

Resilience and Affordability Through Decentralized Power Grids

Puerto Rico Virtual Power Plant Case Study

PREPARED BY

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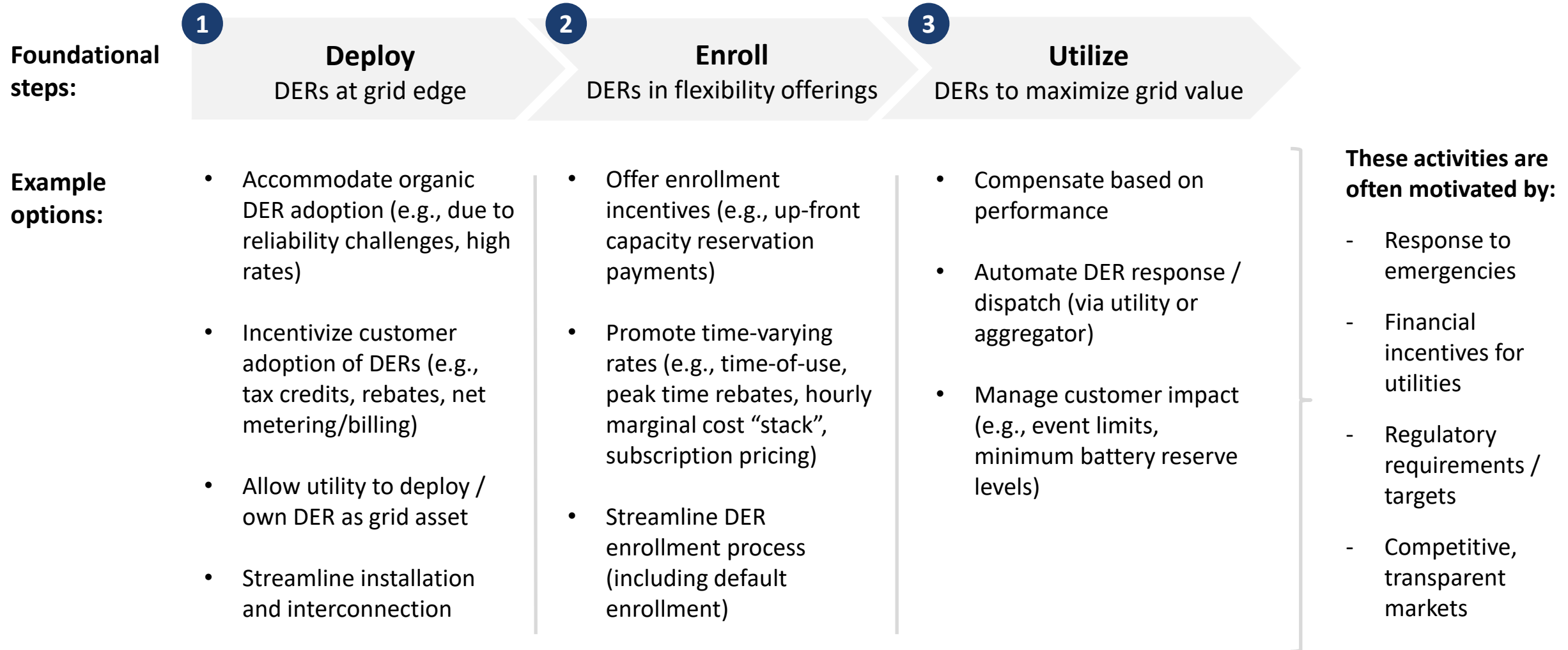
PREPARED FOR

IEA Workshop: “Empowering
Ukraine: From BESS
Deployment to Resilience”

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Successful practices for a decentralized power grid



Puerto Rico case study: Recovering from a devastating hurricane

Background

- After 2017 hurricane, all 1.6 million customers lost power
- Roughly 1 year to fully restore grid; system remains fragile
- Subsequent island-wide blackouts in 2020 and 2022
- Frequent outages persist; 24 outage hours per year (avg)
- Only 53% of total generation capacity is expected to be available at any given time due to failing equipment or scheduled maintenance
- 500 MW supply shortfall (15%) anticipated summer 2025
- Electricity costs are rising; rates approaching \$30 c/kWh
- Despite these challenges, strong clean energy goals; 60% by 2040, 100% by 2050



Puerto Rico case study: Key actions taken

Key actions

- Privatize utility; separate generation business from T&D
- \$6 billion of federal investment
 - Grid hardening
 - Advanced metering
 - Large-scale renewables and storage
 - Customer-sited solar and storage (focus on low income)
- Ongoing customer adoption of solar and storage; utility must connect all customer solar/storage systems
- Use net metering as incentive for behind-the-meter solar development and community support
 - Utility buys back solar power at \$0.10 per kWh or the avoided fuel costs, whichever is greater
 - 75% of buy back goes directly to the customer, the remaining 25% is credited toward public school electricity bills
- **Introduce “Customer Battery Energy Sharing” Program**



Puerto Rico case study: Features of the customer battery program

Key features of the CBES program

- Participants enroll batteries through an **aggregator**
- Utility pays \$1.25/kWh to aggregators and aggregators pay **simple incentive** of \$1/kWh to participants for energy during emergencies
- Utility **funds payouts** through existing demand-response and capacity-reserve tariffs that are **cheaper than the cost of new thermal capacity**
- Manual communication of grid events to aggregators; aggregators then **automatically dispatch batteries**
- Emergency event duration **limited** to 2-4 hours, often with **day-ahead notification**
- **Customers choose** how much battery capacity is available to be dispatched and can opt out of events
- Batteries **not dispatched during storms**

Key participating aggregators

SUNRUN

T E S L A

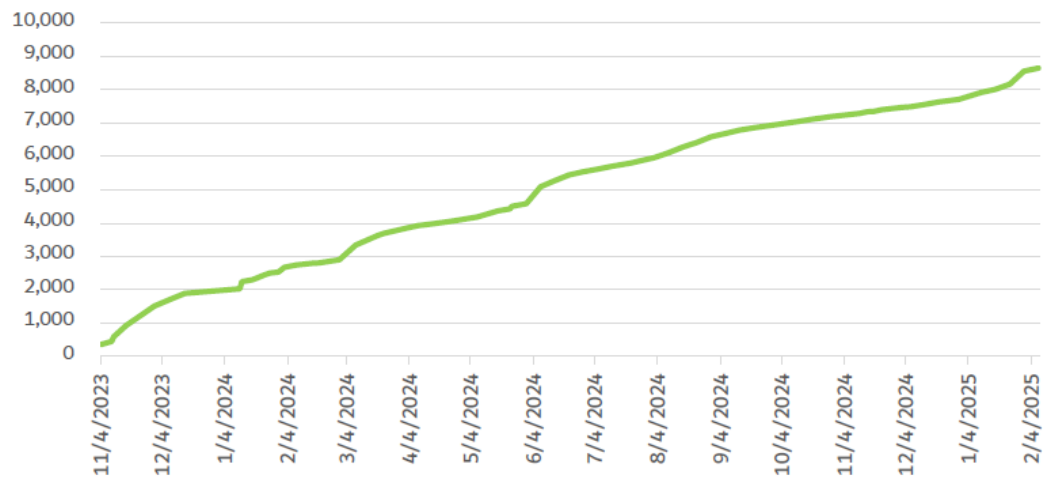
sunnova

Puerto Rico case study: Scaling up to first Virtual Power Plant (VPP)

Outcome

- Pilot program scaled to **nearly 50 MW of enrolled capacity in ~1 year**; transitioned from pilot to full-scale Virtual Power Plant (VPP) program with funding secured until least 2028
- All customers with batteries are now **auto-enrolled into VPP program with a default level of 30% of battery capacity**
- In the summer of 2025, **the program helped address a nearly 50-megawatt generation shortfall for 3+ hours**, preventing power outages in many areas across the island
- As of Q2 2026, 82,490 participants customers were enrolled in the program, **totaling 512.5 megawatts (MW) of battery capacity**

CBES Pilot Enrollment



Challenges

- Continuing to scale program
- Managing customer fatigue
- Increasing realized energy dispatch of VPP during events
- Migrating to DERMS-enabled dispatch

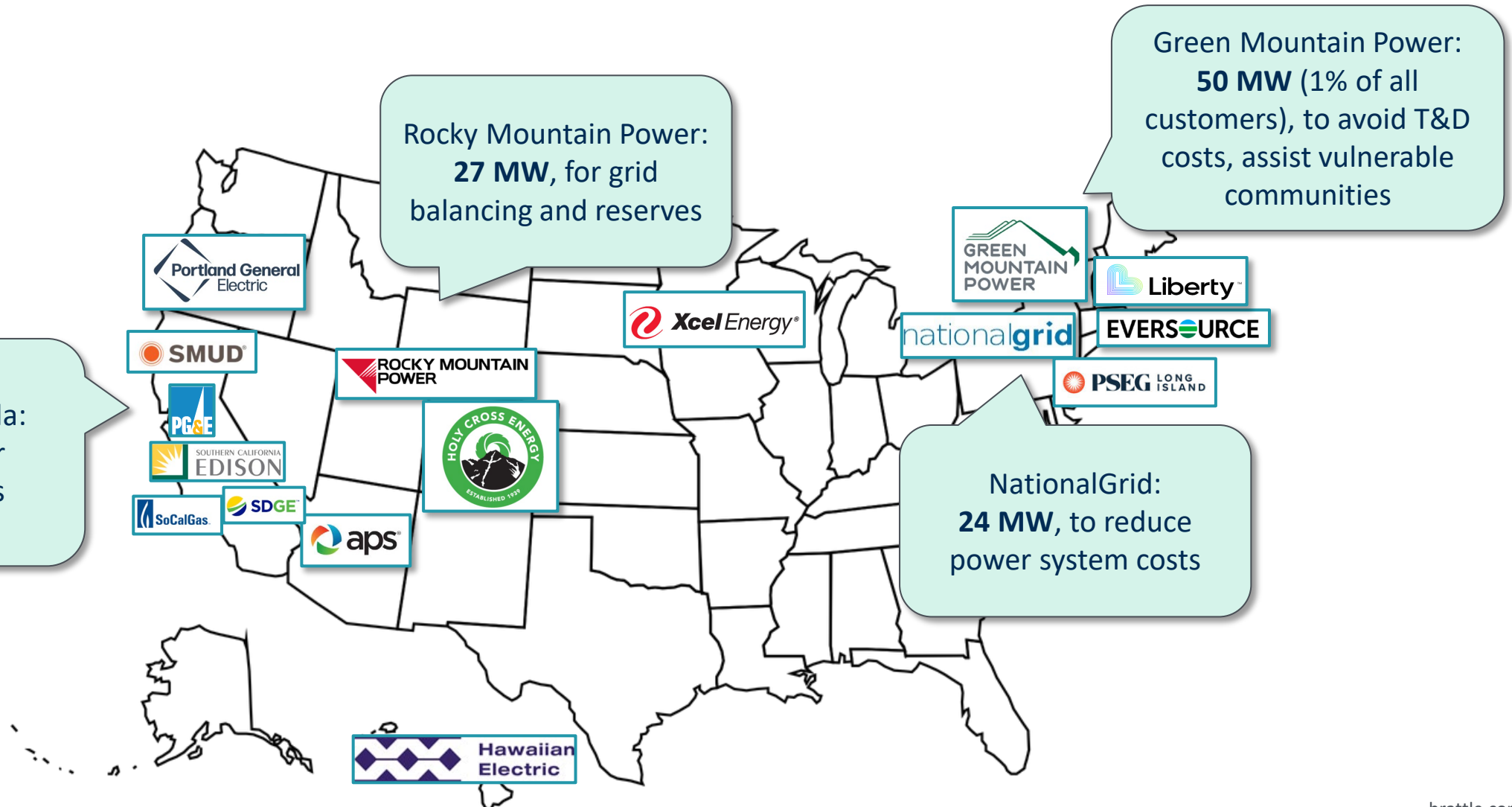
Other storage programs like Puerto Rico's are beginning to scale

Rocky Mountain Power:
27 MW, for grid
balancing and reserves

Green Mountain Power:
50 MW (1% of all
customers), to avoid T&D
costs, assist vulnerable
communities

SunRun & Tesla:
350 MW, for
emergencies

NationalGrid:
24 MW, to reduce
power system costs

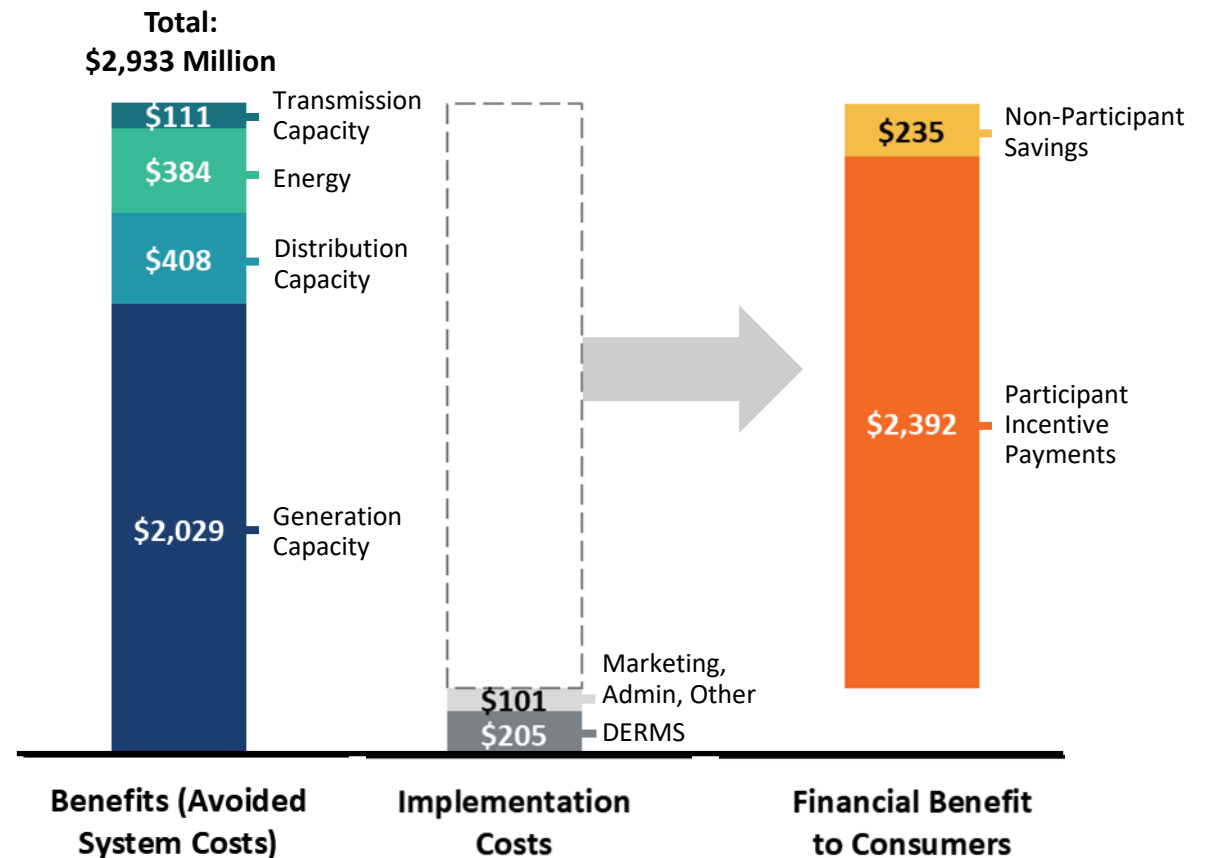


At scale, DER programs significantly improve energy affordability

We estimate that 20% of New York's peak could be served from DERs and demand flexibility

- Nearly \$3 billion/year in avoided system costs (capacity, energy, distribution, transmission)
- Only ~\$300 million/year in implementation costs (systems, admin, marketing)
- Over \$2 billion/year in cost savings returned to **customers**, with portion of value also retained as savings for non-participants

New York Demand Flexibility Potential Benefits (2040)



Potential next steps for Ukraine

Understand the DER opportunity

- Market assessments, customer surveys inform design

Pilot with a plan to scale

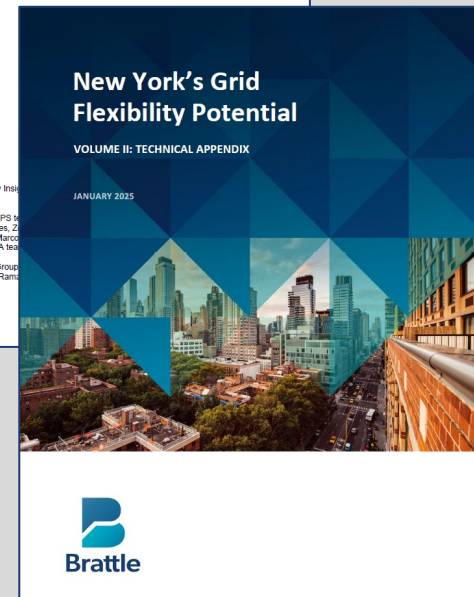
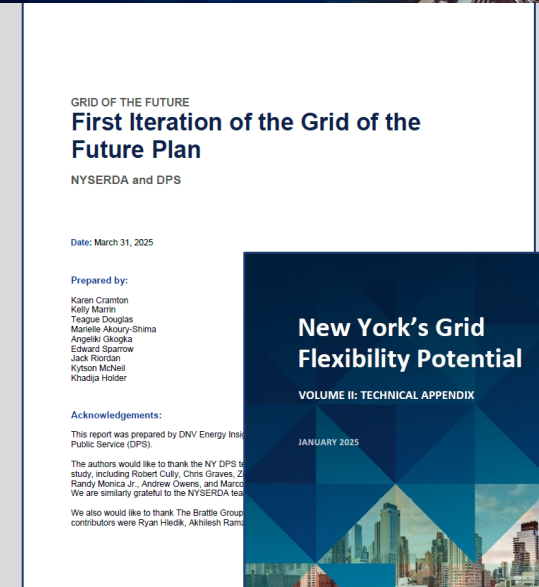
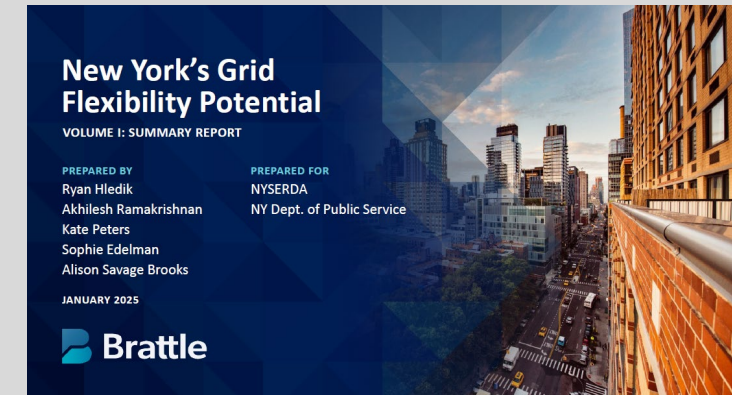
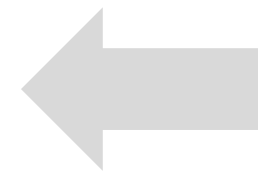
- Assume the pilot will succeed; be ready to build when it does

Ensure basic DER communications infrastructure is in place

- It's much more expensive to retrofit DERs after they're installed

Enable aggregator participation in wholesale market

- With appropriate accompanying consumer protections



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Appendix A:

Additional DER Resources

Utility ownership: A path forward for DERs?

There is emerging interest in the “Distributed Capacity Procurement” model

Approach

- Identify **constrained** locations of the grid
- Determine if DERs are the most **cost-effective** option to relieve constraint
- Allow utility to **deploy, own, and operate** DERs at the location
- Utilities earn a **return** on the DER assets, may also operate DER to provide **private benefits** to customer

Advantages

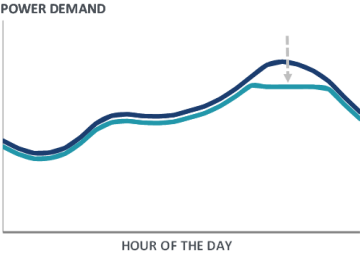
- **Participant:** Revenue from hosting DER asset, improved reliability
- **All customers:** Reduced rates (relative to more expensive traditional solutions)
- **Private sector:** Large counterparty (utility); reduced/eliminated customer acquisition costs
- **Utility:** Expanded rate base while pursuing cost-minimizing solution

For more information, see [Sparkfund website](#).

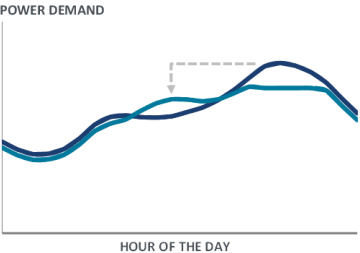
Benefits of VPPs

VPPs provide many operational benefits, along with the potential to mitigate other concerns such as lengthy resource interconnection delays and unprecedented uncertainty in load forecasting.

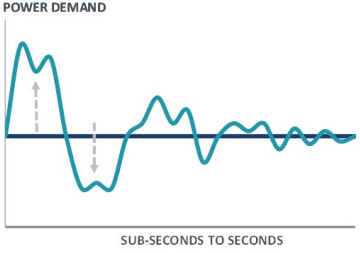
Sources of VPP Operational Value



Peak demand reduction
Dispatchable and event-based, with a limited number of events per season. Primarily provides capacity value.



Load shifting
Occurs frequently. Provides capacity and energy value, and potentially GHG emissions reductions. Helps to integrate renewables by reducing curtailments.



Real-time grid balancing
Some VPPs elements, such as batteries or grid-interactive water heaters, can provide ancillary services to address real-time imbalances on the grid.

Speed and Flexibility of VPPs

Resource development timeline

Resource development flexibility

Supply-centric approach	VPP-centric approach
Transmission-connected resources constrained by 4+ year interconnection approval process	VPPs can be “built” as quickly as customers enroll and the required control software is implemented
Investments in traditional capacity are a 20-40 year commitment once steel is in the ground	VPPs can scale as demand grows and, to an extent, downsize if needed

Other Sources of VPP Value

VPPs can provide other benefits as well, such as:

- Avoided infrastructure buildout
- Increased renewables deployment
- Better power system integration of electrification
- Enhanced customer satisfaction
- Improved behind-the-meter grid intelligence
- Overall energy savings
- Improved resilience

Additionally, VPPs are the only resource that pays customers to participate in the energy transition.

For further discussion, see [Real Reliability: The Value of Virtual Power](#) and [Power Shift](#).

30 strategies to increase enrollment

Marketing

- 1 Concise messaging about program benefits
- 2 Multiple motivators for participation
- 3 Top-of-funnel marketing
- 4 In-person promotional events

Enrollment Process

- 5 Create a seamless enrollment process
- 6 Pre-enroll devices sold on utility marketplaces
- 7 Point-of-sale enrollment at retailers
- 8 Offer easy enrollment in multiple programs
- 9 Integrate value-add services into programs
- 10 Provide referral incentives

Ecosystem Partners

- 11 Harmonized messaging from utilities and OEMs
- 12 Engage customers through trusted entity
- 13 Partner with local installers
- 14 Exchange learnings with other utilities

Incentive Design

- 15 Maximize the financial incentive
- 16 Ensure customer pays a portion of device cost
- 17 Offer ongoing participation payments
- 18 Bundle device financing options with programs
- 19 Align price signals
- 20 Offer active and passive control models

Engagement and Retention

- 21 Improve program design over time
- 22 Regularly remind customers of their rewards
- 23 Compensate through channels customer will notice
- 24 Communicate societal impact of participation
- 25 Call regular testing events
- 26 Offer easy unenrollment
- 27 Offer flexibility to opt out of events
- 28 Limit event notifications in automated programs
- 29 Allow customers to set control range
- 30 Offer technology choice where available

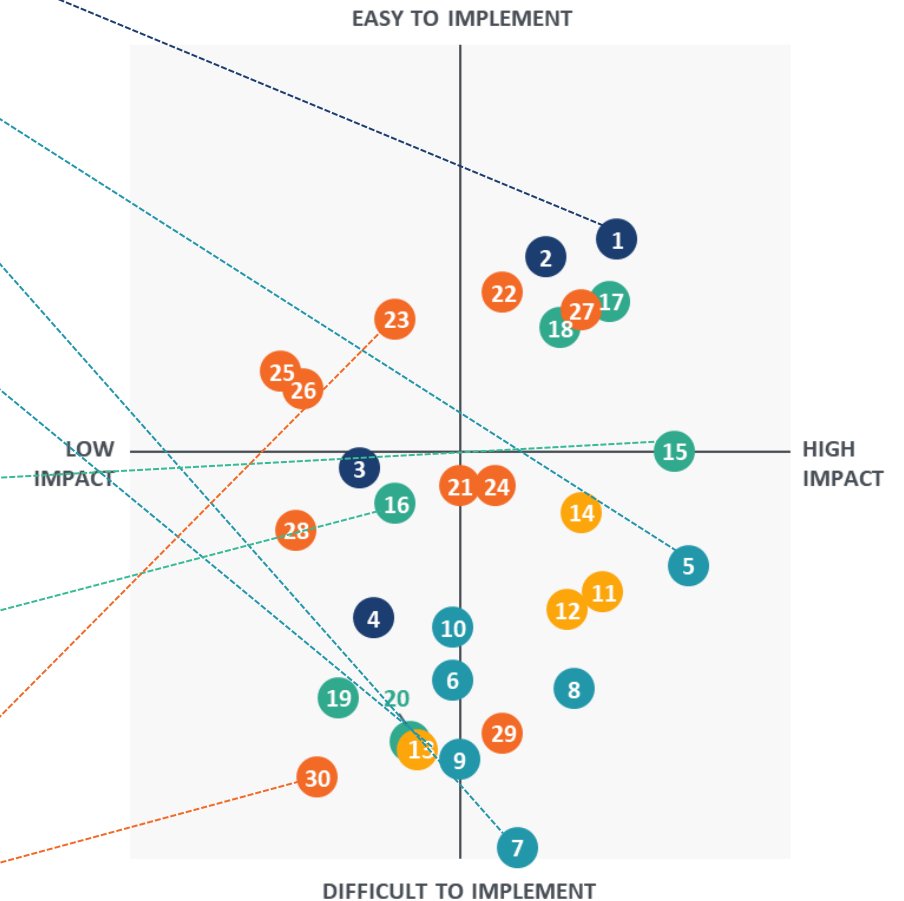
30 Strategies: Impact and Ease of Implementation
Based on perspectives of VPP solutions providers



Key highlights

- 1 **Concise messaging about benefits.** The headline should be the financial incentive. Also, key program features such as the ability to opt out
- 5 **Seamless enrollment process.** E.g., offering multiple options for user authentication, pre-populating forms with customer data, and minimizing the number of clicks/forms
- 7 **Point-of-sale enrollment at retailers.** For example, a checkbox to indicate enrollment when adding a device to the cart on a marketplace or retailer website
- 9 **Package with other value-add services.** For example, subscription pricing or real-time energy monitoring.
- 15 **Maximize the financial incentive.** Requires navigating the tension between financial attractiveness and cost-effectiveness.
- 16 **Ensure customer pays a portion of the device cost.** This ensures customers are emotionally invested in their purchase.
- 23 **Pay through channels customers will notice.** It is important for customers to realize that they are benefitting from participation
- 30 **Offer technology choice where available.** E.g., smart thermostats and A/C switches have different advantages and disadvantages.

30 Strategies: Impact and Ease of Implementation
Based on perspectives of VPP solutions providers



Appendix B:

The Potential Role of DERS in Ukraine

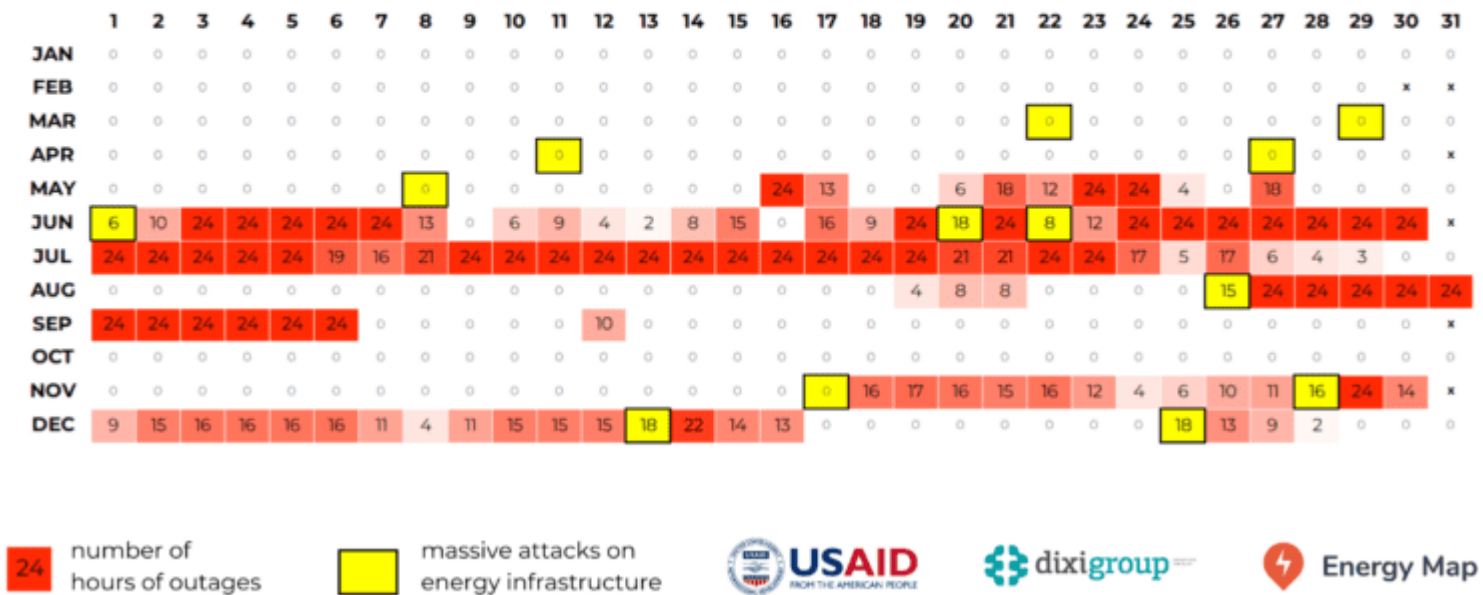
Ukrainian Households Were Left Without Power For More Than a Fifth of All Hours in 2024

After the massive August 26 attack on energy infrastructure, Ukrainian households were left without power for 11 straight days

DERs and microgrids can help bring power back in the wake of massive attacks and rotating outages

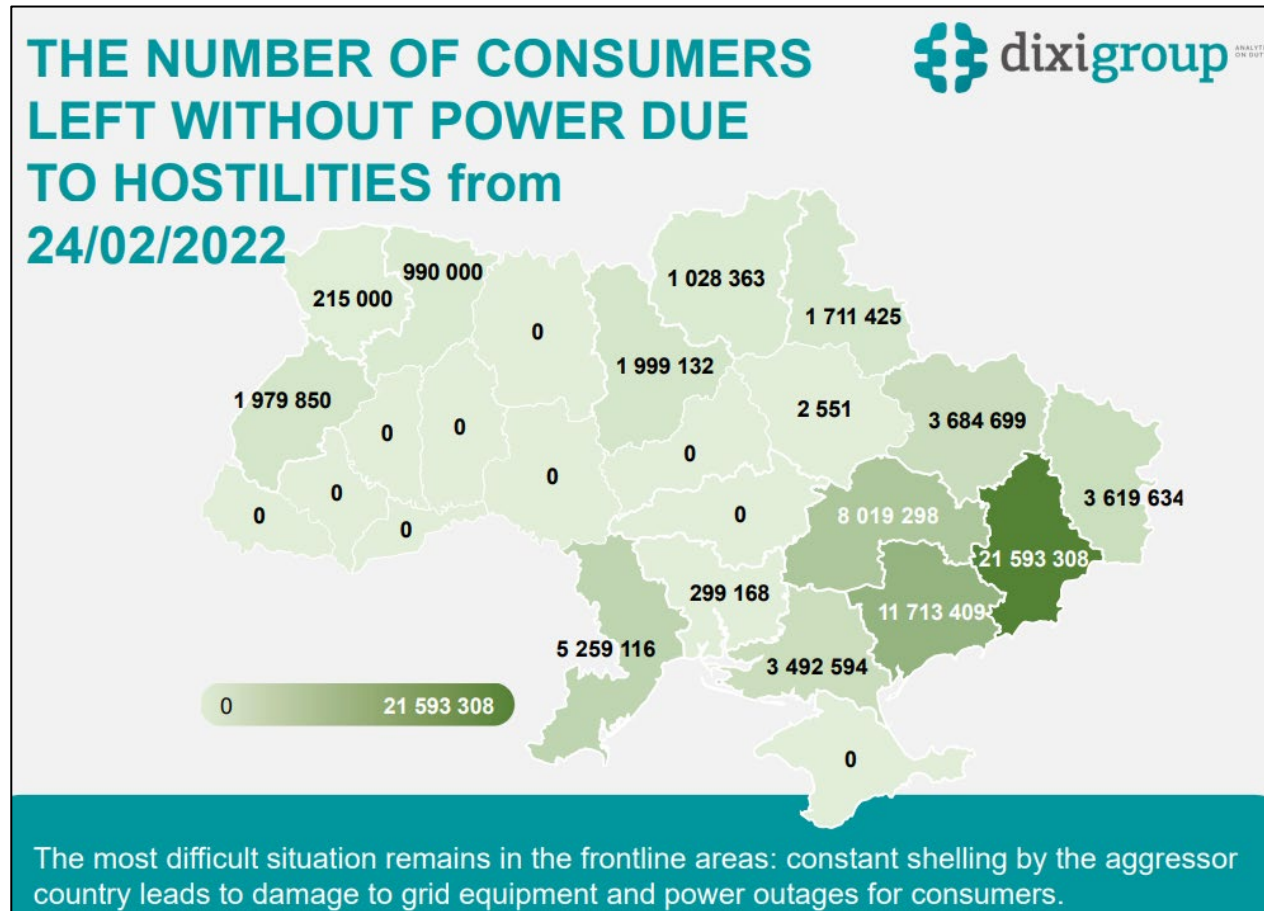
1951 HOURS

with electricity outages in 2024



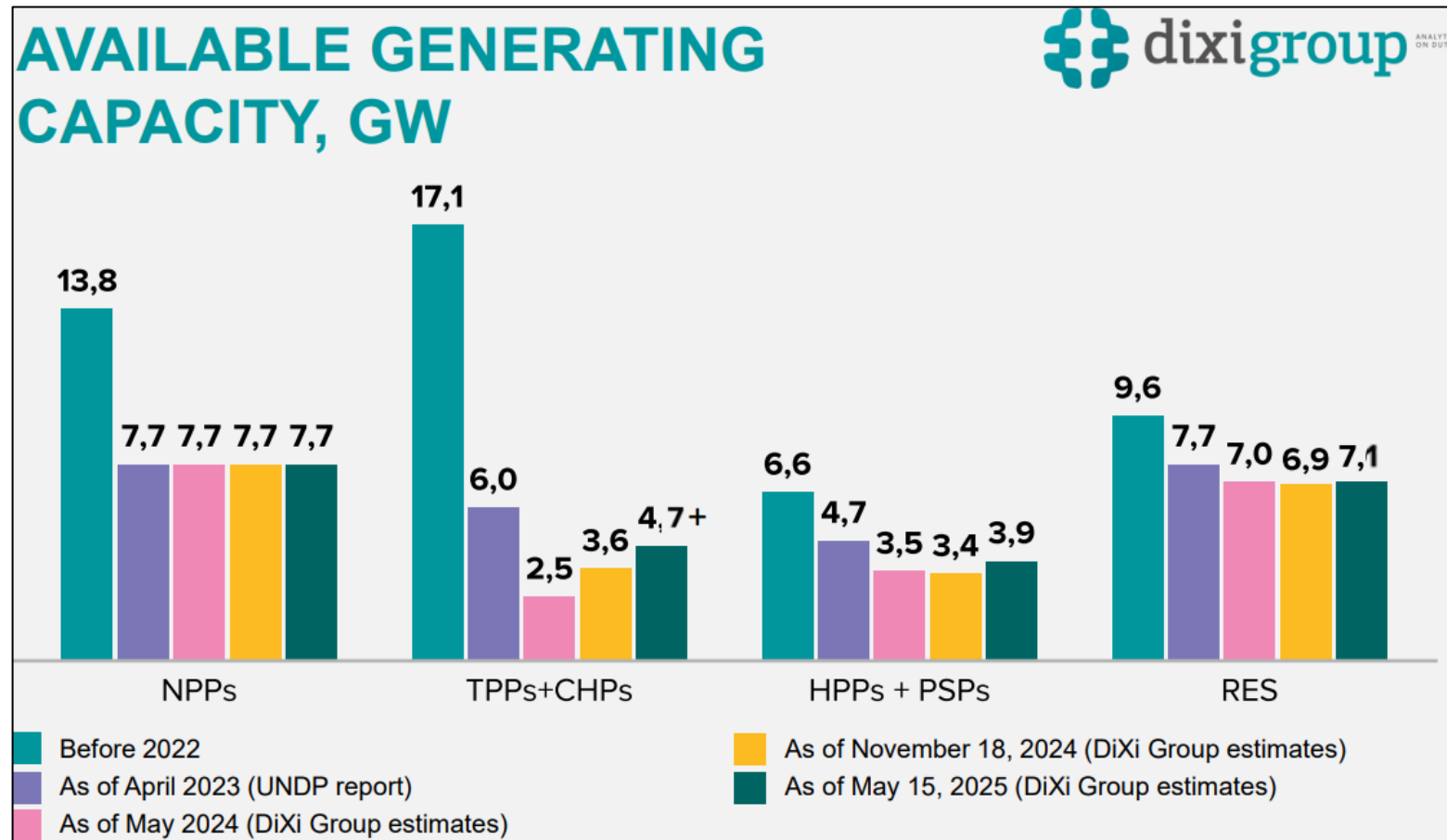
Source: [DiXi Group](#). Scheduled stabilization outages affecting all or most (>50%) of oblasts are reported. Rotating outage schedules implemented on an oblast-by-oblast basis and unplanned emergency outages are not reported in this graphic.

VPP Pilots Could Be Most Impactful in Oblasts Targeted in Attacks on Energy Infrastructure



Attacks Substantially Reduce Ukraine's Bulk Generation Capacity

Distributed generation can help fill the gap in Ukraine's power supply.

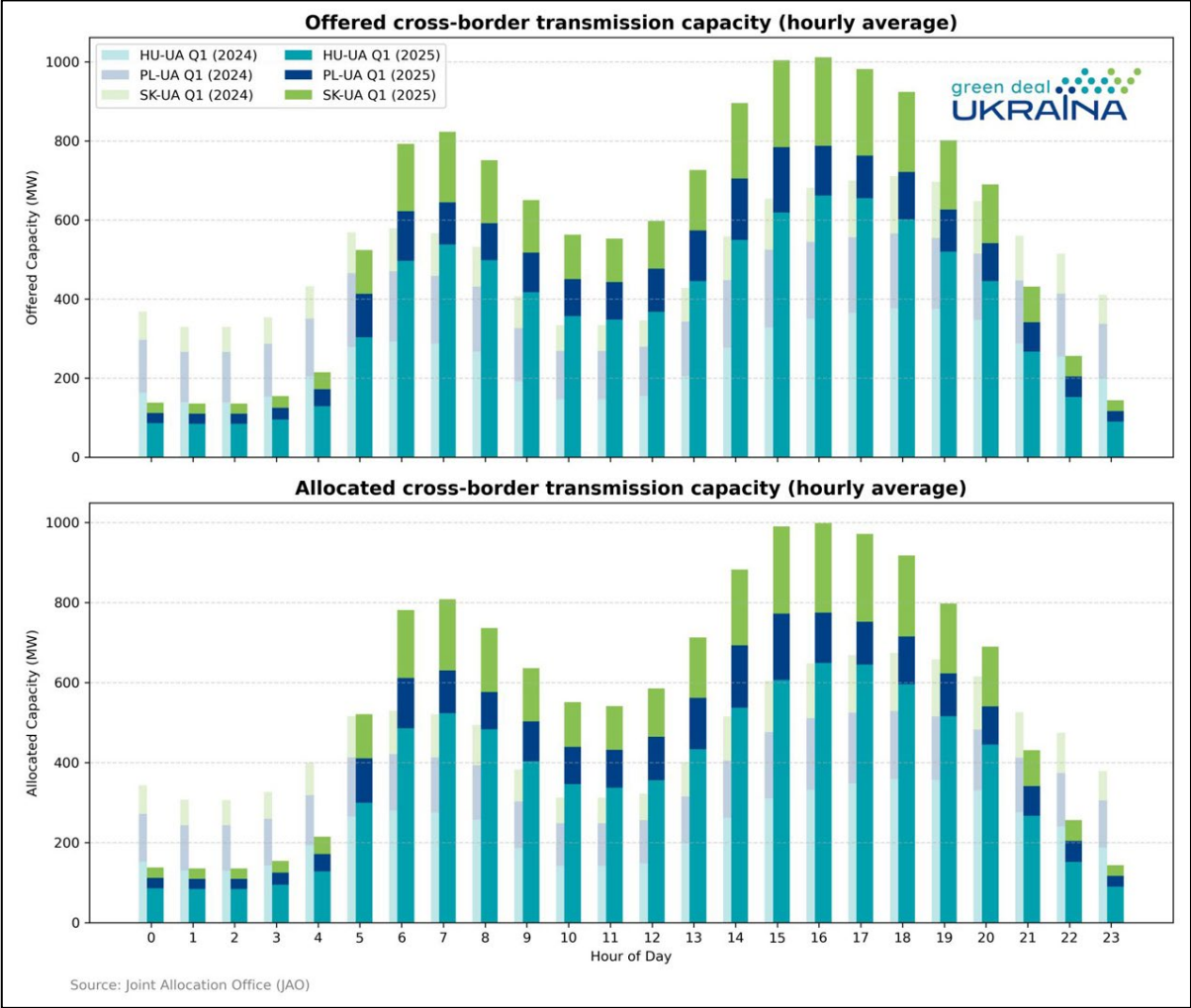


Sources and Notes: DiXi Group. [Summer 2025 Electricity Outlook](#). May 28, 2025. TPP = Thermal Power Plants; CHP = Combined Heat and Power Plants; HPP = Hydro Power Plants; PSP = Pumped Storage Plants; RES = Renewable Energy Systems.

Ukraine's Electricity Imports Peak During Evening Hours and Increase From Q1 2024 to Q1 2025

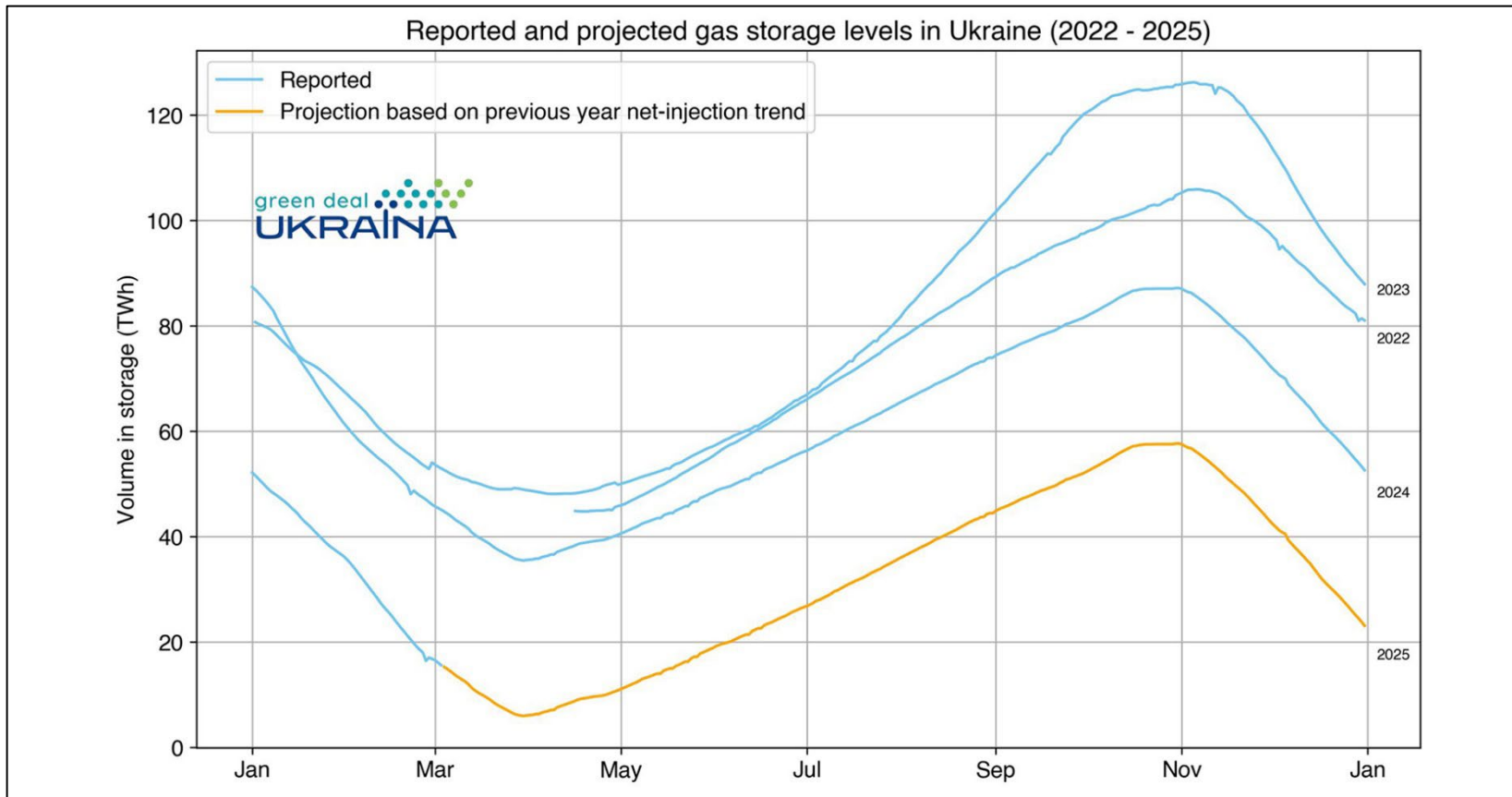
Increasing import volumes since 2024 highlight the need for additional generation capacity.

Continued DER deployment can contribute to serving peak loads during evening hours, when imported energy tends to cost more.



Ukraine's Natural Gas Storage Levels Are Decreasing

Distributed renewable generation, energy storage, and biofuel-powered generators can help reduce reliance on natural gas for distributed generation.



Source: Aggregated Gas Storage Inventory (AGSI), accessed via [Green Deal Ukraina](#).