Biomass Residue-Fueled Micro-Grid for a Rural Community in Puerto Rico

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Acknowledgments

We would like to acknowledge and thank our partners at the Universidad de Puerto Rico - Utuado and Casa Pueblo, for their mentorship and support throughout this project, especially during our time in Puerto Rico.

We would also like to thank Rustam Sengupta for sharing his knowledge and expertise with regards to micro-grid design and installation.

Special thanks to the University of Michigan's School for Environment and Sustainability (SEAS), the SEAS Dean's Office, Sustainability Without Borders, Planet Blue, the Rackham Graduate School, and the College of Engineering, for providing financial support for this project.

Lastly, we would like to acknowledge our advisors, Dr. Jose Alfaro, Dr. Ivette Perfect, and Dr. John Vandermeer for their advice, guidance, and support throughout this project.

Abstract

On September 20, 2017, Hurricane Maria struck Puerto Rico, destroying most of its energy infrastructure and triggering an 11-month blackout. This research looks to micro-grids and their potential for energy stability in hopes of revitalizing Puerto Rico's energy system and making further sustainable improvements. Said micro-grids will be powered by already-existing solar panels and newly-constructed biomass gasifiers located at the headquarters of Puerto Rican NGO, Casa Pueblo, and within the community of El Hoyo, Adjuntas. The gasifiers will utilize locally available agricultural waste, such as coffee husks and tree prunings, and help communities develop energy independence and resilience in the face of future storms. To gather the data needed to create feasibility models assessing the implementation of potential micro-grids, interviews were conducted within El Hoyo, and data was collected from Casa Pueblo's generation and load demand. The data showed that El Hoyo will not have a high enough baseline demand to add a gasifier to their current electrical system, and a purely solar and storage micro-grid would have the lowest NPC ($50,205.39) and LCOE ($0.2425/kWh), even if providing the highest amount of excess electricity (49,767 kWh/yr, 73.7%). Additionally, Casa Pueblo's solar production was found to be underutilized with an excess electricity of 19,836 kWh/yr (91%). Installing a micro-grid with neighboring buildings would put excess electricity to use and also has the potential to be supplemented by a gasifier.

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1. Introduction

In September of 2017, Puerto Rico was hit by two category 5 hurricanes, Hurricanes Irma and Maria. Although Hurricane Irma's center did not hit the island, the 175 mph winds were enough to cause a multitude of power outages throughout the country [1]. Before the Puerto Rico Electric Power Authority (PREPA), could commence reconstruction operations, Hurricane Maria made landfall. Considered one of the worst hurricanes to have ever enveloped Puerto Rico, it destroyed the already crumbling and outdated energy infrastructure and triggered a historic 11-month blackout [2]. Although PREPA has done everything in their power to restore the island's energy infrastructure, the costs and manual labor needed were too overwhelming. So much so, that the Federal Emergency Management Agency (FEMA) was barely able to finance and donate enough to bring the energy system to pre-hurricane conditions [3].

The Puerto Rico Electric Power Authority was formed as a result of a series of acquisitions and mergers, beginning with the inauguration of the island's first large-scale generator in 1915. A government-owned corporation, it is currently the sole provider of electricity for the island with over 1.4 million customers [4]. With six central generators in four locations, PREPA generates 6,085 MW, with 45% of the generation coming from oil. PREPA also owns 2,416 miles of transmission lines with 51 transmission centers and over 30,000 miles of distribution lines with 283 substations and 27 technical offices. Only 4% of generation comes from renewable energy sources [5]. Given its tumultuous background and history, PREPA found itself unprepared for the damages from the hurricanes. Frequent power outages, high dependence on fuel oil and inability to diversify fuel mix, and generators located far from demand centers all affected the area of generation. Transmission and distribution had inadequately maintained infrastructure, high vulnerability to natural disasters, and a $2.5 billion expenditure plan for repairs and maintenance prior to the hurricanes, which skyrocketed to $13 billion to include resiliency after the hurricanes [6]. Lack of institutionalized processes and procedures, as well as outdated information systems, have affected organization within the company and customer service. Additionally, PREPA has a long history of below-standard safety systems and environmental non-compliance. A static business model has left the company at a standstill within an ever-evolving industry. These factors, among many others, have created consumer distrust, prompting consumers to look into self-generation.

A prime example of community self-management and leadership, Casa Pueblo, a local non-governmental organization (NGO), has risen to the challenge of energy independence and resilience. Self-proclaimed as a protector of natural resources, culture, and human life, Casa Pueblo was started in the 1980s as a community allegiance protesting against a government plan to mine copper, silver, and gold which would have destroyed around 36,000 acres of agricultural and residential land within four municipalities. Ever since being victorious and stopping the government plans, Casa Pueblo has become a self-managed community project with headquarters in Adjuntas, PR (Figure 2 and Figure 3). Said headquarters include an artisan store, library, antiquity room, historic photographs gallery, coffee roasting and packaging machinery, plant nursery, laboratories for science classes for children, a music room for teaching, an auditorium, a butterfly garden, a hydroponic system, a community radio station, and a solar energy system [7]. Not only does Casa Pueblo focus on social and environmental justice, but they also lead projects for community improvement and energy independence. Projects include an independent radio station, a hydroponics system, coffee roasting and packing under the brand *Café Madre Isla,* which is managed through volunteers, an initiative to have 50% of the country's power generation come from solar energy, and several community projects where solar panels have been installed as emergency systems during blackouts [8].

Figures 1 (L) and 2 (R): Main Casa Pueblo building; Casa Pueblo location. Adjuntas, PR [9]

2. Background

Following its vision of energy independence and resilience, Casa Pueblo has partnered with The University of Michigan's School for Environment and Sustainability to work on a model for a hybrid micro-grid that includes its (Casa Pueblo's) current solar and storage system and adds a gasifier for energy generation through biomass [10]. Ideally, the hybrid micro-grid will use locally sourced biomass, such as tree prunings or dry coffee husks, for energy generation, and its byproduct, biochar, will be used as a soil amendment for local agriculture.

Out of the many communities Casa Pueblo has aided, El Hoyo in Adjuntas seemed like an ideal location to potentially implement a hybrid micro-grid. As is typical within rural Puerto Rico, communities are formed by nuclear and extended families, with houses passed down from generation to generation. After the hurricanes, many houses within the community suffered damages, some even becoming uninhabitable. Additionally, a substantial number of the members in this community suffer from medical ailments which required constant medical attention. Electronic medical equipment, such as sleep apnea machines and nebulizers, and refrigeration of certain medicines, were crucial to ensure survival. Given such pressing medical needs, Casa Pueblo donated and installed emergency solar panels and storage systems to those homes in which residents had a life-threatening condition. These systems are capable of powering at least a compact medical refrigerator for the medicine, running a nebulizer or dialysis machine at certain times of days for specific periods of times, and maintaining enough power to run sleep apnea machines through the night. Because of the installed solar systems, Casa Pueblo suggested El Hoyo as a case study site to determine if similar communities would be viable settings for hybrid micro-grid systems involving solar and biomass technologies.

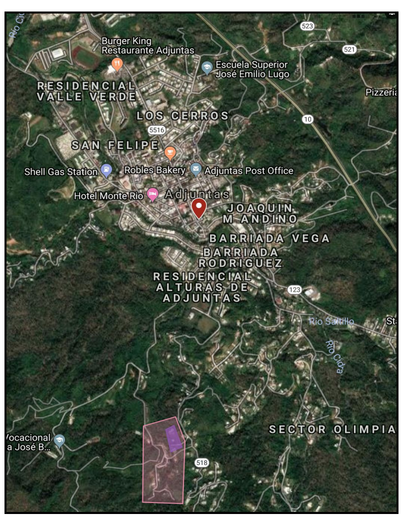
Micro-grids are independent electricity generators that can be islanded from the main grid physically or through technical means. They are generally small in size from a few kW to less than a MW. Many use fossil fuel generators as back-ups but there has been movement towards renewable only micro-grids with storage solutions or dispatchable resources. Micro-grids are considered to create energy independence and produce economic opportunities within communities [11]. Biomass technology offers such an alternative and can be considered renewable with the proper procedures [12]. With the use of a gasifier, unwanted and discarded biomass can be used as the main feedstock for the system. With the process of pyrolysis, or burning of substance with limited or no oxygen, biomass can be converted into biogas (syngas) which is later filtered and connected to a generator for electricity production [13]. The sources of biomass, in the case of Casa Pueblo, can be coffee husks and tree prunings from their coffee farm less than a mile from their headquarters. The process produces a type of charcoal, also known as biochar, as byproduct which, if used as soil amendment, it could help soil fertility to produce more feedstock and thus create a closed-loop system [14].

3. Methods

HOMER, Hybrid Optimization of Multiple Energy Resources, is an electricity grid modeling software that is often utilized to model micro-grids, especially with renewable generation capacity. HOMER optimizes the combination of energy resources based on the Levelized Cost of Electricity (LCOE). This software was used to create numerous micro-grid models throughout the project.

3.1 El Hoyo

The team visited Casa Pueblo in Adjuntas to have a representative accompany them into the community for introductions to all the families within El Hoyo. Although the team originally thought there were only 10 households in El Hoyo, they learned upon their arrival that it actually encompasses 30 houses across a valley intersected by a small stream. An important detail, lost in translation, was that Casa Pueblo had installed an emergency solar system only in 10 out of these 30 households within the community, and those houses were distributed throughout the entire are of the community. Seeing as the community covered such a wide expanse with a high risk of interconnection problems and challenges, the team limited the potential micro-grid model to a section of 10 houses where five of the households had the solar systems installed (Figure 3 and Figure 4).



Figures 3 (L) and 4 (R): El Hoyo community location with respect to Adjuntas and Casa Pueblo (red marker) [15]; Outline of entire community of El Hoyo with observed section highlighted in purple.

Over the span of three to four weeks, two team members conducted electricity-use surveys with the 10 families. Although these surveys were conducted in Spanish, Puerto Rico's first language, the documentation was done in English (Figure 5). The surveys lasted anywhere from an hour and a half to two and a half hours. To keep track of interviews, each family was assigned a number, so as to protect their identities. The interviews were exempt from requiring a permit by the International Review Board (IRB). These interviews were conducted in order to establish an overall load curve for the community, which is necessary to model the hypothetical hybrid system in HOMER. To build an accurate load curve, the survey primarily focused on three questions: how often was an electrical device used, for how long was it used, and when was it used throughout the day.

12. Household Other Electrical Appliances Use (include TV, computer, phone etc)

Brand/Type	Quantity	No of hrs used/day	Power Rating	Main Source of Power

Figure 5: Example of survey question

See Appendix A for a survey example.

The interview data were then extracted to a digital form and used to create an approximate monthly load. There are generic loads built into HOMER that can be scaled to more accurately fit the demands of specific systems. The approximate monthly loads from the interviews were used to determine a distinct scaling factor for each month of the year. The hourly load data in the sample residential load profile, without a peak month, generated by HOMER were then scaled by the corresponding monthly scaling factor to yield an approximate hourly load curve for the community. The scaled load profile of the community is presented in Figure 6.

Current solar system components such as photovoltaic panels, batteries, and converter/inverter were added from a library within the software, which includes information such as lifetime and efficiency. Components not found within the softwares libraries were manually generated within the software using average values found within the Nation Renewable Energy Laboratory (NREL) reports. Using solar influx data found within the software, which was also extracted from NREL, the model was run to analyze how the gasifier system could replace the electricity grid to meet load demands.

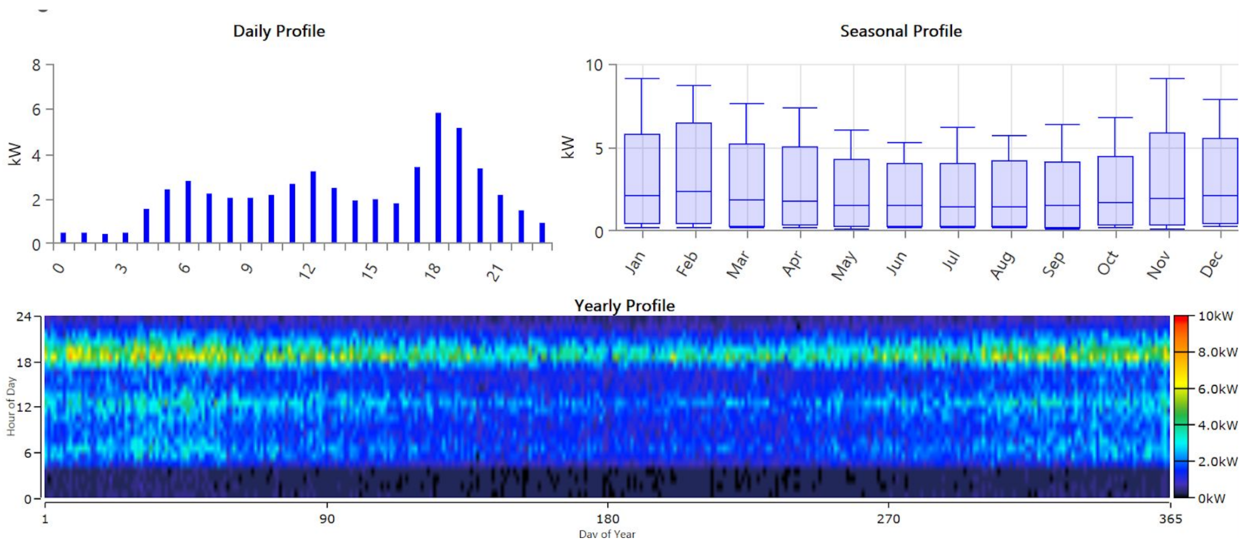


Figure 6: Scaled Load Profile of El Hoyo

The peak load was observed to be 9.2 kW/hour, with peaks usually reach in the afternoon. In terms of seasonal differences, interviews showed that the electricity consumption behaviors of the residents did not vary drastically between seasons, with fans and electric water heaters constituting the majority of difference. As can be seen in Figure 6, there is no discernable peak month, with hourly power consumption average of around 1.8 kW, and daily load demand of 40 kWh/day.

Two models were created in order to assess the hypothetical solar-biogas hybrid micro-grid in El Hoyo, both using the current photovoltaics (PV) and storage capacity of the community as a base to build the models upon. The base consisted of five homes, each with two 150W solar panels and two 6V batteries connected in series, resulting in 1.5kW of solar capacity and 12-6V batteries total. Additionally, four of the homes had a 300W inverter and the remaining had a 600W inverter. The models created were:

1. Adding a biogas-powered generator and its related biomass resource, using biomass only from Casa Pueblo’s coffee farm, to assess the feasibility of sustaining El Hoyo completely off-grid with only solar and biomass resources from Casa Pueblo. This model assumes that solar generation only comes

through the already-installed solar panels in El Hoyo, and does not consider adding in more solar capacity.

2. Adding a biogas-powered generator and its related biomass resource, using an extremely large biomass resource to guarantee it is large enough to meet demand. Adding more solar panels and batteries, allowing HOMER to find the optimal capacities of panels, batteries and converter.

Note that these two cases are benchmarked against the base-case, which is comprised of the electricity grid and the already-installed solar panels in El Hoyo.

System Schematics can be found in Appendix B

3.1.1 Model Specifications

Based on the information obtained from Casa Pueblo on the existing PV systems in El Hoyo, the following specifications were used in the analysis:

Table 01: El Hoyo Flat-Plate PV Specifications
*value altered from HOMER default

Base Panel from HOMER	Generic flat plate PV
Capacity (kW)	0.15
Capital Cost ($)	70.50 [16]
Replacement Cost ($)	28.20 [17]
Operations and Maintenance Cost (O&M) ($/yr)	1.41 [18]
Lifetime (yr)	20
Derating Factor (%)	80

Because the panels and batteries that are part of the base system were donated, their capital costs were set to 0.

All solar panel O&M costs were estimated to be 2% of the capital cost [19].

Table 02: Battery Specifications Used in HOMER
*value altered from HOMER default

Base Battery from HOMER	Generic 1-kWh Li-Ion
Nominal Voltage (V)	6
Nominal Capacity (kWh)	1
Maximum Capacity (Ah)	167
Capital Cost ($)*	209.00 [20]
Replacement Cost ($)*	209.00
O&M ($/yr)	0
String Size*	1
Minimum State of Charge (%)	20

It should be noted that although the current PV systems in El Hoyo utilize a battery string size of two, a string size of one for the additional batteries results in the lowest LCOE.

Table 03: Converter Specifications Used in HOMER
*value altered from HOMER default

Base Converter from HOMER	System Converter
Capacity (kW)*	0.6
Capital Cost ($)*	126.00 [21]
Replacement Cost ($)*	50.00
O&M ($/yr)*	0
Lifetime (yr)*	11

Table 04: Biogas Generator Specifications Used in HOMER
*value altered from HOMER default

Base Generator from HOMER	Generic Biogas Genset (size-your-own)
Capacity (kW)*	12*
Capital Cost ($)	3,000.00
Replacement Cost ($)	1,250.00
O&M ($/op hr)	0.10
Lifetime (hr)	20,000
Minimum Load Ratio (%)	50
Density of Biogas (kg/m^3)	0.72
Forced Outages	9pm - 6am

It was assumed that there would not be someone in the community able and/or willing to feed the biogasifier throughout the night. Additionally, the biogas generator would emit noise, which might disturb residents as they try to sleep. As such, the generator was scheduled to be offline from 9pm to 6am daily for the calculations of both models. However, due to the unviability of the first model with the schedule restrictions, it was also run without the outages.

Table 05: Coffee Husk Biomass Resource Specifications Used in HOMER
*value altered from HOMER default

Lower Heating Value (MJ/kg)*	18.34 [22]
Density of Biomass (kg/m^3)*	260 [23]
Carbon Content (%)*	50.8 [24]
Sulfur Content (%)	0
Average Price ($/tonne)*	99.21 [25]
Gasification Ratio (kg/kg)*	0.83 [26]

A range of $60-120 per ton of coffee husks was found, so the average was taken and converted to metric tonnes per day in order to be used in HOMER. This resulted in $99.21 per tonne of coffee husks.

In the first model, the biomass resource was estimated based on the number of coffee plants that Casa Pueblo has on their coffee farm. This resulted in approximately 0.0091 tonnes/day of coffee husks available for use in the gasifier. In the second model, the biomass resource was set to 1 tonne/day, ensuring that there would be more than enough resource to meet El Hoyo's demand. This allowed HOMER to create the optimal combination of PV, storage, and biogas utilization.

3.2 Casa Pueblo

In order to create the load curve needed to model the hypothetical hybrid micro-grid at Casa Pueblo, the team exported daily load data from Casa Pueblo's online continuous monitoring site, SE Solar-Conext Insight. The energy consumption was reported in kWh, in 10-minute intervals. Due to the level of detail in the data, it was possible to create an accurate load curve, after slight adjustments. Ideally, 2017 data would have been used in order to gain insight into the change in electricity consumption when Casa Pueblo acted as an energy oasis during the months of power outages following Hurricane Maria. Unfortunately, much of that data was missing, most likely due to power outages affecting the monitoring system's ability to relay and store data. As a result, 2018 data was used to create a complete model. It is important to note that HOMER can only use load data for one year. In order to compare 2017 and 2018, the created another model with the available 2017 data and used the 2018 data for the periods of time where there were gaps in the 2017 data. It should also be noted that there were gaps in the 2018 data as well, although significantly fewer, but it was confirmed that they were due to a problem between Casa Pueblo's system and the server that stores the data, not due to a disconnection of the system. In order to address the missing time slots, data in similar days/times were used to fill the gaps.

Two models were created in order to assess the current solar-powered micro-grid at Casa Pueblo:

3. Using the brand and model type of the equipment that Casa Pueblo currently has to determine the optimal size of the micro-grid, i.e. the ideal number of each component needed to meet the current load given the solar resource available.

4. Using the brand, model, and number of components that Casa Pueblo currently has, to determine how much energy is currently being wasted/curtailed.

3.2.1 Model Specifications

Table 06: Casa Pueblo System Components

Type	Brand	Model
Solar Panel	Solar World	290 SW Mono
Battery	MK Power	8G8DLTP-DEKA 12-V 225-Ah Gel
Converter	Schneider Electric	Conext XW + 5548

Table 07: Solar Panel Specifications Used in HOMER: Solar World 290 SW Mono
*value altered from HOMER default

Capacity (kW)*	0.29 [27]
Capital Cost ($)*	258.10 [28]
Replacement Cost ($)*	258.10 [29]
O&M ($/yr)	5.16 [30]
Lifetime (yr)	25
Derating Factor (%)	85

Table 08: Battery Specifications Used in HOMER
*value altered from HOMER default

Base Battery from HOMER	Trojan SPRE 12 225
Nominal Voltage (V)	12
Nominal Capacity (kWh)	2.71
Maximum Capacity (Ah)	226
Capital Cost ($)*	903.00 [31]
Replacement Cost ($)*	903.00 [32]
O&M ($/yr)	10.00
String Size*	4
Minimum State of Charge (%)	20 [33]

The lifetime of the battery was updated according to Figure 6 [34].

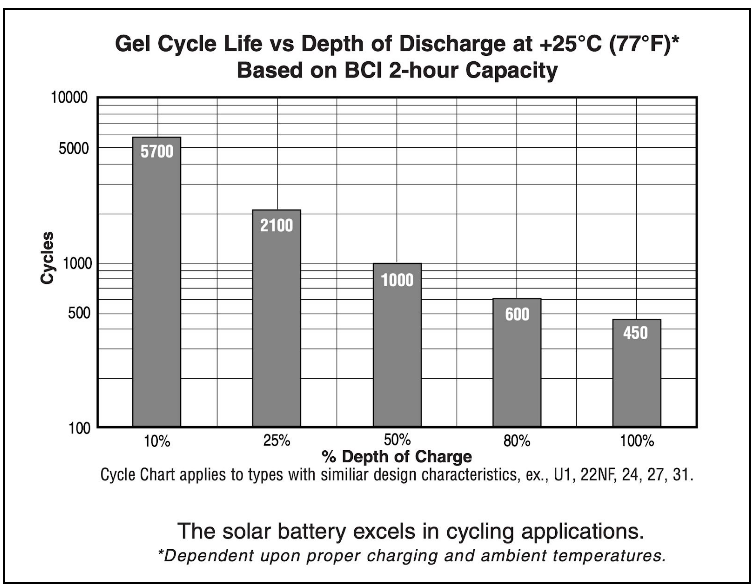


Figure 7: Deka Solar PV Battery Lifetime Data [35]

Table 09: Converter Specifications Used in HOMER: Schneider Conext XW + 5548
*value altered from HOMER default

Capacity (kW)*	5.5 [36]
Capital Cost ($)	2,600.00
Replacement Cost ($)	3,100.00
O&M Costs ($/yr)	0.00

System Schematics can be found in Appendix B

4. Results

4.1 El Hoyo

HOMER determined that the optimal configuration of a micro-grid in El Hoyo, based on minimizing LCOE, would be one that is solely comprised of solar panels. However, to compare the system with and without a biogas generator, both are included in Table 10.

Table 10: El Hoyo Summary of Results

Model	Base Case (Grid)	#1 - Constrained	#2 - Unconstrained, without biogas	#2 - Unconstrained, with biogas
Net Present Cost (NPC) ($)	40,308.57	244,428.20	50,205.39	71,939.48
LCOE ($/kWh)	0.1945	1.18	0.2425	0.3475
Operating Cost ($/yr)	3,118.04	16,122.83	1,391.21	1,087.80
Excess Electricity (kWh/yr)	0	14,100	49,767	24,588
Excess Electricity (%)	0	45.7	73.7	58.1
Total PV Production (kWh/yr)	2,593 (%16)	2,593 (8.4%)	67,521 (100%)	41,578 (98.27%)
Total Generator Production (kWh/yr)	13,568 (%84) - Grid	28,243 (91.6%)	0 (0%)	731(1.73%)
Biomass Resource Needed (tonne/day)	0	0.205	0	0.00522

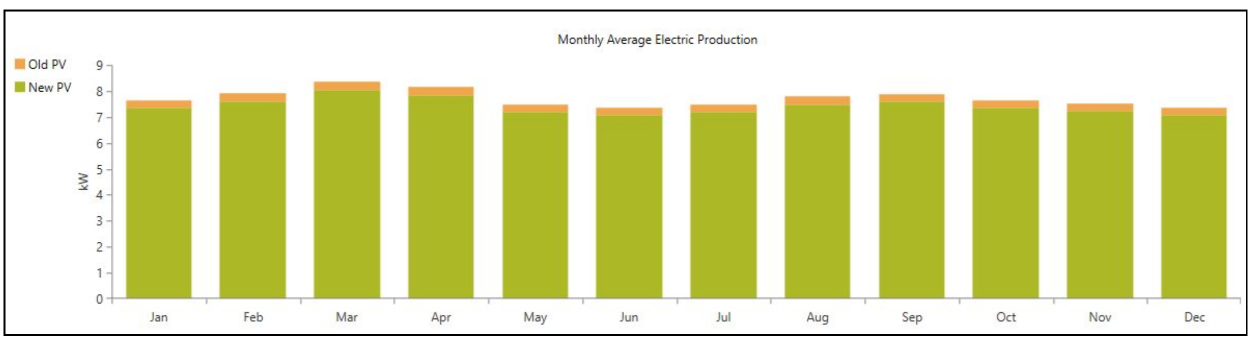


Figure 8: Solar generation distribution for optimized system in El Hoyo

4.2 Casa Pueblo

Table 11: Casa Pueblo Summary of Results

Model	#3	#4
Net Present Cost (NPC) ($)	16,643.91	40,245.92
LCOE ($/kWh)	0.7688	1.86
Operating Cost ($/yr)	574,54	1,175.43
Excess Electricity (kWh/yr)	705	19,836
Excess Electricity (%)	26.1	91.0
Total PV Production (kWh/yr)	2,700	21,803

See Appendix C for full results.

5. Analysis

5.1 El Hoyo

Comparing the four cases in the El Hoyo analysis, the baseline system with the grid results in the lowest NPC, as well as the lowest LCOE. Since the solar panels, batteries, and converters were donated to the community, the analysis did not consider the capital costs associated with setting up the PV system. Despite the grid yielding the least-cost option, it does not address the unreliability issues that the country experienced, which drove the motivation behind the project. Therefore, the grid-case is only utilized as a point of economic comparison for the two models assessed in this analysis.

Given the community's current emergency solar systems, adding a small scale 12kW gasifier system was not enough to meet the entirety of the community's demand. Assigning an operating time between 6:00 am and 9:00 pm, allowing for residents to rest during the evening due to noise attributed to the system, created a non-feasible model where the community would suffer constant capacity shortages throughout operation, specifically at night when the capacity of the batteries wasn't enough to meet the evening demands. Eliminating the scheduling constraint, the gasifier was able to meet the demand, however the system produced 45.7% (14,100 kWh,yr) excess electricity and produced a LCOE of $1.18/kWh. Therefore, resizing and optimization was recommended for the analysis of subsequent models.

One of the main differences between the models disconnected from the grid was the availability of biomass. Model #1 only used biomass that could be obtained from Casa Pueblo's coffee farm, which amounted to 0.0091 tonnes/day. Based on that availability and the biomass needed to meet demand, Casa Pueblo's biomass supply is not sufficient to support El Hoyo under Model #1. Conversely, under Model #2, El Hoyo's system would only need 0.00522 tonnes/day, so Casa Pueblo could fully support it.

It is important to note that although the LCOE of the optimal model (Model #2 without the biogas generator) is the lowest, the excess electricity associated with the model is considerably greater than that of the system with the biogas generator - 49,767 vs. 24,588 kWh/yr (73.7% vs. 58.1% of generation, respectively). While this may seem counterintuitive at first, it makes sense that a completely solar system would have to be larger than a system that also has a biogas generator. Because the solar resource can only be utilized during the day while the sun is up, a fully solar system must have enough generation and storage capacity to store enough electricity to meet demand throughout the night when electricity cannot be generated with the solar system. As a result, the system must be sized to be much larger than what is required to meet the average demand. When a biogas generator is incorporated, much less storage capacity is necessary because the generator will primarily be run during the hours that the solar panels will not produce electricity (outside of the outage hours). This allows the stored electricity to last longer and results in less excess electricity.

Generator Minimum Load Ratio Considerations

The generator minimum load ratio is defined as the minimum allowable load on the generator with respect to the rated design capacity. This design consideration is important in preventing underloading the power system, which may have adverse impacts on the individual components of the generator system as well as the overall power system. Generator systems are designed to run with a certain load, and not meeting the load can lead to shorter engine life and unhealthy engine operation [37].

Different generator types have varying minimum load ratios, as defined by the manufacturer. Biogas generators are typically designed to operate between 70% to 100% of nameplate rating [38]. In other words, if the generator is designed to have a rated capacity of the peak load demand of the community, the typical minimum allowable load ratio of biogas generators dictates that the load demand in the community be higher than 70% of the peak load.

For the case of El Hoyo, it was seen that the peak load for the community was 9.2kW, with an average load of 1.42kW. Further hour-by-hour investigation shows that the load demand for community was mostly between 2-5kW per hour during the day and less than 1kW per hour at night. This quick analysis showed that designing the generator to meet the peak load leads to a frequent violation of the minimum load ratio.

5.2 Casa Pueblo

Comparing the results from Models 3 and 4, it is clear that Casa Pueblo's current system is greatly oversized, resulting in 91% excess electricity (19,836 kWh/yr), as opposed to the 26.5% (719 kWh/yr) for the optimally sized system. This excess electricity is also demonstrated through the difference in the LCOE, $0.752/kWh for the optimally sized model versus $1.65/kWh for the current system.

6. Conclusions and Recommendations

6.1 El Hoyo

Although the objective of the project was to analyze the implementation of a gasifier and biogas generator into the current solar system within the community, it was found that adding a gasifier without also adding solar panels is not sufficient to meet the community's demand. Instead, the optimal system is strictly solar-powered. If El Hoyo wanted to incorporate a biogas generator into their micro-grid, however, it would be necessary to also incorporate more solar panels and batteries. Through the models it was observed that the biomass resource that Casa Pueblo can provide would not be sufficient to provide enough generation capacity to move El Hoyo completely off grid. It would be sufficient, however, to support a generator in a system with additional solar panels and batteries. As a result, the most economic system would add only solar panels and batteries, but if the community wanted a biogas generator (to minimize excess electricity, for example), Casa Pueblo could provide all of the necessary biomass resource.

6.2 Casa Pueblo

Due to the extent of excess electricity, the addition of a gasifier is not currently justified at Casa Pueblo. There are many homes and small businesses around Casa

Pueblo, however, so it is recommended to add these electric loads to the current model to observe the quantity of surrounding buildings the current system can support. Once that is established, a gasifier can be added to the model to see how many more homes and/or businesses can be supported by the expanded micro-grid.

While completing fieldwork, the team found a coffee company that donated dried coffee husks to use as feedstock. This company, however, is approximately an hour and a half from Adjuntas, and as such, would not be an ideal source of feedstock. A much closer source of biomass would be Casa Pueblo’s own coffee farm. If the coffee husks are used for the El Hoyo community, there would not be enough to source both the community and Casa Pueblo. Unfortunately, most of the plants were destroyed by the hurricane, and so they will not be producing coffee, or the trimmings that would be used as feedstock, for a few years to come. The trees and plants that were knocked down during the storm, however, could potentially serve as a temporary source of biomass. In the meantime, Casa Pueblo is buying coffee beans from other farms for production, and could use those farms as sources of biomass.

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Appendix A - Example of Interview Survey

Questionnaire for Household Energy Use
Adjuntas, Puerto Rico
May 2018

1. **Logistics**
   Name of Primary Interviewer:
   Name of Secondary Interviewer:
   Date:
   Time:
   Recording? ( ) Yes   ( ) No   *If yes, name of recording file*:
2. **Characteristics of Household**
   Number of members in household
3. **Sources of Household Energy Use**
   3.1 Electricity Use
   What is your main source of electricity?
   ( ) Grid   ( ) Solar PV   ( ) Generator   ( ) Other, specify:
   If main source is grid, do you have a backup source of electricity? Specify:
   Is access to electricity bills possible? *If yes, gather data in Excel sheet*.
   If solar panels are present, fill in table below.

Number of panels	
Capacity of panel (kW)	
Is battery storage employed?	( ) Yes ( ) No
If yes, brand of batteries? Number?	
Capacity of battery	
Type of use	( ) Main ( ) Backup

4. **Household Lighting Equipment Use**
   What is your main source of lighting?
   ( ) Electricity   ( ) Candles   ( ) Kerosene   ( ) Other, specify:

Room	Quantity of bulbs	No of hrs used/day	Power Rating	Main Source of Power

5. **Household Refrigeration Equipment Use**

Brand/Type of Refrigerator	Quantity	No of hrs used/day	Power Rating	Main Source of Power

   How does the average daily use change seasonally?

6. **Household Medical Equipment Use**
   Are there any medical equipment that needs electricity? ( ) Yes   ( ) No

Brand/Type of Medical Device	Quantity	No of hrs used/day	Power Rating	Main Source of Power

Fill in Excel sheet.

How does the average daily use change seasonally?

7. Household Air Conditioning / Fan Use

Do you have any form of air conditioning in the house? ( ) Yes ( ) No

Brand/Type of AC	Quantity	No of hrs used/day	Power Rating	Main Source of Power

How does the average daily use change seasonally?

Do you have any fans in the house? ( ) Yes ( ) No

Brand/Type of Fan	Quantity	No of hrs used/day	Power Rating	Main Source of Power

How does the average daily use change seasonally?

8. Household Water Heating Equipment Use

Does the household use any electric or solar water heating equipment? ( ) Yes ( ) No

Brand/Type of Water Heater	Quantity	No of hrs used/day	Power Rating	Main Source of Power

9. Household Washing/Drying Machine, Dishwasher Use

Does the household use any electric washer, dryer and dishwasher?
( ) Yes ( ) No

Brand/Type	Quantity	No of hrs/cycle	Cycles/week	Power Rating	Main Source of Power

10. Household Other Electrical Appliances Use (include TV, computer, phone etc)

Brand/Type	Quantity	No of hrs used/day	Power Rating	Main Source of Power

11. Effect of Power Outages

How often did you encounter power outages before the hurricane?
How often have you encountered power outages since the hurricane?
How has power outages (cuts) affected your household?
( ) Positive ( ) Moderate – low effect ( ) Negative ( ) Very Negative
Are you happy with the service being provided by your power utility (ECG, NED, VRA)?
( ) Yes ( ) No
How would you grade the performance of the utility?
( ) Excellent ( ) Good ( ) Average ( ) Bad ( ) Very Bad
What are your biggest concerns with your current methods of obtaining power?

12. Assessment of interest in micro-grid

Explain what a micro-grid is, how the information we're using could potentially be used to design one...

How do you feel about the idea of being completely off-grid?
How would you feel about sharing electricity with other homes (through a potential micro-grid)?

How do you feel about being a co-owner of the electric utility or participating in a coop arrangement?

How much you be willing to pay for electric supply that is more reliable than your present situation?

Would you be willing to engage in maintenance work of the micro-grid in order to keep the costs low and the reliability high?

13. Assessment of interest in energy efficiency measures

Do you employ any energy efficiency measures in the house? Examples might include energy efficient refrigerators, LED or energy saving light bulbs…

( ) Yes ( ) No

If answered yes to previous question, please specify.

14. Aspirational Energy Use

In the future do you hope to have other appliances that use electricity?

If so what would you like to have and for how many hours a day do you think you would use it?

Appendix B - System Schematics

El Hoyo

Model 1

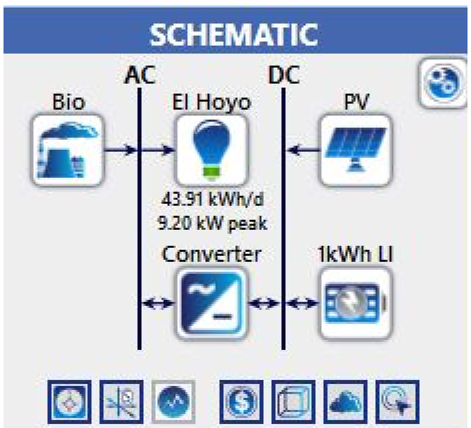


Figure 9: Model 1 - Schematic

Model 2

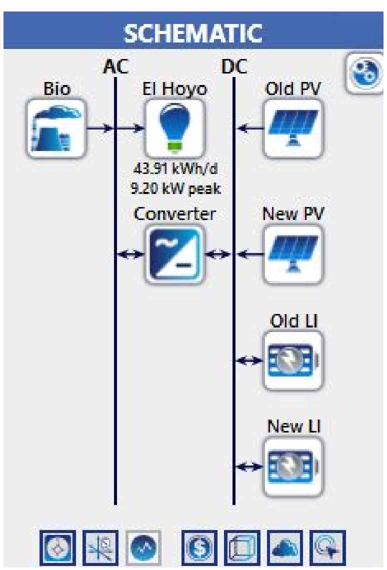


Figure 10: Model 2 - Schematics

Casa Pueblo

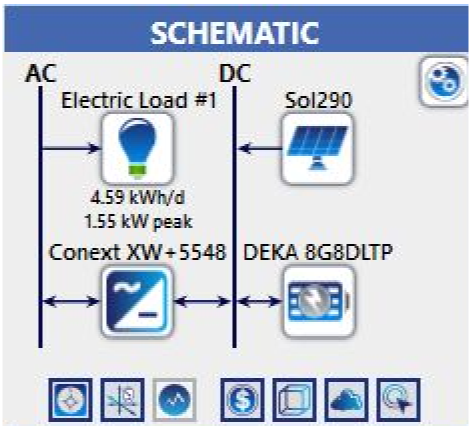


Figure 11: Model 3 & 4 - Schematics

Appendix C - Results for El Hoyo and Casa Pueblo

El Hoyo

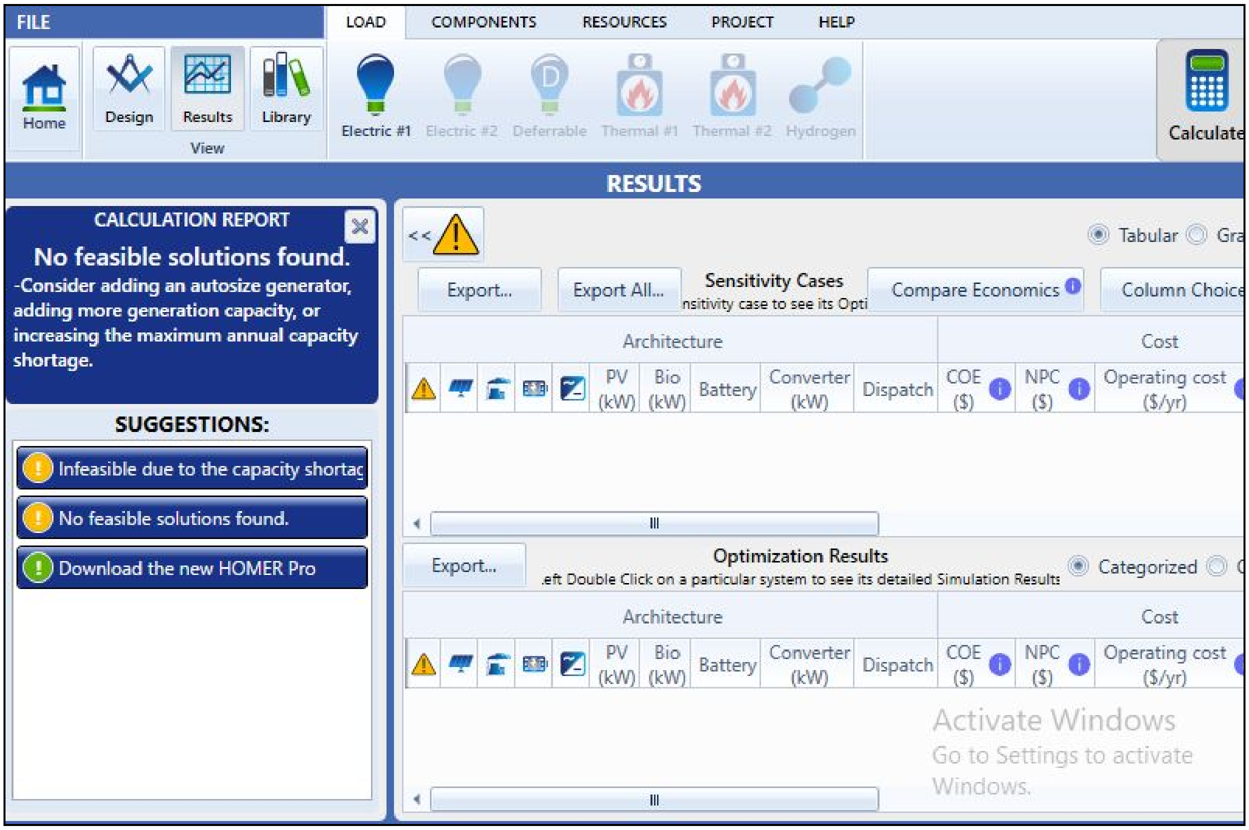


Figure 12: El Hoyo Model with Gasifier - Not Feasible

Casa Pueblo

Model #1 - Optimal Sizing

Cost Summary

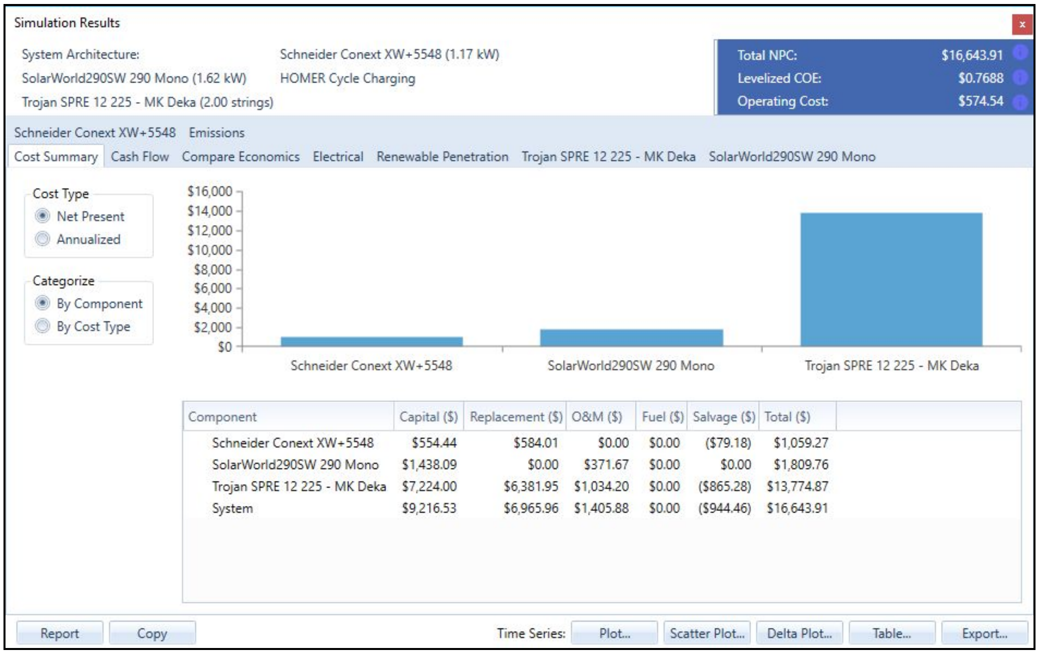


Figure 13: Model 3 - Cost Summary

Electrical

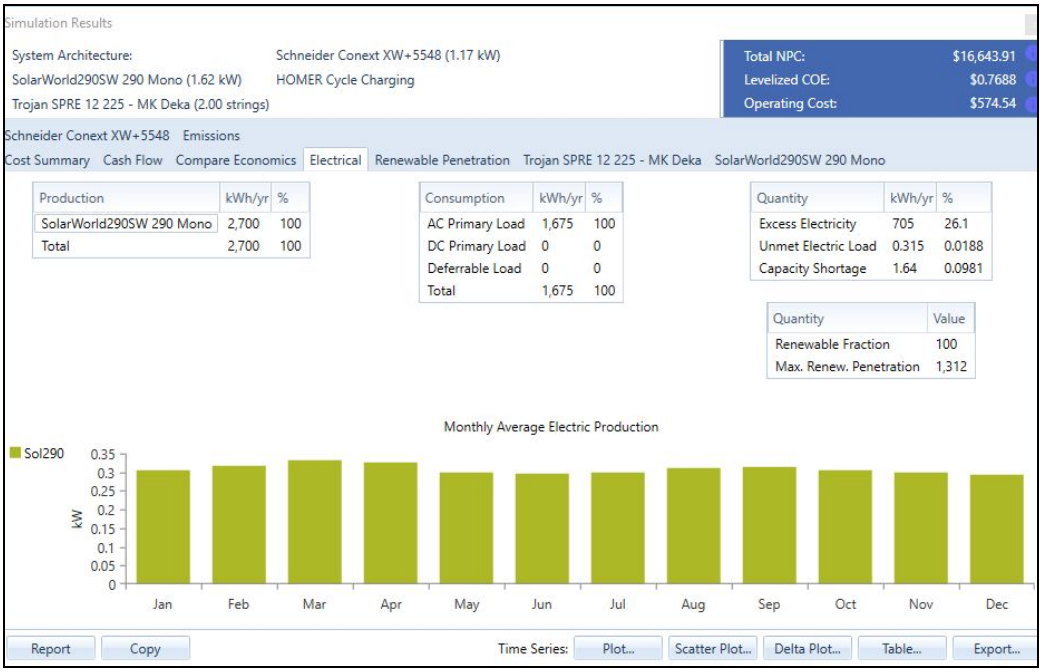


Figure 14: Model 3 - Electrical Production

Batteries

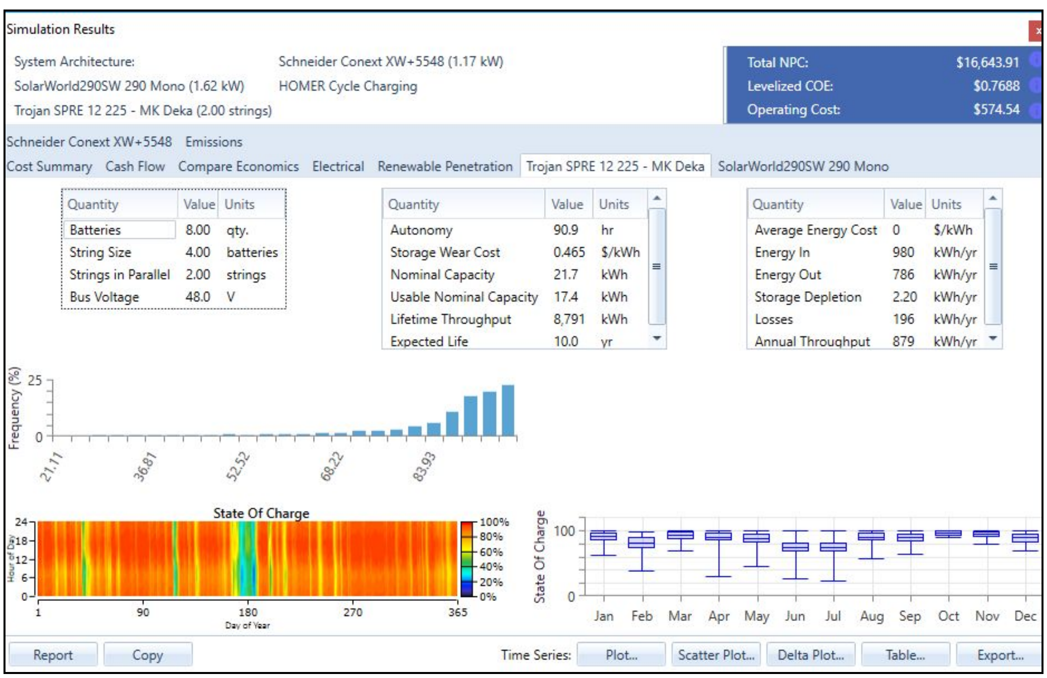


Figure 15: Model 3 - Battery Output

Solar Panels

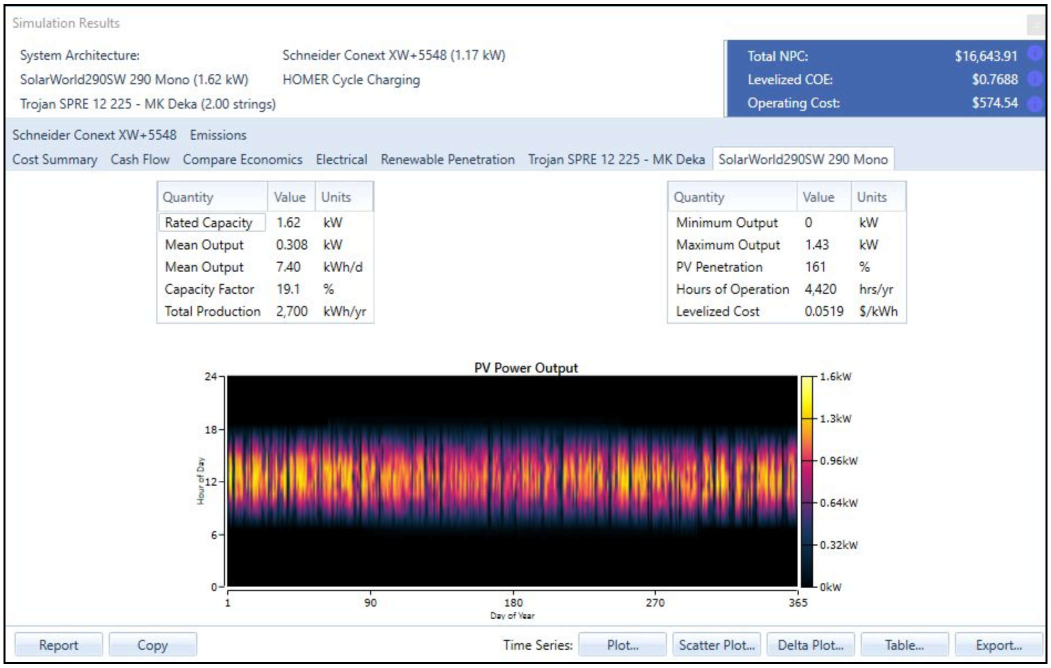


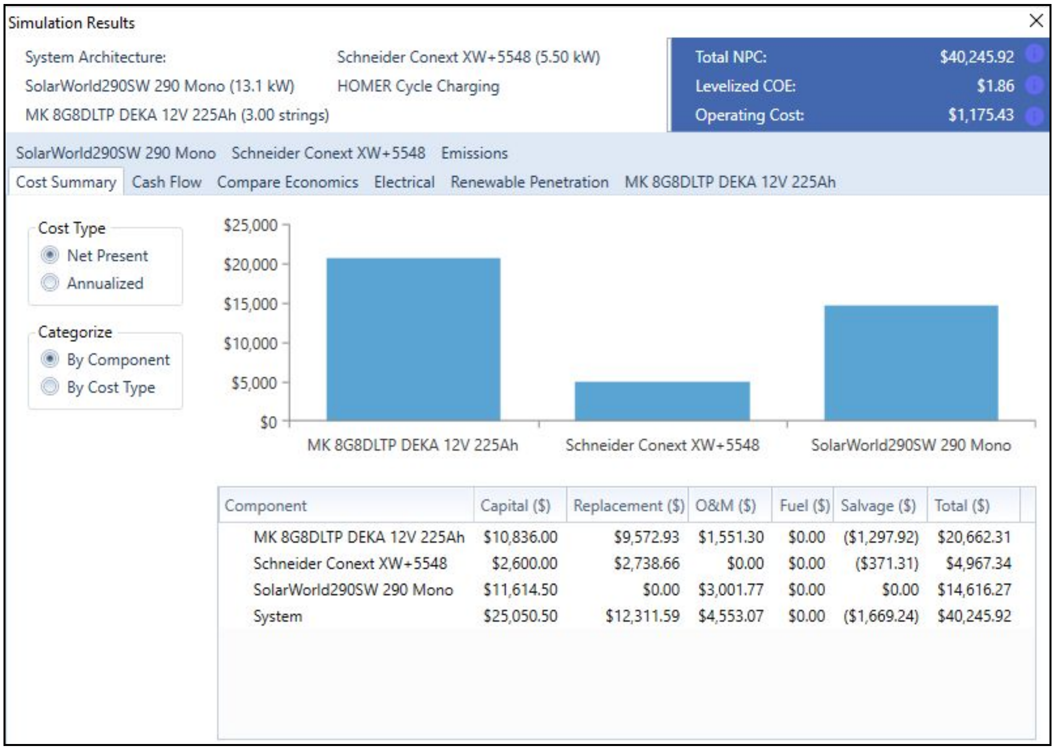
Figure 16: Model 3 - Solar Photovoltaic Generation

Inverter/Converter

Figure 17: Model 3 - Converter/Inverter Output

Model #2 - Energy Curtailment

Cost Summary



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
MK 8G8DLTP DEKA 12V 225Ah	$10,836.00	$9,572.93	$1,551.30	$0.00	($1,297.92)	$20,662.31
Schneider Conext XW+5548	$2,600.00	$2,738.66	$0.00	$0.00	($371.31)	$4,967.34
SolarWorld290SW 290 Mono	$11,614.50	$0.00	$3,001.77	$0.00	$0.00	$14,616.27
System	$25,050.50	$12,311.59	$4,553.07	$0.00	($1,669.24)	$40,245.92

Figure 18: Model 4 - Cost Summary

Electrical

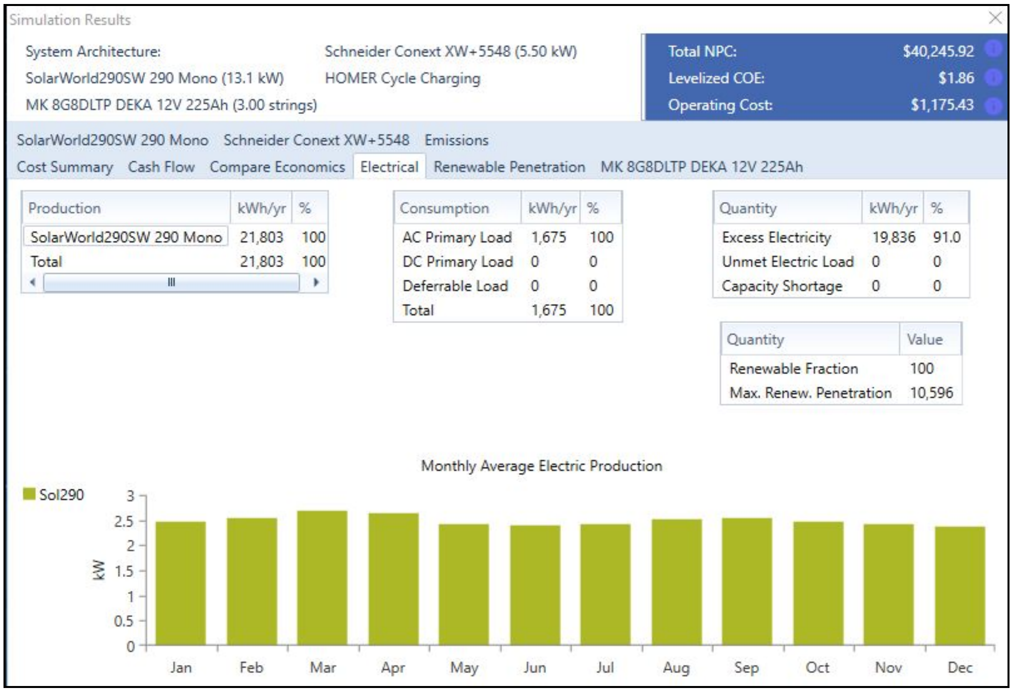


Figure 19: Model 4 - Electrical Production

Batteries

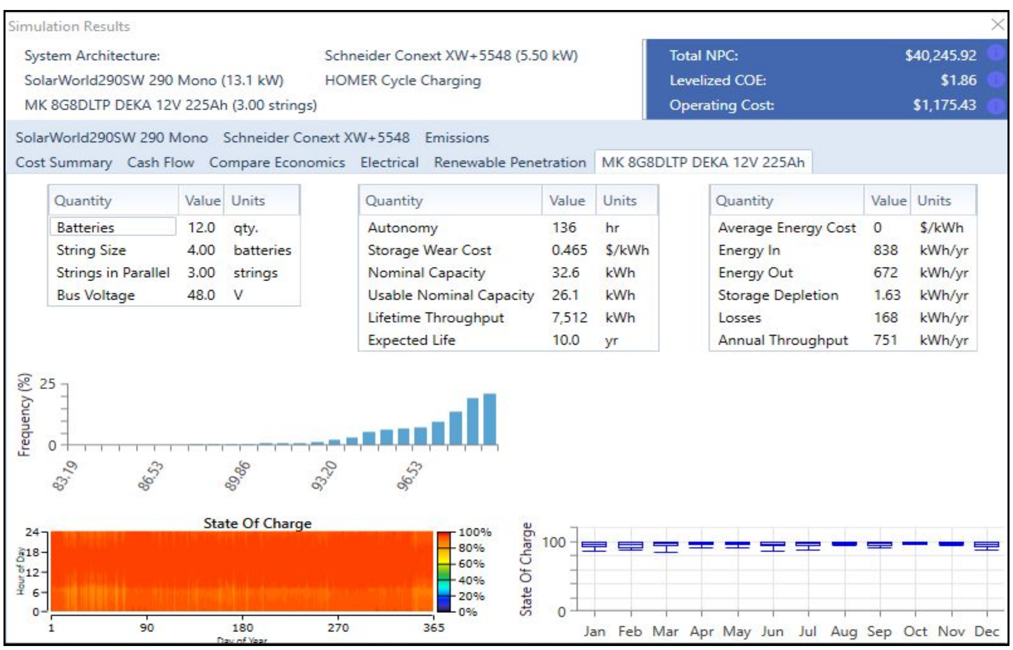


Figure 20: Model 4 - Battery Output

Solar Panels

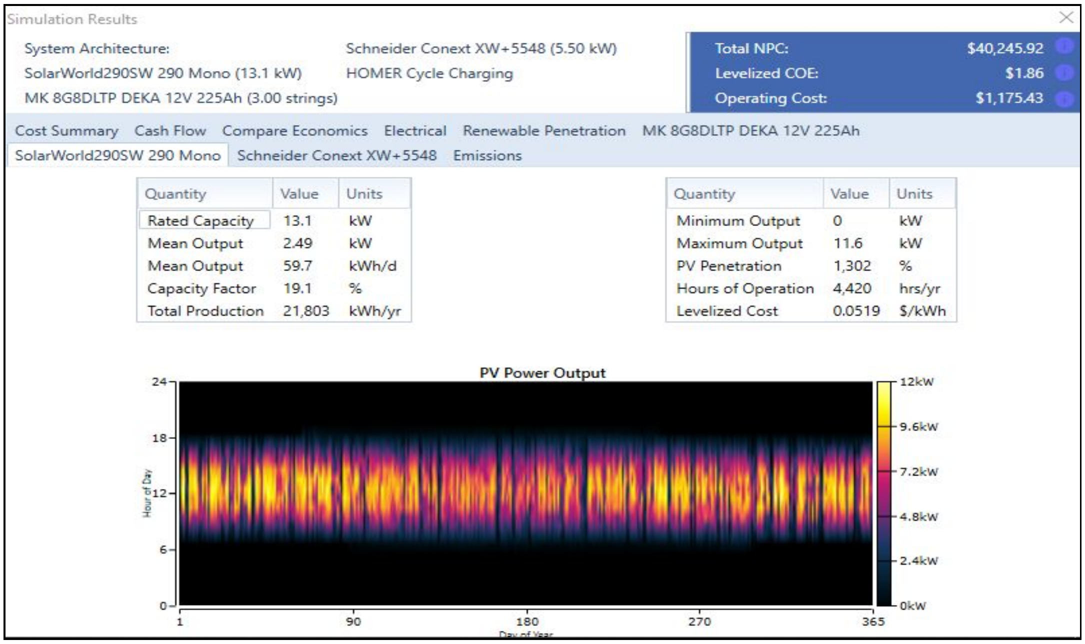


Figure 21: Model 4 - Solar Photovoltaic Generation

Inverter/Converter

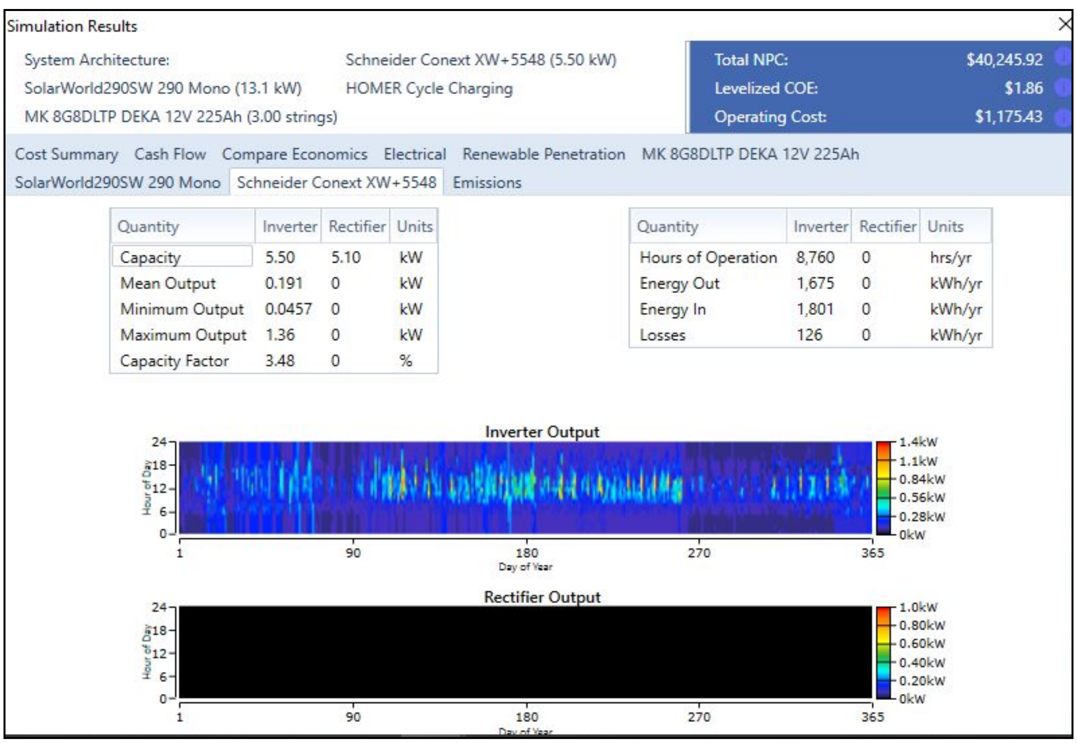


Figure 22: Model 4 - Converter/Inverter Output

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