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# A cost comparison of technology approaches for improving access to electricity services

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A B S T R A C T

The UN's *Sustainable Energy For All* initiative has made universal access to energy by 2030 a key target. Countries wherein budgets are constrained and institutions stressed are faced with the challenge of further extending energy services – and doing so significantly. To meet this goal for the power sector in a cost-effective way, governments have to consider the deployment of a mix of stand-alone, mini-grid and grid-based solutions. To help inform analysis, planning and the decision process, this paper presents a simple, transparent, least-cost model for the electrification of rural areas. The approach builds on four key parameters, namely: (i) target level and quality of energy access, (ii) population density, (iii) local grid connection characteristics and (iv) local energy resources availability and technology cost. From an application perspective, this work can be used both for (1) fast assessments of specific energy access projects, and (2) to inform more complex regional studies using a geo-referencing software to analyze the results. Such applications are presented in the results using country case studies developed for Nigeria and Ethiopia. These show how the strategy for expanding energy access may vary significantly both between and within given regions of energy-poor countries.



## 1. Introduction

Over 1.3 billion people in the world still lack access to meaningful quantities of electricity [1]. The corresponding gap in access to modern energy services affects the socio-economic development of energy-poor countries, and acts as a brake on economic growth. Universal access to electricity by 2030 is one of the key goals of the UN Sustainable Energy for All (SE4All) initiative [2]. Additionally, Sustainable Development Goal number 7 (SDG7) is to 'ensure access to affordable, reliable, sustainable and modern energy for all' [3]. However insufficient financial resources, lack of effective planning, and fast population growth are just some of the many challenges to achieving this goal. Local utilities and governments struggle to find solutions that can provide an acceptable level of energy access to the larger proportion of their population without exceeding the limited budgets that they have to work with. A combination of energy solutions is required in order to bridge the gap in an optimal way.

In this context, the cost comparison of various technologies, including on-versus off-grid energy technologies for energy access, is significant. Such an assessment can be made on different scales ranging from local, to national, regional and continental levels. A limited and selective description of some of those studies follows.

At a local level insights are drawn from case studies that involve specific circumstances. For instance, rural electrification options have been compared with multi-criteria approaches for general rural areas [4] and for rural communities in the Brazilian Amazon [5]. A recent study assessed the energy supply and use patterns for a rural village in West Africa, presenting results focusing on the potential for the development of micro-grid and off-grid solutions [6]. Local conditions determining the cost-competitiveness of certain off-grid electrification solutions have been addressed for a rural village in Algeria [7]. Decentralized energy approaches were also compared for a 'hypothesized' village in India examining the economic sustainability of different system configurations [8]. In general, local approaches show how the solutions for one region might not be appropriate for another [9].

At a national level, recent studies compare grid and off-grid energy solutions in countries such as Liberia [10], Ghana [11] and Papua New Guinea [12], amongst others. The Energy Sector

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Management Assistance Program (ESMAP), for example, has developed several studies evaluating techno-economic characteristics of energy solutions for electrification [13] and provides national-scale models for evaluating the cost of energy technologies for low- and middle-income countries [14].

Other approaches use global models for the comparison of electrification solutions on a larger scale [15]. Various global resources have been developed in order to support a wide range of analysis. The International Renewable Energy Agency (IRENA) has developed studies and databases of resource potentials for several renewable energy technologies [16], for example.

Interestingly, much of the afore mentioned analysis develops ad hoc or context specific approaches and case studies. New tools might be developed, or an off the shelf model calibrated to a new setting. Doing so helps ensure analysis is locally appropriate. However, while technical solutions are often different, key aspects of the dynamics of their selection are similar – in particular when these relate to costs. Thus articulating a simplified general approach to indicate the cost-optimal choice of electrification technology has value. It can help strip off superfluous detail that is part of existing toolkits, while providing a 'bare metal' starting point for others. In particular it might be: rapidly calibrated to a specific setting for a coarse and direct assessment; easily adapted and adopted into a broader array of analysis; or used as the starting point for the development of new, or more nuanced approaches. It therefore needs to be as simple as necessary, transparent, and easily accessible. We identify four key parameters:

a. Target level and quality of energy access
b. Population density
c. Local grid connection characteristics
d. Local energy resources availability and technology cost

These parameters and their effect on the choice of electrification technology will be defined. The parameters are used to calibrate a straightforward formulation in a spreadsheet using standard parameter ranges and technology data that can easily be tailored to a specific locality (Country, State, etc.). For consistency, the research is directly related to the World Bank SE4All electricity access metrics, which are likely to be key metrics for SE4All and SDG7 in the medium term. Finally, the adoptability of the approach can inform broader efforts. For example, its use in a geo-referenced framework formed an essential component of GIS-based assessments of Nigeria and Ethiopia as a contribution to the International Energy Agency World Energy Outlook 2014 [17].

## 2. Methodology

A cost comparison between selected grid, mini-grid and stand-alone energy technologies available for energy access – presented in Table 1 – was conducted by varying the values of key techno-economic parameters within representative ranges.

**Table 1**
Technologies compared for energy access.

| Category | Supply technology |
|---|---|
| Grid connection (Grid) | National grid |
| Mini grid systems (MG) | Solar PV |
| | Wind turbines |
| | Diesel generators |
| | Mini-Hydro |
| | Biogas generators |
| Stand alone systems (SA) | Solar PV |
| | Diesel generators |

The cost model was built to represent the energy system in a simplified way. As such, two cost metrics were used to compare technology options and evaluate the effect of selected key parameters. These are the Levelised Cost of Electricity (LCOE), and total cost per household connected between 2015 and 2030. The LCOE for a specific energy source represents the final cost of electricity required for the overall system to breakeven over the project lifetime. The LCOE is given by Equation (1):

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

where, for a specific system, in year $t$, $I_t$ is the investment expenditure, $O\&M_t$ are the operation and maintenance expenditures, $F_t$ are the fuel expenditures, and $E_t$ is the electricity generation. Further, $r$ is the discount rate and $n$ the life expectancy of the system.

The total cost per household was calculated for the timeframe 2015–2030. It is the total cost of giving a single household access to energy in a given context – i.e. for a given set of parameter values – over the model time period. The total cost per household can be calculated using Equation (2).

$$Total\ cost\ per\ household_{2015-2030} = \frac{\sum_{t=1}^{n} \frac{I_t + O\&M_t + F_t - S_t}{(1+r)^t}}{hh} \quad (2)$$

where, $S_t$ is the salvage cost of elements being dismissed in year $t$ and $hh$ is the number of households served by the energy system in question: $hh$ is equal to 1 for stand-alone solutions, and to the settlement size (number of households) for grid and mini-grid based solutions. Transmission and distribution needs for grid and mini grid technologies are determined based on a methodology using a simple tree-like structure to assess the length of power lines required to reach a settlement [15]. The specific costs and technology assumptions used in this analysis are reported in Annex A.

The LCOE and the Total cost per household from 2015 to 2030 were calculated for all selected technologies, across all parameter combinations as summarized in Table 2. This mapping confirmed important system dynamics involved in the selection of electrification options for rural areas.

The following paragraphs contain detailed presentations of both the cost parameters and the subsequent metrics used to quantify them.

### 2.1. Level and quality of energy access

The fact that the quantity and diversity of services to be provided using electricity influences the choice of the energy solution has been proven in a number of studies [18]. Other literature discusses the nebula of different metrics that exist to measure energy access [19]. Although there is no universally agreed-upon definition of energy access [2], this research adopts the multi-tier categorization of household Energy Access proposed by the World Bank's Global Tracking Framework for SE4ALL. This metric was chosen in order to help support a number of ongoing efforts promoting its use within the Sustainable Energy For All programme. Further, this structure has been officially adopted within all related WB projects and an increasing amount of relevant national data is (and will be) made available following this format. This represents a relevant advantage considering data paucity issues that usually affect energy access studies [20].

Operationally, this metric relates a level of household appliance use to a specific tier of energy access as defined in Table 3. From the appliances that characterize a specific tier, an average electricity