ELECTRIFYING ECONOMIES

DETAILED COST MODELS AND BENCHMARKS

COMPARING COSTS OF AN INTEGRATED APPROACH VERSUS PURE GRID EXTENSION

This study models and compares the costs of electrifying a grouping of four hypothetical communities via an integrated approach compared to simple grid extension. It considers both upfront capital costs and ongoing operation and maintenance costs over a 25-year lifespan.

In this case, the integrated approach can reduce the whole-system cost of providing adequate, reliable electricity by US$0.125/kWh. The annual cost of the grid extension approach is $660.000, compared to the integrated approach which reduces cost to below $490.000 per year.

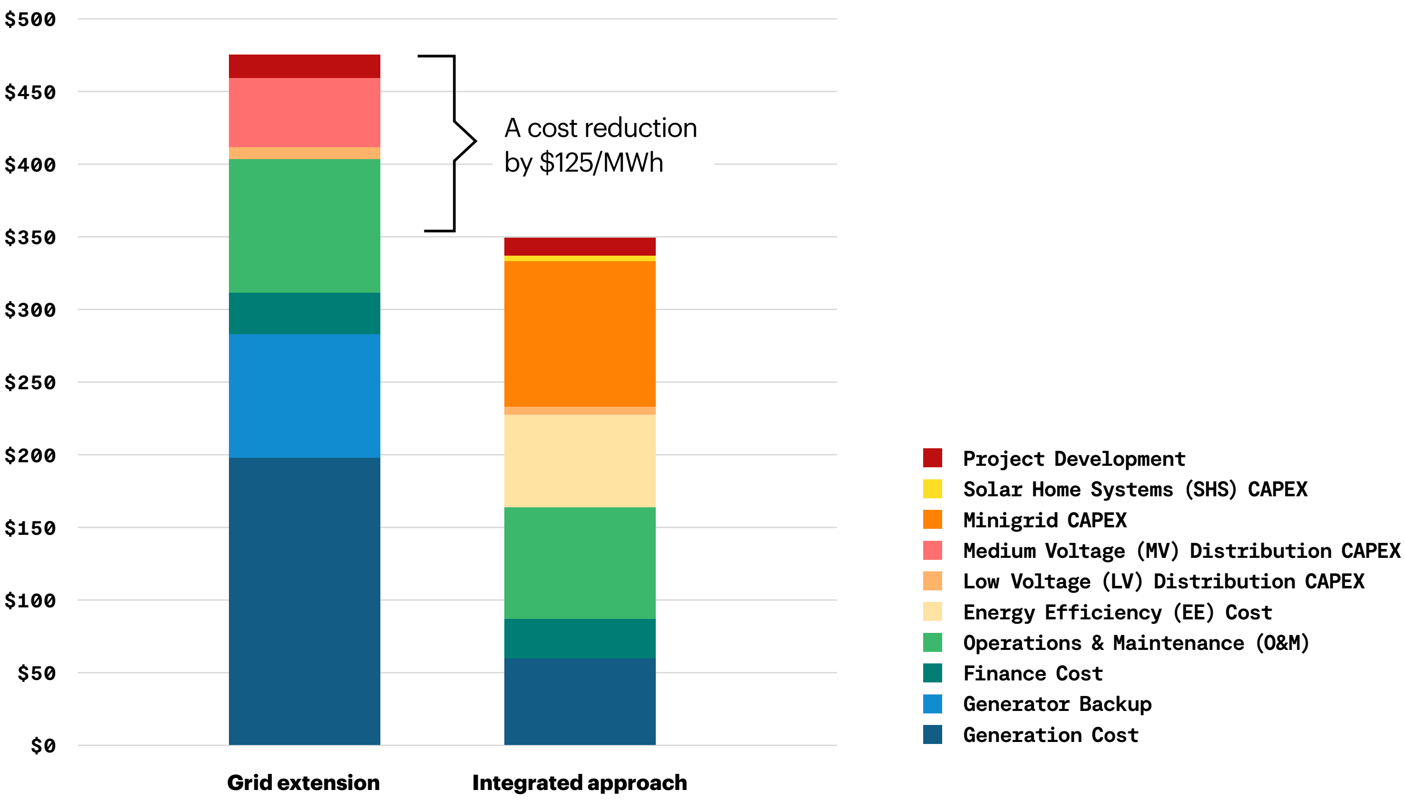
The results of this analysis are specific to this scenario. The precise costs and the design of the optimal approach will look different in every region, depending on the physical layout and the energy demand of the communities served. In urban regions with excess generating capacity and efficient distribution companies (Kampala for example), the least-cost approach is likely to use the grid, meaning the integrated approach will look identical to the pure grid extension scenario. In more rural regions, or areas with unreliable power supply, integrated approaches are likely to see significant savings from the widespread use of distributed energy, as shown here.

This datasheet illustrates the calculation methods, models, and cost benchmarks used to calculate and compare the grid extension and integrated approach scenarios.

COST BENCHMARK

Annual Cost per Unit for Model Community Electrification Comparing Grid Extension to an Integrated Approach

Cost per unit of electricity
$/MWh, using equivalent consumption after energy efficiency



INTRODUCTION TO THE STUDY

The purpose of this study is to model electrification of a district using grid extension or an integrated approach with a distributed energy system. It is constructed with elements of both rural and peri-urban access problems as well as grid reliability challenges. With the premise that providing sufficient and reliable power enables social and economic development, the study analyzes the costs of establishing the power system via different approaches.

This analysis is limited to a single example and cannot cover every potential situation that arises in countries underserved by electricity access. Cost will shift based on consumption levels and distance from existing infrastructure, and the quality of grid supply varies. However, by demonstrating these calculations using pre-defined scenarios, economic and technical assumptions, and result matrices, the study tries to:

- Construct scenarios that represent various methods of electrification
- Show the routes to providing the average 200kWh/capita identified previously on the Electrifying Economies website as the minimum threshold for kickstarting rural development
- Employ a new evaluation matrix for assessing electrification pathways
- Share the methodology and parameters of economic analysis for electrification

Throughout this study, costs are shown on an annualized basis, including capital expenditure, project development costs, financing costs, and operation and maintenance (O&M) costs. Generally, costs are normalized by unit of power supplied (US$/kWh). This cost of power is an easily comparable metric throughout the study and helps understand the global least-cost scenarios for power provision. For achieving least-cost electrification, this metric is deemed to be more useful than a simple cost per connection, which has no bearing on the actual impact of electrification or the whole-system costs.

For the distributed energy approach, the cost of energy efficiency appliance deployment is also separated from minigrid cost as it’s a critical pillar to shape and meet the demand, and needs special attention when planning projects. Grid power is supplied at the estimated cost of service for generation and transmission.

DEFINITION OF COMMUNITIES

The study constructs a scenario with a population of roughly 10,000 people spread over four communities. Three are remote rural communities, which represent the majority of areas where initial electrification projects are needed today. As significant urban population power access issues also exist, the final community is designed as peri-urban, where some household are supplied via grid, and others are electrified via grid densification or undergrid minigrids[1].

To further illustrate the benefits of undergrid development and include the factor of reliability, the study sets a garment factory in the peri-urban community that uses a distributed energy system as a backup and partial replacement of its grid supply in order to minimize its energy cost.

To show project economics in various community sizes and levels of activities, the study designed these communities with different population, density, and consumption levels. The communities' consumption profiles are built bottom-up with varied household consumption levels and community and productive activities. These loads draw heavily on previous work by RMI and follow the same basis as the **Energy Ladder Datasheet** linked earlier in the **Electrifying Economies** website.

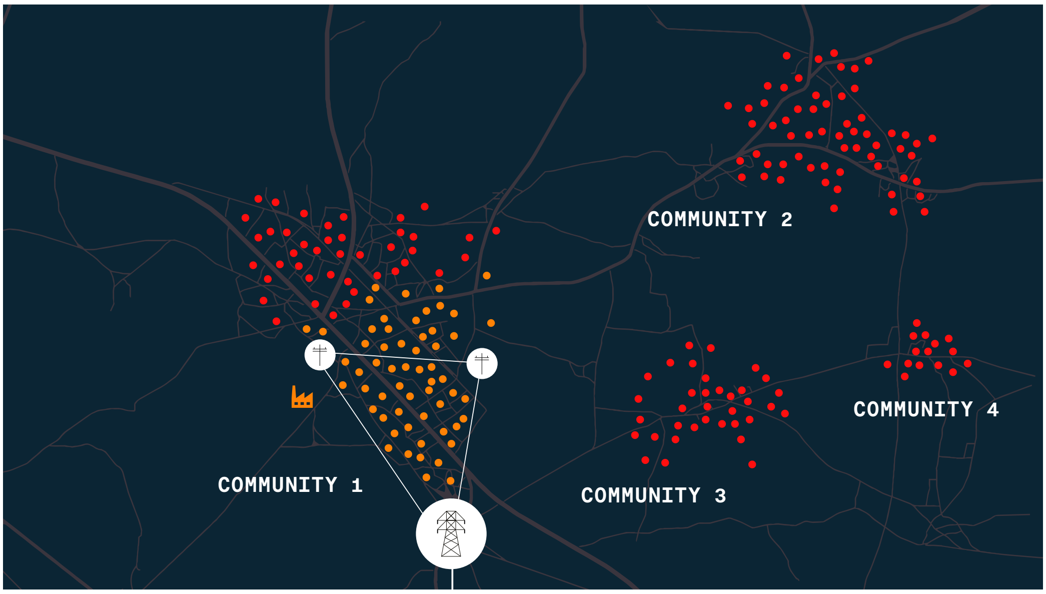
1. A minigrid built under the main grid to enhance or supplement grid services

Low Voltage Distribution

Medium Voltage Distribution

MODEL OF REPRESENTATIVE COMMUNITIES
One dot = 10 households

- No Energy Access
- Unreliable Power
- Reliable Power



Community 1 is a peri-urban community with a garment factory as the core industry. There is already rich economic activity and relatively complete public services are available. Grid supply extends to some of households in the town, but it's often unreliable. In our model, this community achieves universal access, and the garment factory secures a reliable supply.

Community 2 is a large rural village without any energy access. It develops to a community with rich economic activity and relatively complete public service. The electrification project needs to meet high demand due to various household, social wellness, and income generation activities.

Community 3 is a medium-size rural village without any access. It will develop to a community with some economic activities and limited public service. The electrification project here needs to achieve universal access with medium load.

Community 4 is a small rural village without any access. While it's being electrified, there is very limited economic activity and few public services. In the early stages of electrification, people living in this community may travel to larger communities for healthcare and jobs. The electrification project faces a limited customer pool with very low consumption.

The model communities' population and designed consumption levels when fully electrified are showed in the table below.

	Community 1	Community 2	Community 3	Community 4
Population	4500	2700	1575	675
Annual consumption level when universal access is first achieved kWh per capita	292	257	176	71

ELECTRIFICATION APPROACHES

As the study tries to compare the costs of electrification between a traditional grid extension path and a distributed energy integrated approach, this section introduces the major settings and cost assessments for both approaches.

Cost assessment

Based on the premise that electrification projects need to supply sufficient power to meet service levels to drive social and economic development, the study uses a new evaluation matrix for assessing electrification pathways. As the consumption level of a customer indicates both the quality of service and the amount of electricity bill, the cost of power should be measured and compared with power volume as its main criteria, instead of the number of customers connected as is the typical method for assessing electrification. Therefore, cost per kWh is a better metric than cost per connection in term of assessing a system's economic impact, especially if we envision an expandable and adjustable load. Tariff setting, cross-subsidization, and national energy policies will define the prices individual users pay. However, the final cost will always be borne by the citizens of the country where the infrastructure is sited, through taxation and energy bills, and the least-cost optimization carried out at a system level means this overall cost is as low as possible.

Analysis of the cost of power could be misdirected if we focus solely on increasing the load. The final goal is not the volume of power delivered, but the improvement of lives and livelihoods. Therefore, the power volume needs to be estimated based on the actual services empowered, along with energy efficiency considerations, instead of focusing on the direct actual consumption. Under this setting, the unit cost of both approaches is calculated using annual costs divided by the annual power consumption after considering energy efficiency measures, instead of the annual generation of each approach.

In order to compare like with like, the grid extension approach incurs additional backup generation costs to reach the same level of reliability as a distributed energy system and generates more power due to lack of deployment of energy efficiency measures. The integrated approach includes additional upfront energy efficiency deployment cost on top of system infrastructure development cost.

The study uses annual cost instead of net present value to balance the cost contribution from upfront costs and ongoing costs. For upfront costs, which include capital expenditures and project development, the study uses annual depreciation with 0% residual rate as its yearly cost.

Integrated approach

The specific integrated distributed energy systems modeled here include several methods of electrification based on community needs and appropriate costs. The model deploys the following:

1. A hybrid minigrid system with solar panels, a diesel generator, and a lead-acid battery for main power supply together with energy efficiency deployment for demand side management. This system aims to provide reliable supply for rural communities and unelectrified household clusters in a peri-urban community with a 5% maximum annual capacity shortage.

2. Stand-alone solar systems (often abbreviated to solar home systems, or SHS) for areas with low household density in rural communities. This integrated approach provides sufficient power for basic household demand, saving the cost of building a distribution system.

3. An undergrid minigrid to provide one-hour autonomous backup energy for the grid-connected garment factory with solar panels and a battery. This system will not only increase the reliability of power supply for production, but also save on the factory's electricity bill by replacing some of its grid consumption with zero marginal cost solar power.

Note: We haven't considered the benefit of feeding solar power back to the grid, which can create a significant amount of revenue under net-metering policies or other feed in tariffs. This could also complement the capacity shortage of the main grid system and reduce overall system costs. Regardless of these benefits, the final economics analysis is based on the actual consumption of the garment factory, ignoring excess power production that this distributed energy system could generate.

The study uses HOMER[2] as the modeling tool for minigrid optimization settings. Based on the component costs input, HOMER gives the least-cost design specifications for components' installed capacity and fuel consumption. As HOMER doesn't have the same cost granularity as the economic analysis model used here, the costs of components are aggregated[3], and the economics of the project are re-calculated based on the installation capacities of the system and granulated cost.

The components' costs used in this study are a mixture of existing best practice from field experience and the 2020 predicted costs from recent analysis and publications. To achieve these cost points, efforts on supply chain improvement, bulk purchasing, as well as policy and regulatory support are needed.

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2. Hybrid Optimization of Multiple Energy Resources software – see https://www.homerenergy.com/
3. In HOMER, hardware and installation cost are combined for components' capital cost, and project development cost are ignored

Grid extension approach

To achieve universal access, the grid extension approach requires building more distribution infrastructure to connect users. This infrastructure represents significant costs, especially when connecting to remote villages via medium-voltage distribution line or building distribution systems for an area with very low household density. Moreover, building distribution lines outside the community faces problems in acquiring land usage right. The associated costs could be very uncertain and high both economically and politically.

In addition to the CAPEX and OPEX costs of grid generation and distribution systems, consumers often need to install small diesel backup generators, as the grid cannot provided reliable supply. This creates significant additional cost from both CAPEX and OPEX perspectives for the system. In our modeling, 25% of total demand is supplied by diesel generators which cost twice as much as average grid generation.

RESULTS

This section gives a summary of results and the cost comparison between the grid extension and integrated approaches. It is organized by community in order to allow comparison of the electrification costs among different communities. Detailed electrification specifics are shown in the detailed results section.

The main findings of the comparison between two approaches among four communities are:

- The integrated approach uses distributed energy systems to provide significant cost savings in the provision of adequate and reliable universal access.
- Compared with traditional grid extension approach, the integrated approach requires significantly more upfront capital cost, but has great economic advantages in operational costs.
- Effective demand stimulation is needed for affordability, as communities with high consumption levels have lower cost for power in general.
- Energy efficiency is an essential driver for cost reduction.
- There are huge opportunities for demand shaping to increase solar utilization, which will further reduce system costs.

The cost of power varies significantly due to different geographic and economic attributes for each community. Communities far from existing infrastructure bear high cost under both approaches if treated as an isolated system. However, the integrated approach is more cost-effective than grid extension in most cases, especially for electrifying remote rural villages. By aggregating multiple communities and using integrated approaches for system design, the least-cost solution can be achieved, and the high cost of power for these remote communities could be offset by other users, making electricity affordable to everyone.

By comparing results across communities, the study shows non-residential demand like productive use of agriculture or a health clinic is critical. On one hand, these non-residential demands can shape the load curve to utilize more zero-marginal-cost solar power, therefore reducing the average cost of power. On the other hand, non-residential activities are the main driver for a community's economic development, increasing employment opportunities and income for villagers.

By comparing the two electrification approaches, the analysis shows that unreliability of grid supply is a huge hidden cost for customers served by grid. Customers spend significant amounts to set up and maintain backup generators required in instances of grid breakdown. In the grid extension approach, this problem is enlarged, and the backup cost takes a huge portion in the total system cost. **The Reliability-Adjusted Cost of Electricity (RACE): A New Metric for the Fight Against Energy Poverty** report further illustrates this issue.

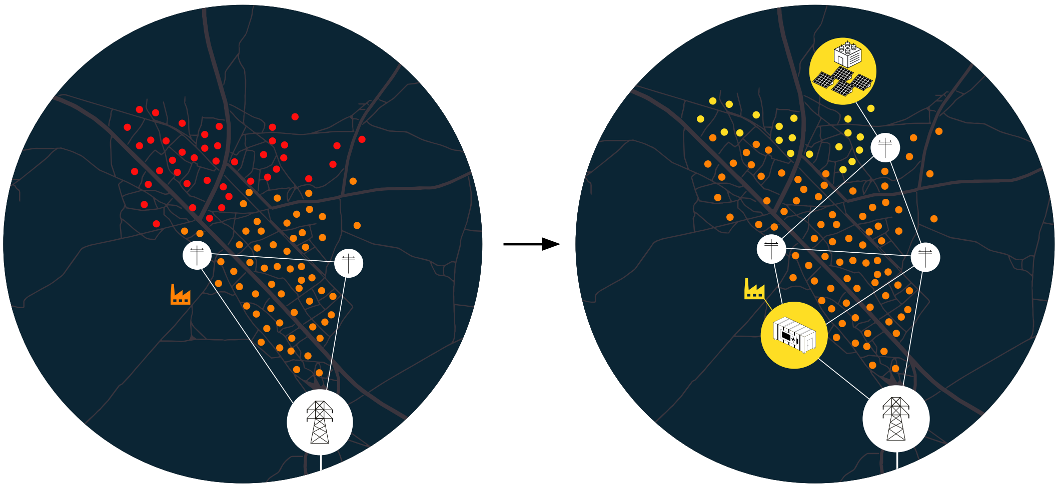
Energy efficiency is another major leverage for cost reduction. This needs to be achieved by the joint programs of demand stimulus and energy efficiency deployment. In the integrated approach, the study estimates the annual electricity saving from deploying energy efficiency appliances could exceed 1.3 GWh. This reduces the size (and therefore costs) of infrastructure development without compromising people's quality of life.

For each minigrid system, there is still room for improvement on demand stimulation and demand shaping. By eliminating solar curtailment, the cost of power could be reduced by 30% or more.

Community 1

MINIGRID SYSTEM

SOLAR BACKUP SYSTEM



Community 1 is a peri-urban community with rich economic activity and relatively complete public service, as well as sizeable industrial load from a garment factory. Regardless, it still has problems related to reliability and access. The electrification of Community 1 needs to achieve universal access and provide reliable power supply to the garment factory.

The layout of households in Community 1 is tight. Among all 1000 households, 920 of them are close to the community center, 80 are in surrounding areas, and none are remotely scattered. The cost to build distribution lines, therefore, is low.

In both approaches, 600 households are already connected to the grid and 200 households will be electrified by grid densification, which solves the power access problem but doesn't guarantee a reliable supply. The integrated approach helps relieve grid pressure as it brings more generation and flexible resources, therefore increasing the service to 800 grid-connected households. The cost of power for serving these customers is quite low as it involves less new infrastructure development, and cannot be accurately compared as access is mainly composed of the current unreliable service grid provided. (This part is separately listed in the detailed result section and excluded from the summary results below.)

The study compares the costs of two approaches to provide reliable power to the remaining 200 unelectrified households and the garment factory in Community 1. Considering all commercial activities and the factory, the consumption level of Community 1 is highest. The high consumption level combined with low need for building distribution infrastructure makes the cost of power for Community 1 the lowest among the four communities. (Note: This cost has room for further improvement as the modeling tool we use can only find a sub-optimal distributed energy solution for the grid-connected factory.) The cost of grid extension is also low for Community 1 as there is less need to build medium-voltage distribution lines.

HIGHLIGHTED RESULTS

Load profile

- Total demand: 756,243 kWh/year
- Energy saving potential: 367,913 kWh/year
- Consumption per capita after electrification: 292 kWh/year
- Non-residential consumption share: 61%

Grid extension approach

- Infrastructure: MV line 1.6 km, LV line 2.8 km
- CAPEX: $8,885/year
- OPEX: $145,906/year
- The cost of power: $399/MWh

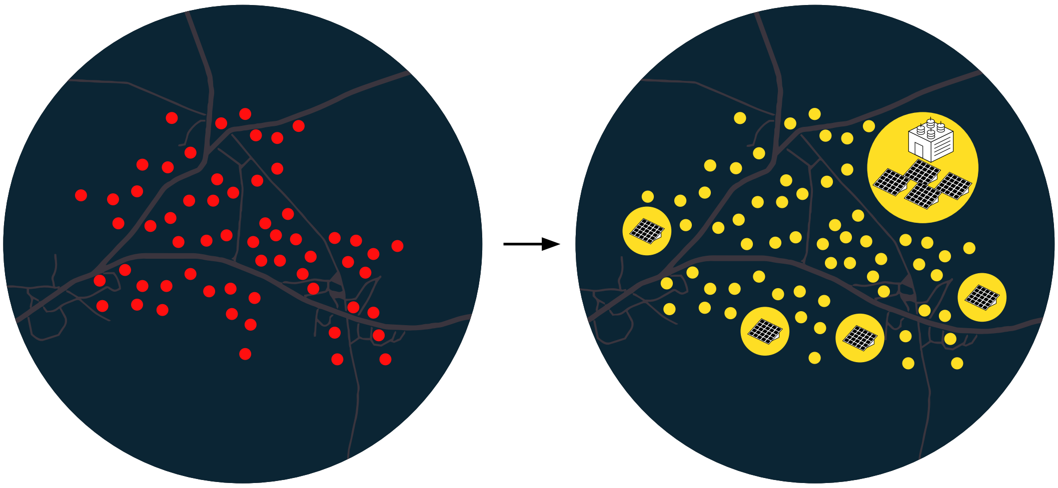
Integrated approach

- Infrastructure: Solar 242 kW, battery 532 kWh, LV line 2.8 km, 0 solar home system
- CAPEX: $55,816/year (including $17,148 for energy efficiency measures)
- OPEX: $56,183/year
- The cost of power: $288/MWh

Community 2

MINIGRID SYSTEM

SOLAR HOME SYSTEM



Community 2 will develop to a large rural village with rich economic activity and relatively complete public service. It has community infrastructure like a telecom tower, schools, a health clinic, and plenty of drinking water pumps. It also has rich quantity and variety of small commercial and agriculture productive loads. The households in Community 2 are set close together. Among all 600 households, 400 of them are close to community center, 150 are at surrounding areas, and only 50 are remotely scattered. Electrifying Community 2 is very cost-effective for both approaches as there is enough load and affordability created from non-residential activities. Especially in the integrated approach, the productive and public service demand could better utilize the zero-marginal-cost solar power, making the cost of power lower than the average level.

HIGHLIGHTED RESULTS

Load profile

- Total demand: 1,330,850 kWh/year
- Energy saving potential: 636,624 kWh/year
- Consumption per capita after electrification: 257 kWh/year
- Non-residential consumption share: 57%

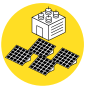
Grid extension approach

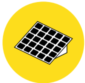
- Infrastructure: MV line 23 km, LV line 9.5 km
- CAPEX: $30,917/year
- OPEX: $266,370/year
- The cost of power: $433/MWh

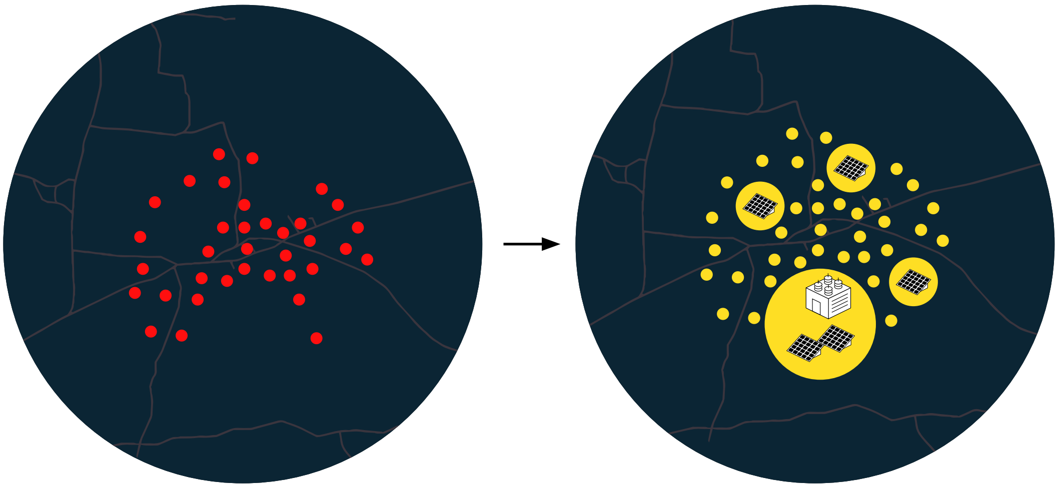
Integrated approach

- Infrastructure: Solar 437 kW, battery 1242 kWh, LV line 6 km, 100 solar home systems
- CAPEX: $128,185/year (including $45,837 for energy efficiency measures)
- OPEX: $94,675/year
- The cost of power: $341/MWh

Community 3


MINIGRID SYSTEM


SOLAR HOME SYSTEM



Community 3 will develop to a medium-sized rural village with some economic activity and limited public service. It has a school and some drinking water pumps. It also has various small commercial and agriculture productive loads, but in limited quantity.

The layout of households in Community 3 is neither dense nor disperse. Among all 350 households, 250 of them are close to community center, 70 are in surrounding areas, and 30 are remotely scattered.

As there is some productive and institutional demand in Community 3, the cost of power is better than the current standard cost of minigrid power ($0.55/kWh). However, it's higher than the average system level in this modeling and has room for improvement.

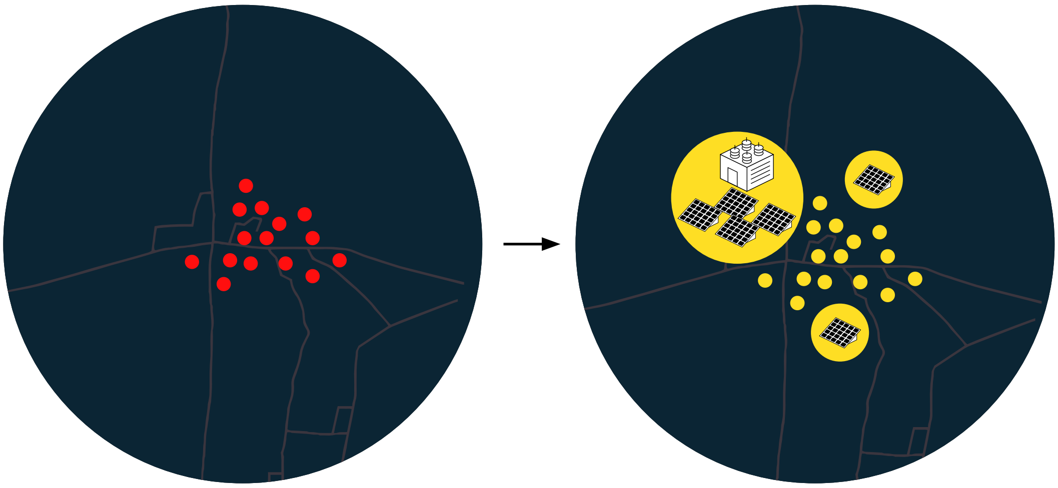
HIGHLIGHTED RESULTS

Load profile
- Total demand: 559,414 kWh/year
- Energy saving potential: 281,929 kWh/year
- Consumption per capita after electrification: 176 kWh/year
- Non-residential consumption share: 52%

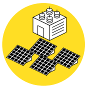
Grid extension approach
- Infrastructure: MV line 24.4 km, LV line 5.4 km
- CAPEX: $29,157/year
- OPEX: $118,657/year
- The cost of power: $533/MWh

Integrated approach
- Infrastructure: Solar 198 kW, battery 552 kWh, LV line 2.5 km, 100 solar home systems
- CAPEX: $60,646/year (including $45,837 for energy efficiency measures)
- OPEX: $51,524/year
- The cost of power: $404/MWh

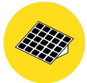
Community 4



MINIGRID SYSTEM



SOLAR HOME SYSTEM



HIGHLIGHTED RESULTS

Load profile

- Total demand: 116,168 kWh/year
- Energy saving potentials: 67,947 kWh/year
- Consumption per capita: 71 kWh/year
- Non-residential consumption share: 45%

Grid extension approach

- Infrastructure: MV line 28 km, LV line 2.8 km
- CAPEX: $30,050/year
- OPEX: $34,744/year
- The cost of power: $1,344/MWh

Integrated approach

- Infrastructure: Solar 33 kW, battery 95 kWh, LV line 0.8 km, 70 solar home systems
- CAPEX: $14,115/year (including $45,837 for energy efficiency measures)
- OPEX: $28,121/year
- The cost of power: $876/MWh

Community 4 will develop to a small rural village with very limited economic activity and basically no public service. It has a few drinking water pumps, a limited number of small shops, and agriculture productive use.

The layout of households in Community 4 is disperse. Among all 150 households, 80 of them are close to community center, 50 are in surrounding areas, and 20 are remotely scattered.

Community 4 reflects the awkward situation of many remote rural villages, where lack of income-driving activities results in low consumption levels, which in return drives up the cost of electrification blocking the possibility for increasing demand. No matter which approach is adopted, the community will have affordability issues. However, an integrated approach could provide the most cost-effective solution and has a better chance to engage with the community on bottom-up demand stimulation. Aggregated electrification planning could provide subsidy opportunities to offset the high cost of supplying this demand, requiring only a small portion of overall system consumption.

DETAILED RESULTS

Peri-urban community electrification results		Household supplied by grid		Undergrid	
		Grid connected	Grid densification	Grid extension approach	Integrated approach
Infrastructure development	Medium-voltage line (km)	—	—	1.6	—
	Low-voltage line (km)	0	2	2.8	2.8
	Solar installed capacity (kWp)	—	—	—	242
	Battery installed capacity(kWh)	—	—	—	532
	Diesel installed capacity (kW)	—	—	—	56
Demand	Final demand (kWh/year)	694,226	231,409	756,243	388,330
	Avoided consumption from EE deployment (kWh/year)	—	—	—	367,913
Consumption	Consumption from grid (kWh/year)	694,226	231,409	567,182	71,677
	Consumption from backup generator (kWh/year)	—	—	189,061	—
	Consumption from minigrid PV (kWh/year)	—	—	—	254,305
	Consumption from minigrid diesel (kWh/year)	—	—	—	62,348
	Consumption from SHS (kWh/year)	—	—	—	—
CAPEX	MV line ($/year)	—	—	$1,024	—
	Transformer ($/year)	—	—	$400	—
	LV line ($/year)	—	$676	$946	$946
	Connection ($/year)	—	$1,088	$720	$724
	CAPEX delay cost ($/year)	—	—	$792	—
	Project development ($/year)	—	—	$5,003	$4,531
	SHS CAPEX ($/year)	—	—	—	$0
	Minigrid CAPEX (exclude distribution & connection) ($/year)	—	—	—	$32,467
	EE deployment cost ($/year)	—	—	—	$17,148
OPEX	Generation ($/year)	$69,423	$23,141	$75,624	$20,102
	Generation backup ($/year)	—	—	$32,917	—
	Finance cost ($/year)	—	—	$1,971	$8,997
	O&M ($/year)	$9,927	$5,295	$35,394	$27,084
Total cost	Total cost ($/year)	$79,350	$28,436	$154,791	$111,999
	Cost of power ($/MWh)	Excluded from the comparison, as these households are provided with identical power solutions in both approaches		$399	$288

DETAILED RESULTS

Rural community electrification results		Community 2		Community 3		Community 4	
		Grid extension approach	Integrated approach	Grid extension approach	Integrated approach	Grid extension approach	Integrated approach
Infrastructure development	Medium-voltage line (km)	23.0	—	24.4	—	28.0	—
	Low-voltage line (km)	9.5	6.0	5.4	2.5	2.8	0.8
	Solar installed capacity (kWp)	—	437	—	198	—	33
	Battery installed capacity(kWh)	—	1242	—	552	—	95
	Diesel installed capacity (kW)	—	150	—	62	—	13
	Solar Home System (unit)	—	100	—	100	—	70
Demand	Final demand (kWh/year)	1,330,850	694,226	559,414	277,485	116,168	48,221
	Avoid consumption from EE deployment (kWh/year)	—	636,624	—	281,485	—	67,947
Consumption	Consumption from grid (kWh/year)	998,137	—	419,561	—	87,126	—
	Consumption from backup generator (kWh/year)	332,712	—	139,854	—	29,042	—
	Consumption from minigrid PV (kWh/year)	—	439,835	—	182,862	—	28,847
	Consumption from minigrid diesel (kWh/year)	—	248,141	—	88,373	—	14,999
	Consumption from SHS (kWh/year)	—	6,250	—	6,250	—	4,375
CAPEX	MV line ($/year)	$14,720	—	$15,616	—	$ 17,920	—
	Transformer ($/year)	$400	—	$400	—	$400	—
	LV line ($/year)	$3,211	$2,028	$1,825	$845	$946	$270
	Connection ($/year)	$2,160	$1,810	$1,260	$905	%540	$290
	CAPEX delay cost ($/year)	$5,250	—	$4,894	—	$5,074	—
	Project development ($/year)	$5,177	$8,101	$5,163	$4,374	$5,170	$1,712
	SHS CAPEX ($/year)	—	$1,516	—	$1,516	—	$1,061
	Minigrid CAPEX (exclude distribution & connection) ($/year)	—	$68,893	—	$32,707	—	$5,889
	EE deployment cost ($/year)	—	$45,837	—	$20,299	—	$4,892
OPEX	Generation ($/year)	$133,085	$44,050	$55,941	$16,497	$11,617	$3,231
	Generation backup ($/year)	$57,928	—	$24,350	—	$5,056	—
	Finance cost ($/year)	$13,070	$18,232	$12,184	$8,593	$12,634	$1,707
	O&M ($/year)	$62,286	$32,394	$26,182	$26,435	$5,437	$23,183
Total cost	Total cost ($/year)	$297,287	$222,861	$147,814	$112,170	$64,794	$42,236
	Cost of power ($/MWh)	$428	$321	$533	$404	$1,344	$876

KEY ASSUMPTIONS

The assumptions and parameters of this analysis are shared here, to provide a baseline and reference point for planning work or calculations by others. In addition to the value employed in our analysis, we also provided multiple values for some parameters here as they have multiple data points from various reference sources that affect the final economics.

General	Values for this analysis	Reference and other data point
Discount rate	8%	Consistent with previous minigrid analysis, drawing on project data[ii]
Debt: equity ratio	60%	
Interest rate	10%	
Loan tenor	10 years	
Residual rate	0%	

Grid extension

The project development cost of grid extension is significant and varies case by case. This study doesn't consider the cost of acquiring land usage right for building distribution lines outside the communities, which could be very expensive and politically controversial. It uses the same parameters of minigrid project development cost (community engagement; engineering; system integration; financial modeling; environmental impact assessment (EIA), due diligence (DD) and legal support; duties and fees; and site preparation) as a conservative estimation.

Grid cost	Values for this analysis	Reference and other data points
Cost to distributor	$0.10/kWh	Average tariffs for distributors in following countries: Ethiopia ($0.09/kWh[iii]), Lesotho ($0.20/kWhi[v]), Uganda ($0.08/kWh[v]), Nigeria ($0.04/kWh[vi]), Kenya ($0.12/kWh[vii]) and Ghana ($0.06/kWh[viii])
LV line hardware and installation	$8,450/km	Data from Kenya based study[ix]. Other data points: $4,250/km (GEP[x]), $17,475/km (RMI analysis adapted from 2018 project data[ii])
MV line hardware and installation	$16,000/km	Average of current typical cost ($25,000/km[xi]) and cost in GEP ($7000/km[x]). Other data points: $3,750/km (ESMAP, SWS solution[xi])
Cost per service transformer	$5,152/unit	Data from Kenya based study[ix], 150 kVA transformer. Other data points: $4,250/unit (GEP, 50 kVA transformer[x])
Cost per MV to LV transformer	$10,000/unit	Cost in GEP[x]
Cost of a connection (meter + wiring)	$90/household	Use the same assumption of meter and connection costs in minigrid, combining hardware and installation costs
Grid reliability	25%	Estimated based on AFD study[xii]
Backup diesel generator generation cost	$0.20/kWh	RMI modeling result, aligned with lower bound in IFC report[xiii]
Backup diesel generator capital cost	$808/kW	Use the same assumption of small size diesel generator in minigrid, combine hardware and installation costs
Transmission construction delay	3 year	RMI analysis
O&M	5% of CAPEX	Assumes average 25-year lifespan
Grid-connected customer annual consumption level	257 kWh/capita	Uses the same consumption level of the modeled large community (community 2)

Solar Home System

Solar Home System cost	Values for this analysis	Reference and other data point
SHS system capacity	0.05 kW	Estimated based on Tier 2 household consumption defined by ESMAP[xiv]
SHS capital cost	$379	Estimated based on the capacity of SHS and cost from GEP[x]
Annual consumption for SHS	62.5 kWh	Estimated based on Tier 2 household consumption defined by ESMAP[xv]

Minigrid

The minigrid cost is based primarily on data collected from existing minigrid projects. For costs with high reduction potentials in the near future, the study uses a conservative cost reduction assumption to make the prediction. For values that have multiple reference points, this study tends to choose a median level value as the input for the model.

Minigrid cost	Values for this analysis	Reference and other data point
Minigrid/Solar PV/other component lifespan	25 year	Consistent with previous minigrid analysis, drawing on project data[ii]
Lead-acid battery lifespan (year)	5 year	
Diesel generator lifespan	8 year	

UPFRONT COSTS

Hardware	Values for this analysis	Reference and other data point
Solar CAPEX (incl. panel, rack, inverter)	$645/kWp	Including panel $230/kW (field studies and RMI analysis), inverter $115/kW (ESMAP, 2018 benchmark[i]), racking and others[4] $300/kW (RMI analysis adapted from 2018 data[ii] with $20 reduction assumption for near future value).
Battery CAPEX	$161/kWh	Including battery $147/kWh (ESMAP, 2018 benchmark[i]), rack and housing $14/kWh (RMI analysis adapted from 2018 data[ii]). Other data point: $189/kWh (RMI analysis adapted from 2018 data[ii])
Diesel CAPEX (generator and housing)	$502/kW(>100kW) $800/kW(<100kW)	Including diesel genset (>100 kW) $442/kW (RMI analysis adapted from 2018 data[ii]), diesel genset (>100 kW) $740/kW (RMI analysis adapted from 2018 data[ii] and ESMAP Africa data[i]), housing $60/kW (RMI analysis adapted from 2018 data[ii]). Other data point: $700/kWh (RMI analysis adapted from 2018 data[ii])
Controller/battery inverter CAPEX	$158/kW	RMI analysis adapted from 2018 data with $17 reduction assumption for near future value
Distribution CAPEX	$8,450/km	Installation cost included. Data from Kenya based study[ix]. Other data points: $4,250/km (GEP[x]), $17,475/km (RMI analysis adapted from 2018 project data[ii])
Connections CAPEX	$44/connection	RMI analysis adapted from 2018 data[ii] with $5 reduction assumption for near future value
Meters CAPEX	$40/meter	ESMAP 2018 benchmark price[i]. Other data points: $95/meter (RMI analysis adapted from 2018 project data[ii])
Other CAPEX	$18/kWp	RMI analysis adapted from 2018 data[ii] with $2 reduction assumption for near future value

4. Includes foundation, BOS, AC station, comms/monitoring system, inverter replacement, etc.

Installation	Values for this analysis	Reference and other data point
Solar installation	$47/kWp	RMI analysis adapted from 2018 project data[ii]
Battery installation	$20/kWh	
Diesel installation	$8/kW	
Controller installation	$15/kW	
Connections installation	$3/connection	
Meters installation	$3/meter	

Project Development	Values for this analysis	Reference and other data point
Community engagement	$428/project	RMI analysis adapted from 2018 data[ii] with 50% reduction[5] assumption for near future value
Engineering, system integration, financial modeling	$10,500/project	RMI analysis adapted from 2018 data[ii] with 50% reduction[5] assumption for near future value
EIA & DD & legal support	$2,000/project	RMI analysis adapted from 2018 project data[ii]
Duties and fees	25% of hardware	RMI analysis adapted from 2018 project data[ii]
Site preparation	$2,044/project	RMI analysis adapted from 2018 data[ii] with 50% reduction[5] assumption for near future value
Project delays	$8,835/project	RMI analysis adapted from 2018 data[ii] with 50% reduction[5] assumption for near future value as this highly depends on the specific project
Other	$2,500/project	RMI analysis adapted from 2018 data[ii] with 50% reduction[5] assumption for near future value

ONGOING COSTS

Site Operations	Values for this analysis	Reference and other data point
Local operational management	$15,199/year	RMI analysis adapted from 2018 project data. Including O&M ($8219/year), guards ($730/year), customer relations ($6250/year), land lease cost ($0/year), Network lease costs($0/year), travel($0/year)
Company overhead (per site)	$7,356/year	RMI analysis adapted from 2018 project data. Including management staff ($4,550/year), bookkeeping ($608/year), transportation ($565/year), clerk/driver ($243/year), office costs ($800/year), contingencies ($350/year), company insurance ($240/year)
Other (taxes, licenses, insurance)	$0.0143/kWh	Represents taxes, fees, and other marginal cost that the site operator pays with each kWh sold to the customer in order to secure business licenses and minigrid assets insurance. RMI analysis adapted from 2018 project data
Fuel	$0.66/L	RMI analysis adapted from 2018 project data

5. World Bank report shows community engagement, feasibility and site prep can be reduced significantly (e.g. through portfolio approach)

Energy efficiency

The energy efficiency potential is defined as "100% - consumption after EE/consumption before EE". In this study, the energy efficiency potentials are calculated based on the same data points and references as the energy ladder[xv]. Below, we listed the energy efficiency potentials of user types that are not included in the energy ladder, however, they are also built bottom up using energy efficiency data of appliances from the energy ladder.

EE potentials	Values for this analysis	Reference and other data point
Household	50%–70%	Household appliances have various EE potentials from saving more than 80% energy by replacing incandescent light with LED, to 50%-75 energy saving from fridge and freezer, to 50% EE potentials of TV and washing machine, and 10-30% energy saving from fan. Therefore, households that adopt different appliances will have different consumption levels and EE potentials. As lighting dominates the energy consumption for household with fewer appliances, the EE potential for small-consumption households is large. With more modern appliances kicked in, the consumption level of households increase and their EE potentials decrease, but still at a rough 50% level as large-consumption appliances all have high EE potentials. Estimated based on users' consumption level, it's corresponding appliances usage in ESMAP study[xiv] and EE potentials in energy ladder
Garment factory	48%	Estimated base on EE potential of lighting in energy ladder, and 55% EE potential from sewing machine[6] [xvi]

EE deployment cost	Values for this analysis	Reference and other data point
Payback period for EE deployment	3 year	RMI analysis

6. Sewing machine has full energy efficiency potential at 75%. The study uses 55% as a conservative assumption due to technical and management gaps in Africa.

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ELECTRIFYING ECONOMIES

The Electrifying Economies project
demonstrates the role distributed energy will play in ending energy poverty and catalyzing a green and equitable recovery from the Covid-19 crisis. It draws on the latest data and research from around the world to show how distributed renewables can provide sustainable, affordable, and reliable power for all. The project provides information to support policy makers and investors in taking action today, to realize this potential.