# AN ANALYSIS OF THE FEASIBILITY AND ENVIRONMENTAL IMPACT OF INCORPORATING CLEAN ENERGY INTO AN ISLANDED MICROGRID IN SIERRA LEONE

by
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# ABSTRACT

Clarity Project is a fine jewelry company and social enterprise that recently began mining diamonds in Sierra Leone as part of its mission to improve the quality of life of artisanal miners in West African communities. This has presented a new challenge to the company: the site of Clarity Project's new mining compound is distant from the country's modest electric grid, leaving Clarity Project to procure its own electric power.

The purpose of this project is to determine Clarity Project's electricity needs, analyze its alternatives for meeting those needs, and evaluate the costs and environmental impacts of those alternatives. Using data obtained on site in Sierra Leone and meteorological data from NASA, we developed a model that predicts the load profile of the mining compound, forecasts the expected amount and temporal availability of electricity from photovoltaic arrays on site, and projects the use of diesel generators and battery storage to supplement the solar power. The model then calculates the present value of the capital and operating expenses for the microgrid as well as the carbon dioxide emissions associated with generating electricity for the compound.

Our analysis has determined that (1) the least expensive option, based on capital expenses and operating expenses discounted to present value, would be to rely solely on diesel generators; (2) the cost of relying solely on renewable energy during Sierra Leone's dry season would be approximately double the all-diesel option over a five-year time horizon and about 60 percent greater over a 25-year time horizon (and the availability of renewable energy falls significantly during the rainy season); and (3) incorporating solar power and battery storage, while more expensive, would allow Clarity Project to avoid emitting nearly 20 metric tonnes of carbon dioxide per year.

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# I. Executive Summary

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# II. Background: Sierra Leone, Mining, and Clarity Project

## *A. Sierra Leone*

The small West African country of Sierra Leone, or "Lion Mountain" in Portuguese, is bordered by Guinea to the north and Liberia to the southeast. The country is known internationally for its mineral and mining industry, and is most notable for its diamonds. The diamond industry is the most important industry in the country with 200 M USD to 300 M USD in minerals extracted annually[1]. Diamonds also account for nearly half of the country's exports. Agriculture and tourism are also important economic drivers. With 61 percent of the population living outside of urban centers[2], the country depends heavily on agricultural and fishery resources and nearly half of the working age population engages in subsistence farming[3]. This accounts for two-thirds of the total population[4]. Agricultural exports include rice, coffee, peanuts, bananas, cocoa, ginger, and citrus fruits. Tourism is a small but growing industry focused primarily around beach destinations and tropical rainforests.

Sierra Leone is extremely poor, and in 2013 had a Human Development Index (HDI) ranking of 177 out of 187 countries. This rating places the country in the category of least develop nations on the measure of three basic dimensions: health, education, and income. It also places Sierra Leone below the regional average in sub-Saharan Africa[5]. This low HDI rating can be attributed in large part to a violent ten-year civil war that ended in 2002. The war left a lasting impact on the country's social fabric and physical infrastructure, which continues to restrict economic development.

Sierra Leone had 146 MW of grid connected installed electric capacity in 2008. Of this capacity, 91 MW are grid connected diesel generators and the remaining 50 MW come from one large hydro generator. Aside from hydro, there is no renewable energy generation connected to the national grid[6].

Eighty-seven percent of the population does not have access to grid-connected electricity. This population powers homes, businesses, and factories with islanded diesel generation. There is an estimated six MW of small hydro capacity installed nation-wide, and three important biofuel resources exist in Sierra Leone: cassava, groundnut, and sweet sorghum.

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[1] Healey, Christina. "Sierra Leone." *Our World: Sierra Leone* (August 2011): 1. *Points of View Reference Center*, EBSCO*host* (accessed October 31, 2013).

[2] Central Intelligence Agency, "World Factbook." Accessed March 7, 2014. https://www.cia.gov/library/publications/the-world-factbook/geos/sl.html.

[3] "World Factbook."

[4] Healey, *Sierra Leone*.

[5] United Nations Development Programme, "Human Development Reports." Last modified 2014. Accessed March 7, 2014. http://hdrstats.undp.org/en/countries/profiles/SLE.html.

[6] ECOWAS Observatory for Renewable Energy and Energy Efficiency, "Sierra Leone Country Profile." Last modified 2008. Accessed March 7, 2014. http://www.ecowrex.org/country_profile/384/2008.

## *B. Alluvial mining*

Alluvial diamonds are deposits that have been displaced from their original Kimberlite source rock and moved over time through a process of erosion to new locations. Since erosion is often caused by rivers and streams, and can take millions of years, many of these deposits are found close to the surface of the earth and are near bodies of water[7]. Alluvial mining refers to the process of recovering gravel deposits from these near surface deposits and sifting through them to recover diamonds.

Three primary types of alluvial deposits are recovered: dry land near surface deposits; alluvial deposits with thick sterile overburden coverage; and, river deposits[8]. Because alluvial deposits are often dispersed across large geographic expanses, they are difficult to mine industrially. For this reason, most alluvial deposits are recovered through small-scale "artisanal" mining.

## *C. Artisanal and small-scale mining (ASM)*

Twenty to thirty million people globally are involved in artisanal and small-scale (ASM) alluvial mining[9], and fourteen percent of the rough diamonds recovered worldwide are recovered through this practice[10]. Primarily poor rural communities undertake ASM as a form of livelihood. For some, it is their principal form of livelihood, while for others the work is seasonal or supplementary. Because ASM can generate income up to five times greater than alternatively available work (primarily in agriculture or forestry), full families, including women and children, will participate in mining activities[11].

Although many underdeveloped communities could greatly benefit from this economic activity, governments, international development banks, and non-profits have paid little attention to the sector. This neglect is due in large part to the informality of the work and the cultural and economic marginalization of the workforce, and has lead many governments to favor development of more professionalized industrial mining operations (often owned and operated by foreign corporations) over ASM. The lack of attention perpetuates a myriad of political, legal, social, and economic

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[7] World Diamond Council, "Alluvial Diamond Mining Fact Sheet." Accessed February 8, 2014. http://www.diamondfacts.org/pdfs/media/media_resources/fact_sheets/Alluvial_Mining_Background.pdf.

[8] Priester, Michael, Estelle Levin, Johanna Carstens, Geert Trappenier, and Harrison Mitchell. *Mechanisation of Alluvial Artisanal Diamond Mining: Barriers and Success Factors*. Ottawa: DDI International, 2010. Print.

[9] Abbi Buxton, *Responding to the challenge of artisanal and small-scale mining*, (IIED: www.iied.org, 2013).

[10] "Alluvial Diamond Mining Fact Sheet."

[11] Buxton, "Responding to the challenge of artisanal and small-scale mining."

barriers to the formalization and development of this work. ASM is thus characterized by weak labor and environmental standards.

One key barrier facing the formalization and development of ASM is a lack of mechanized mining[12]. This work, often conducted using basic shovels, sieves, and picks axes, can be very grueling and inefficient. The simple use of a backhoe to remove over burden and dirt deposits, of water pumps to remove groundwater from open pits, and of a motorized jig and sluice box, can greatly improve the efficiency and safety of an operation. Barriers to the mechanization of many ASM sites include financing, administrative and legal requirements, and the impact of government instability on the investment climate[13]. In Sierra Leone, for example, mechanization for ASM license holders was prohibited until January of 2014. ASM license holders now pay more than 10,000 USD in additional government fees in order to be eligible to use machinery such as backhoes on their sites. A fee of this amount is insurmountable for most local miners, and is a strong deterrent for outside investors.

The informality of ASM also perpetuates a number of environmental concerns. A lack of understanding of the land, time and financing constraints, leads many to mine large open pits without thought of reclamation. Nutrient rich overburden is left in unutilized piles, and groundwater fills pits that are left open to attract insects and disease.

### *D. Clarity Project*

Clarity Project is a fine jewelry company that sources gems, diamonds and precious metals, and designs and sells jewelry. Their products are customizable and the quality of the company's diamonds and gems is equal or superior to that of top jewelry brands. Their product however is uniquely differentiated. The company's mission is to improve the quality of life of artisanal miners in West African communities. Clarity Project reinvests its profits into the mining communities in which it works, and is dedicated to sourcing its metals and gems from companies with more ecologically sensitive and socially responsible mining practices.

Many of the mines that they source from been certified by the Diamond Development Initiative's Development Diamonds Standards™ (DDS) certification. This certification aims to ensure that ASM miners and operators, often the most vulnerable mining group, and their communities, are

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[12] Michael Priester, Estelle Levin, Johanna Carstens, Geert Trappenier, and Harrison Mitchell, *Mechanisation of Alluvial Artisanal Diamond Mining: Barriers and Success Factors.* (working paper, Diamond Development Initiative, 2010).
[13] Priester, "*Mechanisation of Alluvial Artisanal Diamond Mining: Barriers and Success Factors.*"

supported. This certification considers a broader ecosystem of development standards, including the transparency of supply chains, the traceability of the gems, the socio-political context on the ground, and the country level laws and regulations governing ASM[14].

Three young entrepreneurs from California founded Clarity Project in 2009. Traditionally, their diamonds have been sources from ASM sites in Namibia, South Africa, and Sierra Leone, and Clarity Project has worked to ensure that productive relationships with miners, communities, and allies across the value chain are maintained. As relationships with local partners grew, it became apparent that through vertical integration, Clarity Project could have a deeper impact in the ASM communities where they worked. If executed properly, opening a mine site would create well-paid jobs and introduce high ethical, labor, and environmental standards to communities with youth unemployment rates of more than 60 percent[15]. With this vision in mind, in 2013, Clarity Project announced plans to open their very own ASM site in Sierra Leone's largest diamond producing district, Kono District. Plans were also announced to utilize a progressive reclamation-mining model at this site.

## *E. The mining site*

Exploratory mining began on three adjacent land licenses in the Kono District in late 2013. Each plot measures 200 feet by 200 feet, and two of these plots sit on the local Bafin River. The third plot extends up a hill, and all three are covered in heavily wooded forest and an interspersed cacao plantation. Miners, mine's managers, and security personnel were hired from the local towns and the nearby city of Koidu, and all workers were given high quality boots and gloves – a practice surprisingly rare on ASM sites in Sierra Leone.

If exploration is successful and the site has the potential to be profitable, a compound will be built adjacent to the land licenses to allow workers a place to gather and rest during the day, and to provide sleeping quarters for 24-hour security personnel. The compound also will comprise a 200 foot by 200 foot plot and will be surrounded by a fence and protected by a security system.

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[14] Diamond Development Initiative, "DDI's ethical diamond certification project." Accessed January 10, 2014. http://www.ddiglobal.org/dds/.

[15] "Sierra Leone." *Overview*. World Bank, 1 Nov. 2013. Web. 15 Apr. 2014. <http://www.worldbank.org/en/country/sierraleone/overview>.

Clarity Project expects to operate the mine during Sierra Leone's dry season, which lasts from approximately November until approximately April, and to maintain a more limited staff (still requiring electricity, though in reduced amounts) during the rainy season.

## III. Methods

In order to evaluate the costs and environmental impacts of possible microgrid designs that would provide electricity to Clarity Project's mining compound, we developed a model in Microsoft Excel. As depicted in ***Figure 1***, the inputs of this model include (1) Clarity Project's electricity needs; (2) data on weather, equipment and fuel costs, and equipment operating specifications; and (3) assumptions such as the appropriate discount rate, project time horizon, and certain equipment operating specifications that cannot be known with certainty in advance such as the actual energy conversion efficiency that solar photovoltaic (PV) panels will achieve in the field. The model is designed so that the assumptions and cost of diesel fuel can be easily changed using spin buttons and combo boxes. The model considers the electricity needs and generating schedule on an hourly basis; we feel this level of time granularity is sufficient to allow for meaningful estimation and accurately reflect the actual operation of the mine.

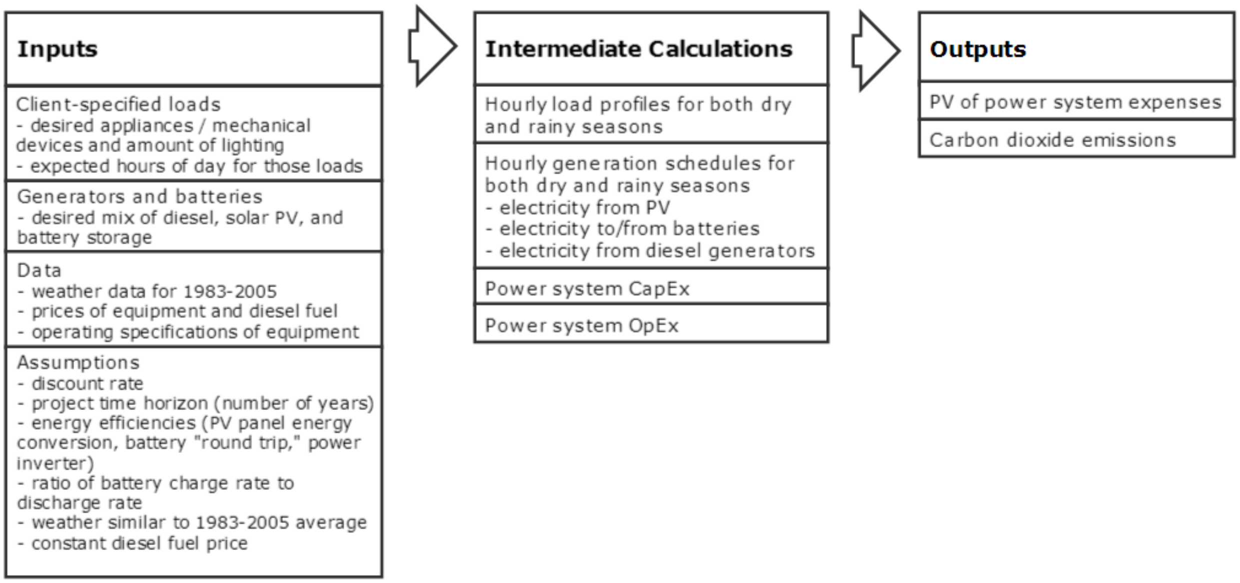

**Figure 1. Model schematic.**

From these inputs, the model calculates, for each of the dry and rainy seasons, (1) an hourly load profile; (2) an hourly schedule of electric power generation from PV, batteries, and diesel generation;

and (3) the total capital expenses (CapEx) and operating expenses (OpEx) of the microgrid. Finally, the model outputs the present value of the microgrid expenses (including all operations and maintenance (O&M) costs) as well as the expected carbon dioxide emissions from electricity generation. These two final outputs form the basis on which Clarity Project can evaluate alternative microgrid designs and ultimately select one that meets its cost and environmental objectives.

## *A. Technical and operational aspects of the microgrid*

Our model is based on the following analytical framework. The first step was to determine the quantity and timing of electric load during a typical day for each of the dry season and the rainy season. The result of this step is the microgrid's load profile. Second, we determined the means of serving that load. This second step itself consisted of predicting how much electricity any PV panels would supply, then predicting the charge or discharge of any batteries incorporated into the microgrid, and finally allocating any otherwise unserved load to diesel generators. The result of this second step is an hourly generation schedule. Subsections one through four below provide a detailed description of these steps.

Before describing those details, we note again that these are necessary but only intermediate steps in our analysis. With the load profile and generation schedules, our model then proceeds to calculate (1) the amount of carbon dioxide emitted by the system and the (2) CapEx, O&M expenses, and present value of the total expenses for the system.

### *1. Electricity needs*

Due to the relatively small scale of Clarity Project's mining operation in Kono District, the nature of its mining practices, and certain decisions related to the purchase of mining equiptment, Clarity Project's electricity needs relate to the mining compound rather than any heavy equipment one might otherwise associate with the operation of a mine. More specifically, Clarity Project identified the devices requiring electric power as (1) interior lighting for the compound's rooms, (2) exterior lighting on the compound's exterior, (3) a security system, (4) three computers, (5) five phone chargers, (6) one small refrigerator, (7) one television, (8) five ceiling fans, (9) a pump which fills an on-site tank of potable water, and (10) if possible, lighting along the one-third-mile-long access road leading from the compound. Our model allows the user to select either light emitting diode (LED) or metal halide lamps for the exterior lighting; the values reported in this paper assume LEDs were selected, for the reasons described below.

Our claculation of the estimated electricity needs proceeded in three stages. First, through discussions with Clarity Project staff on site in Sierra Leone and in Durham, North Carolina regarding the specific device types together with research regarding the amount of power these devices would require, we created a listing of the amount of power each device would draw while operating. Second, we created a schedule indicating which devices would be operating during each hour of the day. Finally, we multiplied the listing of electricity loads by the schedule array to obtain an array of load values for each hour of the day. We conducted these steps for both the dry season and the rainy season.

### *2. PV generation*

In order to model the expected amount of electricity that could be generated by PV, we began with the Surface meteorology and Solar Energy (SSE) dataset (version 6.0) made available by the Atmospheric Science Data Center (ASDC) within the National Aeronautics and Space Administration[16]. ASDC collected the SSE dataset from over 200 satellites over 22 years (July 1983 through June 2005) "specifically for photovoltaic and renewable energy system design needs." The data used for our model related specifically to the region of the earth's surface bounded by longitude -11 in the west to negative ten in the east, and latitude nine in the north to eight in the south. This area includes the site of the mining operation, the village of Koidu in Kono District, and other surrounding areas.

The data obtained from the ASDC include average values, for each month of the year, for the following.

- Daily solar insolation on a horizontal surface, including average, minimum, and maximum solar insolation, in kWh per square meter, as well as average time of solar noon and average number of daylight hours;
- Minimum available insolation over a consecutive-day period, in percent, for each of one-day, three-day, seven-day, 14-day, 21-day, and monthly periods;

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[16] Data was accessed at the ASDC website, https://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?skip@larc.nasa.gov

- Solar radiation deficits below expected values incident on a horizontal surface over a consecutive-day period, in kWh per square meter, for each of one-day, three-day, seven-day, 14-day, 21-day, and monthly periods;
- Monthly averaged insolation incident on a horizontal surface, in kWh per square meter, for the hour beginning at each of midnight, three AM, six AM, nine AM, noon, three PM, six PM, and nine PM local time (which is GMT); and
- Monthly averaged minimum, maximum, and average earth skin temperature, in degrees Celsius.

We were comfortable basing our model on data for a horizontal surface for two reasons. First, we knew we would not control the actual installation of the panels and believed it reasonably safe to assume the panels would actually be oriented either horizontally or at such an angle as to improve the amount of solar energy harnessed. Therefore, we felt that an assumption that the panels would be horizontal would, if anything, underestimate the actual amount of power from PV. Second, given the low latitude of the site, the difference between a horizontal panel and one which is optimally-tilted (or even tracking) is not as great as it would be for higher latitudes. Should Clarity Project or the installers of the solar panels wish to orient them not horizontally but at such an angle as would improve power generation, the SSE dataset includes relevant data.

As noted above, the SSE dataset contains both average daily total solar insolation, broken out for each month, as well as average solar insolation for certain hours of the day (starting at midnight and continuing at three-hour intervals), again broken out for each month. In light of the goal of predicting PV electricity generation for each hour of the day, rather than at three hour intervals, we imported the data into MATLAB and conducted a spline interpolation to estimate solar insolation values at hourly intervals. The MATLAB script for the interpolations and plot can be found in *Appendix A*.

In order to increase our level of confidence in the reliability of the interpolation, we first calculated for each month the sum of the actual and interpolated values for daily insolation. We then compared this calculated sum to the daily insolation values reported in the SSE dataset. We found that each of our 12 sum values (one for each month) fell short of the SSE reported value for that month by between 1.5 and 3.2 percent, with a mean shortfall of 2.5 percent.

From the hourly average insolation values $E_{insolation}$, the cross-sectional area of the PV panels $A$, and an assumed value $\varepsilon_{PV}$ = 0.13 for the efficiency of the panels in converting solar energy to electricity, we calculated the amount of electricity $E_{PV}$ one could expect PV to actually produce during that hour for each of the dry and rainy seasons using the formula:

$$E_{PV} = \varepsilon_{PV} * E_{insolation} * A_{panels}$$

We recognize that solar panel efficiencies may deviate from this assumed value but believe it is a reasonable and conservative expectation given the efficiencies achieved in similar climates and at similar price points.

From the above, our model predicts the amount of electricity Clarity Project may expect the PV panels to supply, on average, for each hour of the day during each of the dry and rainy seasons. However, because PV panels produce direct current (DC) while the microgrid loads require alternating current (AC), an inverter is necessary to transform the DC power to AC. We therefore calculated the amount of power from PV that is available to serve the loads by multiplying the PV panel power generation by an assumed inverter efficiency of 0.80. We felt that this assumed value was reasonable, and the model is structured such that Clarity Project can easily adjust this value if it is able to determine the conversion efficiency of whatever inverter it selects.

### *3. Batteries*

Batteries present the advantage of storing any excess electricity generated from PV during daytime hours and then discharging electricity to serve nighttime loads. Similarly, batteries can allow for some reliability benefits[17] and "smoothing" during daytime hours when, for example, a passing cloud reduces PV generation, thereby reducing the number of occasions when diesel generators would need to start during the daytime to serve load that suddenly is not met by a relatively short-lived drop in PV generation.

Of course, chemical batteries are not the only potential energy storage technologies: others include pumped hydro, compressed air, and flywheels[18]. For a discussion of these alternatives, please see the "Other technologies considered" section below. In the end, we selected lead acid batteries as the

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[17] IEEE 2009.

[18] IEEE 2009.

preferred storage technology due to familiarity, relative ease of maintenance, and financial considerations.

We evaluated a number of lead acid battery models before ultimately identifying two options that are specifically designed for use in conjunction with PV installations and other "deep cycle" applications. For each option, we calculated the energy capacity per battery as the product of the voltage and the charge capacity (the latter measured in amp-hours), both as indicated in the manufacturers' specification sheets. We also obtained the maximum charge rate in amps from the spec sheets, and multiplied this number by the voltage to yield the charge rate in watts. However, the manufacturers did not provide discharge rates; therefore, we made an assumption that the batteries would charge 90 percent as quickly as they would discharge (which value would be fairly typical) and used this relationship to estimate the discharge rates.

In order to model the actual charge to and discharge from the batteries, we first calculated, for each hour of the day during each of the dry and rainy seasons, the amount by which the amount of electricity generated from PV exceeded or fell short of the predicted load. For any hour during which PV generation exceeded load, we assumed that the amount of the excess, subject to three modifications, could be charged to the batteries. The first of those modifications relates to the inverter: the value for the amount by which PV electricity exceeds load reflects power inverter losses, but because both PV and batteries operate on DC and thus suffer no inverter losses between them then the electricity surplus should be adjusted to remove the effect of the inverter losses. Second, the amount of electricity charged to the batteries must be constrained by both the maximum capacity of the batteries (which is the product of the energy capacity per battery and the number of batteries) and the battery charge rate. Third, because battery charge and discharge is not perfectly efficient, the amount of energy discharged will always be less than the amount of energy charged. We assumed that this "round-trip" efficiency for the batteries would be 75 percent (*i.e.*, 25 percent of the energy would be lost), which is a typical value.

Similarly, the model calculates discharge from batteries as follows. For any hour during which PV generation is insufficient to serve all load, any energy stored in the batteries will be discharged, subject to the discharge rate constraints described above. Of course, the energy discharged is discounted by the power inverter efficiency in calculating the amount of electricity that actually serves load because the batteries are on a DC circuit and the loads are on AC.

### *4. Diesel generation*

As noted above, for any hour during which electricity from PV and battery discharge (in both cases, discounted by inverter losses) falls short of load, diesel generators will supply the shortfall.

## *B. Carbon dioxide emissions of the microgrid*

Given the generation schedule described above, the model predicts the carbon dioxide emissions from electricity generation on the microgrid over various time periods. It does this is four steps. First, it converts the amount of electricity provided by the diesel generators in an average day from kilowatt-hours to gallons of diesel, using the values for the generator's fuel consumption (in liters per hour) and power generation at that rate of consumption found on the manufacturer's specification sheet. Second, it converts those gallons of diesel into grams of carbon, using an assumed value of 2,778 grams per gallon, which is the value used by the U.S. EPA in calculating carbon dioxide emissions from motor vehicles with diesel engines[19]. We recognize that the carbon content of diesel fuel available locally at the mining site could differ from this value but feel this is a reasonable assumption given the lack of more appropriate data. Third, it calculates the amount of carbon dioxide emitted as a result of the reaction $C + O_2 \rightarrow CO_2$, whereby each unit of mass of carbon results in 3.66 units of mass of carbon dioxide. Finally, it multiplies this result (which represents $CO_2$ emitted per day) by the number of days in a year to calculate the annual emissions. From that point, one can easily compare annual $CO_2$ emissions from the microgrid given various different configurations, such as an all-diesel or diesel-free option, to determine the amount of carbon dioxide abated by, for example, incorporating PV into the system.

## *C. Financial aspects of the microgrid*

To understand the financial implications of different generation profiles, our model conducts a present value analysis. This allows Clarity Project to compare the costs associated with these options, and to adjust for the sensitivity of inputs at the project specific level.

Model inputs include CapEx and O&M expenses for a variety of diesel, PV, and battery options and equipment specifications. CapEx estimates include the purchase price of the equipment itself as given by suppliers as well as the total installation cost as a percent of CapEx. Installation costs take

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[19] EPA 2005.

into consideration labor, transportation, and additional equipment needs. They consider the location of the mine site and the level of technical capacity in country and in Kono District. For example, because diesel generation is the primary form of electricity generation in Kono District, the technology and expertise in how to install it exists close to the mine site, meaning that the installation cost as a percent of CapEx will be lower. Since very few solar installers are present in the country and the cost of labor and delivery for PV are significantly higher. Additional equipment needed is specific to each type of technology and includes items such as an inverter, charge controller, fuse panels, sockets, cables, battery shelves etc.

O&M expenses included the cost of diesel fuel, labor, down time for servicing, and additional parts and equipment such as spark plugs and oil. O&M expenses are also calculated to scale up and down as a percentage of the initial cost of the equipment.

The final present value cost of the project takes into consideration all of the generation inputs (mentioned in above). The most notable inputs include the: (1) equipment decisions regarding desired mix of diesel, solar PV, and battery storage, (2) discount rate, (3) project time horizon, and (4) cost of diesel fuel.

For our final model, we assumed a discount rate of 18.5 percent. This rate was calculated by taking the average discount rate for the Metals and Mining Industry of 9.83 percent[20] [21], and increasing the value to account for risk associated with the growth phase, size, cash flow, location, type of mining, and technological considerations of the project.

Finally, the model also considers the financial implications of different load considerations. The CapEx and O&M costs of all load inputs are considered, and one load specific choice is examined in detail. Because the greatest load costs come from exterior lighting on both the access road and mining compound, load options for exterior lighting were considered. The two lighting options considered are LEDs and metal halide light fixtures. O&M costs for this comparison are driven by

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[20] "Betas by Sector." *Betas*. NYU Stern, 1 Jan. 2014. Web. . <http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/Betas.html>.

[21] Note: This value is a global average generated by Capital IQ. This was calculated using the most recent fiscal data as of January of 2014. For most companies this data was from 2012 financial statements.

the useful life of each respective lighting type[22] and the load requirement from the access road and mining compound in kWh per year.

## D. Other technologies considered

Aside from diesel generators, PV, and lead acid batteries, we considered the following alternative technologies when designing the microgrid. The reasons for ultimately rejecting the technologies are given below.

### 1. Natural gas microturbines

The benefits of microturbines (turbines that produce 30-500 kVA) and larger combustion turbines include relatively low capital costs, lower air pollution compared to reciprocating engines, the potential for heat recovery, and relatively low maintenance costs[23]. However, many potential microgrid locations suffer from high fuel costs or low fuel availability that make combustion turbines too expensive or even impossible to operate. In the case of Sierra Leone and Clarity Project's mining site, the lack of natural gas transmission and distribution infrastructure precluded this option.

### 2. Wind turbines

Wind turbines suffer from relatively high capital cost and intermittency but have relatively low O&M costs by virtue of requiring no fuel, and they produce no pollution. Regrettably, the mining site is not appropriate for wind. Wind power generation with a nameplate capacity of ten kW or less requires wind speeds above five meters per second (about 12 miles per hour)[24], but wind speeds in this region of Sierra Leone range only from zero to 1.3 meters per second[25]. Furthermore, the mining site has particularly poor wind resources: it lies along a river, in a valley with dense forest and trees standing approximately 50 feet tall. Given those trees, even if the area had strong wind resources above the forest canopy it would be necessary to build the turbine above that height, which adds significant cost.

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[22] The useful life used was 50k hours for LEDs and 17.5k for metal halides.

[23] IEEE 2009.

[24] Wind Energy Foundation, "Wind Power Your Home." Accessed March 7, 2014. http://www.windenergyfoundation.org/wind-at-work/wind-consumers/wind-power-your-home.

[25] International Renewable Energy Agency, "Global Atlas." Accessed March 7, 2014. http://irena.masdar.ac.ae/?map=399.

### *3. Small hydro*

Micro or pico hydroelectric power systems convert the kinetic energy of moving water into electrical energy. The amount of power that hydroelectric systems can generate depends to a large extent on two factors relating to the siting of the system (1) the water flow rate and (2) the "head," or the difference in elevation between the water intake and the turbine[26]. The best sites for hydroelectric systems feature both high flow rates and high heads, but either one of these alone may be sufficient for certain pico hydro systems to generate sufficient power for remote locations with lower electrical power requirements. Pico hydro systems feature low O&M costs and relatively modest capital costs (compared to PV, for example), but they are completely dependent on the site providing sufficient water flow and head. Unfortunately, the Bafin River along which the mining site lies is characterized by a very slow flow rate and no significant vertical drops at any point near the mining site. For this reason, pico-hydro is not a suitable option for Clarity Project's location.

### *4. Bio-energy*

The use of bio-energy either through anaerobic digestion or direct combustion of biomass is an additional generation option for small, off-grid applications. If harvested resources are replanted, and life-cycle emissions are taken into account, bio-energy can considered to be carbon neutral[27]. As mentioned previously, there are a number of biomass feedstocks grown in Sierra Leone, namely: (1) plants, such as cassava, groundnut, and sweet sorghum, and (2) manure from livestock, such as sheep, goats, chickens, and cows.

To produce electrical energy from either biomass or biogas, a large amount of feedstock is required. This is due to the fact that energy density in biomass is much lower than that found in other hydrocarbons. For example, the fuel energy density for woody biomass with 50 percent moisture is eight GJ per ton, while the fuel energy density for liquefied natural gas is 56 JG per ton[28].

Biomass produced from plants, or cellulosic biomass, yields 17 MJ of energy per kilogram of

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[26] Farriz Basar, Mohd and Masjuri Musa Othman 2013.

[27] "IEA Energy Technology Essentials: Biomass for power generation and CHP." *International Energy Agency*. (2007). http://www.iea.org/techno/essentials3.pdf (accessed March 7, 2014).

[28] Peter McKendry, "Energy production from biomass (part 2): conversion technologies," *Bioresource Technology*, 83, no. 01 (2002): 47-54, http://www.sciencedirect.com/science/article/pii/S0960852401001195 (accessed February 22, 2014).

biomass[29]. This means that 182 lbs of plant mass[30] would be required to produce the 92 kilowatts-hours of electricity needed per day for the compound[31]. Maintaining a consistent source of biomass for this system would require the identification of a local biomass supplier. Since no current suppliers exist in the area, and this generation option would be difficult.

If a biomass supplier existed and the feedstock was available at a feasible price, there are still further complications with this option. In the case of biogas, digesters require a high level of precision and attention to run properly, and generation cannot be ramped up or down. For example, a biogas plant with a mesophilic digester[32](operating between 98 to 103 degree F) takes anywhere from 14 to 21 days to digest its feedstock. Variability in fuel input leads to digester upsets which decrease the quality of biogas making the biogas difficult to burn. In the worst case, varying the fuel input could result in a complete system restart, which is both time consuming and costly. Because energy output can also not be altered, at times when energy supply outstrips demand, the system would likely need to flare excess gas. This comes at a cost.

In the case of biomass, although generation can be ramped up and down, other issues exist. The systems' steam turbine loop requires softened and demineralized water, which is not available at the site. Additionally, biomass must be dried out before it can be processed in order to allow for efficient combustion. Due to the six-month rainy season in Kono, biomass would not be an option for half of the year. Finally, there is a lack of local knowledge of steam generation technology, and failure to properly manage this system can be very costly. For these reasons, we do not recommend Clarity Project utilize bio-energy resources.

### *5. Energy storage*

Chemical batteries, particularly lead-acid batteries, are the most common and best-established technology, but they suffer from low round-trip efficiencies (*i.e.*, the amount of energy one can

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[29] "An Assessment of Biomass Feedstock and Conversion Research Opportunities." *Stanford University Global Climate & Energy Project.* (2005). http://gcep.stanford.edu/pdfs/assessments/biomass_assessment.pdf (accessed March 7, 2014).

[30] $\left(\frac{92\ KWh}{day}\right)\left(\frac{1}{.38}\right)\left(\frac{1\ biogas}{.55\ CH4}\right)\left(\frac{3.6\ MJ}{1KWh}\right)\left(\frac{1}{.38}\right)\left(\frac{1\ M^3 CH4}{36\ MJ}\right)\left(\frac{1\ ton}{580\ m^3}\right) = .2\frac{tons}{day}\ or\ 181.81\frac{lbs}{day}$ ; Where the digester and generator have an efficiency rating of 38 percent. This is consistent with the efficiency of GE's Jenbacher system, but varies with load.

[31] Banks, Charles. University of Southampton, "Optimising anaerobic digestion." Last modified March 25, 2009. Accessed March 7, 2014. http://www.forestry.gov.uk/pdf/rrps_AD250309_optimising_anaerobic_digestion.pdf/$FILE/rrps_AD250309_optimising_anaerobic_digestion.pdf.

[32] Typically is a low rate digester.

retrieve from a battery is typically in the range of only three quarters of the energy deposited into it). Pumped hydro storage involves pumping water to a storage area (typically one located at higher elevation or otherwise having potential energy) during periods of excess power generation, then using the stored water to power micro hydro turbines during periods of excess load. Because pumped hydro depends on access to significant water storage capacity on site, it is not feasible in all locations. Compressed air functions analogously to pumped hydro: during times of excess power generation, pumps compress air into high-pressure storage, and that compressed air can be used to power a turbine during times of excess load. This technology is much less well-established than chemical batteries or even pumped hydro. Finally, flywheel storage involves converting electrical energy into the kinetic energy of a rapidly rotating ring-shaped wheel using a motor that doubles as a generator. The round-trip efficiency of flywheel storage is superior to that of electrochemical batteries, but flywheels suffer from losses due to friction and related "self-discharge" losses[33].

## IV. Results

As noted above, our model allows Clarity Project to input various generating assets and receive as outputs the total system cost in present value and the expected carbon dioxide emissions. In order to elucidate the general trade-offs involved in selecting different system components, we report our results below for each of four different systems: (1) a "diesel only" system, with no PV or batteries, (2) a diesel plus PV system, without batteries, (3) a system with all three (diesel, PV, and battery technology), and (4) the lowest-cost system that would have sufficient PV and batteries to run without diesel generation during the dry season (though it still would require diesel generation during the rainy season). *Table 1* summarizes these four systems.

| | **Diesel** | | **PV** | | **Batteries** | |
|---|---|---|---|---|---|---|
| **System** | **Number** | **Total Cap (kW)** | **Number** | **Total Cap (kW)** | **Number** | **Total Cap (kWh)** |
| 1 | 2 | 8 | 0 | 0 | 0 | 0 |
| 2 | 2 | 8 | 4 | 4 | 0 | 0 |
| 3 | 2 | 8 | 4 | 4 | 6 | 12.6 |
| 4 | 2 | 8 | 58 | 58 | 78 | 163.8 |

**Table 1. Microgrid systems described in this report.**

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[33] Hebner et al. 2012.

### *A. Load profile and generation schedule*

As described above, the initial step in our analysis was to produce a load profile for the microgrid. ***Figure 2*** shows that load profile for the dry season. The arrays of load values for both the dry and the rainy season can be found in ***Appendix B***.

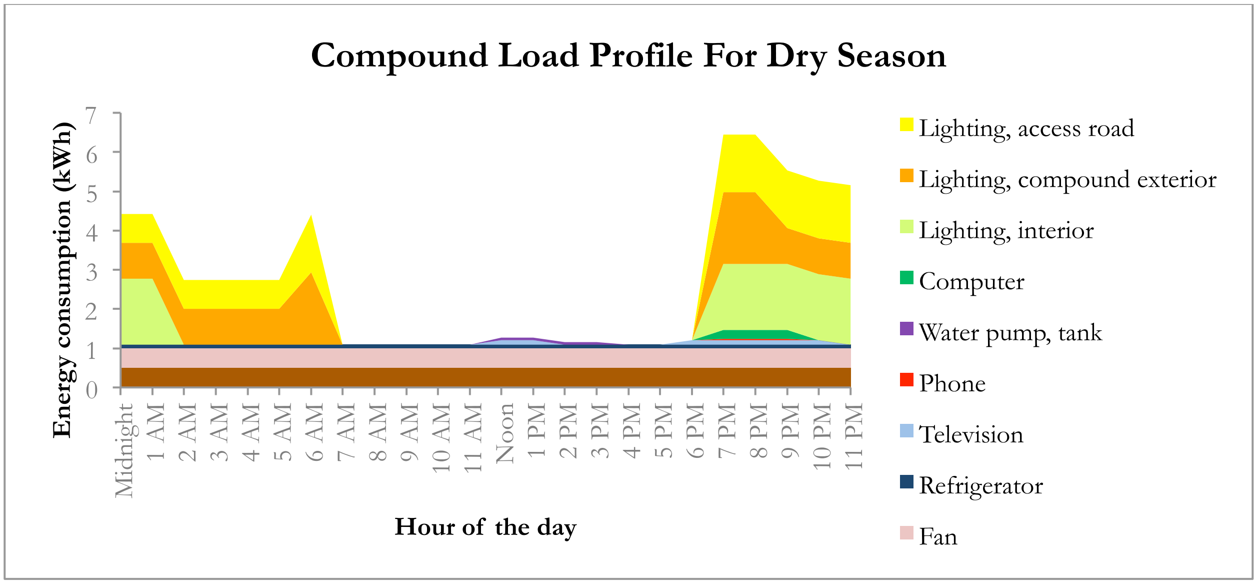

**Figure 2. Load profile during dry season.**

As described above, to produce our power generation schedule our model first calculates the amount of power expected to be produced by the PV arrays, and the calculated values are based on insolation values obtained from NASA and interpolated values. ***Figure 3*** contains the known average insolation values as well as interpolated insolation values and a line of best fit. Based on these insolation values, and thus the expected PV generation, our model generates a schedule of diesel generation and battery charge or discharge. ***Figure 4*** contains the generation schedule for our third system, which incorporates diesel, PV, and battery storage.

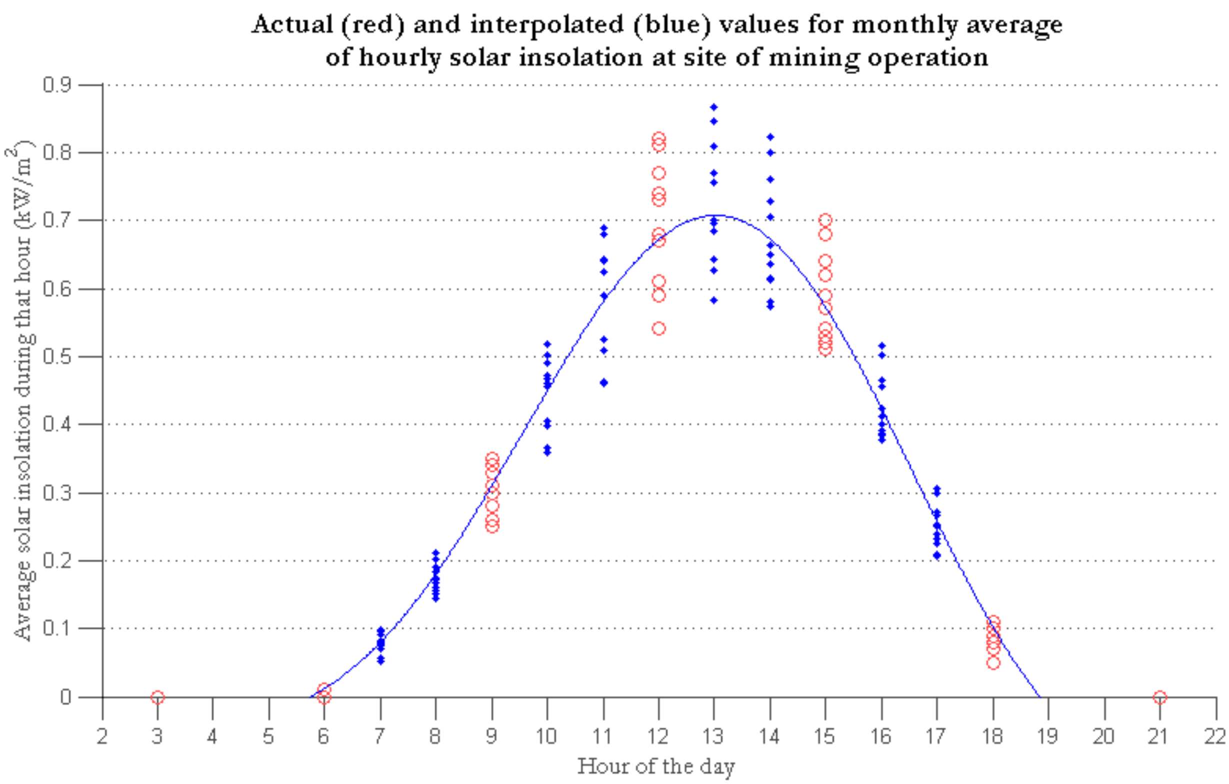

Figure 3. Insolation at the mining site.

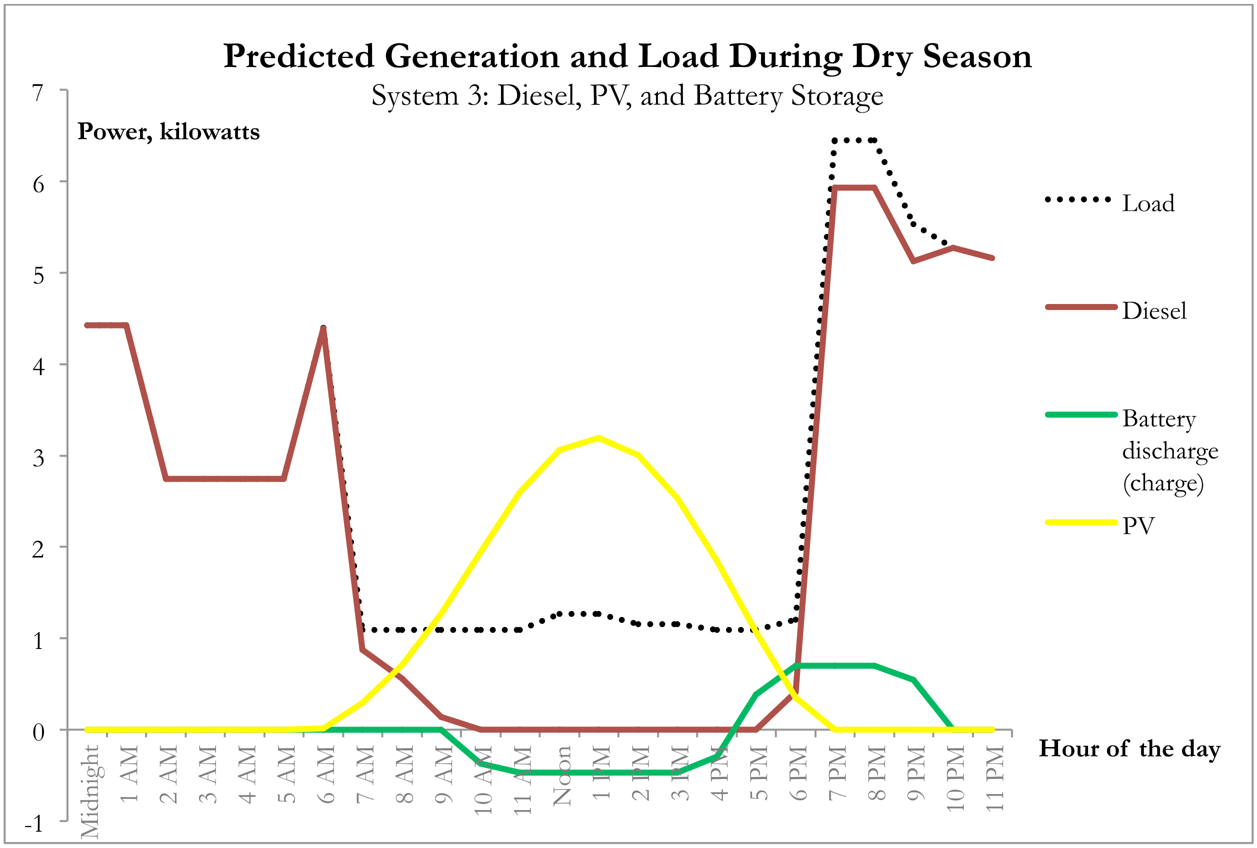

Figure 4. Generation schedule during dry season for system 3.

This model assumes that LEDs and motion sensors are used for all exterior light fixtures. The use of LEDs and motion sensors reduces the total daily load by 112.2 kWh or 41 MWh per year when compared to a system that utilizes metal halides without motion sensors. See ***Table 2*** for additional details.

| Total Project Load Comparison with Various Lighting Options | | | |
|---|---|---|---|
| | | kWh/day | kWh/yr |
| No motion sensors | Metal Halides | 178.94 | 65,176.37 |
| | LEDs | 97.10 | 35,366.81 |
| Motion Sensors | Metal Halides | 101.54 | 36,984.04 |
| | LEDs | 66.77 | 24,319.35 |

**Table 2. Total project load comparison with various lighting options.**

### *B. Carbon dioxide emissions*

Our model calculates the total tonnes of carbon dioxide emissions produced by each of the four different generation systems for a single year as well as over the life of a 25 year long project. Results showed that system one, the "diesel only" system generated the largest amount of carbon dioxide followed by systems two, three, and four respectively. ***Figure 5*** illustrates the total tonnes of emissions generated by each system.

The use of LEDs and motion sensors reduces the total potential CO2 emissions by 43.09 tonnes per year or 1,022.30 tonnes over a 25 yearlong project.

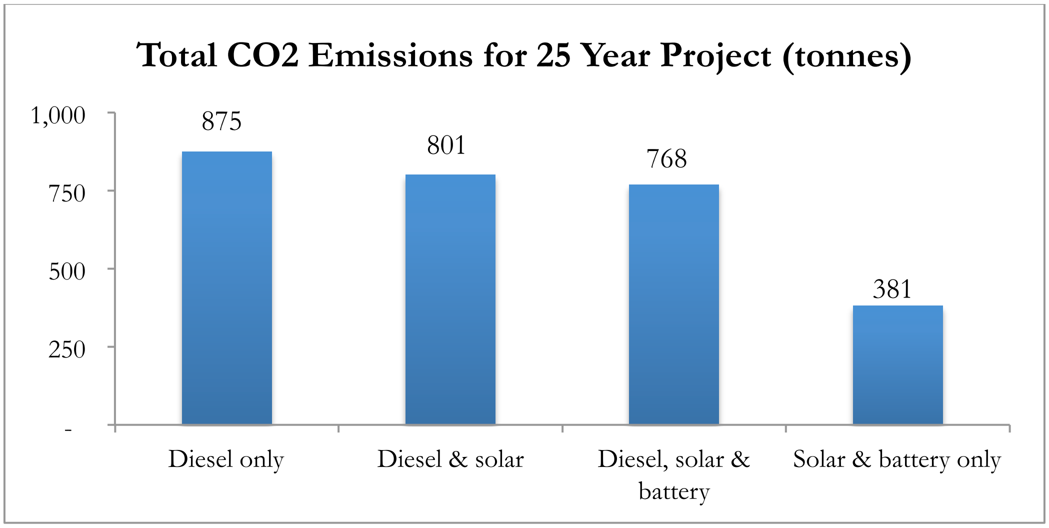

**Figure 5. Total CO2 emissions for 25-year project (tonnes).**

## *C. System cost*

Our final results show that the system with the lowest carbon dioxide emissions is not the system with the lowest cost. In fact cost increases linearly with emissions abatement. ***Figure 6*** details the net present value (NPV) of the four system options.

Assuming the use of motion sensors across both scenarios, a system which utilizes LEDs rather than metal halide light fixtures along the access road will reduce the present value of the total system cost by nearly $44K for a project with a 25-year project life. At the compound, LEDs have a similar present value cost to metal halide lights, even over a 25-year project life. This is due to the fact that the totally kWhs required per year at the compound is considerable lower than that of the access road, and therefore the benefits of the lower O&M costs associated with LED fixtures is not fully realized.

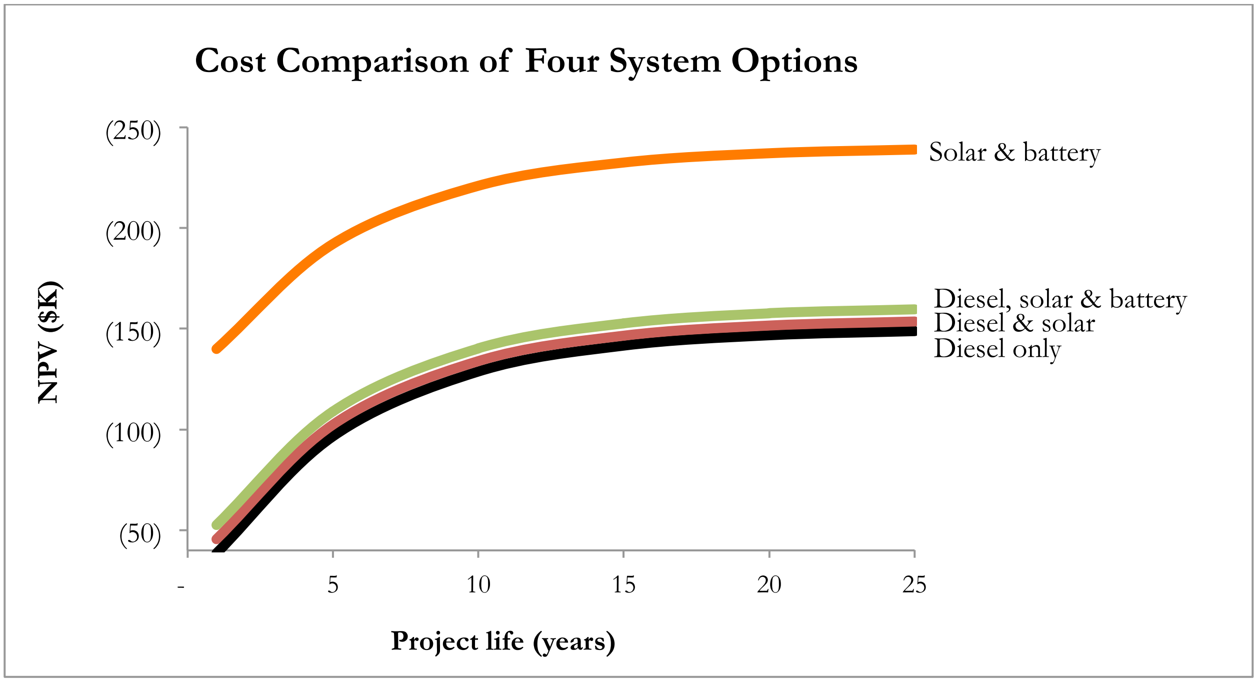

**Figure 6. Cost comparison of four system options in thousands of dollars.**

# V. Recommendations

Based on our findings, we have recommendations for Clarity Project that can be applied to both generation and load decisions.

On the generation side, we recommend that Clarity Project design a system with an installed nominal capacity of eight kW of diesel, four kWp of solar PV, and 25.2 kWh of batteries. The combination of diesel and solar PV capacity will allow the company to meet its clean energy goals at a reasonable price point. Battery capacity will help to smooth evening net load and prevent the use of diesel during days when cloud coverage is significant. Additionally, this system accounts for a 20 percent reserve margin or the ability to increase the system load by 20 percent without adding additional generating units.

When considering load, there are a number of choices that can be made while the project is being constructed that will reduce costs and increase the amount of carbon dioxide abated. We recommend the installation of LED rather than metal halide light fixtures for the exterior lighting along the access road and compound. Finally, the use of motion sensors on these fixtures will eliminate unnecessary load while ensuring Clarity Project's security needs are also met.

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# Appendix A
# MATLAB script for interpolation of insolation values

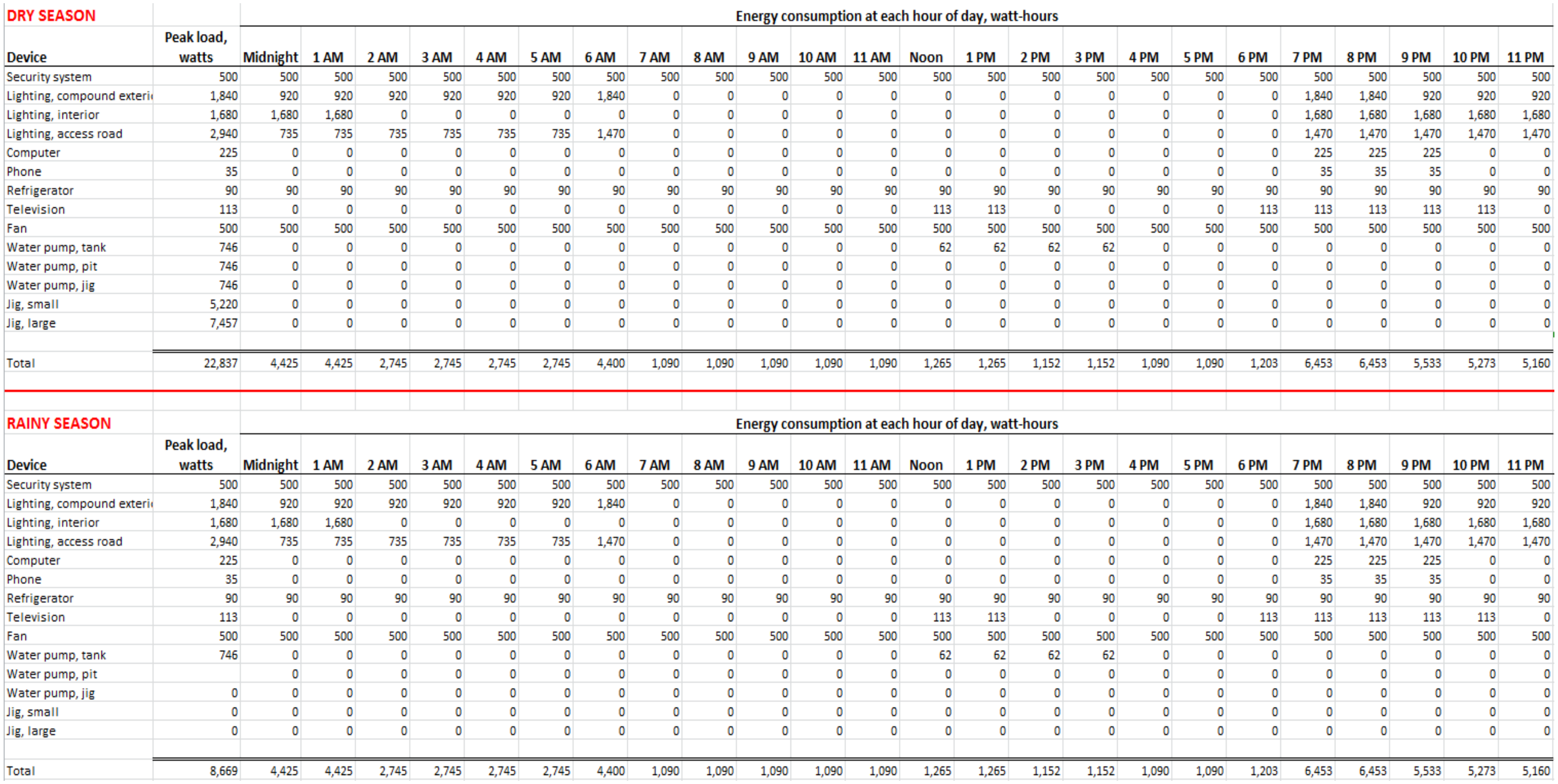
```
%% Import data from csv file
data = xlsread('Y:\MP\Models\Solar_times.csv');

%% Prep the data
% Identify first column as times, then transpose
time = data(:,1);
time = time';

% Assign each row to a time variable
for i = 3:3:21
    % timei = i
    eval(['time' num2str(i) '= data(i/3,:);']);
end

% Assign each column to a month
jan = data(:,2);
feb = data(:,3);
mar = data(:,4);
apr = data(:,5);
may = data(:,6);
jun = data(:,7);
jul = data(:,8);
aug = data(:,9);
sep = data(:,10);
oct = data(:,11);
nov = data(:,12);
dec = data(:,13);

% Remove time column from each row
for i = 3:3:21
    % timei = timei(2:13)
    eval(['time' num2str(i) '= time' num2str(i) '(2:13);']);
end

%% Run a spline interpolation for missing times in each month
timeMissing = [4, 5, 7, 8, 10, 11, 13, 14, 16, 17, 19, 20];

% January
sunMissingJan = interp1(time,jan,timeMissing,'spline');
jan1 = line(time,jan); hold on
jan2 = line(timeMissing,sunMissingJan); hold on

% February
sunMissingFeb = interp1(time,feb,timeMissing,'spline');
feb1 = line(time,feb); hold on
feb2 = line(timeMissing,sunMissingFeb); hold on

% March
sunMissingMar = interp1(time,mar,timeMissing,'spline');
mar1 = line(time,mar); hold on
mar2 = line(timeMissing,sunMissingMar); hold on
```

```
% April
sunMissingApr = interp1(time,apr,timeMissing,'spline');
apr1 = line(time,apr); hold on
apr2 = line(timeMissing,sunMissingApr); hold on

% May
sunMissingMay = interp1(time,may,timeMissing,'spline');
may1 = line(time,may); hold on
may2 = line(timeMissing,sunMissingMay); hold on

% June
sunMissingJun = interp1(time,jun,timeMissing,'spline');
jun1 = line(time,jun); hold on
jun2 = line(timeMissing,sunMissingJun); hold on

% July
sunMissingJul = interp1(time,jul,timeMissing,'spline');
jul1 = line(time,jul); hold on
jul2 = line(timeMissing,sunMissingJul); hold on

% August
sunMissingAug = interp1(time,aug,timeMissing,'spline');
aug1 = line(time,aug); hold on
aug2 = line(timeMissing,sunMissingAug); hold on

% September
sunMissingSep = interp1(time,sep,timeMissing,'spline');
sep1 = line(time,sep); hold on
sep2 = line(timeMissing,sunMissingSep); hold on

% October
sunMissingOct = interp1(time,oct,timeMissing,'spline');
oct1 = line(time,oct); hold on
oct2 = line(timeMissing,sunMissingOct); hold on

% November
sunMissingNov = interp1(time,nov,timeMissing,'spline');
nov1 = line(time,nov); hold on
nov2 = line(timeMissing,sunMissingNov); hold on

% December
sunMissingDec = interp1(time,dec,timeMissing,'spline');
dec1 = line(time,dec); hold on
dec2 = line(timeMissing,sunMissingDec) ;

% Calculate and plot a single line of best fit for the interpolated data
x = [4,5,7,8,10,11,13,14,16,17,19,20] ;
x = x' ;

data = NaN(12,12) ;
data(1,:) = sunMissingJan ;
data(2,:) = sunMissingFeb ;
data(3,:) = sunMissingMar ;
data(4,:) = sunMissingApr ;
```

```
data(5,:) = sunMissingMay ;
data(6,:) = sunMissingJun ;
data(7,:) = sunMissingJul ;
data(8,:) = sunMissingAug ;
data(9,:) = sunMissingSep ;
data(10,:) = sunMissingOct ;
data(11,:) = sunMissingNov ;
data(12,:) = sunMissingDec ;

yRaw = [sum(data(:,1)), sum(data(:,2)), sum(data(:,3)), sum(data(:,4)),
sum(data(:,5)), sum(data(:,6)), sum(data(:,7)), sum(data(:,8)),
sum(data(:,9)), sum(data(:,10)), sum(data(:,11)), sum(data(:,12))] ;
y = yRaw / 12 ;
y = y' ;
[y2, gof] = fit(x, y, 'smoothingspline') ;
bestFit = plot(y2, 'b') ;

Title = title('Actual (red) and interpolated (green) values for monthly
average of hourly solar insolation at site of mining operation') ;
XLabel = xlabel('Hour of the day') ;
YLabel = ylabel('Average solar insolation during that hour (kW/m^2)') ;
set([XLabel, YLabel], 'FontName', 'Garamond', 'FontSize', 12) ;
set(Title, 'FontName', 'Garamond', 'FontSize', 14, 'FontWeight', 'bold') ;

set([jan1, feb1, mar1, apr1, may1, jun1, jul1, aug1, sep1, oct1, nov1,
dec1],...
  'LineStyle'       , 'none'      , ...
  'Marker'          , 'o'         , ...
  'Color'           , [1 .3 .3]  );

set([jan2, feb2, mar2, apr2, may2, jun2, jul2, aug2, sep2, oct2, nov2,
dec2],...
  'LineStyle'       , 'none'      , ...
  'Marker'          , '.'         , ...
  'Color'           , 'b');

set(gca, ...
  'Box'         , 'off'     , ...
  'TickDir'     , 'out'     , ...
  'TickLength'  , [.02 .02] , ...
  'XMinorTick'  , 'off'     , ...
  'YMinorTick'  , 'on'      , ...
  'YGrid'       , 'on'      , ...
  'XGrid'       , 'off'      , ...
  'XColor'      , [.3 .3 .3], ...
  'YColor'      , [.3 .3 .3], ...
  'XTick'       , 0:1:24    , ...
  'YTick'       , 0:0.1:1.2, ...
  'LineWidth'   , 1         );

ylim([0 1])

%% Transpose each "sunMissing" vector, then export to Excel file
sunMissingJan = sunMissingJan' ;
sunMissingFeb = sunMissingFeb' ;
```

```
sunMissingMar = sunMissingMar' ;
sunMissingApr = sunMissingApr' ;
sunMissingMay = sunMissingMay' ;
sunMissingJun = sunMissingJun' ;
sunMissingJul = sunMissingJul' ;
sunMissingAug = sunMissingAug' ;
sunMissingSep = sunMissingSep' ;
sunMissingOct = sunMissingOct' ;
sunMissingNov = sunMissingNov' ;
sunMissingDec = sunMissingDec' ;

d = {'sunMissingJan', 'sunMissingFeb', 'sunMissingMar', 'sunMissingApr',...
    'sunMissingMay', 'sunMissingJun', 'sunMissingJul', 'sunMissingAug',...
    'sunMissingSep', 'sunMissingOct', 'sunMissingNov', 'sunMissingDec'} ;

xlswrite('Y:\MP\Models\Interpolated_data.xls', d, 'Insolation', 'A1')
```

# Appendix B
# Predicted loads



| DRY SEASON | | Energy consumption at each hour of day, watt-hours | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Device** | **Peak load, watts** | **Midnight** | **1 AM** | **2 AM** | **3 AM** | **4 AM** | **5 AM** | **6 AM** | **7 AM** | **8 AM** | **9 AM** | **10 AM** | **11 AM** | **Noon** | **1 PM** | **2 PM** | **3 PM** | **4 PM** | **5 PM** | **6 PM** | **7 PM** | **8 PM** | **9 PM** | **10 PM** | **11 PM** |
| Security system | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| Lighting, compound exteri | 1,840 | 920 | 920 | 920 | 920 | 920 | 920 | 1,840 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,840 | 1,840 | 920 | 920 | 920 |
| Lighting, interior | 1,680 | 1,680 | 1,680 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,680 | 1,680 | 1,680 | 1,680 | 1,680 |
| Lighting, access road | 2,940 | 735 | 735 | 735 | 735 | 735 | 735 | 1,470 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,470 | 1,470 | 1,470 | 1,470 | 1,470 |
| Computer | 225 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 225 | 225 | 225 | 0 | 0 |
| Phone | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 35 | 35 | 35 | 0 | 0 |
| Refrigerator | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| Television | 113 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 113 | 113 | 0 | 0 | 0 | 0 | 113 | 113 | 113 | 113 | 113 | 0 |
| Fan | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| Water pump, tank | 746 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 62 | 62 | 62 | 62 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Water pump, pit | 746 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Water pump, jig | 746 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jig, small | 5,220 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jig, large | 7,457 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 22,837 | 4,425 | 4,425 | 2,745 | 2,745 | 2,745 | 2,745 | 4,400 | 1,090 | 1,090 | 1,090 | 1,090 | 1,090 | 1,265 | 1,265 | 1,152 | 1,152 | 1,090 | 1,090 | 1,203 | 6,453 | 6,453 | 5,533 | 5,273 | 5,160 |

| RAINY SEASON | | Energy consumption at each hour of day, watt-hours | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Device** | **Peak load, watts** | **Midnight** | **1 AM** | **2 AM** | **3 AM** | **4 AM** | **5 AM** | **6 AM** | **7 AM** | **8 AM** | **9 AM** | **10 AM** | **11 AM** | **Noon** | **1 PM** | **2 PM** | **3 PM** | **4 PM** | **5 PM** | **6 PM** | **7 PM** | **8 PM** | **9 PM** | **10 PM** | **11 PM** |
| Security system | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| Lighting, compound exteri | 1,840 | 920 | 920 | 920 | 920 | 920 | 920 | 1,840 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,840 | 1,840 | 920 | 920 | 920 |
| Lighting, interior | 1,680 | 1,680 | 1,680 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,680 | 1,680 | 1,680 | 1,680 | 1,680 |
| Lighting, access road | 2,940 | 735 | 735 | 735 | 735 | 735 | 735 | 1,470 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,470 | 1,470 | 1,470 | 1,470 | 1,470 |
| Computer | 225 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 225 | 225 | 225 | 0 | 0 |
| Phone | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 35 | 35 | 35 | 0 | 0 |
| Refrigerator | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| Television | 113 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 113 | 113 | 0 | 0 | 0 | 0 | 113 | 113 | 113 | 113 | 113 | 0 |
| Fan | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| Water pump, tank | 746 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 62 | 62 | 62 | 62 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Water pump, pit | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Water pump, jig | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jig, small | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jig, large | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 8,669 | 4,425 | 4,425 | 2,745 | 2,745 | 2,745 | 2,745 | 4,400 | 1,090 | 1,090 | 1,090 | 1,090 | 1,090 | 1,265 | 1,265 | 1,152 | 1,152 | 1,090 | 1,090 | 1,203 | 6,453 | 6,453 | 5,533 | 5,273 | 5,160 |

Note: Because the model was built to accommodate mining equipment such as jigs and additional water pumps, these items are listed here and included in the "peak load" calculation. However, as noted in the report, our analysis reflected our instructions to exclude these items, as the current plan is not to include them in the microgrid.