Achieving both Economic and Environmental Objectives for a Solar Farm with Co-located Battery Storage

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A low-carbon future NEEDS energy storage.

"Energy storage allows more renewable sources to connect to the grid."

There is an environmental cost to energy storage.

What is the tension between monetary and environmental objectives?
CONTEXT
Context: West Solent Lymington Array

Lymington Array – Hampshire, UK – 2.4 MW

Owned and financed by West Solent Solar Cooperative

Revenue from Power Purchase Agreement with energy retailer, and Feed-in-Tariff subsidy from UK government

Conservation activities – wildflowers, insects, bats, sheep
Context: Grid export limit at the Lymington Array

Grid export limit imposed by distribution network operator: 2.0 MW

PV capacity installed: 2.4 MW

What if battery storage was installed to allow PV expansion beyond the export limit?
SIMULATION
Simulation: System Description

Introduction

Context

Simulation

Results

Discussion

Simulation: System Description

Rated power $P_{PV}$

Capacity $E_B$

Gridlim = 2.0MW

$P_{gen}(t)$

$P_{charge}(t)$

$P_{toGrid}(t)$

$\eta_B$
Simulation: Operation Strategy

Daytime regime (11am – 6 pm):
• Export all PV generation up to export limit
• Charge battery with any excess
• Do not charge faster than the power limit
• Do not charge above SoC = 90%

Night-time regime (6pm – 11am):
• Calculate setpoint export power = (energy stored at 6pm) / 14 h
• Export all PV generation, plus battery discharge
• Do not discharge below SoC = 10%
Simulation: Variables and Parameters

PV capacity ($P_{PV}$): 3.0 MW, 3.5 MW, 4.0 MW

Battery capacity ($E_B$, kWh)

Power converter capacity ($P_{conv}$, kW)

Battery price ($p_B$): £400/kWh, £300/kWh, £200/kWh, £100/kWh, £50/kWh

To find:
- Net Present Value (NPV)
- Discounted lifetime CO2 savings

Taking into account:
- Costs of PV, battery, converter
- Embodied CO2 of the above
- Electricity sale price
- Carbon intensity of grid generation

1.00 GBP = 83.09 INR
= 1.11 EUR
= 1.30 USD
RESULTS
Results: Optimising for Carbon Emissions Reduction

Compared to base case
2.4 MW / no battery

The more PV, the more battery storage and the more powerful the converter to maximize carbon emissions reduction

All expansion plans make a loss; the more PV, the worse the loss

<table>
<thead>
<tr>
<th>Battery size</th>
<th>Converter power</th>
<th>Lifetime profit w.r.t. base case (million £)</th>
<th>Lifetime CO2 saved w.r.t. base case (kton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_B$ (MWh)</td>
<td>$P_{conv}$ (MW)</td>
<td>3.0</td>
<td>3.0</td>
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<tr>
<td></td>
<td></td>
<td>3.5</td>
<td>5.5</td>
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<td>4.0</td>
<td>8.17</td>
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1.00 GBP = 83.09 INR = 1.11 EUR = 1.30 USD
Results: Financial loss and Required carbon price

Always loss-making, even for batteries down to £50/kWh

Ranges from £86/ton - £547/ton
– the World Bank recommends $40/ton - $80/ton (€30/ton - €60/ton)
Results: Carbon Price as decision-making metric

PV + battery: £90 - £500 / ton

Offshore wind: £0/ton

Hinkley C: £100/ton

PV elsewhere: £20/ton

Original UK feed-in tariff for utility-scale PV: 36 p/kWh ≈ £700/ton

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Results: Sensitivity Analysis

PV price: £900 - £1000 / kW
PV CO2: 1500 – 2100 kg/kW

Battery CO2: 60 – 100 kg/kWh
Battery price change: -6 to -10 %/y

Converter price: £80 – £120 / kW
Converter CO2: 50 – 90 kg/kW
Converter price change: -4 to -6 %/y

<table>
<thead>
<tr>
<th>Battery price, $P_B$ (£/kWh)</th>
<th>$p_{CO2}(P_{PV})$ (£/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>208</td>
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<td>333</td>
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<td>55</td>
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<td>126</td>
<td>94</td>
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</tbody>
</table>

$P_{PV}$ (MW) 3.0 3.5 4.0
DISCUSSION
Battery storage for curtailment avoidance when expanding PV capacity is not yet economical.

Things that would help:

- Cheaper batteries  \( \rightarrow \) 2nd-life electric vehicle batteries
- Longer-lasting batteries
- Higher electricity sale price (e.g. private wire PPA)
- Additional services (frequency/voltage regulation, reserves)
Thank you!