

Mobile Energy Storage: Flexibility for the Energy Transition

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The Grid's Growing Challenge

Electricity grids worldwide face a critical challenge: the supply and demand of energy is growing faster than the infrastructure needed to support it. In 2024 alone, global additions of renewable capacity totaled 685 gigawatts (GW)—nearly three times the amount added in 2019 (IEA 2025b). Meanwhile, electricity demand is growing as homes switch to electric heating, drivers adopt electric vehicles, and power-hungry AI data centers surge in number (IEA 2025a).

This growth creates two fundamental problems for the grid infrastructure (IEA 2024). First, renewable generation doesn't always align with demand—the sun shines brightest at midday, but residential demand peaks in the evening. Second, renewable projects often locate where resources are best, rather than where demand is highest, which can strain transmission lines that were never designed for these flows. When transmission lines reach capacity limits, electricity prices can spike dramatically on one side of the congested line, while the other side experiences low prices due to excess supply. These costly congestion bottlenecks slow the integration of clean energy.

Battery storage has emerged as a promising solution to these challenges. By charging when renewable power is abundant and prices are low, and discharging when demand peaks and prices rise, batteries can smooth the temporal price mismatches.

Battery capacity in the United States grew from effectively zero in 2020 to 26 GW in January 2025 (EIA 2025). Yet despite this explosive growth, battery developers face mounting risks. Once installed, a stationary battery is fixed in place for a lifetime, typically between 15 and 20 years, leaving developers vulnerable to two threats: shifting congestion patterns as the grid evolves, and competition from other batteries locating at the same profitable sites.

A deeper policy problem underlies these risks: current market and regulatory structures typically assume that storage assets are stationary and long-lived. Transmission planning, interconnection procedures, and capacity accreditation are designed around fixed infrastructure. In reality, the main driver of storage profitability—congestion—is dynamic, and the most valuable locations change over time. This mismatch between dynamic congestion patterns and static regulatory assumptions creates risk for investors and can slow the deployment of storage that system planners want for reliability and renewable integration.

To inform how policy can respond, we examine *mobile energy storage systems* (MESS)—grid-scale batteries mounted on truck trailers that can relocate to follow profit opportunities. Using six years of electricity market data from PJM Interconnection (PJM), the largest U.S. grid operator, we ask:

1. What drives battery profitability across locations?
2. How does competition from new batteries impact existing installations?
3. Can mobile batteries improve outcomes for both developers and the grid?

Our findings show that mobile storage increases developer profits between 11 and 47% compared to the best stationary sites while providing up to 22.5% more congestion relief, and that 9.9–15 gigawatt-hours (GWh) of mobile capacity could operate

profitably in PJM alone. For regulators and system planners, the implications are clear: mobile storage can complement transmission investment and accelerate renewable integration, but only if regulatory frameworks are updated to accommodate temporary, relocatable assets.

The Storage Profit Puzzle

For regulators and system planners, two questions arise:

1. Where does storage create value?
2. How stable is that value over time?

We analyze day-ahead market (DAM) and real-time market (RTM) wholesale electricity prices at 339 high-voltage nodes in PJM (between 2019 and 2024) to measure arbitrage profit—buying when prices are low and selling when they are high—as the main revenue stream that varies by location. We limit our analysis to arbitrage revenue (i.e., the major revenue stream that varies geospatially), and do not consider other streams of revenue from ancillary services and capacity payments. The battery operations model is described in Rana et al. (2025). Figure 1 summarizes annual arbitrage profit across these locations.

Profitability varies by up to a factor of six across locations. The best site earns over \$63,000 per megawatt (MW) annually, while most earn only a fraction of that. Real-time markets yield higher profits than day-ahead markets due to greater price volatility but also greater unpredictability. Among locations in the top 5% for profitability in 2019, only 23.5% remained in the top 5% in later years.

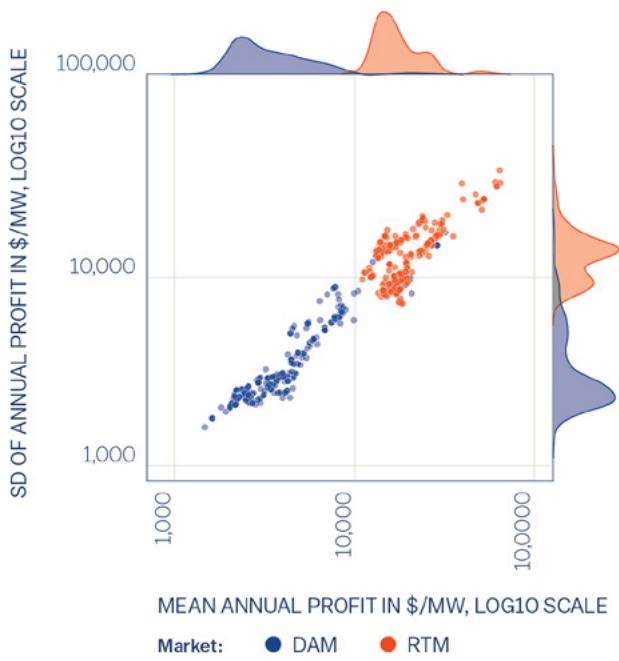
For storage developers and system planners, this inconsistency in high-profit locations implies that *where* storage is most valuable changes over time and that long-term, location-specific planning assumptions may be misaligned with reality. Additionally, virtually all variation in profitability across locations comes from congestion prices. At the most lucrative sites (99th percentile), congestion accounts for 70% of total profit. Figure 2 illustrates the split between energy and congestion components at representative nodes.¹

This dependence on congestion prices at the most profitable nodes exposes developers to an unavoidable risk: congestion patterns are not persistent.

Among the 100 most congested nodes in any given year, only 48–77% remained highly congested the following year, and just 29–50% stayed congested three years later (Table 1). For developers making 20-year investment decisions, this transience is a major risk. For regulators, it reinforces that planning and interconnection rules built for fixed assets may not fit a world where value is dynamic.

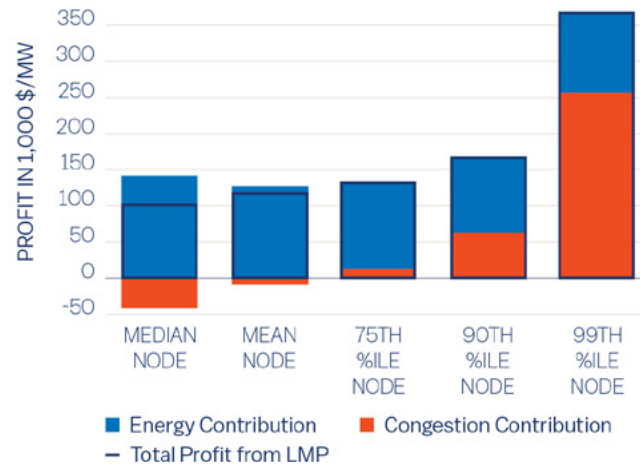
¹ At mean and median nodes, congestion contribution can be negative, because charging and discharging are driven by total locational marginal price (LMP); see Rana et al. (2025).

Figure 1: Mean and Standard Deviation of Annual Profit from Battery Storage at 339 Nodes in PJM



Source: Rana et al. (2025)

Figure 2: Energy and Congestion Contribution for Arbitrage Profit from Locational Marginal Price at Select Nodes



Source: Rana et al. (2025)

Table 1: Persistence of Congestion Across PJM Nodes: Overlap of the Top 100 Congested Nodes Per Year

	2019	2020	2021	2022	2023	2024
2019	100	77	45	46	33	29
2020	77	100	53	46	30	32
2021	45	53	100	75	44	36
2022	46	46	75	100	48	39
2023	33	30	44	48	100	50
2024	29	32	36	39	50	100

Source: Rana et al. (2025)

The Storage Competition Effect

A second risk for stationary storage is competition. The most profitable locations attract multiple developers. When new storage is added at a node, it compresses price spreads and reduces arbitrage profit for all batteries located there. We estimate this effect using the entry of 48 large battery installations across PJM and the California Independent System Operator (CAISO), comparing each installation node to a control node on the same transmission line before and after entry.² Table 2 reports the impact on daily arbitrage profit (columns 1 and 2) and on congestion contribution (columns 3 and 4).

Each new MW of storage reduces daily arbitrage profit at that location by about \$0.29 per MW. For a median 73.6 MW battery, that implies roughly \$7,820 per MW less annual profit for existing batteries—a 12.4% reduction at the most profitable nodes. At the end of 2024, 386 battery projects totaling over 40,000 MW were queued in PJM (Rand et al. 2024); at the busiest locations, with nearly 500 MW of planned storage additions, existing developers could see large profit erosion of up to 84% over a project’s lifetime. For system planners and policymakers, the lesson is that storage deployment that relies only on local arbitrage can be fragile when many developers target the same nodes, suggesting a role for market design or complementary revenue streams that do not depend solely on shrinking local price spreads.

Table 2: Effect of Battery Storage Installation on Daily Arbitrage Profit (Columns (1) and (2)) and Daily Congestion Contribution (Columns (3) and (4))

	(1) Profit	(2) Profit	(3) Congestion	(4) Congestion
Average Impact (in \$/Day)	-6.0222** (2.8576)		-6.0943* (3.3158)	
Average Impact by Capacity (in \$/MW-Day)		-0.2911*** (0.0649)		-0.2002*** (0.0745)
Month × Year Fixed Effects	Yes	Yes	Yes	Yes
Cohort (pair) Fixed Effects	Yes	Yes	Yes	Yes
Observations	5,642	5,642	5,642	5,642
Cohorts (pairs)	48	48	48	48

Notes: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Rana et al. (2025).

² See Rana et al. (2025) for the stacked difference-in-differences empirical framework.

The Mobile Storage Alternative

Mobile energy storage systems (MESS) offer a different model: grid-scale batteries on truck trailers that can relocate to follow shifting profit opportunities. Companies such as Nomad Power, Power Edison, and Zenobe have piloted commercial MESS, and utilities like Eversource in the Northeastern U.S. have used MESS for backup during outages and transmission maintenance (Figure 3).

Operating MESS is costlier than stationary storage; the policy-relevant question is whether flexibility justifies the cost. We model MESS relocation decisions using forecasted arbitrage profits, transportation and interconnection costs, and downtime during moves.³ We then compare profits for stationary storage (median of the ten best locations) and mobile storage (median of units starting from those locations), accounting for the competition effect in Table 2. Table 3 reports net profit between 2019 and 2024 for a two-hour battery and \$1,000/MW per move, under different minimum lengths of stay (in days).

Figure 3: Current Status of MESS Operations

(a) Nomad Power’s Pilot of 1MW, 2-hour MESS



Source: Canary Media

(b) Eversource’s 500MW, 2-Hour MESS Used During Outages



Source: Eversource

Table 3: Net Profit for Stationary and Mobile Energy Storage Between 2019 and 2024

		Minimum Length of Stay (Days):				
		7	14	30	60	90
Day Ahead Market (DAM)	Stationary	158.1	158.1	158.1	158.1	158.1
	Mobile	233.8	221.4	223.2	210.7	193.9
	Percent Increase:	47.9%	40.0%	41.2%	33.3%	22.6%
<i>Units: \$1,000/MW</i>						
Real Time Market (RTM)	Stationary	357.4	357.4	357.4	357.4	357.4
	Mobile	461.2	463.8	430.0	418.9	401.6
	Percent Increase:	29.0%	29.8%	20.3%	17.2%	12.4%

Discharge duration is 2 hours; moving costs fixed at \$1,000/MW per move

³ Baseline moving cost are \$1,000/MW per move (transportation and labor/interconnection) and relocation decisions use smoothed historical profit; see Rana et al. (2025) for details.

Mobile storage raises net profit by 20–48% with weekly to monthly relocation, and by 12–33% even with less frequent moves. For DAM operations with a 60-day minimum stay requirement at a location, MESS earns \$223,200/MW over six years compared to \$158,100 for stationary batteries—a 41% increase.

For investors, with an upfront cost of \$555,000 per MW (Lazard 2025), payback is shorter for mobile than for the best stationary sites (7 to 17 years compared to 9 to 21 years). This advantage holds until moving costs exceed roughly \$6,300–7,900/MW per move—several times our baseline—and these results are robust to higher relocation costs.

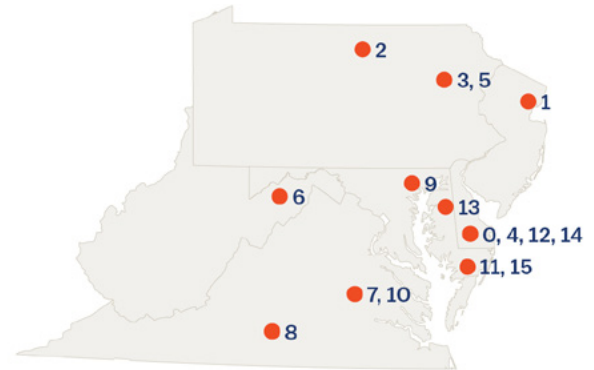
Grid Benefits for Mobile Storage

Beyond developer returns, mobile storage can deliver distinct grid benefits. First, MESS serves many locations over time. With a 60-day minimum stay, the average unit visits 16 locations in six years, with 62.5% of moves to sites that unit had not previously served (Figure 4). That spreads temporary storage capacity to short-term congestion hotspots instead of concentrating it at a few permanently attractive nodes.

Second, MESS captures more value from congestion, and thus provides more congestion relief. The best stationary battery in our data earns 65% of profit from congestion; MESS starting from that location earns 72%, or 22.5% more congestion contribution in absolute terms. Columns (3) and (4) of Table 2 show that battery operations compress congestion spreads (adding demand when congestion is low and supply when it is high), which reduces grid stress.

Because MESS operates more frequently at high-congestion nodes and captures more congestion value, it provides proportionally greater grid relief than stationary batteries, making MESS particularly valuable when transmission constraints are binding and building new transmission lines is slow or expensive.

Figure 4: Map of Locations Visited by MESS in PJM



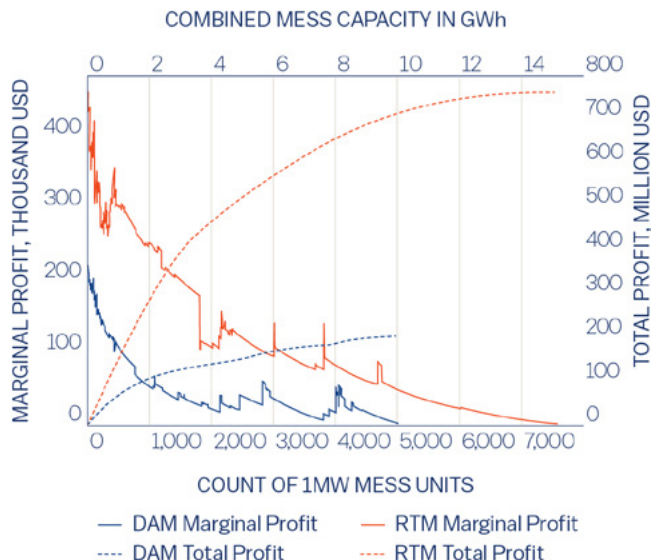
Numbers represent the order of visits starting from 0.

Source: Rana et al. (2025)

The Scaling Potential

We simulate a fleet of MESS units entering PJM sequentially, with each new unit reducing arbitrage profits where it operates (using our competition estimates) until the marginal unit is no longer profitable. With 60-day minimum stays and \$1,000/MW moving costs, PJM could support about 5,000–7,500 one-MW units in DAM and RTM combined. For two-hour duration, that amounts to between 9.9 and 15.0 GWh of mobile capacity, roughly 38–58% of PJM’s current installed battery capacity (Figure 5).

Figure 5: Simulated Marginal and Total Profit for a Fleet of 1 MW MESS Units



Source: Rana et al. (2025)

Risks and Institutional Context

From a broad policy view, mobile storage introduces administrative and operational complexity. Relocation implies repeated interconnection or re-registration at new nodes, which are not currently streamlined. Market design questions include how MESS participates in capacity and ancillary markets when it moves across nodes, and how congestion cost allocation treats mobile assets. Safety and permitting may differ by jurisdiction and could slow deployment. Finally, mobile storage is a complement, not a substitute, for transmission expansion.

When persistent congestion is best solved by new lines, MESS can provide interim relief but cannot replace long-term grid build-out. Strategies to mitigate these risks and support integration of mobile storage include:

1. Tiered interconnection reviews for short-duration stays (e.g., under 90 days)
2. Pre-certified “fast lanes” at recurring congestion locations
3. Clear market rules for participation across multiple nodes
4. Pilot programs in stressed corridors to build evidence before scaling

Addressing these risks does not remove the tradeoffs but makes them explicit and manageable for regulators and developers.

More crucially, integrating mobile storage requires regulatory and institutional engagement across multiple levels. At the national level, the Federal Energy Regulatory Commission (FERC) rules and market participation standards assume fixed resources and capacity accreditation does not yet treat mobile storage in a consistent way. Across regional Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs), as previously highlighted, interconnection queue processes and upgrade cost allocation are built for permanent installations and relocation for MESS could require new studies and agreements.

At a granular state and local level, siting, permitting, and safety rules vary and may not distinguish short-term mobile deployments from permanent plants. No single agency can fix these differences alone.

FERC can clarify how mobile storage fits under existing market and planning rules and encourage RTOs to develop lighter-touch procedures for temporary deployments. RTOs can create expedited interconnection pathways for pre-identified congestion nodes and standardize re-registration for relocating units. State Utility Commissions can clarify siting and permitting for mobile storage. A dedicated discussion of institutional constraints and reform pathways would help policymakers prioritize next steps.

Policy Implications

Mobile storage can accelerate renewable integration. Transmission construction faces long delays and siting opposition. Mobile batteries can provide temporary congestion relief at bottle-necks while permanent upgrades advance.

Policymakers should treat MESS as complementary infrastructure; not a replacement for transmission, but a tool to bridge gaps. A practical step is an ISO-led pilot deploying mobile units in recurring stress corridors during high-risk periods, with evaluation of congestion and reliability impacts.

Regulatory frameworks must adapt. Interconnection and market participation were designed for permanent, fixed assets. MESS needs lighter-touch permitting for temporary deployments, including possible pre-approved fast lanes at recurring congestion locations. Grid operators can draw on existing protocols for mobile generators used in emergencies. Concrete options include:

1. Tiered interconnection studies with simplified reviews for stays under 90 days
2. Pre-certification of high-congestion nodes where mobile storage clearly helps the grid
3. Clearer market rules and standard permitting for multi-location participation

Align developer incentives with grid needs.

Stationary storage at good locations already provides congestion relief; MESS does so more dynamically by following congestion signals. Policy-makers can reinforce this through location-based incentives (e.g., capacity payments or tax treatment that rewards storage serving multiple congested nodes).

Regions with similar challenges to PJM could particularly benefit. California’s “duck curve” (from massive midday solar generation followed by steep evening ramps) creates predictable but geographically dispersed congestion patterns ideal for mobile storage. The Electric Reliability Council of Texas (ERCOT) grid, with extensive wind resources in West Texas far from large demand centers, faces evolving transmission constraints that MESS could help address.

Conclusion

Electricity systems need more flexibility as renewables and demand grow. Mobile energy storage is one way to provide it. Our analysis shows that mobile batteries can outperform the best stationary sites in profit while delivering more congestion relief, and that a meaningful scale of mobile capacity could be economic under current cost assumptions. The main obstacles are regulatory—updating interconnection processes, market participation, and planning rules designed for an era of permanent and centrally-operated power plants.

The message for policymakers is twofold. First, storage value and congestion are dynamic; planning and market design that ignore this aspect will misallocate investment and may slow deployment. Second, enabling geospatial mobility for storage can reduce stranded-asset risk and channel capacity to where the grid needs it, supporting renewable integration and reliability. With targeted regulatory updates, mobile storage can bridge academic evidence and practical energy policy.

Looking Forward

As renewable energy deployment accelerates, the gap between generation siting and demand centers will widen. Transmission build-out remains essential but cannot happen overnight. Mobile storage offers a flexible, deployable option to ease congestion and integrate renewables in the meantime.

The technology is ready and the economics are favorable; the barrier is regulatory. Policymakers who streamline interconnection and market rules for temporary, relocatable storage can help developers manage competition and uncertainty while directing capacity to stressed parts of the grid. The result can be more renewable integration, less congestion, and a more flexible and resilient system—with mobile storage as one practical tool in the mix.

Bibliography

- IEA (International Energy Agency). 2024. "Integrating Solar and Wind: Global Experience and Emerging Challenges." Technical report. <https://iea.blob.core.windows.net/assets/4e495603-7d8b-4f8b-8b60-896a5936a31d/IntegratingSolarandWind.pdf>.
- . 2025a. "Electricity Mid-Year Update 2025." Technical report. <https://iea.blob.core.windows.net/assets/cc64f0aa-30e4-4497-9cca-1ffae2c55fe5/ElectricityMid-YearUpdate2025.pdf>.
- . 2025b. "Renewables 2025: Analysis and Forecast to 2030." Technical report. <https://iea.blob.core.windows.net/assets/76ad6eac-2aa6-4c55-9a55-b8dc0dba9f9e/Renewables2025.pdf>.
- Lazard. 2025. "Levelized Cost of Energy." Technical report. <https://www.lazard.com/media/5tlbhyla/lazards-lcoeplus-june-2025-vf.pdf>.
- Rana, V., C. Kaps, and S. Netessine. 2025. "Moving Money Around: Mobile Energy Storage and the Value of Geospatial Flexibility." Available at SSRN 5917782. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5917782.
- Rand, J, N. Manderlink, W. Gorman, R.H. Wiser, J. Seel, J.M. Kemp, S. Jeong, and F. Kahl. 2024. "Queued Up: 2024 Edition, Characteristics of Power Plants Seeking Transmission Interconnection as of the End of 2023." Technical report. Lawrence Berkeley National Laboratory.
- EIA (U.S. Energy Information Administration). 2025. "U.S. Battery Capacity Increased 66% in 2024." <https://www.eia.gov/todayinenergy/detail.php?id=64705>.

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