could then be used to develop an electrification plan for these areas.	5
L	The methodology is designed explicitly as a foundation for the development of a more complete, objective and transparent electrification decision-making process in South Africa. Its conclusions are designed to be integrated into the inputs of further tools, and are completely compatible with those tools.	5

3.10 COST AND LEVEL OF TRAINING REQUIRED

This section considers the cost and level of training required to replicate each methodology, such as when a methodology developed by a research team is applied to a target country. For online platforms, the cost of accessing and using the platform is considered.

For example, using the reference of ArcGIS, the price for the basic ArcGSI package is[7]:

Product	Price (excluding VAT) for a perpetual license	Annual Maintenance Price (excluding VAT, a year after purchase)
ArcGIS for Desktop Basic (Single Use)	£ 1648.00	£464.00
ArcGIS for Desktop Basic (Concurrent Use)	£3554.00	£721.00

However, multiple free versions are available with similar functionality, including QGIS and Grass GIS.

Most of the methodologies used unidentified GIS software, with some organisations such as Columbia University developing their own. The financial burdens of such software are not significant for an organisation that regularly utilises spatial mapping or other GIS tools. However, organisations with fewer regular requirements will find very functional free tools, such as QGIS and Grass GIS.[8]

A score of 5 represents no cost of training required, whereas a score of 1 means significant costs and training required.

Table 12: Cost and training assessment

Method	Cost and Level of Training Required	Score (1-5)
A	The reports are freely available online, as well as the GIS maps produced. However, GIS software and training would be required to replicate this project.	3
B	GIS software and training would be required to replicate this project.	3
C	The UN-DESA platform is free to access, and the methodology has been published in academic journals and sites such as ScienceDirect. GIS software and training would be required to replicate this project.	3
D	The Network Planner methodology utilises GIS tools, but the interface for the user is fairly simple and requires no previous training. Online tutorials are available on the host site, and can be done independently.	5
E	GIS software and training would be required to replicate this project, although the methodology could potentially be replicated using Microsoft office-based spreadsheet modelling.	4
F	The IntiGIS tool, once hosted by ECOWREX, will be free to use. If used independently, then ArcGIS would be required (costs shown above). IntiGIS offers self-learning tutorials for independent users.	4

7 From discussion with Esri. Esri is an international supplier of geographic information system software, web GIS and geodatabase management applications.

8 http://qgis.org/en/site/ , https://grass.osgeo.org/

Method	Cost and Level of Training Required	Score (1-5)
G	IED's GEOSIM software is a commercial tool, with the cost depending on the user's organisation and number of licences. The level of training required is not insignificant, and is covered by a 10-day course.*	2
H	The full Electrification Master Plan is available for free online, but replication of the methodology is unfeasible due to the financial resources and technical know-how required.	1
I	No cost or training is required to use the published rankings, but replication would require substantial time and cost to identify and collect the sources required for each country for each identifier.	1
J	No cost or training is required to use or replicate this methodology.	5
K	GIS software and training would be required to replicate this project.	3
L	GIS software and training would be required to replicate this project. Training would also be required to understand the network optimisation algorithm utilised in this methodology.	2

* http://www.ied-sa.fr/images/Fiches_Formation_EN/Rural_electrification_planning.pdf

4. CONCLUSION

The aim of this report, as the first deliverable of the Market Intelligence business line of the African Development Bank's Market Development Project, is to analyse the methodologies available to stakeholders in Africa to assess the potential for mini-grids.

The identification and assessment of these 'opportunity assessment methodologies' will then form the foundation for the second deliverable, the creation of a standard opportunity assessment methodology that can be used to generate actionable, comparable data across African countries. It is not within the scope of this report to provide an opinion on the 'ideal' or best practice methodology, but only to achieve a good understanding of the relevant methodologies and present the results of the assessments.

There is a wide range of methodologies and tools available in this sector, with most using GIS-based data sources and the majority utilising GIS in the mechanics of the methodology as well. However, the relative immaturity of these methodologies, combined with the issues of data availability and quality in Africa, means that there are still substantial differences found among them in terms of the criteria assessed.

In terms of relevance to stakeholders: Although most had a clear developer and decision maker perspective, the lack of consideration of certain key factors, such as expected demand, meant that the conclusions of some methodologies had limited relevance. In addition, four of the twelve methodologies did not consider the distribution of sources of generation within the country or target region, either not considering the supply side of the opportunity or relying on assumptions.

Relevance and quality of outputs: Closely linked to the relevance to stakeholders, the lack of available data was found to be the most common cause of variation observed in the outputs. Methodologies with GIS databases were able to produce very clear and engaging visual representations of the distribution of electrification types or least-cost generation options. Those using remote data or higher-level sources were unable to match this clarity and resolution. As mentioned in the relevance to stakeholders section, a lack of data for key parameters also limited the type of comparisons and conclusions possible for some methodologies.

Data requirements: Only two of the methodologies incorporated field work and ground-level data collection, and these were for projects developing a country's' electrification master plan. The scale of time and resources required to effectively conduct such research meant that most methodologies instead utilised a variety of existing studies, remote datasets and extrapolations. Many of the methodologies were academic in nature, and thus did not have access to the resources made available through an international or government-funded project.

The sources in Africa tended to be two to six years old, even for more static factors such as infrastructure, and there was a lack of government sources in the methodologies. This was somewhat surprising, since data such as the location of infrastructure or the sizes of a country's health centres would be held by the relevant ministries. This points to a lack of easy access to these sources, and to the need for established relationships with the ministries.

Handling of data paucity: Given the lack of up-to-date, ground-level data, most methodologies had to deal with data paucity. The most common approaches were:

- Designing the methodology around the available data sources
- Utilising older data sources if up-to-date ones were not available
- Estimating or extrapolating data from similar countries or theoretical formulas
- Stakeholder consultations.

Values for which there were sources, such as the performance or cost characteristics for a certain type of mini-grid, were commonly given approximate values. These could be easily referenced against industry values and selected global case studies, but were country or situation specific. Stakeholder consultations were sometimes used to provide a local context in these cases.

For datasets on, for example, resource availability, the most common solution was to develop the methodology around the available sources. Another technique observed in several methodologies was to use the missing factor as a variable, giving the output over a range or selection of values. This allowed for the identification of output values and results, but left the methodology limited in some aspects such as the spatial mapping of solutions.

Software requirements: The vast majority of the methodologies examined utilised GIS software, while a few needed no software or were hosted online. The software requirements for GIS were not restrictive, with the minimum operating requirements for programs such as ArcGIS being below the specifications of standard desktop or laptop computers.

Robustness: The two most common issues affecting the robustness of the methodologies were a reliance on out-of-date or inaccurate sources for key parameters, and the choice of weightings or thresholds. Several of the methodologies deployed sensitivity analyses to account for these shortcomings, and one methodology focused entirely on demand-led prioritisation of settlements in order to negate the high sensitivity of supply-led calculations on the estimation of performance and cost characteristics of the different generation options.

Openness and ease of use: The ease of access and of use were considered for tool-based methodologies, while non-tool methodologies were assessed for the ease with which the methodology could be replicated. It was found that the methodologies varied considerably in the clarity and openness of the mechanics and input sources utilised. The split between commercial and non-commercial methodologies was a key indicator for this due to commercial non-disclosure (intellectual property), although some academic methodologies were also still poorly explained.

Overall, however, the replication and use of methodologies was found to be substantially more limited by the GIS training required and the availability of relevant data sources than by other factors. With only a few exceptions, the technical understanding required was found not to be a problem, due in some cases to the availability of tools such as the online Network Planner.

Interoperability with other planning tools: The majority of methodologies had high interoperability, due primarily to the fact that opportunity assessment methodologies are meant to identify and assess opportunities for the development of rural electrification options, and lay the foundation for the use of other decision support tools. For example, system design tools such as HOMER can integrate the results of the opportunity assessment as input parameters. Interoperability is not a concern because the programs are not required to interact automatically and independently of user control.

Cost and level of training required: Commercial GIS software and associated tools cost in range of a few thousand pounds a year, which is not considered prohibitively expensive for organisations utilising spatial mapping on a regular basis. For organisations that use GIS less frequently, some free multi-function software packages are available.

The training required is perhaps the largest barrier to the uptake of GIS-based methodologies and tools, with a 10-day training course offered for IED's GeoSim tool, and multiple online and international courses for software such as ArcGIS. However, this skillset will be broadly applicable to planning organisations and other electrification stakeholders, and will become a standard part of the organisational structure as the use of GIS continues to expand across Africa. Therefore, the training will almost certainly be a long-term investment rather than a project expense.

NEXT STEPS

This report has shown the variations in the methodologies available to stakeholders in Africa. The input parameters checklist in Figure 14 shows that no methodology considered all of the parameters, and that only two parameters were considered by the majority of methodologies. Similarly, the methodologies had many different approaches to other aspects such as handling of data paucity, size and resolution of target area, and types of sources used.

The second deliverable of this project, the "creation or choice of an opportunity assessment methodology in order to generate comparable data across countries," will draw heavily from the findings of this report. There is clear scope for combining various aspects of the methodologies to develop a template methodology that can to be used across Africa to assess the potential of green mini-grids in rural areas.

ANNEX: METHODOLOGY SUMMARY SHEETS

METHODOLOGY A: GIS-BASED COST COMPARISON OF SOLAR PV, MINI-HYDRO, DIESEL AND GRID EXTENSION FOR AFRICA (EC JOINT RESEARCH COMMISSION, SZABO S. ET AL.)

Methodology Type:	**Coverage:**	**Uses Spatial Mapping:**
Supply-led	Africa	Yes

Summary:

This methodology was developed by the Joint Research Commission in a series of analyses from 2011 to 2013, to identify the potential of different renewable options. Of specific consideration was the variance in diesel costs between rural and urban communities, and how to circumnavigate the lack of comprehensive country-level data.

The levelised costs of solar PV, mini-hydro and diesel generation were compared, with grid extension considered viable within a fixed distance of the existing grid network. Later studies incorporated fixed grid extension costs and the assessment of mini-hydro potential. The cost estimates were considered against two Ability-to-Pay (ATP) scenarios, and spatial mapping was used to show differently coloured regions across Africa where each option was the lowest-cost solution (or where no options were viable within the ATP scenario). This was combined with a population density map to indicate the percentage of the population best served by each electrification solution.

Input Parameters:	**Sources:**
Renewable data	
Solar irradiation	PVGIS database (HelioClim-1).
River average annual flow rate	Bódis K. (2009). Development of a data set for hydrological modelling – Global Runoff Data Centre.
Pico hydro performance and cost estimates	Energypedia (2011). https://energypedia.info/wiki/Pico_Hydro_Power.
Network and energy data	
Accessibility and travel time (to major cities)	Nelson A. (2008). Estimated travel time to the nearest city of 50,000 or more people in year.
Diesel prices (national)	GIZ International Fuel Prices: BMZ.
Transportation costs	United Nations University (2007). The Significance of Transport Costs in Africa Policy Brief n.5.
Existing grid network	Africa Infrastructure Country Diagnostic (2009). Kaijuka E. (2007). GIS and Rural Electricity Planning in Uganda. Szabo S. et al. (2010). Building the African Renewable Energy Platform: Integrating Support Tools for Sustainable Energy Development in Africa.
Grid extension cost	Ministry of New and Renewable Energy, Government of India (2011). Energy Access – Draft, Sub-Group Report, p.3/19.

Mechanics:

This methodology was developed over three stages, with the addition of mini-hydro potential assessment in the second phase and updated cost estimates and grid extension cost methodology in the third phase.

In one of the outputs of this methodology, the *Energy Solutions in Rural Africa* paper (Szado et al. 2011), the lowest-cost solution of either diesel generators, grid extension or solar PV mini-grids was compared and mapped using GIS. The viability of an option was defined by two ATP scenarios, 0.25 and 0.3EUR/kWh, and the potential population (in millions) best served by each electrification option was then shown for both thresholds.

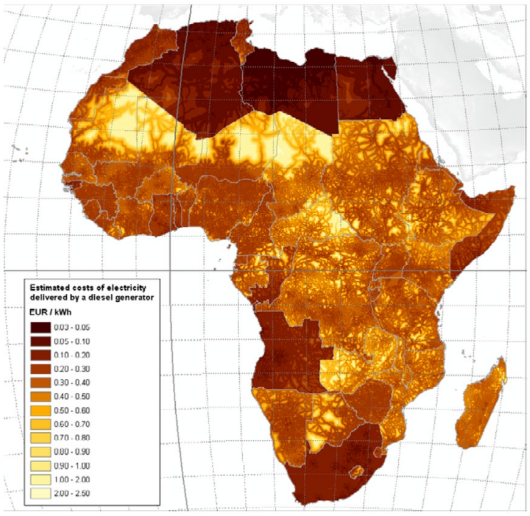
Grid extension

The boundary for the area electrified under grid extension was set on a continent level to 50, 30 and 10km from high, medium and low power lines, respectively, and within this boundary, grid extension was considered economical. The levelised cost of energy for diesel or solar PV was considered within these boundaries, and identified separately for regions where only grid extension was viable. The 2013 Sustainable Energy Planning; Leapfrogging the Energy Poverty Gap report, updated this methodology, using a fixed grid extension cost of 2.5EURc/kWh/km instead of a set boundary.

Diesel generation

The local cost of diesel was calculated by adding the national diesel prices to a transportation cost proportional to the travel time, including road, off-road and water-based travel, from the nearest major city (Nelson [2008]. JRC accessibility map). All other variables, such as diesel generator efficiency and volume of diesel transported per vehicle, were fixed.

Figure A.1: Diesel cost map



Solar PV

The solar solution was approximated using a 15kWp (kW peak) system, with the PV array and battery size optimised to this rating, depending on the average incident irradiation. All inputs and costs other than system size were fixed.

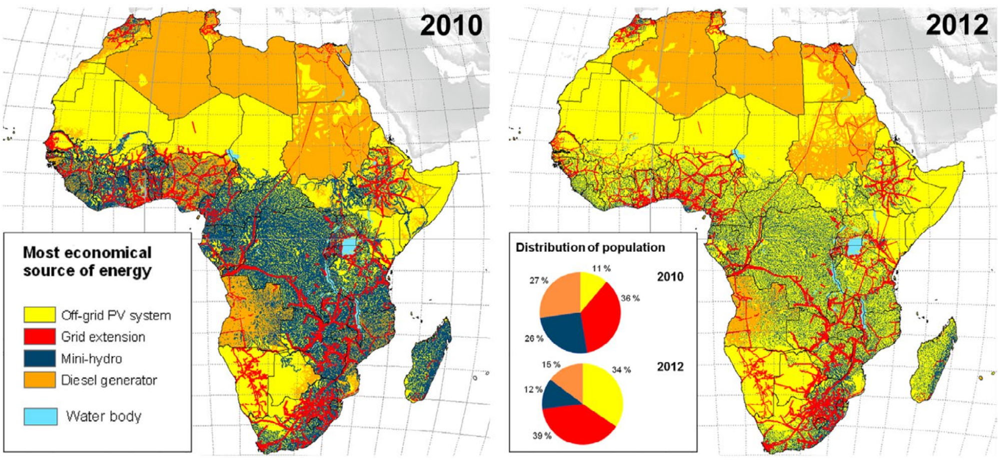
Population factors, including demand, were not considered, but are reflected in the choices of the ATP scenarios. These cost estimates were updated in 2013 in the *Sustainable Energy Planning* report.

Mini-Hydro

For the *Renewable Energies in Africa* report (Szabo 2011), this was further combined with continent-scale assessments of hydro, wind and biomass resources, although only hydro was given a levelised cost of electricity (LCOE). Hydro data were derived from a continental-scale remote assessment using global elevation datasets to approximate mean annual stream flow.

The LCOE was calculated from a fixed production cost of 15EURc/kWh and a fixed grid extension cost of 2EURc/km from the population to the nearest hydro resource. The hydro resource was required to be a permanent river with greater than 1 percent gradient, greater than 4m^3/s annual flow and a catchment size of greater than 100km^2. By comparing the diesel and solar PV options at the ATP level of 0.3EUR/kWh, the area potentially best served by mini-hydro was identified. The biomass and wind resources were mapped separately for reference, with no LCOE given for comparison.

Figure A.2: Comparing the lowest cost options between the original methodology (including mini-hydro) and the updated methodology and costs in the Sustainable Energy Planning report.



Commentary:
This was a high-level methodology that did not incorporate ground-level or population data but nonetheless catalysed additional, more detailed work into comparison of electrification options. The consideration of travel times from major cities to calculate diesel costs is an approach that has been adopted widely, but the lack of consideration of population factors (especially population density and economic situation) in this case meant that only indicative country-level assessments of solar PV and grid extension potential were possible.

The remote hydro resource assessment technique was very useful for a resource that usually requires extensive data collection. Clearly this information was very useful as an indicative country-level estimate of mini-hydro potential, but it could not be used in isolation without further onsite data collection.

The diesel vs. solar PV calculation has been integrated into the JRC's RE2nAF African Renewable Energy Technology [GIS] Platform.

Highlights:

- Did not include population density or energy demand
- Fixed boundaries used for grid expansion
- Renewable energy resources considered: solar and hydro; no wind or biomass
- Only variable in the solar PV calculation was the sizing of the PV systems
- Micro-grid was considered only for solar PV but not for PV-diesel, wind-PV, or other hybrid systems
- Hydro information only allows for an estimation of the hydro potential

Links:
African Renewable Energy Technology Platform - RE2nAF Tool
http://re.jrc.ec.europa.eu/re2naf.html

S. Szabo et al. (2011). Energy Solutions in Rural Africa: Mapping Electrification Costs of Distributed Solar and Diesel Generation versus Grid Extension

A. Belward, S. Szabo et al. (2011). Renewable Energies in Africa.

S. Szabo et al. (2013). Sustainable Energy Planning: Leapfrogging the Energy Poverty Gap in Africa

METHODOLOGY B: GIS-BASED COMPARISON OF SOLAR, WIND, DOMESTIC AND CENTRALISED DIESEL AND GRID EXTENSION IN THE MUNICIPALITY OF LORCA (CENTRE FOR ENERGY, ENVIRONMENT AND TECHNOLOGY AND POLYTECHNIC UNIVERSITY OF MADRID, J. AMADOR, J. DOMINGUEZ)

Methodology Type:	**Coverage:**	**Spatial Mapping:**
Supply-led	Municipality of Lorca, Murcia (Spain)	Yes

Summary:
Verified using the municipality of Lorca, this methodology was developed by researchers at CEIMAT and EUTI UMP to validate the use of GIS to identify the appropriate conventional or renewable technologies for electrification. Comparing solar, wind, diesel and grid extension, a 1km^2 resolution grid with least-cost technology options was generated using demand estimation and population density to determine the local load.

Input Parameters:	**Sources:**
Renewable data	
Solar annual radiation	Ramırez L. et al. (2003). Global Solar Radiation in Spain from Satellite Images.
Wind speed	Ramırez L, et al. (1999). Renewable Energy Resources in Murcia Region.
Cost estimates	Vallve X, Serrasolses J. (1997). PV Standalone Competing Successfully with Grid Extension in Rural Electrification: A Success Story in Southern Europe. Notton G, et al. (1997). What Hypothesis for an Economic Study of Electric Generators for Rural Areas? Literature Survey and New Suggestions. Pantoja A, et al. (1992). Analysis of Generation Experiences and Operation-Maintenance and Costs of the Photovoltaic Systems of Hidrola. Energia Solar 53.
Network and energy data	
MV grid infrastructure	Iberdrola (1999). Analysis and Tracing of Overhead Cable of Low and Medium Voltage. Madrid.
Demographic data	
Population density	*Not Known*
Economic values/residential demand	REE (1998). Atlas of the Spanish Electric Demand. INDEL Project. Madrid.

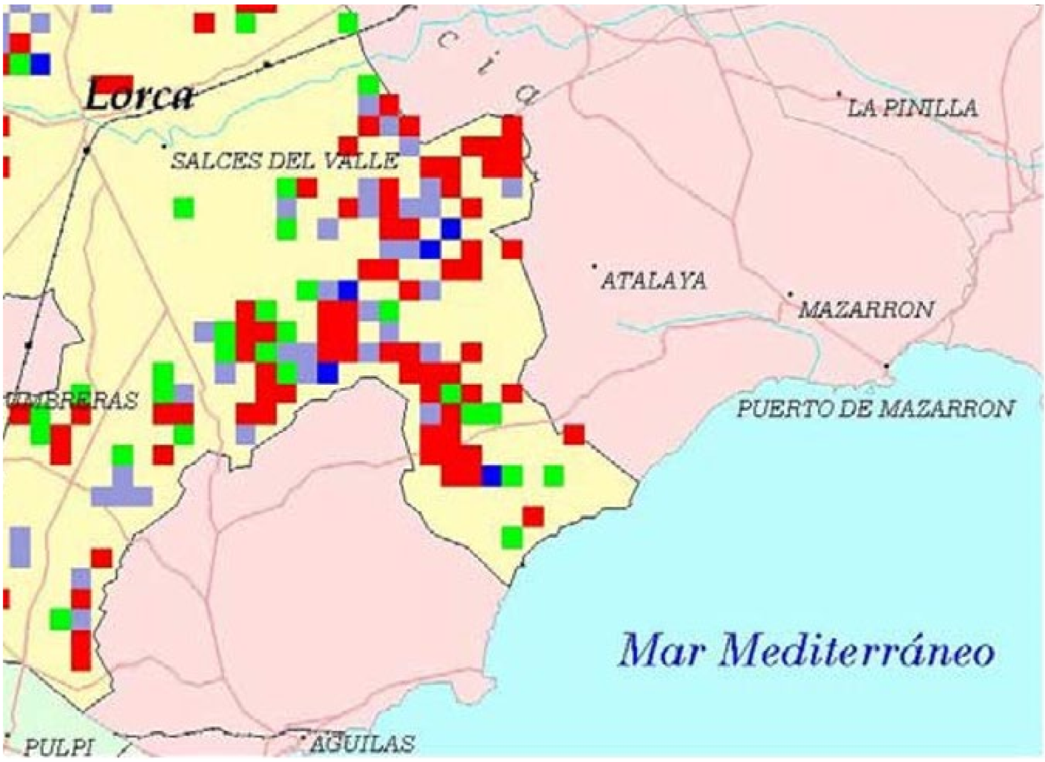
Mechanics:
The cost of energy was calculated for solar PV, wind, central and domestic stand-alone diesel and grid extension. The load level for each pixel was calculated as the household density multiplied by the demand levels, which were attributed based on a matrix of economic level and average household sizes (different for renewable and centralised systems).

A spatial analysis methodology was used to perform a sensitivity analysis on the different variables in the LCOEs of diesel, wind and solar, which was illustrated for the rural households of the Lorca municipality.

Grid extension
Connection costs for centralised systems were assumed to be fixed. The cost of medium-voltage overhead cables (no high voltage used on a municipal level) was calculated using a non-linear relation to the length of the line, with short line extensions having a higher cost/km.

Distributed generation (diesel, solar PV, wind)
The load, calculated above, was used to determine the scale of the distributed generation system required. The result was combined with the resource yield inputs to calculate the associated capacity factors. The levelised cost was then found for each technology option using fixed design parameters, such as EUR/kWp investments costs, and the lowest cost option displayed.

Figure B.1: The final lowest-cost model output



Commentary:

This methodology provided a clear visual presentation of distribution of least cost technology options, with the inclusion of a simple consumption estimation based on economic level and household size. This was a crucial variable to be considered, as shown in the sensitivity analysis, but one that is not always included in other studies. The sensitivity analysis also highlighted the sensitivity on certain factors such as demand, storage life, fuel price and incident radiation.

However, except for the medium-voltage cost equation, there was a lack of clarity on the methodology used – especially cost assumptions – which limited its usefulness apart from in the utilisation of GIS.

Highlights:

- Included population density and energy demand
- Grid expansion cost assumed fixed centralized costs
- Renewable energy resources considered: solar, wind but not biomass or hydro
- Micro-grid was considered only for solar PV but not for PV-diesel, wind-PV or any other type of hybrid system
- Hydro information only allowed for an estimation of the hydro potential

Links:

J. Amador, J. Dominguez (2004). Application of Geographical Information Systems to Rural Electrification with Renewable Energy Sources

J. Amador, J. Dominguez, 2005. Spatial analysis methodology applied to rural electrification.

METHODOLOGY C: GIS-BASED LOWEST-COST ASSESSMENT OF SOLAR, WIND, MINI-HYDRO, BIOGAS AND DIESEL TECHNOLOGIES AGAINST GRID EXTENSION, CONSIDERING LARGE MINERAL INDUSTRY DEMAND (KTH ROYAL INSTITUTE OF TECHNOLOGY, D. MENTIS, F. F. NERINI ET AL.)		
Methodology Type: Supply-led	**Coverage:** Nigeria and Ethiopia	**Spatial Mapping:** Yes

Summary:
This methodology was developed primarily by the KTH Royal Institute of Technology to address the perceived need for a standardised basic toolkit that could provide the foundation on which to build locally appropriate toolkits. The methodology led to the development of the Unite UN-DESA open source electrification tool, which gave a country-wide electrification solution that considered the least cost of energy for each pixel, depending on the parameters of diesel price and energy consumption tier. The total estimated cost of electrification was then given.
The results of these two papers were included in the IEA World Energy Outlook 2014.

Input Parameters:	**Sources:**
Renewable data	
Solar radiation and wind speed	IRENA (2014). Estimating the Renewable Energy Potential in Africa: A GIS-based Approach. Mentis D. et al. (2015). Assessing the Technical Wind Energy Potential in Africa: A GIS-based approach. Renew Energy 83:110–25.
Mini-hydro, existing and potential sites	UNIDO (2013). World Small Hydropower Development Report.
Biogas generators (F.F. Nerni only)	Khan U. et al. Techno-economic Analysis of Small-scale Biogas-based Polygeneration Systems: Bangladesh Case Study.
Other technology cost factors	Info Resources (2006). Sustainable Energy for Rural Poverty Alleviation. Focus. IEA (2012). Energy Technology Perspectives. ESMAP. Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies.
Network and energy data	
Local grid infrastructure, grid extension and power plants	AfDB (2011). Africa Infrastructure Knowledge Program.
Diesel	JRC. Land Resource Management World Data Bank.
Mineral reserves	USGS. Mineral Resources On-Line Spatial Data
Demographic data	
User demand Levels	World Bank Global Tracking Framework
Population density	IEA (2014). Energy Access Database EU Energy Initiative (2005).

Mechanics:
The model first looked at the existing and planned grid network, before using population data to determine whether on-grid or off-grid solutions would best serve the remaining areas. The target level of access, population density and resource availability and costs were then used to determine which technology would be most appropriate for off-grid areas.

Grid expansion

Grid expansion was approximated using AfDB's transmission expansion plan plus the assumption of connecting all planned and existing power plants and mines to the grid via MV lines (maximum 50k). By considering population data, the optimal on/off-grid split was found for the remaining unelectrified population, factoring in the national grid electricity cost and distance to the grid.

The grid extension algorithm of the model is detailed in *Mentis et al.* (2015).

Diesel generation

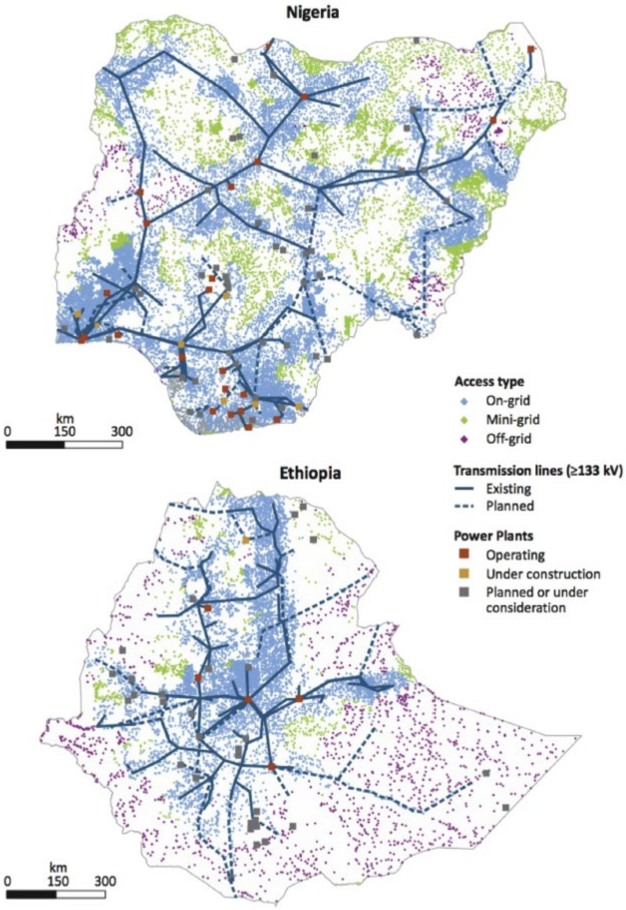
An LCOE cost comparison was then run for the different off-grid options. Diesel cost was taken from the EU JRC methodology, utilising the JRC accessibility database of travel time to big cities, which gave a final cost proportional to this travel time.

Renewable generation

The cost was expressed as both the levelised cost of energy and the total cost per household, with four key parameters used:

- Target level and quality of energy access
- Population density
- Local grid connection characteristics
- Availability of local energy resources and technology costs

Figure C.1: Optimal solutions for Nigeria and Ethiopia



UN-DESA Open Source Electrification Tool

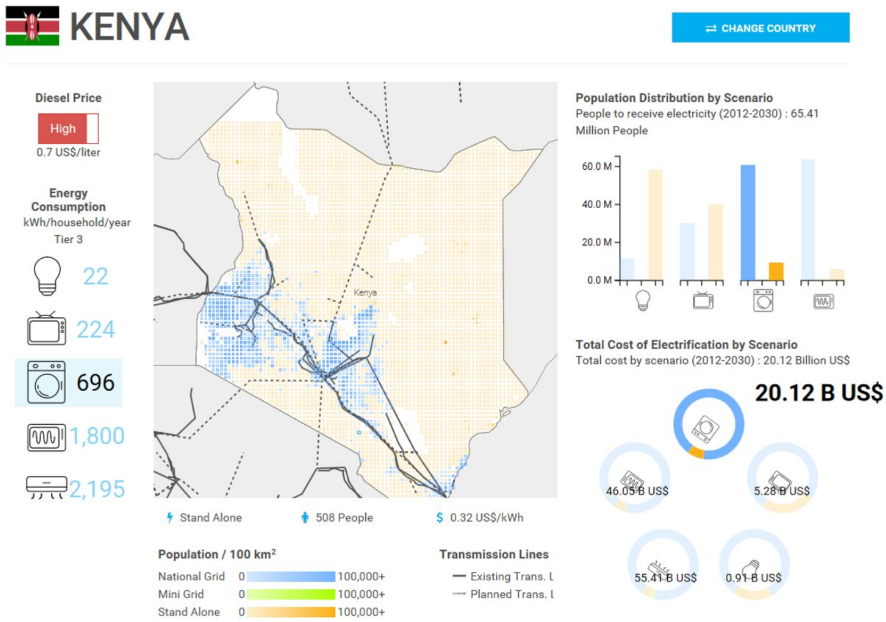
Released in March 2016, the UN-DESA tool, built with KTH using the methodology described above, measured the total electrification costs and optimal technology deployment options for each country in Africa. The split of grid, mini-grid and stand-alone options was based on the two parameters of diesel price and level of energy consumption (as defined by the World Bank tiers of energy consumption).

Commentary:

The methodology looked at changing investment costs and returns up to 2030 to determine the best electrification option. However, it assumed instantaneous implementation, which was unfeasible and potentially skewed the results toward grid extension by omitting long lead-in times. The metrics, especially the energy consumption tiers defined by the World Bank, aligned directly with SE4ALL and utilised relatively readily available data sources.

The newly released UN-DESA open source tool was very clear and usable, with well-presented graphics and interface. The key issue was the lack of mini-grids presented in the model, presumably due to a lack of identified renewable resources or a bug in the first release, which led to proposals that some countries be electrified with only grid or stand-alone options. Clearly this was at odds with other work and evidence in this field, as well as with the methodology, exemplified by Figure C.1, which showed significant mini-grid development in the solutions proposed for Nigeria and Ethiopia.

Figure C.2: Screenshot of the electrification option outputted by the model for tier 3 access with high diesel prices



Highlights:

- Included population density and energy demand
- Grid expansion cost assumed fixed centralized costs
- Renewable energy resources considered: solar, wind but not biomass or hydro
- Micro-grid was considered only for solar PV but not for PV-diesel, wind-PV or any other type of hybrid system
- Hydro information only allowed for an estimation of the hydro potential

Links:

Mentis et al. (2015). A GIS-based Approach for Electrification Planning: A Case Study on Nigeria

Nerini F. et al. (2016). A Cost comparison of technology approaches for improving access to electricity services

World Energy Outlook. IEA. 2014.

Open Source Spatial Electrification Toolkit
https://www.kth.se/en/itm/inst/energiteknik/forskning/desa/projects/ongoing-projects/open-source-spatial-electrification-toolkit-onsset-1.563573

UN-DESA Electricity Access Tool
https://unite.un.org/sites/unite.un.org/files/app-desa-electrification/index.html

METHODOLOGY D: GIS-BASED OPPORTUNITY ASSESSMENT METHODOLOGY USING THE NETWORK PLANNER TOOL (COLUMBIA UNIVERSITY, NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI ENERGY CENTRE, F. KEMAUSUOR ET AL.)

Methodology Type:	Coverage:	Spatial Mapping:
Supply-led	Ghana	Yes

Summary:
With a planning period of 10 years, the Network Planner tool was applied to 2,600 unelectrified communities in Ghana to predict the cost of different generation options (solar PV, diesel, grid extension) for each community. The total cost of electrification was given for each option/mix of options, and a sensitivity analysis was done to ensure the robustness of conclusions. The limiting factor of the tool was its reliance on remote datasets to avoid incompleteness, which meant that wind, mini-hydro and biomass were not considered.

The latest release of the Network Planner, v0.9.7, does allow for consideration wind, hydro and hybrid mini-grids, though this has not yet been demonstrated in practice.

Input Parameters:	Sources:
Renewable data	
Solar irradiation	SWERA (2011). National Renewable Energy Report: Ghana.
Network and energy data	
Grid infrastructure	Ghana: Energy Commission, Electricity Company of Ghana and Northern Electricity Department.
Diesel	Assumed consultation with generator dealers
Demographic data	
Population size and growth rate	Ghana Statistical Service (2010). Population and Housing Census.
Unelectrified community locations	Ministry of Energy. National Electrification Scheme (NES) Master Plan Review (2011–2020).
Elasticity of electricity demand	Bank of Ghana.
Demand	Assumed consultation with experts.
Financial/economic data	
Interest rates	Bank of Ghana
Economic growth rate	Bank of Ghana

Mechanics:
Network Planner is a dedicated support tool for design and costing of electrification options, developed by Modi Research Group at Columbia University. It builds only upon data available for all countries, so does not consider wind, hydro or biomass resources. Solar PV is only considered for off-grid, and not mini-grid, solutions.

The total cost of the electrification, for various penetration rates is then given, and a sensitivity analysis is performed to understand the robustness of the recommended electrification scenarios.

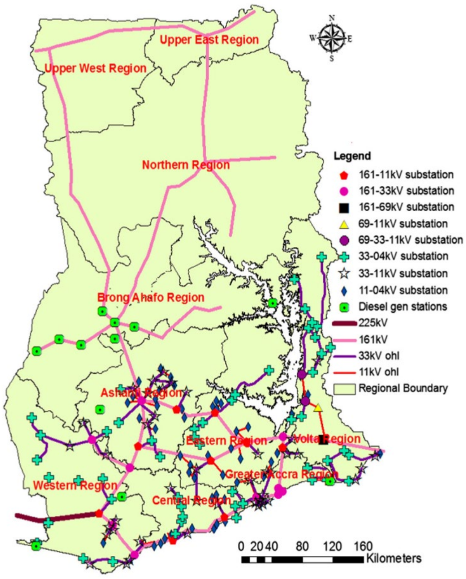
Initial conditions

In general, the model starts with geospatial data, such as settlement locations and distances to the MV grid, and socio-economic and demographic data such as interest rate, economic and population growth rate and mean household sizes.

Demand

Demand is then calculated from the initial conditions, with mean demand based on facility type (house, productive, commercial or institutional) and mean customer size. Population growth data are projected over planning timeframes, used to estimate peak and total demand over the planning period for each settlement. This calculation also includes the tendency for larger settlements with more service facilities (hospitals, schools etc.) to grow at a larger rate than smaller, lower-serviced settlements.

Figure D.1: Grid infrastructure of Ghana. 2011.



Electrification option algorithm

Detailed cost components for the three electrification options (solar PV, diesel generation and grid extension) are input into the model by the user. Cost components include discount rate, operation and maintenance costs and capital costs.

First, the three options are costed for each settlement, using the projections over the planning period. The off-grid option is defined as solar PV with backup diesel generation; the mini-grid is defined as diesel generation with LV distribution; and grid extension is defined as internal and external costs, where internal costs refer to the LV lines, transformers and other equipment that connects a household, and external refers to the MV lines connecting the community to the nearest network.

The lowest decentralised cost option (off-grid and mini-grid) is selected, and then compared against the internal costs of the grid extension for each household. If cheaper, then the selected decentralised option is selected, and all settlements where grid extension is cheapest are noted. A geospatial algorithm tries to connect all of the settlements marked for grid extension within the budget barrier, set by the difference in cost between the decentralised option and the total cost (internal and external) of grid extension for that community. If this is not possible, then the least-

Figure D.2: Final cost of electrification by region and penetration rate

Total and initial cost of all combined electrification technologies at each penetration rate.

Region	Cost of all electrification (US$) (grid, solar off-grid and diesel mini-grid)					
	Penetration rate = 100%		Penetration rate = 60%		Penetration rate = 30%	
	Total	Initial	Total	Initial	Total	Initial
Ashanti	61,100,000	36,200,000	43,4,000,000	26,000,000	27,100,000	11,500,000
Brong Ahafo	61,300,000	33,700,000	44,200,000	24,000,000	28,500,000	11,700,000
Central	57,100,000	33,500,000	41,100,000	24,700,000	25,800,000	14,700,000
Eastern	49,800,000	32,000,000	37,200,000	24,600,000	22,800,000	9,850,000
Greater Accra	2,860,000	2,020,000	2,120,000	1,240,000	1,350,000	718,000
Northern	147,000,000	85,600,000	104,000,000	53,900,000	67,200,000	26,600,000
Upper East	61,600,000	37,600,000	44,700,000	28,400,000	29,900,000	17,600,000
Upper West	68,700,000	40,600,000	48,700,000	31,000,000	30,300,000	12,600,000
Volta	84,200,000	43,600,000	57,800,000	30,700,000	37,500,000	20,100,000
Western	102,000,000	60,800,000	73,500,000	43,400,000	46,700,000	21,600,000
TOTAL	696,000,000	406,000,000	497,000,000	287,000,000	317,000,000	147,000,000

Commentary:
When used in Ghana, the Network Planner tool provided a level of accuracy above that of methodologies that rely predominantly on remote global or satellite sources. The input of specific population factors such as economic and population growth rates and hospitals allowed for a much more accurate discounted total cost projection for the country's electrification plan.

However, the tool was designed to automatically provide the primary datasets required, and therefore did not consider technologies such as mini-hydro or biomass, for which country data were not readily available. Wind also was not included, and the definition of the mini-grid option as diesel generation rather than a renewable source limited the applicability of this methodology for renewable mini-grid projects.

Highlights:

- Renewable energy resources considered: solar
- Population level data collection more accurate than remote data
- Detailed energy demand analyses:
  - Detailed cost components given for the three electrification options (solar PV, diesel generation, grid extension)
  - The only mini-grid considered was solar PV with diesel backup generator; no other RE options taken into account
  - Took into account socio-economic and demographic data

Links:
Kemausuor F. et al. (2013). Electrification Planning Using Network Planner Tool: The Case of Ghana
Electrification planning using Network Planner tool. The case of Ghana

METHODOLOGY E: GIS-BASED COMPARISON OF SOLAR, WIND AND GRID EXTENSION FOR VIETNAM (HANOI INSTITUTE OF ENERGY, K. Q. NGUYEN)

Methodology Type:	**Coverage:**	**Spatial Mapping:**
Supply-led	Vietnam	Yes

Summary:

The methodology did not aim to identify the lowest-cost electrification option for rural settlements in Vietnam. Instead, it was a preliminary assessment of the competitiveness of solar, wind and decentralised diesel generation against grid extension. Settlement-specific data were not considered. The indicative costs of each option were compared for different distances to the grid and household densities.

Due to the lack of available data on unelectrified communities and grid infrastructure in Vietnam, it was possible only to consider estimated variable ranges and indicate the proportion of populations that might be best served by the different electrification options.

Input Parameters:	**Sources:**
Renewable data	
Solar radiation	NASA (2002). Global Surface Meteorology and Solar Energy.
Wind speed	TrueWind Solutions (2000). Wind Energy Resource Atlas of Southeast Asia based on MesoMap, a meso-scale atmospheric simulation system and historical weather data from US National Center for Atmospheric Research).
Economic and technical estimates	Institute of Energy (2000). New and Renewable Energy Planning in Vietnam. Pokharel, S. (2002). Energy Economics of Cooking in Households in Nepal.
Network and energy data	
Network grid charges and extension costs (estimated)	Institute of Energy (2005). The Master Plan for Power Development Stage VI. Hanoi, Vietnam.
Demographic data	
Load profile	Institute of Energy (2000). New and Renewable Energy Planning in Vietnam
Financial/economic data	
Discount rate	Institute of Energy (2005). The Master Plan for Power Development Stage VI. Hanoi, Vietnam.
Inflation (used for O&M escalation rate)	Institute of Energy (2006). Guidelines on Investment Analysis for Power Network Planning Projects. Hanoi, Vietnam.

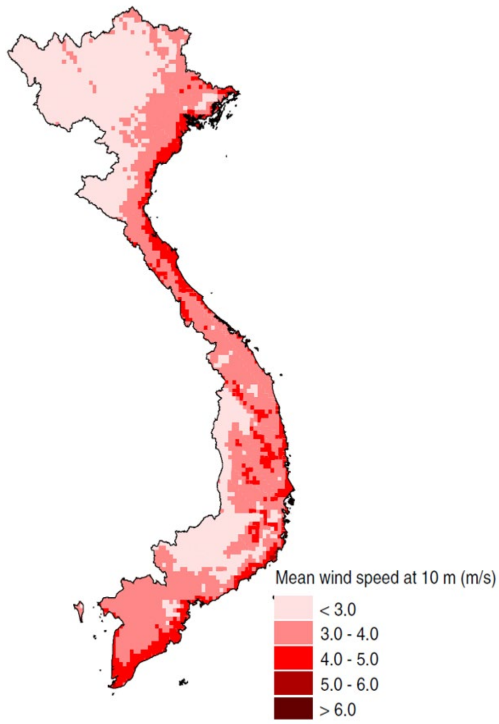
Mechanics:

The methodology used three technology reference cases (solar PV of 100 and 130 Wp, 150W wind turbine) against grid extension and gasoline generation. First the resource availability was converted to cost of energy estimates (VND/kWh) for solar PV, wind and gasoline generation (using system characteristics from IEA 2000, New and Renewable Energy Planning in Vietnam). A typical load profile was then calculated and used to compare the competitiveness of these options with grid-based electrification.

The methodology did not consider specific settlements or corresponding factors such as density or demand, but estimated typical countrywide values (i.e., 0.3kWh/day household demand). The levelised cost and capital cost per connection were then found for each option, with household density as a variable, and used to attain estimates for the proportion of the population that could best be electrified with each option.

Wind speed
Wind speed data were taken from an existing study that utilised an atmospheric model and historical weather data to attain wind speed estimates. The wind speed data were only available at 30 and 65m heights, so were then extrapolated to 10m (using a method from Cavallo et al. 1993, Wind Energy: Resources, Systems, and Regional Strategies). The 10m speed was then converted to a wind speed distribution using the Rayleigh function, which was backed by previous research (Cavallo et al. 1993). This provided good indicative data, but ground-level data collection would still be required in a full analysis to account for the high dependence on local topology.

Figure E.1: Mean wind speed at 10m height



Solar
Solar irradiation was taken from satellite data and combined with standard cost and performance estimates, such as 3- year battery life and 20-year PV module lifetime, to attain a cost of energy.

Diesel generation
The locally available Model EM650 Japanese generator was used for comparison, assuming 4 hours conservative usage and 0.43 l/kWh. Diesel cost was estimated as 50 percent above market rate, and it was assumed that the full 450W would be utilised.

Grid extension
Cost parameters were taken from Institute of Energy (2005), The Master Plan for Power Development Stage VI, and the final cost was shown as a function of household density and distance to the grid.

Commentary:
Simple LCOE comparisons were made utilising country-specific information such as what technologies were locally available. No country-level resource assessments were required, partially due to a lack of consideration for mini-hydro or biomass. The generation calculations for each technology were well founded and accurate.

The critical limitation was the LCOE comparison, which used the length of required MV line as a parameter due to a lack of settlement-level or grid network data. Therefore, the finding of was of the relative costs, and therefore the relative proportion of the population that could be electrified through each option. The grid infrastructure or specific community locations were not considered or spatially mapped.

If grid infrastructure and population factors were included, combined with increased accuracy of the wind speed data and the resolution of solar radiation data, the methodology's outputs would be significantly more applicable.

Highlights:
- Lowest-cost option for decentralized solar, wind and diesel generation vs. grid extension
- Fixed solar PV, wind turbine, diesel generator sizes
- Fuel cost fixed at 50 percent above market rather than distance dependent
- LCOE comparison using the length of required MV line as a parameter

Links:
K. Q. Nguyen (2006). Alternatives to Grid Extension for Rural Electrification: Decentralised Renewable Energy Technologies in Vietnam

METHODOLOGY F: ECOWREX MAPPING METHODOLOGY AND INTIGIS PLANNING TOOL (ECOWAS OBSERVATORY FOR RENEWABLE ENERGY AND ENERGY EFFICIENCY, CIEMAT)		
Methodology Type: Supply-led	**Coverage:** ECOWAS Region	**Spatial Mapping:** Yes
Summary: The ECOWREX mapping methodology was developed to provide accurate knowledge of existing and planned resources and renewable activities in the ECOWAS region, including solar, wind, biomass, hydro and wave projects. The IntiGIS tool was developed to compare the levelised costs of different decentralised technologies, and the second version, IntiGIS 2, will be integrated into ECOWREX to allow for technology comparisons within the ECOWAS region. This will then allow the utilisation of the significant data available through ECOWREX for decentralised planning processes.		

Factors Considered:	**Sources (status to March 2016):**
Renewable data	
Solar radiation (DNI and GHI)	ECREEEE
Existing and planned solar plants	Country Info Indicators - OpenLinkData
Wind speed	World Bank
Existing and planned wind plants	DIVA-GIS
Hydro resources (coming soon)	African Development Bank Group
Existing and planned small hydro plants	African Development Bank Group
Bio-crops temperature and precipitation suitability (camelina, cashew, cassava, crambe, ground nut, jatropha, sweet sorghum)	USAID (developed by Nexant)
Existing and planned biomass plants	Juan Pablo Borda Angel. Characterization of Hybrid System for Rural Electrification with Renewable Energies Using Geographic Information System (GIS).
Existing and planned wave plants	Juan Pablo Borda Angel. Characterization of Hybrid System for Rural Electrification with Renewable Energies Using Geographic Information System (GIS).
Network and energy data	
Conventional generators (large and medium hydro, coal, diesel, gas, heavy fuel) Transmission lines Roads Railways Gas pipelines	
Demographic data	
City populations Administration boundaries Land cover Water	

Policy/political data
RE policies
REEE initiatives

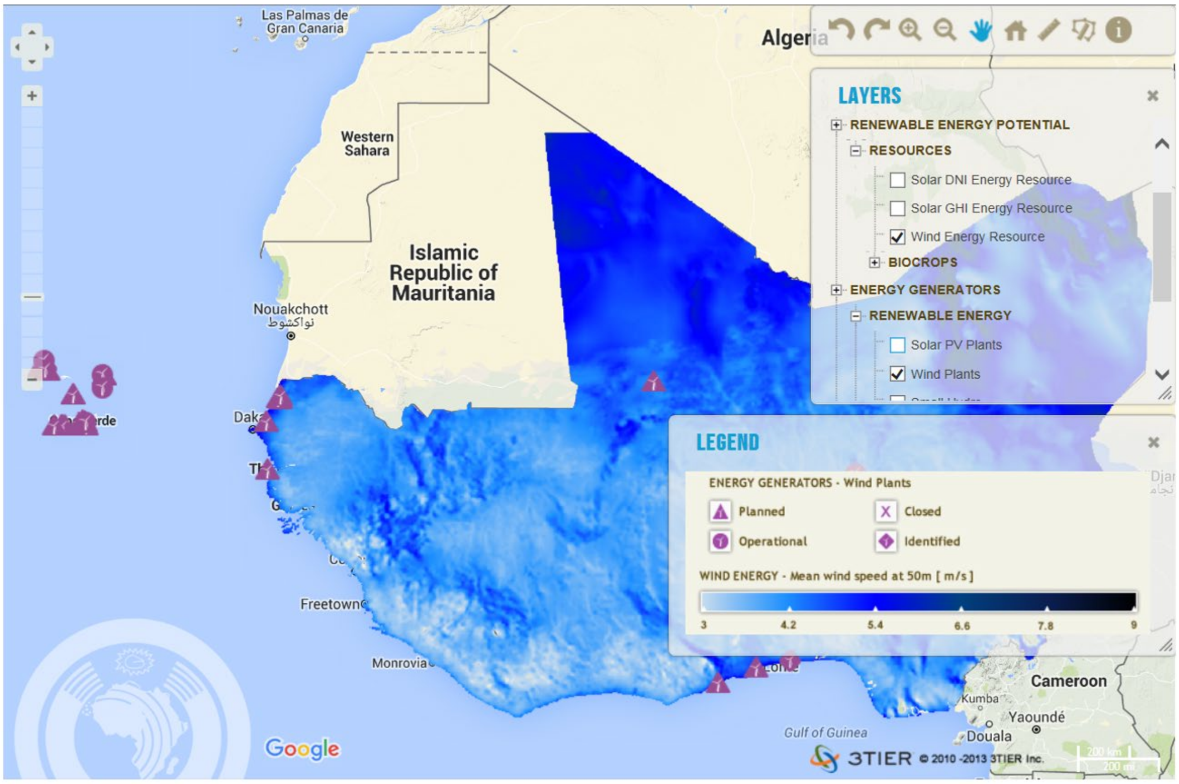
Mechanics:

ECOWREX

ECOWREX is a mapping method showing all of the relevant data for a renewable developer in the ECOWAS region. Data collected by ECREEE is made available via a GIS map viewer, and is accompanied by online country profiles, maps analyses and information on existing stakeholders. Details on the choice of source and how it was interpreted is given on the ECOWREX website, linked below.

A complete spatial data infrastructure is under development to revamp the map viewer on ECOWREX, which will then be fully compliant with OGC services and in line with the European directive INSPIRE.

Figure F.1: Screenshot of the existing and planned wind plants with mean wind speed at 50m for the ECOWAS region



IntiGIS

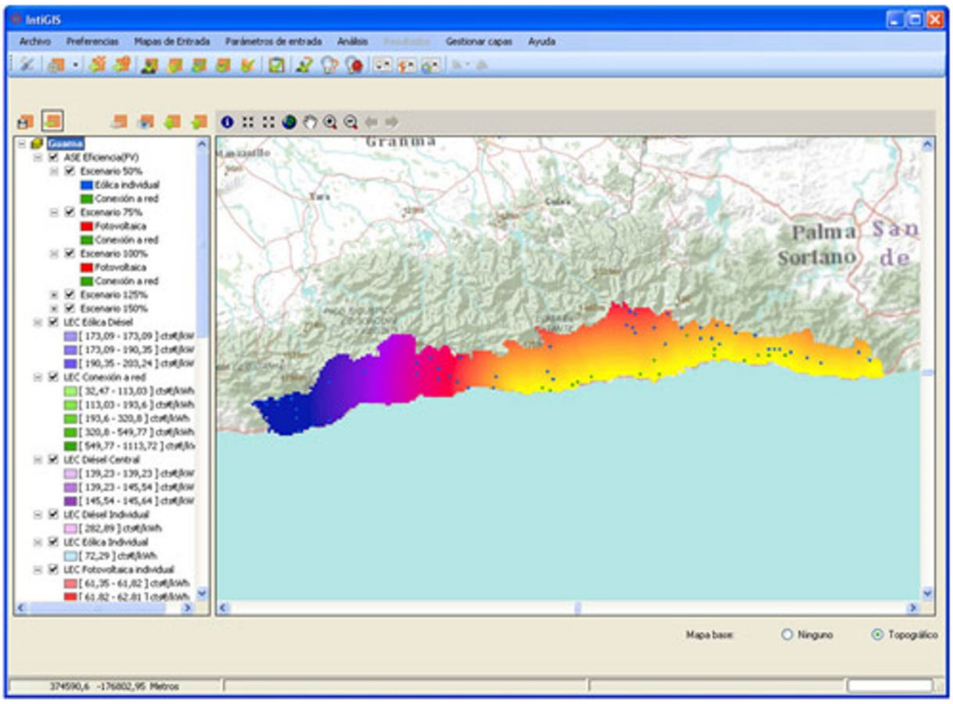
IntiGIS is a free software using RGIS, which is designed to support rural electrification planning. It allows the user to input technical and economical parameters to calculate the levelised cost of six different technologies (PV, wind, diesel, hybrid wind-diesel mini-grid, diesel mini-grid and grid connection).

Additionally, the application allows for the use of a spatial sensitivity analysis to assess the weight of each variable in the case study, analyse the stability of the result, and carry out different scenarios depending on the variability of the parameters.

The second version, IntiGIS 2, is being added to allow the planner to not only identify rural communities that need access to electricity, but also determine the most economically competitive electrification system.

As the software is under development, a full analysis is not possible at this time.

Figure F.2: IntiGIS screenshot showing mapping results



Commentary:

ECOWREX is a clear and useful method that has given planners an idea of the available renewable energy resources. Solar and wind assessment have been completed and integrated into ECOWREX, and hydro assessment is in progress and will be added to the ECOWREX map viewer by the end of 2016. Regarding biomass, only precipitations and temperature are included, to give planners an idea of the possible plants that can be grown.

The methodology is a good starting point for investors in renewable energy. It allows them to have a good idea of the energy situation in any country of the ECOWAS region, to know the legislation and the renewable energy and energy efficiency initiatives and the ongoing and planned projects. However, it does not provide specific information that would be useful to a rural electrification planner or other stakeholders, and also does not provide information on energy demand.

ECOWREX is working on the development of energy access maps for the West African region by using a second version of the software IntiGIS 2. This new software is still under development, and comes from a collaboration agreement between ECREEE, CIEMAT (Madrid) and KNUST (Ghana).

Links:

http://www.ecowrex.org/

http://www.ciemat.es/portal.do?IDM=271&NM=2

METHODOLOGY G: GIS-BASED INTEGRATED RURAL ELECTRIFICATION PLANNING THAT CONSIDERS GRID EXTENSION, SMALL HYDRO AND BIOMASS (INNOVATION ENERGIE DEVELOPPEMENT)

Methodology Type:	Coverage:	Spatial Mapping:
Demand-led	Tanzania, Benin, Mali, Niger, Central Africa Power Pool and Cameroon.	Yes

Summary:

This methodology has been implemented in multiple countries. The case study of Tanzania is used here because it includes more renewable resource data than other projects. The methodology was used to develop the National Electrification Program Prospectus. The basis for the Tanzanian Electrification Master Plan. It considers grid extension and small hydro, biomass and diesel mini-grids.

IED has developed several tools that integrate this methodology, and these tools have been utilised in IED's country-level work. One such tool is GEOSIM, a GIS-based rural electrification planning tool, which is used to design and cost different decentralised options. Other tools cover online GIS interfacing (GIMSYS), demand analysis, and grid design/optimisation (GISELEC). GIMSYS in particular has been utilised in many countries to host an online GIS platform, although many versions show only the grid infrastructure and population centres.

Input Parameters:	Sources:
Renewable data	
Existing SHP Sites	REA
Hydro potential sites	TANESCO
Agriculture industry locations	Minister for Industry
Biomass potential sites	GLOBCOVER
Network and energy data	
Grid infrastructure	Google Earth, IED, REA, TANESCO
Infrastructure (roads, airports, railways)	IED Secondary Research
Demographic data	
Boundaries	Ministry of Lands and Housing, IED Research
Villages	NBS, TANESCO, IED
Population and households (projected)	NBS and IED
Load profiles	IREP Project
Health service sites and type	Ministry of Health and Social Welfare
Education service sites	Ministry of Education and Vocational Training
Policy and rehab centre sites	REA, NBS
Potable water access (13 districts only)	IED Secondary Research

Mechanics:

The methodology was carried out mostly through GEOSIM, IED's rural electrification planner support tool, building primarily off government and national utility datasets.

Development centres – weighted benefit analysis

The ranking of settlements was done through the Indicator of Potential Development (IPD) tool to identify development centres; i.e., settlements of at least 1500 inhabitants with existing social or administrative infrastructures, business activities and good road access roads (as defined by the UNDP Human Development Index). The top 10 percent of the settlements, as ranked by IPD, are defined as development centres.

Grid extension and densification

The methodology considered extension of the grid to non-electrified communities and the connection of new customers to the distribution grid in already electrified communities, with only 60 percent penetration in the capital Dar es Salaam by 2013 and significantly lower penetration in other towns.

Grid expansion was laid out in four phases, Turnkey I-IV, with Turnkey I and II referring to grid extensions that have already been planned or requested by TANESCO. Settlements in later phases will be brought within range of the grid by the previous phases. Turnkey II is currently being implemented. Turnkey III will cover settlements within 10km of the MV network as of 2015. Population size will be used to determine the technology used, with development centres connected by MV lines, and other settlements of 1500 to 2000 inhabitants connected by three-phase lines and SWER technology.

Finally, Turnkey IV will connect development centres within 40km of the existing grid as of 2019, and then further settlements will be connected by MV, three-phase or SWER lines, depending on population size.

Decentralised electrification

Off-grid options were considered for settlements that would not be reached by the ongoing Turnkey II program. Priority was given to development centres that would either remain un-electrified or have to wait until after 2020 to be reached by the next phases of the Turnkey program.

The criteria for off-grid electrification were a 20km proximity to an identified small hydro or biomass source and more than 1500 inhabitants. For development sites without hydro or biomass sources, diesel-PV systems were suggested.

Stand-alone systems for settlements smaller than 1500 inhabitants (not quantified in this plan). Hydro sites in grid extension areas were also considered as generation options for the grid, to feed into the Feed-in Tariff scheme.

Figure G.1: Existing grid and planned extensions under Turnkey's I-IV

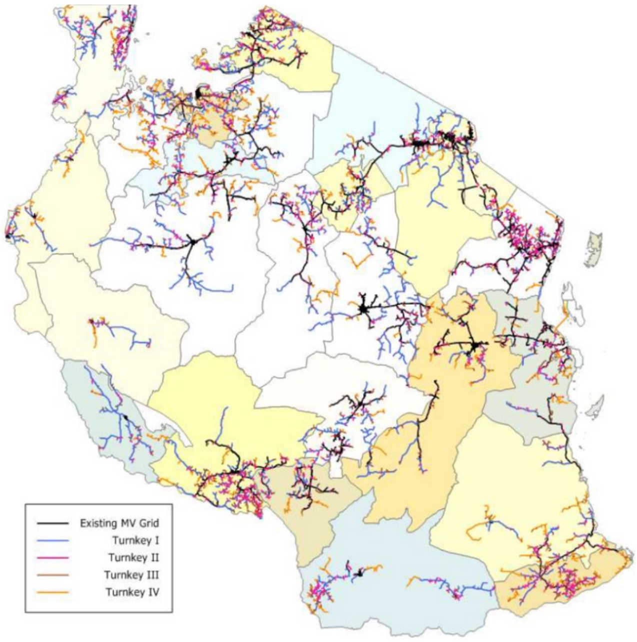
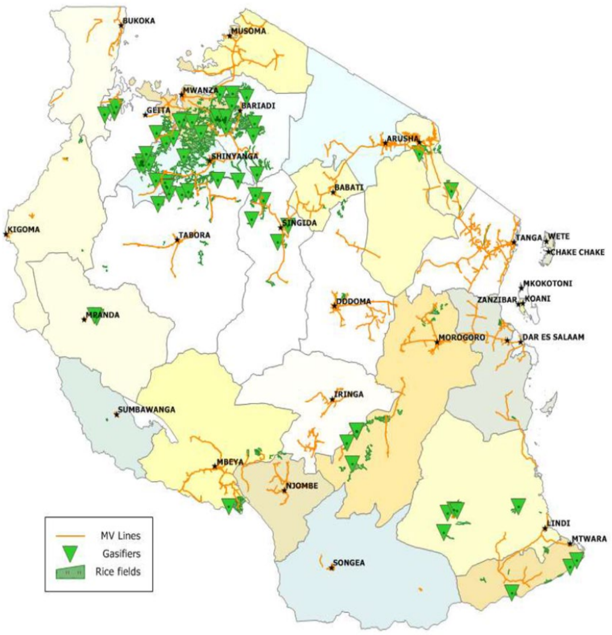


Figure G.2: Identified potential small biomass



Commentary:
The methodology was clear and thorough, but its application resulted in the RE rate only increasing from 7 percent in 2015 to a projected 20 percent in 2020 – below the Government's target. This was due to the fact that the plan targeted social and administrative structures rather than households, which resulted in a strong bias towards grid connection. There was no serious consideration given to stand-alone systems, solar containers or other distributed technologies. The methodology utilised government and utility databases and existing field data to identify mini-hydro and biomass sites. Despite the lack of focus on distributed generation, or the consideration of solar or wind resources, the use of government data sources provided clear support to government decision makers focused on settlement rather than household electrification. A GIS online platform was created based on the preliminary work for this project, the IREP project, in 2012. However, the platform has not been updated since 2013, and does not reflect the National Electrification Program described above.
Highlights: • Target electrification of social and administrative structures rather than an extensive household electrification plan • No full consideration given to stand-alone systems, solar containers or other distributed technologies • Utilises government and utility databases and existing field data to identify mini-hydro and biomass sites • Solar and wind not considered
Links: National Electrification Program Prospectus. July 2014. IED http://www.ied-sa.fr/en/documents-and-links/publications/send/3-reports/33-national-electrification-program-prospectus.html IREP Tanzania – Integrated Geospatial Rural Electrification Planning. June 2011-May2013. IED http://www.ied-sa.fr/index.php/en/documents-and-links/publications/send/3-reports/35-integrated-rural-electrification-in-tanzania.html GeoSim Rural Electrification decision support tool http://www.geosim.fr/index.php?page=home

METHODOLOGY H: THE MASTER PLAN STUDY ON RURAL ELECTRIFICATION BY RENEWABLE ENERGY IN THE KINGDOM OF CAMBODIA (JAPAN INTERNATIONAL COOPERATION AGENCY)		
Methodology Type: Demand-led	**Coverage:** Cambodia	**Spatial Mapping:** Village level
Summary: The Japan International Cooperation Agency prepared an Electrification Master Plan for Cambodia. Submitted in June 2006, it built upon two years of study work, including onsite data collection, community consultations, desk-based research and engagement with government ministries. Micro-hydro, solar, biomass, wind and diesel were considered for mini-grids. The plan represented best practice methodology, as it was the most comprehensive plan feasible for rural electrification in the country. Due to the extensive nature of the study and plan, only the relevant aspects have been assessed for this project. For example there was extensive consideration of the political and economic frameworks in place, which were outside the scope of this project.		

Factors Considered:	**Sources:**
Renewable data	
Micro hydro sites (existing and potential)	Ministry of Mines and Energy. Meritec, NZ Ministry of Foreign Affairs and Trade (2003). Pre-Investment Study of Community Scale Hydro Projects, Cambodia.
River flow rates	Meritec, World Bank (2002). Development of Pipelines for Small Hydropower Projects in Cambodia.
Solar – monthly averaged horizontal incident radiation	Ground-level data collection (2005). NASA Atmospheric Science Data Centre
Wind speed (20m and 50m)	NEDO and MIME - ground-level data collection (2004-05).
Biomass – direct combustion and gasification, bio-digestion and biofuel – Resource availability, use patterns	NASA Atmospheric Science Data Centre. Ground-level data collection (2005). IRRI and other, MAFF (2003), Agricultural statistics (2003-04), DFW (2003), MAFF (2004, JAFTA (1995), Prasertsan and Krukanont (2003), FAO (1997), ADB (1996), World Bank (1995), JAFTA (1995), Top et al. (2004).
Network and energy data	
Grid infrastructure	Department of Industry, Mines and Energy. Asian Development Bank.
Grid performance statistics	Electricity Authority of Cambodia (EAC). Electricite Du Cambodge (EdC).
Grid extension plans	MIME (1999). Cambodia Power Sector Strategy Paper. Mime (2002). Renewable Energy Action Plan. “Regulatory Treatment of Extension and Distribution Grid in Cambodia,” approved by Session No. 27 of EAC dated 28 October 2003
Licence service areas and operation	Electricity Authority of Cambodia (EAC)
Performance of typical licensees	
Diesel price	EAC Annual Report 2003 (October 2004)
Road infrastructure	JICA Study Team – Primary Research Ministry of Transportation

Demographic data	
Land use/land cover	Ministry of Public Works and Transport (2003)
Village electrification level	NIS Census (1998)
Village location and population density	Seila Commune Database (2003)
Provincial electrification and socio-economic level and population density	CSES (1999) CSES (2003/04)
Population and residential demand	

Mechanics:

The overall Master Electrification Plan included plans for both grid extension and rural electrification. Potential areas of grid extension (PAGE) were identified, while the RE component, which covered areas greater than 40km from the grid, considered demand levels, current and planned institutions and policies, population, licence areas and licensees.

Grid extension

The potential limits of grid extension were set by the MIME Energy Strategy of Cambodia as 40km from a provincial capital. The proposed transmission upgrade will connect some of these provincial towns, as shown in Figure H.1. In the first phase of the distribution upgrade, isolated provincial towns within the PAGE will be connected by MV lines.

In the second phase, non-electrified villages will be electrified with MV if the population density is high enough. In the third phase, settlements outside the PAGE may be connected by building new grid sub-stations if the demand density is high enough. Settlements remaining un-electrified by the grid extension master plan, both within and outside of PAGE, will then be are then considered in the rural electrification plan.

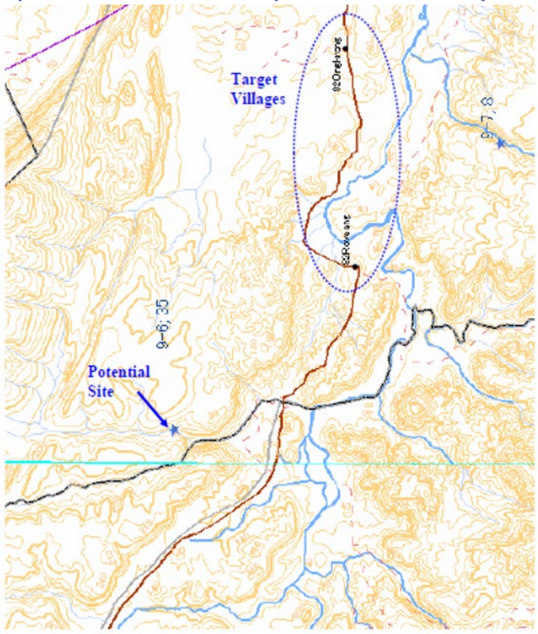
Renewable Resource Assessment

Resources were collated using existing studies and relevant ministry data, as well as ground research over two years at various sites, carried out with the help of local communities. Potential resource sites were identified and studied, along with existing sites and cost factors, allowing for a full assessment of the feasibility and yield potential of each site.

Micro-hydro, solar, biomass gasification, and diesel power were found to be appropriate for Cambodia, based on fuel availability, investment cost recoverability, power at scale, overall unit generation cost, and the ability of villagers to deliver O&M. Direct combustion biomass was not considered viable, as these systems are scaled at greater than 1MW, while rural Cambodia would require an estimated scale of 10-500kW. The wind resource was determined to be too low to be viable.

Mini-hydro and biomass gasification systems were found to be competitive with diesel generation, and so were prioritised in the master plan for mini-grids and grid connection, if available. Solar PV solutions were found to be economically difficult to connect to the grid, and so were limited to stand-alone systems.

Figure H.2: A project sheet for a micro-hydro assessment by the JICA study team



SCHEME NAME (ID)	O Leach Meas (MH1504-01)	DRY SEASON MAXIMUM OUTPUT (kW)	35
PROVINCE	Pursat	TOTAL DEMAND(kW)	17
RIVER NAME	O Leach Meas	NOS. OF Households For Electrification	131
CATCHMENT AREA (km^2)	29	NOS. OF VILLAGES	2
HEAD (m)	60 (Topo map)	NOTE	
DRY SEASON DISCHARGE (m^3/s)	0.09 (Estimated)		

Off-grid areas
Areas both outside and inside of PAGE that remained unelectrified were considered for the off-grid part of the master plan. Two tiers of off-grid electrification were targeted:

Level 1 – battery lighting, through solar battery charging stations, with the aim of 100 percent village electrification by 2020, as per the policy target of the master plan. This tier would utilise government finance and target remote or low ATP villages. However, consideration would be given to the existence of non-electrified public facilities, such as health posts or commune halls, in which case a public PV system could be installed.

Level 2 – electrification for lighting, TV and small appliances, averaging 100W per household. This level could vary from 30W in poorer villages, where a TV is unaffordable, to 200W near provincial capitals or road infrastructure.

The master plan utilised a decision tree to determine first, the level of electrification, and then which resource to utilise. The questions were:

- Does the level of electrification (excluding battery) exceed 10 percent?
- Does the level of TV diffusion exceed 10 percent?
- Has the village applied for a mini-grid or community system?

If the answer to any of these questions was yes, then level 2 electrification, via mini-grid, was recommended. The appropriate generation was then assessed, building on the studies conducted, with hydro prioritized over biomass, which was prioritised over diesel.

The full conditions for diesel generation were:

- No micro hydro potential available
- No biomass potential available
- There was village demand for mini-grids on the in an order of 100W, 10kWh per month per household exists
- Villagers have ability to pay in an order of $3-5 per month
- Transportation of diesel oil to the village was possible via with good road access, particularly in the rainy season
- Grid extension was not expected in the foreseeable future.

For level 1, battery lighting of villages, the type of solution applied depended on the existence of a health post or school or on the level of battery diffusion.

Commentary:
The methodology involved extensive study to assess in detail all factors related to the energy sector and rural electrification in Cambodia, including analysis of GIS systems in place. It included on-the-ground visits and assessments of existing and potential resource sites, data collection and demand profiles. The master plan covered all aspects of electrification, including the establishment of regulatory bodies and tariffs.

Overall, this methodology would not be practical or flexible enough for use across Africa, but it serves as an excellent best practice reference methodology, due to its full consideration of all of the physical and non-physical factors affecting rural electrification, and its and in-depth assessment of user demand and ATP.

Highlights:

- Data collection of load profile
- Plan includes regulatory bodies and tariffs
- RE resources collated using existing studies and relevant ministry data
- Clear conditions for use of diesel generator
- Wind resource considered to be too low to be viable

Links:
JICA (2006). The Master Plan Study on Rural Electrification by Renewable Energy in the Kingdom of Cambodia

METHODOLOGY I: CLIMATESCOPE - GLOBAL CLEAN ENERGY COUNTRY COMPETITIVENESS INDEX (MULTILATERAL INVESTMENT FUND, UK DEPARTMENT FOR INTERNATIONAL DEVELOPMENT, POWER AFRICA AND BLOOMBERG NEW ENERGY FINANCE)		
Methodology Type: Weighted ranking	**Coverage:** Global	**Spatial Mapping:** No
Summary: The ClimateScope Clean Energy Country Competitiveness Index measures the renewable-related energy investment, policy development, and generation instalment (wind, solar, geothermal, biomass, small hydro and biofuel technologies) of 55 countries globally. It also indicates the strength of the enabling environment for the development of clean energy and technologies in these countries. The methodology considered 23 of the 55 countries utilising an augmented off-grid methodology, which assessed their competitiveness against that of other countries for specifically off-grid renewable technologies. The assessments were country level, meaning there was no support for more granular rural electrification decision processes. However, they provided a strong initial indication to stakeholders about on the relative opportunities for on or off-grid renewable-based development between countries.		

Input Parameters:	**Sources:**
Renewable sources	
Renewable Potential (excl. large hydro and nuclear)	BNEF secondary research – government publications, websites, operators, other stakeholders
Network and energy data	
Power sector structure (non-qualitative)	BNEF primary research
Electricity prices (spot, residential, commercial and industrial)	BNEF primary research
Kerosene and diesel prices	BNEF research
Demographic data	
Electrification level	BNEF research
Electricity demand growth	BNEF research
Population using clean cook stoves	Alliance for Clean Cook Stoves mune Database (2003)
Policy/political data	
Policies	BNEF online database
Political risk	World Bank's Worldwide Governance Indicators (WGI) 2014 index
Distributed energy regulation framework	BNEF stakeholder consultation
Energy access policies	BNEF stakeholder consultation
Trade barriers	World Trade Organisation – average import duties levied on clean energy products

Financial/economic	
Clean energy investment and investment growth rate	BNEF proprietary industry intelligence database
Loans, grants and grant program commitments	BNEF proprietary industry intelligence database
Green microfinance (number of operators, loans, borrowers, average cost of debt)	BNEF Survey of Microfinance Organisations
Financial institutions	BNEF primary research
Sector value chains (biofuels, biomass and waste, geothermal, small hydro, solar, wind)	BNEF secondary research
Clean Development Mechanism (historic activity, average processing time for project registration, energy use per kg of oil equivalent)	UN CDM, Verified Carbon Standard and Gold Standard
REDD-readiness score	UN-REDD Programme
GMG emissions and GHG reporting	Global Reporting Initiative (GRI online database)
Partnership for Market Readiness or Nationally Appropriate Mitigation Action	BNEF primary research
Reporting on energy efficiency initiatives or emission reduction policies and initiatives	Bloomberg's Environment, Social and Governance (ESG) database

Mechanics:

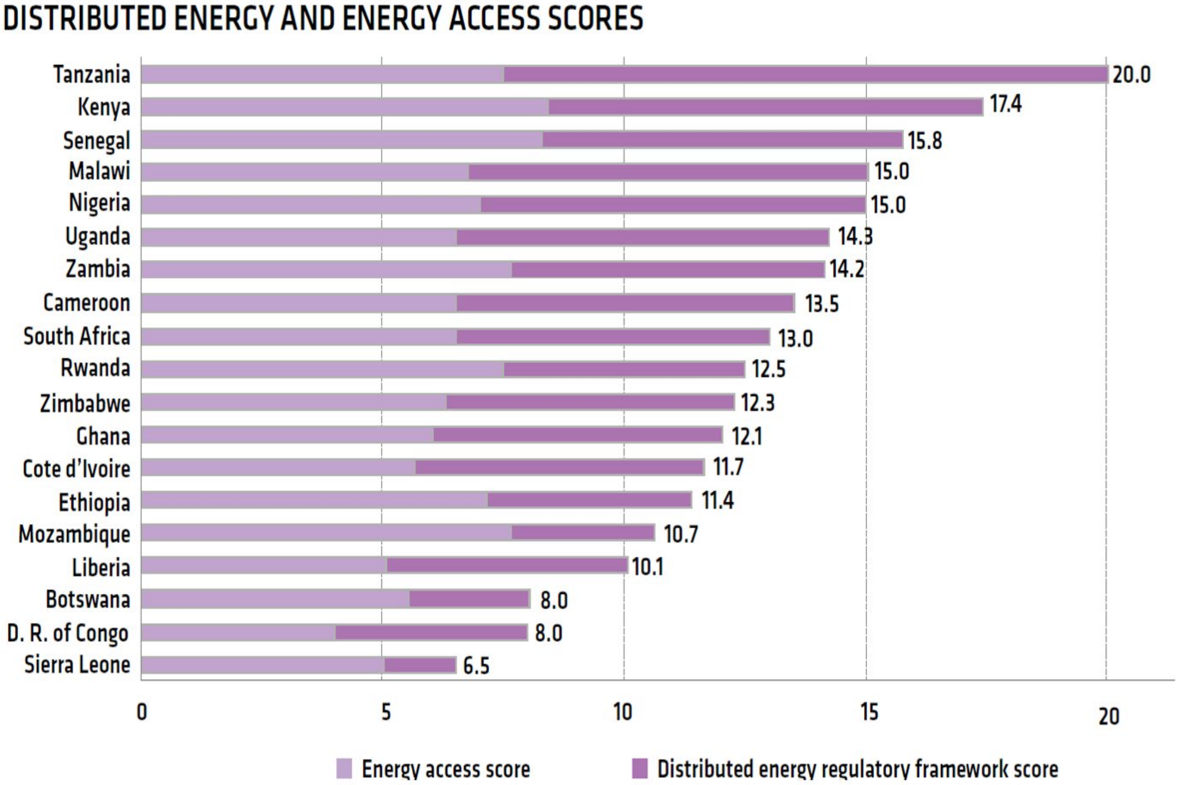
The assessments ranked the 23 countries against 4 aggregated scores: Enabling Framework 40 percent, Financing and Investment 30 percent, Value Chains 15 percent, GHG Management 15 percent. These final scores were based, respectively, on 22, 14, 3 and 13 indicators, including installed clean energy capacity, local investment, number of value chains in the clean energy sector, and the presence of GHG global reporting initiatives.

Some different indicators were used for on-grid or off-grid focused countries. The determination of whether a country was on or off-grid focused depended on five criteria:

- electrification rate
- number of national power outages
- duration of power outages
- power transmission losses
- Human Development Index score

The indicators were scored out of 5, usually levelised, and dependent on metric type. For rural electrification, the lowest electrification rate (highest non-electrification rate) was set as the benchmark, and all countries given a score out of 5 relative to this benchmark. Therefore, a country with twice as high an electrification rate would get a score of 2.5.

Figure I.1: African countries ranked by distributed energy and energy access score



Off-grid specific indicators

Distributed energy regulatory frameworks:

How well does a country's local market structure facilitate off-grid or small-scale development of projects?

Energy access policies:

What local policies exist specifically to spur off-grid activity?

Average local kerosene and diesel prices:

How high are these prices and how attractive do they make potential alternative (cleaner) sources of generation?

Population using solid fuels for cooking:

How many citizens would potentially value alternative fuel sources to cook?

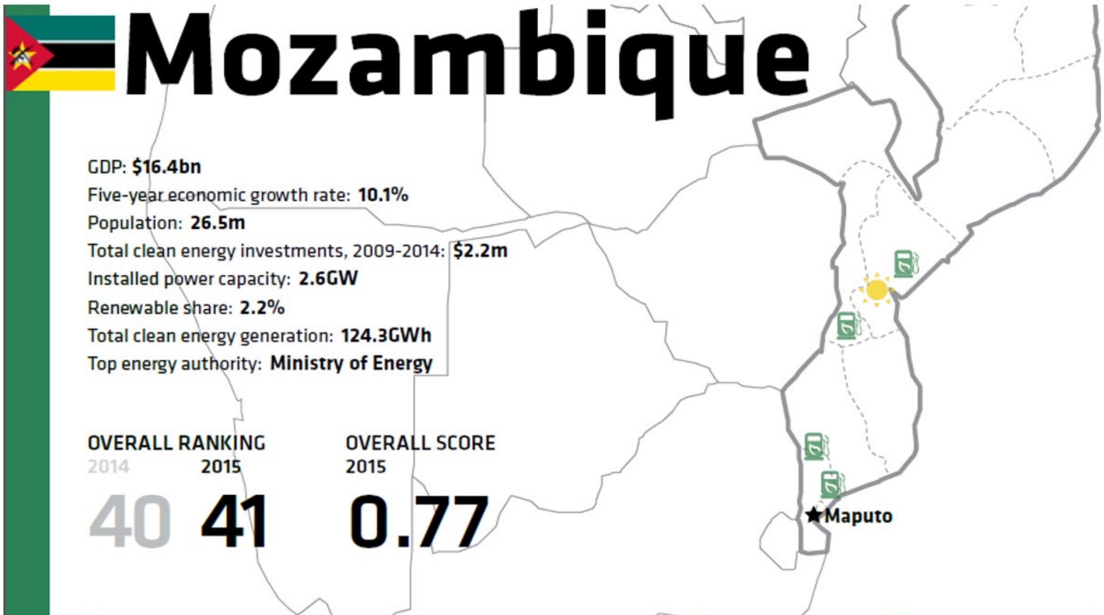
Distributed clean energy value chains:

What local mini-hydro and mini-wind equipment makers, mini-photovoltaic system providers, and other similar types of players exist in the country?

Distributed clean energy service providers:

What local retailers, pay-as-you go facilitators, insurance providers, and others specializing in off-grid and small-scale clean energy services are in the country?

Figure I.2: Example of ClimateScope country summary sheet - Mozambique



PARAMETER	RANKING	SCORE
I. Enabling Framework	43	0.84
II. Clean Energy Investment & Climate Financing	37	0.36
III. Low-Carbon Business & Clean Energy Value Chains	30	1.34
IV. Greenhouse Gas Management Activities	38	0.82

Commentary:

The index presented a global ranking based on 54 indicators and 199 sub-indicators, along with qualitative discussions of the countries' performance against selected factors. The methodology gave separate consideration to countries with on- and off-grid focus, and provided a good indication of the potential for renewable-based development at a country level. However, this methodology did not provide support for in-country rural electrification/ mini-grid planning or development.

Additionally, the huge scale of study, with reliance on a large amount of primary and secondary research, means this type of methodology would not replicable as a stakeholder decision support tool using country-specific metrics. Therefore, it is only useful for private sector investors as a first country reference.

Highlights:

- Provides State-of-the art assessment of electricity access in each country, but no support for rural electrification planning or development

Link:

ClimateScope2015

http://global-climatescope.org/en/download/

METHODOLOGY J: GLOBAL COUNTRY RANKING BASED ON SUITABILITY FOR RURAL ELECTRIFICATION (REINER LEMOINE INSTITUT GGMBH, ANN-KATRIN GERLACH ET AL.)		
Methodology Type: Weighted ranking	**Coverage:** Global	**Spatial Mapping:** No

Summary:

This simple worldwide country ranking gives an indication of the countries' applicability for renewable mini-grids, to aid the development of sustainable business models in these countries. The assessment was at a country level, so no decision support was provided to identify target areas for rural electrification or to assess the relative competitiveness of different electrification options.

Input Parameters:	**Sources:**
Network and energy data	
National diesel prices	GIZ (2012). International Fuel Prices 2010/ 2011, 7th Edition.
Demographic data	
Rural population	World Bank (2010). Rural Population.
Rural electrification rate	United Nations and World Health Organisation (2009). The Energy Access Situation in Developing Countries UNDP Human Development Report (2007/2008) IEA (2004, 2007). World Energy Outlook
Policy/political data	
Political stability	World Bank (2010). Worldwide Governance Indicators
Corruption Perception Index	Transparency International (2011).
Financial/economic	
Inflation	World Bank (2009/2010). Inflation, consumer prices
Ease of Doing Business Index	World Bank and International Finance Corporation (2011)
Travel warnings	German Federal Foreign Office

Mechanics:

Exclusion criteria – a country is not suitable for rural electrification if:

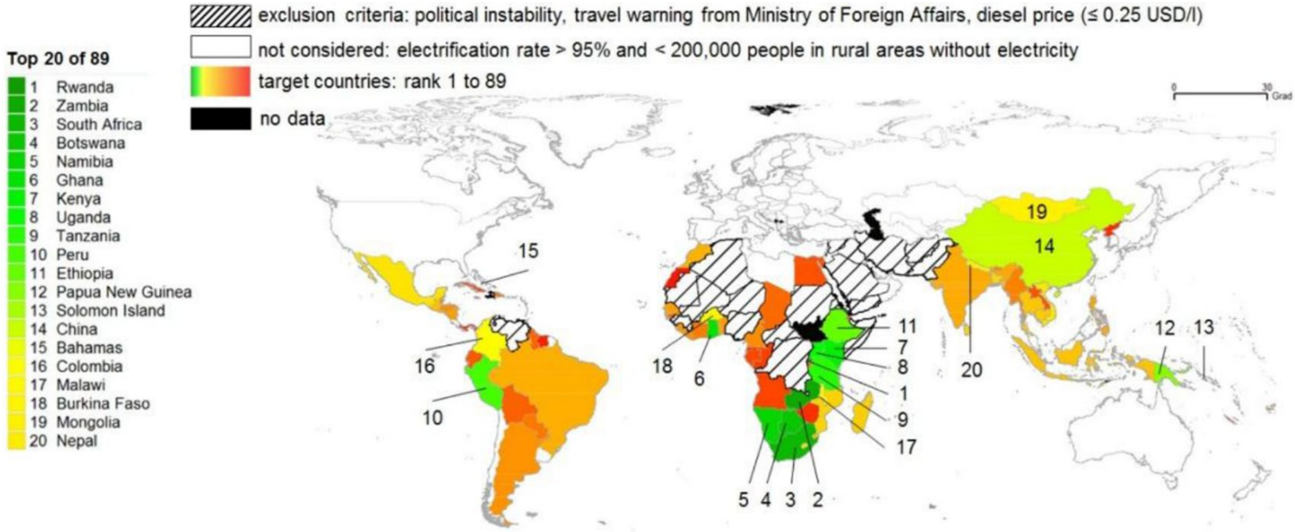
- it has a 95 percent electrification rate or greater
- it has more than 200,000 electrified rural citizens
- is in the lowest 5 percent of the Worldwide Governance Indicators political stability index
- it is the subject of a travel warning from the German Ministry of Foreign Affairs
- it has diesel pump prices lower than US$0.25 per litre.

After these exclusions, 89 countries remain that are suitable for rural electrification, predominantly in Africa, Asia and South America.

Weighting criteria:

- Market potential 40%
  - — Electrification rate 12%
  - — Un-electrified rural population 20%
  - — Pump diesel price 8%

Figure J.1: Top 20 from 89 non-excluded countries, based on market potential and political and financial enabling environment



Political and financial environment – 60 percent

- Political stability 9%
  - — Corruption Perceptions Index 12%
  - — Inflation 9%
  - — Ease of Doing Business Index 30%

Commentary:

Simple methodology using remote datasets, which allows for quick identification of countries with the right enabling environment for green mini-grids. However, an improvement would be to include factors such as the existence of off-grid activities, rural electrification agencies and regulators, as well as gauging the prioritisation of rural electrification in national and regional governments' plans.

Highlights:

Simple methodology.

Looks only at general criteria (diesel cost, rural electrification rate, policy, corruption and inflation) to consider GMG as a viable solution for the country

Link:

A.K. Gerlach et al (2013). Comprehensive Country Ranking for Renewable Energy Based Mini-Grids Providing Rural Off-Grid Electrification

METHODOLOGY K: GIS-BASED, DEMAND-LED RURAL ELECTRICITY PLANNING METHODOLOGY FOR UGANDA (IT POWER, E. KAIJUKA)		
Methodology Type: Demand-led	**Coverage:** Uganda	**GIS/Spatial Mapping:** Yes

Summary:
The methodology was used to identify patterns of demand and priority areas for investment, rather than create a comprehensive electrification plan. The approach was in response to the extremely slow rate of rural electrification in Uganda, and therefore the need to increase investors' awareness of demand-led opportunities, leading to the creation of supply-side system designs based on resource availability.

Factors Considered:	**Sources:**
Network and energy data	
Grid and road infrastructure	Uganda Bureau of Statistics, Africon Engineering International Ltd, Rural Electrification Criteria Workshop (24th January 2005)
Demographic data	
Population size and demand centres (villages, local government, schools)	Uganda Bureau of Statistics, Africon Engineering International Ltd, Rural Electrification Criteria Workshop (24th January 2005)
Demand centres – health centres	Uganda Bureau of Statistics, Makere University, Rural Electrification Criteria Workshop (24th January 2005) Indicative Rural Electrification Master Plan Project, IREMP

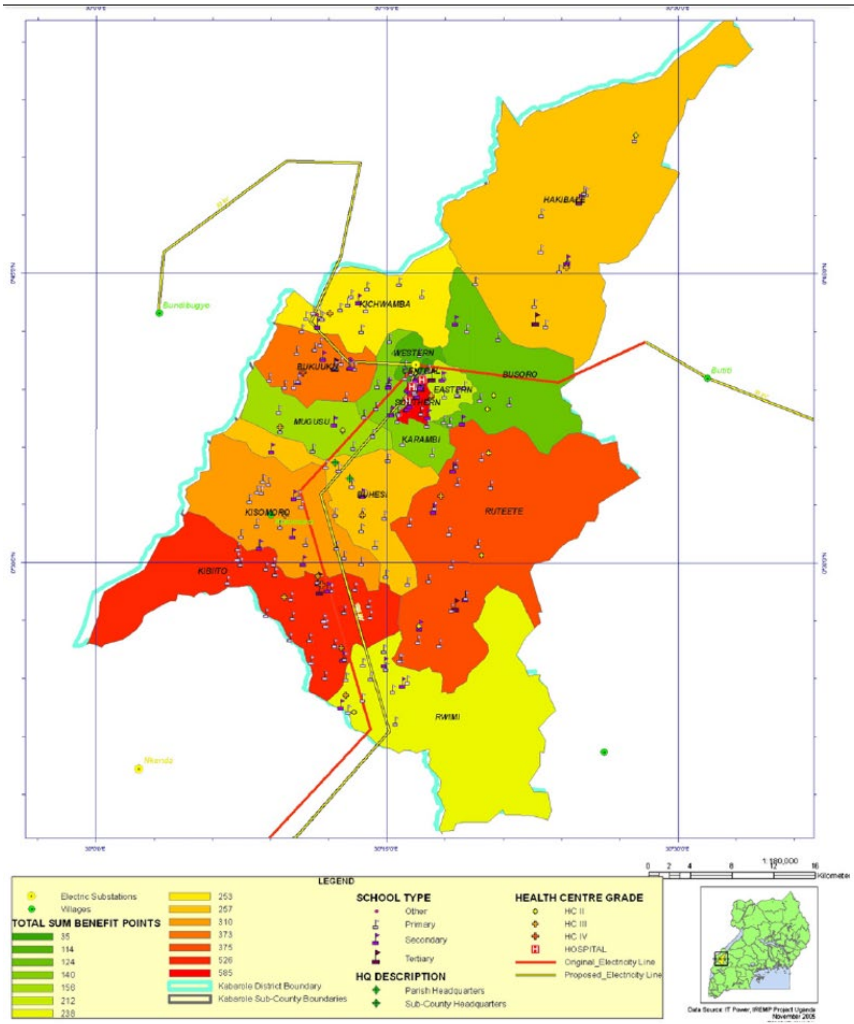
Mechanics:

The initial demand centres targeted by the methodology were health centres, schools, households, and local government headquarters. A weighted benefit points score was awarded for each demand sector, including households, and the sub-counties were given a cumulative score based on the sectors within their boundaries.

Benefit points were awarded based on type and size of demand; for example, a secondary school received 12 points plus 0.025 point per pupil. These weightings were inspired by studies in South Africa and Namibia, and agreed upon in consultation with stakeholders. Households were calculated on a sub-county level assuming 5 people per household, and health centres were given a higher weighting than schools, with further weighting above households.

The sub-county total benefit points were then presented as the parameter for prioritisation of electrification in that county, to aid the development of targeted supply-side solutions.

Figure K.1: Kabarole district benefit point allocation by sub-county. Red indicates greater benefits and higher priority; green indicates lower benefits



Commentary:

The methodology provided solid justification for prioritising a minimised electrification option and for assessing the relative electrification needs of sub-counties. There was no technical or cost assessment of the electrification options, and no consideration of tariffs or investment costs. However, in combination with a supply-side tool, this methodology could help budget-constrained developers or stakeholders to prioritise projects.

Highlights:

- Methodology focused on demand assessment
- No technical or cost assessment considered

Link:

E. Kaijuka. 2005. GIS and Rural Electricity Planning in Uganda

METHODOLOGY L: GIS-BASED ELECTRIFICATION PLANNING DECISION SUPPORT METHODOLOGY FOR SOUTH AFRICA (RURAL AREA POWER SOLUTIONS ET AL., D. I. BANKS ET AL.)		
Methodology Type: Demand-led	**Coverage:** South Africa (Northern Transkei region example)	**Spatial Mapping:** Yes

Summary:

This methodology was created to help the planning of rural electrification in South Africa, where there has been a huge difference in the level of development between settlements that have and have not been electrified. For grid-connected settlements, heavy cross-subsidies of up to R5000 per household, with no minimum monthly charges and connection fees of only R100, have meant a significant boost in productivity and human development indicators, while unelectrified settlements have been left behind. This has created an urgent need for effective decision-making in electrification planning, and particularly for off-grid planning for more remote communities that have not been a focus of the South African national utility, Eskom.

Input Parameters:	**Sources:**
Renewable data	
Renewable resource and cost estimates	HELP GIS database system – not referenced.
Network and energy data	
Grid infrastructure and cost estimates	HELP GIS database system – not referenced.
Demographic data	
Income	At time of publication, data from the South African Central Statistical Services were unavailable, so a fixed value for ATP was used.
Household density Schools Clinics Police stations	Banks, D.I.: Electrification modelling for South Africa: discussion of the methodology employed.

Mechanics:

The model was aimed at maximising the development impact of electrification for each un-electrified settlement, and prioritising their electrification. This approach was taken rather than a direct comparison of on and off-grid solutions due to an expected lack of robustness of such a result.

The model prioritised settlements with high development impact, such as those with schools, hospitals and/or administrative buildings, and with a correspondingly higher demand. Some settlements were found to have sufficient demand to be likely candidates for grid connection, and a network algorithm was used to minimise the total line of grid extension required. If grid extension was found to be uneconomic, then the viability of mini-grid or stand-alone systems was assessed.

Algorithm:

Weighted development benefit analysis

- Weighted development benefits points were awarded to each settlement for service facilities such as hospitals, to get a "total benefit index"
- From the available budget and number of settlements, the maximum grid expenditure per settlement, or its allowance, was determined, weighted by the benefit points for that settlement

Grid-prioritised planning

The Kruskal algorithm was utilised to minimise the total line length required to connect all settlements set for grid extension.

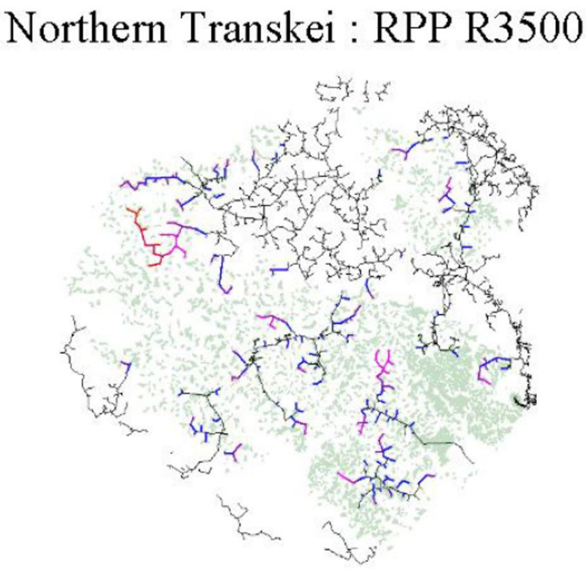
- For each settlement, if the cost of a local grid that would be required to meet its demand was greater than its allowance, then the settlement would be a candidate for stand-alone solar home systems
- If the remaining extension allowance after construction of the required local grid (reticulation) were enough to allow connection to the network, then the settlement was a candidate for grid connection. If not, then it was a mini-grid candidate

Each time the grid was extended, other settlements were checked to see whether they now had enough allowance to join the grid.

Costing of electrification options

- For those settlements that remained unelectrified, it was determined whether a stand-alone or mini-grid system would be more appropriate
- The final costs for the electrification solution were determined

Figure L.1: Electrification solution possible with maximum cost per point of R3500. Points were awarded based on electrification benefit, such as a hospital receiving 15 points.



Commentary:

The methodology was based on the assumption that a direct cost comparison of grid and off-grid solutions would not provide a robust solution without a high level of analysis, due to the different levels of service offered by the two types of solutions and a high dependence on input parameters. Therefore, the focus was grid extension, especially as the priority was to electrify settlements with a high level of services and corresponding energy demands.

The prioritisation of settlements required detailed, ground-level demographic, income, planning and infrastructure data in order to allocate a benefit score to each settlement. The data utilised in the paper were poorly referenced and so could not be assessed, but the paper did provide a clear approach to rural electrification that was well suited to helping stakeholders identify appropriate solutions within budgetary restraints. The methodology could be improved by giving greater consideration to different technology options for decentralised generation.

Clarity on sources, and on the technology options and parameters considered, was seriously needed.

Link:

D. I. Banks, F. Mocke, E. C. Jonck, E. Labuschagne, R. Eberhard. Electrification Planning Decision Support Tool
http://www.academia.edu/2947133/Electrification_planning_decision_support_tool

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