University of Michigan School for Environment and Sustainability (SEAS)

Fueling a transition: Evaluating the feasibility for a hybrid renewable microgrid in Beni, Democratic Republic of Congo

Calli VanderWilde, Tyler Fitch, Elissa Mueller
4-17-2018

Acknowledgements

We would like to acknowledge our partners at Kivu Green Energy for their assistance through all stages of this project. We would like to thank them for their time and considerable efforts in providing us with information and educating us from afar about their city, their company, and how we could create a project together that would help them achieve their goals.

We would also like to thank Juhudi Dupac and his team of researchers at Université Chrétienne Bilingue du Congo (Christian Bilingual University of Congo, UCBC) for their feedback on the survey instrument and their continued efforts in deploying said survey to local farmers.

Lastly, we would like to acknowledge our advisors Dr. Jose Alfaro and Dr. Todd Levin for their advice and support throughout the project process.

Abstract / Executive Summary

This project (1) explores the economic feasibility of a 600-kW renewable energy microgrid in the city of Beni, Democratic Republic of Congo, (2) creates a survey instrument to assess local farmers' willingness-to-accept payment for providing agricultural residues for use in a biomass gasifier, (3) performs optimization analysis for the design of a solar and biomass powered microgrid. The overarching goal of the study is to determine whether a renewable microgrid could provide reliable power at a lower cost than diesel generators. A framework has been established so that once available, survey results can be smoothly integrated into the techno-economic model. The more accurate picture of biomass costs and availability will better inform system design decisions. Model results indicate that the optimal portfolio for this renewable grid is a combination of 238 kW of solar generation, 380 kW of biomass generation, and 689 kWh of battery storage. Our model indicates a levelized cost of electricity range for this portfolio between $0.32 and $0.43 per kWh, which suggests that our proposed system will be able to achieve cost-parity with the diesel generation commonly available in the city.

Introduction

In Beni City in the North Kivu province of the Democratic Republic of Congo (DRC), social venture and electricity provider, Kivu Green Energy (KGE), seeks to provide residents with reliable access to cleaner, more affordable energy by changing its fuel portfolio from fossil fuels to renewables. KGE has built one 55 kW solar microgrid to date and aims to expand to 10 MW of renewable energy generation by 2023. The goal of reducing cost further and developing a productive, mutually-beneficial partnership with local cocoa farmers to secure biomass for gasification purposes has prompted KGE to seek out a means of determining the combination of renewable energies that could produce the cheapest, most reliable mix for the community.

Objective

KGE has reached out to this University of Michigan team to determine system costs for an optimal energy portfolio that helps meet these goals. This study (1) creates a survey instrument to quantify the willingness of farmers to accept payment for their biomass residues, (2) proposes a framework to integrate the findings as inputs for HOMER modeling software, and (3) performs optimization analysis for the design of a solar and biomass powered microgrid. Results of the HOMER optimization will answer two critical questions for KGE: (1) *What renewable electricity generation portfolio is most cost-effective for providing reliable electricity in Beni, Eastern DRC?* and (2) *Can a hybrid-renewable microgrid system compete with the diesel generators?*

Background

The Democratic Republic of Congo

The DRC has one of the lowest per capita electricity consumption rates in the world (International Energy Agency, 2017a). In 2014, per capita electricity consumption in the DRC was 109 kWh per capita versus 12,987 kWh the U.S. that same year. Only 15.2% of the DRC is electrified (International Energy Agency, 2017a). Previous government attempts to increase generation capacity have fallen short and the majority of available power has traditionally been allocated to the mining sector (USAID, 2017). In 2014, the national government approved a new Electricity Code that authorized the creation of regulatory and rural electricity agencies and opened the power sector to private investment. Implementation of the Electricity Code is ongoing.

Lack of access to modern electricity services compromises the health, education and potential for economic growth for millions of Congolese. While the government has set a bold target in the energy sector—to provide 60% of the population with access to electricity by 2025—it has yet to implement plans to meet this target (International Rivers, 2013).

Beni, North Kivu

Beni is a city of roughly 200,000 that, like the rest of the country, has been plagued by political unrest and violence, hindering development in both urban and rural areas (J. Shaw, personal communication, 2017). Energy poverty significantly hinders the community's ability to adequately and efficiently utilize its resources, and Beni's substantial distance (over 3,000 kilometers by road) from the capital and other population centers make the extension of a natural grid unlikely. Diesel-powered microgrids produce the limited electricity that is available and local forest biomass provides fuel for cooking (Yang, 2017). The energy sources currently utilized by residents of Beni are unsustainable across multiple dimensions: diesel fuel is delivered through an inconsistent supply chain, leading to unpredicted price shocks; diesel generators and traditional wood-fueled stoves have negative local air pollution effects; and local forest biomass increases the risk of land use conflict with a bordering conservation area. Nevertheless, household-scale diesel generators remain the only way to access electricity services for most residents of Beni.

Kivu Green Energy

Jonathan Shaw co-founded KGE, a nationally incorporated energy company based in Beni City, in 2015 after acquiring the largest commercial energy provider in the area. KGE seeks to redefine the local energy market by improving the reliability of electricity, reducing consumer costs, and converting all diesel-generated power to renewables. KGE installed its first commercial solar microgrid—the first solar microgrid in eastern DRC—in June 2017. The pilot project represents the first step in KGE's ambitious plan to implement 10 MW of renewable energy in eastern DRC by 2023.

Given the proximity of Beni City to large farming areas that generate significant quantities of cocoa biomass residue (cocoa pod husks), electricity generation through biomass gasification holds enormous potential for KGE as the company looks to cost-effectively expand its operations

Microgrids

For about 100 years, electricity generation, distribution and consumption has relied on large networks and economies of scale to deliver power: large, fossil-fueled or hydroelectric power plants produce electricity for a region, and then a complex distribution system, operated by professional grid operators, coordinates power supply to match demand.

Such a model faces challenges in an energy development context. Given the urgency of the problem of energy access and the ambition with which the international development community is approaching this issue, it is sometimes not possible to expand the central grid fast enough. In the past, grid extension has been plagued by political complexity and slow progress. Furthermore in cases of remote, rural communities, extending the larger grid may be quite expensive. As an alternative, remote, rural communities have historically turned to pollutant-heavy diesel generators for their needs.

Yet, decreasing costs for renewable energy generation and storage have unlocked the potential of microgrids around the world. Because microgrids do not rely on a connection to a larger grid, they are well-suited for increasing access to energy in remote and rural areas. At the same time, cell phone proliferation has made microgrid payment, operation, and monitoring easier than ever before. Because of these factors, microgrids are becoming the preferred option in many contexts for expanding access to energy.

In a development context, microgrids generally operate without a connection to an external grid. In general, they can be thought of as small, stand-alone power systems that utilize local generation resources to meet local electricity supply and demand. And any type of electricity generation, from solar power to a diesel generator, can power a microgrid.

The International Energy Agency (2017b) projects that by 2030, renewable energy sources will power over 60% of new access, with off-grid and mini-grid systems providing the means for all half of that new access. A vast majority of the 1.1 billion people who do not currently have access to electricity will depend on microgrid technologies for electricity. In those communities, rural microgrids will deliver benefits to communities by replacing diesel generators and increasing the types of available energy services . These lead to health, environmental, social, and livelihood/economic improvements.

HOMER Modeling Software

The U.S. National Renewable Energy Laboratory (NREL), developed the Hybrid Optimization Model for Electric Renewables (HOMER) software to aid in the design, feasibility assessment, and system optimization of microgrid projects. The software is now independently managed by HOMER Energy LLC and has been widely used to analyze configurations of systems and power generation technologies for a range of applications around the world. The tool includes model components PV, wind, biomass, and hydro technologies, and performs load balancing at a one-hour resolution.

HOMER performs three major functions: energy system simulation, optimization, and sensitivity analysis. During the simulation process, HOMER models the operation of a given micro-grid system configuration over the lifetime of the system, assessing technical viability, optimal operation, and life-cycle costs of the system. HOMER's optimization function requires that the user identify a number of decision variables, as well as possible values for each decision variable. Optimization proceeds by simulating grid operation for each potential permutation of decision variable levels and identifying the least-present cost system as the optimal system (Lambert, Gilman, & Lilienthal, 2006). A proprietary Optimizer algorithm allows users to specify a maximum and minimum for decision variables; the algorithm defines appropriate variable levels and adjusts decision variable levels at decreasing increments as the system converges on a least-cost configuration (Walker, 2016). Sensitivity analysis runs multiple optimizations based on user-defined variables and allows the user to compare least-cost systems across sensitivity scenarios.

While HOMER has become widely known as an industry standard for microgrid and energy system modeling, previous studies in Africa focus on much smaller systems than what KGE seeks. However, the projects still offer helpful insights with regards to technologies of interest and key system design aspects.

Abdulah et al.'s (2016) analysis of a project in Botswana offers a framework for modeling a PV-biomass-battery storage system at a small (<10 kW) scale. The project utilizes a fixed-dome biomass digester that converts a combination sewage, animal waste and plant residue into a useful gas. The study compares several cases of separate and combined PV and biomass systems, both with and without battery storage, to show that the solar PV and biomass systems used together can yield lower electricity costs than either generation type alone. The project also clearly demonstrates that the addition of storage to that combined system allows for smaller PV and biomass installations and lower overall costs.

Sigarchian et al.'s (2015) feasibility study models a system consisting of solar PV, wind, and biogas backup that would supply electricity to a rural village in Kenya. The project compares this system to one with diesel backup generators to show that biogas is a more affordable backup than a diesel generator system. The study further confirms the idea that a mixture of renewable generation types helps to offset costs. The research also confirms the idea that in rural contexts where fossil fuels are expensive, renewables provide a cleaner and more affordable option.

A Somaliland feasibility study by Abdilahi et al. (2014) uses HOMER to model a solar and wind power system with diesel backup. This project offers insight into the use of HOMER for an urban-based system design. The area of implementation for this system has some similarities to Beni, such as an urban center with little electrical infrastructure, a history of political instability, highly fluctuating fuel prices and extremely high costs; as such, it provides a useful resource for understanding energy access in similar areas.

Biomass gasification

Gasification has proven successful in developed countries not only in hybrid systems, but also as a stand-alone technology. Several examples of operational biomass microgrids are available in developing countries such as India and Liberia (Dasappa, 2011a; USAID Liberia & Winrock International, 2012). Multiple studies have confirmed the viability of cocoa pod husks as a renewable energy source (Duku, Gu, & Hagan, 2011; Kamp & Østergård, 2016; Martinez-Angel, Villamizar-Gallardo, & Ortiz-Rodriguez, 2015; Syamsiro, Saptoadi, Tambunan, & Pambudi, 2012; Winrock International, 2014).

Biomass gasification systems convert organic matter, such as agricultural residues, into energy and a carbon rich effluent called 'biochar.' These renewable energy systems jointly provide electricity as well as a useful byproduct. Coupled with appropriate electricity transmission infrastructure, biomass gasifiers provide electricity for lighting, heating, transportation, communication and mechanical power—all of which support better education and health, higher incomes, and overall improvements in quality of life. Additionally, biochar can be used as a soil amendment by farmers to enhance soil fertility. Given the high carbon, macro- and micronutrients content that the crop residues often contain, returning the gasification byproduct (biochar) to farmers provides an important means of organically returning nutrients to soils (Smil, 1999). Previous household surveys show poor soil quality to be a dominant concern for Congolese farmers (Secure Livelihoods et al., 2015). Using biochar as a soil additive also functions as a means of carbon sequestration, simultaneously helping mitigate anthropogenic climate change (Woolf, Amonette, Street-Perrott, Lehmann, & Joseph, 2010). The nature of biomass gasification, its use of local agricultural residues for feedstock, makes it an especially promising technology in rural, agrarian settings.

Biogasification and Cocoa

To date, cocoa has not seen widespread adoption as a bio-gasification feedstock in any context, despite the massive scale of cocoa agriculture in many tropical regions (Syamsiro et al., 2012). In part, this lack of take-up is due to the high moisture content, necessity of processing the husks into pellets, and the logistical difficulties of collecting cocoa husks, as they are typically left at the site of harvest (Syamsiro et al., 2012).

Nevertheless, cocoa pod husks hold potential as a biomass fuel. Martínez-Ángel et al. (2015) concluded that there are major possibilities for energetic valuation of cocoa pod husks via gasification. Velaquez-Araque and Cárdenas' (2016) similarly confirmed the promise of cocoa pod husks as a renewable energy source. Smil (1999) highlights the variety of benefits to be realized from cocoa biomass gasification: substituting current fossil fuel energy with energy from biomass gasification increases energy sovereignty because it draws on a resource that is under the community's control, reduces the need for significant effort to store and treat cocoa by-products, and provides an important means of maintaining soil quality without requiring external nutrient inputs.

HOMER's biomass module allows the user to specify the availability, cost, carbon content, and energy content of the biomass feedstock, as well as the ratio of biogas generated to the biomass feedstock consumed in the gasifier. Values for cocoa pod-husk carbon and energy content, and biogas-to-biomass ratios are available in the literature. (Syamsiro et al., 2012) estimate the fixed carbon mass ratio of cocoa pod husks at 20.5%. Spilacek et al. (2016) established a gasification ratio of 83%. Various studies place the heating value of cocoa pod husks between 15.48 MJ/kg (lower heating value) to 20.2 MJ/kg (high heating value) (Mohammed, Mokhtar, Bashir, & Saidur, 2013; Syamsiro et al., 2012; Velazquez-Araque & Cárdenas, 2016). For comparison, a study of biomass resources in Ghana showed the lower heating values of coffee (12.56 MJ/Kg), maize (15.48 MJ/Kg), and sugarcane (13.38 MJ/Kg) are comparable to that of cocoa (Duku et al., 2011). Available data on the Congolese cocoa industry indicates no shortage of biomass availability—cocoa farmer co-operatives in the Kivu region have memberships in the several thousands.

Over the last two decades, the Congolese cocoa industry has experienced rapid growth. While the DRC exported 600 million tons (MT) of cocoa in 2000, the country exported more than 10,000 MT of regulated cocoa between 2014-2015 (yet the Association des Exportateurs du Cacao Café de la RD Congo (ASSECCAF) estimates that actual cocoa production could be closer to 33,000 to 35,000 MT) (Neiburg, 2017). Furthermore, within the DRC, North Kivu is a hub for cocoa production. This means that the DRC's an annual production of 10,000 MT of marketable cocoa generates an approximate lower-bound of 15,000 MT worth of residues, while annual production of 35,000 MT of cocoa generates an approximate upper-bound of 52,500 MT worth of residues. A cocoa pod weighs between 200 and 1000 grams with the average pod weighing 400 grams and yielding 35 to 40 grams of marketable dried cocoa beans. The roughly 1:4 ratio of cocoa pod to crop, means that the DRC's annual production of 10,000 MT of cocoa generates roughly 40,000 MT worth of residues. Annual production of 35,000 MT of cocoa would generate roughly 140,000 MT worth of residues. However, biomass availability not only depends on production, but also human effort for harvesting, transporting, and storing residues all of which has an associated cost.

Work to-date has not established an average cost per ton of cocoa pod husk feedstock, as the costs and incentive structures necessary for community participation in a biomass procurement scheme remain elusive and unprecedented. To this end, we have designed a survey instrument to assess cocoa farmers' willingness to provide KGE with cocoa residues.

Justification

Need for Techno-Economic Modeling

Renewable energy technologies hold the potential to provide Beni residents with reliable and sustainable electricity, and expanding business opportunities by partnering with local agricultural could further strengthen community resilience. Through smart procurement and grid operation, renewable energy technologies might also be combined synergistically, such that each technology compensated for shortcomings of the others (e.g. biomass generation at night, or stored solar energy to cover peak demand) (Sen & Bhattacharyya, 2014). However, maintaining reliable performance of multiple hybridized and intermittent generation technologies is a complex undertaking, and there are many possible combinations of available technologies that could fill the needs of the Beni community. In particular, appropriate software for identifying feasible generation configurations and identify a most cost-effective solution should: (1) Conduct granular grid-balancing simulation; (2) simulate resource intermittency that is endemic to renewable electricity generation technologies; (3) Identify synergies and interactions between different technologies' capabilities; and (4) Include a capacity for sensitivity analysis.

Biomass Procurement and Willingness to Accept Compensation

Despite a robust literature on technical-economic modeling of microgrids in developing contexts using HOMER, previous studies have utilized proxy values to determine the availability and cost of biomass resources (Sen & Bhattacharyya, 2014; Shahzad et al., 2017). In reality, provision of biomass resources for biogasification and electricity presents significant complexity, including competing demands for agricultural residues (such as nutrient cycling and fodder) and site-specific availability, as well as potential trade-offs and synergies with food production and environmental quality, interactions with small-scale farmer livelihoods, gender impacts, and land-use impacts (Creutzig et al., 2015; Dasappa, 2011). Therefore, the availability, cost, and logistics of biomass resources at a project-specific level are all critical factors for understanding the feasibility of biomass-integrated electricity provision.

Methods

Technical Modeling

Before HOMER model definition began, the team conducted an assessment to better understand the context that the microgrid will operate within, the organizational objectives of the microgrid developer, and the region's level of access to renewable energy technologies. Information was gathered through a review of relevant energy access literature and conversation with experts. The most important insights were available from practitioners at KGE, who were best positioned to describe available technologies, the prevalent electricity generation regime in the area, institutional relationships with microgrid customers, potential agricultural partners, and anticipated microgrid demand. Where appropriate or necessary, literature values for Eastern Congo were recorded (e.g. average solar irradiation).

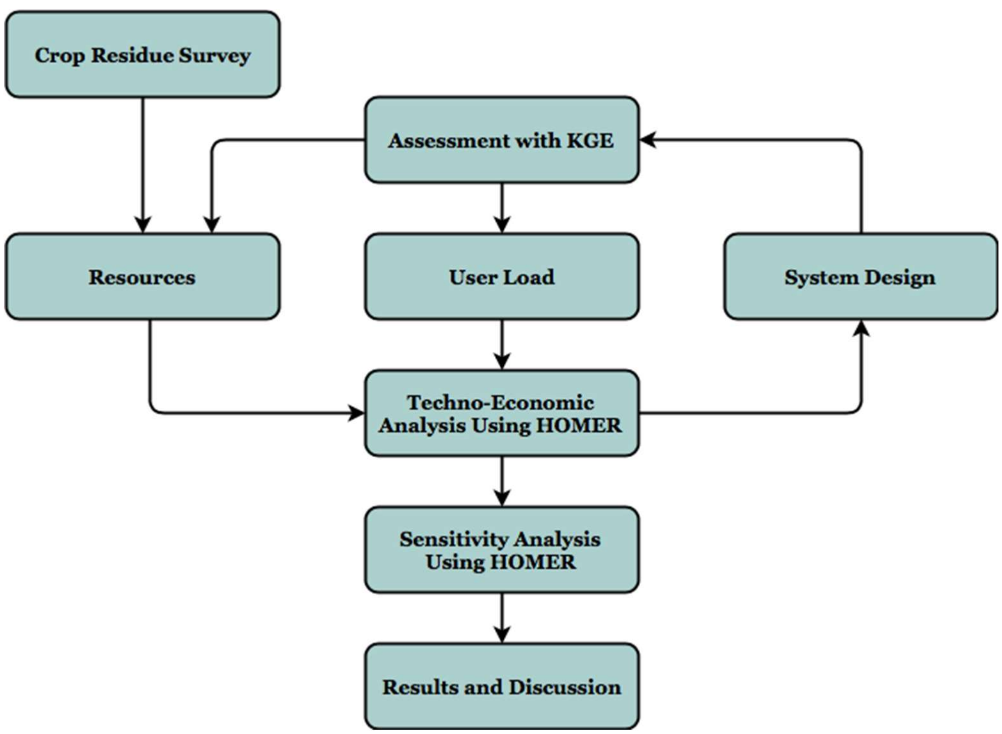

Figure 1. *A schematic diagram of the methodology used in analysis.* Inputs to HOMER for user load, available biomass and solar resource, renewable generation technologies, and grid operation are based on assessment done in partnership with KGE. Information gathered was then used to configure decision variables (capacity for each generation or storage type as applicable) for optimization. Based on initial optimization results, sensitivity analysis was conducted to determine potential impacts of key variables on

the optimal portfolio and the levelized cost of energy for the system.

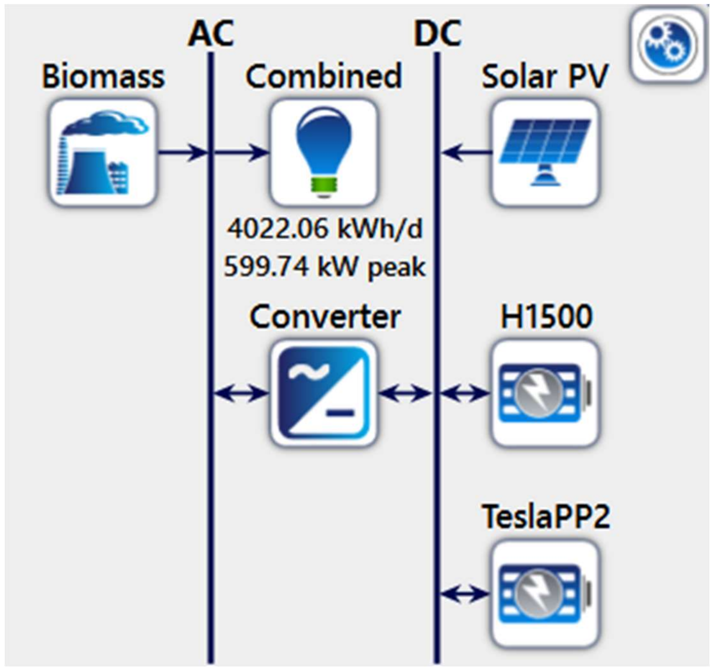

Figure 2. *HOMER schematic of generation, storage, AC/DC converter, and load for proposed microgrid.* Hourly system load is met by a combination of renewable generation technologies (biomass gasification and solar photovoltaic panels), with the assistance two types of battery technologies (Lithium-Ion and lead acid). HOMER optimization determines which components are present in any given simulation run.

It is assumed that the grid operator uses a load following dispatch strategy and requires an operating capacity reserve of the greater of 10% of the system's instantaneous load or 25% of the solar component's instantaneous generation.

Specification for each component of the HOMER model is provided below. Procuring technically accurate, contextually appropriate data can be a challenge, and this study relies on multiple sources for input parameters. To the greatest extent possible, this study relies on quotes and data directly from KGE, else a combination expert input and literature references are used.

Resources & Generation

Solar Resource

Data on Beni’s available solar resource was obtained from NASA Surface Solar Energy Data Set. The data specifies daily average global horizontal irradiance (GHI) as well as a daily clearness index. Beni experiences an average GHI of 5.19 kWh/m^2/day, and at a fairly consistent rate throughout the year.

Biomass Resource

Biomass resource availability is based on consultation with local agricultural cooperative leaders, local energy access practitioners, and literature reference values. The only biomass resource assessed for this analysis was cocoa pod husk, although other biomass resources and even other residues (especially coffee husks) could be sourced by KGE. Given the scale of cocoa farming in the region around Beni we assume that the biomass resource is not volume-constrained. Currently, no market exists for cocoa pod husks in Beni; Our analysis assumes a cost of $30/ton or $0.03 per kg based on cocoa co-operative expert consultation and literature review (D. Moreels, personal communication, September 2017; IRENA, 2012a).

A plan to survey cocoa agriculturalists in North Kivu is currently being developed to better understand a potential market for purchasing cocoa pod husks and exchanging biochar with farmers. In future analysis, survey results will be directly incorporated to define the total available biomass resource over time, variance in seasonal availability, and the market price and price elasticity of supply for cocoa pod husks in Beni. Results may also shed light on institutional and logistical elements of a potential market, including the likely amount of time required to develop a market and farmer interest in biochar. Forthcoming research will pull insights and implications for biomass electrification from these survey results.

System of Interest

This section offers a brief description of the main components that comprise the considered microgrid system. Each description is followed by a list of all parameter assumptions for that generation type.

Solar Module Parameters

KGE is already familiar with solar project deployment and maintenance and has already sourced a cost-competitive supplier with a quoted installation cost of $2.25 per Watt (J. Shaw, personal communication, January 2018). Technical specifics of the PV modules, increasing temperature degradation coefficient and solar efficiency, were based on literature reference values.

Table 1. *Key Economic and Technical Parameters, Photovoltaic Solar.*

Solar Module Cost & Technical Parameters			
Parameter	Unit	Value	Source
Manufacturer & Model	--	General	--
Capacity	kW	Optimized by HOMER	--
Base Capital Cost	$/kW	$2,250	J. Shaw, Personal Communication, February 2018
Replacement Cost	$/kW	$2,250	J. Shaw, Personal Communication, February 2018
Solar Efficiency (% of energy converted to electrical energy)	%	17.3	IRENA, 2012b
O&M Cost	$/kW	$0	--
Average solar resource	kWh/m^2/ day	5.19	NASA Surface Solar Energy Data Set
Lifetime	years	20	Conservative estimate from 10-20 years (IRENA, 2012a)

Derating factor	%/year	96%	Conservative estimate from 2%/year in rural India (Zhu et al., 2017)

Biomass Module Parameters

Despite the proliferation of low-cost fuel and a number of successful pilot projects of biomass gasification for electricity production, familiarity with biogasification technology is not widespread (International Renewable Energy Agency, 2012a). While KGE has made connections with multiple biogasification suppliers, no quotes have emerged. To date, the HOMER model uses reference values from IRENA to estimate the cost of purchase and operation for a biomass gasifier.

Notably, the minimum load ratio (the lowest fraction of total capacity at which the system can operate) has been set at 50%. This was due to concerns about emissions and fuel economy during operation at low load factors as well as concerns with actual operations at lower load ratios (Fracaro, Souza, Medeiros, Formentini, & Marques, 2011).

Table 2. *Key Economic and Technical Parameters, Biomass Gasifier.*

Biomass Gasifier Cost & Technical Parameters			
Parameter	Unit	Value	Source
Manufacturer & Model	--	General	--
Generator Type	--	Gasifier	--
Capacity	kW	Optimized by HOMER	--
Base Capital Cost	$	$3,000	Estimate from $2,140 - $5,700 / kW (IRENA, 2012).
Replacement Cost	$/kW	$1,250	--
O&M Cost	$/hr	$0.05	J. Alfaro, personal communication, January 2018
Lifetime	years	10 years	Conservative estimate from 20-25 year economic life

			(IRENA, 2012).
Minimum load ratio	%	50%	(Fracaro et al., 2011)
Minimum runtime	minutes	0	--

Battery Module Parameters

KGE is evaluating the relative benefits of two potential technologies for energy storage: the lithium-ion Tesla Powerpack 2 and the lead-acid Hoppecke 12 OPvZ 1500. Price assumptions are based on quotes that KGE has received from multiple financial partners offering these technologies. Additional technical specifications emerge from manufacturer details.

Table 3. *Key Economic and Technical Parameters, Lithium-ion Storage.*

Storage (Li-Ion; Tesla Powerpack 2)			
Parameter	Unit	Value	Source
Manufacturer & Model	--	Tesla Powerpack 2	Personal correspondence with Jonathan Shaw
Capacity	kWh/unit	210	Telsa 2018
Amount	# of units	Optimized by HOMER	--
Capital Costs	$/unit	$250,000	J. Shaw, Personal Communication, February 2018
Replacement Costs	$/unit	$250,000	J. Shaw, Personal Communication, February 2018
O&M Costs	$/unit	0	--
Lifetime	years	10	Conservative estimate (not provided by Tesla)
Depth of Discharge	%	80	Conservative estimate from Tesla's 100% specification (Tesla, 2018)

KGE has access to purchase of Tesla Powerpacks on a one-off basis, shipped to Beni, for $250,000 each (J. Shaw, personal communication, 2017). Tesla Powerpack 2 technical specifications are elusive; the manufacturer does not provide a depth-of-discharge-cycle lifetime curve. Instead the technical specifications note explicit values for a depth-of-discharge of 100% and a lifetime of 10 years (Tesla, 2018). This analysis uses 80% as an appropriate depth-of-discharge, which is more in line with storage operations best practices.

Table 4. *Key Economic and Technical Parameters, Lead-Acid Storage.*

Storage (Lead Acid; Hoppecke 12 OPzV 1500)			
Parameter	Unit	Value	Source
Manufacturer & Model	--	Hoppecke 12 OPzV 1500	J. Shaw, Personal Communication, February 2018
Capacity	kWh/unit	3.59	Technical specification (Hoppecke, 2018)
Amount	# of units	Optimized by HOMER	--
Capital Costs	$/unit	$2,607	J. Shaw, Personal Communication, February 2018
Replacement Costs	$/unit	$2,607	J. Shaw, Personal Communication, February 2018
O&M Costs	$/unit-year	$5	--
Lifetime	years	10	--
Lifetime	cycles	2,400	Estimated value at 60% discharge (Hoppecke, 2018)
Depth of Discharge	%	60	(Hoppecke, 2018)
String size		24	J. Shaw, Personal Communication, February 2018

Hoppecke Lead-acid batteries are available to KGE through the integrated microgrid provider Exeron. To use this supplier, KGE would purchase Hoppecke batteries, 24 cells at a time, by purchasing all-in-one grid products from Exeron (J. Shaw, Personal Communication, February 2018).

Load

System load estimates were provided directly by KGE. The system serves two distinct portfolios of customers: a commercial and small industrial “C&I” portfolio, and a mixed-use “community” portfolio serving light commercial and residential. Specific hourly load forecasts were not available, but KGE provided general estimates of hourly operation, and daily and annual peak demand requirements for each portfolio. The model used KGE’s peak demand and daily energy use specifications for each portfolio as parameters to estimate daily and annual load profiles using synthetic commercial and community load shapes. These individual profiles were summed to create a final combined load profile. In total, the KGE microgrid will serve 4,000 kWh per day, on average, with a summer peak demand of 559 kW. Over a year, the load incorporates day-to-day and hour-to-hour random variation to better approximate actual grid operation.

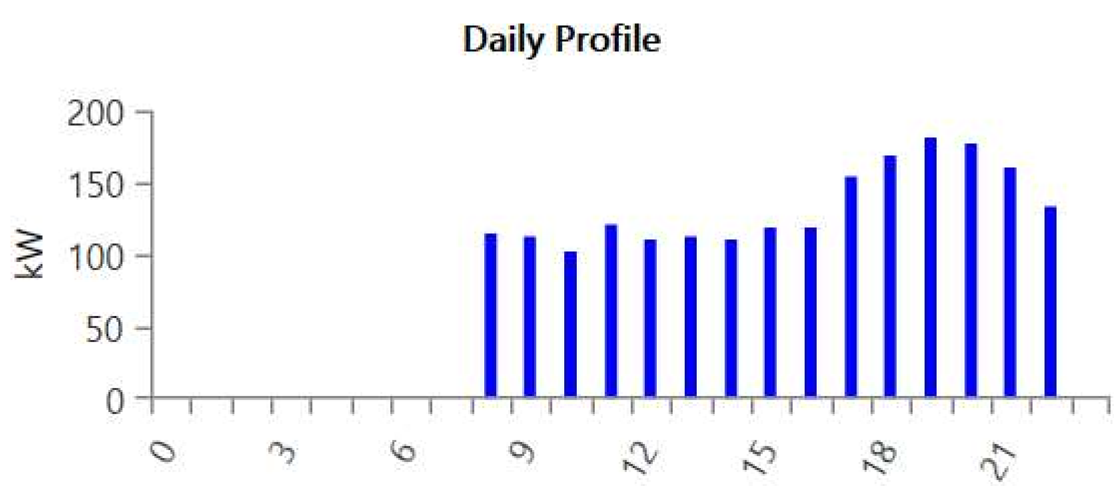

Figure 3.a. *Average Hourly Load, Community Portfolio.*

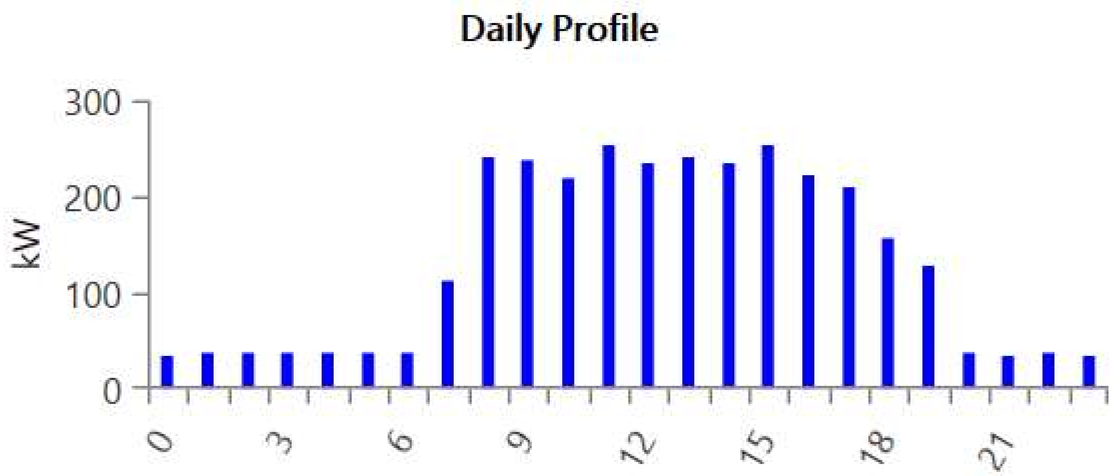

***Figure 3.b**. Average Hourly Load, Commercial Portfolio.*

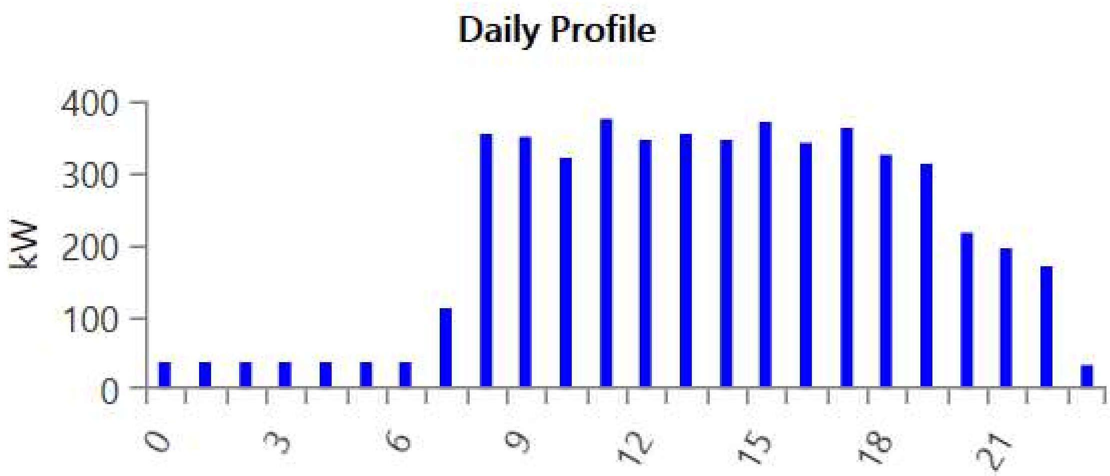

Figure 3.c. *Average Hour Load, Combined Portfolio*

***Figure 3.** Average hourly load profiles for the proposed microgrid.* The x-axis represents hours of the day, and the y-axis represents average power demanded. Figure 3.a. represents the 'Community' portfolio; Figure 3.b represents the 'Commercial' portfolio; Figure 3.c. represents the two portfolios combined.

The seasonal profile (Figure 4.) displays variation in energy generation by month. The estimated demand peaks in winter months due to seasonal energy requirements for processing agricultural produce.

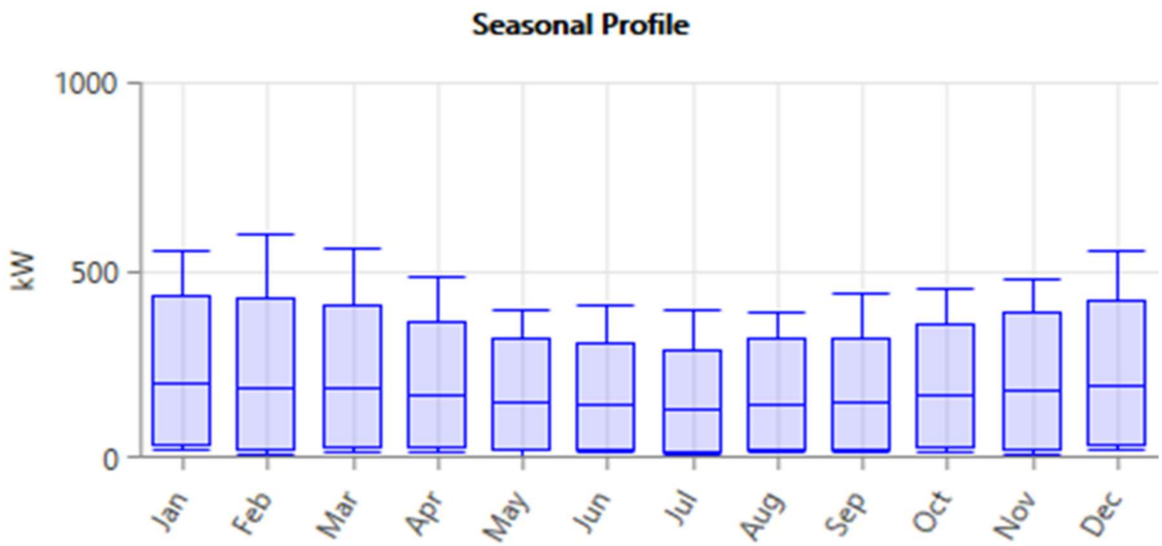

Figure 4. *Box-and-whisker plot of average demand, by month.* Whiskers represent maximum and minimum instantaneous demand, while the box center represents the average and the top and bottom of the box represent the first and third quartile.

Required Social Modeling

As of yet, limited research is available on the incentives required to drive community participation in biomass collection. Novel procurement schemes have been developed in Mali and Thailand (Practical Action Consulting, 2009). As part of the Mali Jatropha Electrification Initiative for the electrification of Garalo, Mali a private power company, ACCESS, relies on farmers to supply biofuel to their power plant. A cooperative of producers purchases biomass from farmers at 9.8 cents per kg. A development project in Thailand utilizes Jatropha seeds to produce biofuel and generate electricity. The cooperative established as part of the initiative provides “financial incentives for its members to take part by fixing and guaranteeing prices for buying/selling raw materials and end-products.” Different materials carry different prices: \$0.20/kg seeds, \$0.01/kg hulls or leaves or stems.

To the best of our knowledge, the work of He et al. (2016) in China's Hubei province provides a singular example of research on willingness-to-accept compensation (WTA) for agricultural waste recycling (AWR). Using contingent valuation methodology, the researchers sought to answer: "How much compensation is enough for motivating households to participate in AWR?" and "What are the factors that influence the WTA value of households for AWR?" The findings from this proposed project thus represent a significant contribution of WTA research in this much neglected area. He et al. found that over 80 percent of households are willing to participate in AWR when compensation rates fall between 1.08 to 1.31-percent of annual household income.

Willingness-to-pay (WTP) and WTA are two alternative approaches to performing an economic valuation of goods, that is to determine what people would be willing to trade (to give up or to receive) so that they are equally satisfied before and after a change in condition. Both methods consider the potential trade-offs between money and the value of a good or service that will leave one's utility unchanged from some base level. To illustrate the difference between WTP and WTA, consider an experiment in which a subject is given an item, such as a bar of cocoa, and then offered money to return it to the researcher. The dollar amount the subject requests in exchange for the chocolate is his/her WTA. If the subject were not given chocolate but instead asked to pay for a bar, the dollar amount proposed would be his/her WTP.

There are two primary approaches to determining WTP and WTA in the literature: contingent valuation and choice modelling. Contingent valuation seeks to quantify WTP/WTA through direct questions and has been successfully used to estimate the value of goods that are not exchanged in regular markets. In contrast, choice modelling secures rankings and ratings of alternatives to infer WTP/WTA. Choice modelling is conducted via choice experiments, contingent ranking or rating, and paired comparisons. Choice modelling is preferable when it is necessary to investigate values based on the individual characteristics or attributes of a good or service. For this study of WTA, we do not seek to isolate values of individual attributes or characteristics of a biomass procurement scheme, but rather to estimate the value of a given unit of biomass. Contingent valuation is thus a more appropriate method.

Contingent valuation has been utilized for over seven decades, beginning with Bowen (1943) and Ciriacy-Wantrup (1947) which provided respective valuations of "social goods" and "collective extra-market goods." Contingent valuation can be carried out using various elicitation formats, the most common of which include: open-ended, bidding game, payment card, and dichotomous choice (See Table 1).

Table 5. *Contingent Valuation Formats. Adapted from Pearce & Zdemiroglu (2002).*

Contingent valuation format	**Example**	**Pros**	**Cons**
Open-ended	What in the minimum amount you would be willing to accept for 1 kg of cocoa pod husks?	• Straightforward • No anchoring bias • Minimum WTA can be identified for each respondent • Requires relatively straightforward statistical techniques	• Large non-response rate, protest answers, zero answers, outliers • May not accurately mimic markets
Bidding game	Would you be willing to accept $X for 1 kg of cocoa pod husks? An initial dollar value is continuously raised (lowered) until the	• May encourage respondents to more thoughtfully consider preferences and may facilitate	• May influence respondents' starting values (anchoring bias) • Leads to outliers and

	respondent accepts (declines) compensation.	respondents' thought processes	possibly false responses ('yea-saying)
Payment card	Which of the listed amounts would you be willing to accept for 1 kg of cocoa pod husks? Possible values are listed and respondents are asked to pick the amount on the card that best represents his/her WTA	• Provides context to bids while avoiding starting point bias • Reduces the number of outliers in comparison to other formats • Can include values of other market goods as benchmarks	• The range of numbers used in the card can introduce biases
Dichotomous choice	Would you willing to accept $X for 1 kg of cocoa pod husks? There are only two possible responses: "yes" and "no." The bid value, $X, is randomly varied across respondents.	• Simplifies the task facing respondents (they only have to make a judgement about one given price) • Minimizes non-response • Avoids outliers • Endorsed by NOAA	• Values are significantly larger than those elicited in open-ended questions • Yea-saying is possible • Requires larger samples making surveys more expensive and results more sensitive to statistical assumptions • May be starting point bias

While there is debate surrounding the best method, open-ended questioning offers the best balance for this study.

Especially in developing country contexts researchers should be cautious in setting bid prices. The tendency is to select too narrow of a range of prices, with the lowest prices too high and the highest price too low (Whittington, 1998). The open-ended format will facilitate the survey tool's future use as it avoids the need to define equally valid bid ranges for other regional or country contexts.

Design of a Willingness to Accept Payment Survey

The survey developed in for this study consists of questions in four main areas: (1) general household demographics, (2) general agricultural practices, (3) cocoa residues practices, and (4) willingness-to-participate in a biomass procurement scheme. The general household assessment solicits information about household gender, age, education level, and income. Questions related to current agricultural practices seek to understand farm size including non-cocoa crops or livestock breeding. Explicit questions about cocoa residues prompt respondents to share what steps they currently take to manage cocoa crop residues and how they value cocoa crop residues. The willingness-to-participate portion of the survey asks if respondents are willing to accept compensation for transporting cocoa with the added bulk of cocoa pod husks: "Would you be willing to sell whole (in pod) cocoa to KGE?" This question is a yes or no question. If respondents answer "yes," then the survey continues with additional questions, including asking for an open-ended response to the level of compensation that is required for the farmer to participate in biomass procurement.

The questionnaire was elaborated and repeatedly modified with the consultation of researchers at UCBC. Working with local expertise helped to refine questions to fit the specific context and to define a reasonable bid range.

For security reasons to the survey will be conducted in the Rwenzori region.

Cases of kidnapping and armed groups are common in other surrounding areas. The Rwenzori sector, surrounded by the Virunga National Park, is located east of Beni City and stretches to the DRC-Uganda border (See Figure 5.). The sampling matrix includes 3772 farmers across 98 villages (J. Duparc, personal communication, March 2017).The survey will be deployed to 300-400 farmers in order to achieve a 95% confidence level. The survey will be conducted by local UCBC enumerators and survey data will be collected and stored using KoboToolbox.

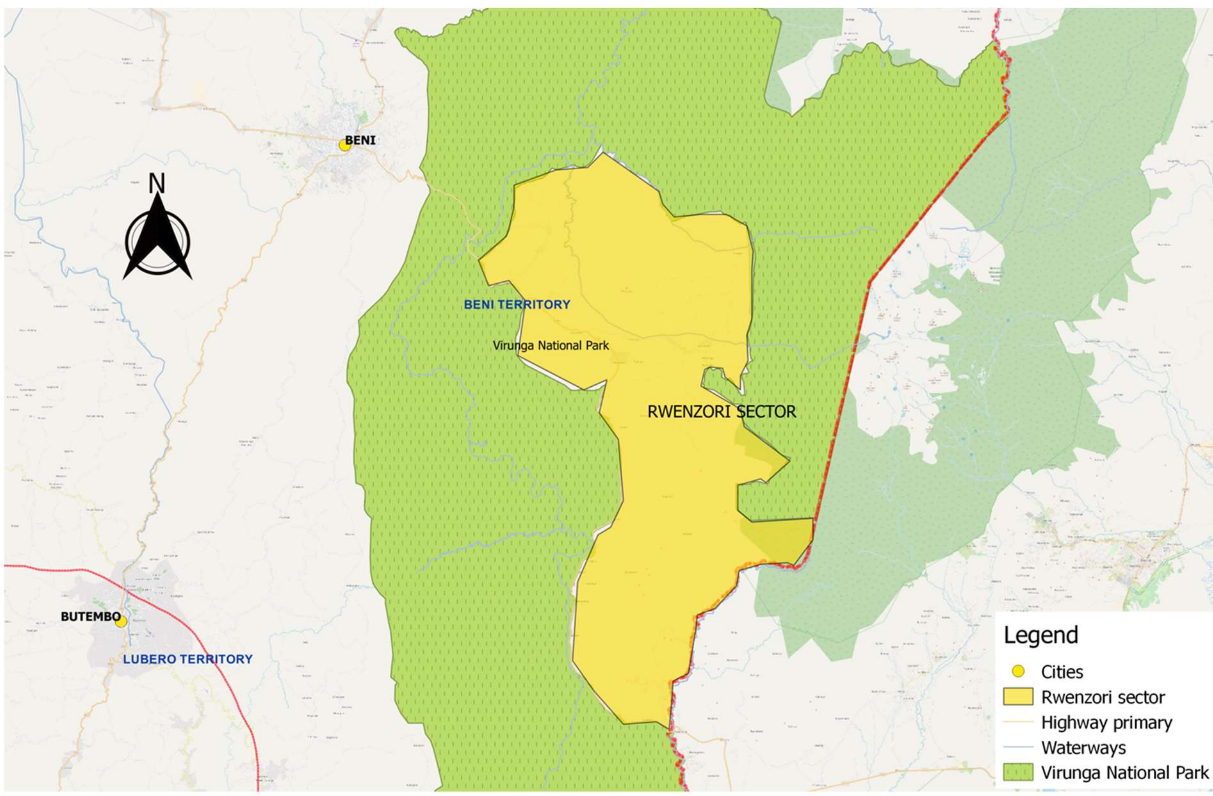

Figure 5. *Map of the Rwenzori region where the survey instrument will be deployed.*

Bias Handling

A pilot study will be conducted to refine the questionnaire before official field data collection begins. Introducing households to the basic conditions of selling cocoa pod husks, including the potential benefits, and providing participating households with a standard of other households' willingness will and reduce information and imaginary bias. Investigators will emphasize the academic research purpose of the survey to reduce strategic bias. Partnering with experienced, trained investigators and using a face-to-face method will reduce investigation way bias and the investigator bias.

While extenuating circumstances have prevented the deployment of the survey earlier on in the research process, the tool is ready for use. Plans to conduct surveys are in development with in-country partners. Once collected, survey results will elucidate the costs and incentives related to cocoa residue procurement. The determination of such values has important implications for HOMER inputs on the average cost per ton of the biomass feedstock, and in turn the techno-economic feasibility of operating and maintaining a cocoa residue-based microgrid. Future models and research will incorporate local agriculturalists' responses to the willingness-to-accept.

Economic & Financial Factors

The goal of this analysis is not only to identify the most cost-effective technically feasible renewable microgrid, but also to evaluate the financial feasibility of the project. The relevant economic and financial parameters of the KGE system are given in Table 5.

Table 5. *Key Financial Parameters*

Financial Details			
Parameter	Unit	Value	Source
Discount rate	%	15%	J. Shaw, Personal Communication, February 2018
Inflation rate	%	2.50%	Based on long-term US inflation
Project lifetime	years	25	J. Shaw, Personal Communication, February 2018

Personal communication with KGE confirmed that a 15% discount rate is a reasonable approximation for the Eastern DRC. The elevated discount rate compared to similar projects in other regions represents the perception of risk that surrounds infrastructure investments in areas with political instability and a lack of prior investment (J. Shaw, Personal Communication, February 2018).

Results

Baseline Scenarios

The calculated cost-optimal arrangement of generation and storage for the potential load in Beni is a hybrid renewable system, comprised of a 238 kW solar array, a 380 kW biomass gasifier, and 8 24-cell strings of 3.59 kWh Hoppecke lead-acid batteries, for about 690 kWh of total storage (2.5 hours of storage autonomy). The up-front cost of the system is $2.2 million, with a levelized cost of electricity of $0.373 per kilowatt-hour. Ultimately, Hoppecke lead-acid batteries were preferred over Tesla Lithium-ion batteries because of the estimated identical 10-year storage lifetimes, cheaper price point, and the increased sizing customizability (3.59 kWh Hoppecke cells versus 210 kWh Tesla Powerpacks). Despite its lower levelized cost of production ($0.18/kWh), solar makes up a minority of total electricity provision (Figure 6).

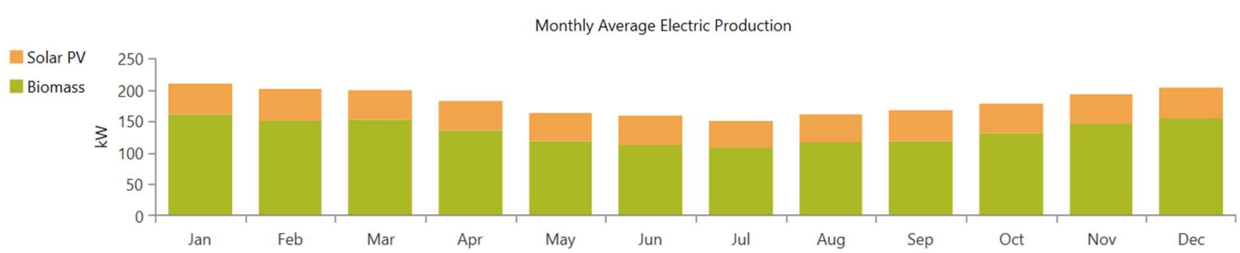

Figure 6*. Monthly Average Electric Production, in kW, by Generation Type.* Biomass represents the majority in all months. The solar component provides 25.8% of the

electricity generated by the system, while the remaining 74.2% is provided by biomass. Biomass generation dominates in part because of a high minimum load factor for biomass plant operation (in this simulation, the plant is incapable of operating at capacity factors less than 50%) and because it is a dispatchable source.

A typical day of grid operation entails the biomass plant running from about 8am to 11pm, where solar providing much of the mid-day power and biomass ramping up to provide additional generation in the evening. Batteries were most often discharged to offset intermittent solar production or overnight, when load is too low to justify turning on the biomass plant and solar is not providing electricity.

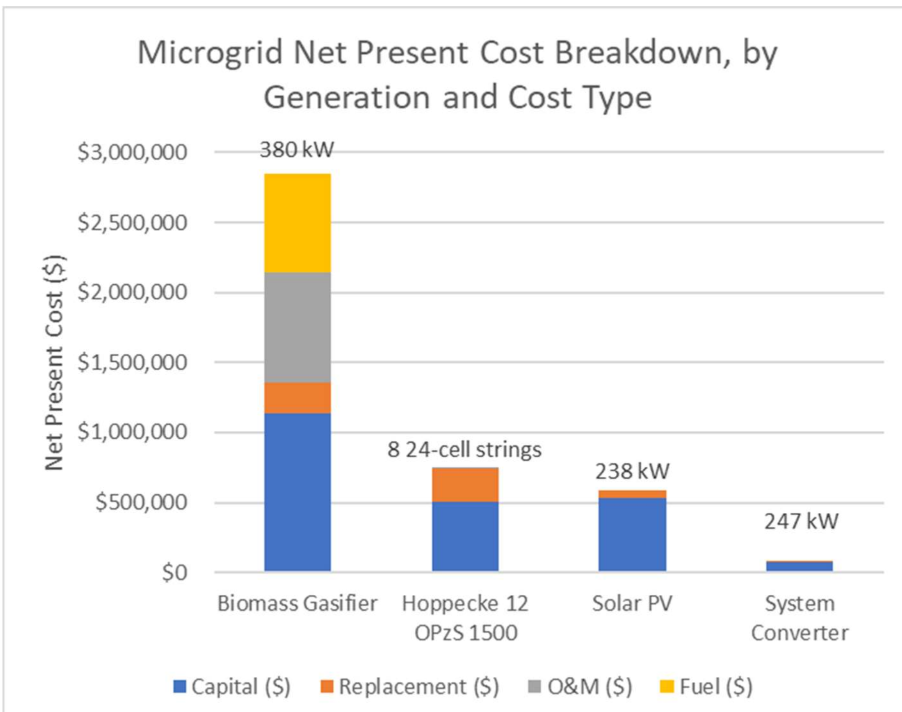

Figure 7*. Net Present Cost Breakdown, by Generation and Cost Type. Capacity, in kW or battery amount, is provided for each component.*

The breakdown of net present costs (Figure 7), shows that the biomass gasifier dominates the total cost of the system. This is in part because of the relatively short projected lifetime for the gasifier (10 years) which results in multiple replacements over the microgrid's lifetime. Compared to solar generation, biomass also has non-zero variable operating costs once purchased. However, the costs are outweighed by the benefits provided by dispatchable generation, a critical feature for a renewable-powered, 24-hour microgrid.

Sensitivity Analysis

Sensitivity analyses reveal the overall impacts of changes to biomass or solar costs on (1) the cost of electricity and (2) the mix of generation technologies for a cost-optimized grid. Two separate sensitivity analyses were conducted, one for biomass fuel costs and one for and solar capital costs.

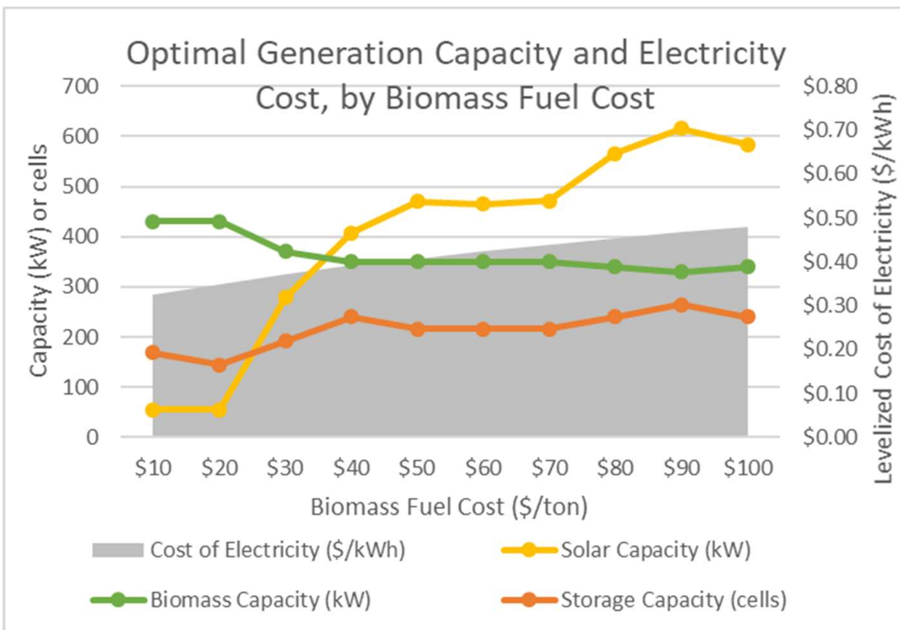

Figure 8. *Optimal Generation Capacity and Cost of Electricity, by Biomass Fuel Cost Scenario.* Lines represent total capacity for solar (kW), biomass (kW), and storage (3.59 kWh cells), while the grey area shows levelized cost of electricity ($/kWh).

When the cost of biomass is $20/ton or less very little solar power is needed, although storage capacity is relatively constant across all scenarios to manage overnight load (Figure 8). As biomass fuel costs increase, the solar capacity and cost of electricity increase, while biomass capacity decreases. Non-linear movement at higher fuel costs demonstrates the complex tradeoffs between higher up-front costs of more solar procurement and higher operating costs of high-cost feedstock. Further, capacity increments for the biomass and storage systems (10 kW and 24 cells, respectively) may cause non-linearity as the optimal configuration alternates across capacity increments Overall, the system levelized cost varies from $0.32/kWh to $0.48/kWh as biomass fuel costs vary between $10/ton and $100/ton.

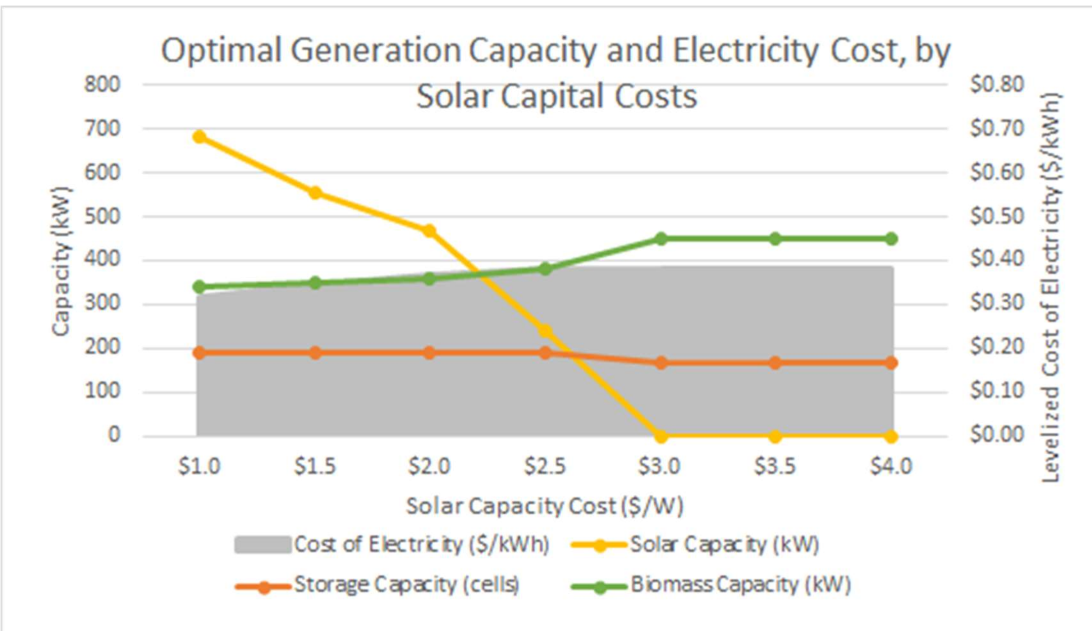

Figure 9. *Optimal Generation Capacity and Cost of Electricity, by Biomass Fuel Cost Scenario.* Lines represent total capacity for solar (kW), biomass (kW), and storage (3.59 kWh cells), while the grey area shows average cost of electricity ($/kWh).

While solar provision is highly sensitive to capacity costs, biomass provision is relatively insensitive, because biomass capacity is driven by evening demand, when solar power is unavailable (Figure 9). The persistence of storage on a biomass-only system is because of the 50% minimum load ratio. Running the biomass plant at its minimum load ratio overnight would exceed the load on the system and cause imbalance on the grid, so batteries are instead charged during the day and discharged overnight to satisfy overnight load. As solar capital costs increase, the biomass capacity and levelized cost of electricity increase, while solar capacity rapidly decreases to 0 kW when the cost reaches $3.00/kW. Due to this high level of cost sensitivity, we recommend that Kivu Green Energy secure a firm price from developers before designing their microgrid system.

KGE decision-makers will need to make decisions on procuring generation equipment, building infrastructure, and constructing a microgrid in an environment of uncertainty. A number of factors that could not be included in this study in detail, including shipping and sourcing logistics to a remote area, will need to be factored into these decisions. Key variables that might have substantial impacts on the optimal configuration of equipment and the overall economics of the project may shift or differ from initial projection.

The refining of the baseline values for this analysis and based upon solar cost trends and data from the anticipated survey results could have significant impacts on the initial results of this report, particularly if the initial projections on farmer participation (and therefore the availability of biomass for fuel) is low.

Discussion

Based on the technological options available to KGE, a cost-effective renewable microgrid would be best served by a mix of solar, storage, and biomass technologies. Although the levelized cost of solar power is cheaper than biomass, a dispatchable biomass generator and flexible storage capacity is required to meet load demands when no solar generation is available. If solar capacity costs or biomass fuel costs are significantly higher or lower than anticipated, the sensitivity analysis shows that a combination of generation technologies still is more cost-effective than a solar-plusstorage-only or biomass-only system.

Diesel generators currently dominate electricity service provisioning in Beni. Yet, diesel generators are dependent on unreliable supply lines, negatively impact human and environmental health, and are expensive to obtain and run. Residents estimate that the lifetime levelized cost of energy from diesel generation is approximately $0.80/kWh and with the variable cost of generation around $0.41/kWh (J. Shaw, Personal Communication, November 2017). Variable cost incorporates only the costs of fuel, operations, and maintenance, and does not include social costs of carbon emissions, local air pollution, or unreliability.[1]

The optimized generation scenario, using a 238 kW solar array, a 380 kW biomass plant, and 690 kWh of lead-acid storage, provides a lifetime levelized cost of electricity of $0.37/kWh. Even without incorporating the upfront capital costs or the social and environmental costs of diesel generation, the hybrid-renewable option provides reliable, clean electricity at a discount of about 10% compared to the variable cost of diesel generation. If carbon externalities are internalized, the discount increases to 14-18%. Costs of interruptions to supply or changes in fuel prices could further increase the actual price of diesel and the discount of switching to hybrid-renewable electricity. Although there are limitations to this analysis, an initial high-level result that places hybrid-renewable electricity generation at cost parity with diesel generation is a strong indication that hybrid-renewable microgrids can be cost-competitive with diesel.

---

[1] Using EIA estimates of $20/ton and $50/ton for the social cost of carbon, and assuming an emission factor of 22.4 pounds CO_2 per gallon, diesel generation's variable social costs are $0.43/kWh and $0.45/kWh, respectively (US Energy Information Administration, 2018) .

Limitations

As a feasibility study, the primary concern for HOMER model specification was aligning with the on-the-ground reality for KGE and Beni. Particularly, equipment options available for KGE do not reflect the complete universe of available technologies, and transportation logistics for acquiring new equipment is uniquely difficult in Eastern Congo. This analysis is designed to reflect KGE's ability to provide a technically and economically feasible microgrid system; other potential systems (with higher-efficiency equipment or longer lifetimes) may be more cost-effective, but they were not modeled because they are not currently available to KGE. Further, these results assume that the biomass feedstock supply is unconstrained at the specified cost. KGE experts approved this model assumption, but if feedstock availability is limited, further assessments should be conducted using appropriate biomass fuel volume constraints.

Many of the costs of constructing and operating a microgrid are outside of the scope of the HOMER model, but should be considered when evaluating the feasibility of a project. Services like engineering, procurement, or construction, alongside the actual physical infrastructure to distribute electricity, are assumed to have been provided at no additional cost. While some material is already procured and will be available for this project, additional costs are very likely. Grid operation, tariff design, customer acquisition and management, and financial development will also take time and money.

At the same time, techno-economic analysis is less effective for understanding the social and organizational transformations required to create an agricultural residue market, construct and acquire customers for a microgrid, and conduct daily operation of the microgrid. The implications of new markets on soil quality and agriculturalist livelihoods have not been examined, and affordability for Beni residents was measured relative to another electricity provision technology, but not relative to income. Impacts of this project on development outcomes and Beni resident livelihoods requires more study.

Conclusions

Based on extensive input from on-the-ground practitioners in Beni and a techno-economic model, this analysis attempts to ascertain a) what arrangement of renewable energy technologies would reliably and cost-effectively power a 600kW microgrid; and b) whether that optimal hybrid renewable microgrid could compete with the dominant diesel-generation regime that currently provides the bulk of electricity to Beni residents. To reflect the technologies available to Beni electricity providers, available renewable technologies included a solar photovoltaic system, Lithium-ion and lead acid batteries, and a biomass gasification system fueled by feedstock from local cocoa agriculture. If a hybrid renewable electricity generation system proves feasible and competitive, implementing it could reduce the cost of electricity to residents, contribute to a symbiotic relationship between agriculturalists and energy providers, and reduce carbon emissions and local air pollution, and provide a replicable example for hybrid generation for electricity access.

Model results show that a hybrid-renewable electricity generation microgrid system is technically feasible in Beni, and that it is cost-competitive with the diesel status quo. Technical viability and cost competitiveness are also reasonably resilient to unexpected increased costs in key sensitivity variables (solar capital costs and biomass fuel costs). Although the techno-economic model omits some costs and complications for constructing a working commercial microgrid, this analysis shows that such a project is fundamentally viable versus fossil fuel alternatives, and that the myriad benefits of hybrid renewable generation are feasible in Beni. Farmer attitudes, availability of biomass fuel, and a locally appropriate price for fuel will be characterized through a pending survey, and future modeling results will incorporate those insights

References

Abdilahi, A. M., Mohd Yatim, A. H., Mustafa, M. W., Khalaf, O. T., Shumran, A. F., & Mohamed Nor, F. (2014). Feasibility study of renewable energy-based microgrid system in Somaliland׳s urban centers. *Renewable and Sustainable Energy Reviews*, *40*, 1048–1059. http://doi.org/10.1016/j.rser.2014.07.150

Bowen, H. R. (1943). The Interpretation of Voting in the Allocation of Economic Resources. *The Quarterly Journal of Economics*, *58*(1), 27.

Ciriacy-Wantrup, S. V. (1947). Capital returns from soil-conservation practices. *American Journal of Agricultural Economics*, *29*(4), 1181.

Creutzig, F., Ravindranath, N. H., Berndes, G., Bolwig, S., Bright, R., Cherubini, F., … Masera, O. (2015). Bioenergy and climate change mitigation: an assessment. *GCB Bioenergy*, *7*(5), 916–944. http://doi.org/10.1111/gcbb.12205

Dasappa, S. (2011a). Potential of biomass energy for electricity generation in sub-Saharan Africa. *Energy for Sustainable Development*, *15*(3), 203–213. http://doi.org/10.1016/j.esd.2011.07.006

Dasappa, S. (2011b). Potential of biomass energy for electricity generation in sub-Saharan Africa. *Energy for Sustainable Development*, *15*(3), 203–213. http://doi.org/10.1016/j.esd.2011.07.006

Duku, M. H., Gu, S., & Hagan, E. Ben. (2011). A comprehensive review of biomass resources and biofuels potential in Ghana. *Renewable and Sustainable Energy Reviews*, *15*(1), 404–415. http://doi.org/10.1016/j.rser.2010.09.033

Fracaro, G. P. M., Souza, S. N. M., Medeiros, M., Formentini, D. F., & Marques, C. A. (2011). Economic feasibility of biomass gasification for small-scale electricity generation in Brazil.

Ghaem Sigarchian, S., Paleta, R., Malmquist, A., & Pina, A. (2015). Feasibility study of using a biogas engine as backup in a decentralized hybrid (PV/wind/battery) power generation system – Case study Kenya. *Energy*, *90*, 1830–1841. http://doi.org/10.1016/j.energy.2015.07.008

He, K., Zhang, J., Zeng, Y., & Zhang, L. (2016). Households' willingness to accept compensation for agricultural waste recycling: taking biogas production from livestock manure waste in Hubei, P. R. China as an example. *Journal of Cleaner Production*, *131*, 410–420. http://doi.org/10.1016/j.jclepro.2016.05.009

Hoppecke. (2018). OPzV solar.power.

International Energy Agency. (2017a). Energy access database. Retrieved from http://www.iea.org/energyaccess/database/

International Energy Agency. (2017b). *Energy Access Outlook 2017*. IEA. http://doi.org/10.1787/9789264285569-en

International Rivers. (2013). *Congo's Energy Divide: Hydropower for Mines and Export, Not the Poor Fact Sheet*. Berkley, CA. Retrieved from https://www.internationalrivers.org/sites/default/files/attached-files/inga_factsheet_eng_dec13.pdf

IRENA. (2012). *Renewable Energy Cost Analysis: Biomass for Power Generation* (Vol. 1).

Kamp, A., & Østergård, H. (2016). Environmental sustainability assessment of fruit cultivation and processing using fruit and cocoa residues for bioenergy and compost. Case study from Ghana. *Journal of Cleaner Production*, *129*, 329–340. http://doi.org/10.1016/j.jclepro.2016.04.065

Lambert, T., Gilman, P., & Lilienthal, P. (2006). Micropower Modeling System with HOMER. In *Integration of Alternative Sources of Energy* (pp. 379–418). John Wiley & Sons, Inc.

Martinez-Angel, J. D., Villamizar-Gallardo, R. A., & Ortiz-Rodriguez, O. O. (2015). Characterization and evaluation of cocoa (Theobroma cacao L.) pod husk as a renewable energy source. *Agrociencia*, *49*, 329–345. Retrieved from http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1405-31952015000300008&nrm=iso

Mohammed, Y. S., Mokhtar, A. S., Bashir, N., & Saidur, R. (2013). An overview of agricultural biomass for decentralized rural energy in Ghana. *Renewable and Sustainable Energy Reviews*, *20*, 15–25. http://doi.org/10.1016/j.rser.2012.11.047

Neiburg, O. (2017). Cocoa in the Congo: Emerging origin for organic chocolate makers. Retrieved from https://www.confectionerynews.com/Article/2017/07/20/Cocoa-in-the-Congo-Emerging-origin-for-organic-chocolate-makers

Pearce, D., & Zdemiroglu, E. (2002). Economic Valuation with Stated Preference Techniques Summary Guide Department for Transport, Local Government and the Regions: London.

Practical Action Consulting. (2009). *Small-Scale Bioenergy Initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa*.

S. Abdulah, M., Matlokotsi, T., & Chowdhury, S. (2016). *Techno-economic feasibility study of solar PV and biomass-based electricity generation for rural household and farm in Botswana*. http://doi.org/10.1109/PowerAfrica.2016.7556572

Secure Livelihoods Research Consortium: Overseas Development Institute, Food and Agriculture Organization, & Feinstein International Center:Tufts University Humanitarian Aid and Reconstruct. (2015). *Congo, Dem. Rep. - Livelihoods, Basic Services, Social Protection and Perceptions of the State in Conflict-affected Situations Household Survey 2012, First Round*.

Sen, R., & Bhattacharyya, S. C. (2014). Off-grid electricity generation with renewable energy technologies in India: An application of HOMER. *Renewable Energy*, *62*, 388–398. http://doi.org/10.1016/j.renene.2013.07.028

Shahzad, M. K., Zahid, A., ur Rashid, T., Rehan, M. A., Ali, M., & Ahmad, M. (2017). Techno-economic feasibility analysis of a solar-biomass off grid system for the electrification of remote rural areas in Pakistan using HOMER software. *Renewable Energy*, *106*, 264–273. http://doi.org/10.1016/j.renene.2017.01.033

Smil, V. (1999). Crop Residues: Agriculture's Largest Harvest. *BioScience*, *49*(4), 299–308. Retrieved from http://www.jstor.org.proxy.lib.umich.edu/stable/10.1525/bisi.1999.49.4.299

Spilacek, M., Lisy, M., Balas, M., & Skala, Z. (2016). The Comparison of Wood Chips and Cocoa Shells Combustion. *Advances in Environmental Sciences, Development and Chemistry*, 217–220.

Syamsiro, M., Saptoadi, H., Tambunan, B. H., & Pambudi, N. A. (2012). A preliminary study on use of cocoa pod husk as a renewable source of energy in Indonesia. *Energy for Sustainable Development*, *16*(1), 74–77. http://doi.org/10.1016/j.esd.2011.10.005

Tesla. (2018). Powerpack Specification. Retrieved from https://www.tesla.com/powerpack

US Energy Information Administration (EIA). (2018). Frequently Asked Questions How much carbon dioxide is produced by burning gasoline and diesel fuel?

USAID. (2017). Power Africa in Democratic Republic of the Congo | Power Africa Fact Sheet. Retrieved from https://www.usaid.gov/powerafrica/democratic-republic-congo

USAID Liberia, & Winrock International. (2012). Detailed Project Feasibility Report Volume 1 - Main Report: Kwendin Biomass Electricity Project, *I*.

Velazquez-Araque, L., & Cárdenas, J. (2016). *A Preliminary Study of Pelletized Ecuadorian Cocoa Pod Husk for its Use as a Source of Renewable Energy*. *Journal of Systemics, Cybernetics and Informatics* (Vol. 14).

Walker, M. (2016). HOMER Optimizer^{TM}, a Faster Path to Finding Least-Cost Microgrid

Options - HOMER Microgrid News and Insight _ HOMER Microgrid News and Insight.

Whittington, D. (1998). *Administering Contingent Valuation Surveys in Developing Countries*. *World Development* (Vol. 26). http://doi.org/10.1016/S0305-750X(97)00125-3

Winrock International. (2014). *USAID'S LIBERIA ENERGY SECTOR SUPPORT PROGRAM (LESSP) LIBERIA NATIONAL ELECTRICAL GENERATION DESK STUDY*. Monrovia, Liberia. Retrieved from http://pdf.usaid.gov/pdf_docs/PA00K8PB.pdf

Woolf, D., Amonette, J. E., Street-Perrott, F. A., Lehmann, J., & Joseph, S. (2010). *Sustainable Biochar to Mitigate Global Climate Change*. *Nat. Commun.* (Vol. 1).

Yang, M. (2017). Rural Electrification : GEF Experience in Renewables-based Microgrids 2 . Challenges and Opportunities to the Renewable-based Microgrids, 1–8.

Zhu, W. J., Liu, Z. G., Cheng, T., Robert, F. C., Sisodia, G. S., & Gopalan, S. (2017). An Intelligent Approach to Strengthening of the Rural Electrical Power Supply Using Renewable Energy Resources Influence of Grid Reinforcement Placed In Masonry Bed Joints on Its Flexural Strength Adam Piekarczyk - A Systematic Multi-Time Scale Solution for Regional Power Grid Operation An Intelligent Approach to Strengthening of the Rural Electrical Power Supply Using Renewable Energy Resources. *Series: Earth and Environmental Science*, *83*. http://doi.org/10.1088/1755-1315/83/1/012005