CLEAN ENERGY INVESTMENT ACCELERATOR

Summary: Techno-Economic Analysis of Solar Photovoltaics and Battery Energy Storage at a Vietnam Industrial Park

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Analysis Overview

CEIA conducted a case study analysis of **battery energy storage system (BESS)** feasibility for an industrial park in Vietnam using **NREL's REopt® platform** (a distributed energy modeling and optimization tool) to evaluate how BESS may:

- Reduce electricity costs
- Increase utilization of onsite renewable energy generation
- Improve resilience to utility grid outages.

This presentation summarizes the analysis and key takeaways.

- CEIA-Vietnam's Co-leads Hang Dao and Tung Ho contributed significantly to the research of this study.

Will Distributed Energy Resources (DERs) Work for Your Site?

Renewable Energy Resource

Technology Costs and Incentives

Site Goals (Economics, Resilience, Clean Energy)

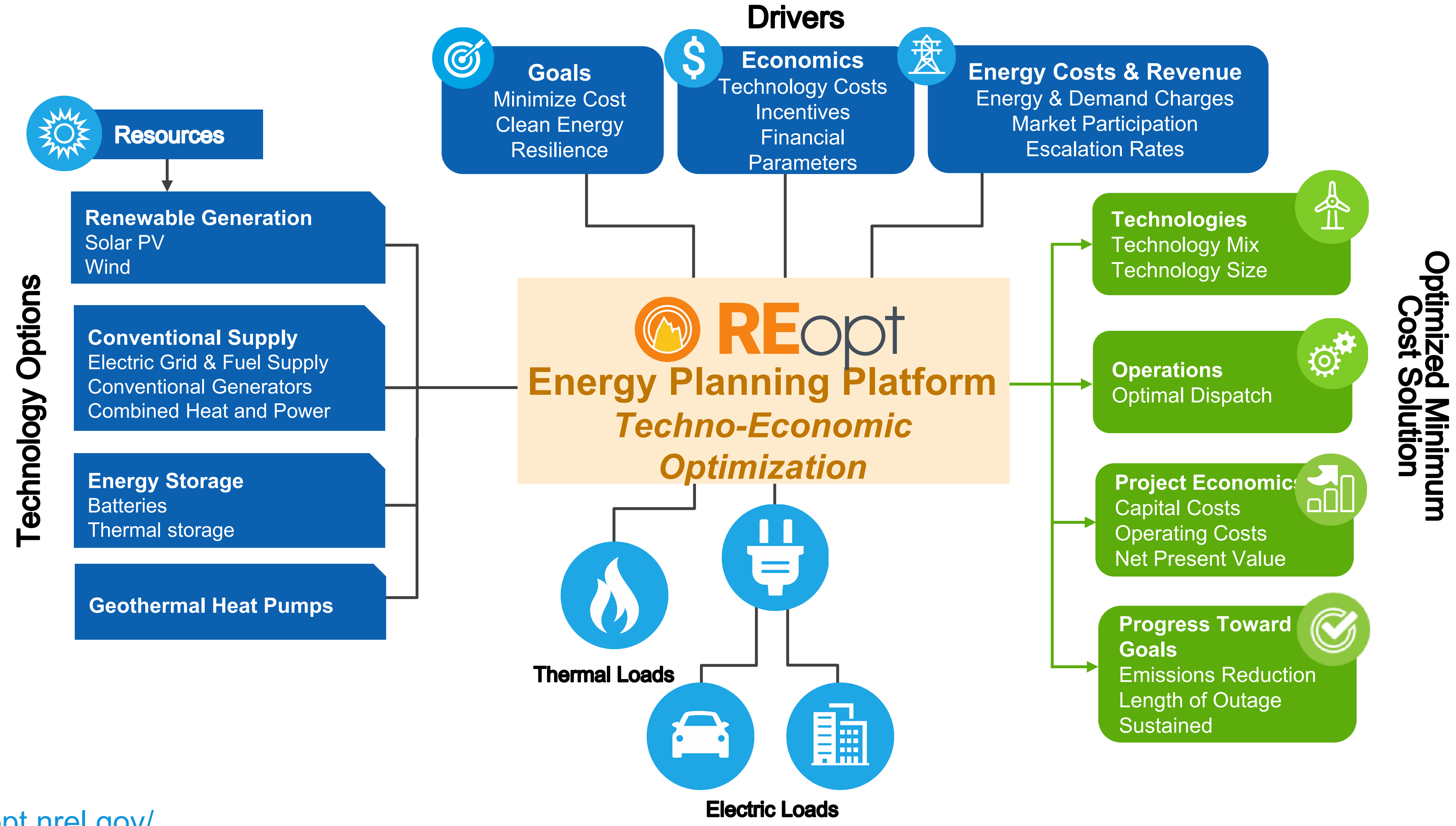
Utility Cost and Consumption

Financial Parameters

Many factors affect whether distributed energy technologies can provide cost savings and resilience to your site, and they must be evaluated concurrently.

REopt Overview

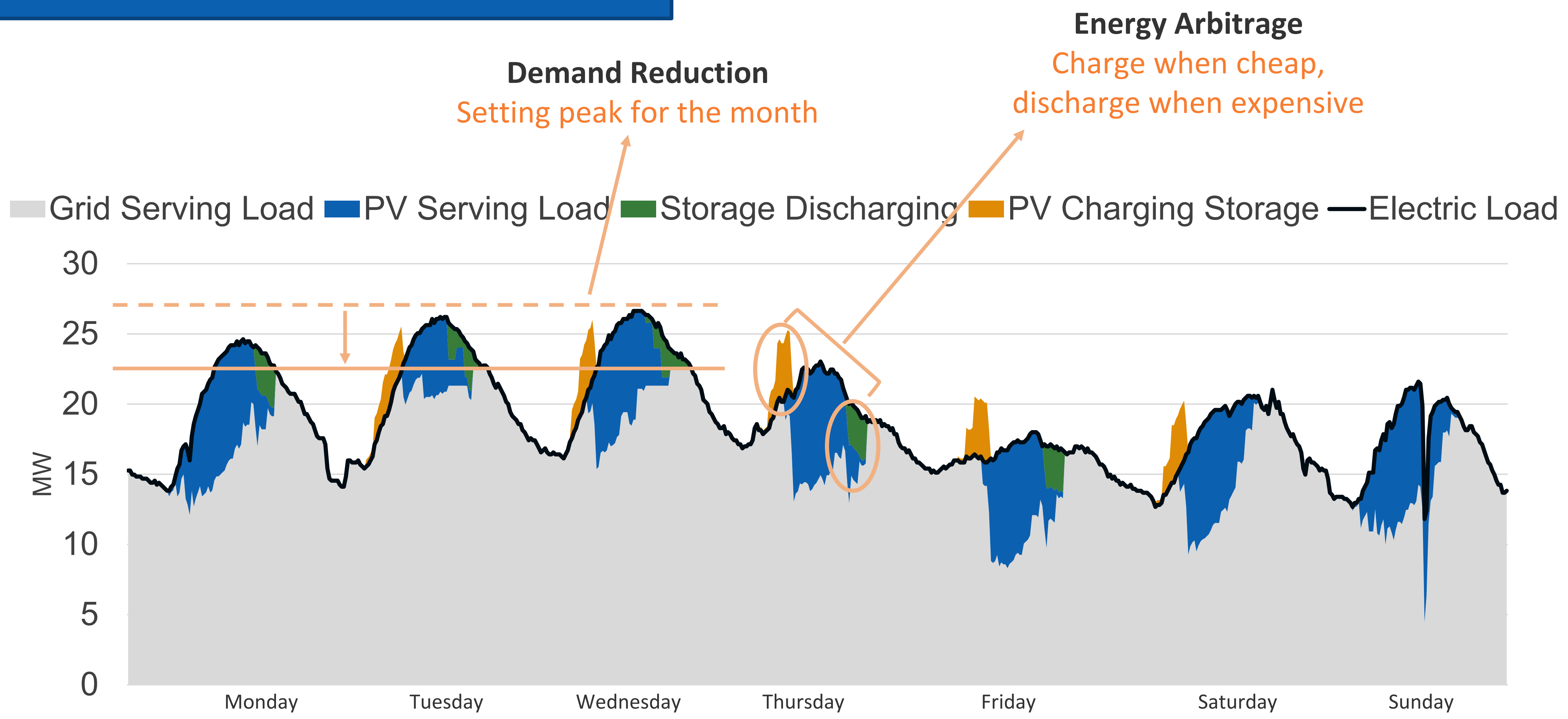
Formulated as a mixed integer linear program, REopt provides an integrated, cost-optimal energy solution.



https://reopt.nrel.gov/

Grid-Connected Value of PV + Storage

REopt considers the trade-off between ownership costs and savings across multiple value streams to recommend optimal size and dispatch.



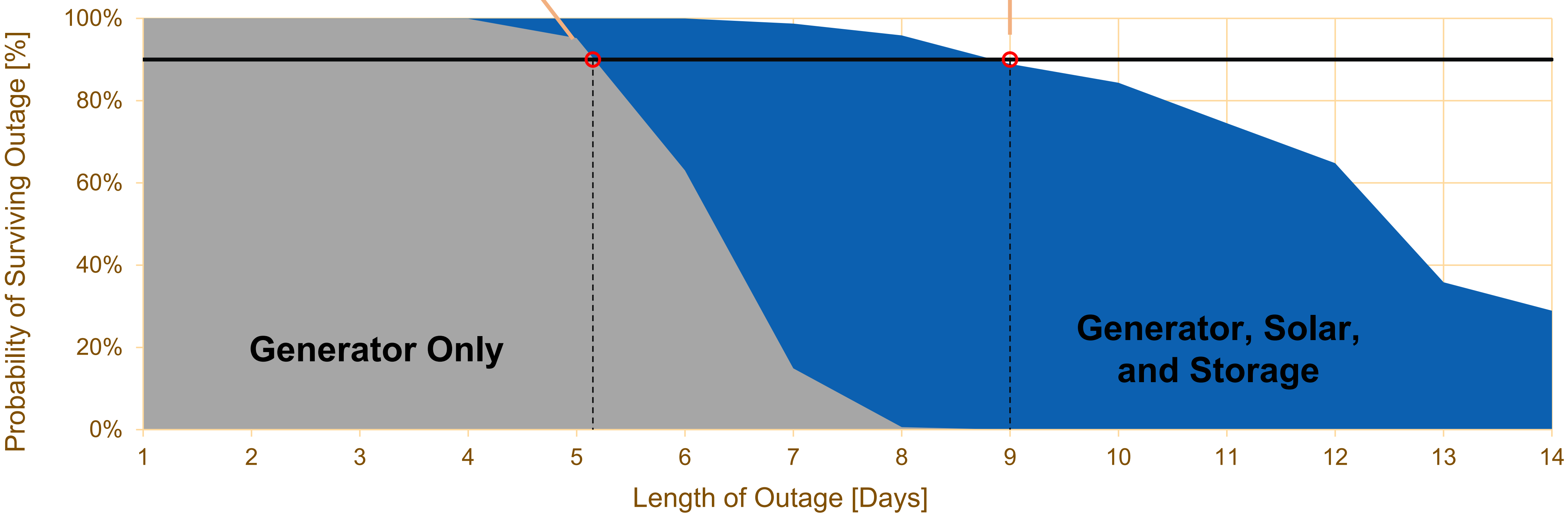
Example of optimal dispatch of PV and BESS

Resilience Value of PV + Storage

REopt finds the system size and dispatch that minimizes life cycle energy costs for grid-connected operations and survives a specified grid outage. It evaluates thousands of random grid outage occurrences and durations to identify the probability of survival.

Existing generator with fixed fuel supply sustains the critical load for 5 days with 90% probability.

Adding solar and storage to the existing generator increases survivability from 5 to 9 days by extending fixed diesel fuel supplies and provides utility cost savings while grid-connected.



Site Overview and Assumptions

Site Overview

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The industrial park is located in **Vietnam** and hosts tenants primarily from the **industrial sector**, including chemical processing, steel, logistics, manufacturing, and petro-logistics.

The industrial park buys power from the state utility, Vietnam Electricity Corporation (EVN), on wholesale time-of-use (TOU) rates, and sells electricity to tenants, while also operating the park's distribution system.

Total annual electric loads on the two feeders evaluated are currently (2022) estimated at 138,000 MWh/year. In the future (2029) these loads are **projected to reach 429,000 MWh/year** given high planned capacity growth expected over the next 5-10 years.

- The industrial park provided historical hourly load interval data to capture timing of load. The future load profile projection was developed by scaling the historical interval data to the projected future consumption also provided by the industrial park.

Industrial park has approximately 4 MW of onsite renewable energy generation and plans to scale up their renewable energy penetration significantly in the future.

Electricity Tariffs

The industrial park buys power from EVN at industrial zone wholesale prices on TOU rate schedules. The two different feeders evaluated connect at different voltage levels and thus are on slightly different rates:

TOU Period		Feeder A (22kV) ($USD/kWh)	Feeder B (110kV) ($USD/kWh)
Peak	Mon-Sat: 9:30-11:30, 17-20	$0.1238 USD	$0.1187 USD
Standard	Mon-Sat: 4-9:30, 11:30-17, 20-22 Sun: 4-22	$0.0670 USD	$0.0650 USD
Off-peak	All other hours (Sun-Sat: 22-4)	$0.0435 USD	$0.0415 USD

References:

- Rates: https://en.evn.com.vn/d6/news/WHOLESALE-ELECTRICITY-TARIFF-9-28-260.aspx.
  Feeder A: Industrial zone – Wholesale tariff for medium-voltages electricity at the 110/35-22-10-6kV substations – Voltage levels from 22kV to below 110kV
  Feeder B: Industrial zone – Wholesale charge at the 110kV busbars of 110/35–22-10-6kV substations - Total capacity of transformers exceeding 100MVA.
- TOU periods: https://en.evn.com.vn/d6/news/TIME-OF-USE-ELECTRICITY-CHARGE-9-28-264.aspx.

Notes:

- Costs and benefits listed throughout slides are in US Dollars (USD), based on a currency conversion of 22,759.86 VND = 1 USD (Jan 5, 2022).
- Loss factors for 22kV and 110kV are 0.9% and 1.3%, respectively (i.e. the park needs to purchase 0.9% and 1.3% more from EVN than tenants use).
- Due to REopt rate modeling structure of “weekday” vs “weekend” pricing, Saturday cost of electricity was conservatively modeled as off-peak along with Sunday. Where cost of electricity changes at the half hour, the lower cost of electricity was used to represent that hour’s electric costs.

Economic and Grid Assumptions

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Economic & Grid Inputs	Assumptions
Analysis period	10 years *Note: 10-year analysis period was selected to align with expected battery lifespan rather than a 25-year analysis to align with expected PV lifespan (with battery replacement in year 10). This decision was made due to the focus of this analysis on BESS economic feasibility and the significant uncertainty in current commercial-scale BESS prices in Vietnam; future BESS prices are even more uncertain.*
Ownership model	Direct purchase by the industrial complex
Discount rate (real)	Expected internal rate of return (IRR) of at least 11%
Grid electricity cost escalation rate (real)	Analysis conservatively assumes 3%/year. Per https://uk.practicallaw.thomsonreuters.com/4-628-5349: *"Under the Prime Minister's Decision No. 24/2017/QD-TTg (from June 2017), EVN can increase the average power retail price when input costs rise by 3% (this threshold was previously set at 7%). Depending on the input costs increase, EVN can raise the retail price by 3% to up to 5%. For increases of 5% or more, EVN must receive approval from the competent government ministries, such as the MOIT and the Ministry of Finance…Wholesale prices are set by the five power corporations that supply retailers in provinces and cities. However, the prices must be within the price brackets approved by either the Prime Minister (for remote areas) or the MOIT."*
Grid CO2 emissions rate	0.8458 tCO_2/MWh per most recent report, shared by CEIA Vietnam team
Net metering	Energy export to EVN is not currently legal in Vietnam, so analysis assumes no net metering (and no feed-in-tariff).

PV Assumptions

Solar PV Inputs	Assumptions
System type	Rooftop PV
Technology resource & performance	Historical PV performance data of existing PV system
Capital costs (for new PV only)	$600/kW-DC for new/additional systems, based on cost of existing PV system *Note: because analysis period is 10 years, but PV systems are expected to last 25-40 years, residual value of PV system at 10-year point is calculated assuming 30-year life and straight-line depreciation. Because the cost of electric grid purchases is likely to increase over time (projected at 3%/year in this analysis), this methodology is likely to underestimate the value of PV throughout its entire lifecycle of 25+ years.*
O&M costs	$8.76/kW/year with performance guarantee, based on existing 2.1 MWp PV system
Rooftop rental costs	$13/kW/year
PV degradation rate	0.5%/year

BESS Technology Assumptions

BESS Inputs	Assumptions
System type	Lithium ion (**Li-ion)** battery
Rectifier & inverter efficiencies	96%
Roundtrip efficiency	97.5% DC-DC, 89.9% AC-AC (includes rectifier/inverter efficiencies)
Minimum state of charge	20%
Capital costs	**Due to uncertainty in Vietnam-specific Li-ion BESS market pricing, a sensitivity study on BESS costs was performed:** • **Low cost:** \$200/kW + \$100/kWh *(equivalent to \$400/kW for a 2-hour battery, \$600/kW for a 4-hour battery)* • **Medium cost:** \$325/kW + \$162.50/kWh *(equivalent to \$650/kW for a 2-hour battery, \$975/kW for a 4-hour battery)* • **High cost:** \$450/kW + \$225/kWh *(equivalent to \$900/kW for a 2-hour battery, \$1,350/kW for a 4-hour battery).* **These three scenarios of assumptions were selected to cover a range of possible BESS cost scenarios, based on the following market research:** Wood Mackenzie "all-in," whole-system costs for 2-hr front-of-the-meter energy storage costs in Asia-Pacific region, per https://www.energy-storage.news/analysts-predict-30-reduction-in-asia-pacific-regions-grid-battery-storage-costs-over-five-years/. • China: \$554/kW (2020); \$369/kW (2025 projection) • South Korea: \$821/kW (2020); \$578/kW (2025 projection) • Australia: \$990/kW (2020); \$658/kW (2025 projection). U.S. market references for 2021: • NREL ATB shows all-in U.S. BESS market costs of \$853/kW for 2-hr utility-scale (60 MW) BESS • 2021 Q4 Wood Mackenzie U.S. Storage Monitor shows median \$1175/kW (low: \$900, high: \$1500) for 2-hr, median \$1725/kW (low: \$1250, high: \$2350) for 4-hr front-of-the-meter BESS, all-in costs. *In order to break down overall battery system costs to \$/kW + \$/kWh component costs (required for REopt modeling), modeling inputs are based on the assumption that the \$/kW cost is approximately twice the \$/kWh cost.* *Note: Battery O&M costs are not included in the model but are relatively low.*

Scenarios and Sensitivities Summary

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The following scenarios/sensitivities were evaluated:

Scenario/ Sensitivity	Assumptions:
Current vs. future load projections	• **Current (2022) loads:** 138,000 MWh/year • **Future (2029+) load projections:** 429,000 MWh/year
Technology options	• Business-as-usual (BAU): no new PV or BESS • Cost-optimal BESS only • Cost-optimal PV + BESS • Planned high-penetration PV + cost-optimal BESS (for future load projection only)
BESS capital cost sensitivity study ("all-in" including equip, labor, etc.)	• **Low:** $200/kW + $100/kWh, all-in • **Medium:** $325/kW + $162.50/kW, all-in • **High:** $450/kW + $225/kWh, all-in

Results

Key Takeaways

- Adding **new PV appears cost effective, with or without BESS,** at the industrial park.
- **BESS begins to become cost-effective in Vietnam at the lowest price point evaluated: $200/kW + $100/kWh.** This converts to a total of $400/kW all-in for a 2-hour BESS or $600/kW all-in for a 4-hour BESS. These costs are in the lower end of the range of current BESS costs across Southeast Asia[1]:

2-hour BESS cost comparison	China	South Korea	Australia	Vietnam results
2020 BESS costs	$554/kW	$821/kW	$990/kW	Cost effective at or below ~$400/kW
2025 BESS cost projections (from 2020)	$369/kW	$578/kW	$658/kW	

- Where BESS is cost-effective, the **value of combined PV plus BESS is greater than** the value of **standalone PV plus** the value of **standalone BESS.** In the high-penetration RE scenario, adding BESS significantly (~1.75x) increases the value of PV generation.
- Considering the **resilience value** that these technologies provide as alternatives to backup diesel generation **could improve the project economics**, but larger systems than those identified as cost-optimal would be required to provide reliable resilience of normal full-load operations.
- Note: The **net present value (NPV)** of each system identified is relatively small compared to the overall cost of electricity at the site. (NPV/ lifecycle costs (LCC) of electricity < 1% for all scenarios.)

[1] **Reference:** Wood Mackenzie "all-in," whole-system costs for 2-hour front-of-the-meter energy storage costs in Asia-Pacific region, per https://www.energy-storage.news/analysts-predict-30-reduction-in-asia-pacific-regions-grid-battery-storage-costs-over-five-years/.

Results Summary: Grid-Connected Economics

Cost-optimal new system sizes for normal grid-connected economics

Load year:	Current (2022) Loads				Future (2029+) Load Projections					
New technologies considered:	Cost-optimal BESS only		Cost-optimal PV + BESS		Cost-optimal BESS only		Cost-optimal PV + BESS		Cost-optimal BESS with High-penetration PV	
BESS capital cost assumptions:	Low	Med/ High	Low	Med/ High	Low	Med/ High	Low	Med/ High	Low	Med/ High
New PV capacity (MW)	---	---	14.1	10.7	---	---	24.0	20.1	60.0	60.0
New BESS energy capacity (MWh)	27.7	0	21.3	0	32.4	0	24.6	0	79.7	0
New BESS power capacity (MW)	7.0	0	5.4	0	8.2	0	6.2	0	20.1	0
Net present value (NPV)[3] ($)	$73.9k	$0	$269.5k	$155.8k	$86.5k	$0	$320.0k	$188.6k	$313.1k	$177.3k
Electricity cost savings[4] (%)	0.2%	0%	0.6%	0.3%	0.2%	0%	0.6%	0.4%	0.6%	0.3%

Note: Solutions with NPV > $0 exceed the required IRR of 11%.

Footnotes:

[1] Results depend on assumptions presented in these slides, including 10-year analysis period, 11% IRR / discount rate, and 3%/year utility cost escalation rate.

[2] Dash (---) indicates that technology was not considered in that scenario. Zero (0) indicates that technology was considered but does not appear cost effective in that scenario.

[3] Net present value (NPV) is the difference (savings) in lifecycle costs (LCC) of electricity facilitated by the new PV and/or BESS, relative to the BAU scenario. Lifecycle costs are calculated as the present value of capital costs, O&M costs, and grid purchases throughout the 10-year analysis period. (NPV = $LCC_{BAU} – LCC_{OPT}$).

[4] Electricity cost savings percent calculated as NPV divided by LCC_{BAU}, or ($LCC_{BAU} – LCC_{OPT}$)/ LCC_{BAU}.

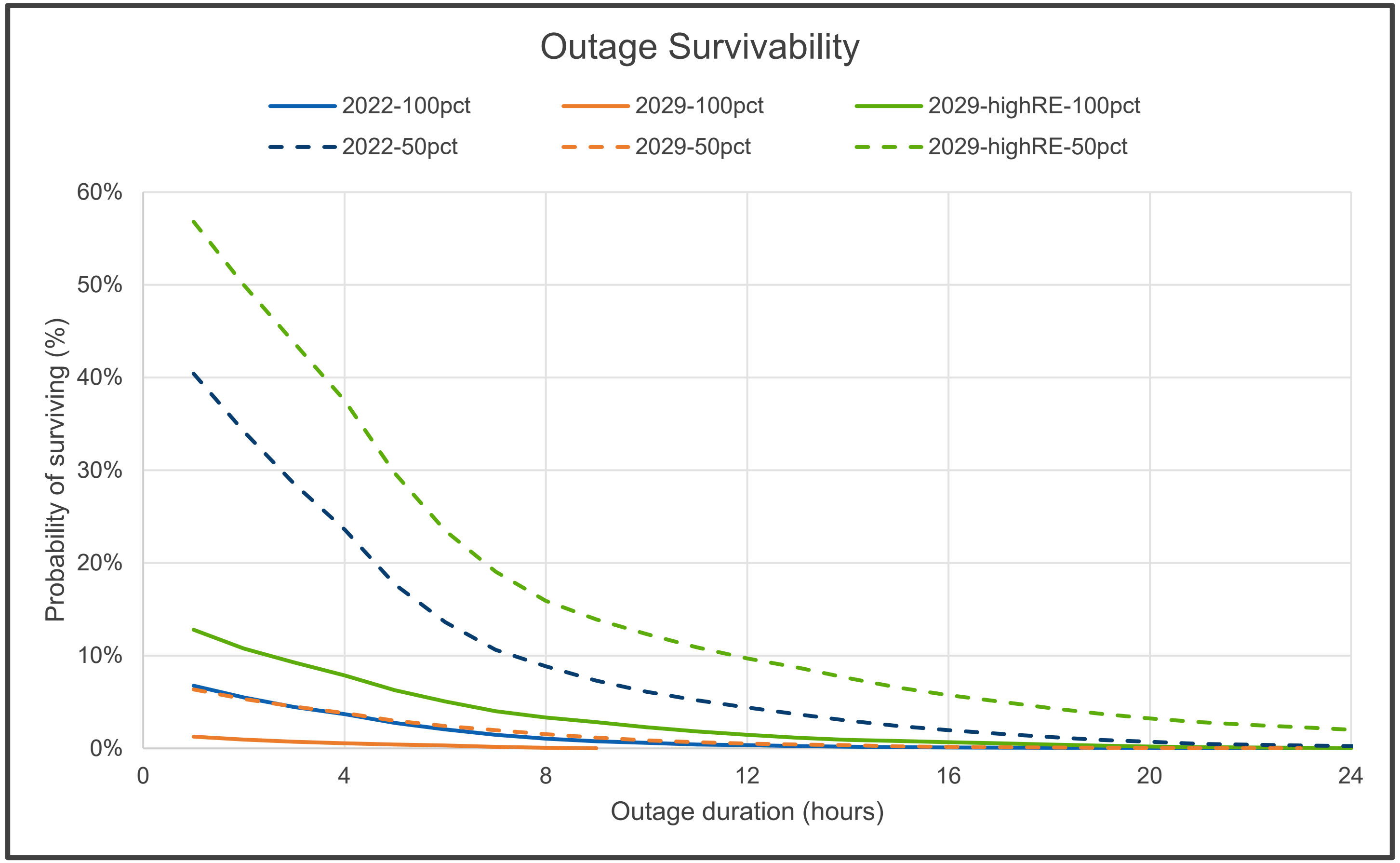
Resilience Value and Outage Survivability

In addition to the electric bill savings during normal grid-connected operations, PV + BESS systems can provide resilience value in the case of a grid outage.

The plot to the right shows the **outage survivability (probability of surviving outages of various durations)** of the systems identified on the previous slide as cost-optimal (Low BESS capital cost assumption).

Results indicate that larger PV and/or BESS systems would be required for reliable backup power at full load, even for a 1-hour outage. However, shedding load allows these PV-BESS systems to provide resilience to critical loads.

Outage survivability: Probability the cost-optimal PV / BESS could sustain full (100%) or part (50%) load operations during outages of varying durations



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