Analysis of trade-off between investment cost and sustainability for renewable energy integration in a neighborhood

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Abstract -- By 2023. the Dutch government plans to make 16% of all energy used in the Netherlands sustainable. [21] – The objective of this paper is to investigate the trade-off between price and energy production by simulating different battery sizes on different photovoltaic (PV) sizes and compare the cost of system with the savings. This paper finds that the effect of using larger size batteries with the current market prices is insignificant on savings and energy consumed from PV in the case of distributed battery storage.

I. INTRODUCTION

As the costs of fossil fuels rise and climate change is becoming worse [1], there has been a rise in the distribution of renewable energy sources such as wind and solar. This is since such renewable energy sources have the potential to reduce stress on the electric grid whilst decreasing the greenhouse gas emission in the electric sector [2]. Unfortunately, both wind energy and solar photovoltaics have varying and uncertain output unlike the dispatchable sources most countries rely on for electricity generation today. The inconsistency of the output of these sources has raised questions over the reliability of an electric grid that obtains a significant amount of its energy from these sources as well as the costs of their implementations. Since the weather cannot be manipulated, it is important to have adequate energy storage systems to compensate. The simulation can help with visualizing the generation and consumption of the system and quantify an 'adequate' system and its corresponding costs.

II. PROBLEM DEFINITION

With the Netherlands setting out to miss its 2020 green energy targets [5], households remain doubtful of whether an investment into PV is worth it, despite the fact it can help the Netherlands reach its sustainability goal. Therefore, it is intriguing to inspect how much it would cost to have a significant amount of energy consumption to come from renewables. The addition of energy storage to the solar grid can increase the use of solar energy from between 50 to 80 % up to almost 100% [22]. The size of the solar grid will depend on the household consumption; whereas the capacity of energy storage will depend on both the solar grid size and the consumption. The amount of storage and solar panels used will depend on the costs and benefits. Thus, the first research question:

- How much energy will a certain financial investment return in terms of energy production and storage?

Additionally, some sub-questions have also been defined:

- At what cost would the solar panel provide enough electricity for the three months of summer?
- How would this produced and then stored energy be used efficiently?

III. METHODOLOGY

To answer these research questions, this paper will study a simulation model of a neighborhood consisting of 24 'earth-houses' built in Olst, The Netherlands. This neighborhood is inspired by Earthships of architect Michael Reynolds and plans to be softly isolated from the utility network regarding electricity and heat [4]. At present, this neighborhood is equipped with a certain number of electrical components as shown in table 1.

Table 1: Distribution of electrical equipment in the neighborhood.

Item	Number of households
Photovoltaic panels	All 24 houses
Battery	All 24 houses
Flexible appliance-washing machine	All 24 houses
Flexible appliance - dishwasher	13 houses

A model of this neighborhood is created using DEMKit; a python simulation provided by the University of Twente. This model will be simulated over one month of each season of the year as it would provide a reasonable insight on the energy production of the solar grid and the consumption over that season. The averaged values of the entire neighborhood are taken over an hour interval. Three solar grid sizes were considered: 10 m^2, 20 m^2, and 30 m^2. Moreover, since the average efficiency of a PV panel is between 15% and 22.5%; an efficiency of 18% was set in the model. The PV was also set with a 35-degree inclination and azimuth pointing south. This simulation provides quantitative data which will be used to answer the research questions. There is a total of three values to be observed, which are net costs, energy self-consumed and State of Charge (SOC). The first, net costs, is the difference between the import and export costs which would tell us the net money spent or earned. Secondly, energy self-consumed, is the energy produced by the PV and used within the household whether on appliances or charging the battery which will provide us with the savings in consumption. Finally, SOC is simply how full the batteries of the PV are, which will aid in finding the percentage of days with an empty battery and help in determining an adequate battery capacity.

IV. ANALYSIS

The initial cost of installation has been a challenge for adopting alternative energy technologies with no exception to the PV system. The cost of installing the PV system can vary depending on the size of the system, type of PV cells used, and whether the system is grid connected or has a battery unit to store surplus energy for later use, or both [3]. In addition, the grid-tied PV system allows the neighborhood to export any unconsumed electricity back to the grid. Until 2020, households will be paid the same amount per kWh of exported energy as the cost per kWh of imported energy. However, after 2020, the Dutch government is introducing feed-in tariffs which make households get paid 30% less per kWh exported than the price households pay per kWh imported [23]. This would make people lean more towards to consuming the energy their households produced rather than export it. And so, making energy storage systems a more attractive option.

In order to estimate an enough home battery capacity, a simulation using a very large battery capacity (1 GWh) and an initial state of charge of 1 MWh was executed. These values were chosen as they allow the energy to be maintained in the system. The model was simulated over April, July and October. Since the PV energy production in winter is very low, the batteries would rarely be useful and so, this season was not considered. This simulation was repeated over different solar grid sizes. It is expected that the battery will store an excess of energy, from which the drops in SOC will be analyzed to find a daily capacity requirement for one of these drops.

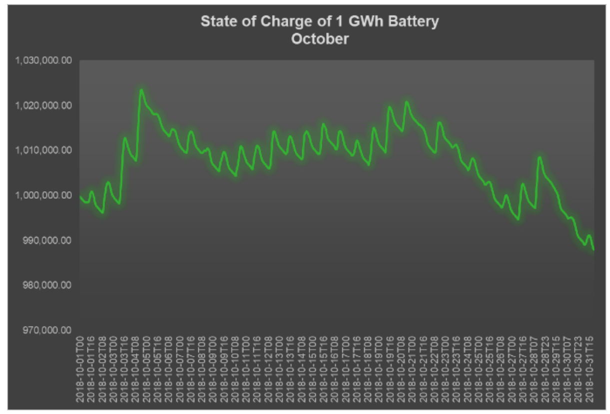

Figure 1: Values are in kWh; State of charge (y-axis); time (x-axis)

From figure 1, the drop in the value of state of charge over days of low PV production was calculated and then averaged. The averaged results of the simulations can be seen in table 2 shown below.

Table 2: Average drop in SOC. Values in kWh

	Month			
Size	April	July	October	Average
$10 m^2$	17.00	14.50	17.00	16.00
$20\ m^2$	9.00	14.00	11.00	11.00
$30\ m^2$	5.00	10.00	7.00	7.33

Unfortunately, the available home energy storage currently on the Dutch market can store a maximum of 14 kWh [6]. Some of the available products on the market are shown in Table 3.

Table 3: Available home energy systems in The Netherlands

Battery brand	Battery Chemistry	Usable Capacity [kWh]	Cost [€]	Warranty in years
Tesla Powerwall 2 [7]	Lithium-ion	13.5	7,980 (inc. installation costs)	10
Fronius Solar Battery 12.0 [8]	Lithium-ion	9.6	8,052	20 +
LG Chem RESU 10H [9]	Lithium-ion	12	5,519	10
Panasonic LJ-SK84A [10]	Lithium-ion	8	4,500	10
SolarWatt My Reserve[11]	Lithium - ion	11	TBD	10

Multiple different capacities of distinct battery brands were tested in the simulation according to the averages in Table 2 and results were compared. To cover the required calculated battery size for a 10 m^2 solar grid size, two 8kWh Panasonic LJ-SK84A batteries connected in series would be necessary. The cost of such battery capacity could be lower if a single battery of such capacity was available. On the other hand, for other grid sizes, a single battery would be necessary.

Table 4 shows the cost and peak power of solar grid sizes provided by a Dutch provider. This table will be of use when determining the relation between energy production/storage and financial investment.

Table 4: The cost and peak power of PV [12]

PV size	Peak power [W]	Cost [€]
10 m^2	1470 - 1543	1690 - 1730
20 m^2	2941– 3086	3380 - 3460
30 m^2	4411 - 4630	5070 - 5190

V. RESULTS

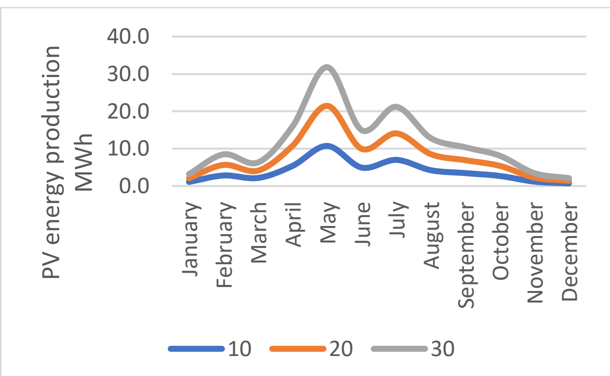

Figure 2: Annual PV energy production over entire neighborhood

Figure 2 shows the energy production of the PV for the whole neighborhood over an entire year. The values over the months which were not simulated were extrapolated using the values of the simulated months and the ratio of sunny hours retrieved from [13]. It is assumed here that the solar irradiance is similar through all sunny hours. As expected, there is low PV production during winter and then peaks during summer. The larger the PV grid size, the more energy was produced.

Tables 5 and 7 show the net costs from importing-exporting energy under the net metering scheme currently followed by the Dutch government.

Tables 6 and 8 represent the savings made by using the energy produced by the solar system instead of importing that same energy from the main electric grid. The values represented in these tables follow a pricing scheme of 0.16-euro cents per kWh of energy self-consumed [14]. The values of energy self-consumed of which these savings were calculated from can be found in tables 10 and 11 in the Appendix.

What can clearly be seen from tables 5 to 8 is the effect of PV grid size on the net costs and savings. A 20 m^2 solar grid led to a drop in just energy import costs by 19% during the month of January and by 28% during October. Moreover, the tables show that there is only a slight change in net costs and savings as the capacity of the battery is altered under multiple PV grid sizes.

Table 5: Net costs (in euros) of PV sizes: 10 m^2 and 20 m^2(negative values imply income from exporting energy)

		Battery Size		
Month	PV size	12 kWh	13.5 kWh	16 kWh
January	10m^2	37.40	37.33	37.22
	20m^2	30.49	30.43	30.32
April	10m^2	4.82	4.67	4.40
	20m^2	-18.97	-18.85	-18.64
July	10m^2	-2.73	-2.71	-2.53
	20m^2	-33.12	-33.00	-32.79
October	10m^2	24.25	24.19	24.10
	20m^2	6.87	6.52	6.11

Table 6: Saving from self-consumed energy from PV at 0.16 euro cents per kWh [14] of PV sizes 10 m^2 and 20 m^2

		Battery Size		
Month	PV size	12 kWh	13.5 kWh	16 kWh
January	10m^2	8.48	8.51	8.59
	20m^2	17.97	18.00	18.07
April	10m^2	41.42	41.85	42.58
	20m^2	46.06	46.16	46.48
July	10m^2	44.01	44.57	44.92
	20m^2	47.46	47.60	47.87
October	10m^2	23.11	23.15	23.19
	20m^2	44.86	46.08	47.52

The biggest difference happens between a battery capacity of 13.5 kWh and 16kWh in which the latter saves an extra 1.5 euros during the month of October and only a few cents more during other months in the case of a 20 m^2 PV. Once the Dutch government introduces feed-in tariffs, less energy produced by the PV would be exported, but rather used for self-consumption and so possibly increasing the savings represented in tables 6 and 8.

Table 7: Net costs (in euros) of PV size 30 m^2

	Battery Size		
Month	9.6 kWh	11 kWh	13.5 kWh
January	23.89	23.89	24.06
April	-42.02	-41.91	-41.71
July	-63.13	-63.02	-62.83
October	-5.52	-5.83	-6.19

Table 8: Saving from self-consumed energy from PV at 0.16 euro cents per kWh [14] for PV size of 30 m^2

	Battery Size		
Month	9.6 kWh	11 kWh	13.5 kWh
January	27.02	27.63	27.74
April	45.61	45.77	46.03
July	42.78	42.94	43.21
October	48.36	49.36	50.49

The same can be said for other grid sizes on this matter, which proves that the effect of battery capacity on the profits is insignificant. The other variable to look at when choosing the battery capacity is the percentage of occurrences where the battery is full or empty. A table demonstrating the percentages can be found in table 12 Appendix I. The values there also show insignificant difference which is not worth the larger investment. In the case of solar grid sizes of 10 m^2 and $20m^2$ the most suitable options are the LG CHEM RESU 10H (10 kWh capacity) and the Tesla Powerwall 2 (13.5 kWh). However, since the cost of the Powerwall 2 includes both the inverter and installment cost; it stands out to be the smarter investment. In the case of a 30 m^2 grid, the most convenient batteries would be Solar Watt's My Reserve and Tesla's Powerwall 2. What will determine which is a more suitable option would be the pricing which unfortunately the pricing of Solar Watt is not available, so the Tesla Powerwall 2 is chosen again. Now that the battery brand is decided, a relation between energy produced and investment cost can be made using the prices in table 4. This is shown in figure 3.

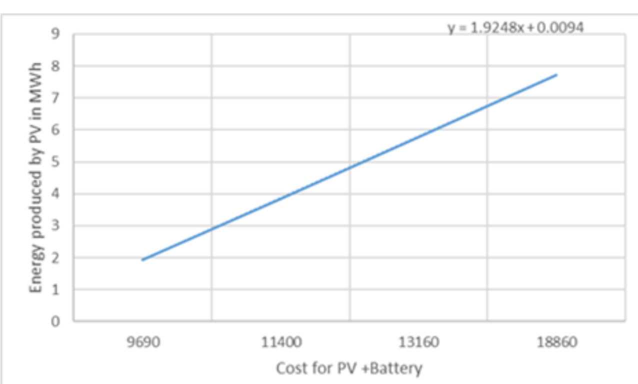

Figure 3

Figure 3 shows a linear relation between energy produced and investment cost. So, for a PV system size of 10 m^2 it would cost 4994 euros per MWh; whereas a 20 m^2solar grid system would cost 2961 euros per MWh and a $30m^2$ grid would cost 2277 euros per MWh. However, the payback time of each size will also differ. If we extrapolate the savings from energy self-consumed under the same pricing scheme, we find that for $10\ m^2, 20m^2 and\ 30\ m^2$, a household saves 345, 486, and 537 euros respectively annually by consuming the energy self-produced rather than importing it from the main grid.

Table 9: Self-consumed energy (in kWh)

Month/PV size	10 m^2	20 m^2	30 m^2
January	53.2	112.5	175.4
April	261.5	279.39	287.7
July	278.6	272.5	270.1
October	144.7	288.0	315.5

According to [20], an average Dutch household in 2015 consumed 2.996 MWh a year; which estimates to around 247 kWh a month. So, in the case of summer, this can be covered by either solar grid size. This is seen in table 9, where the energy produced and consumed by the household is above 247 kWh under all PV sizes. This is expected since the PV can support the households electrically during months of high PV production. The choice of PV size becomes more important during months of low PV production such as January and October. The larger the PV size, the more energy of the household consumption is covered by the PV, and the lower the amount of energy imported from the grid.

Even though a high need for increased electricity storage capacity is anticipated, it is not clear whether most of required storage will consist of centralized or decentralized storage systems. [15] finds that a centralized energy storage system has 13.34% reduction in grid dependency than that of a decentralized system in the case of a random load and 31.39% in the case of a shifted linear load. This is also confirmed by [16] that finds that using a large-scale storage with the same charging power and capacity as the sum of all home storages in one grid can on average half the losses incurred by the grid storage operation. [16] also finds that implementing large-scale storage can significantly reduce the high voltage overshoot due to high PV penetration in comparison to home storage. Currently, there are multiple existing technologies for application of energy storage systems. Multiple studies find that in grid-related applications where performance is valued as much as cost and scale, the low-cost Na-S battery system is preferred [17]. Moreover, [18] compared different technologies for energy storage applications and found that in high energy applications which includes supply and demand management balancing of the load curves and peak shaving, storage technologies which utilize daily charge–discharge cycles to insure economic gains, such as fuel cells and sodium–sulfur (NaS) batteries are better suited. In addition, installing a centralized battery would be more economically efficient. Saft's Internsium Mini energy storage system can store from 80 kWh up to 480 kWh; which is enough to store the entire neighborhood's energy. Such energy storage was deployed in a project in Spain and was expected to reduce the project's power bill by 8% [19].

VI. CONCLUSIONS AND RECOMMENDATIONS

This paper initially set out to study the relation between investment and sustainable energy production by comparing different solar grid sizes and energy storage capacities and the costs they imply. It also aimed to find other methods to increase efficiency of a solar system. This paper concludes that the effect of battery capacity on the energy used from the PV does not outweigh the increase in price that a higher capacity implies. The values in this paper are simulated, and so the effect of different storage capacity could have played a larger role in the case of real-life implantation. However, in the context of this paper, the Tesla Powerwall 2 remained the most viable option due to its low cost and high capacity. Moreover, the costs to set up a solar system inclusive of solar panels and energy storage were found. It was also found that a 10 m^2 is sufficient to cover the summer energy consumption Furthermore, several studies have found that a centralized storage system would be more optimal in the case of a neighborhood, and it allows for more room in the battery chemistry of batteries since home storage batteries tend to be Lithium-ion. This paper recommends further research on suitable energy storage system and the respective chemical compound of the battery.

VII. APPENDIX

Table 10: Self-consumed-energy in kWh) for PV size $30\ m^2$

	Battery Size		
Month	9.6 kWh	11 kWh	13.5 kWh
January	168.88	172.68	175.35
April	285.08	286.04	287.70
July	267.37	268.36	270.09
October	302.24	308.52	315.54

Table 11: Self-consumed energy (in KWh) for PV sizes $10\ m^2$ *and* $20\ m^2$

		Battery Size		
Month	PV size	12 kWh	13.5 kWh	16 kWh
January	$10m^2$	52.98	53.22	53.70
	$20m^2$	112.32	112.50	112.92
April	$10m^2$	258.90	261.54	266.10
	$20m^2$	287.88	289.39	290.52
July	$10m^2$	275.04	278.58	280.74
	$20m^2$	271.62	272.52	274.20
October	$10m^2$	144.42	144.66	144.96
	$20m^2$	280.38	288.00	297.00

Table 12: % occurrence where State of charge of battery is either empty or more than half its capacity (C)

Month	Battery Size	PV size	% empty	$\% > \frac{1}{2}C$
January	9.6 kWh	30 m^2	48.66%	7.12%
	11 kWh	30 m^2	47.85%	6.59%
	12 kWh	10m^2	83.06%	0%
		20m^2	65.99%	1.21%
	13.5 kWh	10m^2	82.93%	0%
		20m^2	65.99%	0.81%
		30 m^2	47.18%	6.32%
	16 kWh	10m^2	81.81%	0%
		20m^2	65.73%	0%
April	9.6 kWh	30 $m2$	0%	98.12%
	11 kWh	30 $m2$	0%	98.52%
	12 kWh	10$m2$	9.14%	41.5%
		20$m2$	0%	95.7%
	13.5 kW	10$m2$	8.47%	39.92%
		20$m2$	0%	97.58%
		30 $m2$	0%	98.52%
	16 kWh	10$m2$	6.59%	39.65%
		20$m2$	0%	98.39%
July	9.6 kWh	30 m^2	0%	79.93%
	11 kWh	30 m^2	0%	97.4%
	12 kWh	10m^2	0.81%	81.45%
		20m^2	0%	93.82%
	13.5 kWh	10m^2	0%	83.33%
		20m^2	0%	95.16%
		30 m^2	0%	98.65%
	16 kWh	10m^2	0%	87.40%
		20m^2	0%	95.16%
October	9.6 kWh	30 $m2$	6.04%	61.69%
	11 kWh	30 $m2$	4.29%	47.11%
	12 kWh	10$m2$	54.17%	1.21%
		20$m2$	12.48%	39.73%
	13.5 kW	10$m2$	54.3%	42%
		20$m2$	9.40%	37.3%
		30 $m2$	1.61%	71%
	16 kWh	10$m2$	54.3%	0%
		20$m2$	7.57%	35.3%

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