The Anchor-Business-Community Model for Rural Energy Development: Is it a Viable Option?

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Executive Summary

Electricity is an enabler of development and has become an essential element of the human condition. However, according to the International Energy Agency, 1.2 billion people worldwide lack access to modern electricity, and the majority of those people live in isolated and rural areas where grid extension does not make economic sense. In a time where the rural electricity access market is underdeveloped or nonexistent, innovative business models are required to decrease this persistent energy deficit.

One such model gaining attention is the Anchor-Business-Community (ABC) model, which is a business model that allows energy service companies to serve entire energy systems in rural areas by dividing customers into three main categories: 1) Anchor customers which provide continuous energy demand, 2) Business customers which require energy for productive use but do not require continuous demand, and 3) Community customers that require energy for basic household needs and where affordability is a major concern. This customer distinction allows energy service companies to leverage the continuous demand from the anchor customers to provide a reliable revenue stream, thereby reducing the risk of providing energy to the other customer types in rural areas.

The major presumed benefits of this electrification model compared to others is that it is commercially viable for private sector-led electrification, reduces risk for power suppliers, and provides lower cost and cleaner energy options for customers. However, after discussions with practitioners at USAID, concerns arose about ABC model viability because it is not being implemented at the rate or scale one would expect, given its many benefits in theory. The purpose of this study is to understand why that might be the case by evaluating the viability of the ABC model.

In order to assess the ABC model, this study focuses on the economics of the system and asks the question: Assuming that all customers will be electrified, is the cost of electrifying customers through the ABC model less than the cost of electrifying each customer individually? In other words, is it more economical for the anchor customer to electrify itself onsite and leave the energy service company to electrify the community separately (current situation), or is it more economical for the energy service company to electrify both the anchor customer and the community together with shared costs and infrastructure? This study does not include business customers in the modeling analysis as there was not sufficient data.

In order to answer this question, the study needed to begin with one particular location and determine customer profiles, as a change in such variables could alter the results. The case location in this study is India and the anchor customer leveraged in the ABC model scenarios are telecom towers. This study devised and assessed eight customer demand scenarios using HOMER Software, an energy modeling analysis tool that allows comparison between individually electrifying all customers and electrifying all customers through the ABC model by taking into account energy infrastructure and technology, fixed and variable costs of each scenario, and other costs. HOMER produced levelized costs of electricity for each system.

Modeling the eight scenarios yielded four main comparisons between individual or standalone

electrification of each customer and electrification through the ABC model: 1) Small tower and small community, 2) large tower and small community, 3) large tower and large community, and 4) small tower and large community. Three of the four comparisons indicated that the ABC model produced electricity at a lower cost to society on the whole but place a cost burden on one particular customer, meaning that there is an economic disincentive for that customer type to participate in the ABC model.

In order to incentivize actors to engage in the ABC model and to capture the resulting societal benefits, there is a role for the public sector to step in and help reduce costs both through transaction cost interventions and transfer cost interventions. In terms of reducing transaction costs, the public sector could assist in spatial analysis and planning to help identify those towers and communities that would likely succeed in the ABC model based on size and proximity as well as create forums where the ABC model stakeholders can engage as they have not previously had the proper channels. In terms of transferring and reducing costs, the public sector could offer direct subsidies to the energy service provider or the community customers. The public sector could also foster and help design a cross-subsidization scheme that will allow one customer to pay higher costs to subsidize lower costs for another customer.

In further study, business customers should be added to the scenarios to examine how different energy loads from a business customer standpoint affect the economics of the ABC system. In addition, quantification of societal benefits and risks should be included, as these would help determine if the ABC model is practical in specific locations. Lastly, location specific data should be collected and pilot projects planned to assess how the economics of the system work in practice as well as how external sociopolitical factors affect the practicality and scalability of the ABC model in different locations.

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Introduction

Electricity is considered to be a driver and enabler of economic growth. In fact, electricity has become essential to bettering the human condition, especially in developing communities. Electricity is not the sole driver of economic development but it is a necessary component. Access to electricity creates the opportunity for better education, better health, gender equality, increased social status, increased income, and increased household and community security.[1] Despite the overwhelming benefits of reducing energy poverty, 1.2 billion people lack access to modern electricity, and that number continues to grow.[2] Asia and Sub-Saharan Africa account for the majority of the population lacking electricity access with South Asia contributing to 42% of the world's population without electricity access.[3]

In addition to electricity access, reliability of electricity remains a concern. Even those who do have access to electricity may not have reliable or constant electricity. For example, Nepal suffers from blackouts of up to 14 hours a day because of high demand, low supply, and unreliable energy infrastructure, despite urban communities having access to the national grid.[4] To further complicate the issue of electricity access, the majority of those who lack electricity are located in rural areas. In addition, many governments consider a rural community electrified if 10% of the community has 4 hours of electricity a day[5], which is not enough to provide development opportunities and is inconsistent with the outcomes of modern electricity. Furthermore, many households still rely on traditional forms of biomass and kerosene for heating and cooking, which prove to be detrimental for human and environmental health.[1] Clean, reliable, and affordable electricity in the developing world is hard to come by, especially for poor, rural communities.

While the international focus for developed nations looks toward greenhouse gas mitigation, developing nations look toward basic energy development to stimulate more economic growth in-country. As a result, the international community is beginning to explore ways to form cohesive strategies that achieve seemingly disparate goals. Just this past year, in 2015, the Sustainable Development Goals were announced and Goal 7 reads: "Ensure access to affordable, reliable, sustainable and modern energy for all."[6]

One of the biggest challenges with electrifying developing countries is overcoming the significant rural-urban gap. Grid electricity is a popular and desired method for electrification by developing nations but because of hurdle and infrastructure costs rural electrification is difficult and, in some cases, impossible.[7,8] The alternative to grid extension is off-grid electrification or distributed energy, which can take on many forms such as a micro-grid or standalone system (variable in size). Three distinct models of electrification are listed below with their main advantages and disadvantages.

Table 1. Electrification Model Advantages and Disadvantages[9]

Grid Extension	**Micro-grids**	**Standalone Systems**
High infrastructure costs	Unlikely Bankability	Limited ability to support demand growth
Unstable power	Difficult to scale	Discontinuous supply
Slow implementation	Needs public support and effective management	Difficult payment collection
Environmental impacts	Responsive to local needs	Low efficiency from DC supply

Because of the associated challenges with grid extension and the lack of development and productive-use potential for small standalone systems, focus has shifted to micro-grids for the ability to increase electrification enough to spur economic development in rural areas.[10] While the technological aspects of micro-grids are fairly mature and developed, the economics and regulatory systems in place worldwide are not always favorable to micro-grid development, making the shift from grid extension to distributed generation for rural electrification expensive and challenging.

The unique challenges for distributed generation technologies require creative business models to incentivize scale-up of development. Business models for energy delivery can be classified in the following ways: (1) public utility that distributes and generates electricity, (2) private utility that distributes and generates electricity, (3) public-private partnership that produces and distributes electricity, and (4) community model where the community owns and operates the electricity production. Other business models may fall somewhere between these four major categories.[11]

International Organizations, World Banks, and National Governments have piloted and researched several business models for rural electrification but nothing has been implemented at scale and sustainability is a major concern. In addition, a model that works in one location may not work in another due to external sociopolitical and economic factors. The purpose of this thesis is to identify a potential business model for rural electrification and assess the model for viability.

Potential Solution: Anchor-Business-Community Model

One business model that has attracted interest in recent years is called the Anchor-Business-Community (ABC) Model (or alternatively, the Smart Power Model, Telecom-Energy Initiative, Community Power from Mobile Model). The ABC Model is business model that uses market forces to incentivize energy service companies to build micro-grid infrastructure in isolated and rural areas and provide electricity to the entire community by dividing customers into different categories.[12] The purpose of this customer division is so that the energy service companies leverage customers with larger and more reliable demand to reduce the risk of providing electricity to customers who create unreliable and variable demand. If the energy service company can ensure revenue that covers cost of operation, the company can grow thereby developing jobs and increase its presence in rural communities, and ultimately reducing energy poverty.

The customer groups within the ABC model framework are:[13]

Anchor Customers represent day/night time load, are predictable in nature, and require continuous power delivery. Anchor customers reduce the risk to a private energy developer of building a rural off-grid power system by assuring a steady demand and revenue stream. Examples of anchor customers include mobile telecom towers, dairy farms, health clinics, and mines.

Business Customers are local, commercial establishments where power is a critical input for productivity and income generation but where continuous power is rarely needed. Examples include carpentry, blacksmith, and laundry services.

Community Customers are generally individual households that require electricity for everyday uses such as lighting, cooking and phone charging. Community customers have many pressing needs, one being energy access; however, affordability is a major concern. Conversely, community customers create risk for the energy service providers because community demand is intermittent and uncertain.

Under the ABC model, all three customer types need a reliable source of energy at an affordable cost, and all three customer types obtain electricity. The intermediary, which would be the energy service company, can provide that service and gain the benefit of reliable revenue from the anchor customer while also providing electricity to the vulnerable and poor rural communities. The alternative scenario, which in many locations is the current situation of rural energy provision, is when the anchor load provides its own energy from a diesel generator while the energy service company has the option to provide electricity to the community, incurring large financial risk and uncertainty or a disincentive to provide the energy service.[14]

In addition to electrifying communities, the concept behind the ABC model is that it can also initiate community economic development by creating productive uses of the electricity (or income-generating activities) thereby continuing to reduce the cost and increase the affordability of rural electrification.

Organizations and practitioners have taken interest in the ABC Model because of the associated benefits for the private sector and community:[13]

1. Commercial viability for private sector-led energy provision
2. Risk reduction for small, private power suppliers by creating continuous energy demand and predictable revenue
3. Lower cost and cleaner energy delivery options for customers

In theory, the ABC model is a viable method for rural electricity access by changing the economics of rural electrication to make the venture for private energy service companies bankable and profitable, while keeping electricity affordable for customers. However, after discussions with practitioners at USAID,[i] the model is not being implemented at the rate or scale that one would expect given its potential advantages. The goal of this study is to examine the viability of the ABC system and determine why this might be the case.

Research Question

Many factors are relevant in determining viability of the ABC model but the four main categories include technical, economic, regulatory, and social factors. Technical feasibility studies include factors such as system design, environmental impacts, and infrastructure requirements. Economic feasibility studies examine factors including long and short term system costs, system risks, and financial barriers. Regulatory feasibility studies examine current and potential regulatory systems and policies for barriers and opportunities to the ABC model, and social factors include community motivations, community needs, and community involvement.

Given time and resource constraints, this study will examine economic and technical factors, acknowledging that the other factors are important and should be examined in future research. In addition, not only do economic factors indicate market conditions but they can also indicate regulatory status and reflect potential underlying social and political barriers and opportunities.

Framing the problem in an economic context, the question becomes:

Assuming that all customers will be electrified, is the cost of electrifying customers through the ABC model less than the cost of electrifying each customer individually? In other words, is it more economical for the anchor customer to electrify itself onsite and leave the energy service company to electrify the community separately (current situation) or is it more economical for the energy service company to electrify both the anchor customer and the community together with shared costs and infrastructure?

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[i] Phone interview with Kate Steel, USAID

In defining this question, it is important to note that this study does not include the business customers in the economic model due to insufficient data. This will be important to include in future studies because the results might shift depending on the type of business and the electricity demand of the customers. However, the question being asked allows insight into the ABC model operation to determine the potential economic factors that might be impeding sustainability and scalability of the model.

In answering the research question, two potential outcomes can be hypothesized. The first is that the model does prove economically viable, in which case there is evidence suggesting that other non-economic barriers are impeding ABC model scalability. The second is that the model does not prove economically practicable for all parties involved, in which case the claims warrant more investigation as to why the economics do not favor the model, and what can be done to alleviate economic stress on the parties. The results of this study can then be examined in larger contexts, such as implications of the ABC model and how it interacts with the external environment (sociopolitical, regulatory, national, global) to identify other barriers and opportunities.

Choosing the Location: India

Location is an important factor for whether or not the ABC model is successful. For the purpose of this study, India will be the country context in which the ABC model will be examined. Because of political and socioeconomic systems, as well as environmental factors, the results of the ABC model evaluation will vary with each location, making it difficult to assume and model at large scale. For example, the ABC model would fair better in a country with policies in place that support distributed generation compared to a country that favors large scale energy production and grid expansion as a priority. Additionally, two major locations are being considered for electrification through business models similar to the ABC model: Sub-Saharan Africa and India. Of the two locations, India is the model location with the assumption that electrification by the ABC model of a sparsely populated community will be unsuccessful if electrification of a densely populated community is unsuccessful, given the evidence of economies of scale and large infrastructure costs.[ii]

The population in India is 1.3 billion and it continues to grow, putting strain on electricity production. India's electricity consumption is currently 744 kWh/capita,[15] which is low compared to developed countries and many developing countries but this is primarily because the population in India is so large and the electricity supply is still lacking. Based on the Energy Development Index (outlined by the IEA using an electricity indicator, clean cooking indicator, public services indicator, and the productive use indicator), India ranks 41 out of 80 developing countries with a score of 0.31.[16] This low indicator value means that India has a heavy dependency on dirty fuel for cooking, has low infrastructure and capacity development for effective and efficient delivery of electricity services, and has low productive (income-generating) uses of electricity.

Of India's total population, 25% lacks access to electricity, making India the country with the largest total population without electricity access.[3] As energy poverty persists in rural India, communities are unable to develop, leaving them vulnerable to health implications, decreased education, low or no income, lack to household energy uses, and other impacts. Currently, 80 million households lack adequate grid electricity while another 20 million households receive less than four hours of electricity a day.[14] More than half of the underserved households are confined to five Indian states: Uttar Pradesh, Bihar, Odisha, West Bengal, and Madhya Pradesh.[17]

India's energy policy focuses primarily on securing energy sources to meet the needs of its growing economy. Energy consumption has more than doubled between 1990 and 2011, yet the per capita energy consumption remains low.[18] India relies heavily on coal, traditional biomass, natural gas, and crude oil for energy production. The biggest challenges for India in terms of ensuring electricity meets demand include lack of infrastructure, current subsidy schemes, high capital costs, and regulatory structure. Several policies and programs have been implemented to increase rural electricity access; some have been focused on using renewable energy as a source

[ii] Phone interview with Kate Steel, USAID

and others have focused solely on access. Major policies and programs implemented in India are outlined in the chart below.

Table 2. Electrification Policies and Programs in India[19]

Policy/Program	Explanation
Rural Electrification Corporation (REC) established in 1969	Support for rural electrification schemes. Two major focuses include irrigation pump electrification and village electrification. REC acts as implementation agency to central government programs.
Bright Hut Scheme in 1988	Provided single-point lighting connections to households below the poverty line.
Rural Electricity Supply Technology Mission in 2002	Goal to electrify all villages and households by 2012 through renewable energy sources, decentralized technologies, and conventional grid connection.
Accelerated Rural Electrification Program in 2003	Subsidy provided for state utilities carrying out rural electrification activities. Limited to electrification of smaller, unelectrified villages and tribal villages through conventional and non-conventional energy sources.
The Electricity Act of 2003	Specific instructions for expanding rural electricity access. First statute mention of rural electrification. Mandates state and central governments to provide electricity access to all.
Accelerated Electrification of Villages and Households in 2004	Accelerated electrification by merging the AREP and Bright Hut programs.
National Electricity Policy in 2005	Access to electricity for all households and demand to be fully met by 2012. Minimum

	lifeline consumption of 1 kWh/household/day by 2012.
RGGVY (Rural Electrification Program) in 2005	Scheme for developing rural electricity infrastructure and expanding household electrification. Connection is provided free for households below poverty line.
Rural Electrification Policy in 2006	Extension of the National Electricity Policy. Specific recommendations for rural electrification program.

For a long time, India has made strides to enact policies that support rural electrification. However, India has only recently switched from a focus of grid extension for productive energy use to distributed generation technologies that provide more power than single light fixtures. Few subsidies exist for small energy providers to reduce risk of servicing rural areas as many subsidies in India are set to incentivize large investments and large companies. The Electricity Act of 2003 was the first legislated step the national government took to ensure that action was taken by state and central governments to electrify the nation.

In 2005, the goals became more specific with RGGVY, and schemes were developed to increase infrastructure in rural areas for electricity access. However, still, a focus was on grid extension, although recommendations have come about that insist on the use of distributed generation and renewable energy sources, such as solar. India has demonstrated public commitment by putting policies in place to reduce energy poverty, including ambitious goals of total electrification by dates that have already passed. However, there is still not an established market for rural electricity as electrification tariffs can be at least 10 times that of what urban and grid customers currently pay for electricity,[iii,16] and private involvement in the process is lacking.

[iii] Average electricity price in India fluctuates around \$.05 per kWh for grid electricity and the modeled cost of electricity for rural communities seen later in this study range from \$.4 to \$.8 per kWh.

Choosing the Anchor: Telecom

One option for anchor customers that stands out in developing countries, especially rural communities, is a telecom tower. A telecom tower fits the profile of an anchor customer well because of its ability to provide a predictable demand and give the energy service company a chance for growth, which is an essential element of the ABC model. Telecom towers are also fairly uniform and widespread, which would allow the ABC model to be scalable in multiple locations. The telecommunications industry is booming worldwide, with a global penetration of 96% and is projected to continue to grow.[20] In addition, towers are beginning to explore new opportunities and new electrification methods, including the use of renewable sources of power.[21]

Base tower stations (BTS) also are a good option for anchor loads because many are strategically located in and near rural communities that lack electricity access. For a BTS to be used as an anchor, the tower would have to be located off-grid so that it can be powered by a distributed generation micro-grid. An estimated 701,000 bad-grid towers and 320,100 off-grid towers are operational throughout the international space.[22] Off-grid implies that the tower is detached from the grid, likely located in a rural area, and powers itself by a diesel generator. Bad-grid implies that the tower is powered by the grid but receives unreliable electricity and must supply backup power from a diesel generator to ensure continuous electricity for tower operation.

Anchor Towers in India: The Opportunity

Of the 1.3 billion people that live in India, 68% of the population lives in rural areas.[15] In addition, 237 million people in India lack access to electricity and 75% of them are located in rural areas. The electricity outlook for communities seems dim; however, the story is different for telecom towers. In India, there are 70,000 rural off-grid telecom towers out of a total 400,000 towers and a mobile subscriber base of 933 million. Of those subscribers, 40% are located in rural areas and have access to towers. Synergies between towers that need electricity and communities that need electricity can be bridged with the partnership of third party energy service companies.

Table 3. Opportunity with Towers and Rural Electrification in India by the Numbers[23,15]

Off-Grid Towers	70,000
Bad-Grid Towers	170,000
Mobile Coverage (% of Population)	73%
Mobile Subscribers	933 million
Rural Subscribers	40.49%
Urban Subscribers	59.51%
Population without Electricity	237 million
National Electrification Rate	86%
Rural Electrification Rate	74%
Urban Electrification Rate	96%

There is an apparent opportunity for cross-sector collaboration between energy companies, telecom companies, and communities for rural electrification. Tower companies are beginning to partner and share infrastructure, and it isn't long before energy service companies can partner and supply telecom companies with energy allowing infrastructure sharing to electrify communities and businesses.

Analytical Approach

The aim of this study is to model and evaluate the ABC approach in a representative Indian community. In order to understand costs of the system, the first step is to know what grid type needs to be evaluated. This means designing the technically and economically optimal micro-grid system, using HOMER Software[iv] and India-specific data. The comparison of costs between ABC model electrification and standalone electrification can happen once the grid system is designed. The comparison between electrifying individual communities and towers and electrifying the two customers as a combined unit is crucial in assessing the viability of the ABC model.

[iv] Refer to Appendix I.

In order to answer this question, the study makes comparisons between the costs and economics of different electrication scenarios while examining 2 main variables. The first variable is the system electrification type, meaning the customers are either electrified individually as standalone systems or they are electrified as a unit through the ABC model. The second variable is size of the customer, which allows the study to examine how load size and combination of customer size affects the ABC model. Examining these variables result in four distinct comparisons:

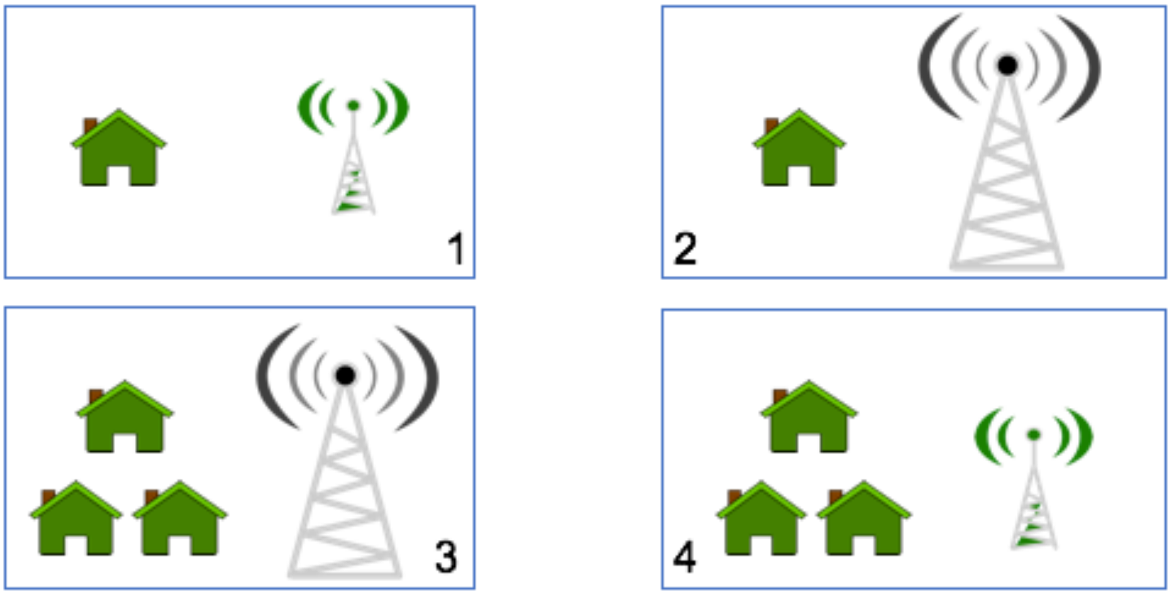
1. Standalone: Small Community and Small BTS vs. ABC: Small Community + Small BTS
2. Standalone: Small Community and Large BTS vs. ABC: Small Community + Large BTS
3. Standalone: Large Community and Large BTS vs. ABC: Large Community + Large BTS
4. Standalone: Large Community and Small BTS vs. ABC: Large Community + Small BTS

In effect, this project models eight different customer scenarios and yields four distinct cost comparisons when examining standalone or individual electrification with ABC model electrification. The eight modeling scenarios and four comparisons are laid out below.

Table 4. Electrification Scenarios

Eight Electrification Modeling Scenarios
Small Standalone BTS
Large Standalone BTS
Small Standalone Community
Large Standalone Community
Small BTS + Small Community
Large BTS + Small Community
Large Community + Large BTS
Large Community + Small BTS

Figure 1. Standalone vs. ABC Model Electrification Comparisons



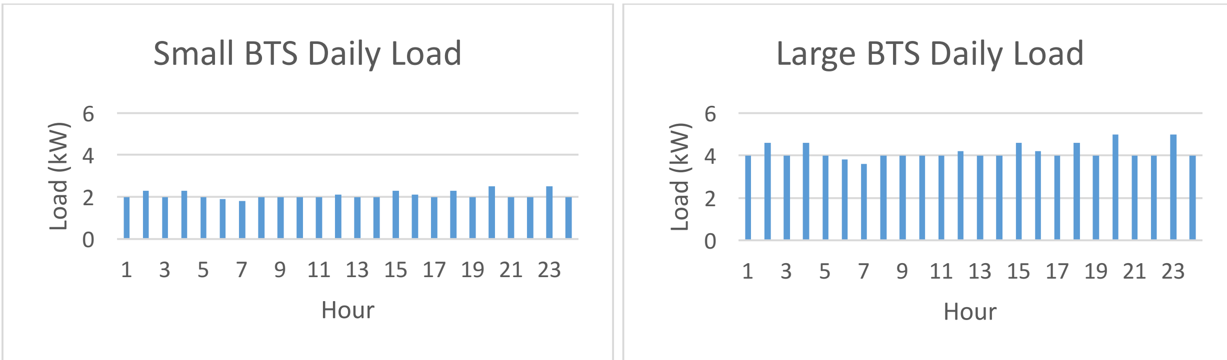
Load Modeling

In order to model the costs of each scenario, the load profiles must be defined. Load profiles are daily energy use profiles for customers in kW, that allow the energy provider to know how much electricity is required at a certain time of day. The loads in this study are representative of what one might find in a rural Indian community but will not represent one specific site. In other words, the customer loads are defined by using national averages in energy data.

Energy systems are designed around a peak load, meaning that the energy system must be large enough to meet the largest demand at any given time. Load modeling for each customer in the scenarios above allows determination of peak load for any given customer base, where the fluctuations are in demand, and how reliable the demand will be. This information is used by HOMER to determine the proper size and technology of the micro-grid for each scenario. As previously stated, there will be no business customer included in this study but the load profiles for representative towers and households are below.

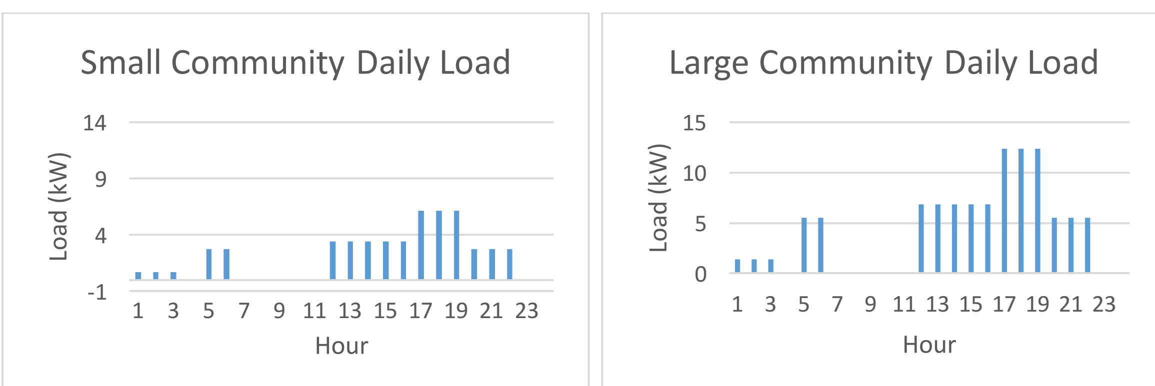
Standard rural Indian BTS's range from 1 to 5 kW in size but the majority are smaller.[24] The small BTS used in this model is 1.5 kW and the larger BTS is 3 kW. The peak loads in each BTS are higher than the nameplate energy use due to fluctuations in energy use for seasons, demand growth, and because BTS accounts for 50-80% of the energy use in towers sites.[22] Other loads at the tower come from electronics, battery chillers, and other miscellaneous equipment. The two BTS load profiles can be seen below.

Figure 2. Small and Large BTS Daily Load Profiles[25]



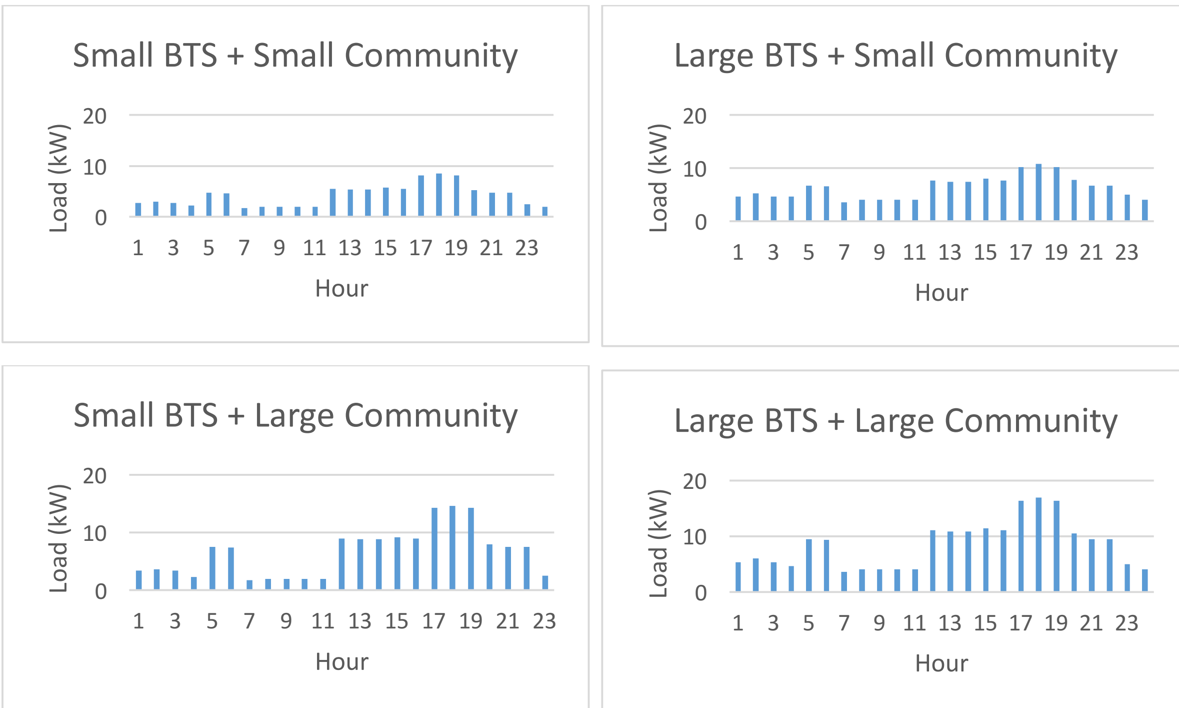
The average rural Indian household requires electricity to power a fan, charging of a mobile telephone, and two compact fluorescent light bulbs for around 5 hours per day.[16,26] The peak for energy use in the households tend to be late afternoon. For the community profile, the average household electricity profile was scaled up to make community sizes of 50 households and 100 households, and were loaded into HOMER to allow evaluation of what the ABC model does with increasing community scale. The two community load profiles, large and small, can be seen below.

Figure 3. Small and Large Community Daily Load Profiles



In addition to standalone modeling in HOMER, the objective of this study is to assess how the combination of the anchor and community customer changes the economics of electrifying the system. This means that the two load profiles must be combined to make the ABC load. All combinations were assessed in HOMER, and the load profiles can be seen below.

Figure 4. Daily Load Profiles for ABC Electrification Scenarios



Modeling Inputs and System Design

The following technologies were considered during the building of the model in HOMER:

1. Diesel Generator
2. Solar PV
3. Battery
4. Wind Turbine

HOMER takes the technologies and applies them to the given demand or load profiles and simulates each technological combination possible to make up an optimal micro-grid for each demand scenario by evaluating the fixed costs, operation and maintenance costs, emissions, available resources, and other economic data to produce a levelized cost of electricity and net present cost to allow easy comparison of different scenarios. The resource availability was added for both wind and solar. This data was taken from the National Renewable Energy Laboratory database[27] and assumed to take on characteristics of a location such as Bihar, India, which is a location being assessed by the Rockefeller Foundation for potential ABC Telecom Model pilot projects.[28]

Modeling Results

System schematics were ranked by levelized cost of electricity allowing the choice of the optimized system for each scenario. The schematic with the lowest levelized cost of electricity is the one that is chosen to compare across scenarios. For all scenarios, the micro-grid system schematic had elements of solar PV, diesel generator, and battery storage. The example schematic for a small community and small BTS (ABC) can be found below. For complete schematics of each micro-grid system, refer to Appendix II.

Figure 5. Energy System Schematic for ABC electrified small community and small BTS

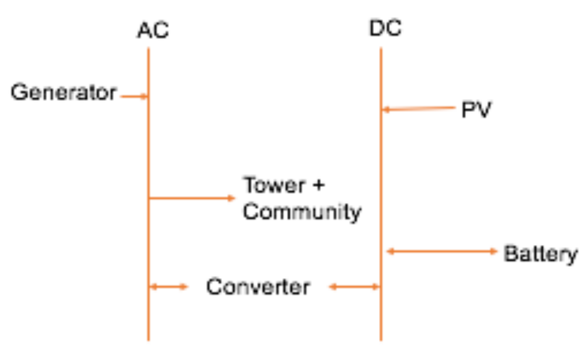
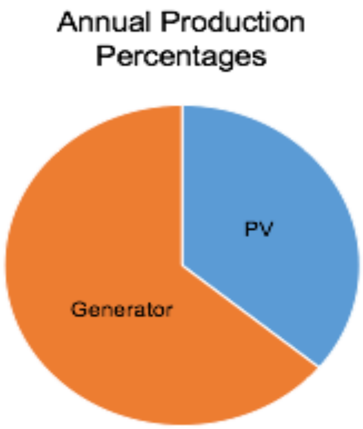


Figure 6. Power Production Proportions from ABC Schematic for small community and small BTS



The graph above illustrates that the ABC model allows for a shift of almost a third of the system's power away from diesel and towards solar, which is important knowing that many rural grids and towers are currently powered by diesel alone. The micro-grid schematics are important because one claim of the ABC model is that a cleaner energy source option is provided to customers. The fact that solar PV is cost effective and crucial to providing energy to customers in each scenario is favorable to such claims.

As one of the objectives was to discover if the ABC model was more economically viable than electrifying individual customers as standalone systems, comparisons of the levelized costs of electricity can be found in the table below. In addition to levelized costs of electricity (LCOE), carbon emissions, net present cost, and excess electricity are also recorded for each scenario. For a more detailed picture of costs, refer to Appendix III.

Table 5. Levelized Costs of Electricity for Each Electrification Scenario

Scenario	LCOE
Small BTS	$.412/kWh
Small BTS + Small Community	$.456/kWh
Large Community	$.485/kWh
Small Community	$.545/kWh

Large BTS + Small Community	$.62/kWh
Large BTS + Large Community	$.676/kWh
Small BTS + Large Community	$.7/kWh
Large BTS	$.785/kWh

When ranking the eight scenarios from least cost to highest cost, immediately standalone small BTS is the cheapest option. However, this does not mean that standalone electrification is the cheapest option for society. In looking at the first comparison (standalone small BTS and standalone small community versus the ABC small BTS and small community), assuming the small BTS operators act rationally, they will choose to electrify themselves onsite, leaving the small communities to be electrified alone through the energy service provider. However, this is not the cheapest option for the community.

Table 6. Small BTS and Small Community LCOE Comparisons

Standalone Small BTS	$.412/kWh
Standalone Small Community	$.545/kWh
ABC Small BTS + Small Community	$ .456/kWh

The cheapest option on the whole for society is electrifying all customers through the combined system, or the ABC model. However, despite the lower electrification costs of the system, if the tower enters into the ABC model, their individual costs will increase and therefore they will carry the cost burden of the ABC system. This means that the tower operators will need an incentive to participate in the ABC model in order to lower the costs of electrification to society and capture the benefits of community electrification.

Table 7. Large BTS and Large Community LCOE Comparisons

Standalone Large BTS	$.785/kWh
Standalone Large Community	$.485/kWh
ABC Large BTS + Large Community	$.676/kWh

When evaluating the second comparison (Large BTS and Large Community), the cheapest option appears to be the standalone community. Again, if the community and the energy service company acts rationally, they will choose to individually electrify themselves, leaving the towers to electrify themselves at an undesirable rate. What is seen in this comparison is that, again, on the whole for society, the electrification costs are cheaper through the ABC model than by electrifying both customers individually. In this comparison, however, the cost burden would be placed on the large community.

Table 8. Large BTS and Small Community LCOE Comparisons

Standalone Large BTS	$.785/kWh
Standalone Small Community	$.545/kWh
ABC Large BTS + Small Community	$.62/kWh

Similar to the second comparison, the third comparison (Large BTS and Small Community) demonstrates that the cheapest option for society on the whole is the ABC model even though one of the individual customer types, the community in this case, incurs the cost burden and may require incentives to engage in the ABC model.

Table 9. Small BTS and Large Community LCOE Comparisons

Standalone Small BTS	$.412/kWh
Standalone Large Community	$.485/kWh
ABC Small BTS + Large Community	$.7/kWh

Alternatively, however, when the small BTS and large community scenarios are compared with standalone and ABC options, the least cost electrification method is the individual electrification of each customer instead of combined electrification of the system through the ABC model. This anomaly could be explained by the high infrastructure costs to the community for transmission simply being so high that the costs of the ABC system aren't worth building out. Alternatively, the certainty in demand from the small BTS is not enough support the uncertainty in demand in the large community. While the small BTS would reduce the risk to the energy service provider, the risk would still be too present and the energy provider would not have an incentive to participate in the ABC model.

Sensitivity Analysis

Because the model results have a potential to change as parameters change, sensitivity analysis is important to undertake in a model such as this. Three main parameters were used in sensitivity analysis for each scenario: (1) Discount Rate, (2) Diesel Price, and (3) Project Lifetime. The levelized cost of electricity does change with the different parameters but the overall results are not changed; however, one parameter affects the cost of electricity much more than the others and in fact impacts the results of the model. Diesel price greatly affects the cost of production, ranging the LCOE for a particular scenario from $.2/kWh to $1/kWh with diesel prices of $.5/L and $2/L respectively[v]. Not only does the diesel price affect the LCOE but it affects the optimal micro-grid schematic and the associated pollution and emission levels.

This sensitivity result is particularly important for towers and India because off-grid towers without this ABC model rely primarily on diesel generators and India has particularly volatile diesel pricing.[16] The price of diesel in India could both help and hurt the investment towards the ABC model for electrification, depending on when the project is proposed. Looking ahead, the price of diesel continues to rise and therefore the ABC model might be a safer option than individual electrification so that the micro-grid can diversify its energy resources with renewables and so the model allows for cost sharing of the electricity for each participant.

Results Discussion

The ABC business model, based on the HOMER model analysis, becomes more complicated than once predicted. None of the four partnership scenarios experience a win-win levelized cost of electricity, meaning the cost of electricity is never cheaper for both customers in the partnership model compared to individual electrification. However, in three of the four partnership scenarios, the ABC model LCOE was lower for the society as a whole. As the modeling results illustrated in every case, one customer type bore more of the cost of

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[v] Diesel price in India currently fluctuates around INR 60 per liter, which almost $1 per liter. This price is volatile and varies across states.

electrification than the other, which means in order to capture the societal benefits of community electrification through the ABC model the burdened customer must be incentivized to participate in the ABC model.

Table 10. Recommendations for Electrification Scenarios

Electrification Scenario	ABC or Standalone?
Small BTS, Small Community	ABC --- benefits community, cost borne by BTS
Small BTS, Large Community	Standalone --- ABC hurts both customers
Large BTS, Small Community	ABC --- benefits BTS, cost borne by community
Large BTS, Large Community	ABC --- benefits BTS, cost borne by community

The table above lists for each scenario which customer type bears the cost of a partnership despite a lower cost of electrification for the system as a whole. The small BTS + small community scenario indicates a cost borne by BTS. Two of the four partnership scenarios experience a levelized cost of electricity that places the burden on the households and communities, which makes the community electrification more expensive than standalone electrification. The fourth partnership (small BTS + large community) would place a burden on both customer types, indicating that the individual electrification would be more economically favorable.

What becomes clear from this analysis is that the ABC model is not enough to bring the costs of electrification to all parties down sufficiently to make it economically competitive on its own through the private sector. This indicates that in order to capture and transfer the benefits that are provided through the model to society, the public sector must step in and provide subsidies, policy, or planning assistance to the private sector.

Role for Public Sector

In order to make the ABC model a more viable option, and for individual customer groups to be incentivized to participate in order to capture societal benefits, the public sector must engage in planning and enact policies that will address the unfavorable economic burden of the ABC model. The government can address this issue in two major ways. The first is to reduce transaction costs of the ABC model by assisting with spatial analysis and planning and perhaps engagement forums. The second is to transfer costs between parties to make the ABC model more favorable through direct subsidization or cross-subsidization, keeping in mind each customer's willingness to pay.

Looking at the transfer cost option more closely, one possible public intervention could be direct subsidization. This could mean direct subsidization to the energy producers or customers. For example, if the government wanted to incentivize the community, subsidies can take place in the form of tax reductions, direct cash investments, or a lower cost of electricity. For example, Costa Rica started a rural electrification program with low interest loans provided from USAID and in Ireland, investment costs were paid for, either partially or in full, by the national government through grants.[29] Chile also implemented a subsidy program for rural energy development where the government set aside a special fund to competitively allocate a one-time direct subsidy to private companies to cover investment costs incurred through rural electrification projects.[30] The ABC model has high potential to be a partially subsidized model that would help the electrification get off the ground but not make the model dependent upon subsidization long term.[31]

Another example of direct subsidization is a direct cash payment for a bill pay assistance for community members. This is a subsidy that focuses less on protecting the energy provider and more on protecting the customer groups. In terms of the ABC model, this subsidy would need to be directed at the customer group that takes on the burden of participation in the ABC model. One example of this type of subsidy can be seen in Thailand's history. When Thailand was launching its rural electrification program the government had set aside budgetary allocations for direct subsidies to energy customers that supported electricity tariffs.[29] Mexico also has a direct tariff subsidy that supports electricity customers.[29]

Another form of subsidization, and a more likely option in the ABC model is cross-subsidization. This form of subsidization is initiated by the government but is a form of cost transfer between customers. The government could initiate this cross-subsidization or the private energy service provider can create a unique pricing structure that supports needy customers. This cross-subsidization structure can be seen in Thailand where the residential tariff is lower than the commercial and industrial tariff in order to support those customers where affordability is a major concern.[29] Other examples of cross-subsidization in practice around the world in electricity sectors (as well as others) can be found below.

Table 11. Cross-subsidization in Practice Around the World

Quebec	Residential consumers pay less for electricity than institutional, industrial, and commercial customers[32]
Thailand	Different charge structures for electricity (higher cost for larger energy users)[29]
UK: Aravind Eye Hospital	Same hospital product to all customers but at a different price based on income[33]
UK: d.light	Offer a higher-priced upgraded product to cover the cost of providing discounted basic services for low-income customers[33]
Belarus	Revenues from industrial tariffs subsidize heating for households[34]
United States	Duke Energy charges a higher $/kWh price for residential customers than industry, creating a cross-subsidy for industrial customers[35]

Cross-subsidization is applicable to many cases within the ABC model. In the scenarios where the telecom benefits by the ABC model and the community bears the cost, cross-subsidization means the telecoms would pay a higher price for electricity than the community members. This would incentivize the community to engage in the ABC electrification scheme and as long as the cross-subsidized price for telecoms stays under the willingness to pay and the market remains uncompetitive, this intervention appears to be feasible.

For two of the scenarios outlined above, cross-subsidization would be a legitimate public intervention that would incentivize each individual actor to engage in the ABC model. See below for examples.

Table 12. Cross-subsidization for Small Community and Small BTS ABC Electrification Scenario

Small BTS	$.412/kWh
Small Community	$.545/kWh
Small BTS + Small Community	$ .456/kWh
Subsidy	.456 - .412 = .044
New Community Price	.456 + .044 = .5

Table 13. Cross-subsidization for Small Community and Large BTS ABC Electrification Scenario

Large BTS	$.785/kWh
Small Community	$.545/kWh
Large BTS + Small Community	$.62/kWh
Subsidy	.62 - .545 = .075
New BTS Price	.62 + .075 = .695

In the cases of the large BTS + small community and the small BTS + small community, not only do the cross subsidies keep the LCOE under the willingness to pay of rural BTS's, which is $.7/kWh,[21] but the new LCOE price for the benefiting customer remains under what they would have paid individually for electrification absent the ABC model. This is not the case for the large BTS + large community scenario, however, and other subsidizing methods or policies might be more appropriate.

The public sector can also provide assistance in spatial analysis and planning. This would allow paring of towers to needy communities at appropriate scales[vi]. In other words, the government can avoid paring small BTS towers with larger communities as the model indicated this

[vi] The public sector can either perform spatial analysis independently or partner with NGO's to assess the market for where tower and community partnerships are most likely to succeed. For example, New Ventures, which was funded by World Resources Institute has developed maps for India where private enterprises should target for distributed generation electrification. These maps can be paired with maps of telecom tower locations and potential can be assessed spatially. More information can be seen here: http://www.nvindia.biz/resources-micro-markets-for-clean-energy-access.html

partnership hurts both customers. Once the government can assist in planning the energy service companies can initiate pilots and scale up the projects as they see fit.

Lastly, the government can initiate forums of communication between the ABC model stakeholders. This practice will help identify motivations and needs, and allow a safe space for the actors to communicate and plan for electrification. This also ensures that all actors have a voice in the process.[5]

Additional Considerations

Some of the outcomes within the HOMER analysis either resulted in excess electricity or unmet load. This is also a very important factor to consider when deciding on whether or not the ABC model is viable. Unmet load means that the tower may not be sustained, which would be a disincentive for the BTS customers to engage in the ABC model. Excess electricity is a problem only if it does not get used. However, if the excess electricity is used as a charging station, this problem can easily be avoided in an individual electrification or ABC electrification scenario.

Another issue to consider is the payment method used in the business model for the anchor customer. Many business models rely on Power Purchase Agreements, but differ on whether the customer is charged a flat rate monthly fee or a on per kWh basis. Towers are hesitant to enter into long term PPA's but energy service companies prefer PPAs as a business approach.[22,36] In addition, a per kWh basis gives more certainty to long term demand whereas flat rate PPA's incentivize the customers to use more energy per month, and becomes a disincentive for energy efficiency.

As previously mentioned, this modeling analysis did not include business electricity use, but should an entity decide to pilot the ABC model in a community, data must be collected on potential business use and income generation. This will also give more insight into potential growth capability for the micro-grid and determine if the ABC model is viable long term.

In the future, identification of real-world public interventions for rural electrification and their application to the ABC model and India will be crucial for the ABC model's success. In addition, quantification of societal benefits resulting from the ABC model might prove beneficial to investors in the process of attracting investment for the ABC model. Additional research should identify non-economic barriers to the ABC model scalability in India such as current policy and subsidy schemes. Collection of location-specific data will be crucial to the model's success as every location will be different and might prove varied outcomes for the ABC model. This process could be done through a series of pilot projects. Ultimately, this research will determine a viable rural energy delivery model for sustainable development with the participation of private and public sectors.

Conclusion

This study determined that the ABC model could be viable but only if the public sector were involved in pricing and cost transfer to incentivize individual actors. This study also determined that the ABC model does change the economics of rural electrification to a lower cost of electricity provision for a system of customers (ABC) in comparison to electrification of individual customers (standalone) by providing a lower cost of electricity to society as a whole. This study also reinforced the concept of expensive rural electrification compared to urban grid electrification because of infrastructure cost, inability to pay, uncertain demand, lack of incentives, and a lack of an established market.

When comparing the results of HOMER to the original claims of the ABC model, this study determines that:

- The ABC model is not commercially viable because it cannot be sustained without public support and intervention and therefore is not private sector-led.
- The ABC model does create continuous energy demand and reduces risk for energy service providers but careful planning has to be done to ensure that the anchor load creates enough demand to counterbalance the uncertainty in the community customer load.
- The ABC model can create a lower cost energy source for customers but some customer types might bear a greater portion of the cost than others.

- The ABC model does encourage cleaner energy, as each model scenario required the use of solar PV and batteries in conjunction with diesel instead of just a diesel generator, which is the current baseline approach to rural telecom electrification.

These conclusions do not mean that the ABC model cannot be piloted and cannot be a successful initiator of rural electrification. But this study does caution the complexity of model implementation and highlights the need for public involvement in India and potentially elsewhere.

Appendix I. Hybrid Optimization of Multiple Energy Resources Modeling

HOMER is a micro-grid modeling and optimization software that was originally developed by the National Renewable Energy Laboratory and is now owned and managed by HOMER Energy. The HOMER model is described by the company as, "the global standard in micro-grid software…HOMER's optimization and sensitivity analysis algorithms allow you to evaluate the economic and technical feasibility of a large number of technology options and to account for variations in technology costs, electric load, and energy resource availability."[37] The main functions consist of three things:

1. Simulation of an energy system
2. Optimization of costs and technology
3. Sensitivity Analysis on multiple assumptions and variables

The model is unique because it simulates both the technical aspects of a system as well as the economics within the same model allowing the analysis to be streamlined and more comprehensive. The model takes into account cost and technical information, optimizes the grid system for a specific demand, and compares all of the options by levelized cost of electricity (LCOE) as well as net present cost. The model helps determine what mini-grid system would be best for a certain area, which then allows for further policy and economic analysis.

Most variables in the model can be adjusted by the model user such as cost information, discount rates, project technology, resource availability, and resource price. The sensitivity analysis aspect of the model allows the user to identify what specific variables have an impact on the final result. In addition to the HOMER applicability for this evaluation, HOMER has been cited in countless articles and helps planners of distributed generation plants. For these reasons, HOMER is used in this project to evaluate the ABC model with telecom towers in India.

Appendix II. Optimized Energy System Architecture

Small BTS

PV	Generic Flat Plate	5 kW
Generator	Diesel	3 kW
Battery	1 kWh Li-ion	3 strings
Converter	System Converter	25 kW
Dispatch Strategy	Cycle Charging	

Large BTS

PV	Generic Flat Plate	10 kW
Generator	Diesel	8 kW
Battery	1 kWh Li-ion	9 strings
Converter	System Converter	100 kW
Dispatch Strategy	Cycle Charging	

Small Community

PV	Generic Flat Plate	7 kW
Generator	Diesel	10 kW
Battery	1 kWh Li-ion	10 strings
Converter	System Converter	25 kW
Dispatch Strategy	Cycle Charging	

Large Community

PV	Generic Flat Plate	20 kW
Generator	Diesel	15 kW
Battery	1 kWh Li-ion	10 strings
Converter	System Converter	25 kW
Dispatch Strategy	Cycle Charging	

Small Community + Small BTS

PV	Generic Flat Plate	10 kW
Generator	Diesel	10 kW
Battery	1 kWh Li-ion	10 strings
Converter	System Converter	25 kW
Dispatch Strategy	Cycle Charging	

Small Community + Large BTS

PV	Generic Flat Plate	20 kW
Generator	Diesel	10 kW
Battery	1 kWh Li-ion	50 strings
Converter	System Converter	25 kW
Dispatch Strategy	Cycle Charging	

Large Community + Large BTS

PV	Generic Flat Plate	30 kW
Generator	Diesel	20 kW
Battery	1 kWh Li-ion	20 strings
Converter	System Converter	25 kW
Dispatch Strategy	Cycle Charging	

Large Community + Small BTS

PV	Generic Flat Plate	30 kW
Generator	Diesel	20 kW
Battery	1 kWh Li-ion	20 strings
Converter	System Converter	25 kW
Dispatch Strategy	Cycle Charging	

Appendix III. Cost Information

Net Present Cost ($) of Electrifying Small BTS

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
PV	10000	0	646	0	0	10646
Diesel Generator	1500	7443	7007	57035	-346	72638
Battery	2100	1822	388	0	-280	4030
Converter	7500	3182	0	0	-599	10083
System	21100	12447	8041	57035	-1225	97398

Net Present Cost ($) of Electrifying Large BTS

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
PV	20000	0	1293	0	0	21293
Diesel Generator	21600	41894	28254	87288	-2311	176725
Battery	6300	39047	1164	0	-540	35970
Converter	30000	12728	0	0	-2396	40332
System	77900	83669	30711	87288	-5247	274321

Net Present Cost ($) of Electrifying Small Community

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
PV	1400	0	905	0	0	14905
Diesel Generator	5000	6936	8036	66513	-655	85830
Battery	7000	13621	1293	0	-712	21202
Converter	7500	3182	0	0	-599	10083
System	33500	23739	10233	66513	-1966	132020

Net Present Cost ($) of Electrifying Large Community

Component	Capital	Replacement	O&M	Fuel	Salvage	Total

PV	40000	0	2586	0	0	42586
Diesel Generator	7500	15087	16812	124303	-329	163373
Battery	7000	10641	1293	0	-78	18856
Converter	7500	3182	0	0	-599	10083
System	62000	28910	20690	124303	-1006	234897

Net Present Cost ($) of Electrifying Small Community + Small BTS

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
PV	20000	0	1293	0	0	21293
Diesel Generator	5000	17210	16925	127800	-870	166065
Battery	7000	13354	1293	0	-935	20712
Converter	7500	3182	0	0	-599	10083
System	39500	33745	19510	127800	-2404	218151

Net Present Cost ($) of Electrifying Small Community + Large BTS

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
PV	40000	0	2586	0	0	42586
Diesel Generator	27000	53085	36055	118882	-2275	232747
Battery	35000	46571	6464	0	-6182	81853
Converter	7500	3182	0	0	-599	10083
System	109500	102838	45104	118882	-9055	367269

Net Present Cost ($) of Electrifying Large Community + Large BTS

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
PV	60000	0	3878	0	0	63878
Diesel Generator	54000	102343	68257	204633	-7762	421471

Battery	14000	54954	2586	0	-2954	68586
Converter	7500	3182	0	0	-599	10083
System	135500	160479	74721	204633	-11315	564018

Net Present Cost of Electrifying Large Community + Small BTS

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
PV	60000	0	3878	0	0	63878
Diesel Generator	54000	80968	60035	179784	-1682	373105
Battery	14000	49639	2586	0	-1250	64975
Converter	7500	3182	0	0	-599	10083
System	135500	133789	66499	179784	-3531	512041

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