Simulate Prosumers in a Net-Metered Grid Connected Market

Description:

Prosumers are collected as a model with the consumption, generation, net energy and pricing data avaialble. The prosumer data has been built based on Tier1 installations for the purposes of modeling a typical prosumer. The limits on the capacity for Teir1 are also considered. In this simulation parameters for the gross power ratings, AC/DC conversion, will be considered as well as the generation limits.

What is Net-Metering? Net metering is an electricity billing mechanism that allows consumers who generate some or all of their own electricity to use that electricity anytime, instead of when it is generated. This is particularly important with renewable energy sources like wind and solar. We can define the payment for a prosumer in the state of Florida by the retail pricing provided to the prosumer for every kWh that is injected back into the Grid.

Considerations when Net-Metering in FPL territory (FPL Net Metering Guidelines):

1. The gross power rating or the alternating current (AC) rating for the system is the array direct current (DC) rating multiplied by 0.85. The AC rating determines the tier that the system falls under for agreement purposes. There are three tiers by system size; tier 1 is 10 kW and below, tier 2 is above 10 kW up to 100 kW, and tier 3 is above 100 kW up to 2,000 kW (2 megawatts).

2. Customer-owned renewable generation shall include a utility-interactive inverter, or other device certified pursuant to FPL's net-metering agreement, that performs the function of automatically isolating the customer-owned generation equipment from the energy grid in the event of a grid outage. This requirement is necessary to prevent dangerous back feed, which can endanger restoration personnel who may be working to restore the grid.

3. Customer generation is limited to 90 percent of the FPL service capacity. FPL will upsize facilities for customer generation at the customer's expense. FPL will not increase the size of the distribution equipment greater than required for a renewable energy system designed to offset all of the customer's annual energy use.

Steps:

1. Data Gathering

```
- Pull in the data from locally built dataset
- Define payment method and generate profit/expense values
- Pay prosumers for excess energy generated
```

- Charge prosumers for excess energy consumed

2. Analysis of Performance

- Totals for each prosumer
- Market view

3. Summary and Further Analysis

- What results shown?
- Next steps

In [19]:
```
#import data from sources
import pandas as pd
from functools import reduce
import requests
import os
import pathlib
from datetime import datetime
import matplotlib.pyplot as plt
from numpy import random
from tabulate import tabulate
import math
```

Step 1 : Data Gathering

1.1 Collecting Data From Local Dataset

The prosumer data has been built into a Comma-Sperated file that can be parsed with the following format:

time	demand	generation	consumption	net_energy	price	id
2020-11-01 00:00:00	621.143	1115.12	0	-493.98	12	1
2020-10-01 00:00:00	1110.06	1178.87	0	-68.8135	11.49	1
2020-09-01 00:00:00	1226.16	1026.59	199.568	0	11.97	1
2020-08-01 00:00:00	1002.64	972.796	29.8479	0	11.61	1

...(continued)

Parsing the dataset by the 'id' col. allows us to collect individual prosumer data. The next step is to put the prosumer data into an object class that contains some of the functionality we will perform on the data.

In [63]:
```
#Import the data to local csv
all_prosumers_data = pd.read_csv('data/prosumer_N3_model_20210129_1416.csv')
all_prosumers_data["time"] = pd.to_datetime(all_prosumers_data['time'], format='
```

```
all_prosumers_data.sort_values(by='time')
prosumer_data = [pd.DataFrame(y) for x, y in all_prosumers_data.groupby('id', as

#print(prosumer_data[0]) #show the first prosumer in the dataset
print(all_prosumers_data)
```

	time	demand	generation	consumption	net_energy	price	id
0	2020-11-01	713.636892	1001.611236	0.000000	-287.974344	12.00	1
1	2020-10-01	1033.715254	1124.283176	0.000000	-90.567922	11.49	1
2	2020-09-01	1169.504690	1200.000000	0.000000	-30.495310	11.97	1
3	2020-08-01	745.056436	1118.585765	0.000000	-373.529328	11.61	1
4	2020-07-01	1088.967130	1075.337671	13.629459	0.000000	11.71	1
5	2020-06-01	1202.880127	979.940026	222.940101	0.000000	11.53	1
6	2020-05-01	839.217153	945.914118	0.000000	-106.696964	9.84	1
7	2020-04-01	726.229347	1042.016842	0.000000	-315.787495	11.71	1
8	2020-03-01	1136.909963	767.108299	369.801664	0.000000	11.64	1
9	2020-02-01	405.862473	787.888820	0.000000	-382.026347	11.76	1
10	2020-01-01	666.182080	788.227717	0.000000	-122.045637	11.73	1
11	2019-12-01	785.346708	491.636087	293.710621	0.000000	11.62	1
12	2019-11-01	638.907999	466.653885	172.254114	0.000000	12.09	1
13	2019-10-01	785.747309	567.176089	218.571220	0.000000	11.66	1
14	2020-11-01	751.491540	1200.000000	0.000000	-448.508460	12.00	2
15	2020-10-01	762.847690	1102.706306	0.000000	-339.858616	11.49	2
16	2020-09-01	985.274160	1077.522948	0.000000	-92.248789	11.97	2
17	2020-08-01	1231.715100	1004.639607	227.075492	0.000000	11.61	2
18	2020-07-01	1132.463515	1200.000000	0.000000	-67.536485	11.71	2
19	2020-06-01	723.598878	1200.000000	0.000000	-476.401122	11.53	2
20	2020-05-01	935.236513	964.290192	0.000000	-29.053679	9.84	2
21	2020-04-01	686.698848	888.174155	0.000000	-201.475307	11.71	2
22	2020-03-01	650.421040	913.950349	0.000000	-263.529309	11.64	2
23	2020-02-01	754.921915	718.946917	35.974998	0.000000	11.76	2
24	2020-01-01	637.803627	880.472852	0.000000	-242.669225	11.73	2
25	2019-12-01	793.764068	439.250888	354.513179	0.000000	11.62	2
26	2019-11-01	638.090831	621.538424	16.552407	0.000000	12.09	2
27	2019-10-01	706.638381	897.462539	0.000000	-190.824158	11.66	2
28	2020-11-01	783.506280	731.021485	52.484795	0.000000	12.00	3
29	2020-10-01	1256.561563	883.816246	372.745318	0.000000	11.49	3
30	2020-09-01	1338.021939	929.304281	408.717657	0.000000	11.97	3
31	2020-08-01	737.868197	1177.708923	0.000000	-439.840726	11.61	3
32	2020-07-01	732.703553	691.806280	40.897274	0.000000	11.71	3
33	2020-06-01	845.578525	1181.059231	0.000000	-335.480705	11.53	3
34	2020-05-01	809.429409	1200.000000	0.000000	-390.570591	9.84	3
35	2020-04-01	942.248731	1200.000000	0.000000	-257.751269	11.71	3
36	2020-03-01	648.239619	945.389520	0.000000	-297.149901	11.64	3
37	2020-02-01	715.936170	1100.551040	0.000000	-384.614870	11.76	3
38	2020-01-01	687.859185	663.106509	24.752677	0.000000	11.73	3
39	2019-12-01	917.458586	682.124809	235.333777	0.000000	11.62	3
40	2019-11-01	818.159911	664.579529	153.580382	0.000000	12.09	3
41	2019-10-01	996.729985	392.570712	604.159273	0.000000	11.66	3

1.2 Define the Prosumer Object

To transform the data we will collect it as an object with functions for use in the simulation.

In [48]:

```
class Prosumer:
    def __init__(self,data, cost_of_energy):
        self.id = data['id'].iloc[0]
        self.data = data #time,demand,generation,consumption,net_energy,price,id
        # Calculate the profit given the price and net energy
        self.data['profit'] = cost_of_energy(net_energy=self.data['net_energy'],
        # Calculate the expense given the price and net energy
```

```
        self.data['expense'] = cost_of_energy(net_energy=self.data['consumption'
    def get_total_profit(self):
        return self.data['profit'].sum()
    def get_total_expense(self):
        return self.data['expense'].sum()
    def table(self):
        print(tabulate(self.data, headers = 'keys', tablefmt = 'github',showinde
    def plot_energy(self):
        # plot all curve associated with prosumer
        self.data.plot(x='time',y=['demand','generation','consumption','net_ener
        plt.show()
    def plot_ledger(self):
        # plot all curve associated with prosumer
        self.data.plot(x='time',y=['expense','profit'],title=f"Energy - Ledger -
        plt.show()
```

1.3 Define the Cost of Energy Method

To generate the payment and profit needed we need to utilize the net meter payment method. The retail price of electricity will be used to pay the customer for excess energy. It will also be the method to charge the customer for any energy consumed.

In [49]:

```
def cost_of_energy(price,net_energy):
    # convert to dollars from cents
    return abs(net_energy)*(0.01*price)
```

1.4 Update each prosumer with Profit/Expense data

Each prosumer will have to draw energy from the grid. When it does it will incurr an expense for that energy at the retail rate for electricity.

In [50]:

```
# Generate prosumers based on normalized curves from data gethering stage
prosumers = []
for data in prosumer_data:
    prosumers.append(Prosumer(data,cost_of_energy))

# number of prosumers retrieved from dataset
N = len(prosumers)
```

Step 2: Analysis of Performance

2.1 Analyze the Performance by Prosumer

Each prosumer will consume energy and pay retail price for it. At the same time each prosumer will get paid for the generated net energy at the reail price. This allows us to look at the revenue for each prosumer given its individual performance. The result shows the demand for energy during the winter months. The simulation coincides with experimental assumptions of the data.

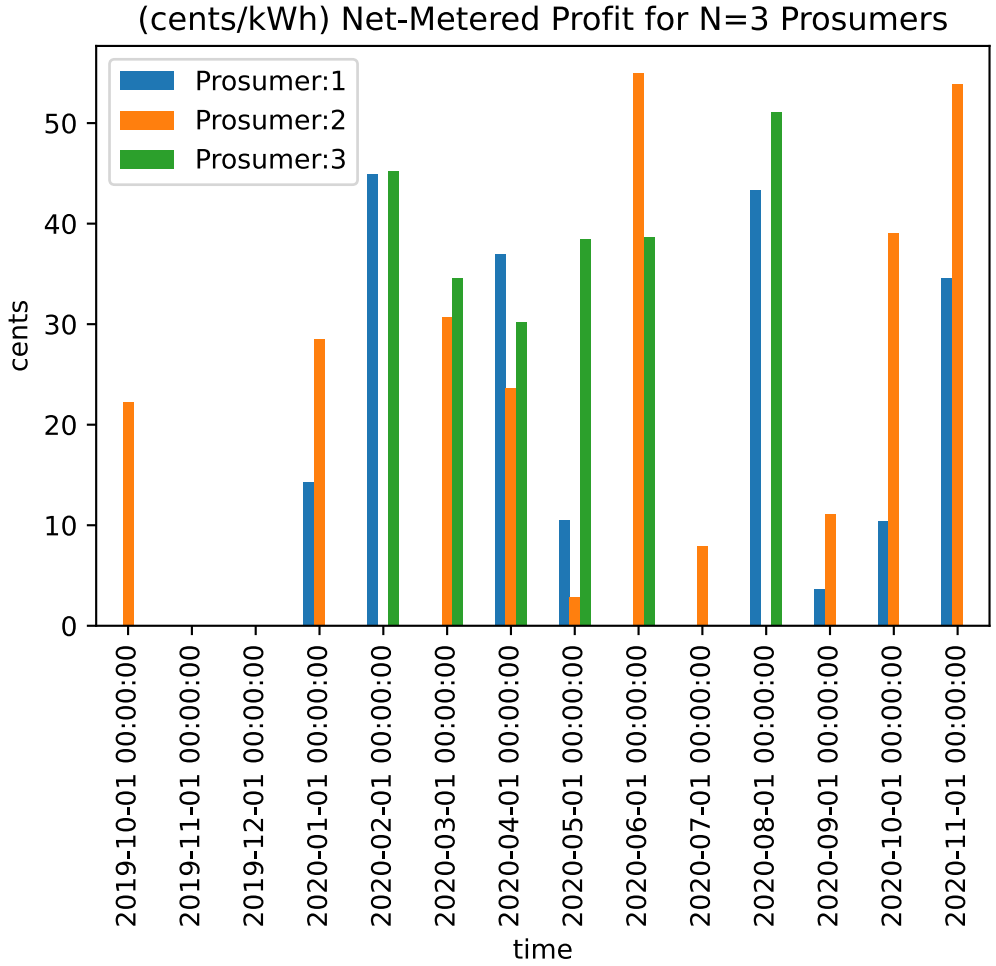
The winter season would yield the lowest net generation and the greatest consumption of energy.

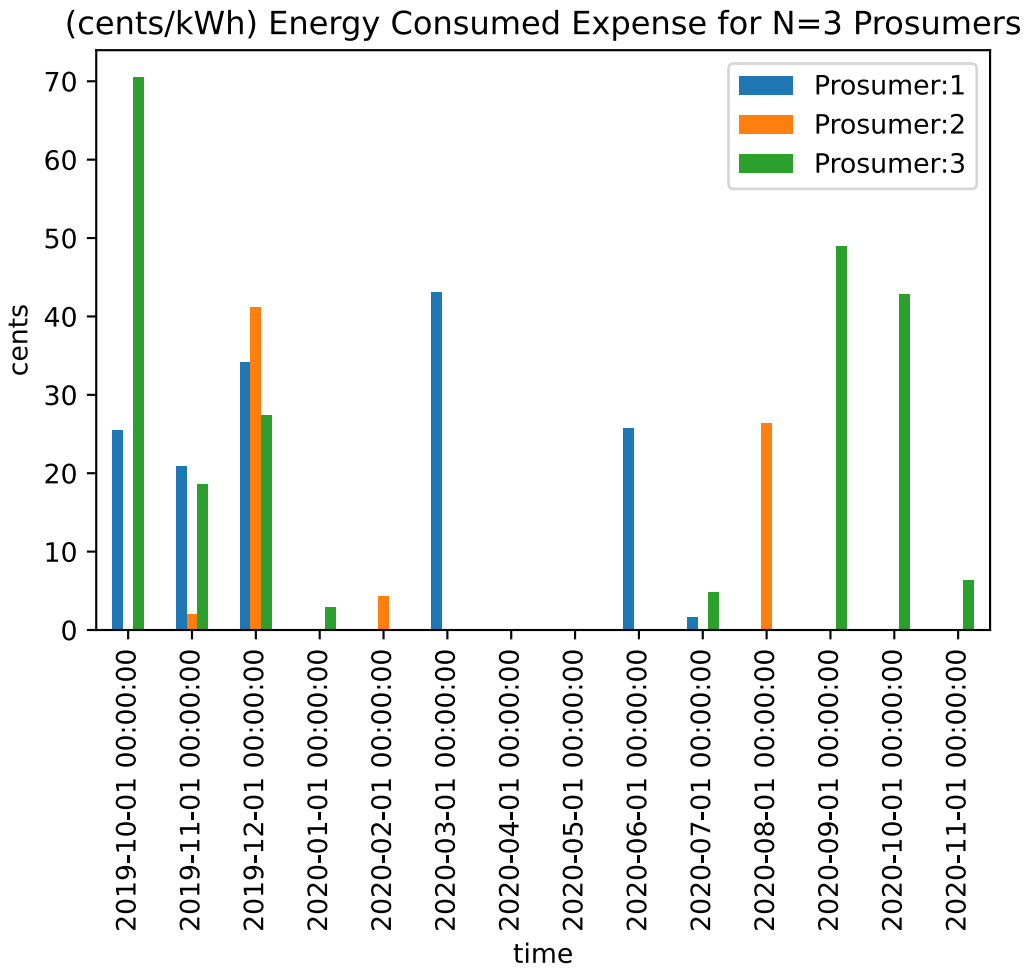
In [75]:

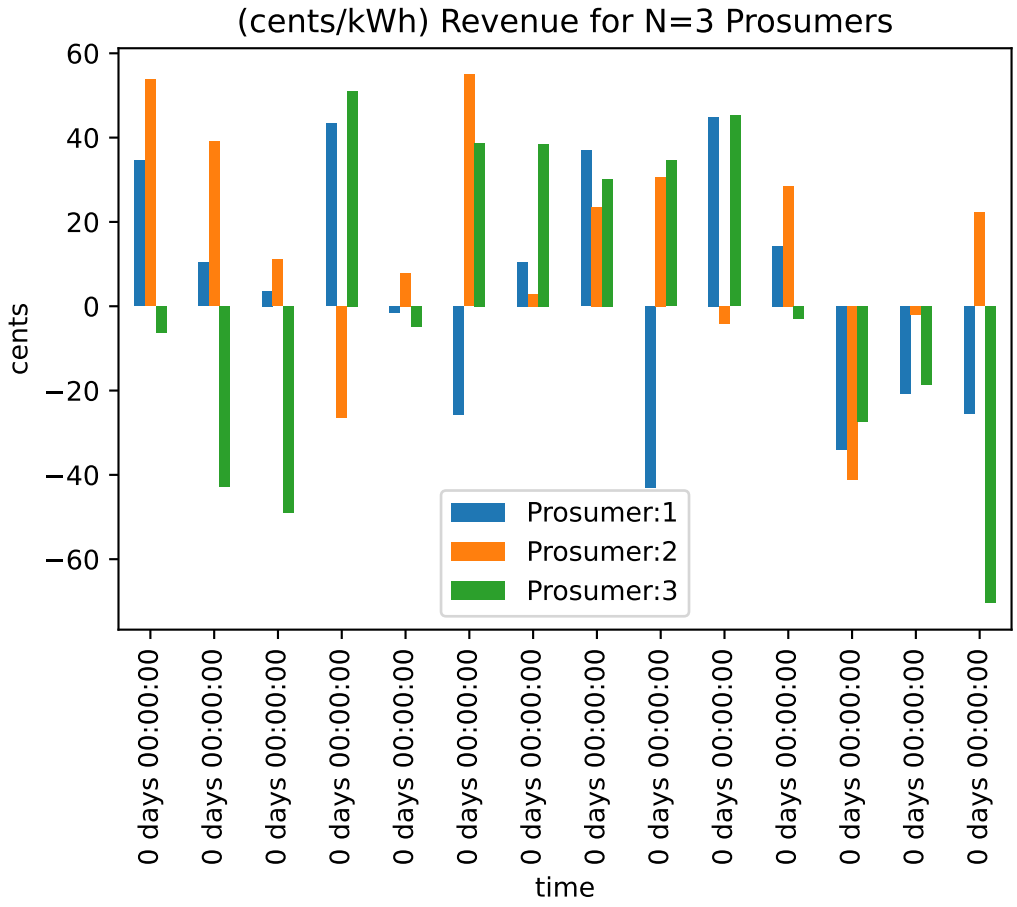
```
def get_curve_accross_prosumers(type_name):
    prosumers_arr = []
    for prosumer in prosumers:
        prosumers_arr.append(
            pd.DataFrame(list(zip(prosumer.data['time'],prosumer.data[type_name]
            columns=['time',f'Prosumer:{prosumer.id}']))
    return reduce(lambda left,right: pd.merge(left,right,on=['time'],how='outer'

#show pricing for all prosumers
all_profits = get_curve_accross_prosumers('profit')
all_expenses = get_curve_accross_prosumers('expense')
all_revenue = all_profits - all_expenses

ax = all_profits.sort_values(by='time').plot.bar(x='time',title=f"(cents/kWh) Ne
ax.set_ylabel("cents")
ax = all_expenses.sort_values(by='time').plot.bar(x='time',title=f"(cents/kWh) E
ax.set_ylabel("cents")
ax = all_revenue.sort_values(by='time').plot.bar(x='time',title=f"(cents/kWh) Re
ax.set_ylabel("cents")
#plt.legend('')
plt.show()
```




(cents/kWh) Energy Consumed Expense for N=3 Prosumers
Prosumer:1
Prosumer:2
Prosumer:3
cents
0
10
20
30
40
50
60
70
2019-10-01 00:00:00
2019-11-01 00:00:00
2019-12-01 00:00:00
2020-01-01 00:00:00
2020-02-01 00:00:00
2020-03-01 00:00:00
2020-04-01 00:00:00
2020-05-01 00:00:00
2020-06-01 00:00:00
2020-07-01 00:00:00
2020-08-01 00:00:00
2020-09-01 00:00:00
2020-10-01 00:00:00
2020-11-01 00:00:00
time


(cents/kWh) Revenue for N=3 Prosumers
Prosumer:1
Prosumer:2
Prosumer:3
cents
−60
−40
−20
0
20
40
60
0 days 00:00:00
time

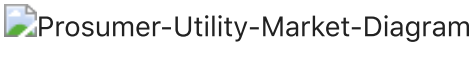
2.2 Analysis of the Market Performance

The total market performance can include the following players:

1. Utility (Grid Owner)
2. Prosumer
3. Consumer

Where the Grid Owner, is considered the Utility company providing the power to the consumers and prosumers. When there is a prosumer that does not generate any net energy it would be considered a consumer for that period. When a consumer purchases power to meet its demand the total consumption would come directly from the Utility.

Utility Market Diagram



In [105…

```
print("\nProfit Table")
print(tabulate(all_profits,headers='keys',tablefmt = 'github',showindex=False))
print("\nTotal Profits")
print(f"{all_profits.sum()}")

print("\nExpense Table")
print(tabulate(all_expenses,headers='keys',tablefmt = 'github',showindex=False))
print("\nTotal Expenses")
print(f"{all_expenses.sum()}")

print("\nRevenue Table")
print(tabulate(all_revenue,headers='keys',tablefmt = 'github',showindex=False))
print("\nTotal Revenues")
print(f"{all_revenue.sum()[1:]}")
```

```
Profit Table
| time                |   Prosumer:1 |   Prosumer:2 |   Prosumer:3 |
|---------------------|--------------|--------------|--------------|
| 2020-11-01 00:00:00 |      34.5569 |      53.821  |         0    |
| 2020-10-01 00:00:00 |      10.4063 |      39.0498 |         0    |
| 2020-09-01 00:00:00 |       3.65029 |      11.0422 |         0    |
| 2020-08-01 00:00:00 |      43.3668 |       0      |        51.0655 |
| 2020-07-01 00:00:00 |       0      |       7.90852 |         0    |
| 2020-06-01 00:00:00 |       0      |      54.929  |        38.6809 |
| 2020-05-01 00:00:00 |      10.499  |       2.85888 |        38.4321 |
| 2020-04-01 00:00:00 |      36.9787 |      23.5928 |        30.1827 |
| 2020-03-01 00:00:00 |       0      |      30.6748 |        34.5882 |
| 2020-02-01 00:00:00 |      44.9263 |       0      |        45.2307 |
| 2020-01-01 00:00:00 |      14.316  |      28.4651 |         0    |
| 2019-12-01 00:00:00 |       0      |       0      |         0    |
| 2019-11-01 00:00:00 |       0      |       0      |         0    |
| 2019-10-01 00:00:00 |       0      |      22.2501 |         0    |

Total Profits
Prosumer:1    198.700168
Prosumer:2    274.592171
Prosumer:3    238.180211
dtype: float64

Expense Table
```

time	Prosumer:1	Prosumer:2	Prosumer:3
2020-11-01 00:00:00	0	0	6.29818
2020-10-01 00:00:00	0	0	42.8284
2020-09-01 00:00:00	0	0	48.9235
2020-08-01 00:00:00	0	26.3635	0
2020-07-01 00:00:00	1.59601	0	4.78907
2020-06-01 00:00:00	25.705	0	0
2020-05-01 00:00:00	0	0	0
2020-04-01 00:00:00	0	0	0
2020-03-01 00:00:00	43.0449	0	0
2020-02-01 00:00:00	0	4.23066	0
2020-01-01 00:00:00	0	0	2.90349
2019-12-01 00:00:00	34.1292	41.1944	27.3458
2019-11-01 00:00:00	20.8255	2.00119	18.5679
2019-10-01 00:00:00	25.4854	0	70.445

```
Total Expenses
Prosumer:1    150.786018
Prosumer:2     73.789742
Prosumer:3    222.101300
dtype: float64
```

Revenue Table

time	Prosumer:1	Prosumer:2	Prosumer:3
0 days 00:00:00	34.5569	53.821	-6.29818
0 days 00:00:00	10.4063	39.0498	-42.8284
0 days 00:00:00	3.65029	11.0422	-48.9235
0 days 00:00:00	43.3668	-26.3635	51.0655
0 days 00:00:00	-1.59601	7.90852	-4.78907
0 days 00:00:00	-25.705	54.929	38.6809
0 days 00:00:00	10.499	2.85888	38.4321
0 days 00:00:00	36.9787	23.5928	30.1827
0 days 00:00:00	-43.0449	30.6748	34.5882
0 days 00:00:00	44.9263	-4.23066	45.2307
0 days 00:00:00	14.316	28.4651	-2.90349
0 days 00:00:00	-34.1292	-41.1944	-27.3458
0 days 00:00:00	-20.8255	-2.00119	-18.5679
0 days 00:00:00	-25.4854	22.2501	-70.445

```
Total Revenues
Prosumer:1    47.9141
Prosumer:2    200.802
Prosumer:3    16.0789
dtype: object
```

2.3 Analysis of the Market Performance for 100 Prosumers

To understand the scalability of the market, we will simulate N=100 prosumers. The charts will show the same volatility curves and calcualte the revenue, from the profit and expenses during the demand and generation curves.

In [109…

```
#Import the data to local csv
all_prosumers_data = pd.read_csv('data/prosumer_N100_model_20210129_1414.csv')
all_prosumers_data["time"] = pd.to_datetime(all_prosumers_data['time'], format='
all_prosumers_data.sort_values(by='time')
prosumer_data = [pd.DataFrame(y) for x, y in all_prosumers_data.groupby('id', as
# Generate prosumers based on normalized curves from data gethering stage
prosumers = []
```

```
for data in prosumer_data:
    prosumers.append(Prosumer(data,cost_of_energy))

# number of prosumers retrieved from dataset
N = len(prosumers)
def get_curve_accross_prosumers(type_name):
    prosumers_arr = []
    for prosumer in prosumers:
        prosumers_arr.append(
            pd.DataFrame(list(zip(prosumer.data['time'],prosumer.data[type_name]
            columns=['time',f'Prosumer:{prosumer.id}']))
    return reduce(lambda left,right: pd.merge(left,right,on=['time'],how='outer'

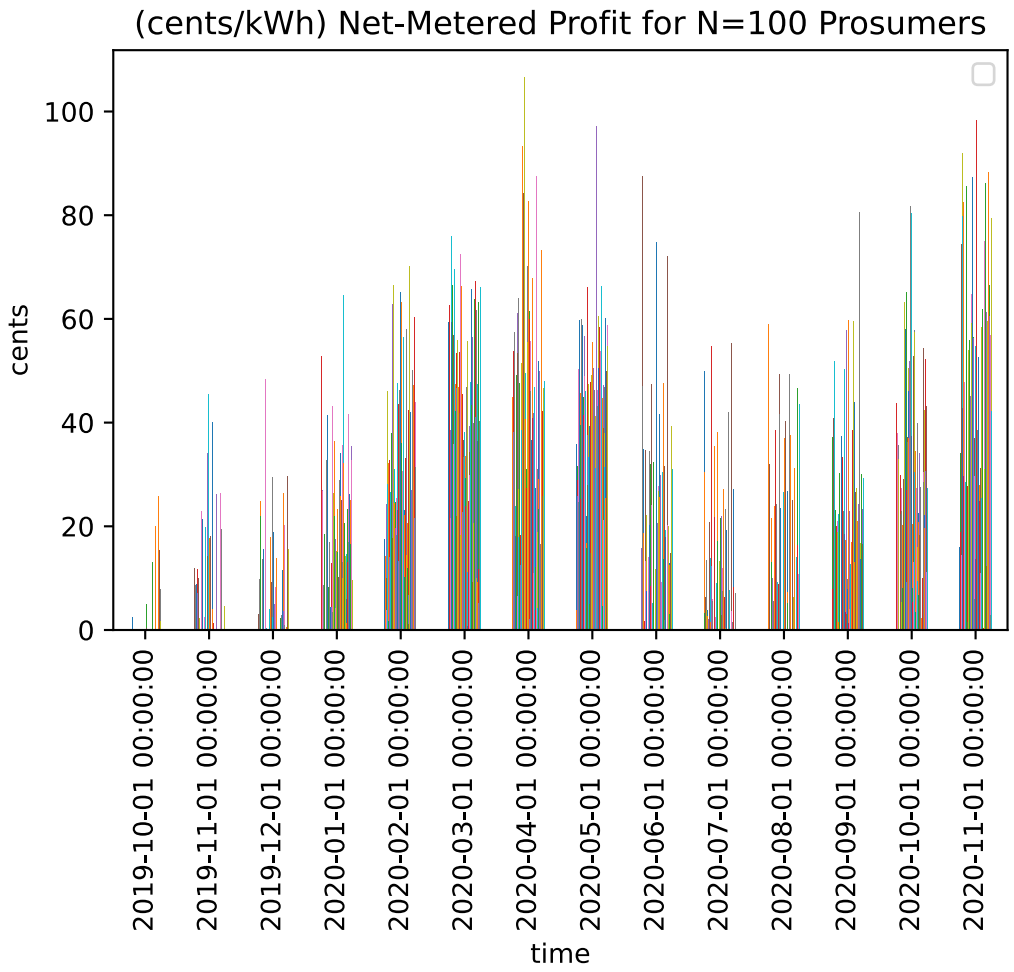
#show pricing for all prosumers
all_profits = get_curve_accross_prosumers('profit')
all_expenses = get_curve_accross_prosumers('expense')
all_revenue = all_profits - all_expenses

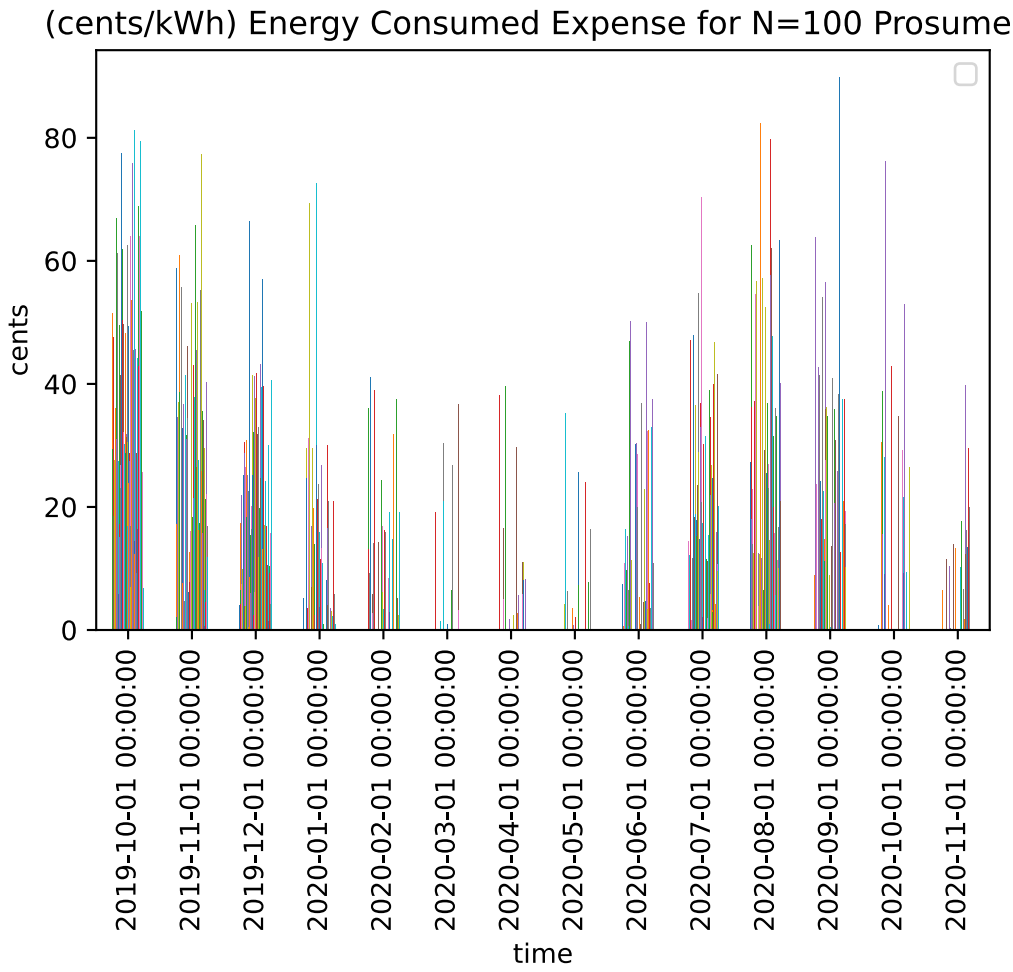
ax = all_profits.sort_values(by='time').plot.bar(x='time',title=f"(cents/kWh) Ne
ax.set_ylabel("cents")
ax.legend('')
ax = all_expenses.sort_values(by='time').plot.bar(x='time',title=f"(cents/kWh) E
ax.set_ylabel("cents")
ax.legend('')
ax = all_revenue.sort_values(by='time').plot.bar(x='time',title=f"(cents/kWh) Re
ax.set_ylabel("cents")
ax.legend('')
plt.show()

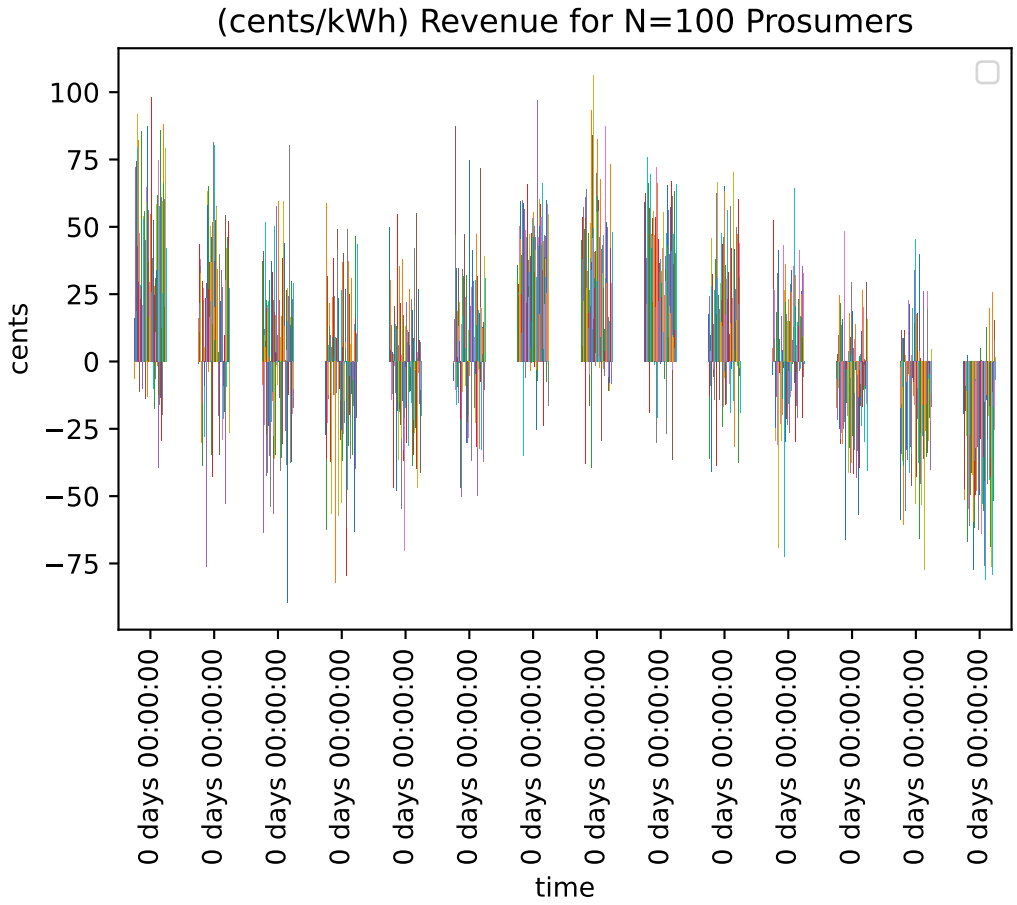
print("\nProfit Table")
print(tabulate(all_profits,headers='keys',tablefmt = 'github',showindex=False))
print("\nTotal Profits")
print(f"{all_profits.sum()}")

print("\nExpense Table")
print(tabulate(all_expenses,headers='keys',tablefmt = 'github',showindex=False))
print("\nTotal Expenses")
print(f"{all_expenses.sum()}")

print("\nRevenue Table")
print(tabulate(all_revenue,headers='keys',tablefmt = 'github',showindex=False))
print("\nTotal Revenues")
print(f"{all_revenue.sum()[1:]}")
```


(cents/kWh) Net-Metered Profit for N=100 Prosumers
cents
0
20
40
60
80
100
2019-10-01 00:00:00
2019-11-01 00:00:00
2019-12-01 00:00:00
2020-01-01 00:00:00
2020-02-01 00:00:00
2020-03-01 00:00:00
2020-04-01 00:00:00
2020-05-01 00:00:00
2020-06-01 00:00:00
2020-07-01 00:00:00
2020-08-01 00:00:00
2020-09-01 00:00:00
2020-10-01 00:00:00
2020-11-01 00:00:00
time


(cents/kWh) Energy Consumed Expense for N=100 Prosumers
cents
0
20
40
60
80
2019-10-01 00:00:00
2019-11-01 00:00:00
2019-12-01 00:00:00
2020-01-01 00:00:00
2020-02-01 00:00:00
2020-03-01 00:00:00
2020-04-01 00:00:00
2020-05-01 00:00:00
2020-06-01 00:00:00
2020-07-01 00:00:00
2020-08-01 00:00:00
2020-09-01 00:00:00
2020-10-01 00:00:00
2020-11-01 00:00:00
time


(cents/kWh) Revenue for N=100 Prosumers
cents
100
75
50
25
0
−25
−50
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time

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-5.54894  |    -18.3783  |     -8.99846 |     -5.78584 |    -27.5186  |     -11.
0341  |       2.47153 |     -36.0588  |     -66.9094  |     -25.6063  |     -30.
9546  |     -50.2156  |     -54.6756  |     -61.2154  |      -2.77768 |    -27.3
119   |      -5.73668 |     -16.2412  |     -49.5181  |     -17.0713  |      -1
5.1111 |     -41.3961  |     -26.776   |    -22.9928   |    -42.2212   |    -32.
6269   |     -77.3923  |    -59.4227   |     -61.8093  |     -50.3316  |     -3
7.0813  |     -49.7065  |     -32.1385  |      -7.41774 |      -6.31353 |     -3
0.1698  |     -19.2555  |     -48.1745  |     -28.7605  |     -20.6303  |    -3
1.8284   |     -31.2538  |     -48.9063  |     -62.491   |     -30.4424  |     -1
6.8324   |    -49.4063   |     -23.841   |      4.96415  |     -28.6722  |      -
27.3176  |      0.386192 |     -63.9087  |     -16.7489  |      -6.92822 |     -5
2.9341   |    -17.6375   |     -53.5365  |    -55.551    |     -35.6224  |      -
75.829   |      -44.5429 |     -15.0457  |     -45.4518  |    -47.6151   |
-81.1521 |     -14.4572  |     -12.3403  |     12.9867   |    -42.1247   |      -
45.6343  |     -28.7702  |     -0.742573 |      -9.15735 |   -20.3481    |      -
44.0829  |     -16.3709  |      19.9069  |     -68.7683  |    -42.8022   |      -
15.8787  |     -36.0071  |     -64.0438  |    -49.6508   |     -76.2775  |     -7
9.3344   |    -11.2513   |     25.7535   |     -51.8271  |      -8.44569 |      -
16.7531  |      15.4114  |      -25.5241 |       7.88565 |       1.58656 |      -
6.8175    |

Total Revenues
Prosumer:1      102.855
Prosumer:2      92.5932
Prosumer:3      96.5919
Prosumer:4      153.259
Prosumer:5      120.287
Prosumer:6       314.05
Prosumer:7      83.0499
Prosumer:8      238.853
Prosumer:9      169.368
Prosumer:10     245.431
Prosumer:11     147.297
Prosumer:12     188.431
Prosumer:13     74.9761
Prosumer:14    -50.4984
Prosumer:15     7.13954
Prosumer:16     130.074
Prosumer:17     35.0667
```

```
Prosumer:18     55.8543
Prosumer:19      53.919
Prosumer:20     88.1443
Prosumer:21     137.418
Prosumer:22     155.463
Prosumer:23     194.814
Prosumer:24     122.152
Prosumer:25    -87.6043
Prosumer:26     52.3355
Prosumer:27     182.534
Prosumer:28     103.514
Prosumer:29     136.896
Prosumer:30     102.605
                 ...
Prosumer:71     188.467
Prosumer:72     149.574
Prosumer:73       106.7
Prosumer:74    -37.4579
Prosumer:75    -36.4869
Prosumer:76     78.8068
Prosumer:77     169.059
Prosumer:78     18.4182
Prosumer:79     86.9514
Prosumer:80     115.319
Prosumer:81     39.8043
Prosumer:82     115.788
Prosumer:83     39.8407
Prosumer:84    -61.3127
Prosumer:85     186.823
Prosumer:86     126.789
Prosumer:87     164.929
Prosumer:88     232.763
Prosumer:89     17.2441
Prosumer:90    -67.0106
Prosumer:91     169.166
Prosumer:92     301.095
Prosumer:93       166.7
Prosumer:94     200.791
Prosumer:95      64.372
Prosumer:96     168.742
Prosumer:97     218.993
Prosumer:98      44.493
Prosumer:99      276.75
Prosumer:100    187.775
Length: 100, dtype: object
```

Step 3: Summary and Further Studies

The total revenue of each prosumer was positive during the simulation. The variability in generation is a key factor in sustained profit to offset the consumption. The retail price per month coincides with the times the utility is expecting the greatest demand. The dynamic pricing results in adjustments to the load expected by the utility. The solar generation covered the load of the homes but would of been even greater if the capacity of the homes generatin units was not limited by the utility. Further analysis should be taken to validate the performance of Tier2/Tier3 systems during the same demand curves. These larger systems should produce more and provide greater revenue.

The cost to transfer power from the utility to the prosumers is embedded in the reail cost of electric consumption. When the prosumers offset the generation they end up getting money back and not paying for the operating maitenance of the distribution of power. This cost is most times injected into the consumers retail price of electricity. Much regulation is pursued by utilities to offset this dynamic. A further analysis would be to understand how much energy is owed in distribution costs and if it can still be offset by the annual revenue from generation of the prosumers.