Investigation of Market Feasibility for Peer-to-Peer (P2P) Energy Accounting

ESENG 503 Final Project Report

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Introduction

Verde Solutions, based in Chicago, IL, is a full-service energy consulting company that provide industrial and small businesses energy improvement solutions. They provide a full approach on understanding their client's energy needs, engineering potential solutions, and implementation services. Category of services include solar, HVAC, lighting, and cogeneration solutions.

This project will focus on their service in renewable solar energy solutions. Currently, they provide retrofitting services to install solar panels and energy storage hardware. To ensure their potential customers will benefit from a solar/energy storage retrofit, a financial analysis is pursued to estimate return on investment over 30 years. Factors that can influence this return include energy production, total project cost, financing terms, tax incentives, current energy bill and billing regulations dependent on region of customers.

Ability to optimize profitability from energy production is important to prove out in these estimates for the return on investment. Currently, customers can store unused energy for later use or sell back unused energy to the utility company for energy credit or financial compensation. Verde Solutions is now beginning to investigate another profit center for unused energy in peer-to-peer (P2P) energy trading. They are working with blockchain developer Powerledger to potentially install and target markets for its application.

Overview of the Project

The main problem being investigated is cheaper ways to account for renewable energy and maximize its use for Verde Solutions customers. By finding markets where these costs can be lowered via P2P energy allocation, it should incentivize more investment into renewable energy because P2P energy is only possible with a prosumer energy model where renewable sources are not centrally owned by a utility company.

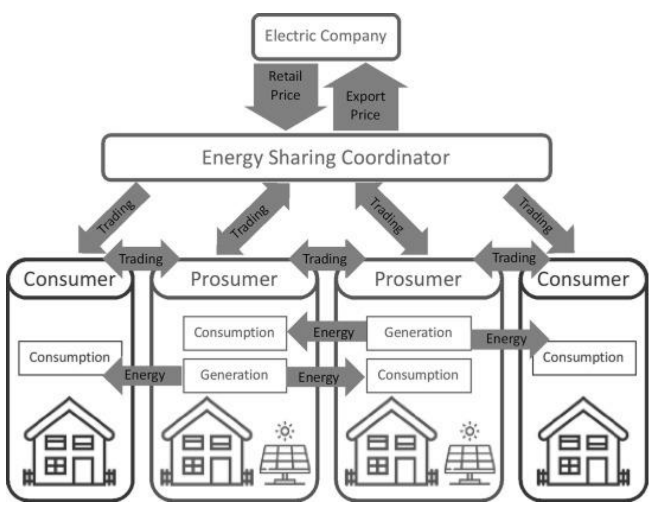
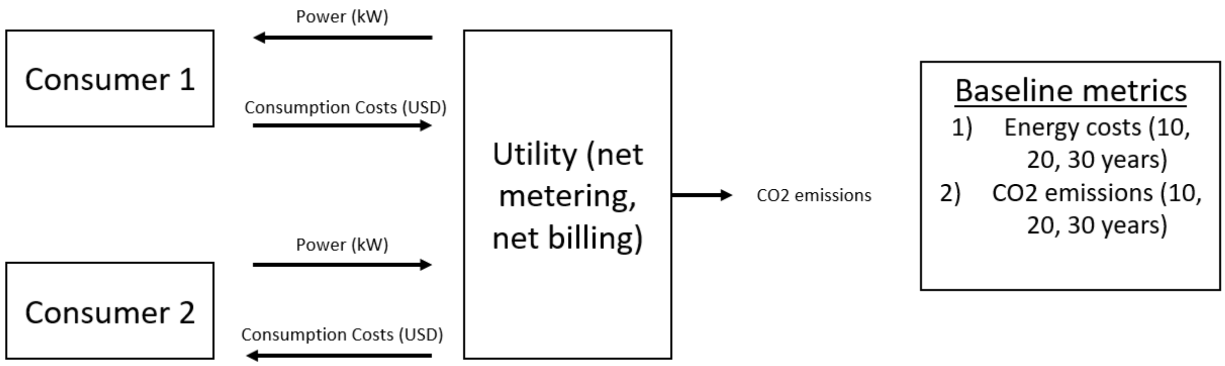


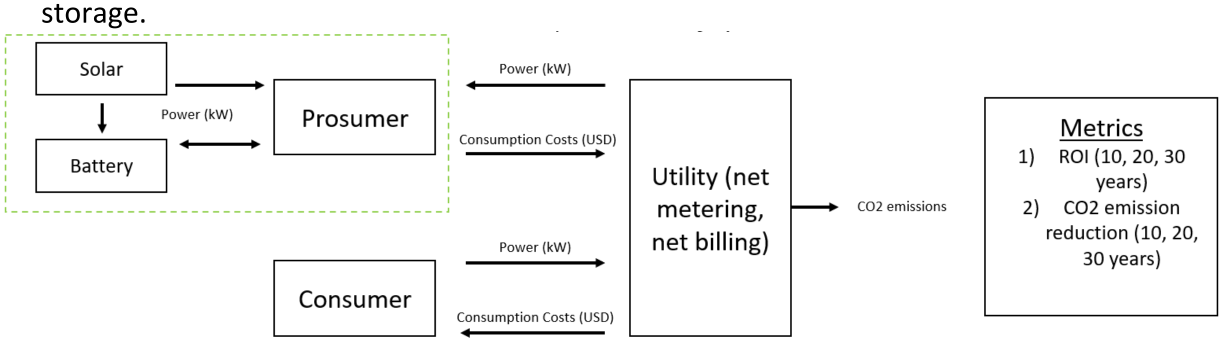
Figure 1: P2P energy flow diagram [1]

This project will involve development of a simulation template using Matlab where a microgrid concept can be analyzed using energy usage and solar production data. The simulation will be tailored toward required inputs mentioned in the introduction. The model will use energy use and solar production data at 15-minute sampling frequency over one year from potential customers. The following four scenarios will be simulated with energy consumers, producers, and prosumers. Metrics that will output from each scenario include energy use, financial impact and CO2 emissions.

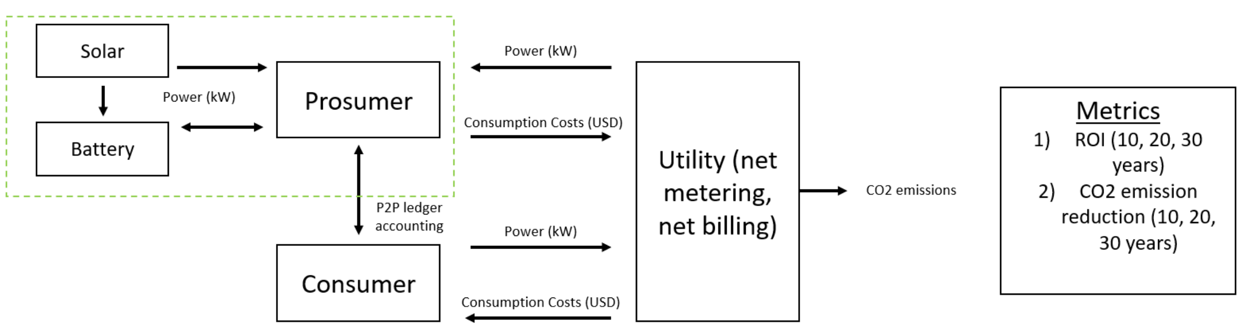
1) **Current:** Energy usage from a customer is transacted with local utility company in monthly billing cycle.



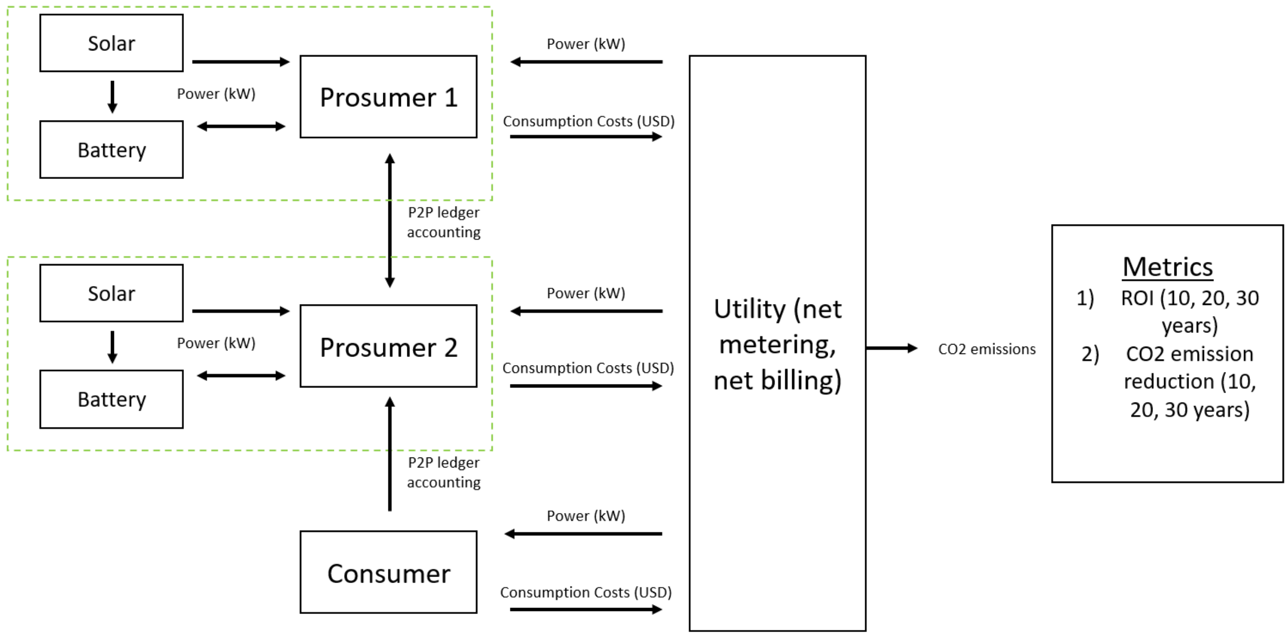
2) **Conventional retrofit:** Energy production is received a solar retrofit, local utility, and energy storage.



3) **Prosumer to consumer:** Build on a conventional retrofit with a simple P2P energy transaction option with a consumer.



4) **Prosumer to prosumer to consumer:** Build onto the prosumer to consumer model with an additional prosumer to prove out scalability of the model.



Once simulations are complete and validated, additional development of an optimization algorithm will be used to identify optimal switching frequency between solar production, energy storage, P2P transaction, or utility-based transaction to maximize financial benefits and minimize CO2 emissions.

Review of Current State Design / Literature Review

The main argument for P2P energy trading, is to give energy consumers and prosumers an alternative option to their local energy billing constraints. Two conventional energy billing methods for prosumers are net metering and net billing, where the unit of account is in energy and local currency, respectively. Both billing techniques have limitations and will benefit one customer more than another given time of peak energy consumptions and production. There are physical benefits to the local grid that are incentivized in these billing techniques as well. This will be further explained a long with current state of P2P energy trading.

Net metering

Net metering works in units of energy for solar/wind prosumers and producers. The main benefits of net metering are to incentivize adoption of solar and wind energy sources in return for energy off set. Because this does not cost the utility company any money for the excess energy not used, they can benefit by lowering the amount of fossil fuels used to power the grid. However, it does limit the ROI and business case for renewable energy only to prosumer customers that can sufficiently use these energy credits produced. Also, when the energy credits can be used depending on cost of peak energy throughout the day. Unused credits can be sold as carbon credits in some regions facilitated by the regional government. [2]

Figure 2: Net metering energy billing [2]

Net billing

Net billing works in units of currency, instead of energy. Therefore, the value of the excess energy produced by a consumer or prosumers can be stored in local currency. This facilitates better ROI on renewable energy production for customers who do not offset their consumption because being a net energy consumer is not required. Another benefit it provides the utility grid the ability to incentivize renewable energy for prosumers who do not have the ability to consume all their produced energy.

Current state of P2P

Due to emergence of renewable energy prosumers and the limitations of the two previous billing structures for prosumers, P2P energy trading has been implemented in areas where net metering limitations are abundant. Also, P2P energy trading allows for legacy billing policies to be used when there is demand and should be taken advantage of. Overall, P2P energy trading could help make a regional energy market more competitive by increasing consumer source options for prosumers.

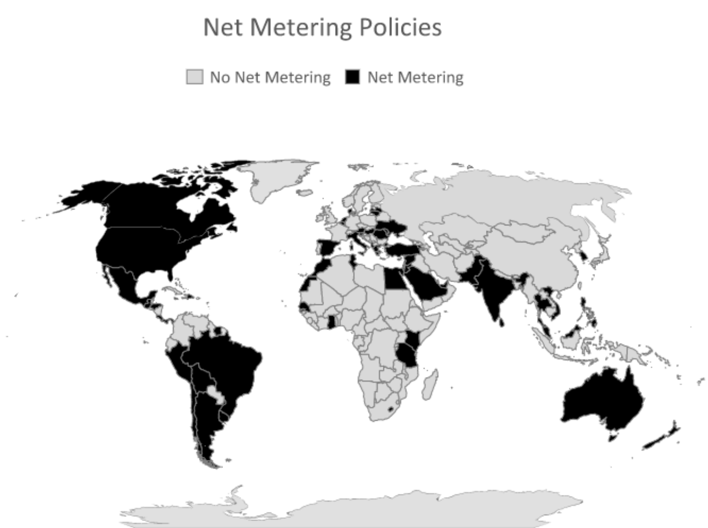


Figure 3: Net metering policy regions [3]

A journal titled, Peer-to-Peer Energy Trading: A review of the literature, from 2021 analyzes six areas of the current state of P2P energy markets. These areas include trading platforms, blockchain, simulation, game theory, optimization, and algorithms.

Trading platform

For energy production and consumption to be accounted for, it needs a platform or exchange to operate on. Currently, selling energy produced back to a centralized producer is accounted on a net metering or billing platform owned by the utility. [4]

Blockchain

Blockchain is defined as an immutable, open-source ledger that provides decentralized transparency and trust. Because of the decentralized nature of P2P energy trading, blockchain is a good application to enable quick settlement for energy production and consumption. Although some early platforms use an intermediary central P2P platform, newer projects are blockchain based.

More specifically, blockchain technology is a secure, distributed database that can manage energy use, billing rates, cryptocurrency integration, and device management. Currently, most decentralized energy platforms are based on Ethereum and Consortium blockchains. One main advantage of using blockchain based accounting is the ability to program layers under the input data for optimization or data interpretation in real time. [4]

Simulation

Because P2P energy provides great data accessibility, simulation is a good tool to analyze market competitiveness and economic game theory. Simulations are helpful to compare cases of unified and identified pricing for energy markets. Unified pricing is the legacy-based system where the central marketplace is used for determining clearing prices. Identified pricing system is where there is enough consumers and producers/prosumers to natural identify the most competitive price for the current supply and demand. [4]

Game Theory

Game theory is applied mathematics which studies interaction within formal incentive structures. It is mainly used to describe economic interactions and the rate of adoption of innovation through economic efficiency improvements. Game theory models have been used to predict P2P energy adoption using simulations of local markets. The study presented in the literature show their game theory models on local energy markets result in more efficient settlement for a P2P transaction process. [4]

Optimization/algorithms

The open source and programmable nature of blockchain data bases allow optimization algorithms that can use input from the system to make optimal decision pointed toward minimizing or maximizing an output in real time frequencies. For example, economic cost per unit of energy at certain times of the day for consumers within a grid can be minimized while also trying to balance minimizing emissions from central energy sources. Also, algorithms can layer onto the blockchain to make real time decisions. One example of this would be price-based demand response given certain number of prosumers and consumers within the microgrid. [4]

Powerledger Blockchain Platform

Powerledger blockchain platform is used for energy trading/traceability and is themed around promoting renewable energy by providing a more efficient settlement process for prosumers. They provide applications for microgrid energy trading among local consumers. Also, there is application for environmental commodities trading and transparency for carbon and renewable energy credits.

Powerledger is an Ethereum based cryptocurrency and platform. The cryptocurrency is built beneath the Ethereum blockchain layer to a cryptocurrency called Power Ledger Core (POWR). POWR is the internal core accounting layer for all Powerledger's applications. Then within a microgrid and the energy trading application, another accounting unit called Sparkz (SPK) is used within the local grid to facilitate quick peer-to-peer transactions and other asset management applications.

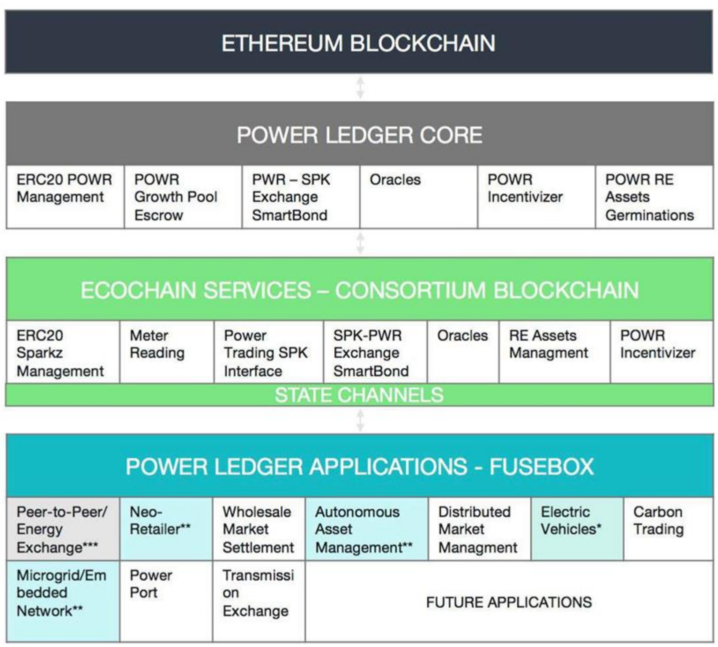


Figure 4: Power Ledger blockchain organization [5]

Powerledger has several applications for tracking produced renewable energy and trading. Their xGrid and uGrid are used for P2P trading. xGrid aims to integrate centralized producers into their network, whereas uGrid aims for P2P trading among a microgrid community, omitting central power from the network. Both applications operate off a smart meter API that integrates into participating hosts' accounts. These trading platforms operate with the SPK layer mentioned before, which then can be exchanged for POWR tokens and then Ethereum.

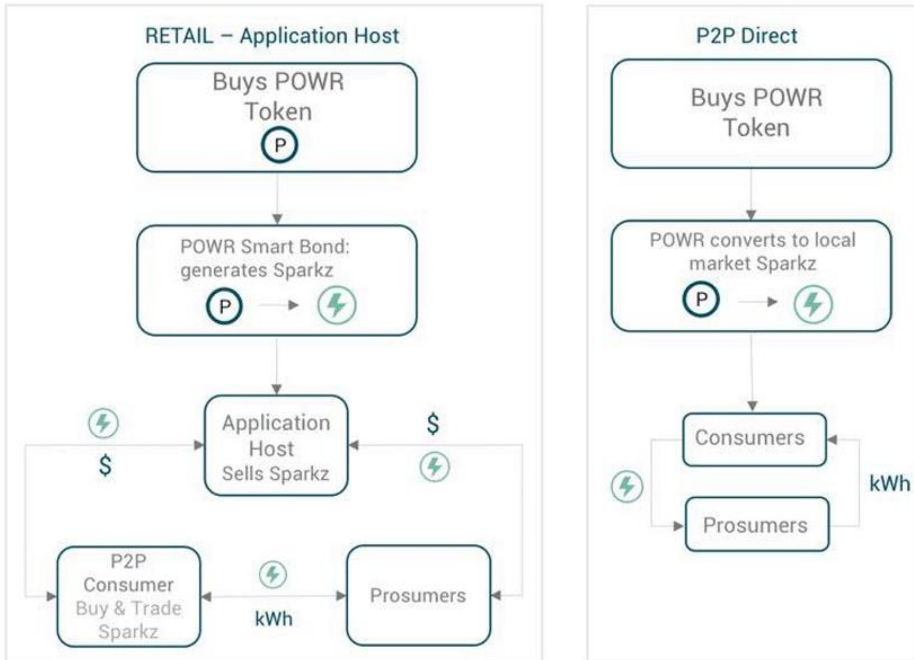


Figure 5: Overview of Power Ledger's P2P application for retail (left) and direct (right) [5]

Project Deliverables and Scope

Developing an accurate model to simulate how P2P energy trading could integrate into a local market with the legacy utility grid, potential customers could be identified by Verde Solutions to adopt this new technology and create win-win situations financially and environmentally for producers, prosumers, and consumers within the local energy market. This would drive a need for installation service of necessary P2P energy hardware and promote additional demand for renewable energy in markets that Verde Solutions could promote and sell.

The goals for this project for Verde Solutions and their customers are the following:

1) An accurate model/simulation to baseline potential customers
2) Expected financial benefits and CO2 emissions from initial solar retrofit
3) An accurate prediction of markets in which customers could benefit from P2P energy trading
4) For customers that could benefit from P2P energy trading, an optimal frequency for sources and sinks within the microgrid

The project scope will focus on previous customer energy data from Verde Solutions. The microgrids and consumer/prosumer energy data will be configured in a non-real-world fashion to prove out functionality and accuracy of the simulation. Local energy regulations and billing constraints will be noted in the assumptions and will be constant among the microgrid configurations. This project will not represent a real world P2P microgrid but have the flexibility to in the future.

Assumptions and Methodology

This section will be organized relative to simulation subcomponents discussed earlier in the project overview and the corresponding assumptions and methods that will be used. The final configuration of all subcomponents needed is below again for reference. All energy will be measured in kilowatt-hr, currency measured in US dollars and CO2 emissions kg/kW-hr.

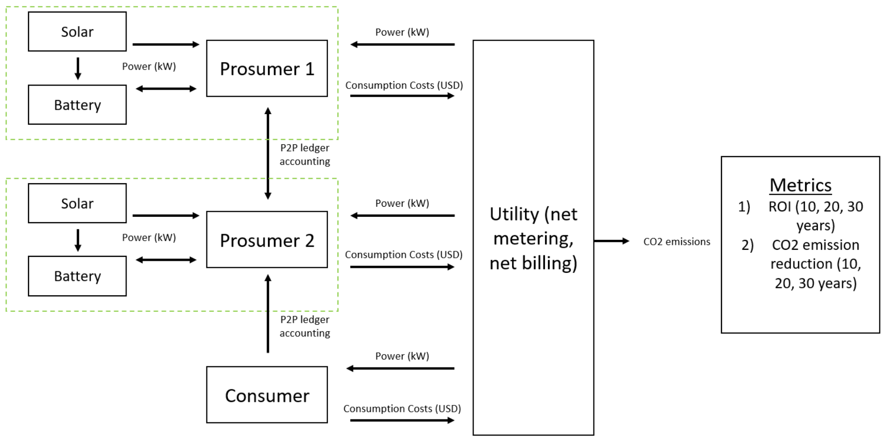


Figure 6: Fully configured microgrid simulation

Prosumer/Consumer Model

The prosumer model is composed of solar production, battery storage and consumption from its production and utility source. Metered data at a 15-minute frequency has been provided by Verde Solutions from several potential customers. This dataset includes date, time, customer consumption, solar power production estimates and net demand categories for one year (approximately 35,000 data points).

The solar and prosumer consumption portion of this model will be using direct input data from the provided estimates. This power data will be used to calculate net usage and energy consumption over a specified time interval. For the consumer model, only consumption data will be used.

Utility/Billing Model

The utility and billing model will be used to account for energy consumed from the fossil fuel power plant. CO2 output data will be calculated using marginal emission factors relative to the RFC (Midwest) region. This will be lookup-based data within the model. For calculating billing rates, Verde Solutions have provided utility rates and will be noted in results.

Accounting/Metrics

Two outputs that will be accounted for are CO2 produced and financial impact over a 30-day billing cycle. CO2 produced will be calculated simply by kWh consumed from the fossil fuel plant within the model by marginal emission factor from the Midwest regional data (RFC). Financial impact will be presented as a percent improvement from the current consumption rate. Overall, a recommendation will be made to pursue P2P energy trading for their client.

Results and Discussion

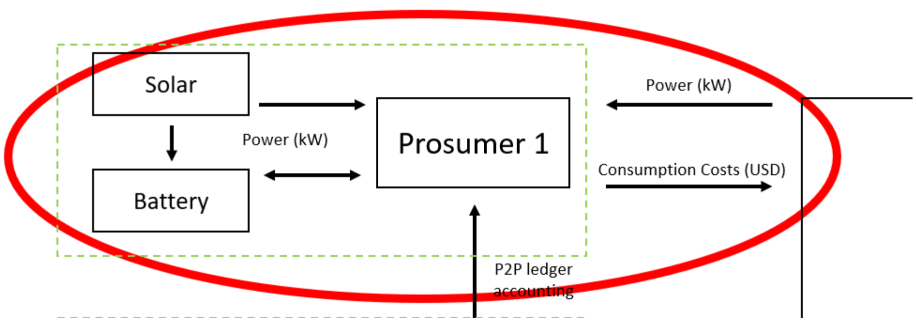
Standalone Simulation

For standalone simulation results, data is presented independently for prosumer #1 (P1), prosumer #2 (P2) and consumer #1 (C1). Also, a direct P2P simulation with no controls will be presented for P1 to P2 and P2 to C1. Power and energy traces will be presented. Cost and CO2 traces will be derived from the resulting energy reduction and presented in Impact/Financial benefits. All data presented is on a 30-day time frame and uses constants from Table 1.

	Cost (usd/kWh)	Marginal Emission Factor (kg/kWh)
Prosumer #1	0.071	731.03
Prosumer #2	0.066	731.03
Consumer #1	0.156	731.03

Table 1: Simulation constant values for cost and emissions

Prosumer #1 (P1):



Prosumer #1 data is a client located in Illinois with an annual energy consumption of 1,895,883 kWh/year and aims to reduce energy costs of $0.071/kWh using solar production. The stand-alone simulation will analyze current utility-based consumption, utility with solar power consumption and utility with solar power plus storage consumption.

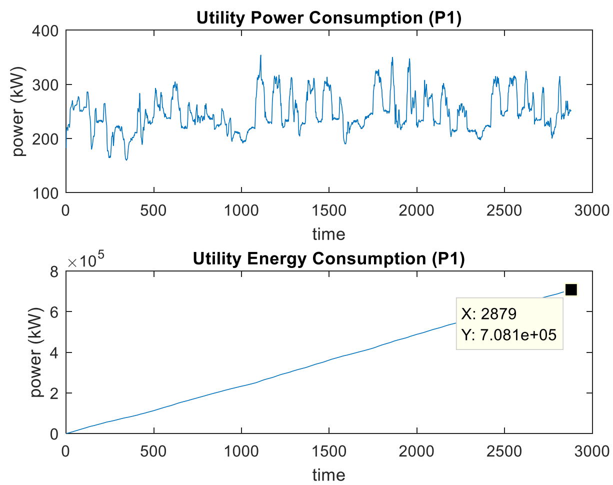


Figure 7: Current utility power/energy use

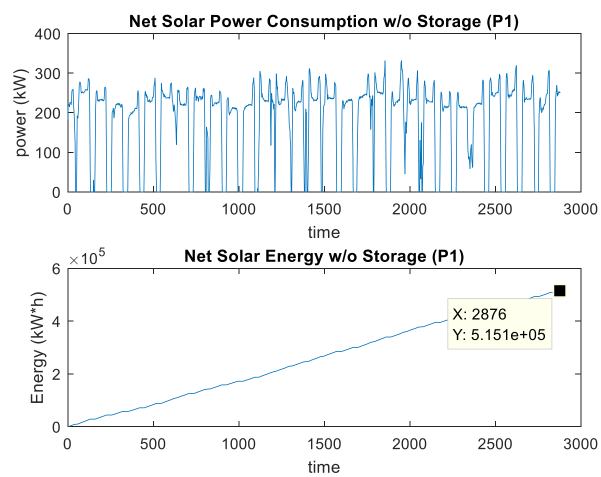


Figure 8: Proposed solar w/o storage power/energy use

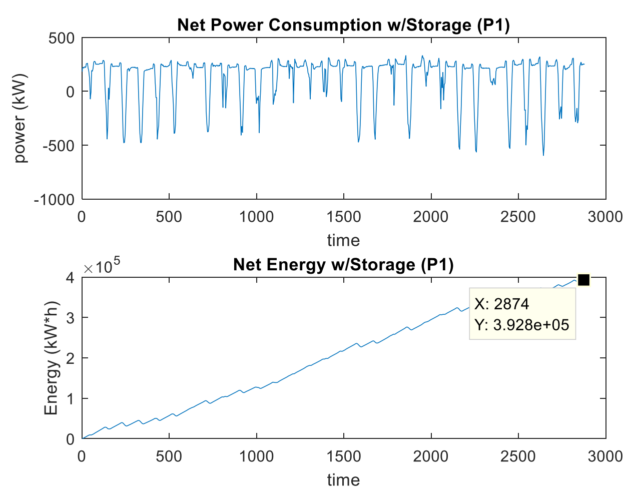


Figure 9: Proposed solar w/storage power/energy use

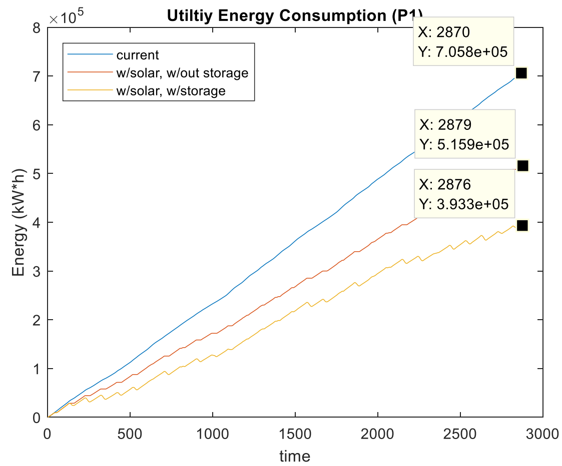
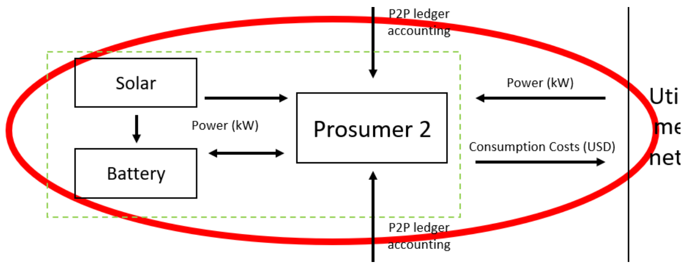


Figure 10: Proposed solar w/storage power/energy use

Prosumer #2 (P2):



Prosumer #2's data is a client located in Illinois as well with an annual energy consumption of 549,574 kWh/year and aims to reduce energy costs of $0.066/kWh using solar production. Again, the stand-alone simulation will analyze current utility-based consumption, utility with solar power consumption and utility with solar power plus storage consumption.

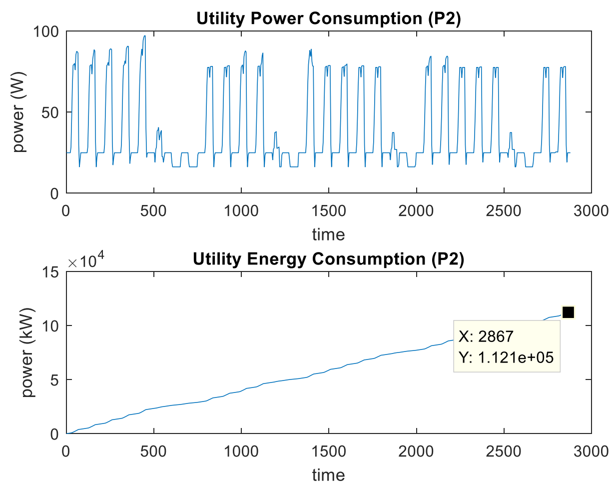


Figure 11: Current utility power/energy use

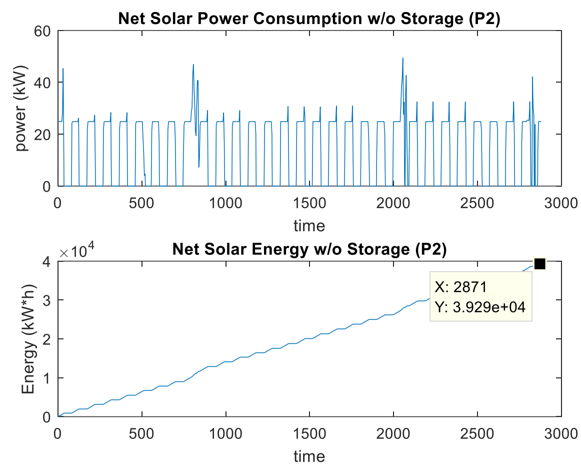


Figure 12: Proposed solar w/o storage power/energy use

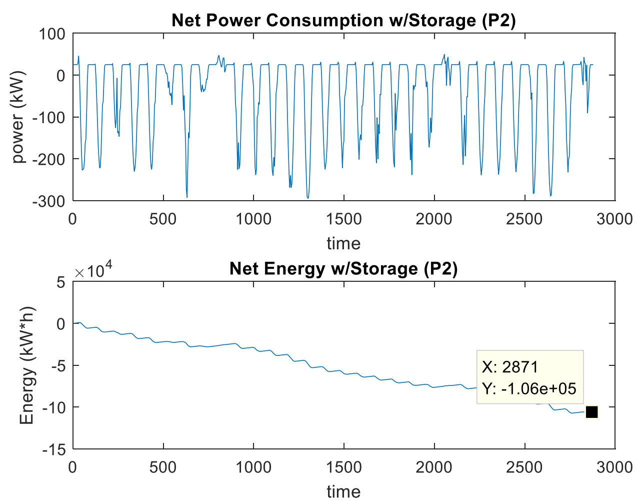


Figure 13: Proposed solar w/storage power/energy use

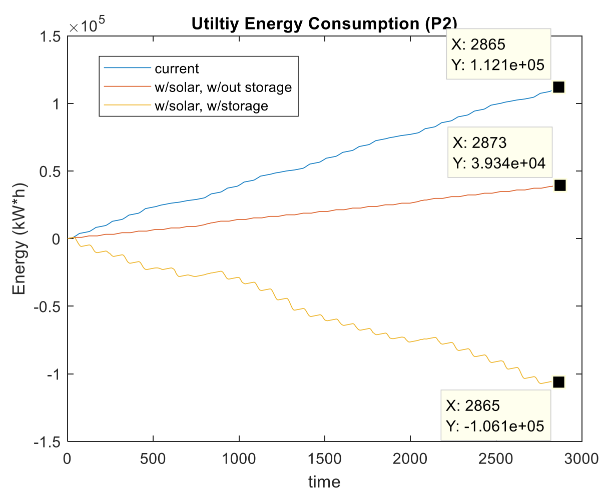
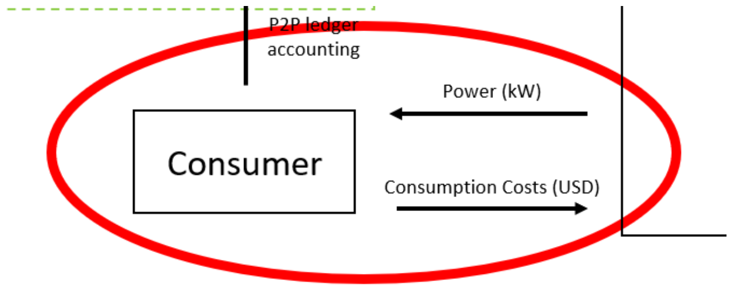


Figure 14: Proposed solar w/storage power/energy use

Consumer #1 (C1):



Consumer #1's data is a client located in Illinois as well with an annual energy consumption of 29,705,957 kWh/year and energy costs of $0.156/kWh. Even though Verde is planning to retrofit this client with solar production, for this simulation the data will be used as only consuming within the microgrid. Again, the stand-alone simulation will analyze current utility-based consumption only.

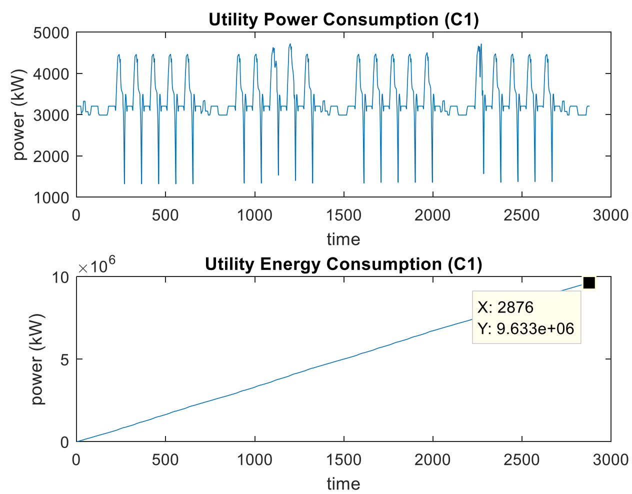
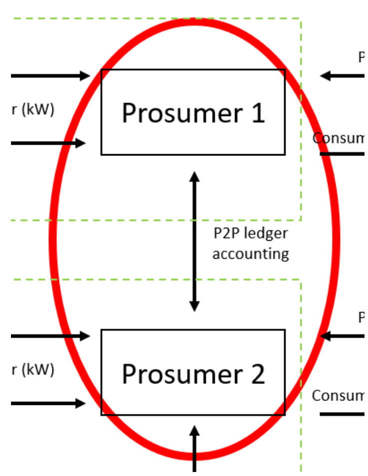


Figure 15: Current utility power/energy use

P1 to P2:



For the initial P2P simulation, P1 and P2 trade energy based on net usage. The logic is as follows. If both are a net user at any interval, then no offset occurs. If one is a net producer and the other is a net consumer at any interval, the net consumer will receive an offset in energy usage, while the producer will receive an offset in costs. If both are net producers, no off set occurs.

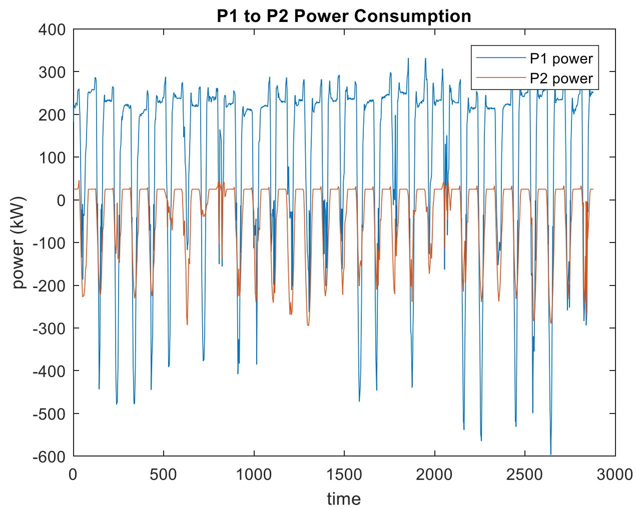


Figure 16: P1 and P2 net power usage over lay

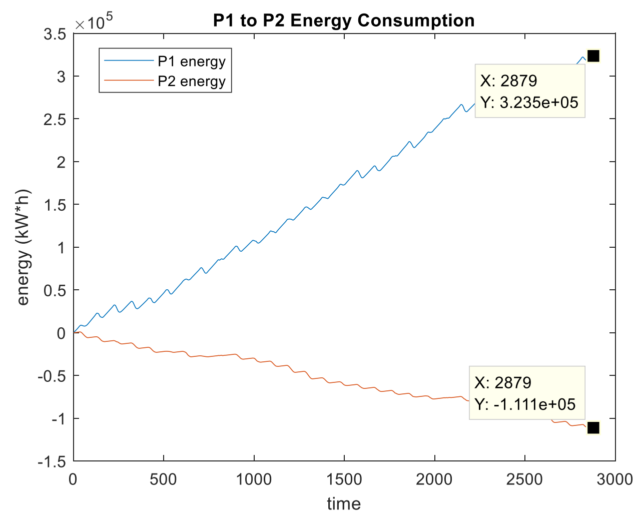
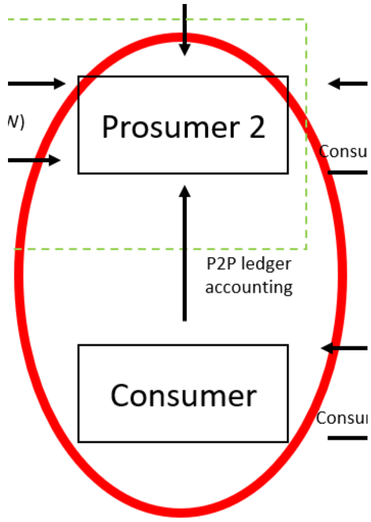


Figure 17: P1 and P2 net energy usage after P2P offset

P2 to C1:



This simulation is direct trading between net production of P2 and consumption only by C1. The logic is simply if P2 is a net producer, then C1 will offset its energy usage with it.

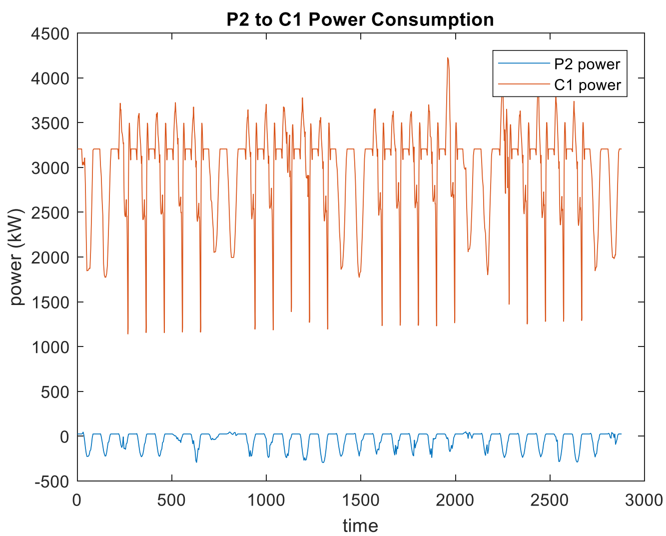


Figure 18: P1 and P2 net power usage over lay

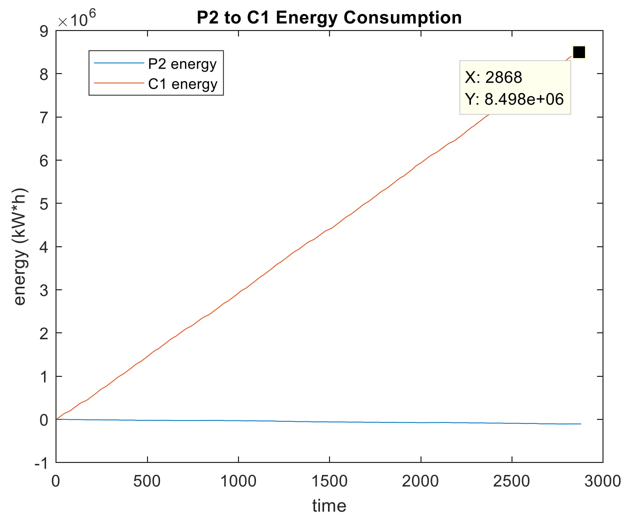
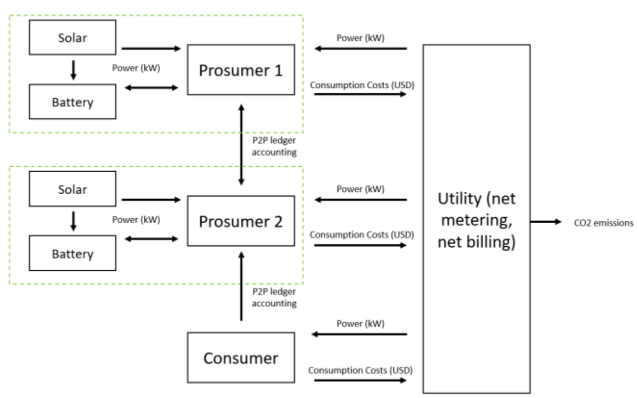


Figure 19: P1 and P2 net energy usage after P2P offset

	current	w/o storage	w/ storage	P2P (P1 to P2)	P2P (P2 to C1)	percent improvement
P1 (kWh)	705800	515900	393300	323500	n/a	54%
P2 (kWh)	12100	39340	-106100	-111100	0	1018%
C1 (kWh)	9633000	n/a	n/a	n/a	8498000	12%

Table 2: Percent improvement on energy consumption for standalone simulations

Configured Microgrid:



After running standalone simulations for P1, P2, and C1 independently and P2P, a configured model was developed. This model used if statement logic to determine which prosumer or consumer has excess energy to trade directly and which one was consuming within the 15-minute sampling interval. If both the consumer and one of the prosumers are consuming in the time step, while the other prosumer is producing energy, logic determines the flow of energy trade based on the energy costs in Table 1. For example, if P2 was producing excess energy while P1 and C1 was consuming, P2 would trade the energy with C1 because of the higher utility rate it can offset. Additionally, this could be set up in a way to compare CO2/carbon credits as the opportunity cost.

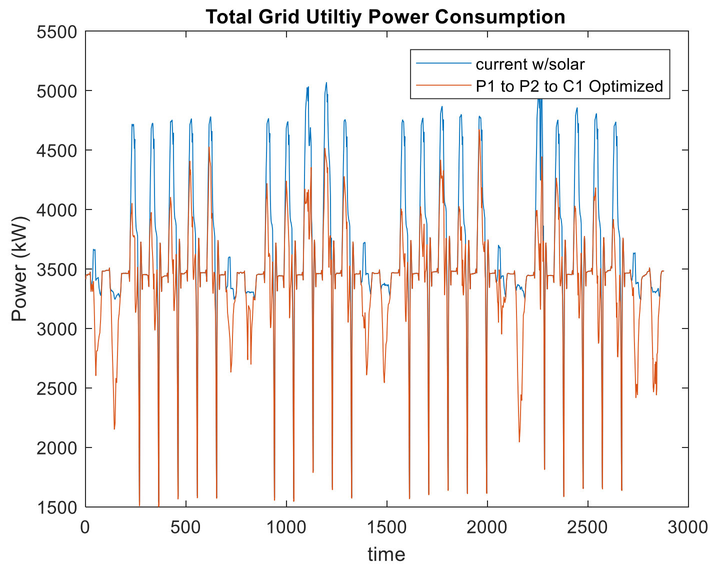


Figure 19: Configured microgrid vs current utility power use

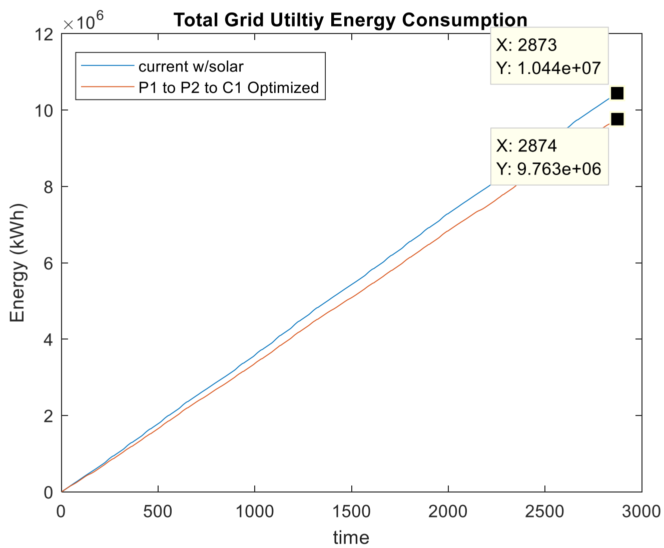


Figure 20: Configured microgrid vs current utility energy use

Overall, the configured/optimized model reduced utility energy from all prosumers and consumers in the microgrid by 6.3 percent over a 30-day period. Additional impacts from cost and emissions will be discussed in the next section.

Impact/Financial Benefits

Standalone Simulations and P1 to P2, P2 to C1

	current	w/o storage	w/storage	P2P (P1 toP2)	P2P (P2 to C1)	percent improvement
P1 (usd)	50270	36630	27980	22970	n/a	54%
P2 (usd)	7419	2606	-6983	-7334	-6983	199%
C1 (usd)	1504000	n/a	n/a	n/a	1331000	12%

Table 3: Cost improvement for standalone models

	current	w/o storage	w/storage	P2P (P1 toP2)	P2P (P2 to C1)	percent improvement
P1 (kg CO2)	346000	252100	192600	158100	n/a	54%
P2 (kg CO2)	54930	19300	-51690	-54300	4170000	199%
C1 (kg CO2)	4712000	n/a	n/a	n/a	-51690	101%

Table 4: CO2 emission reduction for standalone models

For metrics on cost and emissions from utility-based energy, the P1 to P2 and P2 to C1 benefitted the system the most. Because each prosumer and consumer had a different utility energy rate from data provided by Verde, it allowed substantial offset in energy costs. Although, this difference in utility rates from table 1 may not be realistic in real life due to proximity, it does represent reduction in overall utility-based energy and maximizing the use of renewable energy without the additional cost of energy storage. Additionally, there is a similar improvement in CO2 emissions reduction in the same cases in table 4. This offset could allow additional financial benefits through government-based carbon credits in the case for P2 and C1 where negative emissions were reported.

Microgrid Configuration/Optimization

	cost (usd)	emissions (kg CO2)
current (w/o P2P)	1543236	4983400
P1 to P2 to C1 (configured)	2864000	4758000
percent improvement	-86%	5%

Table 5: Cost improvement from configured microgrid

The cost metric for the configured/optimized model did not improve. However, emission reduction improved by 5 percent by allowing the entire gride to depend less on the fossil fuel-based energy source from the utility. The optimization here could be improved with future iterations.

Recommendations

Overall, the standalone and configured simulations proved to reduce reliance on utility-based energy, reduction in CO2 emissions, and in some cases directly reduced monthly energy billing costs. Additional carbon credit financial benefits from reduction in CO2 emissions were not reported but can be assumed clients could take advantage of. It is recommended to Verde Solutions to present P2P energy trading to their clients as a potential solution to maximize their investment in renewable energy generation. Also, P2P energy trading could be a good alternative to installing expensive energy storage for the excess energy. This is a model that can be used for future clients within a microgrid to test feasibility with P2P energy trading.

Summary/Conclusion

This report outlined a project on the potential of P2P energy trading for clients with energy consultant Verde Solutions. Explanation of some of the current issues with prosumer renewable energy generation accounting were presented from net billing and net usage utility billing structures. Then a detailed explanation of the potential for P2P energy trading has for better accounting with renewable energy production. Finally, project objectives to model Verde Solutions clients' potential use of P2P energy trading and results were presented. Overall, P2P energy has potential to be more prevalent to offset the cost of renewable energy generation.

APPENDIX A – MATLAB CODE

Similar for P2 and C1 models

```
clc;
close all;
clear all;

%% PROSUMER #1: load initial data
load prosumer_1_data.mat;
%BystronicManufacturingLLCV1DataFile.csv
C1_p1=BystronicManufacturingLLCV1DataFile;
days=input('days to simulate?')
ts=4*24*days;                                                      %time step=15 min

load MarginalEmissionsFactors.mat;
FRCC=1;
MRO=2;
NPCC=3;
RFC=4;
SERC=5;
SPP=6;
TRE=7;
WECC=8;

region=input('marginal emissions region?')

MEF=MarginalEmissionsFactors{region,2}/1000;                           %kg/kWh

utility_costs=0.071 %input('avoided utiltiy costs (usd/kWh)?');  %usd/kWh

%% PROSUMER #1: INPUTS
time_p1=C1_p1{2:ts,2};                                            %15 min per step
time_length_p1=(linspace(1,length(time_p1),length(time_p1))).';
power_consumption_p1=C1_p1{2:ts,3};                               %kW                           annual
energy consumption=1,895,883 kWh/year
production_p1=C1_p1{2:ts,4};                                      %kW                           avoided
utility cost=$0.071/kWh
net_power_p1=C1_p1{2:ts,7};                                       %kW
net_energy_p1=cumtrapz(net_power_p1);                             %kWh

%% PROSUMER #1 UTILITY CONSUMPTION
% power consumption

% energy consumption
energy_consumption_p1=cumtrapz(power_consumption_p1);

figure
subplot(2,1,1)
plot(power_consumption_p1)
title ('Utility Power Consumption (P1)')
ylabel ('power (kW)')
xlabel('time')

subplot(2,1,2)
plot(energy_consumption_p1)
title ('Utility Energy Consumption (P1)')
ylabel ('power (kW)')
xlabel('time')
hold on

%% SOLAR PRODUCTION W/OUT STORAGE AND SELLBACK #1
figure
plot(production_p1)
title ('Solar Power Production (P1)')
ylabel ('power (kW)')
xlabel('time')
hold on

for i=1:length(net_power_p1);
    if net_power_p1(i)>=0;
```

```
        solar_consumption_power_p1(i)=net_power_p1(i);
    else
        solar_consumption_energy_p1(i)=0;
    end
end

solar_consumption_energy_p1=cumtrapz(solar_consumption_power_p1);

figure
subplot(2,1,1)
plot(solar_consumption_power_p1)
title ('Net Solar Power Consumption w/o Storage (P1)')
ylabel ('power (kW)')
xlabel('time')

subplot(2,1,2)
plot(solar_consumption_energy_p1)
title ('Net Solar Energy w/o Storage (P1)')
ylabel ('Energy (kW*h)')
xlabel('time')
hold on

%% UNUSED POWER/ENERGY P1 #1

for i=1:length(net_power_p1);
    if net_power_p1(i)<=0;
        storage_power_p1(i)=net_power_p1(i);
    else
        storage_power_p1(i)=0;
    end
end

battery_SOC_energy_p1=cumtrapz(storage_power_p1);

figure
subplot(2,1,1)
plot(storage_power_p1)
title ('Excess Power (P1)')
ylabel ('power (kW)')
xlabel('time')

subplot(2,1,2)
plot(battery_SOC_energy_p1)
title ('Excess Energy (P1)')
ylabel ('Energy (kW*h)')
xlabel('time')
hold on

figure
subplot(2,1,1)
plot(net_power_p1)
title ('Net Power Consumption w/Storage (P1)')
ylabel ('power (kW)')
xlabel('time')

subplot(2,1,2)
plot(net_energy_p1)
title ('Net Energy w/Storage (P1)')
ylabel ('Energy (kW*h)')
xlabel('time')
hold on

%% W/OUT SOLAR vs W/SOLAR, NO STORAGE vs W/SOLAR, W/STORAGE

figure
plot(time_length_p1,energy_consumption_p1);
hold on
plot(solar_consumption_energy_p1');
hold on
plot(time_length_p1,net_energy_p1);
```

```
hold on
title ('Utiltiy Energy Consumption (P1)')
ylabel ('Energy (kW*h)')
xlabel('time')
legend('current','w/solar, w/out storage', 'w/solar, w/storage')


%% PROSUMER #1 UTILITY CONSUMPTION COSTS/EMISSIONS
%cost
cost_current_p1=utility_costs*energy_consumption_p1;
cost_solar_p1=utility_costs*solar_consumption_energy_p1;
cost_solar_storage_p1=utility_costs*net_energy_p1;

figure
CP1=[cost_current_p1(length(cost_current_p1)) cost_solar_p1(length(cost_solar_p1))
cost_solar_storage_p1(length(cost_solar_storage_p1))];
c=categorical({'current','w/solar, w/out storage', 'w/solar, w/storage'});
bar(c,CP1)
title('30 day utility cost (P1)')
ylabel('Cost (USD)')

hold on

%emissions
emissions_current_p1=MEF*energy_consumption_p1;
emissions_solar_p1=MEF*solar_consumption_energy_p1;
emissions_solar_storage_p1=MEF*net_energy_p1;

figure
EP1=[emissions_current_p1(length(emissions_current_p1)) emissions_solar_p1(length(emissions_solar_p1))
emissions_solar_storage_p1(length(emissions_solar_storage_p1))];
bar(c,EP1)
title('Emissions (P1)')
ylabel('CO2 Emissions (kg CO2)')
hold on
```

Similar for P2 to C1 model

```
clc;
close all;
clear all;

%% PROSUMER #1: load initial data
load prosumer_1_data.mat;
%BystronicManufacturingLLCV1DataFile.csv
C1_p1=BystronicManufacturingLLCV1DataFile;
days=input('days to simulate?');
ts=4*24*days;                                                    %time step=15 min

% PROSUMER #1: INPUTS
time_p1=C1_p1{2:ts,2};                                           %15 min per step
time_length_p1=(linspace(1,length(time_p1),length(time_p1))).';
power_consumption_p1=C1_p1{2:ts,3};                              %kW                          annual
energy consumption=1,895,883 kWh/year
production_p1=C1_p1{2:ts,4};                                     %kW                          avoided
utility cost=$0.071/kWh
net_power_p1=C1_p1{2:ts,7};                                      %kW
net_energy_p1=cumtrapz(net_power_p1);                            %kWh


%% PROSUMER #2: load initial data
load prosumer_2_data.mat;                                        %WestsideTractorSales-
LislePreliminaryProposalV1-DataFile.csv
C1_p2=WestsideTractorSalesLislePreliminaryProposalV1DataFile;
ts=4*24*days;                                                    %time step=15 min

% PROSUMER #2: INPUTS
time_p2=C1_p2{2:ts,2};                                           %15 min per step
time_length_p2=(linspace(1,length(time_p2),length(time_p2))).';
power_consumption_p2=C1_p2{2:ts,3};                              %kW
```

```
production_p2=C1_p2{2:ts,4};                                          %kW                        annual
energy consumption=549,574 kWh/year
net_power_p2=C1_p2{2:ts,7};                                           %kW                        avoided
utility cost=$0.066/kWh
net_energy_p2=cumtrapz(net_power_p2);                                 %kWh

%% MEF and Cost data
load MarginalEmissionsFactors.mat;
FRCC=1;
MRO=2;
NPCC=3;
RFC=4;
SERC=5;
SPP=6;
TRE=7;
WECC=8;

region=input('marginal emissions region?')

MEF=MarginalEmissionsFactors{region,2}/1000;                              %kg/kWh

utility_costs_p1=0.071 %input('avoided utiltiy costs (usd/kWh)?');  %usd/kWh
utility_costs_p2=0.066 %input('avoided utiltiy costs (usd/kWh)?');  %usd/kWh

%% PROSUMER #1 to PROSUMER #2

for i=1:length(net_power_p2);
    if (net_power_p1(i)>=0) && (net_power_p2(i)>=0);
            P1_power(i)=net_power_p1(i);
            P2_power(i)=net_power_p2(i);
        else if (net_power_p1(i)<=0) && (net_power_p2(i)>=0);
                P1_power(i)=net_power_p1(i);
                P2_power(i)=net_power_p2(i)+net_power_p1(i);
            else if (net_power_p1(i)>=0) && (net_power_p2(i)<=0);
                    P1_power(i)=net_power_p1(i)+net_power_p2(i);
                    P2_power(i)=net_power_p2(i);
                else (net_power_p1(i)<=0) && (net_power_p2(i)<=0);
                            P1_power(i)=net_power_p1(i);
                            P2_power(i)=net_power_p2(i);
                end
         end
    end
end

P1_energy_consumption=cumtrapz(P1_power);
P2_energy_consumption=cumtrapz(P2_power);

figure
plot(P1_power)
hold on
plot(P2_power)
hold on
title ('P1 to P2 Power Consumption')
ylabel ('power (kW)')
xlabel('time')
legend('P1 power','P2 power')

figure
plot(P1_energy_consumption)
hold on
plot(P2_energy_consumption)
hold on
title ('P1 to P2 Energy Consumption')
ylabel ('energy (kW*h)')
xlabel('time')
legend('P1 energy','P2 energy')

%% PROSUMER #1 TO PROSUMER #2 UTILITY CONSUMPTION COSTS/EMISSIONS
%cost
cost_p1_p2=utility_costs_p1*P1_energy_consumption;
```

```
cost_p2_p1=utility_costs_p2*P2_energy_consumption;
load('cost_current_p1.mat');
load('cost_current_p2.mat');

figure
CP1P2=[cost_current_p1(length(cost_current_p1)) cost_p1_p2(length(cost_p1_p2));
cost_current_p2(length(cost_current_p2)) cost_p2_p1(length(cost_p2_p1))];
c=categorical({'P1','P2'});
bar(c,CP1P2)
title('30 day utility cost')
ylabel('Cost (USD)')
hold on

%emissions
emissions_p1_p2=MEF*P1_energy_consumption;
emissions_p2_p1=MEF*P2_energy_consumption;
load('emissions_current_p1.mat');
load('emissions_current_p2.mat');

figure
EP1P2=[emissions_current_p1(length(emissions_current_p1)) emissions_p1_p2(length(emissions_p1_p2));
emissions_current_p2(length(emissions_current_p2)) emissions_p2_p1(length(emissions_p2_p1))];
bar(c,EP1P2)
title('Emissions')
ylabel('CO2 Emissions (kg CO2)')
hold on
```

Configured/optimization model

```
clc;
close all;
clear all;

%% LOAD P1, P2, C1 DATA

%energy_consumption_p1
%net_energy_p1
%load('cost_current_p1.mat');
%load('energy_consumption_p2.mat')
%cost_solar_p2
%cost_solar_p1
%load('emissions_solar_p1');
%load('net_energy_p2.mat')
%load('energy_consumption_c1.mat')

load MarginalEmissionsFactors.mat;
FRCC=1;
MRO=2;
NPCC=3;
RFC=4;
SERC=5;
SPP=6;
TRE=7;
WECC=8;
region=input('marginal emissions region?');

MEF=MarginalEmissionsFactors{region,2}/1000;                                %kg/kWh
load('net_power_p1.mat');
load('net_power_p2.mat');
load('power_consumption_c1.mat');

%load('cost_current_p2.mat');
%load('cost_current_c1.mat');

%load('emissions_current_c1');
%load('emissions_solar_p2');

p1_cost=0.071;  %usd/kWh
p2_cost=0.066;  %usd/kWh
c1_cost=0.156;  %usd/kWh
```

```
for i=1:length(net_power_p2);
    if (net_power_p1(i)>=0) && (net_power_p2(i)>=0) && (power_consumption_c1(i)>=0);          %111
        p1_utility_power(i)=net_power_p1(i);
        utility_costs_p1(i)=p1_cost;

        p2_utility_power(i)=net_power_p2(i);
        utility_costs_p2(i)=p2_cost;

        c1_utility_power(i)=power_consumption_c1(i);
        utility_costs_c1(i)=c1_cost;

    else if (net_power_p1(i)<0) && (net_power_p2(i)<0) && (power_consumption_c1(i)>=0);         %001
        p1_utility_power(i)=net_power_p1(i);
        utility_costs_p1(i)=p1_cost;

        p2_utility_power(i)=net_power_p2(i);
        utility_costs_p2(i)=p2_cost;

        c1_utility_power(i)=power_consumption_c1(i)+net_power_p2(i);
        utility_costs_c1(i)=p2_cost;

    else if (net_power_p1(i)<0) && (net_power_p2(i)>=0) && (power_consumption_c1(i)>=0);         %011
        p1_utility_power(i)=net_power_p1(i);
        utility_costs_p1(i)=p1_cost;

        p2_utility_power(i)=net_power_p2(i)+net_power_p1(i);
        utility_costs_p2(i)=p2_cost;

        c1_utility_power(i)=power_consumption_c1(i);
        utility_costs_c1(i)=c1_cost;

    else if (net_power_p1(i)>=0) && (net_power_p2(i)<0) && (power_consumption_c1(i)<0);          %100
        p1_utility_power(i)=net_power_p1(i)+net_power_p2(i);
        utility_costs_p1(i)=p2_cost;

        p2_utility_power(i)=net_power_p2(i);
        utility_costs_p2(i)=p2_cost;

        c1_utility_power(i)=power_consumption_c1(i);
        utility_costs_c1(i)=c1_cost;

    else if (net_power_p1(i)>=0) && (net_power_p2(i)>=0) && (power_consumption_c1(i)>=0);         %110
        p1_utility_power(i)=net_power_p1(i);
        utility_costs_p1(i)=p1_cost;

        p2_utility_power(i)=net_power_p2(i);
        utility_costs_p2(i)=p2_cost;

        c1_utility_power(i)=power_consumption_c1(i);
        utility_costs_c1(i)=c1_cost;

    else if (net_power_p1(i)<0) && (net_power_p2(i)>=0) && (power_consumption_c1(i)>=0);          %010
        p1_utility_power(i)=net_power_p1(i);
        utility_costs_p1(i)=p1_cost;

        p2_utility_power(i)=net_power_p2(i)+net_power_p1(i);
        utility_costs_p2(i)=p2_cost;

        c1_utility_power(i)=power_consumption_c1(i);
        utility_costs_c1(i)=c1_cost;

        else                                                                                     %101
        p1_utility_power(i)=net_power_p1(i)+net_power_p2(i);
        utility_costs_p1(i)=p2_cost;

        p2_utility_power(i)=net_power_p2(i);
        utility_costs_p2(i)=p2_cost;

        c1_utility_power(i)=power_consumption_c1(i);
        utility_costs_c1(i)=c1_cost;
```

```
        end
        end
        end
        end
        end
    end
end

%% TOTAL UTILITY POWER, ENERGY, COST, EMISSIONS vs CURRENT

%power (kW)
MEF=MarginalEmissionsFactors{region,2}/1000;                                %kg/kWh
load('power_consumption_p1.mat');
load('power_consumption_p2.mat');

total_utility_power_curr=power_consumption_p1+power_consumption_p2+power_consumption_c1;
for i=1:length(net_power_p2);
    total_utility_power_opt(i)=p1_utility_power(i)+p2_utility_power(i)+c1_utility_power(i);
end

%time_length_p1,
figure
plot(total_utility_power_curr);
hold on
plot(total_utility_power_opt);
hold on
title ('Total Grid Utiltiy Power Consumption')
ylabel ('Power (kW)')
xlabel('time')
legend('current w/solar','P1 to P2 to C1 Optimized')


%energy (kWh)
total_utility_energy_curr=cumtrapz(total_utility_power_curr);
total_utility_energy_opt=cumtrapz(total_utility_power_opt);

figure
plot(total_utility_energy_curr);
hold on
plot(total_utility_energy_opt);
hold on
title ('Total Grid Utiltiy Energy Consumption')
ylabel ('Energy (kWh)')
xlabel('time')
legend('current w/solar','P1 to P2 to C1 Optimized')

%utility cost (usd)
load('cost_solar_p1.mat');
load('cost_solar_p2.mat');
load('cost_current_c1.mat');

total_utility_cost_curr=cost_solar_p1+cost_solar_p2+cost_current_c1.';
p=utility_costs_p1+utility_costs_p2+utility_costs_c1;
total_utility_cost_opt=total_utility_energy_opt.*p;

figure
plot(total_utility_cost_curr);
hold on
plot(total_utility_cost_opt);
hold on
title ('Total Grid Utiltiy Costs Consumption')
ylabel ('USD')
xlabel('time')
legend('current w/solar','P1 to P2 to C1 Optimized')

%emissions (CO2 kg)
total_utility_emissions_curr=total_utility_energy_curr*MEF;
total_utility_emissions_opt=total_utility_energy_opt*MEF;
```

```
figure
plot(total_utility_emissions_curr);
hold on
plot(total_utility_emissions_opt);
hold on
title ('Total Grid Utiltiy Emissions')
ylabel ('kg CO2')
xlabel('time')
legend('current w/solar','P1 to P2 to C1 Optimized')
```

References

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[5] P. Ledger, "Power Ledger White Paper," p. 28, 2019.