MICROGRIDS IN THE DEMOCRATIC REPUBLIC OF THE CONGO:

A UTILITY'S TRANSITION FROM DIESEL TO SOLAR GENERATION

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Executive Summary

Kivu Green Energy serves 260 commercial and residential electric customers in Beni, a city in the North Kivu region of Democratic Republic of the Congo via two distribution networks. The utility is in the process of transitioning its primary resource from diesel generation assets to solar photovoltaic (PV) electricity production paired with battery energy storage systems (BESS). The client, Kivu Green Energy (KGE), desires an onsite islanded microgrid, comprised of solar and battery storage, to provide clean and reliable electricity to their office space for business operations. The purpose of this Master's Project is two-fold: 1) Propose an onsite microgrid design for KGE's office space, and 2) Quantify the reduction of carbon emissions in transitioning both of KGE's microgrids from diesel generation to solar PV + battery storage with diesel backup.

Section I introduces the client by describing the current state of the generation assets owned by Kivu Green Energy and how the company's founding vision is challenging them to pursue clean energy alternatives for their Beni customers.

Section II provides background information on the Democratic Republic of the Congo, Kivu Green Energy's involvement in the local and regional energy sector, and an overview of microgrid technologies that KGE should evaluate to grow their clean energy business.

Section III describes the two renewable energy modeling platforms, National Renewable Energy Laboratory's PV Watts, and Energy ToolBase, used in determining an appropriately sized microgrid for KGE's office space. A carbon emission baseline is established using diesel consumption data prior to June 2017. This base case is compared to carbon emissions of their grid infrastructure at varying levels of solar and battery penetration, quantifying the potential emission reductions of future renewable procurement.

Section IV recommends a final microgrid solution for KGE's office space based on the outputs of the solar photovoltaic and battery energy storage system optimization models.

Section V provides details on the limitations and assumptions used in this study, suggests routes that future research could take to add further value to Kivu Green Energy's business, and summarizes the application of the findings to the broader energy access context.

The key findings and recommendations of this report are as follows:

- KGE can meet all electricity needs with an onsite, emission free microgrid using 8.4 kW of solar PV and a 12 kWh / 6 kWh BESS.
- A 4 year, 10% interest loan from a funding organization such as United Solar Initiative, would require a monthly loan payment of $836 for 48 months after which time KGE's electricity would be free.
- KGE currently pays $0.34/kWh to a competitor for diesel generated electricity. The levelized cost of energy (LCOE) over the lifetime of the proposed microgrid is $0.11/kWh, equating to a 67% reduction in energy costs.
- By replacing the diesel generator on the Town Center distribution grid with a solar + storage system of comparable size to the Boikene system, KGE can reduce their carbon emissions by a minimum of 129 tonnes of CO_2 per year.

I. Introduction

Kivu Green Energy (KGE) is the largest electricity provider in Beni, a city in the North Kivu region of Democratic Republic of the Congo, serving 260 commercial and residential customers with two separate distribution grids (Figure 1). In June 2017, KGE replaced the primary generation asset, a 88 kW diesel generator, or genset, powering the Boikene Grid (yellow), with 55 kW of solar photovoltaic (PV) and 2274 amp-hours of battery energy storage, while transitioning the genset to a backup resource. KGE elected to disconnect the Town Center Grid (red) in May 2017 due to the high fuel and maintenance costs incurred from diesel generation and conflicts with the company's vision to provide clean energy. This means that the 150 customers previously served by the second distribution infrastructure have been forced to find alternative sources of electric generation, either from KGE's competitors in town or by purchasing small diesel gensets for their individual consumption. Kivu Green Energy does not intend to bring the Town Center Grid back online until a solar PV + battery system is installed in its place. Since its office space is connected to the inoperable grid, KGE must currently purchase electricity for its own business operations from a competitor.

***Figure 1. Kivu Green Energy's Grid Infrastructure*[1]**

[1] Bidong, E. 30 July 2017. Personal Interview.

The Congolese utility provider, Kivu Green Energy, is currently pursuing investments to fund the Town Center Grid reconnection and the expansion of its clientele through solar + storage project installations in population centers within and beyond the city of Beni. KGE aims to finance this and other similar capital-intensive clean energy assets through long-term power purchase agreements with “anchor clients,” or established businesses that require significant amounts of reliable electricity. In the shorter term, Kivu Green Energy would like to internally invest in an onsite solar PV + battery microgrid to power its downtown Beni office space. Installing a system of this sort would display Kivu Green Energy’s commitment to providing the Beni community and greater Kivu region with clean and reliable electricity as they look to expand their services to more residents and commercial customers in the coming years, while also ensuring power quality and reliable electricity to fulfill their business needs.

The purpose of this Master’s Project is two-fold: 1) Propose an onsite microgrid design for KGE’s office space, and 2) Quantify the reduction of carbon emissions in transitioning both of KGE’s grids from diesel generation to solar PV + battery storage with diesel backup. Section II provides background information on Democratic Republic of the Congo, Kivu Green Energy’s involvement in the energy sector, and an overview of clean technologies that KGE should evaluate to grow their clean energy business; Section III describes the methodology used in determining an appropriately sized microgrid for KGE’s office space; Section IV recommends a microgrid solution for KGE’s office space; and Section V summarizes the findings by applying the results to the broader energy access context.

II. Background

i. Democratic Republic of the Congo

Political Landscape

Democratic Republic of the Congo (DRC), home of one of the African continent's great rivers, is the second largest country on the continent in land mass after Algeria and fourth largest in population with 78.7 million residents estimated in 2016.[2] The nation is experiencing one of the highest population growth rates in the world at 3.3% per year[3] where 42.6% of the population is under 15 years of age.[4]

Alongside its drastic growth, DRC has experienced multiple periods of social unrest since gaining its independence from Belgium in 1960. In 1971, under the leadership of Mobuto Sese Seko, the country's name was changed to "Zaire" until a civil war in 1997 overthrew the government and returned to its original designation as the Democratic Republic of the Congo.[5] This civil war led to the election of Joseph Kabila in 2006, who was reelected to his final term in 2011. Elections in 2016 were never held, and instead initially postponed until the end of 2017.[6] Under a deal constructed between ruling party supporters and opposition groups, the DRC government remains in the hands of Kabila, stirring up unrest and violent outbursts in recent months with hopes that the election will take place in December 2018.[7]

The tumultuous political landscape is due, in part, to the plethora of economic resources that exist within the DRC's borders. A booming mining industry for minerals such as cobalt, copper, and diamond has brought about economic development,[8] but this wealth is highly concentrated amongst an elite subset of the population. The lack of regulation enforcement within the resource extraction industry has come at a cost to human rights whereby numerous

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[2] World Bank. 2016. Population, total. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=CD
[3] World Bank. 2016. Population, total. https://data.worldbank.org/indicator/SP.POP.GROW?locations=CD
[4] Encyclopedia Britannica. 2016. Democratic Republic of the Congo. https://www.britannica.com/place/Democratic-Republic-of-the-Congo
[5] Encyclopedia Britannica. 2016. Democratic Republic of the Congo. https://www.britannica.com/place/Democratic-Republic-of-the-Congo
[6] Bidong, E. 31 January 2018. Personal Interview.
[7] Bidong, E. 31 January 2018. Personal Interview.
[8] BBC. 2017. DR Congo country profile. http://www.bbc.com/news/world-africa-13283212

child labor and safety allegations have surfaced; especially as cobalt demand for battery manufacturing continues to rise.[9]

National Energy Landscape

In addition to political unrest and dilapidated industrial oversight, only 18% of the population has access to electricity, leaving the DRC in the bottom third in electrification rates for all African nations.[10] The increasing evidence for the correlation between reliable energy access and increased quality of life[11] has led to the United Nations' adoption of ambitious Sustainable Development Goals (SDGs) whereby vast investments in funds and research have been routed to aid in improving electrification across the continent.[12] According to Kelly-Pitou et al., increased access to energy has been tied to greater business opportunities and sustained income.[13] In DRC, these opportunities remain few due to the lack of investments in grid infrastructure combined with a drastic 62% population growth since 2000.[14]

Figure 2. Inverters & Battery Storage (Photo by Bidong, E.)

Figure 3. 55 kW PV Array (Photo by Bidong, E.)

In addition to various stages of grid development across the continent, each African nation has a unique electric market structure, making efficiencies in duplicability across national borders nearly impossible. For example, in stark contrast to Kenya, which has a nationally owned utility provider, the DRC government privatized the energy sector through the

[9] Sanderson, H. 2017. Financial Times. https://www.ft.com/content/930846c2-d047-11e7-b781-794ce08b24dc
[10] International Energy Agency. 2017. Energy access database. http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/
[11] Kelly-Pitou, K., et al. 2017. Microgrids and resilience: Using a systems approach to achieve climate adaption and mitigation goals. The Electricity Journal (30) 23-31.
[12] United Nations. 2017. Sustainable Development Goal 7. https://sustainabledevelopment.un.org/sdg7
[13] Kelly-Pitou, K., et al. 2017. Microgrids and resilience: Using a systems approach to achieve climate adaption and mitigation goals. The Electricity Journal (30) 23-31.
[14] World Bank. 2016. Congo, Dem. Rep. http://data.worldbank.org/country/congo-dem-rep

passing of the 2014 Electricity Law.[15] The relegation of the national utility, Société nationale d'électricité (SNEL), to a private company opened the market up to outside investors in hopes that greater competition would move the country toward its ambitious target of electrifying 60% of the population by 2025.[16] Other sporadic government programs have been enacted to further develop a highly competitive energy sector, including a four-year reprieve of import duties and value-added tax on generation equipment, tools, and parts.[17]

While interest is rising from private industry investors to tap into a new market that is ripe with growth potential, these business ventures require capital-intensive infrastructure and are often bogged down by investors' risk aversion in tumultuous political climates. Ultimately, this type of capital investment will be worthwhile, resulting in greater reliability for electricity users, an expansion of the electric customer base, and returns on investment for successful energy access backers; however, greater trust in the financial institutions and government officials within the DRC will be required first.

Local Energy Landscape & Kivu Green Energy

In 2015, Kivu Green Energy acquired the largest commercial utility in the city of Beni, North Kivu, DRC in which an estimated population of 355,000 reside.[18] This nationally incorporated energy company aims to address the currently unmet demand for electricity, and more generally access to any energy generation, while providing social good through a reliable, low carbon grid infrastructure. KGE is in the midst of transitioning its diesel powered microgrid infrastructure to solar photovoltaic (PV) generation with a battery energy storage system (BESS) in order to serve its 260 small commercial and household customers with clean and reliable electricity.[19]

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[15] African Development Bank & SEforALL. 2017. Green mini grid market development programme. https://greenminigrid.se4all-africa.org/file/183/download
[16] PricewaterhouseCoopers. 2017. Democratic Republic of the Congo. https://www.pwc.com/gx/en/transportation-logistics/publications/africa-infrastructure-investment/assets/drc.pdf
[17] African Development Bank & SEforALL. 2017. Green mini grid market development programme. https://greenminigrid.se4all-africa.org/file/183/download
[18] Kivu Green Energy. 2018. Projects. http://www.kivugreenenergy.com/projects/
[19] Kivu Green. 2018. Who we are. http://www.kivugreenenergy.com/about-us/

There is currently a very small profit margin from electricity sales due to the high fuel costs and volatility in diesel price as well as limits to demand growth based on the restricted infrastructure in Beni; however, Kivu Green Energy aims to roll profits and funds from outside investors into long-term solar solutions that will provide low-cost electricity and encourage business growth in the local community.

In June of 2017, Kivu Green Energy installed the first PV + BESS Microgrid in eastern DRC (Figures 2 and 3). The system is comprised of 55 kW of solar, 2274 amp-hours of storage capacity, and an 88 kW diesel generator for backup reliability.[20] The company aims to grow in phases, rolling out similar systems to reach 10 MW of solar with storage capacity by 2028.[21]

ii. Clean Energy

Renewable Energy Potential of DRC

The DRC has one of the greatest hydro resource in the world due to the Congo River and its tributaries that wind across the nation; however, only 2% of that potential energy has been tapped into.[22] The risk aversion in a tumultuous political environment hasn't drawn the capital needed to see this hydro power captured. Plans for a series of dams, coined the Grand Inga Project, are expected to provide nearly 40 GW of electricity to the DRC and South Africa with an $80 Billion USD price tag. These projects have been in the works for more than a decade with numerous redesigns and lack of funding pushing back the date for construction years into the future.[23]

The African continent receives a plethora of solar with nearly all areas exceeding 5 sun hours/day (hours at 1000 watts/m^2). DRC is no exception with annual averages of approximately 5.5 sun hours/day (Figure 4).[24] The exceptional resource in conjunction with lesser seasonal variations at the equator make the DRC a prime candidate for electric expansion to harness the power of the sun. In 2015, the Congolese government lifted tariffs on

[20] Kivu Green Energy. 2018. Projects. http://www.kivugreenenergy.com/projects/
[21] Kivu Green Energy. 2018. Projects. http://www.kivugreenenergy.com/projects/
[22] World Energy. 2017. World Energy Resources Hydropower 2016. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Hydropower_2016.pdf
[23] International Rivers. 2017. Renewable Riches: How Wind and Solar Could Power DRC and South Africa.
[24] Solar GIS. 2018. World Map. https://solargis.com/maps-and-gis-data/download/world

equipment, tools, and spare components used in electric production for a period of 4 years to increase generation assets throughout the nation. [25] This exemption from taxation should encourage the import of equipment such as solar panels and inverters, ultimately speeding up the adoption of renewable energy onto their underserved grid.

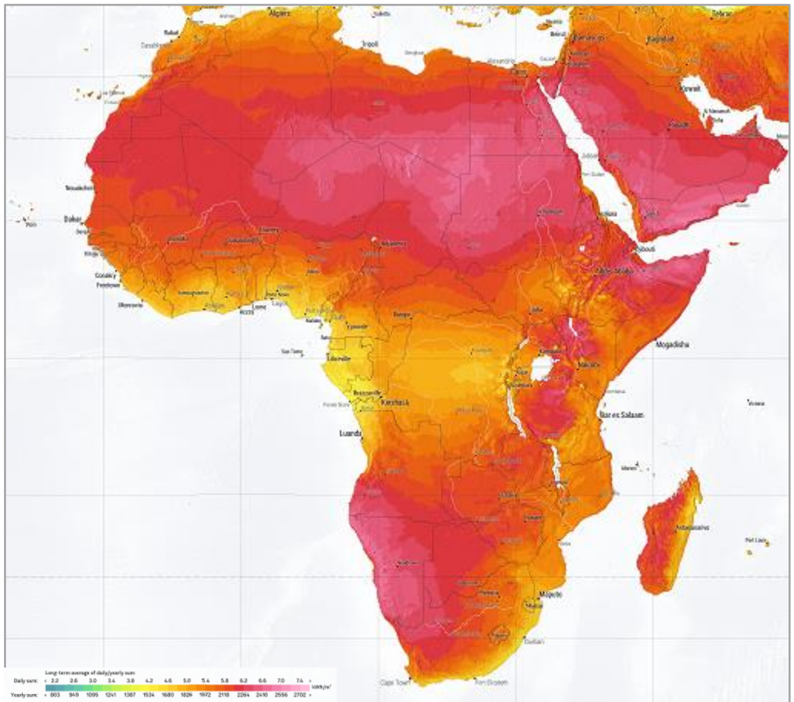

Figure 4. Solar Irradiance Across Africa[26]

Microgrid Technology

According to the US Department of Energy, a microgrid is a “local energy grid with control capability, which means it can disconnect from the traditional grid and operate autonomously.” In a context where grid infrastructure already exists, installing an “islanding” microgrid system can improve the reliability of electric delivery and ensure greater resiliency to protect against outages due to extreme weather or other emergency events. These benefits hold true for a developing country’s context, such as DRC, where microgrids are the only power generation infrastructure. While a centralized grid structure does not exist in my client’s region,

[25] African Development Bank & SEforALL. 2017. Green mini grid market development programme. https://greenminigrid.se4all-africa.org/file/183/download
[26] Solar GIS. 2018. World Map. https://solargis.com/maps-and-gis-data/download/world

a small distribution grid, serving a community of customers rather than a city, region, or nation, can realize the same resilience, reliability, and autonomy.

Components of a microgrid vary by design and the size or type of load that it is serving. Microgrids may serve the demand of a single household or a community of residences and businesses. They can be designed to meet a constant load such as a manufacturing facility or a load with peaks like residential customers who ramp up energy use in the late afternoon. Some common components include generation assets such as solar PV, wind turbines, or other renewable technologies that are paired with lithium batteries and/or fossil fueled generators fueled by natural gas, diesel, or fuel oil. A microgrid controller dispatches the various distributed energy resources (DERs) based on a sequence of operations determined by the owner or microgrid operator. Typically, renewables are dispatched when available because they are free, but must be paired with a predictable technology due to the variability of the sun or wind. When there is not enough renewable generation to meet the demand, battery and/or fossil fuel generation will be called on to make up the remaining balance. Figure 5 below shows a high-level diagram of a potential microgrid design.

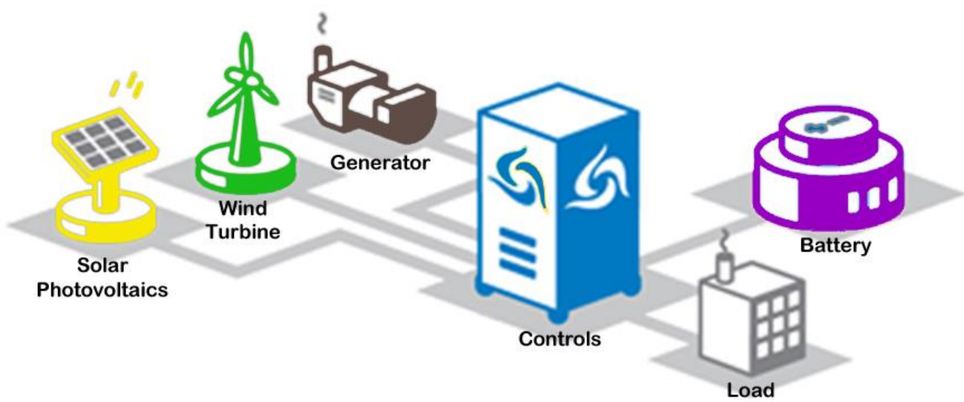

Figure 5. Common Microgrid Components[27]

Tangent to the scalability and resiliency of microgrids, serving one to hundreds of customers, is the economic development that arises with connectivity and electric access. It is easy to imagine how isolation from electricity inhibits participation in regional and global

[27] TONEX. 2018. Microgrid Training. https://www.tonex.com/training-courses/microgrid-training/

markets; however, connection to electricity can provide increased productivity and an expansion of business opportunities through internet access, educational technology, and mechanized industrial processes. In many cases, transmission lines do not exist within a reasonable distance and is cost prohibitive to extend the grid to certain communities and cities.

According to Kelly-Pitou et al, “resilience is important for maintaining the stability of economic development…therefore, resilience from a climate perspective should be understood as both a technical and economic strategy.”[28] This can be applied specifically in the context of energy resiliency whereby access to reliable and consistent electricity provides economic stability to those connected communities, taking place in the form of consistent business operations and educational experiences.

[28] Kelly-Pitou, K., et al. 2017. Microgrids and resilience: Using a systems approach to achieve climate adaption and mitigation goals. The Electricity Journal (30) 23-31.

III. Methods

i. Microgrid Sizing

Kivu Green Energy's headquarters, shown on the map in Figure 1, was served by the Town Center Microgrid until the utility took the diesel generator offline. Since that time, KGE has been purchasing electricity from its competitor, a small and unreliable diesel genset operator. Because of the low power quality of the competitor's electricity and steep prices, Kivu Green Energy has limited its energy use for daily business operations. The current office load totals 10.69 kWh per day (Table 1) to preserve equipment and reduce the high cost of electricity they are charged.[29] KGE pays its competitor approximately $0.34/kWh.[30]

Table 1. Current Office Load, Connected to Competitor[31]

Qty.	Appliance
10	Light Bulbs
10	Phone Charger
7	Laptop
1	Printer

Typical Weekday Energy Use = 10.69 kWh

The ideal load with all office appliances fully utilized is 37.15 kWh per day, nearly 3.5 times higher than their current curtailed usage (Table 2).[32] KGE aims to provide its office space with clean and reliable generation that will meet the needs of its day to day operations. Located in the heart of Beni, KGE also anticipates that the visibility of a solar array on their facility will contribute to their credibility as a clean and reliable electric provider while also providing a platform to challenge the current negative perceptions surrounding solar energy.[33]According to Kivu Green Energy's Chief Technical Officer and my client liaison, Eric Bidong, the Beni population is weary of solar electricity as a result of cheap, low quality PV modules and

[29] Bidong, E. 31 January 2018. Personal Interview.
[30] Bidong, E. 31 January 2018. Personal Interview.
[31] Bidong, E. 15 December 2017. Personal Interview.
[32] Bidong, E. 31 January 2018. Personal Interview.
[33] Bidong, E. 15 December 2017. Personal Interview.

inverters that have been sold to many residents in previous years.[34] These negative experiences with solar electricity have made skeptics out of many prospective customers; however, KGE hopes to amend the reputation of solar energy by providing clean and reliable energy to the residents of Beni and playing host to an observable system that powers their own space.

Table 2. Future Office Load, Islanded Microgrid[35]

Qty.	Appliance
10	Light Bulbs
1	Television
1	Decoder
10	Phone Charger
7	Laptop
1	Coffee maker
1	Fridge
1	Printer
2	Air Conditioner

Typical Weekday Energy Use = 37.15 kWh

After calculating the daily energy requirement and peak demand to meet the daily load, I used PV Watts (Version 5),[36] a solar array sizing tool and production estimator, in conjunction with Energy ToolBase,[37] a battery energy storage optimization and modeling tool, to simulate appropriate sizes for an islanded Solar PV + Battery Energy Storage Microgrid at KGE's office. This system will initially be designed as a stand-alone system with the potential to reconnect to the larger Town Center Microgrid infrastructure once funding is available for construction.

[34] Bidong, E. 15 December 2017. Personal Interview.
[35] Bidong, E. 15 December 2017. Personal Interview.
[36] NREL. 2018. PV Watts Version 5. https://pvwatts.nrel.gov/
[37] Energy ToolBase. 2018. https://www.energytoolbase.com/

Table 3. PV Array Sizing Calculations

(37. 15 kWh consumed per day / 5.67 sun hours) * 0.86 derate factor = 7.6 kW Solar PV
7.6 kW Solar PV * 1.10 = 8.4 kW Oversized Solar PV

The client desires a roof-mounted solar array and based on roof area, panel efficiency, tilt, and solar irradiance assumptions listed in Table 4, the building could host an array as large as 22 kW (Figure 6). The peak demand does not surpass 6 kW based on the appliance list provided by KGE, therefore the roof space far exceeds sizing requirements to meet the office's load.

Table 4. PV Watts Assumptions

Derate factor	86%
Irradiance (Hours of 1000 W/m^2)	5.67
Weekday consumption	37.15 kWh
Tilt (latitude)	0 degrees
Calculated PV Size	7.6 kW
Standard Panel Efficiency	15%
Oversized PV Size (110%)	8.4 kW

Figure 6. PV Watts Roof-Top Array Maximum Size[38]

[38] NREL. 2018. PV Watts Version 5. https://pvwatts.nrel.gov/

Using PV Watts, I found that a 7.6 kW PV system would produce an estimated 11,736 kWh/year, whereas the oversized 8.4 kW array would produce 12,971 kWh/year. Based on KGE's appliance list, the office will use 11,524 kWh/year. The graph in Figure 7 shows the current and future anticipated monthly energy use of the office alongside the estimated production of the two PV array sizes. During the months of April, May, June, and July – in which most precipitation occurs – the energy production of the 7.6 kW system does not meet the monthly demand of the office. The 8.4 kW system, however, exceeds the kWh load of the office throughout all months.

The monthly fluctuation in building energy use is in part due to the days each month, i.e. February's energy use is the lowest, and weekends versus weekdays throughout the month. The energy use is otherwise consistent from month to month because there is very little seasonal change at this latitude and in North Kivu's climate. See Section IV for the final recommendation based on this production and load analysis.

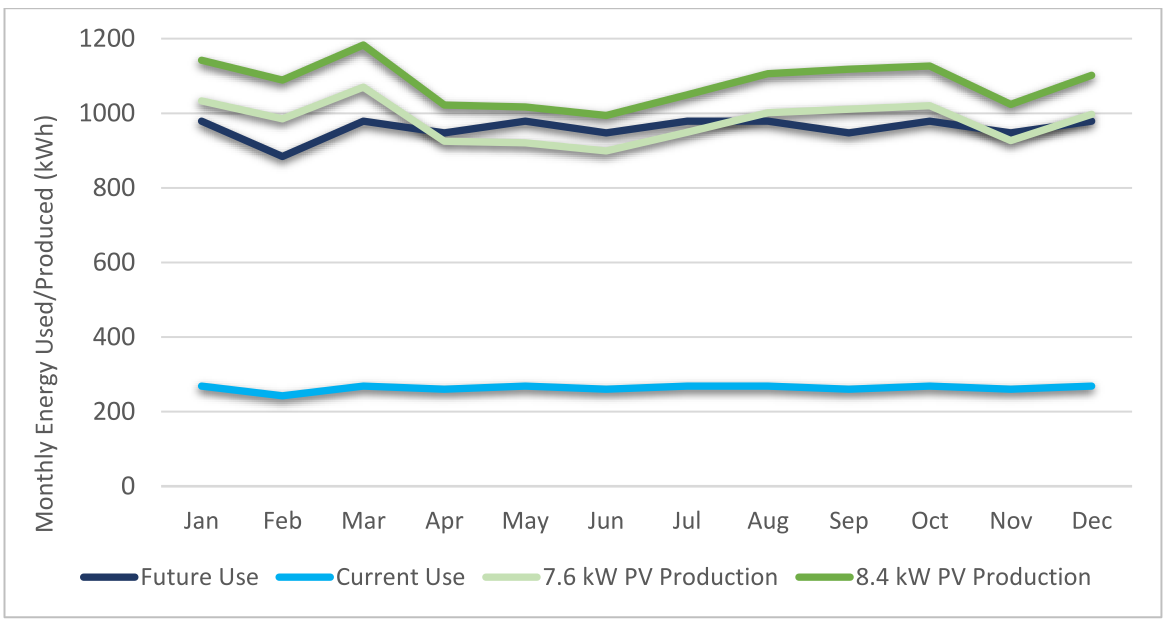

Figure 7. KGE Office Projected Energy Use & Production

The following assumptions were used in the Energy ToolBase (ETB) platform to optimize the size of the battery energy storage system and estimate costs over the lifetime of the system. A US based non-profit, United Solar Initiative (USI), is considering a loan agreement with Kivu Green Energy to provide the upfront capital for an office level microgrid. The financials are therefore evaluated in this study based on a 4 year, 10% interest loan that USI is evaluating.

Table 5. Energy ToolBase Assumptions

Installed Cost of PV	$2.50/W
Installed Cost of Storage	$1000/kWh
Cost of Electricity	$0.34/kWh
O&M Start Year	Year 1
Loan Term	4 year, 10% interest
Max Monthly Loan Payment	$1000
Discount Rate	5%
Cost of Electricity Escalation	3%
PV Degradation Rate	0.1%

After importing the PV Watts generated production data for the two array sizes, 7.6 kW and 8.4 kW, into Energy Toolbase, I used the battery optimizer within the platform to determine plausible storage sizes for the office. A 6 kW battery will suffice for office's peak weekday load but will likely be needed for more than a single hour of peak storage capability on a cloudy day; therefore, I offer a two hour and three hour battery solution which equates to 12 kWh and 18 kWh of storage, respectively. The two battery sizes meet my client's requirements for cost and year-round demand needs.

ii. Carbon Emission Analysis

Prior to the 2017 installation of a 55 kW solar PV and 2274 amp-hour battery storage system on the Boikene Grid, KGE relied only on the two diesel generators to serve their 260 customers. Since the installation, they've experienced a 60% monthly reduction in diesel use at the Boikene site.[39] KGE's decision to halt generation for the Town Center's customers around the same time as the Boikene solar + battery system installation, further reducing their carbon

[39] Bidong, E. 15 December 2017. Personal Interview

dioxide (CO_2) emissions, but resulting in the loss of more than half their customers and revenue.

For the purpose of this emission analysis, the established baseline is considered to be two functioning, diesel powered grids: Boikene Microgrid and Town Center Microgrid (prior to June 2017). Emission calculations assume that, once capital is available, the two operable grids will each be powered with a solar + storage system and backup diesel generator. The results of these calculations may be used to solicit capital from potential investors of the future Town Center Microgrid and to market the environmental benefits of KGE's electricity as compared to their competitors.

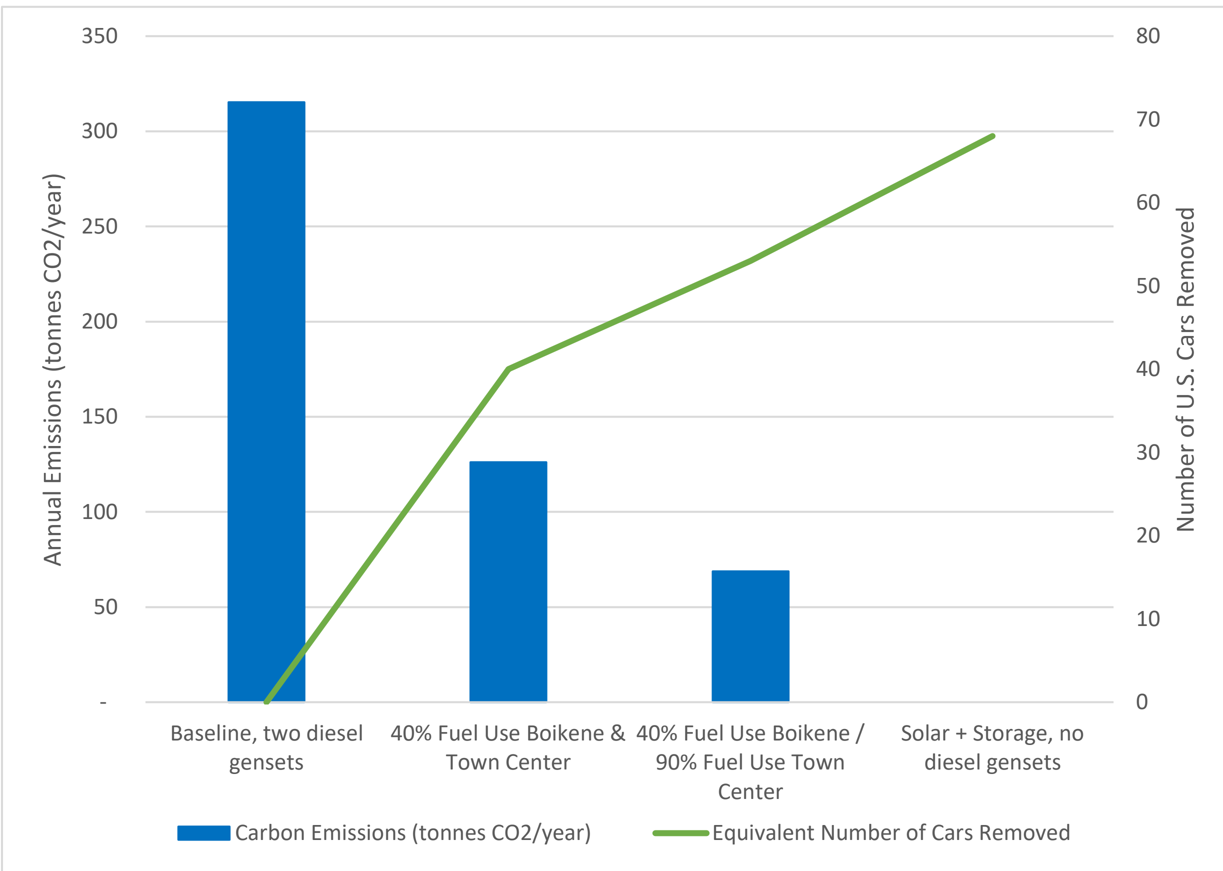

Figure 8. Emissions Analysis of Reduced Diesel Consumption.

Diesel fuel emits 2.62 kg of CO_2 per liter consumed during combustion,[40] and based on the daily average fuel consumption for each site provided by KGE, the baseline emissions for Kivu

[40] EPA. 2018. Emission Factors for Greenhouse Gas Inventories. https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf

Green Energy's electricity operations is an estimated 315 tonnes of CO_2 annually. Given KGE now consumes approximately 40% of their baseline diesel use with the addition of the 55 kW solar + storage system, they have reduced their annual emissions by 115 tonnes of CO_2, or the equivalent of 15 U.S. passenger vehicles driven in one year.[41]

With the installation of a similar sized system for the Town Center Microgrid, also resulting in 60% less diesel use, KGE would reduce their annual emissions by 189 tonnes of CO_2 as compared to the baseline, which equates to removing from the road 40 U.S. passenger vehicles driven in one year.[42] Alternatively, if KGE were to add additional storage capacity to the Boikene Grid and appropriately size the storage bank for the Town Center's future system, resulting in no diesel generation, the company would be responsible for annually removing the equivalent of approximately 68 U.S. passenger vehicles driven in one year.[43] The modeling tool used for this analysis can be found in Appendix D.

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[41] EPA. 2017. Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[42] EPA. 2017. Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[43] EPA. 2017. Greenhouse Gas Equivalencies Calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

IV. Recommendations

To make a final recommendation, I compared four systems: 1) 7.6 kW Solar + 12 kWh BESS, 2) 7.6 kW Solar + 18 kWh BESS, 3) 8.4 kW Solar + 12 kWh BESS, and 4) 8.4 kWh +18 kWh BESS. I recommend the most cost-effective solution based on a levelized cost of energy (LCOE) comparison of the four PV+BESS options.

The difference in total cost for the two PV sizes is minimal; however, with an oversized system I expect that KGE could sell the excess electricity to the office buildings located directly next to them. This will bring in additional revenue, thus lowering the payback period further than this model suggests. The sale of excess electricity is excluded from this study due as it will depend on a number of factors that KGE must internally decide.

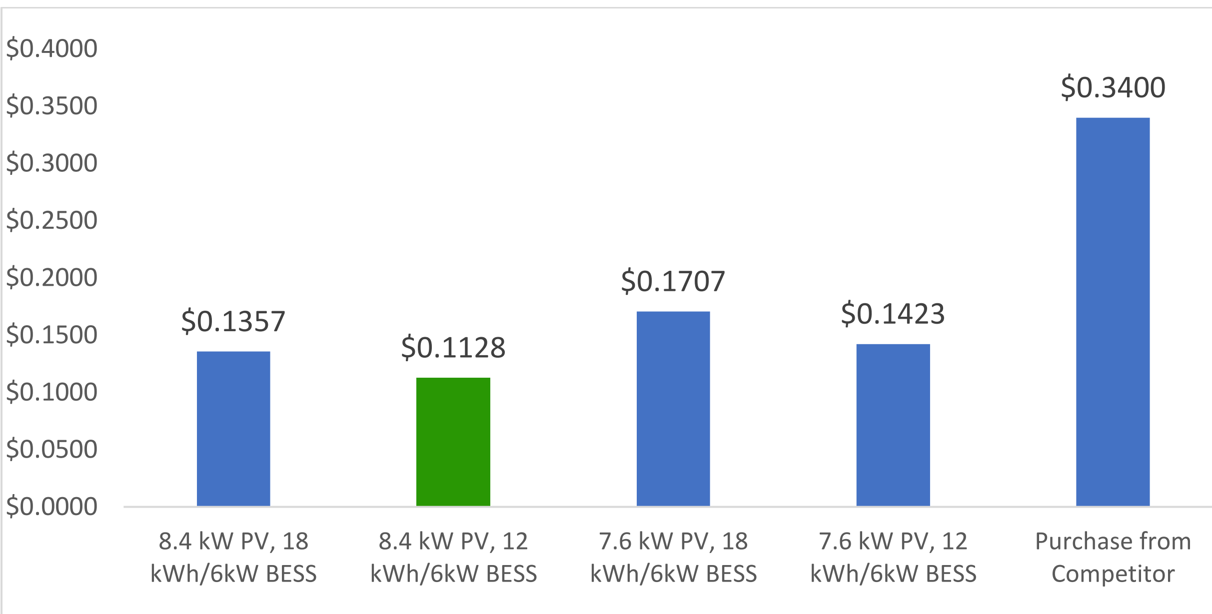

Figure 9. LCOE Comparison

Based on the LCOE comparison shown in Figure 9, my final recommendation for Kivu Green Energy is to install an 8.4 kW Solar PV + 12 kWh / 6 kW BESS system at their office and sell any excess electricity produced by the solar PV to surrounding businesses. See Table 6 for an overview of the system’s financial analysis.

Table 6. Financial Summary

System	Capex (Loan from USI)	Total Payments (after 4 years)	20 year IRR	NPV	Simple Payback	LCOE	Monthly Payment
8.4 kW PV 12kWh/6kW BESS	$32,948	$40,111	15%	$48,849	9.1 years	$0.1128	$836

The load profile for a typical weekday at KGE's office looks much like other office spaces might expect. Figure 10 shows business operations ramping up quickly in the morning hours, remaining consistent throughout the day until late afternoon (shown in blue). The solar generation (green) increases throughout the day with the greatest solar intensity occurring around midday, then dropping off as the sun sets. Solar generation exceeds the load for most of the midday hours, when the excess generation is funneled into the battery storage. The battery reaches full state of charge (red line) in the early afternoon and is then dispatched throughout the evening hours of business operations. The remaining storage capacity is used for the following morning's ramping period until the sun once again meets, or exceeds, the office demand.

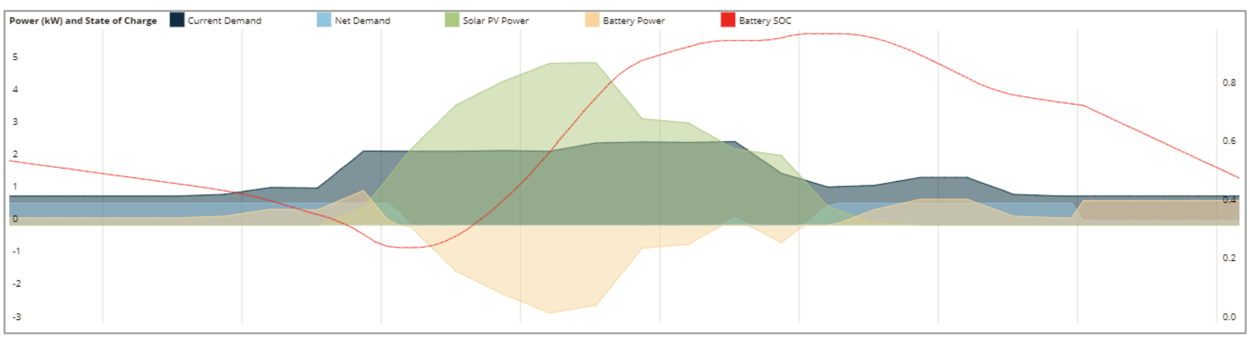

Figure 10. KGE's Weekday Load Profile

Battery life is heavily dependent on the number of charge cycles, or charges and discharges, the battery is subject to. Constantly depleting the battery beyond 20% of full charge shortens the life; therefore, the model inhibits the battery from exceeding 80% discharge. it is also a waste of storage capacity, and money, to greatly oversize the battery.

The projected utilization rate for the battery in the recommended microgrid system ranges from 60-80% of battery utilization for most days throughout the year (Figure 11). The model limits any days from reaching the 80-100% depletion zone in an effort to extend the battery life and there are no days that rely on less than half of the battery capacity, signaling that this storage size appropriately meets the needs of the load.

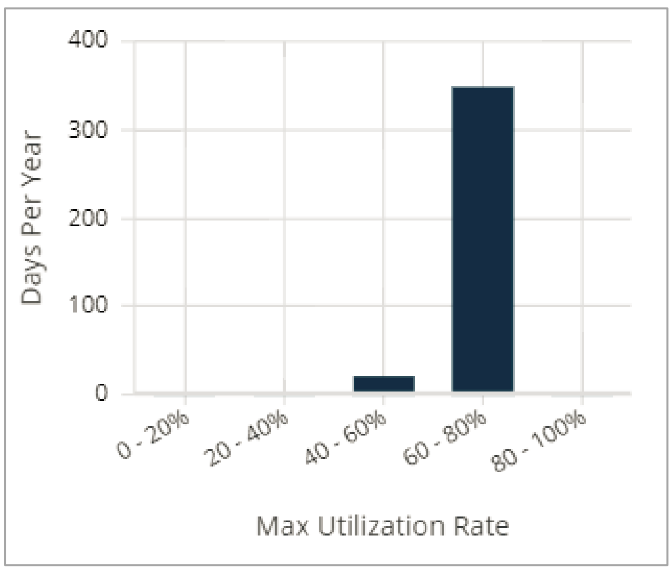

Figure 11. Annual Storage Utilization Projection

V. Conclusions

i. Microgrid Feasibility

The findings this assessment further depict the microgrid model as a feasible energy access solution for cities like Beni. At a community-wide scale, Kivu Green Energy has successfully served 260 small commercial and residential customers, or approximately 2600 Beni Residents,[44] using diesel generators and distribution infrastructure. They currently serve over 100 customers, or approximately 1000 people,[45] primarily with clean generation. By maintaining the diesel generator on the Boikene Microgrid, they combine clean electricity with a level of resiliency that is unmatched by competitors in the area. On a smaller office-level scale, KGE has the opportunity to meet all electricity needs with an onsite, emission free microgrid. The differentiator, therefore, is Kivu Green Energy's ability to generate free electricity once they recover costs from initial solar + storage investments, ultimately driving down the price of electricity within the area and creating a demand for lower emission energy.

ii. Carbon Emissions

KGE could use this information to internally price carbon, further encouraging reduced fossil fuel use company-wide. Using the emissions model built specifically for KGE's internal use (Appendix D), the company will be able to track its daily, monthly, or annual carbon emissions based on its diesel fuel use. This strategy could lead to a next step of approaching the local Beni government about adopting a city-wide carbon pricing strategy based on their internal carbon emission modeling, resulting in emissions reductions from its competitors.

The baseline emission assessment is telling of the environmental damage that diesel generation can cause, and the improvements that would come from substituting gensets with renewable resources. In this context, keeping the diesel gensets as a part of the microgrid system adds essential reliability to the customer base. If KGE were to remove all diesel generation from their asset mix, it would require doubling the battery capacity of the Boikene Microgrid—a hefty investment given they have an operable and reliable solution in place.

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[44] Bidong, E. 15 December 2017. Personal Interview. *Estimates 10 people per household or business.*
[45] Bidong, E. 15 December 2017. Personal Interview. *Estimates 10 people per household or business.*

Additionally, a much larger battery bank would be needed once the Town Center Microgrid is funded, necessitating even more upfront capital. At this time, it doesn't seem affordable for KGE to add storage capacity and replace their diesel gensets; however, as storage prices are continuously falling, in the not-so-long-term, it might make financial sense to ditch the expensive diesel and invest in larger battery banks instead. The feasibility of this will be dependent on the path that the cost of storage takes over the next few years.

iii. Limitations and Future Research

There are limitations to this study and it is important to note the assumptions made in the pricing, sizing, and emissions calculations are reasonable for the point in time in which it was conducted, but are in constant flux due to falling costs of technology and non-linear variations in scalability. Kivu Green Energy should continue to investigate the costs and benefits of sizing their microgrids based on current customer load or whether oversizing for future load growth should be built into initial designs.

Additionally, Kivu Green Energy should evaluate their customer payment method. Currently, customers are charged $48 per ampere. This method does not capture the cost of electricity, typically measured in kWh, but only the amount of current drawn. Customers that draw 1 amp of current all day are charged the same price as customers that draw 1 amp of current for a single hour. This puts additional strain on the generation assets and daily storage and diesel requirements. Alternatively, if KGE adopts a pay-as-you-go (PAYG) method, they can better predict the energy requirements to meet the demand the customers have already paid for. The clientele is largely unaware of this method and will certainly take adjusting from the customer perspective; however, as Kivu Green Energy plans to scale, it will be essential to accurately charge and measure the customer's energy consumption. The PAYG method will require additional metering and trainings, resulting in upfront capital to make the system operable, but will be a vital method to improve the business operations as the customer base expands.

iv. Summary

In summary, proposing a short-term energy solution for Kivu Green Energy's office space allows the company to 1) maintain access to clean, reliable, and high-quality power to run the necessary equipment in order to meet and expand their business operations and 2) exhibit their commitment to clean electricity generation by installing a solar array on the roof of their office, located in the center of town. This messaging can go beyond future customer acquisition, using this office-level microgrid as leverage for future investors of a greater Town Center solar + storage system. With a goal of managing 10 MW of solar generation by 2023,[46] KGE will be able to use successful loan repayments to United Solar Initiative for the proposed system to demonstrate credit-worthiness and allow them to secure future funding for the larger-scale microgrids they aim to own and operate.

[46] Kivu Green. 2018. Who we are. http://www.kivugreenenergy.com/about-us/

VI. Appendix

A. Kivu Green Energy's Current Energy Use

Appliance	Power (kW)	Quantity	Hours (h/day)	Total Power (kW)	Consumption (kWh)
Light Bulbs	0.018	10	13	0.18	2.34
Phone Charger	0.005	10	9	0.05	0.45
Laptop	0.100	7	9	0.70	6.30
Printer	0.400	1	4	0.40	1.60
Total				**1.33**	**10.69**

B. Kivu Green Energy's Anticipated Future Energy Use

Appliance	Power (kW)	Quantity	Hours (h/day)	Total Power (kW)	Consumption (kWh)
Light Bulbs	0.018	10	13	0.18	2.34
Television	0.060	1	9	0.06	0.54
Decoder	0.015	1	9	0.01	0.13
Phone Charger	0.005	10	9	0.05	0.45
Laptop	0.100	7	9	0.70	6.30
Coffee maker	0.800	1	1	0.80	0.80
Fridge	0.140	1	7	0.14	0.98
Printer	0.400	1	4	0.40	1.60
Air conditioner	0.150	2	8	3.00	24.00
Total				**5.34**	**37.15**

C. *Monthly Office Demand and PV Production Estimates*

Month	Office Demand in kWh Future Energy Use	 Current Energy Use	PV Production in kWh 7.6 kW PV Production	 8.4 kW PV Production
Jan	978.74	268.50	1,033	1142
Feb	884.02	242.52	985	1089
Mar	978.74	268.50	1,070	1183
Apr	947.16	259.84	925	1022
May	978.74	268.50	921	1017
Jun	947.16	259.84	899	994
Jul	978.74	268.50	949	1049
Aug	978.74	268.50	1,001	1106
Sep	947.16	259.84	1,011	1118
Oct	978.74	268.50	1,020	1127
Nov	947.16	259.84	927	1024
Dec	978.74	268.50	997	1102
Annual	**11524**	**3161**	**11738**	**12973**
Average	**960**	**263**	**978**	**1081**

Current Energy Use is 27% less than Future Energy Use

Currently paying $0.34 per kWh

D. *Carbon Emissions Modeling Tool*

Shown for 90% Diesel Reduction for Town Center Grid, 60% Diesel Reduction for Boikene Grid

Site	**Generator Nameplate Capacity** *kW*	**Baseline Daily Diesel Use** *Liters*	**Future Daily Diesel Use** *Liters*	**Baseline Annual Diesel Use** *Liters*	**Future Annual Diesel Use** *Liters*	**Baseline Annual CO2 Emissions** *Tonnes of CO2*	**Future Annual CO2 Emissions** *Tonnes of CO2*	**Emission Reduction** *Tonnes of CO2*
Town Center	150	200	20	73000	7300	191.11	19.11	172.00
Boikene	88	130	52	47450	18980	124.22	49.69	74.53
Total						**315.33**	**68.80**	**246.53**

USER INPUTS	
Town Center % Diesel Reduction	90%
Boikene % Diesel Reduction	60%