100% RENEWABLE RESOURCE PLANNING AND TECHNICAL ANALYSIS AT HOURLY GRANULARITY

Burlington Electric Department-ProsumerGrid

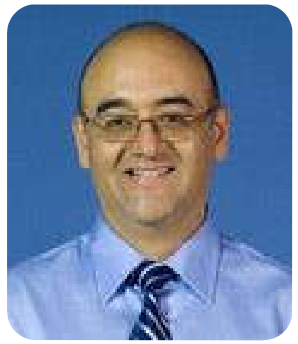
Final Presentation

November 7, 2023

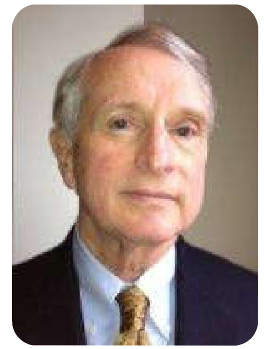
ProsumerGrid™

ProsumerGrid Project Team

Marcelo Sandoval, PhD, MBA, PMP
CEO & Co-founder

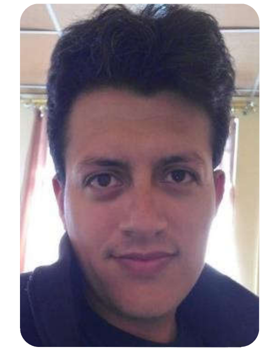


Santiago Grijalva, PhD,
Chairman, CTO & Co-founder



John Higley
VP Industry Engagement &
Co-founder

Sadegh Vejdan, PhD
VP Optimization



David Padilla, Msc
Lead Software Engineer

Offices in Brookhaven, GA and Binghamton, NY.

McNeil Equivalence Analysis

Table 2: Project Deliverables

Deliverables	End of Week
1: Kickoff Meeting Requirements Presentation	1st Week
2: Requirements Elicitation Presentation	2
3: Two McNeil Equivalence Scenarios (McNeil Evaluation: Solar plus Storage; Wind plus Storage)	3
3: Resources and Load Data Assumptions Presentation	4
4: Optimal Resource Planning B.1 Presentation	6
5: Optimal Resource Planning B.2 Presentation	8
6: Scenario Results Presentation	10
7: Final Presentation	12

Equivalence Analysis Objective and Problem Statement.

- ProsumerGrid was tasked with running the following equivalence analyses:
  - Find the lowest capacity values and hour-by-hour energy schedule of **solar power generation** and **storage** (charge and discharge) that are **equivalent to the 8760 hourly McNeill Power Output**
  - Find the lowest capacity values and hour-by-hour energy schedule of **wind power generation** and **storage** (charge and discharge) that are **equivalent to the 8760 hourly McNeill Power Output**
  - Find the lowest capacity values and hour-by-hour energy schedule of **solar, wind power generation** and **storage** (charge and discharge) that are **equivalent to the 8760 hourly McNeill Power Output**
- The analyses was constraint by the 8760 time series data for the McNeill power output, solar & wind power output profiles and energy storage model.
- These equivalence analyses were run for the case when curtailment is allowed and when it is not.
- ProsumerGrid used its Grid+DER Planning Studio^{TM} Software that uses an integrated optimization model. More details about the mathematical optimization models can be found at [1], [2].

[1] ProsumerGrid, EPRI. "Incorporating Energy Storage Resources into Long-Term Capacity Planning Models: An Assessment of the Inclusion of Specific Features on Battery Deployment in the Southeastern United States".
[2] ProsumerGrid, Sandia National Labs. "Optimal DER Portfolio Design". SANDIA REPORT SAND2022-11264 Printed August 2022.

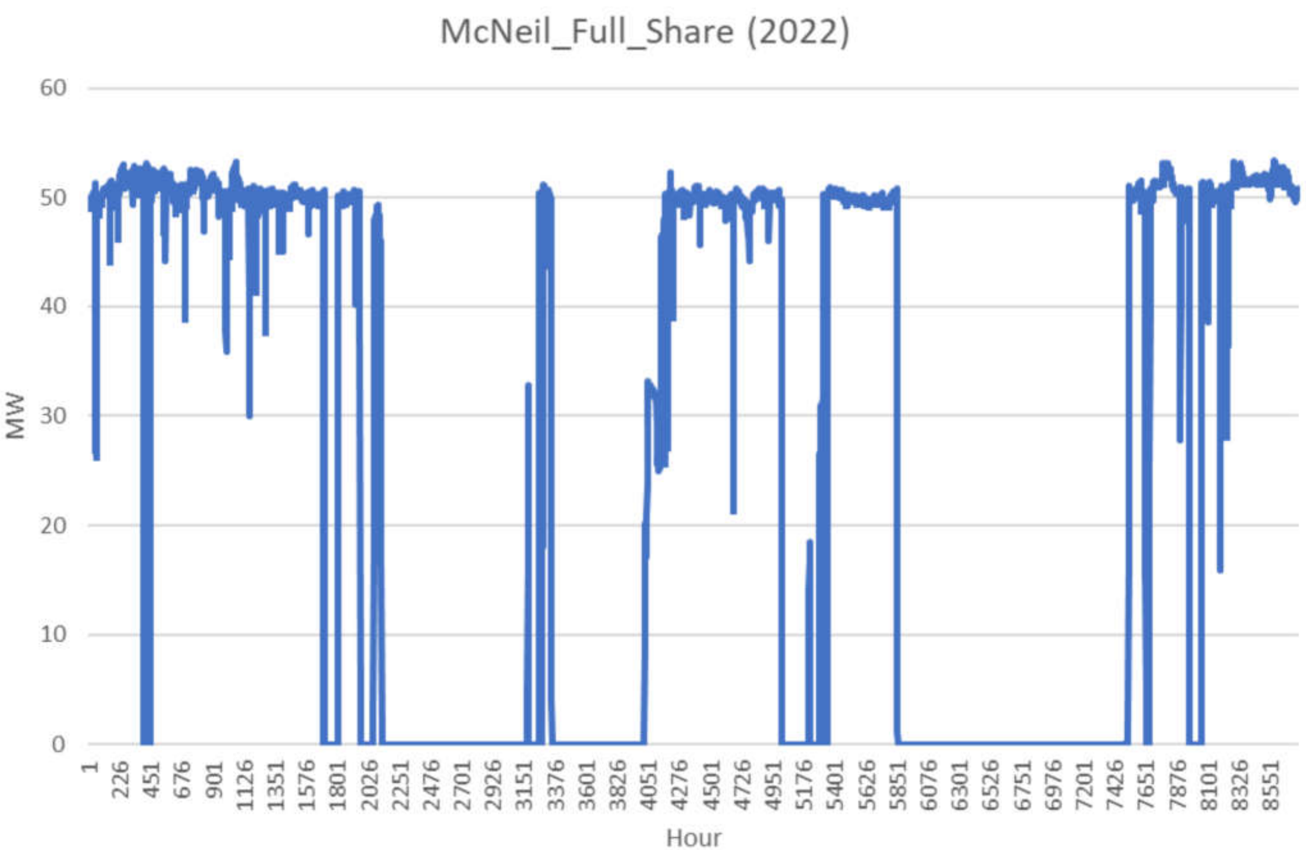
McNeil Equivalence Scenario 1: Solar + Storage

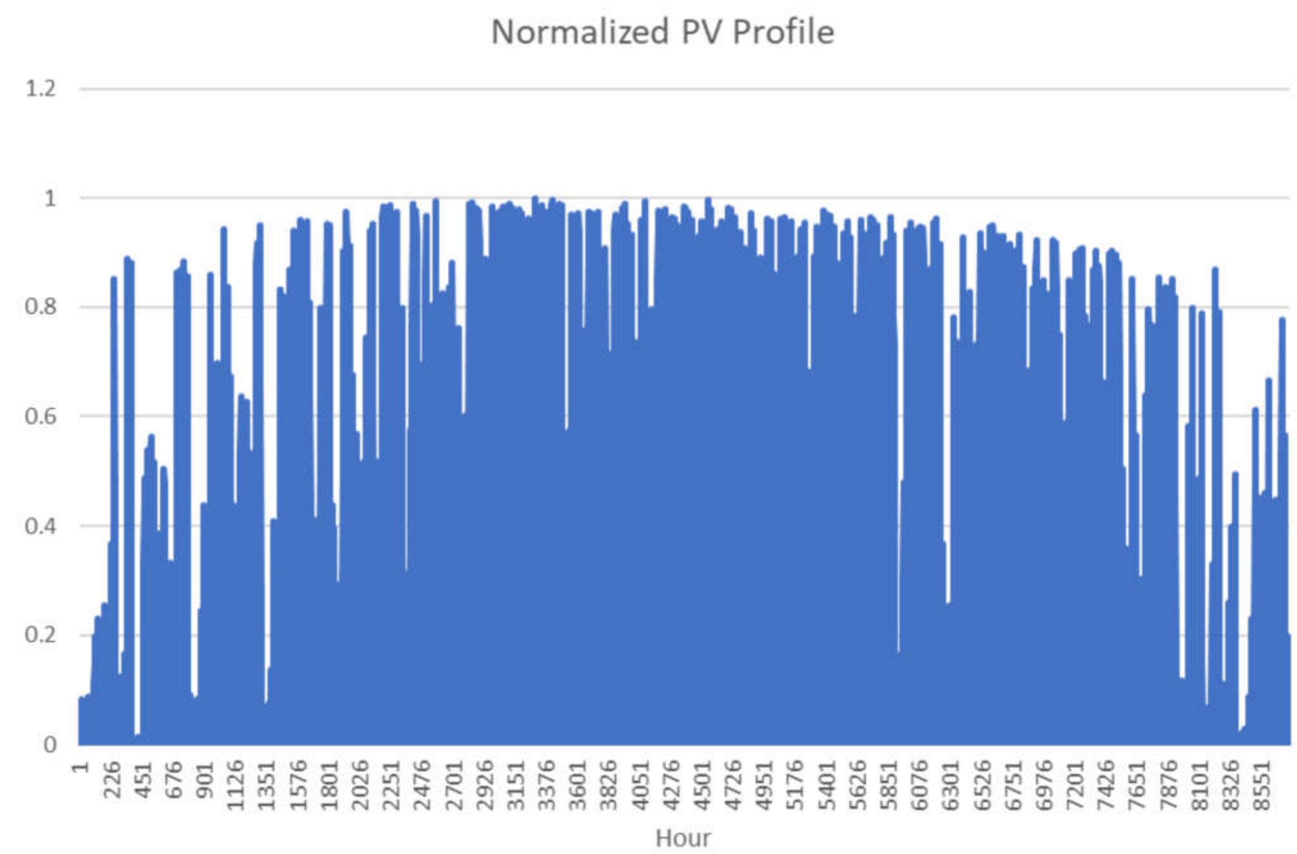
- The objective is to find the solar PV and storage minimum capacities to provide a combined output power equal to the McNeil output for every hour within the simulation horizon.

$$P_{McNeil}(t) = P_{solar}(t) + P_{storage\_discharge}(t) - P_{storage\_charge}(t) \quad \forall t$$

- Based on the data availability, year 2022 is selected as the simulation year.
- The eight solar PV output profiles are averaged and normalized in order to model the normalized profile of the equivalent solar PV.
- A 4-hr Li-Ion battery with 95% roundtrip efficiency is used as the energy storage option.
- Hourly McNeil output (McNeil_Full_Share) for year 2022 is used as $P_{McNeil}(t)$.
- Two cases are considered:
  1. Excess solar generation can be curtailed.
  2. Curtailment is disallowed and all the solar generation needs to be “used”.

McNeil Equivalence Scenario 1: Solar + Storage



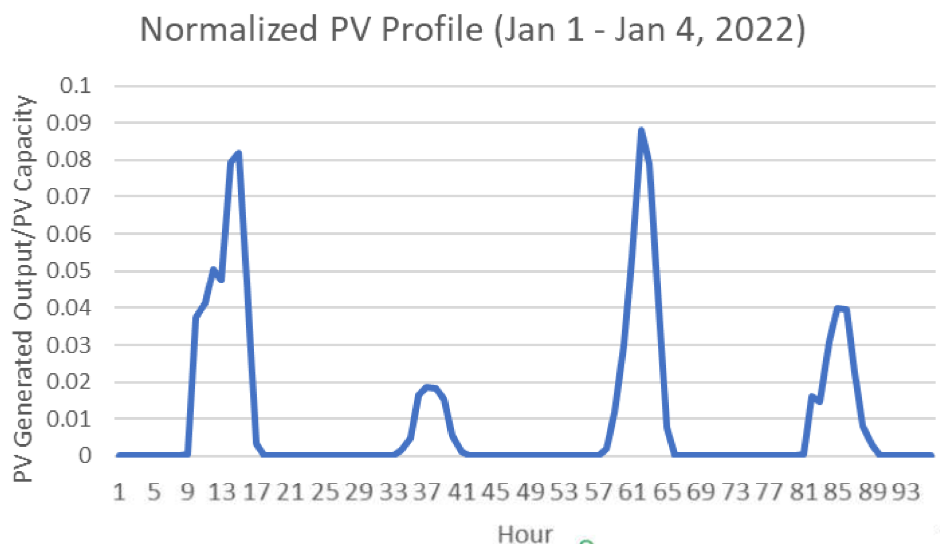


McNeil Equivalence Scenario 1: Solar + Storage

- The optimization simulation results in the following solar and storage capacities:

Case	Solar PV Capacity (MW)	Battery Storage Capacity (MW/MWh)	Solar PV Energy (GW)	Storage Net Loss: discharge - charge (GWh)
With Curtailment	1761	1320/5278	232	3
Without Curtailment	914	5405/21619	1438	1209

- The solar profiles show very low capacity factors for some days that might be due to the cloudy sky. For these days, a large PV capacity is required to match the McNeil output.
- Disallowing curtailment reduces solar PV capacity but requires a larger the battery capacity to store all the excess solar generation.



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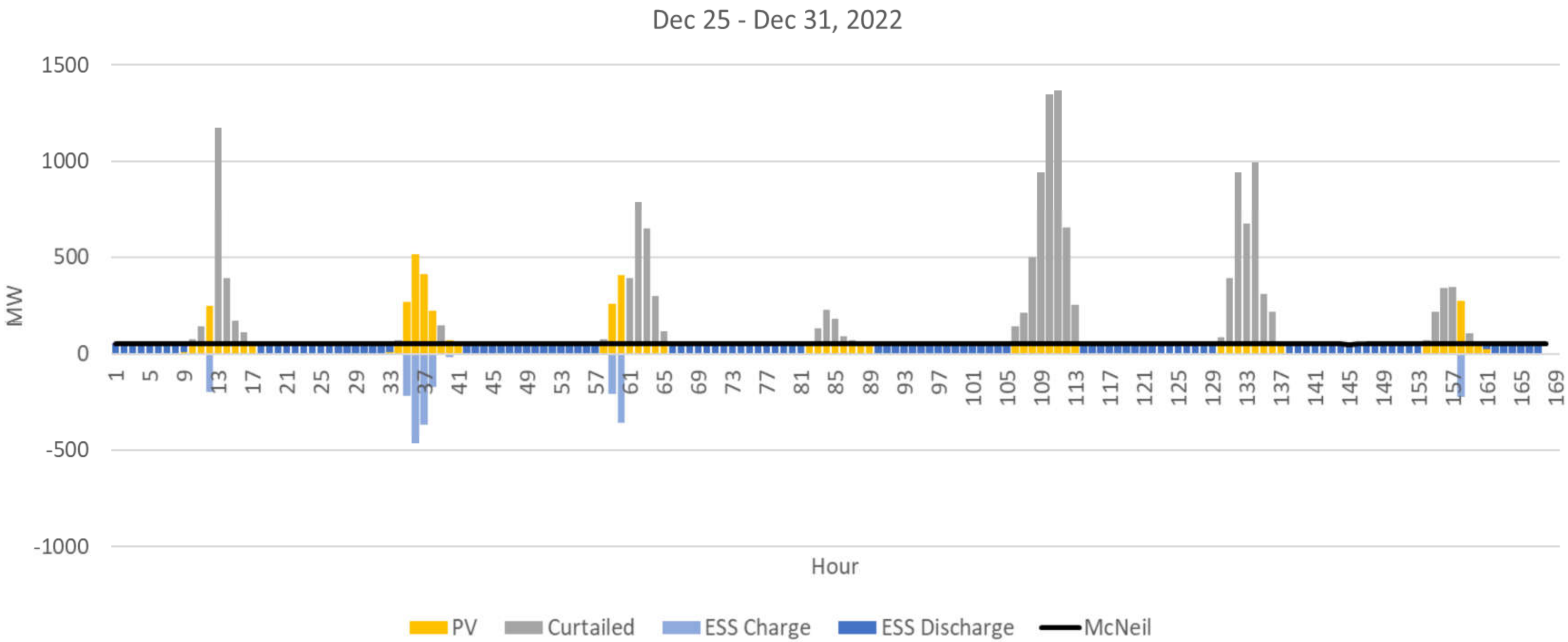
McNeil Equivalence Scenario 1: Solar + Storage (with curtailment)

- With curtailment, solar capacity is selected to be very high while excess generation is curtailed.



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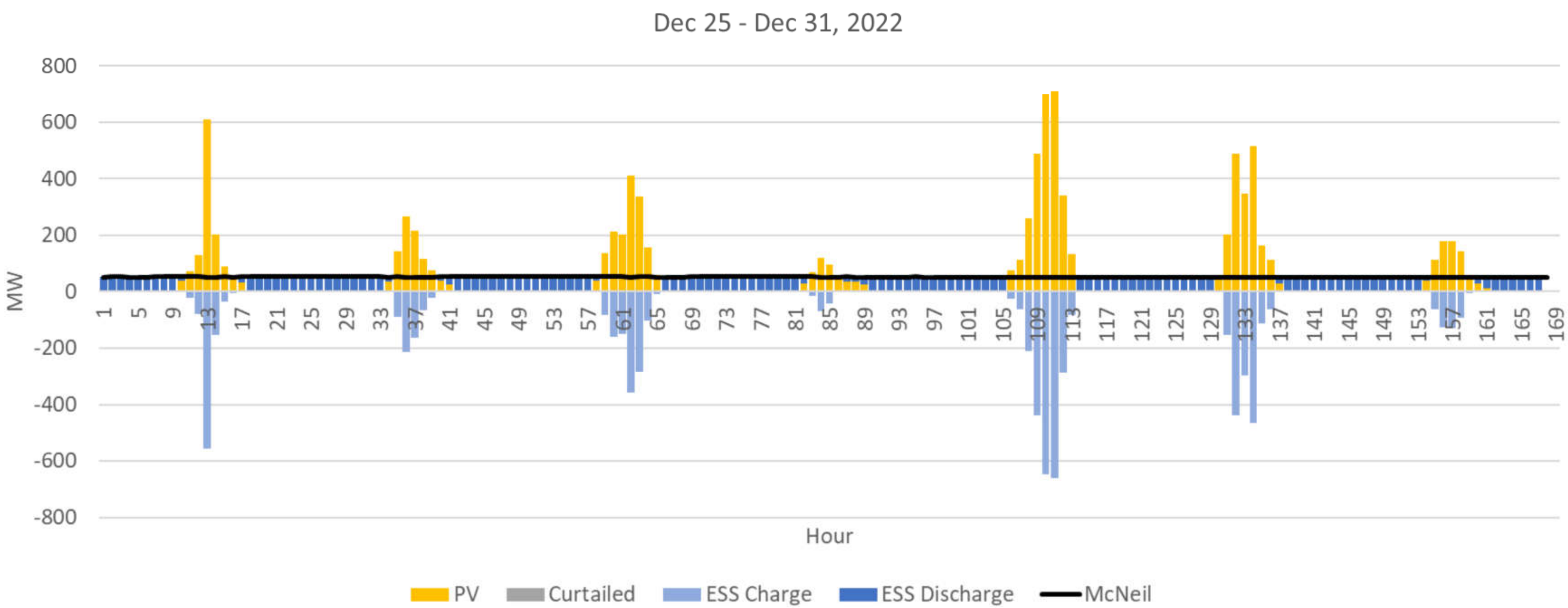
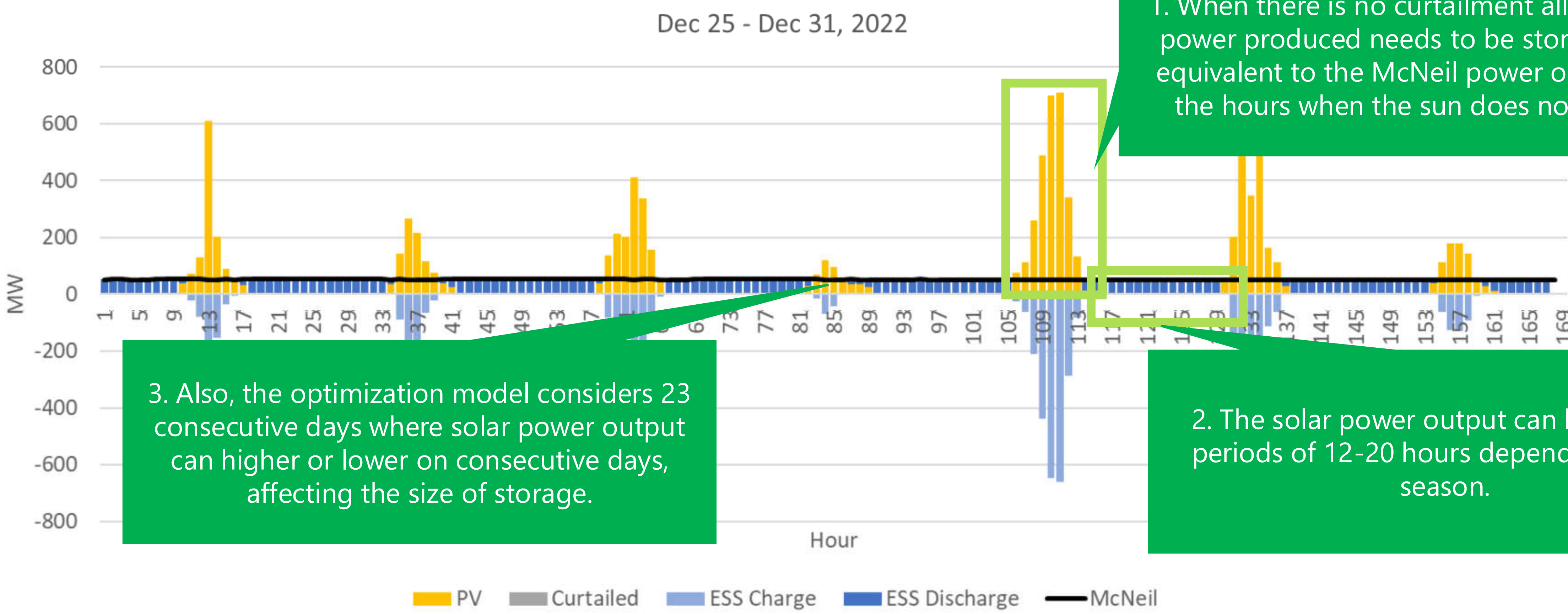
McNeil Equivalence Scenario 1: Solar + Storage (without curtailment)

- Without curtailment, solar capacity is lower but the excess generation needs to be stored completely requiring a larger battery capacity.



McNeil Equivalence Scenario 1: Solar + Storage (without curtailment). Additional Insights.

- Without curtailment, solar capacity is lower but the excess generation needs to be stored completely requiring a larger battery capacity.



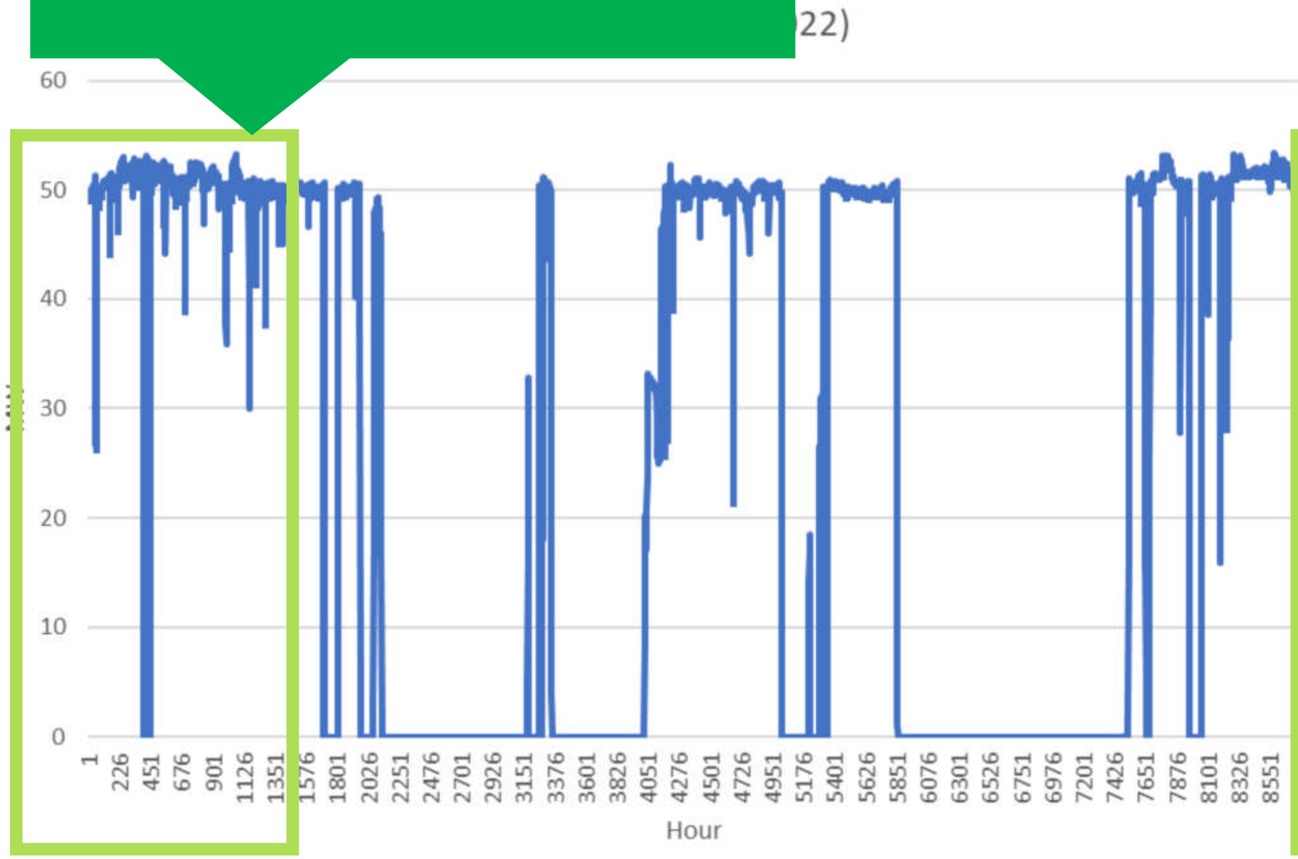
1. When there is no curtailment all the solar power produced needs to be stored to be equivalent to the McNeil power output for the hours when the sun does not shine.

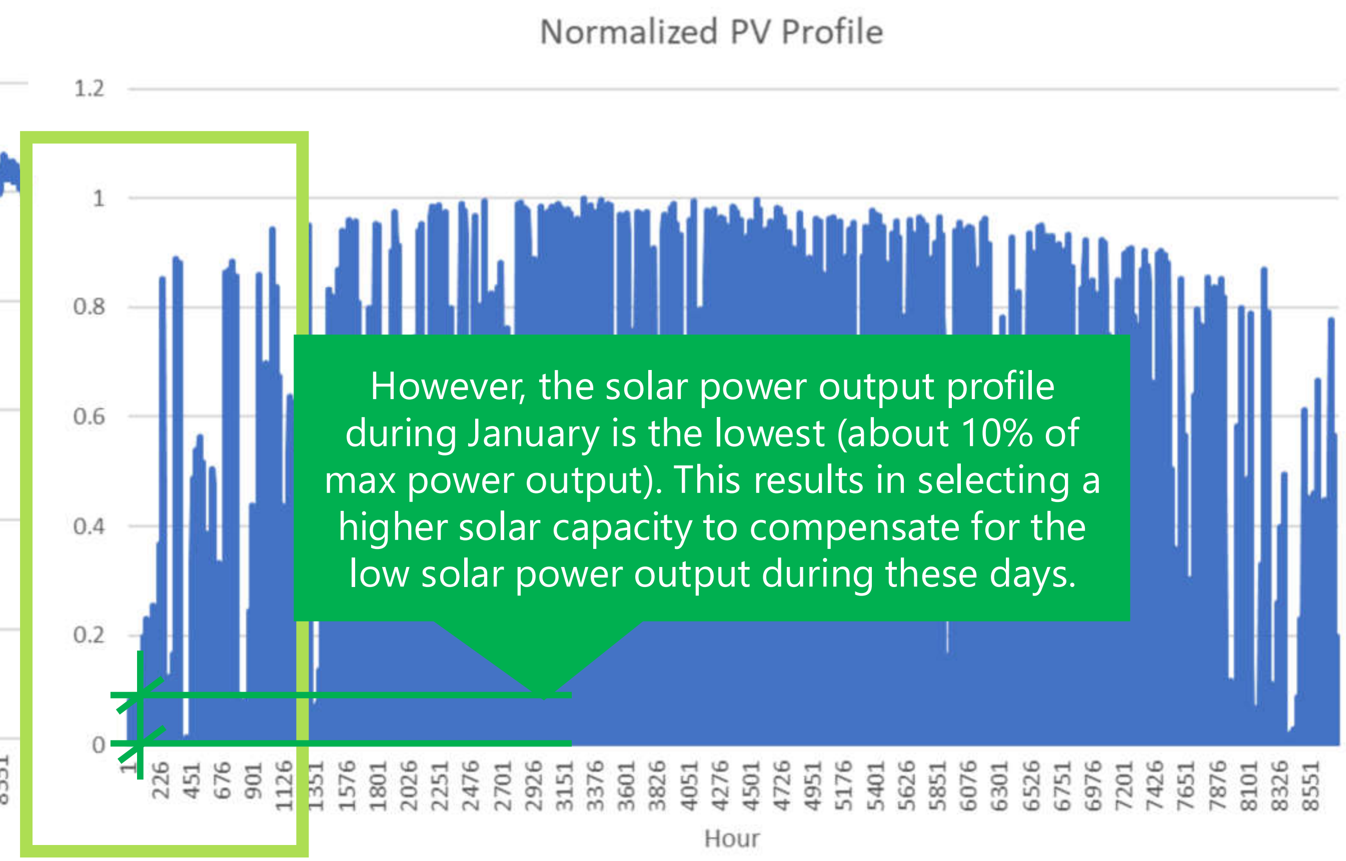
2. The solar power output can be zero for periods of 12-20 hours depending on the season.

3. Also, the optimization model considers 23 consecutive days where solar power output can higher or lower on consecutive days, affecting the size of storage.

McNeil Equivalence Scenario 1: Solar + Storage. Additional Insights.

McNeil Power output is above 51 MW during January, February.





However, the solar power output profile during January is the lowest (about 10% of max power output). This results in selecting a higher solar capacity to compensate for the low solar power output during these days.

McNeil Equivalence Scenario 1: Solar + Storage (without curtailment). Question

- The optimized solar capacity may seem to high. A quick calculation shows to match the annual McNeil energy (~438GWh = 50MW*8760hrs, assuming 100% capacity factor), there needs to be a ~385MW solar PV (assuming a 13% capacity factor).
- However, as shown in the previous slide, the solar capacity factor during the first 23 days is very low ~5.4% while McNeil capacity factor is very high ~96% (of 50MW). Equating the generated energy from both resources results in ~890MW of minimum solar PV.
- Accounting for energy storage and its conversion losses, the optimized solar PV capacity of 914MW seems reasonable and justified.

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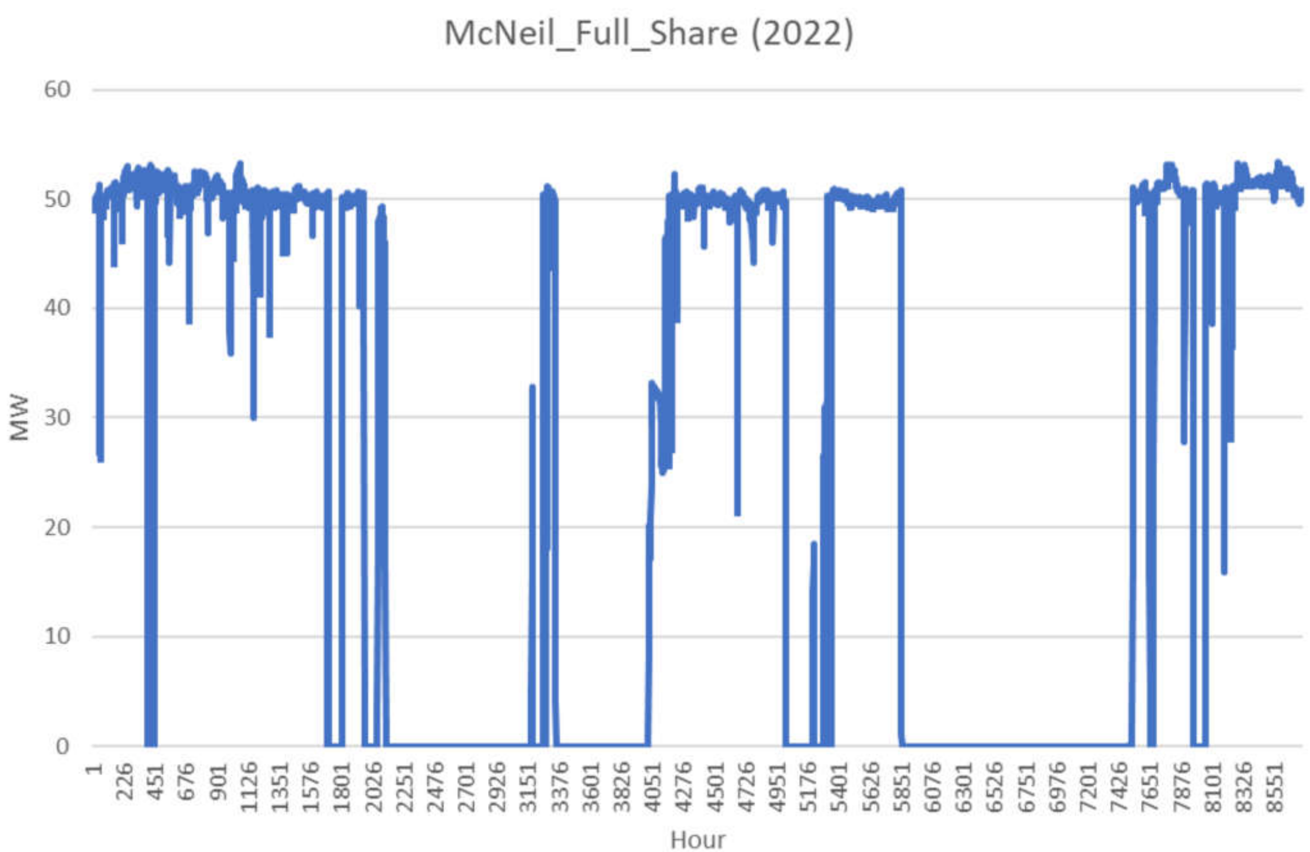
McNeil Equivalence Scenario 2: Wind + Storage

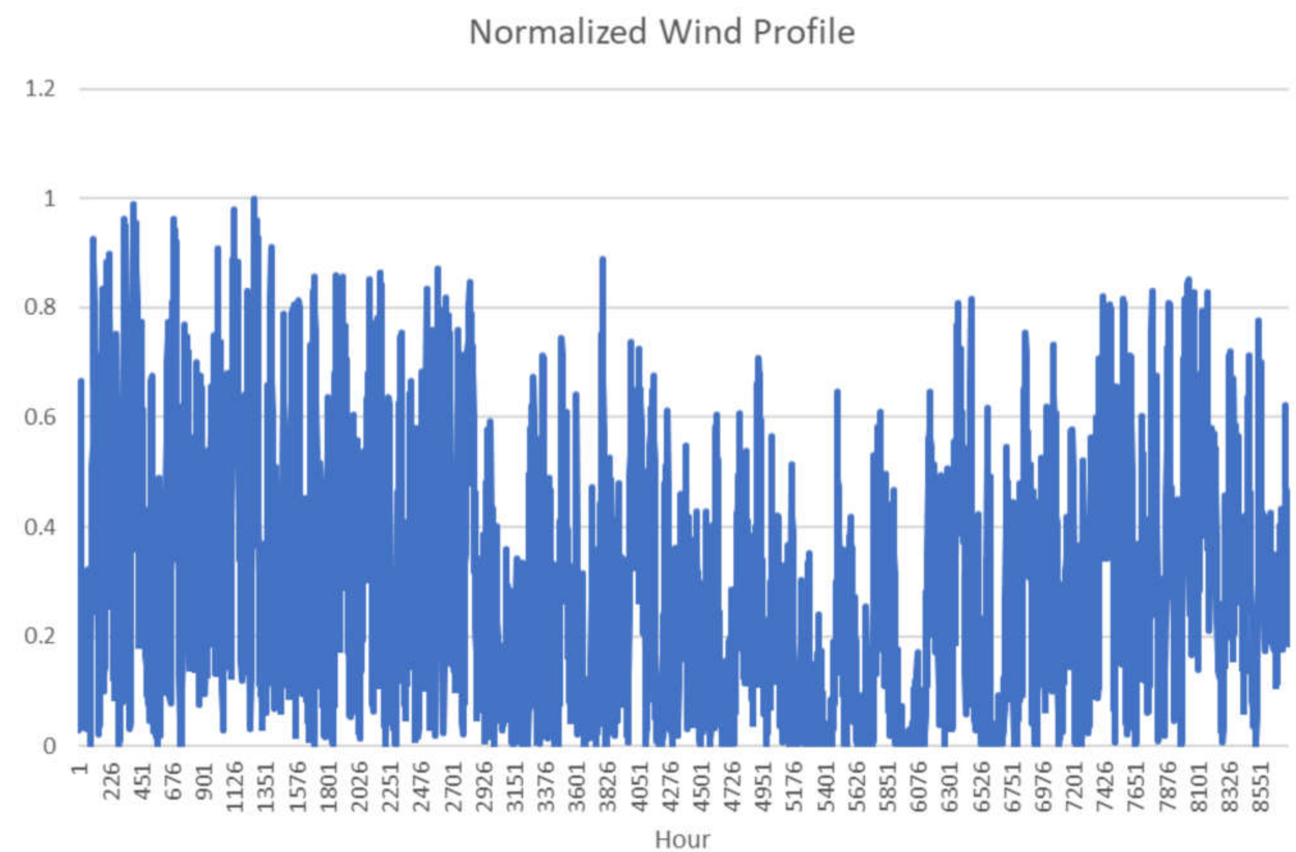
- The objective is to find the smallest wind and storage capacities to provide a combined output power equal to the McNeil output for every hour within the simulation horizon.

$$P_{McNeil}(t) = P_{wind}(t) + P_{storage-discharge}(t) - P_{storage-charge}(t) \quad \forall t$$

- Similar to scenario 1, year 2022 is selected as the simulation year.
- The three wind output profiles are averaged and normalized in order to model the normalized profile of the equivalent wind generation.
- A 4-hr Li-Ion battery with 95% roundtrip efficiency is used as the energy storage option.
- Hourly McNeil output (McNeil_Full_Share) for year 2022 is used as $P_{McNeil}(t)$.
- Two cases are considered:
    1. Excess wind generation can be curtailed.
    2. Curtailment is disallowed and all the wind generation needs to be "used".

McNeil Equivalence Scenario 2: Wind + Storage





McNeil Equivalence Scenario 2: Wind + Storage

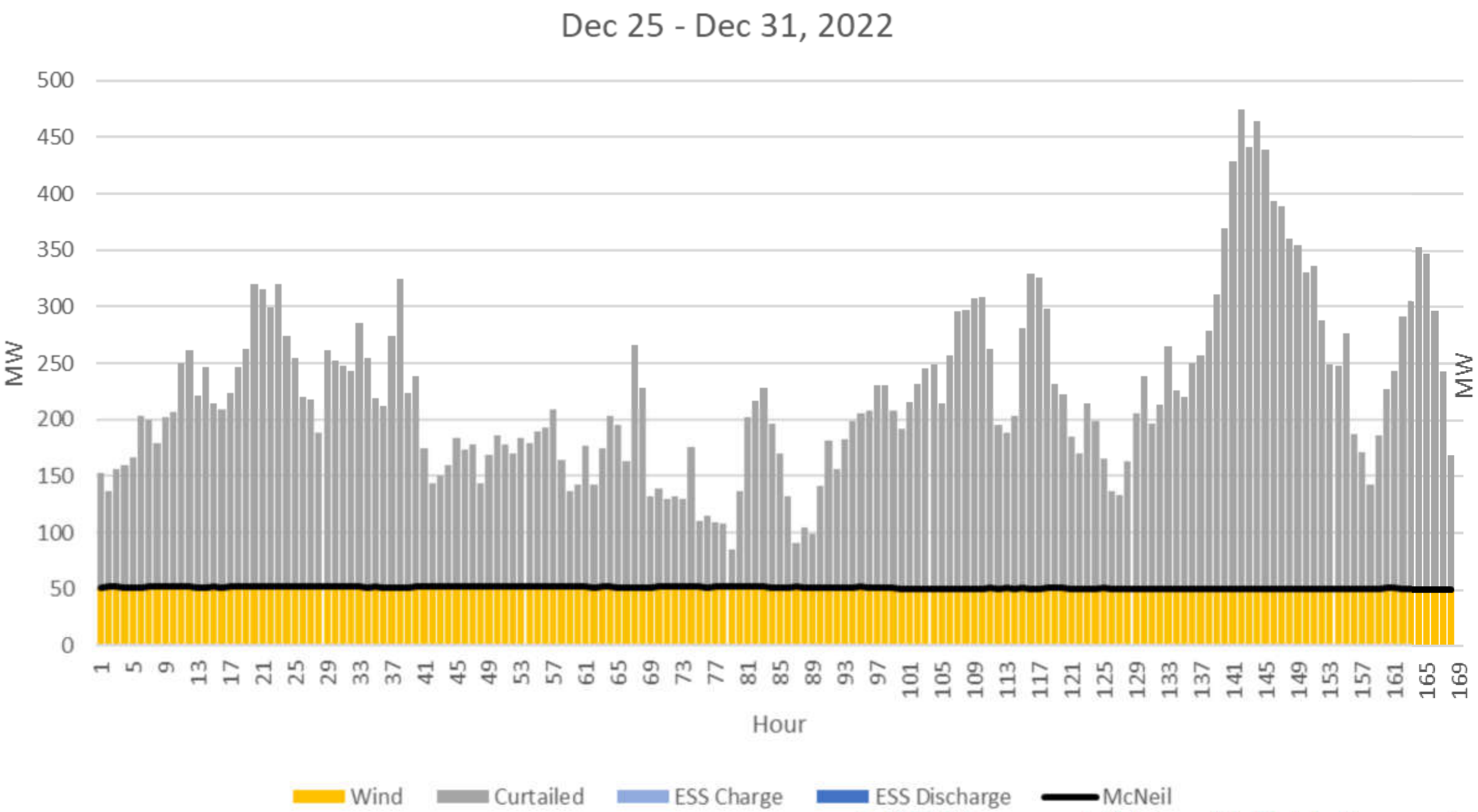
- The optimization simulation results in the following solar and storage capacities:

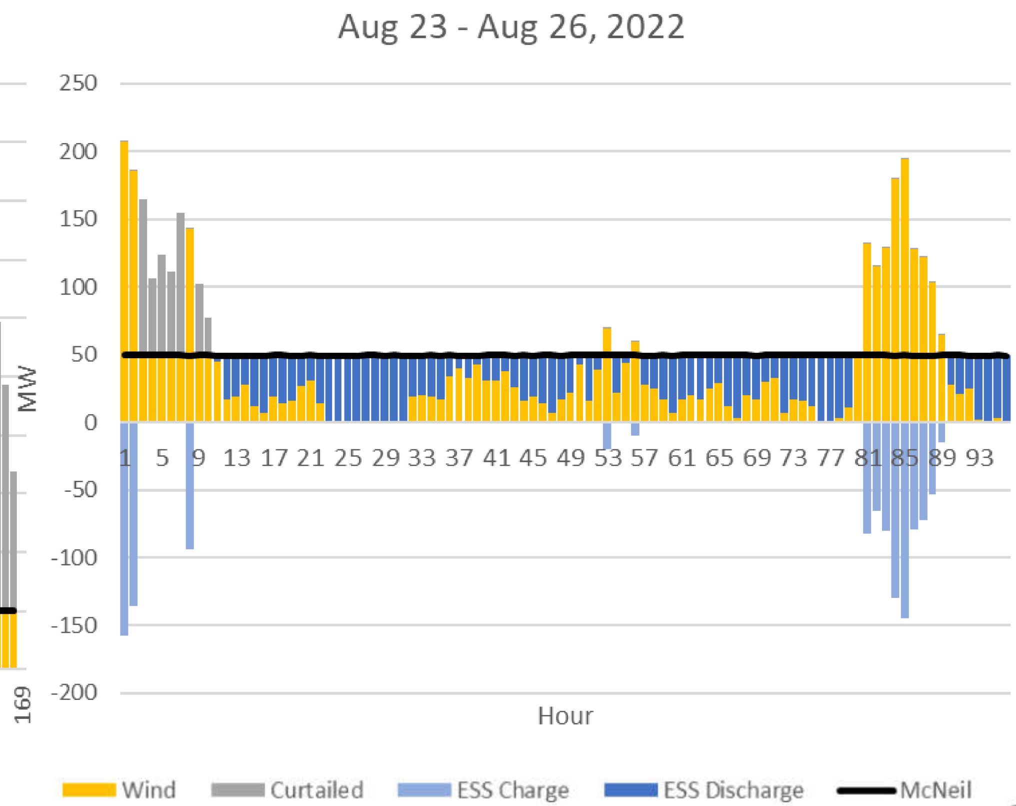
Case	Wind Capacity (MW)	Battery Storage Capacity (MW/MWh)	Wind Energy (GWh)	Storage Net Loss: discharge - charge (GWh)
With Curtailment	763	765/3059	229	0.4
Without Curtailment	355	3062/12248	925	696

- Compared to solar profiles, wind profiles have a higher capacity factor and are more distributed over the hours of the day (not just limited to day time). Therefore, the optimized wind capacity is less than half of solar optimized capacity.
- Disallowing curtailment reduces wind generation capacity but requires a larger the battery capacity to store all the excess wind generation.

McNeil Equivalence Scenario 2: Wind + Storage (with curtailment)

- Due to the high wind generation, no energy storage operation is observed during the last week of 2022. However, having storage is necessary for days where the wind generation is not high enough e.g., in summer months.





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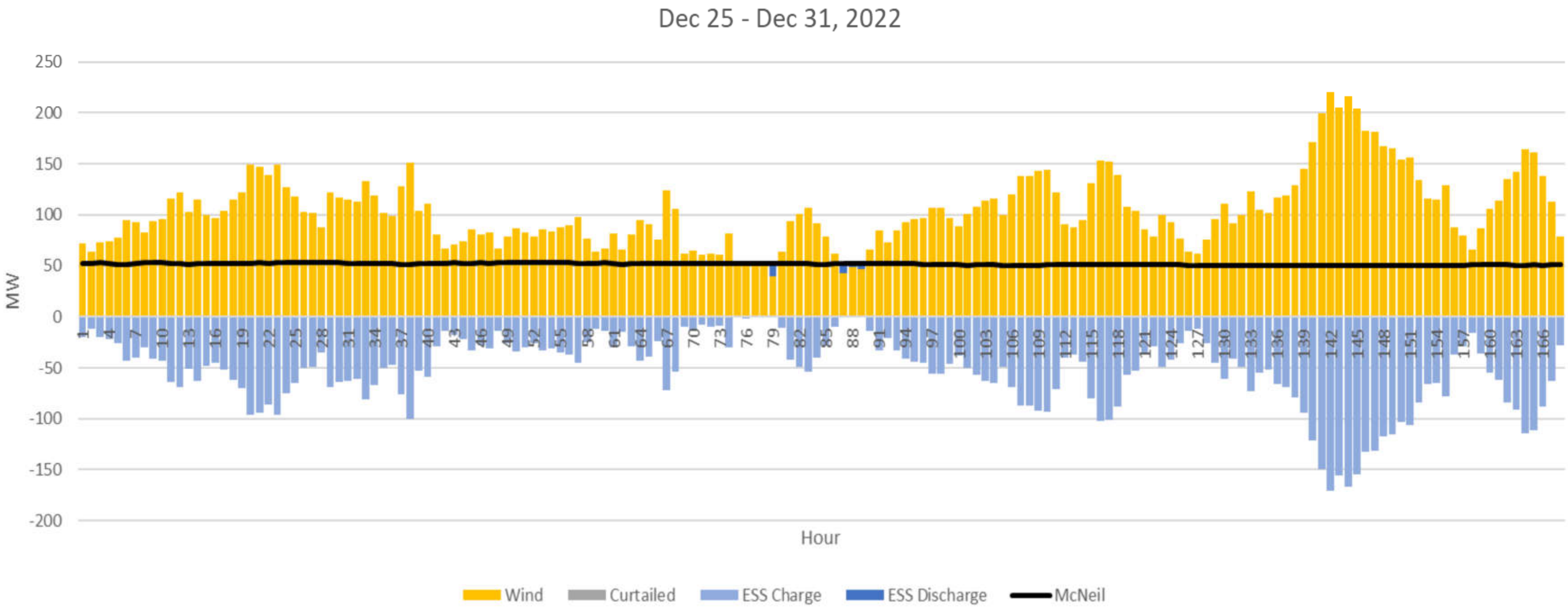
McNeil Equivalence Scenario 2: Wind + Storage (without curtailment)

- Due to the high wind generation during this week, energy storage is in charging mode in almost every hour. This requires a large energy storage capacity (MWh).



McNeil Equivalence Scenario 3: Solar + Wind + Storage

- The objective is to find the smallest solar, wind and storage capacities to provide a combined output power equal to the McNeil output for every hour within the simulation horizon.

$$P_{McNeil}(t) = P_{solar}(t) + P_{wind}(t) + P_{storage-discharge}(t) - P_{storage-charge}(t) \quad \forall t$$

- Year 2022 is selected as the simulation year.
- The normalized solar and wind profiles are used based on the available data.
- A 4-hr Li-Ion battery with 95% roundtrip efficiency is used as the energy storage option.
- Hourly McNeil output (McNeil_Full_Share) for year 2022 is used as $P_{McNeil}(t)$.
- Two cases are considered:
  1. Excess solar and wind generation can be curtailed.
  2. Curtailment is disallowed and all the solar and wind generation needs to be "used".

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McNeil Equivalence Scenario 3: Solar + Wind + Storage

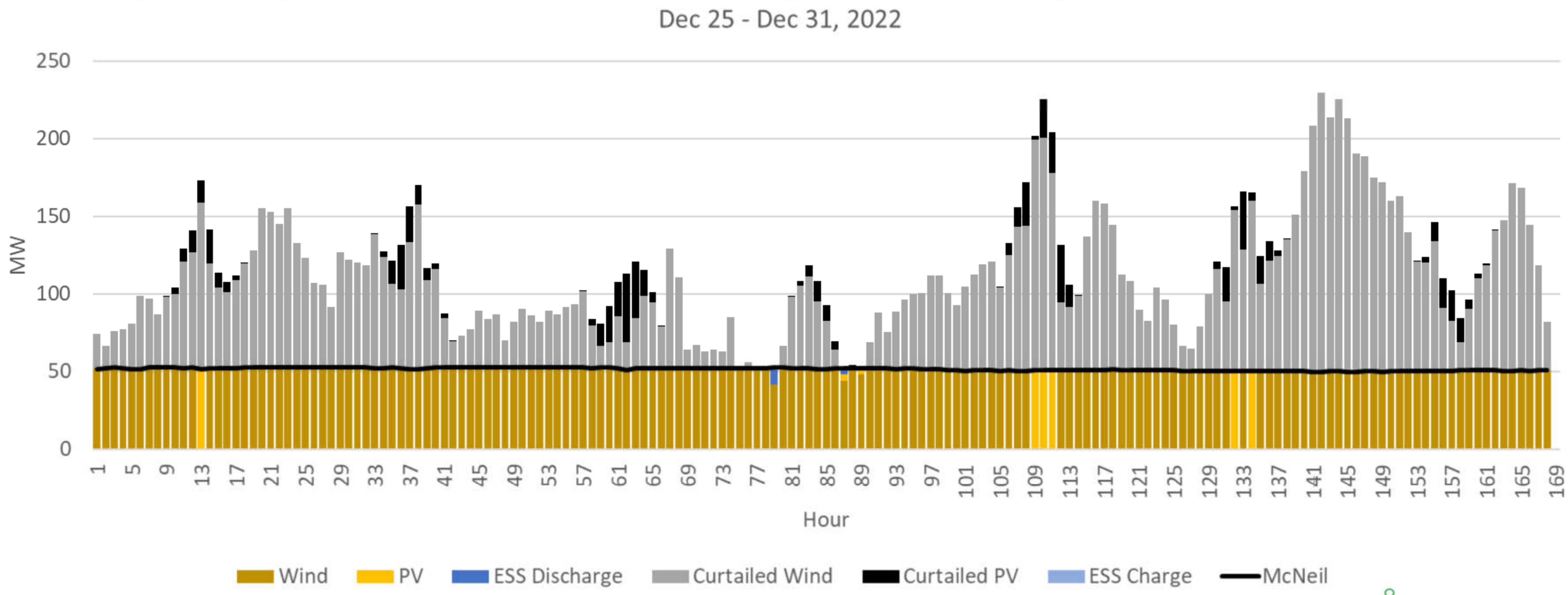
- The optimization simulation results in the following solar, wind and storage capacities:

Case	Solar Capacity (MW)	Wind Capacity (MW)	Storage Capacity (MW/MWh)	Solar Energy (GWh)	Wind Energy (GWh)	Storage Net Loss: discharge - charge (GWh)
With Curtailment	99	370	498/1990	39	189	0.1
Without Curtailment	106	123	1533/6132	166	321	259

- Compared to Scenarios 1 and 2, solar, wind and storage are optimized at smaller capacities. This shows a better match of renewables + storage to equate McNeil output.

McNeil Equivalence Scenario 3: Solar + Wind + Storage (with curtailment)

- Due to the high wind generation, minimal energy storage operation is observed during this week. However, having storage is necessary for times where the wind generation is not high enough and solar is not available e.g., in summer nights.



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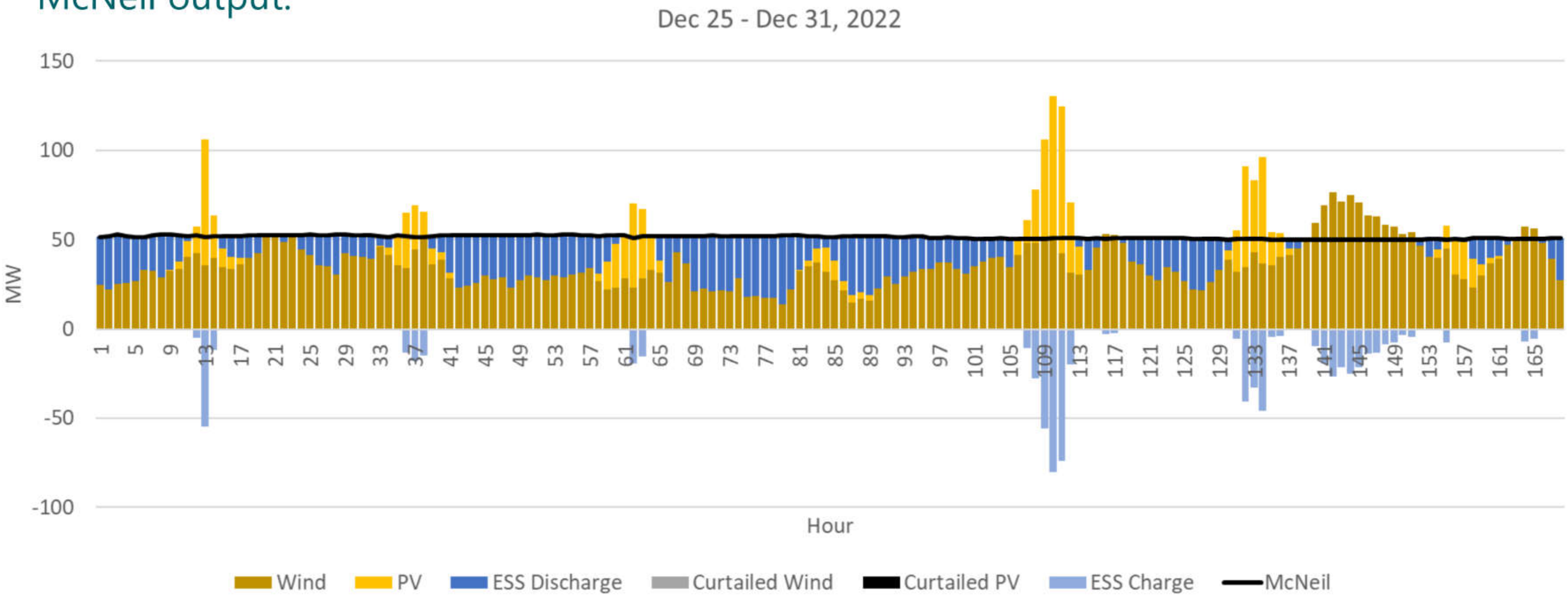
McNeil Equivalence Scenario 3: Solar + Wind + Storage (without curtailment)

- This Scenario-case presents the lowest optimized renewable capacity where the generated solar and wind is complemented by energy storage discharging and charging to equate McNeil output.



McNeil Equivalence Summary

Case: Solar + Storage	Solar PV (MW)		Battery Storage (MW/MWh)	Solar Energy (GWh)		Storage Net Loss: discharge - charge (GWh)
With Curtailment	1761		1320/5278	232		3
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Case: Wind + Storage		Wind (MW)	Battery Storage (MW/MWh)		Wind Energy (GWh)	Storage Net Loss: discharge - charge (GWh)
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