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RE: Distributed rooftop solar photovoltaic plus batteries cost in Puerto Rico

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Key Insights:

Main Points:

- The average COE of rooftop solar PV equipped with batteries in Puerto Rico, which provides resilience at the load, as of September 2023 is in the order of 15.5 cents per kWh.
- The cost of rooftop solar PV with batteries in Puerto Rico for the period between 2019 and 2023 results in a cost comparable to the negotiated price, of 10 cents to 15 cents per kWh, for the Tranche 1 solar farms, at the Point of Common Coupling, that do not include batteries and does not provide resilience to the loads.

Important Takeaways:

- Although the numbers presented in this work show a stable COE for the period studied, there is a fundamental difference between the quotes analyzed, the most recent offers for 2023 are based on a government incentives program that tends to increase the total cost of the same system.
- A tendency for better COE's when the system is designed for specific ranges of Inverter models has been noticed, where 4 kW, 6kW and 8 kW inverter ratings are standard, and widely available in Puerto Rico.
- Developers and the government must consider that COE is improved as the design of the system adjusts the amount of installed PV with the maximum rating capacity of the inverter and specifies an appropriate storage capacity for the system.

Based strictly on the available quotes, the total cost of PV plus Batteries systems (PV+Batts) in Puerto Rico has been stable in recent years. As referred to in this work, COE is the total capital cost of the installed solar system with batteries divided by the calculated kWh generated by the system over 20 years, presuming no batteries, or inverters, replacements¹. There are many factors that suggest COE reductions, including the availability of system equipment and components, the number of distributors and installers, other offers studied but presented in

¹ Assuming no battery replacement is justified in this study since we are evaluating emergency backup systems. In such systems batteries are only used during emergencies and/or during normal outages, where they usually are not fully discharged. Using local data collected through this project (refer to “**Comprehensive survey of residential photovoltaic systems in Puerto Rico**”), people expect between 3 to 4 outages of about 4 hours each week. Presuming maximums, let then be 4 outages per week with each outage lasting 4 hours, and consider that to be 25% the total of a one-day autonomy from the BESS (16 hrs. autonomy). For LiFePO4 batteries, 25% storage equals 1 cycle every 3.2 outages, or 83 cycles per year. Such technology at 5000 (@ 20% SoC) life span cycles represents approximately 60 years of battery life. We are certain that no battery technology would last that long, however, the number suggests that battery replacement is not necessary for backup battery systems.

another work, and the rate of adoption (refer to “**Distributed rooftop solar photovoltaic generation adoption in Puerto Rico**”), to name a few. However, using the quotes available the COE has kept around 15 cents per kWh as will be presented in due course.

1. Cost profile of the Home Energy Resilience Installations Program, August 2023 (Reference Guide 2023-02-200-HA)

In this section we show actual COE for PV+Batt systems in the Island for the second round of the *Home Energy Resilience Installations Program*. The program applications opened in August 2023. Such applications allowed a 30% incentive for the total project cost, up to a maximum amount of \$15,000. Also, the calls for applications established an average cost of PV at \$3,071/kW and \$1,066/kWh for BSS.

Figure 1 shows the cost of energy (COE) versus the total installed PV capacity for such systems. The lowest cost of energy (COE) appears on the system with 5.4 kW of total installed PV, at approximately 11.9 cents/kWh, and the highest of all available quotes stands at 21.6 cents/kWh of installed PV capacity. The average of all systems in this category is 15.9 cents/kWh.

From the data in Appendix A, the total project costs are between \$21,148 and \$42,876.

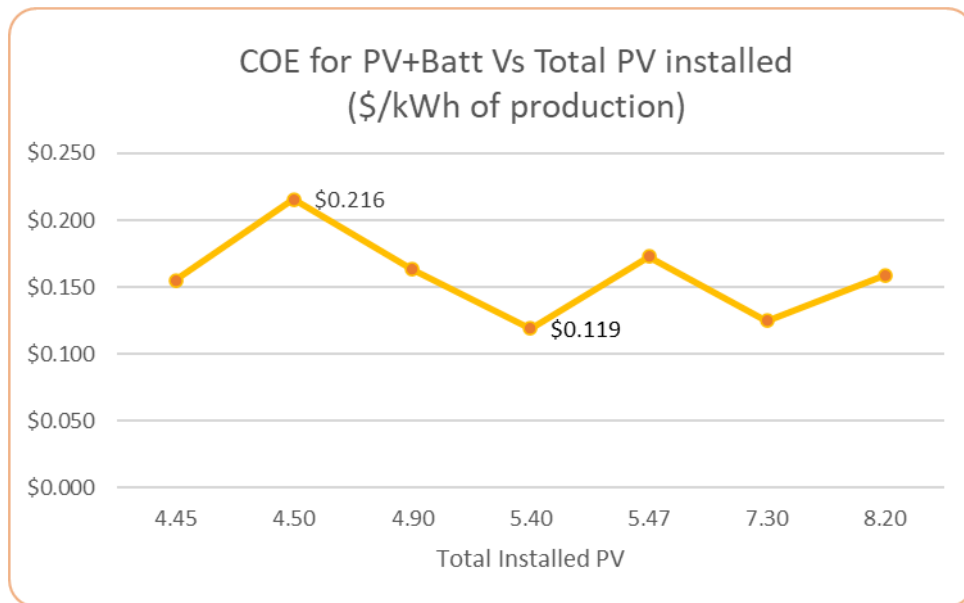


Figure 1. The COE as a function of system capacity for PV+Batt systems in PR, under program 2023-02-200-HA, as of June 2023.

2. Cost profile of installed rooftop solar plus batteries for the period of 2019 to 2022

In this section we show the actual cost and COE for PV+Batt systems as installed in Puerto Rico between the years 2019 to 2022.

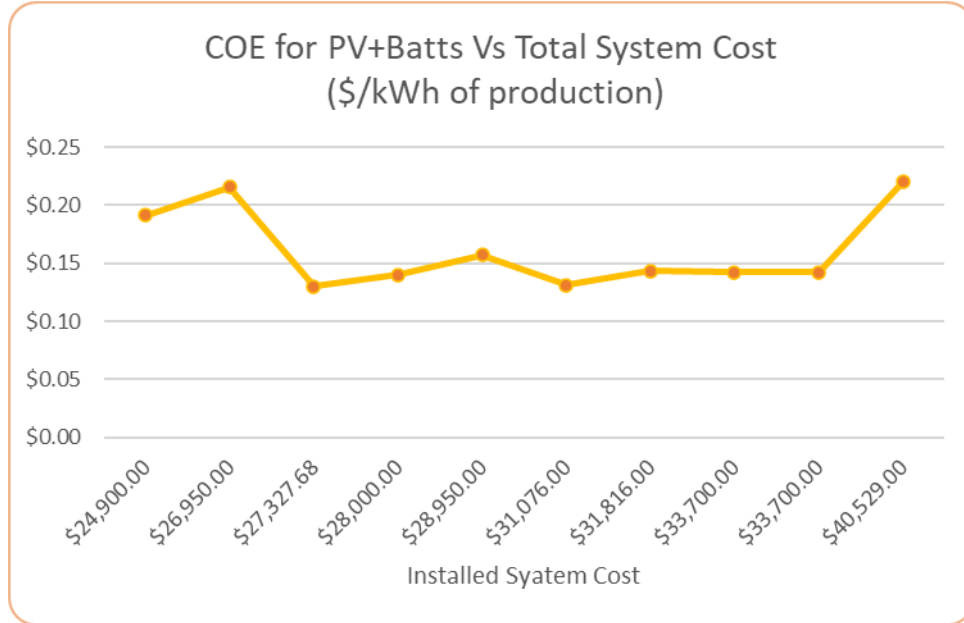


Figure 2. The COE as a function of total system cost for PV+Batt systems in PR for the period of 2019 to 2022, data provided by a Team member, Universidad de Puerto Rico – Mayagüez (UPRM).

Figure 2 shows the COE versus total system cost of installed PV systems with batteries between the years 2019 to 2022. In this figure a range of systems from 27 thousand to 34 thousand USD total cost had the lowest COE, between 13 to 16 cents per kWh, approximately.

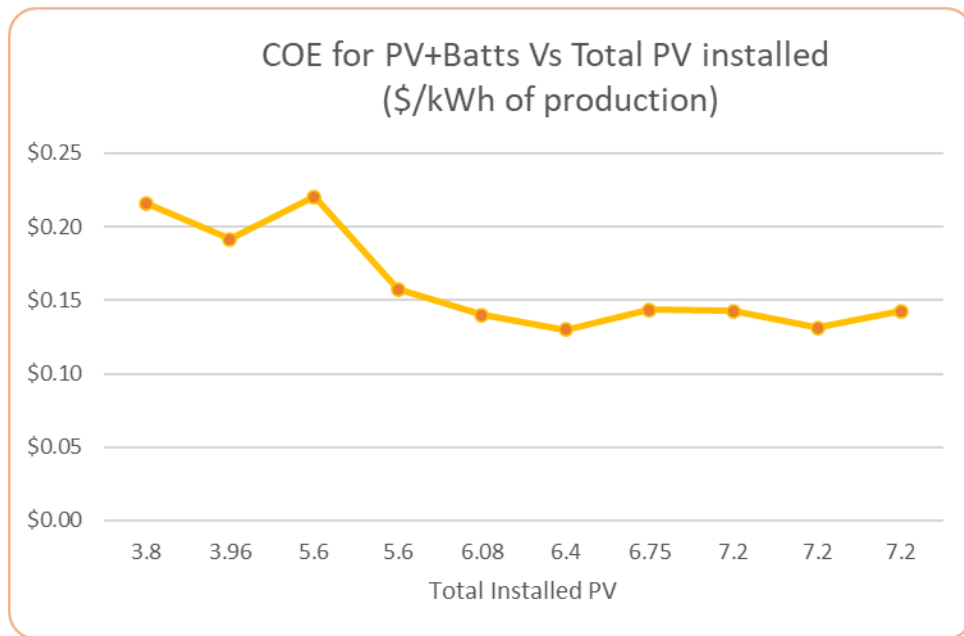


Figure 3. The COE as a function of the installed PV capacity for PV+Batt systems in PR for the period of 2019 to 2022, data provided by a Team member, Universidad de Puerto Rico – Mayagüez (UPRM).

In Figure 3 we show the result from the same systems as in Figure 2 but this time as a function of the total installed PV capacity for such systems. The lowest cost of energy (COE) appears on systems beyond 5.6 kW of installed PV. From the COE one can see that those are the same systems highlighted in Figure 2, systems above approximately \$27,000 total installed costs.

In general, from Appendix B, the average COE of PV+Batts in Puerto Rico for the period of 2019 to 2022 was in the order of 15.4 cents per kWh. Also, from the data we have available, the lowest and highest COEs were around 13 and 21 cents per kWh.

Figure 4 is based on the quotes used for the previews analysis. The cost by category is shown, totaling \$4.75 per Watt. The figure demonstrates that a big portion of the system is soft cost, even though the inverter, the PV module, and the balance of system costs are also significant.

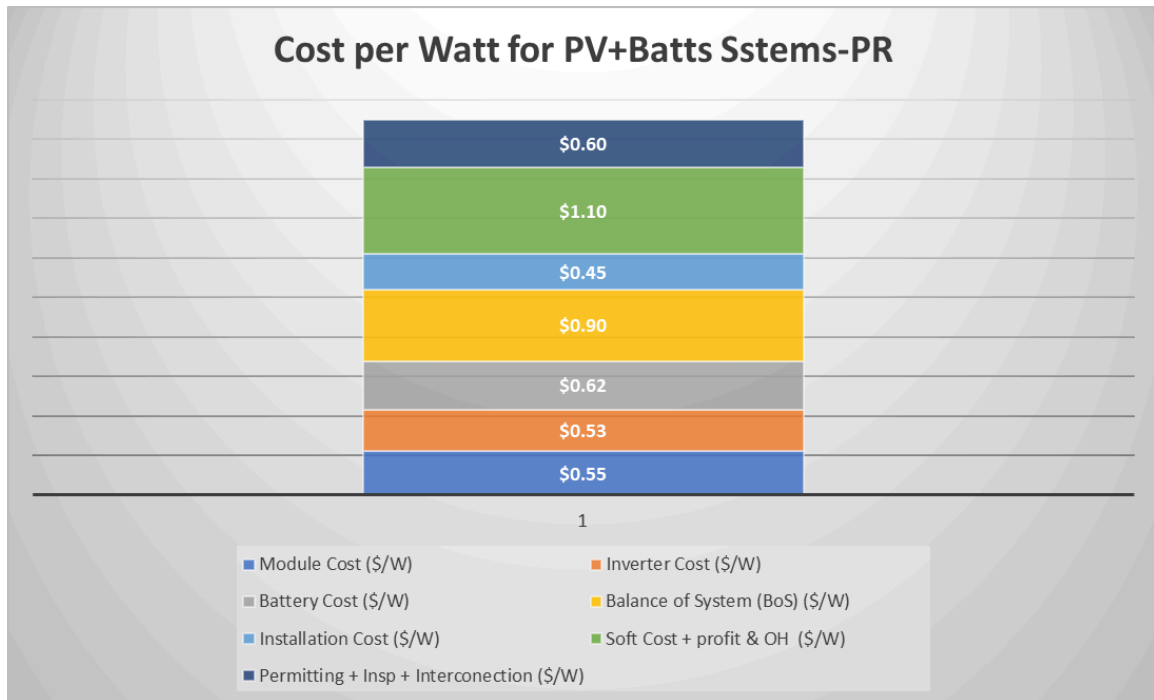


Figure 4. Average values for cost categories of cost estimates for 2023.

3. Discussion on battery costs between the two cases studied.

Referring to the table in Appendix B, the systems mentioned have battery systems between 15 and 28 kWh of total storage. These battery systems are LiFePO4 technology, which gives an effective storage capacity between 12 and 22 kWh, with an average of 20.3kWh of total storage. Energy stored capacities in that range are above the critical loads of most family’s needs, in other words those systems were designed to even power A/C systems during a period of recovery from a utility system collapse.

A discussion is in order over this fact. Appendix A shows that six out of seven battery systems in the Incentivized Program quotes are 13.5 kWh (11kWh), with an average of 14.4kWh of total storage. A comparison of the COE from both sections suggests that the Incentivized Program has artificially increased the total cost of the projects, since the average cost for all systems studied is in the order of 15.5 cents per kWh, but the storage systems have been reduced about 30%. An expectation that a bigger battery bank represents higher total system cost, but this has not been the case when considering incentives provided by the government. On the other hand, battery systems in the order of 10kWh are more suitable for critical loads needed under emergency situations.

In addition, searching our files for a LiFePO4 battery cost by June 2020 and comparing it to the same model as of June 2023, we found out that the cost per kWh has dropped 30.4%, from \$560 to \$454 per kWh. Considering a 30% reduction, the cost of the LiFePO4 storage shows a considerable decrease between 2020 and 2023. All these facts suggest that the average COE for PV plus Battery systems in Puerto Rico, with no incentive programs, must be below the 15 cents per kWh. Also, that the incentives programs blow up the local PV+Batt’s market.

4. Relevance of PV cost in Puerto Rico

The cost of rooftop solar PV systems equipped with batteries for homes and small businesses is important in the context of establishing the least cost option to transition to 100% renewable energy in Puerto Rico. While solar farms have traditionally being showcased as the cheapest way forward, in Puerto Rico the negotiated cost of solar generation at utility scale goes from approximately 10 cents to more than 14 cents per kWh². This is more expensive than rooftop solar options when considering that the solar farm negotiation does not include energy storage, there will be costs related transactions, transmission and distribution, and that grid losses are prevented with the rooftop solar PV systems. When resiliency considerations are integrated in the analysis adding energy storage systems and food security related to protected farmlands, the cost of solar farms prevents the feasibility of those projects to result in a positive outcome.

² See expression by Assistant Secretary of Energy Affairs in Puerto Rico – “Muchos arrancan en los diez centavos o hasta por debajo de los diez centavos, y según van pasando los años, aumentaría hasta 14 centavos y un poco más.”,
https://www.elvocero.com/exclusivo/exclusivo-defiende-ubicacion-de-proyectos-de-energ-a-renovable/articulo_ee710b46-4073-11ee-b3ff-8b33d4130a7f.amp.html.

5. Comparison of COE for the Home Energy Resilience Installations Incentives Program (Reference Guide 2023-02-200-HA) compared to non-incentivized offers as of 2022

A direct comparison of the results in sections 1 and 2 follows. Section 1 presented COE for Home Energy Resilience Installations Program (Reference Guide 2023-01-030-HA), as of 2023. Section 2 presented the analysis of non-incentivized quotes as of 2022. All the numbers analyzed are for LiFePO4 (lithium iron phosphate) technology.

Table 1 presents the comparison of the COE (\$/kWh) for PV+Batts systems in Puerto Rico for the quotes evaluated. Based on the direct contrast of the systems studied, there has been a slight increase of 3.1% in the average COE between the period of 2019-2022 and the year 2023. We have discussed earlier that this increase is resulting from the incentivized programs that are still undergoing. We have presented in another work that other offers published in Puerto Rico during 2023 suggest COE's that average 10 cents per kWh for PV+Batt systems, including installation and net metering.

Table 1. Difference in COE for PV+Batts Systems studied from Home Energy Installations Program (2023-01-030-HA) Vs offers on Instagram.

	HERI 02-200	NO INC '19-'22	% Diff
Ave	\$0.159	\$0.154	3.1%
Max	\$0.216	\$0.206	4.6%
Min	\$0.119	\$0.130	-9.0%

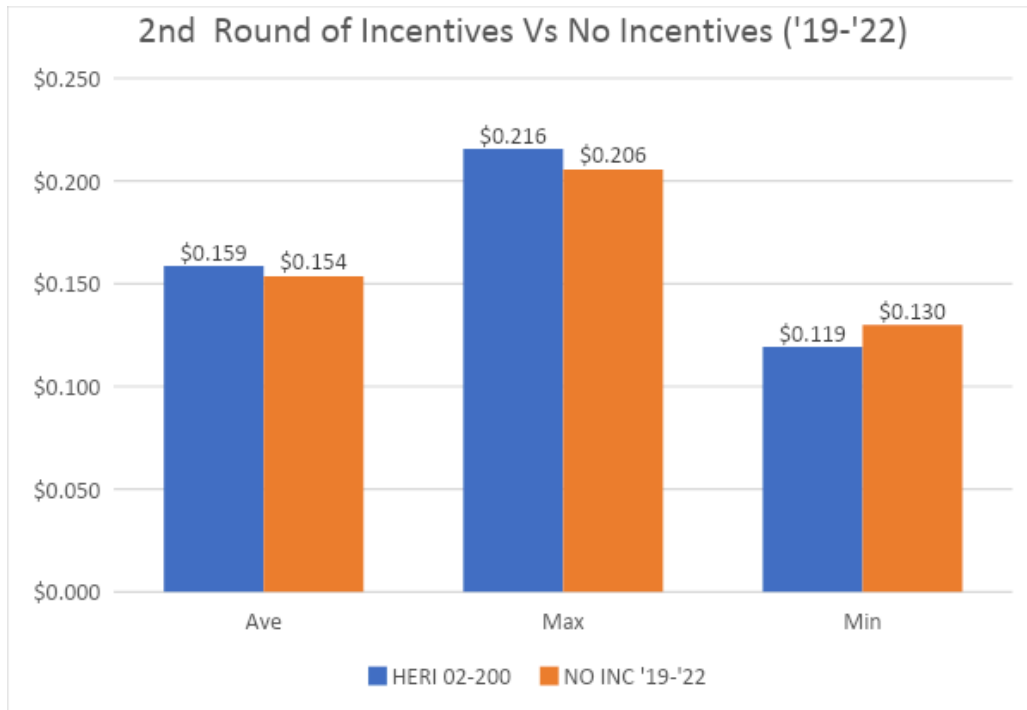


Figure 5. Increase on COE for the Home Energy Resilience Installations Incentives Program (Reference Guide 2023-01-300-HA) compared to non-incentivized quotes as of 2022.

6. Conclusions

The average COE of PV+Batts in Puerto Rico as of June 2023 is in the order of 15.9 cents per kWh. Also, the lowest and highest COEs are in the vicinity of 13 and 22 cents per kWh. These numbers are from quotes submitted to the Home Energy Resilience Installations Incentives Program, March 2023 (Guide 2023-02-200-HA).

As for the COE of PV+Batts during the period of 2019 to 2022, from our data it was in the order of approximately 15.4 cents per kWh. Meanwhile, the lowest and highest COEs were around 12 and 22 cents per kWh.

There has been a slight increase in COE from 2019 to the present. The increase may have occurred by an artificially inflated effect produced by government incentive programs. Nonetheless, the systems studied from 2023 and for the period of 2019 to 2022 were dissimilar, especially considering the storage capacity. Further analysis may reflect bigger price declines.

Also, we noticed a tendency for better COE's when the system is designed for specific ranges of available Inverter models. This is apparent for both periods analyzed, where 4 kW, 6kW and 8 kW inverter ratings are standard, and widely available in Puerto Rico. Analysis of Government Incentives programs and 2019 to 2022 quotes suggests such conclusion. Therefore, developers and the government must consider that COE is improved as the design of the system adjusts the amount of installed PV with the maximum rating capacity of the inverter and specifying an appropriate storage capacity for the system.

Analysis of quotes for government incentive programs show that the costs of the proposed systems are inflated, possibly to maximize profits. The government must consider reviewing the incentives guidelines' considering the results in this work.

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Appendix A

Data tables for PV+Batt system costs for the Home Energy Resilience Installations Incentives Program, March 2023 (Guide 2023-02-200-HA)

	Location ID	Total Cost	Plant Size kW	Effective kW	Storage Tech*	Storage Size kWh	Storage kWh	Life Production kWh @20y	COE con Batts \$/kWh	COE no Batts \$/kWh
1	E60	\$22,700.00	4.45	4.01	0.80	20.00	16.00	146,183	\$0.155	\$0.086
2	E66	\$31,879.00	4.50	4.05	0.80	13.50	10.80	147,825	\$0.216	\$0.164
3	E63	\$26,300.00	4.90	4.41	0.80	13.50	10.80	160,965	\$0.163	\$0.119
4	E62	\$21,148.40	5.40	4.86	0.80	13.50	10.80	177,390	\$0.119	\$0.079
5	E61	\$31,088.00	5.47	4.92	0.80	13.50	10.80	179,690	\$0.173	\$0.133
6	E64	\$29,905.00	7.30	6.57	0.80	13.50	10.80	239,805	\$0.125	\$0.095
7	E65	\$42,876.67	8.20	7.38	0.80	13.50	10.80	269,370	\$0.159	\$0.133
	Ave	\$29,413.87	6.0			14.4	10.8	195,841	\$0.159	\$0.115
	Max								\$0.216	\$0.164
	Min								\$0.119	\$0.079

Appendix B

Data tables for PV+Batt system costs from systems installed between 2019 and 2022

	Location ID	Total Cost	Plant Size kW	Effective kW	Storage Tech*	Storage Size kWh	Storage kWh	Life Production kWh @20y	COE con Batts \$/kWh	COE no Batts \$/kWh
1	P28	\$24,900.00	3.96	3.56	0.80	15.00	12.00	130,086	\$0.191	\$0.131
2	P26	\$30,147.55	5.60	5.04	0.80	15.00	12.00	183,960	\$0.164	\$0.119
3	P10	\$40,529.00	6.00	5.40	0.80	28.80	23.04	197,100	\$0.206	\$0.129
4	P25	\$31,581.00	6.08	5.47	0.80	19.20	15.36	199,728	\$0.158	\$0.105
5	P32	\$26,950.00	6.10	5.49	0.80	14.40	11.52	200,385	\$0.134	\$0.094
6	P35	\$27,327.68	6.40	5.76	0.80	19.20	15.36	210,240	\$0.130	\$0.083
7	P23	\$30,357.00	6.75	6.08	0.80	14.40	11.52	221,738	\$0.137	\$0.103
8	P45	\$33,700.00	7.20	6.48	0.80	28.80	23.04	236,520	\$0.142	\$0.082
9	P46	\$31,076.00	7.20	6.48	0.80	19.20	15.36	236,520	\$0.131	\$0.090
10	P49	\$33,700.00	7.20	6.48	0.80	28.80	23.04	236,520	\$0.142	\$0.082
	Ave	\$31,026.82	6.5			20.3	16.7	213,635	\$0.154	\$0.102
	Max								\$0.206	\$0.131
	Min								\$0.130	\$0.082