

Power Electronics & EnergyNet

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Power electronics what is it?

this is the hardware that converts and controls power flow between systems
= enables efficient, precise control of power and energy at scale

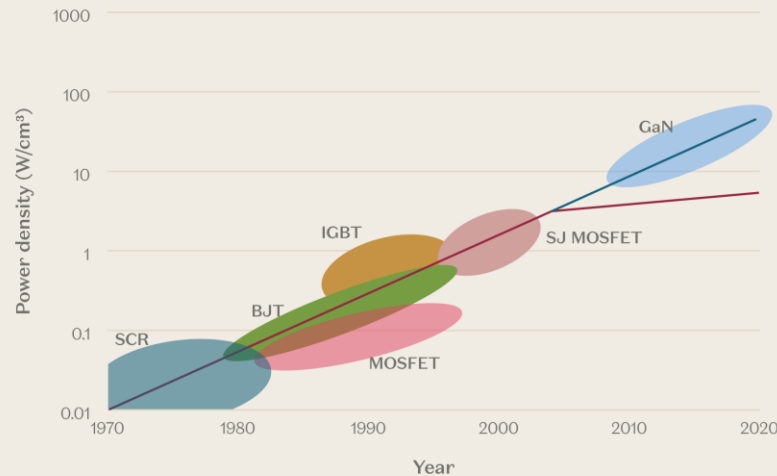


Power electronics Moore's Law

advances in semiconductor technology combined with adoption, ...
= more capacity and performance per unit physical volume at lower cost

The Moore's Law of Power Electronics

Power density has doubled every 4 years since the 1970s – and wide bandgap semiconductors like GaN are keeping the trend alive past silicon's limits.

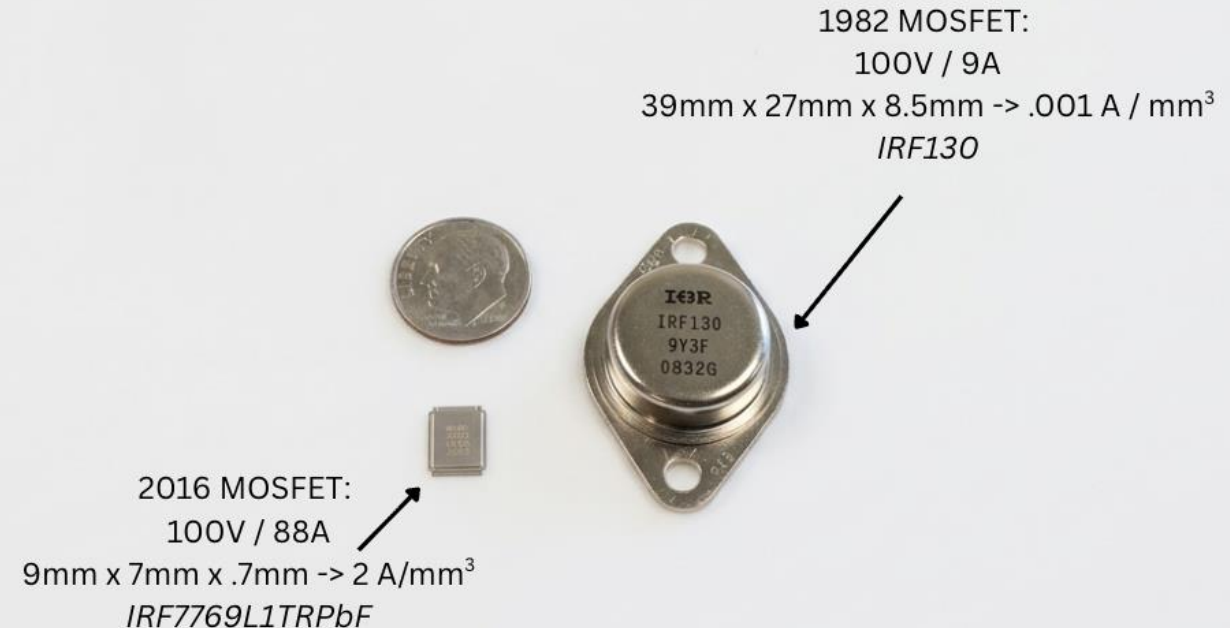


Source: A review on the GaN-on-Si power electronic devices," Zhong et al., 2022

More charts: a16z.news/subscribe

A16Z

>3 orders of magnitude improvement in current density over 3 decades



EV chargers: high-power deployed at scale

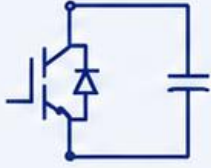
the same technology as phone chargers, at **1000x power**

- mass production: cost reduction
- standardization: improved reliability
- scale: rapid innovation cycles

high-power electronics is now deployed by the millions in EV charging, unlocking cost, speed, and accessibility

= this is the industrial engine enabling energy routers at scale





MODERN POWER ELECTRONICS

Higher performance
Modularity
Digital controllability



ENERGYNET

Distributed architecture
Local energy sharing
Resilient by design



MORE DEGREES OF FREEDOM



DESIGN & OPERATION

How should we build the system?
How should we operate it?



SIMULATION

Explore alternatives
Quantify and compare outcomes

Quantifying EnergyNet performance: a simulation-based framework for decentralized energy networks

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Abstract

Modern power systems are increasingly exposed to severe disturbances caused by extreme weather, infrastructure failures, and geopolitical conflicts. Conventional power systems rely on interconnected transmission and distribution infrastructure to connect generation and consumers, and failures of this infrastructure can disconnect large groups of consumers from their energy supply until service is restored. At the same time, increasing amounts of local generation, storage, and controllable loads are being deployed throughout the power system, creating new possibilities for how electrical energy systems can be organized and operated.

EnergyNet has been proposed as a decentralized, software-defined energy architecture based on interconnected power electronic Energy Routers. Each router coordinates local loads, generation, storage, and grid connections, while bidirectional Energy Links enable energy exchange between routers. Energy exchange is coordinated through the Energy Protocol, allowing routers to communicate energy needs and availability and establish energy transfer across the network. EnergyNet can operate together with the conventional grid, independently from it, or across combinations of grid-connected and isolated regions.

This paper develops a quantitative framework for modeling and simulating EnergyNet systems and calculating their performance under different operating conditions and disturbances. The framework represents network topology, prioritized loads, generation, storage, grid connections, Energy Links, and component constraints. Optimization within a time-stepped, receding-horizon simulation calculates physically feasible energy allocation and exchange. The same framework is used for deterministic disturbance analysis, long-horizon reliability screening, and probabilistic consequence analysis.

The framework is applied to an under-construction neighborhood-scale EnergyNet with ten buildings comprising 290 apartments. Full electrical service is maintained during representative summer and winter operation and following the loss of either one grid interface or one Energy Link. Simultaneous loss of two Energy Links isolates part of the network, containing the disturbance while service within the island is determined by local generation, stored energy, load priority, and repair duration. A protected-reserve sweep quantifies how stored energy affects the critical service that can be maintained throughout the disturbance. Long-horizon screening shows that network-partitioning failures are relatively rare but credible over the system lifetime, while seasonal Monte Carlo analysis shows high critical-load service across varying operating conditions, with full critical service maintained in all summer realizations and a median of approximately 92% continuously maintained in winter.

The framework provides a quantitative basis for evaluating EnergyNet operation and maintained electrical service across network configurations, resource compositions, grid conditions, and component availability.

Keywords: EnergyNet, Energy resilience, Decentralized energy systems, Microgrids, Distributed energy resources

1. Introduction

The increasing electrification of society, together with the rapid deployment of distributed generation, stationary energy storage, controllable loads, and power electronics, is changing both the structure and operation of modern power systems [1]-[4]. At the same time, extreme weather events, infrastructure failures, geopolitical conflicts, and other large-scale disturbances are placing increasing demands on the ability of electrical infrastructure to maintain essential services [5]-[6].

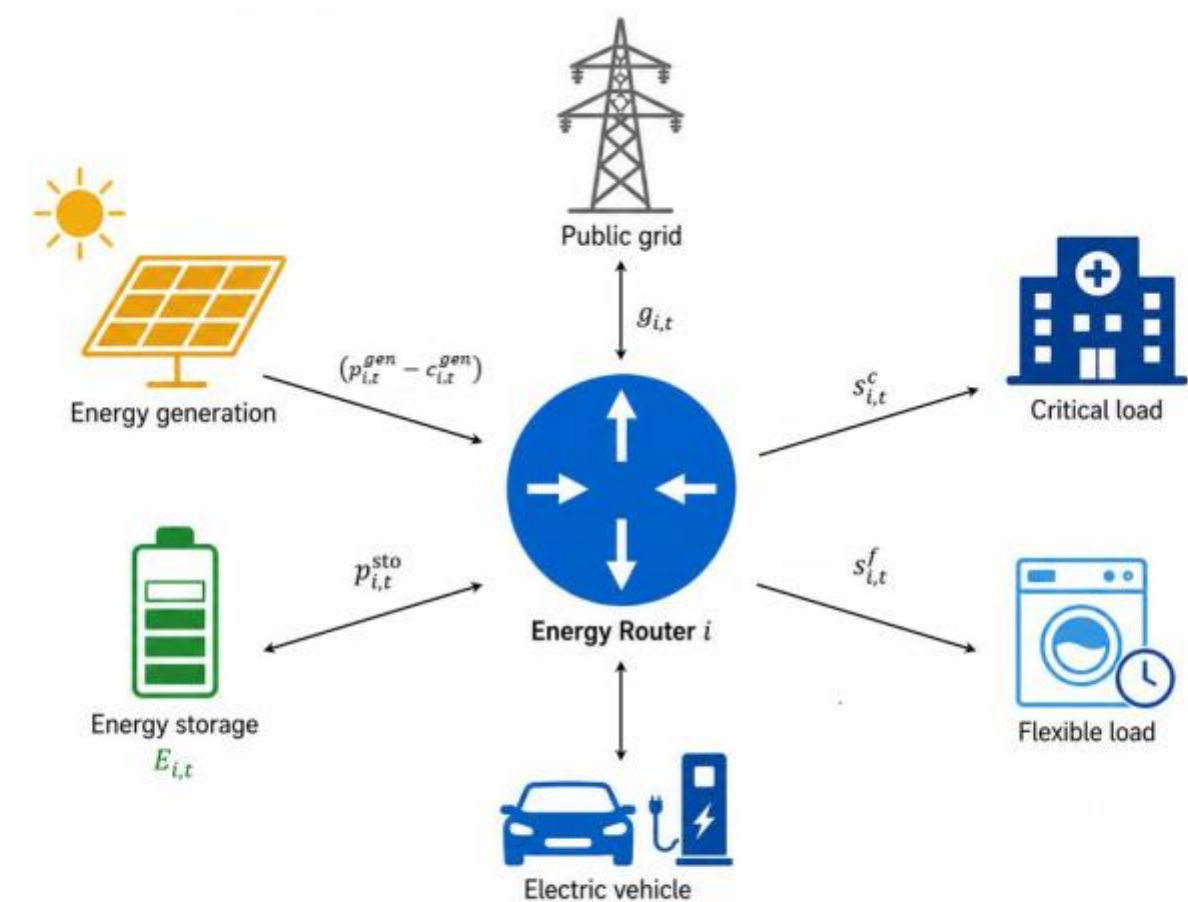


Figure 3: Operational representation of an Energy Router. Each router coordinates local energy generation, stationary energy storage, prioritized electrical loads, bidirectional electric-vehicle charging, and an optional public-grid interface.

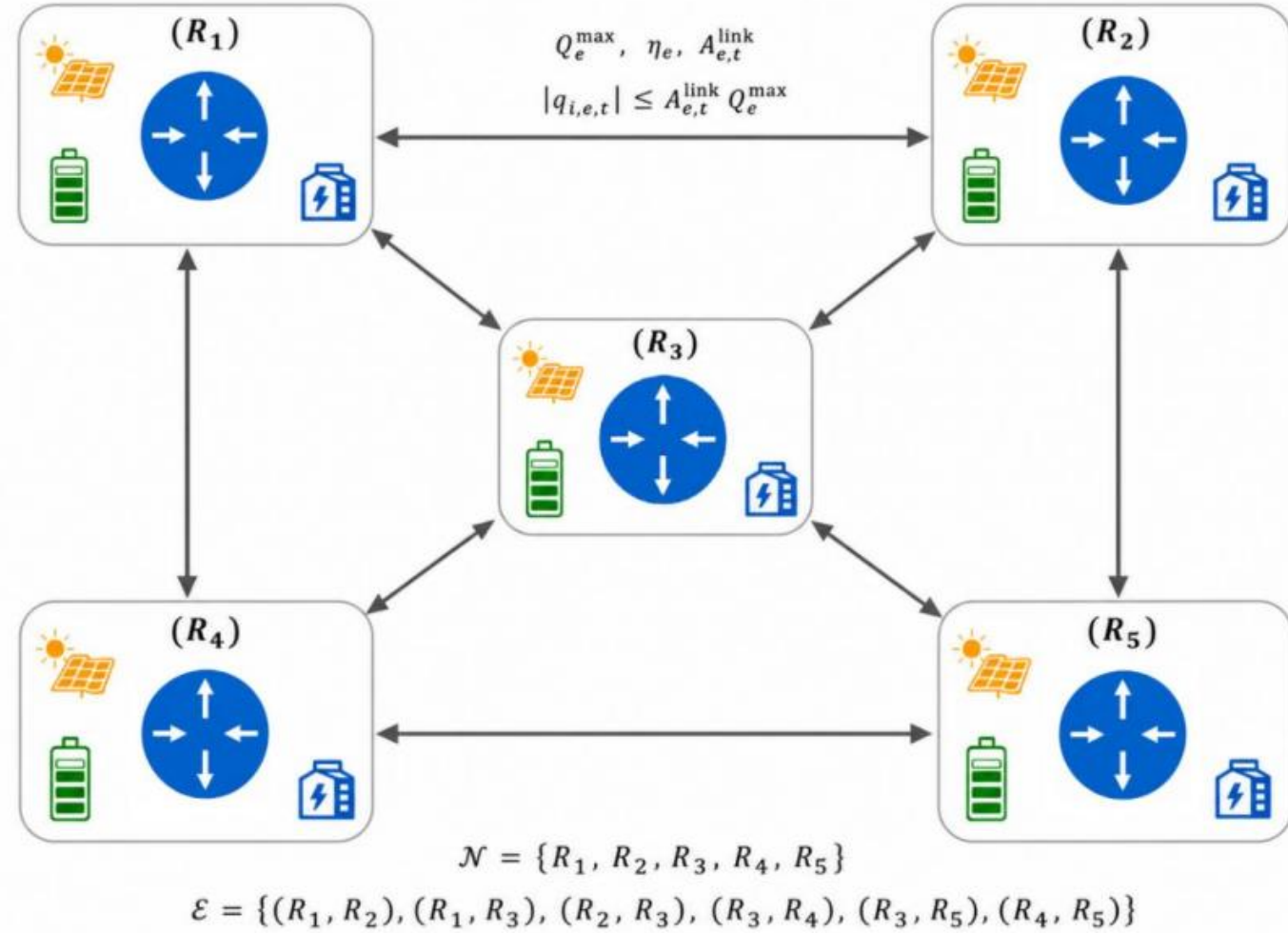


Figure 4: Graph representation of an EnergyNet. Energy Routers form the vertex set $\mathcal{N}$ and Energy Links the edge set $\mathcal{E}$. Each Energy Link e is characterized by transfer capacity $Q_e^{\max}$, efficiency η_e , and availability $A_{e,t}^{\text{link}}$, with $q_{i,e,t}$ denoting the signed power delivered to router i through the link.

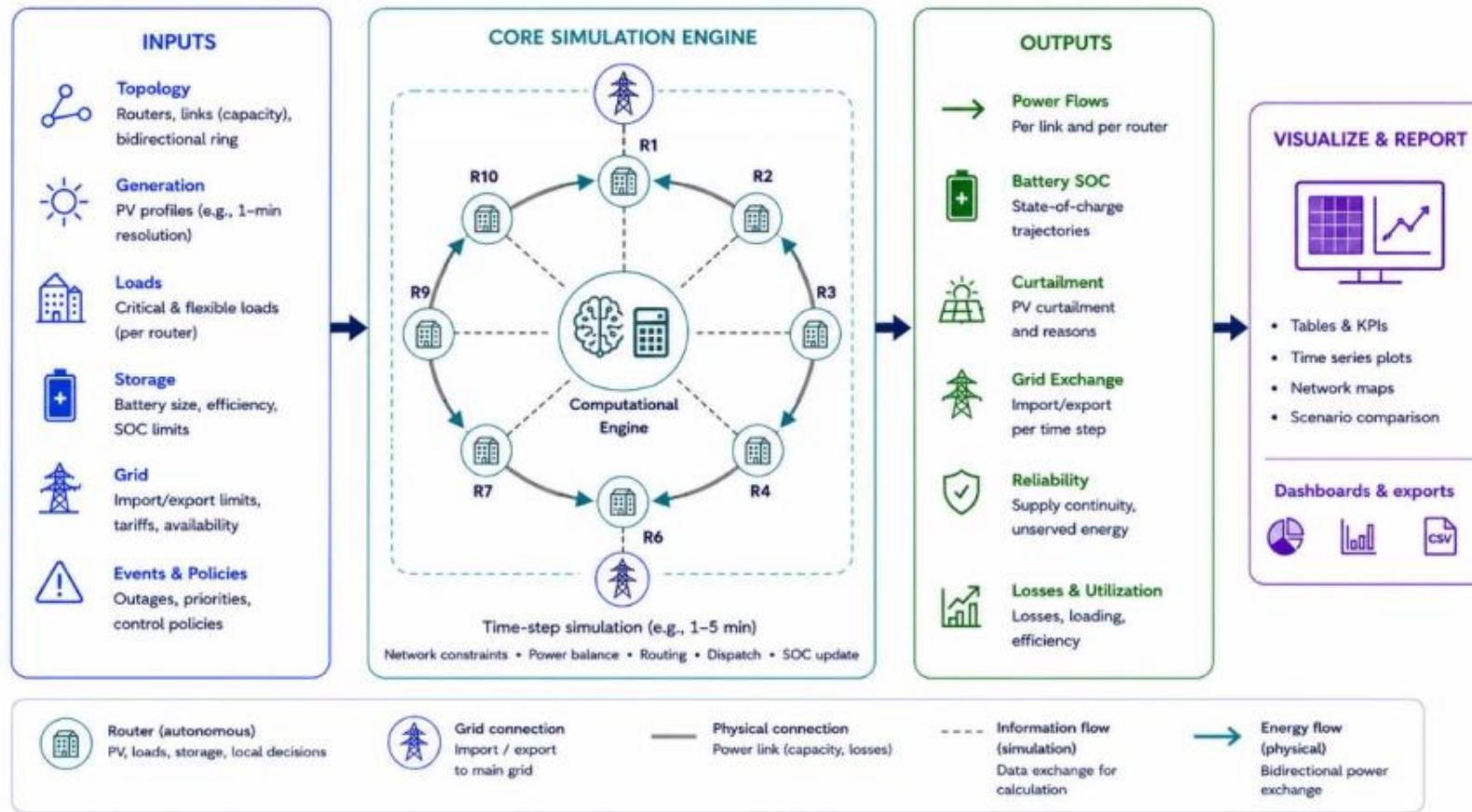


Figure 7: General simulation and evaluation framework for EnergyNet studies. The reusable EnergyNet model and optimization-based dispatch framework are combined with a study-specific system instance, operating conditions, and operational assumptions. Time-stepped simulation produces a complete operational record from which application-specific performance metrics are evaluated. Deterministic, parametric, and Monte Carlo studies modify or sample the study definition while preserving the same underlying model and simulation procedure.

Example EnergyNet in Sweden, customer LKF



10 buildings, 278 homes, use 10000 000 KWh/y
wanted to build solar, got **no** from traditional grid owner.

Unblocked clean energy

- ✓ Solar, battery & EnergyNet (Routers & local grid) reduce grid power with 60% annual
- ✓ For 6 month no old grid is needed
- ✓ Add wind, old grid is only needed 14 days/year
- ✓ Add H2 fuel-cell and no old grid is needed

Investment is made by the real estate company **and is profitable**. ViaEuropa develops the project and is the long term EnergyNet operator.

1. Real-World Geography

Actual district (aerial photo)



- Real buildings, trees, roads
- Exact location and surroundings

2. Model Representation

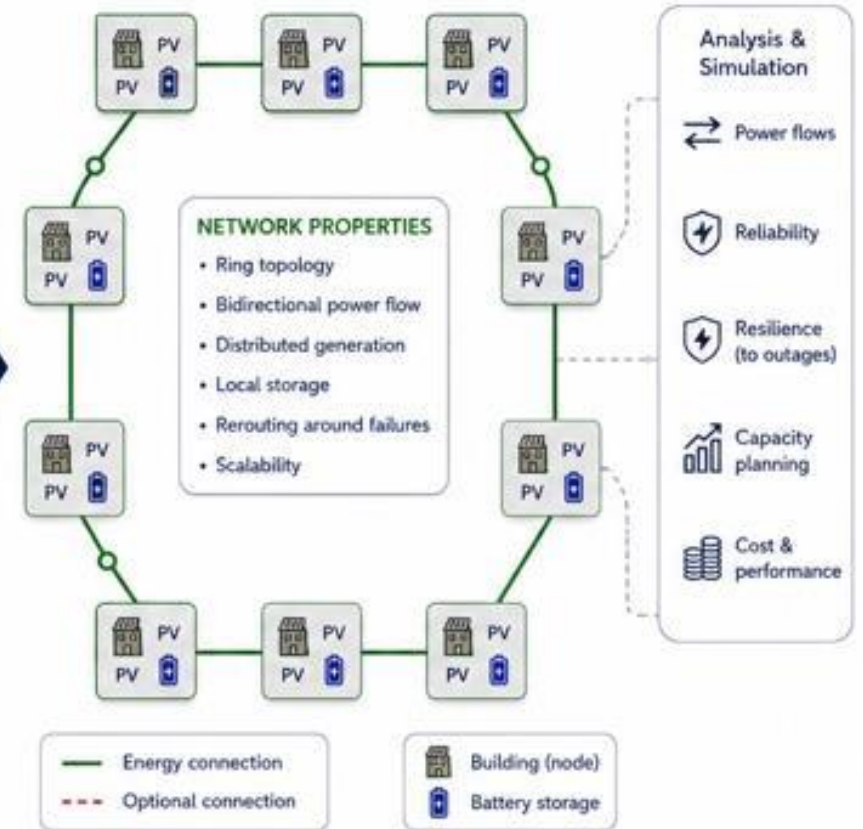
Toy model of the district (for simulation)



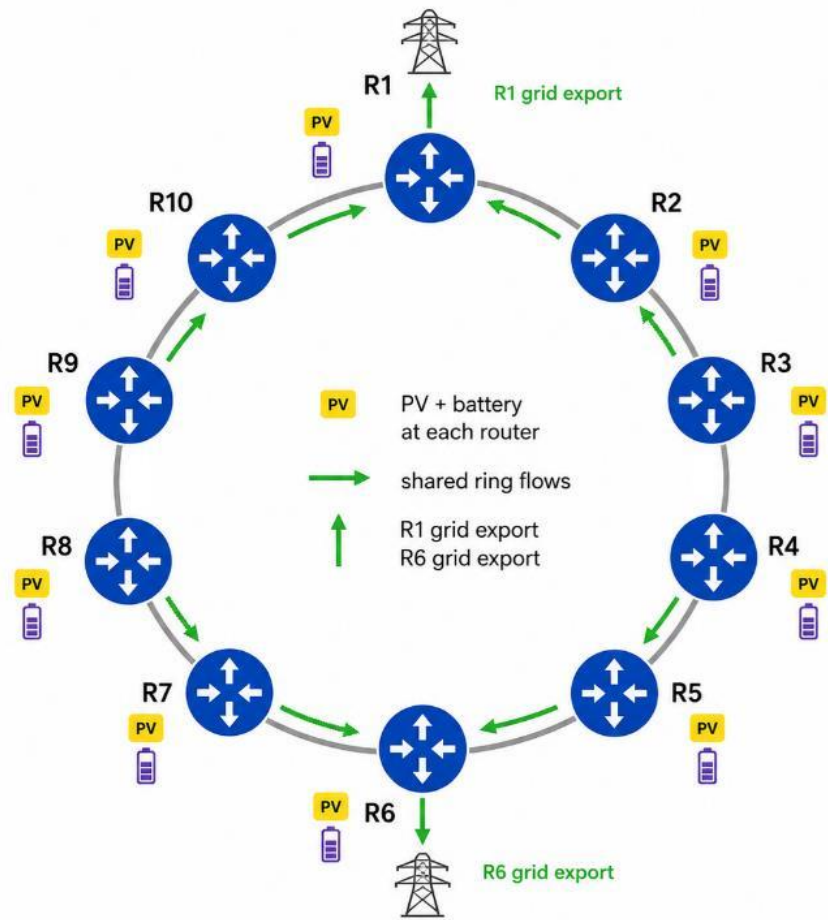
- Buildings with PV, batteries, and loads
- Paths and connections represented
- Input for simulations
- Physical constraints preserved

3. EnergyNet Abstraction

Mathematical abstraction (resilient ring network)

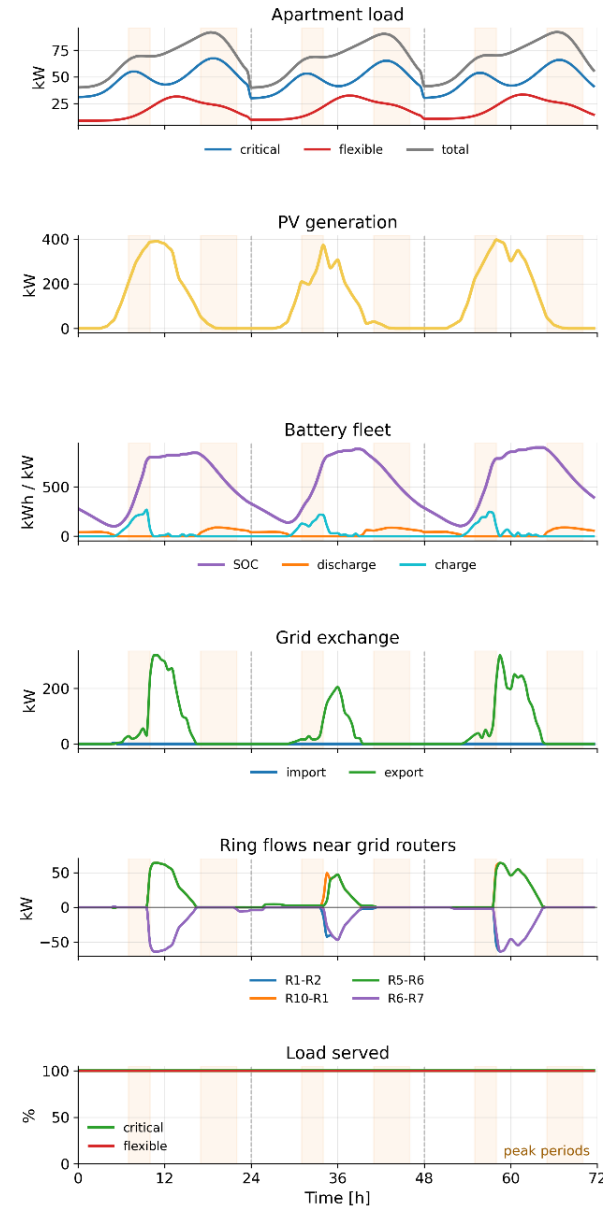


- Buildings become nodes in a ring
- Connections form the EnergyNet topology
- Mathematical model for analysis & optimization
- Used to test scenarios and design for resilience

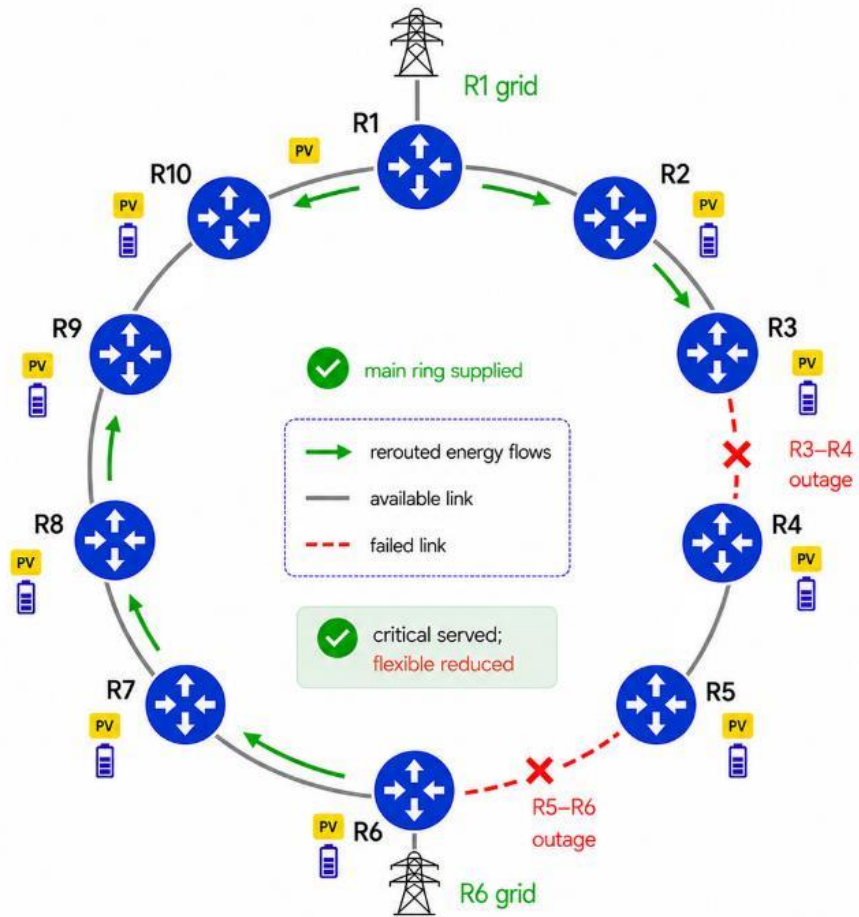


Summer operation: local PV and batteries serve the apartment ring; surplus energy is exported through the grid interfaces.

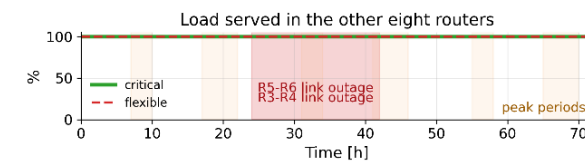
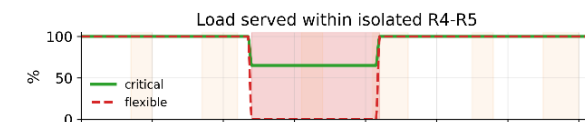
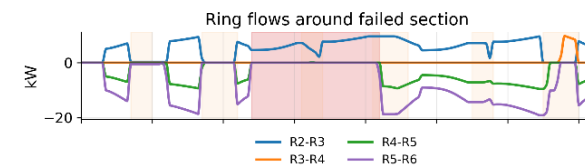
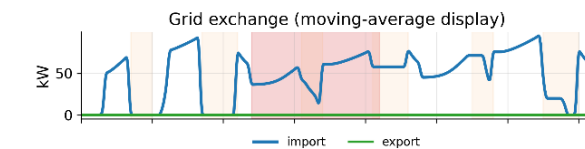
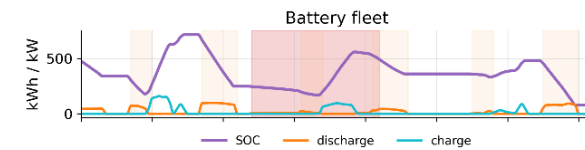
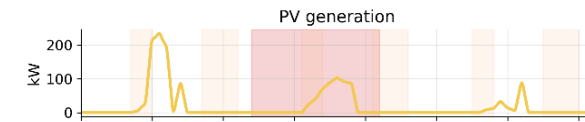
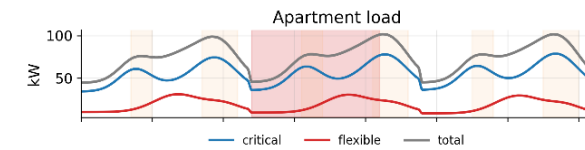
Summer high-solar operating period



C3: stable emergency service with 10% protected reserve



Two internal link failures isolate R4–R5. Critical load remains served while flexible load is reduced.



EnergyNet Simulation use cases



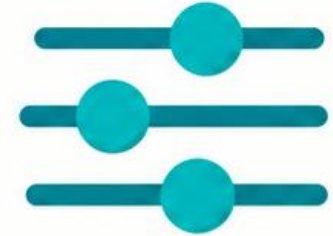
SYSTEM DESIGN

Size routers, solar, batteries and connections



RESILIENCE PLANNING

Test outages, failures and emergency operation



OPERATIONAL STRATEGY

Decide when to store, share, import or prioritize energy



INVESTMENT PLANNING

Compare configurations before committing capital



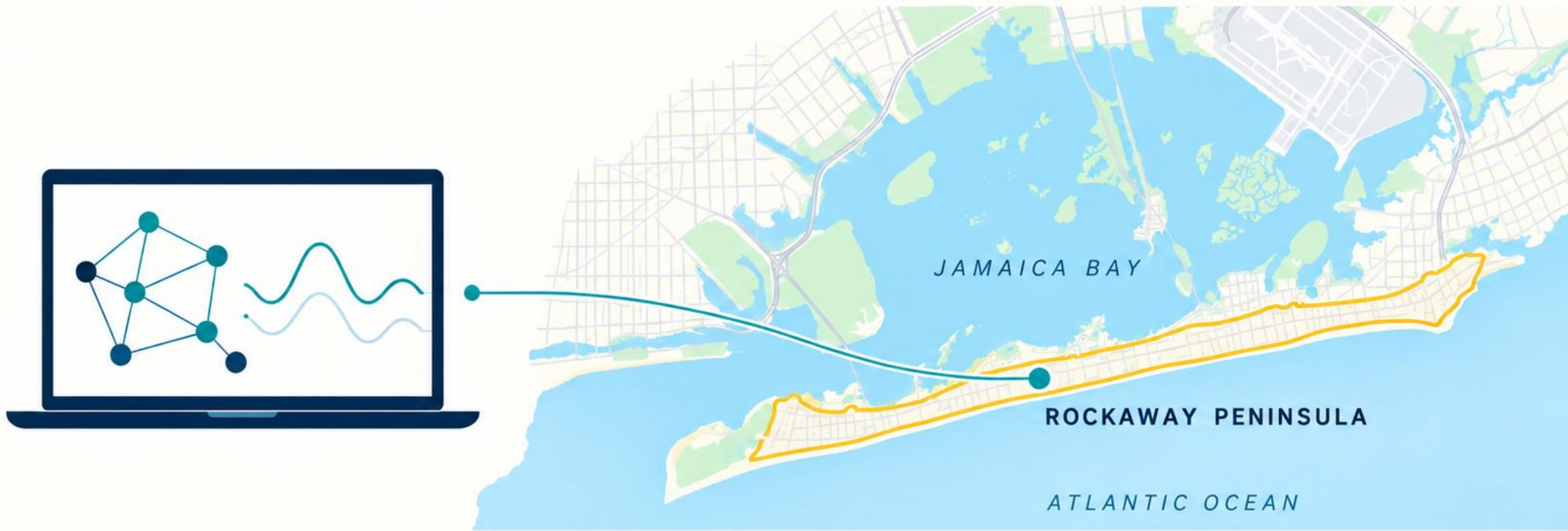
POLICY AND REGULATION

Test tariffs, connection rules and energy-sharing models



EXPANSION PLANNING

Identify where the next site or connection adds the most value



Applying the EnergyNet simulation framework to a real resilience challenge

New York Hurricane Sandy, 2012



GRID OUTAGE Heating Lighting Communications Refrigeration Medical Power

Secure and Affordable Energy for Rockaways

SAER Preliminary Draft Strategy

Project Goal/Summary

Secure and Affordable Energy for Rockaways (SAER) is a plan to dramatically improve energy security and community resilience across the Rockaway Peninsula, one of New York City's most climate-vulnerable regions. This will be achieved through the installation of a new energy distribution system, called the EnergyNet. The EnergyNet establishes a new architecture of decentralized, adaptable, and fault-tolerant energy distribution that will alleviate many present resilience issues in the Rockaways. By installing the EnergyNet across the region, the SAER project reduces dependence on the fragile, centralized grid, enhances disaster response capability, and brings the energy infrastructure into the modern age. With the long term vision of installing the EnergyNet across the entire Rockaway Peninsula, the SAER project begins with the Phase 1 area outlined in this document, located between Arverne and Edgemere, from Beach 28th Street to Beach 60th Street.

The Rockaway Peninsula is highly vulnerable to environmental damage, suffering repeated infrastructure damage in the past during major storms, flooding events, and coastal surges. In particular, the power distribution system, which enables critical functions for everyone through heating, lighting, etc. has repeatedly failed in the face of major storms. The traditional grid (Plain Old Grid System; POGS) is not designed to withstand storm-scale physical damage, or to operate around faults. During events like Hurricane Sandy, outages lasted weeks, withholding essential services such as: heating, lighting, communications, refrigeration, and power for medical devices and community shelters.

POGS improvement efforts have been insufficient because they continue to rely on the centralized, unstable system with inherent single points of failure. While New York City has made progress in deploying site-specific microgrids, these efforts are fragmentary, creating "energy islands" that help individual facilities, but do not provide coordinated resilience across a community or region.

EnergyNet systems installed in the SAER Phase 1 region will improve energy security by introducing a new architecture, on top of the POGS, that contains two foundational shifts in design:

- 1) Software-controlled (smart) microgrids that are electrically isolated and self-monitor;
- 2) A completely bidirectional network of energy distribution between microgrids.

While microgrids alone have already proven valuable for community resilience in New York City and beyond, the combination of advanced microgrids plus a unifying, intelligent routing and communications layer results in a system with no single point of failure. Each element of the system, be it a microgrid or a distribution line, is individually isolated and can be routed around in the event of damage. There are many routes through the network, and with each microgrid producing and storing its own energy, there is always power to flow in the system even when

some elements are damaged. The EnergyNet shifts the outlook of resilience and disaster management from creating isolated cases of power within region-wide power outages to isolated cases of power outage in a region-wide, powered network.

In a disaster, some power is better than none, and the EnergyNet ensures that communities retain access to critical energy even when the POGS is compromised. Power can be redirected around outages, distributed to where it is needed most, and supplemented from neighboring nodes in the network.

The installation of an EnergyNet system as outlined in this proposal is expected to have the following impacts:

- More reliable energy supply during storms, outages, or grid disruptions.
- Enhanced support for critical services, including schools, fire departments, food distribution hubs, and residential buildings.
- A flexible platform for future clean-energy adoption, including EV charging, community solar, and storage coordination.

SAER Phase 1



The SAER Phase 1 area extends from Beach 28th Street to Beach 60th Street in the Rockaway Peninsula. It involves the following 20 projects between Arverne and Edgemere:

1. Arverne East
2. Edgemere Commons
3. Covered Parking Lot at 50-01 Rockaway Beach Blvd.

4. Rockaway Care Center
5. Arverne View
6. La Quinta Inn & Suites Far Rockaway
7. Seaview Home for Adults
8. Seaview Towers
9. Seagirt Residences
10. Beach Green Dunes I
11. Beach Green Dunes II
12. Beach Green Dunes III
13. NYCHA Beach 41st Street
14. NYCHA Ocean Bay Apartments (Bayside)
15. NYCHA Ocean Bay Apartments (Oceanside)
16. The School by the Sea – P.S./M.S. 43Q
17. FDNY EMS Station 47
18. Arverne Branch Library
19. Cardozo School and Playground
20. P.S. 105 The Bay School

These projects together contain over 8,000 housing units, plus critical non-residential facilities, like schools and a fire department. They are selected to incorporate the densest cluster of critical facilities, large residential developments, and projects with existing local generation and storage assets to efficiently make a significant impact. The benefit of this clustering for Phase 1 is that, by covering a smaller area, less new cable installation is required to connect the systems, improving efficiency and lowering potential costs. The SAER Phase 1 area, beyond just the 20 chosen buildings, covers a population of 20,000, who will all benefit from the strengthened infrastructure and improved disaster response enabled by an EnergyNet system.

Issues with the Existing Grid

The POGS is fundamentally the same energy distribution system that it was when created in the late 1800s, with two major issues. It is a centralized system that routes power in one direction: from a few large power plants, to consumers; the loss of one of these power plants, or any damage to the wires delivering power, causes huge impacts to the system. It also relies on analog controls and real-time balancing, resulting in an unstable system that must be carefully balanced and finely tuned or else the system shuts down, like in the 2025 Iberian Peninsula blackout.

What is the EnergyNet?

The EnergyNet is an **energy distribution system** using a **network of smart microgrids** created in Sweden. The size of these microgrids can vary, but typically cover an individual building or home. Each microgrid is capable of independent operation, and all other standard benefits of traditional microgrids, but it also interfaces with the network, enabling coordinated

How EnergyNet enables SAER



HIGH-PLACEMENT INSTALLATIONS

Equipment remains above expected flood levels.



ACTIVE SAFETY MONITORING

Continuous monitoring helps prevent short-circuit house fires.



MODULAR FLOOR WIRING

Unaffected floors can remain powered.



RAPID EMERGENCY CONNECTIVITY

Modular ports let generators and replacement links plug in quickly.



NETWORK-LEVEL REROUTING

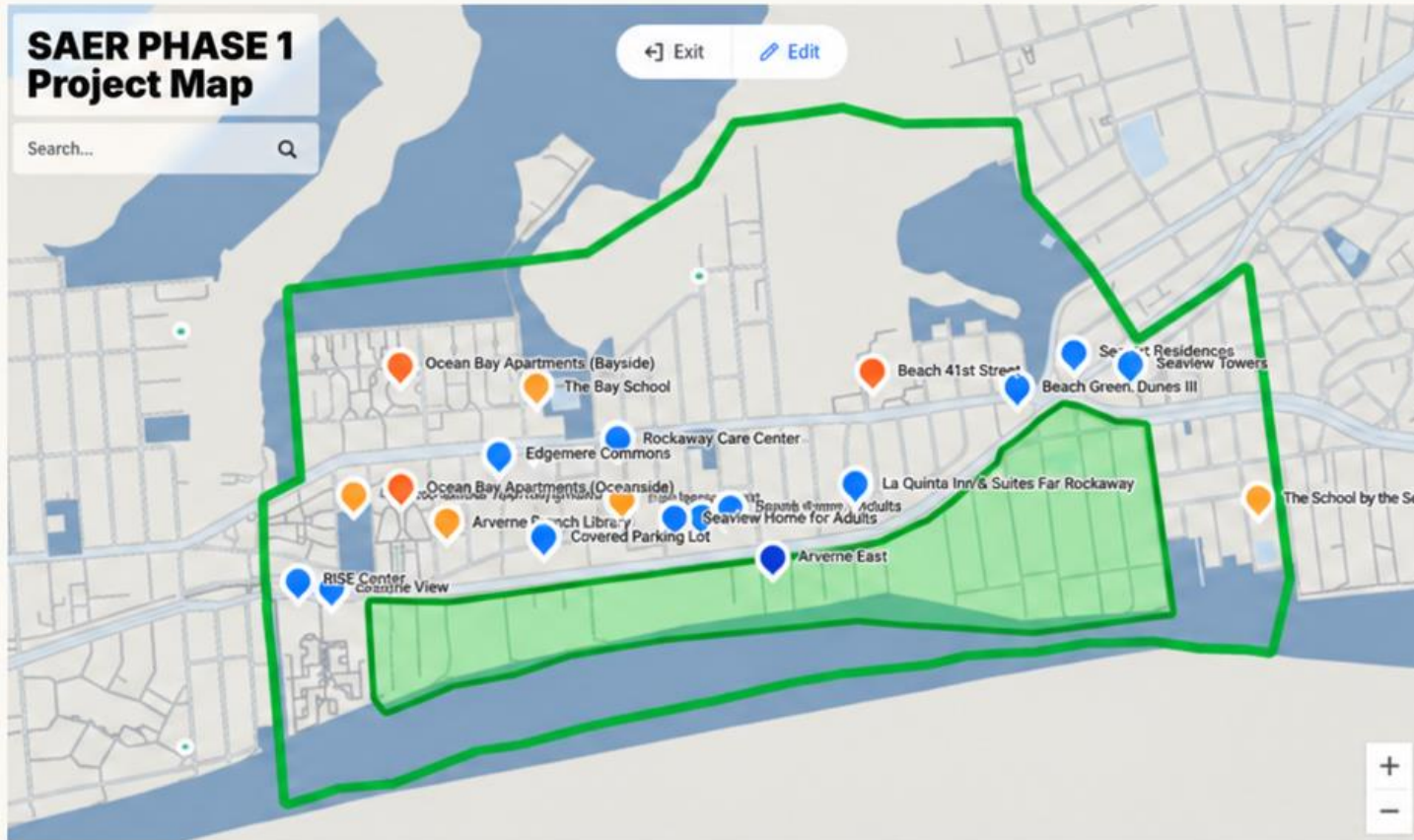
Power automatically bypasses damaged elements.



CRITICAL-LOAD PRIORITIZATION

Choose which loads to prioritize—such as hospitals and fire departments.

SAER Phase 1 Project Map

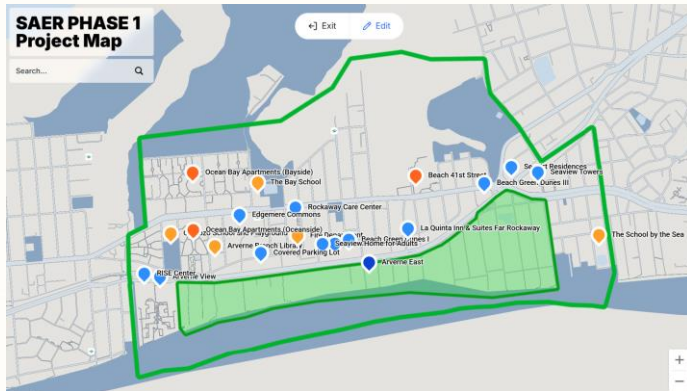


1. Arverne East
2. Edgemere Commons
3. Parking Lot Rockaway Beach Blvd.
4. Rockaway Care Center
5. Arverne View
6. La Quinta Inn & Suites
7. Seaview Home for Adults
8. Seaview Towers
9. Seagirt Residences
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18. Arverne Branch Library
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20
sites / short grids

8000+
housing units

20,000+
people



SAER PORTFOLIO



ENERGYNET MODELS



QUANTIFIED OUTCOMES

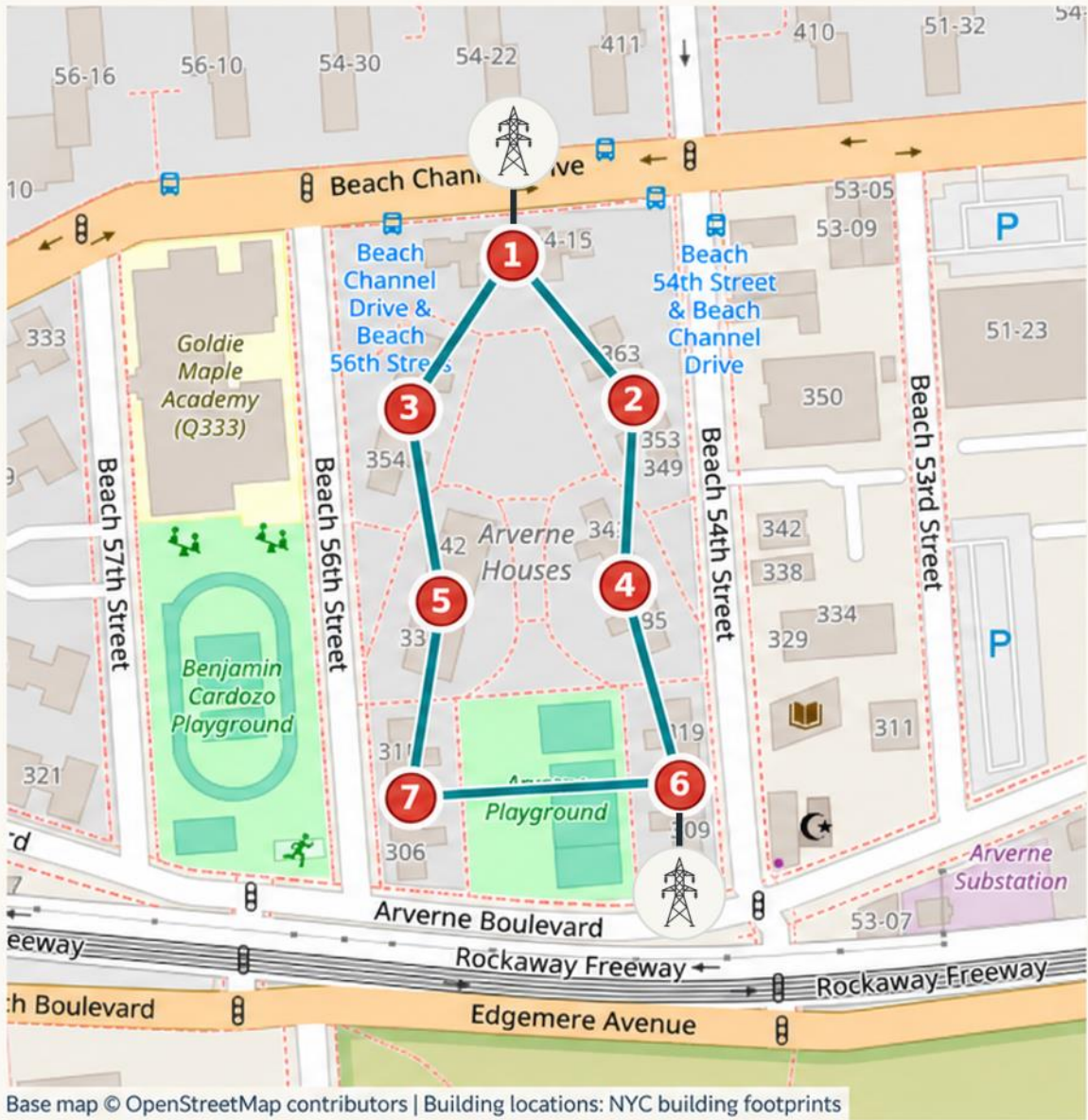
Study NYCHA Ocean Bay Apartments (Oceanside)

seven apartment buildings comprising 418 homes – one EnergyNet ring

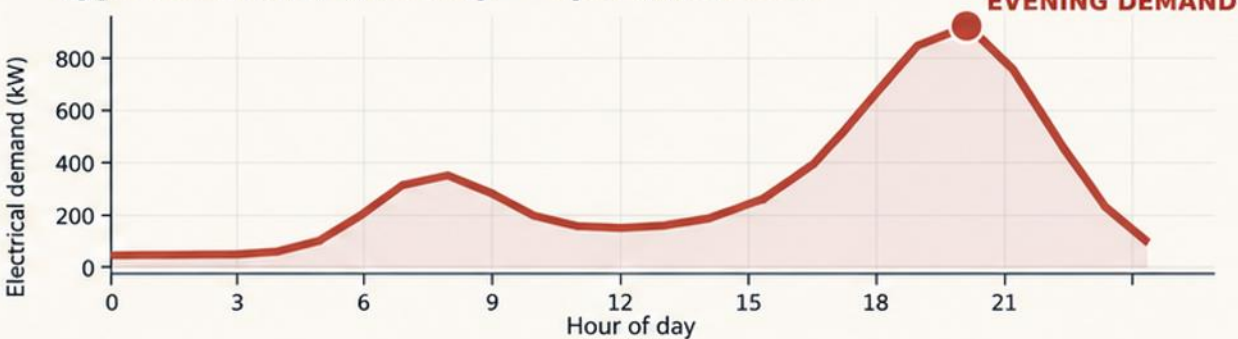


Seven buildings become one EnergyNet

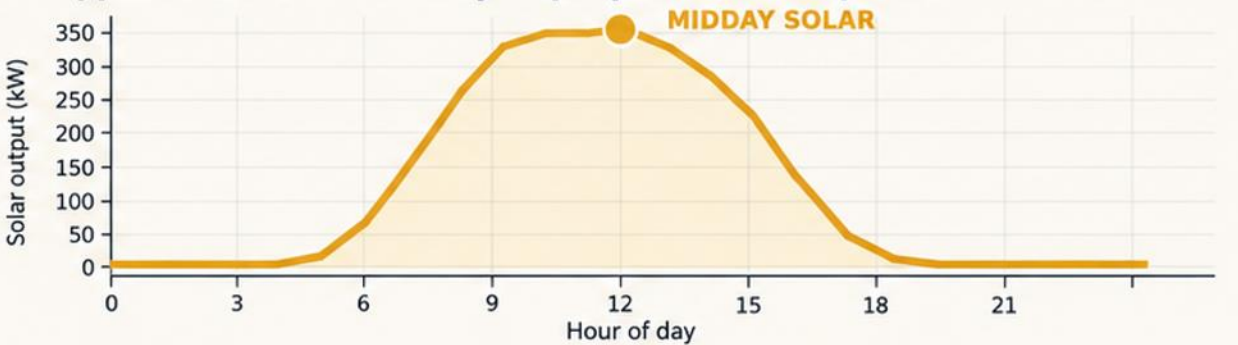
Each building can generate, store and consume energy independently – and exchange with neighbors



Typical summer weekday — apartment load



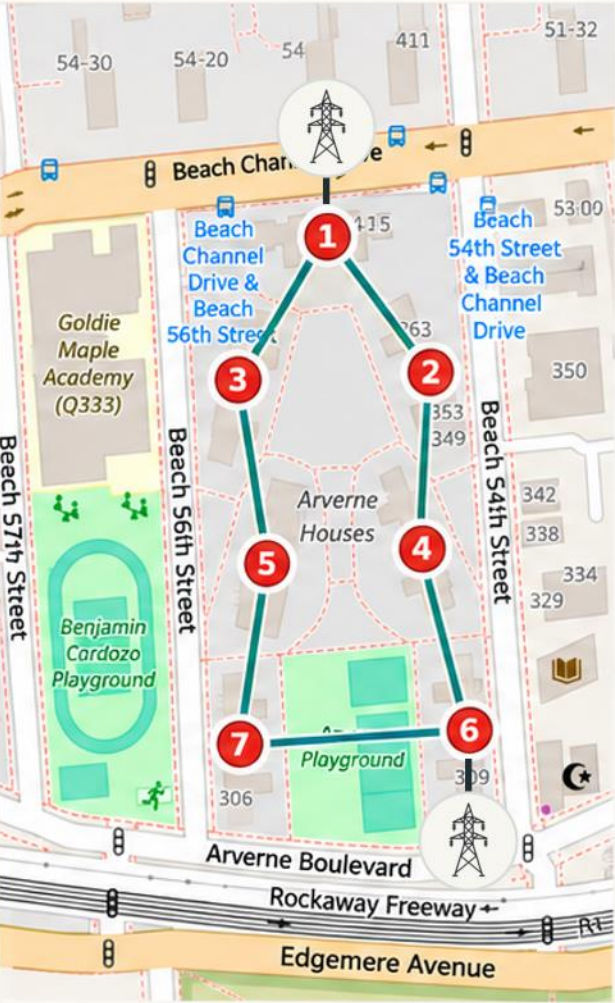
Typical summer weekday — proposed rooftop solar



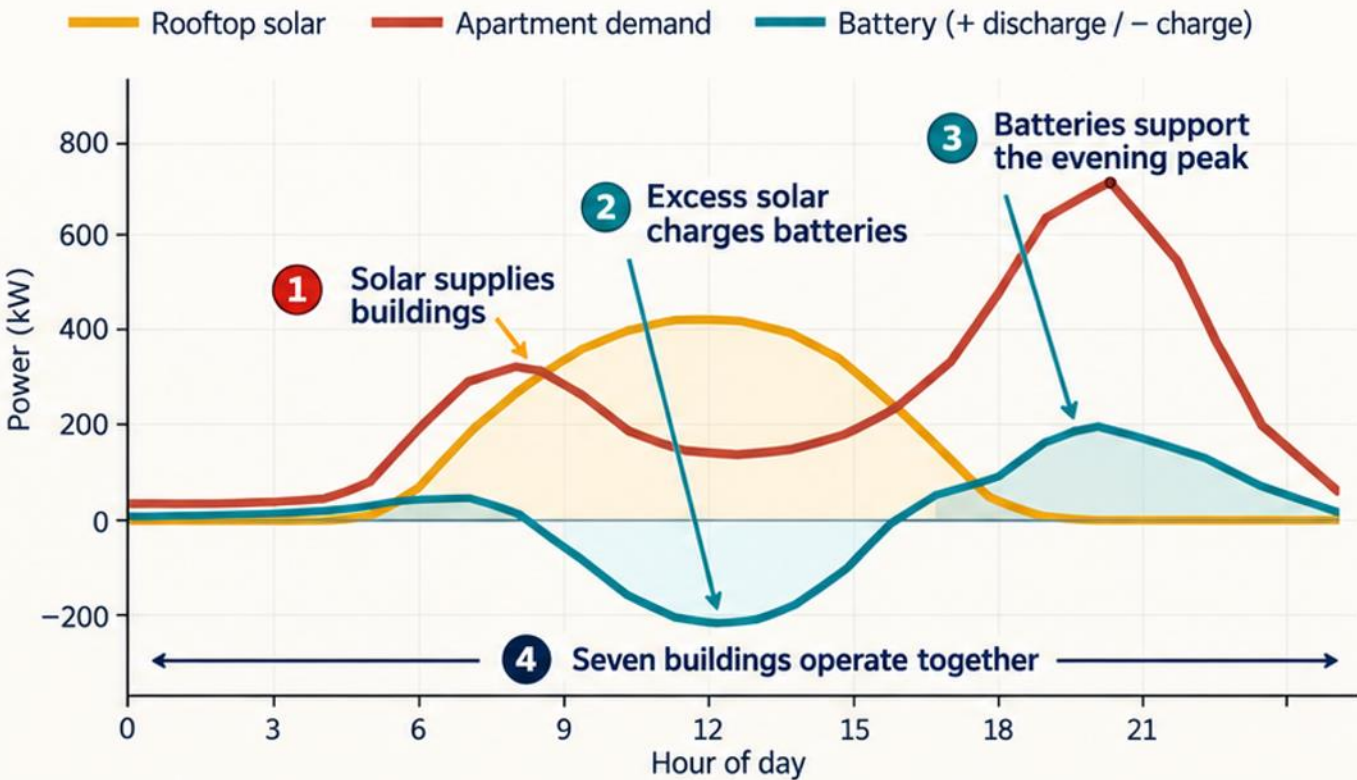
- 7 buildings
- 418 homes
- 500 kWp rooftop solar
- 500 kW / 2 MWh battery
- 7 energy routers

The ring keeps each building connected even if a link fails.

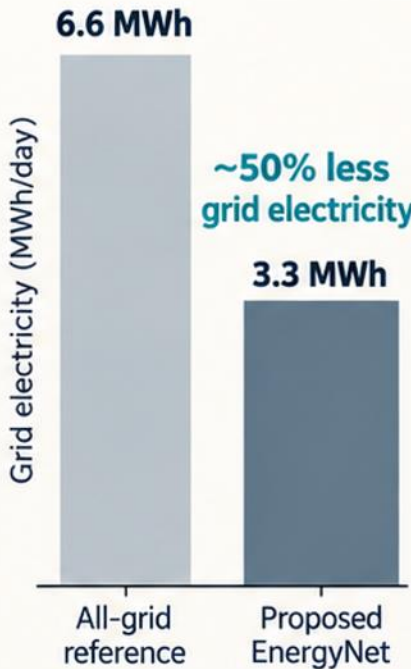
NYCHA Ocean Bay Apartments (Oceanside) – normal operation



Seven buildings. Seven energy routers. One coordinated ring.



Illustrative sunny day



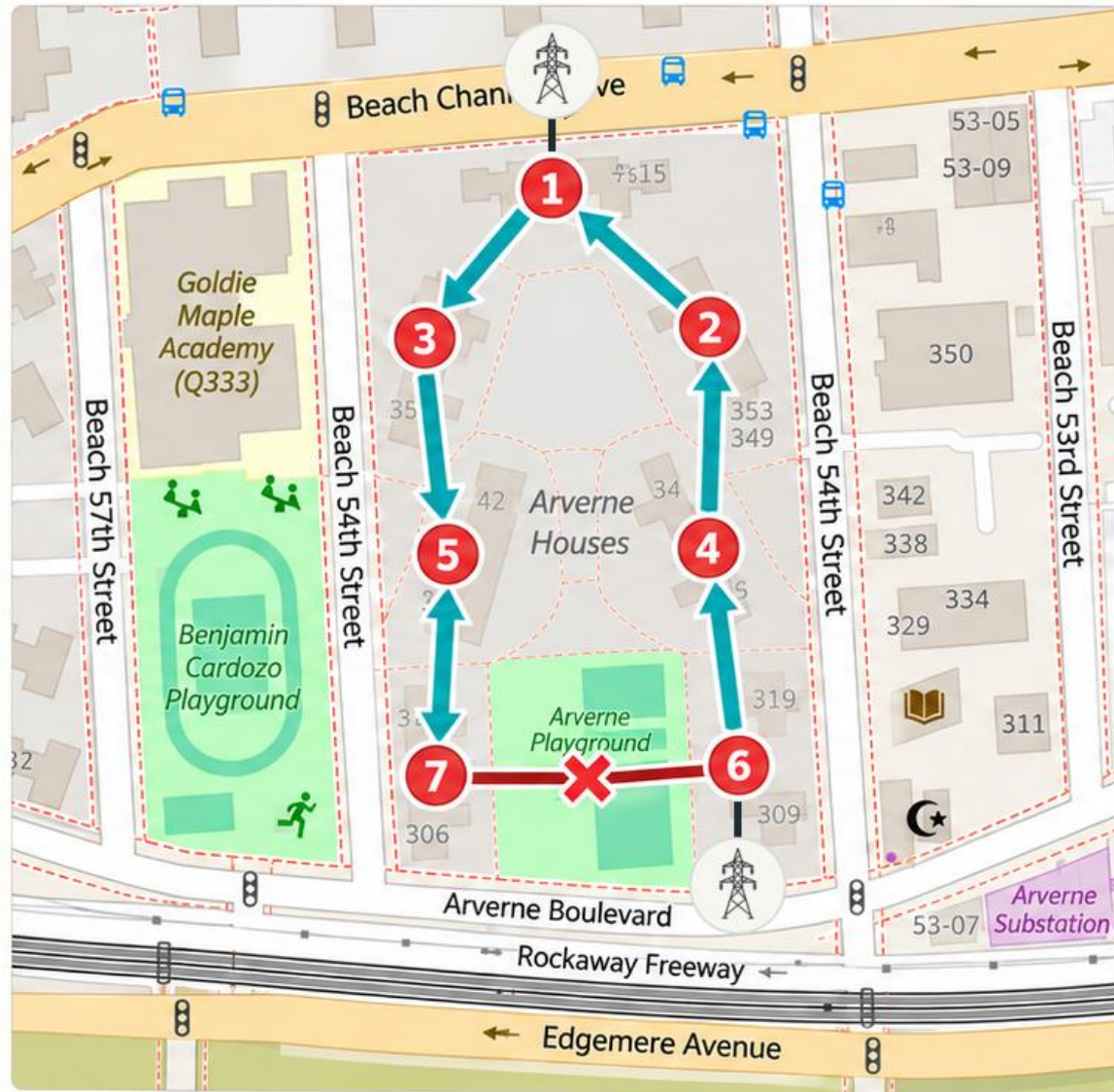
3.3 MWh
solar generated

1.2 MWh
shifted through batteries

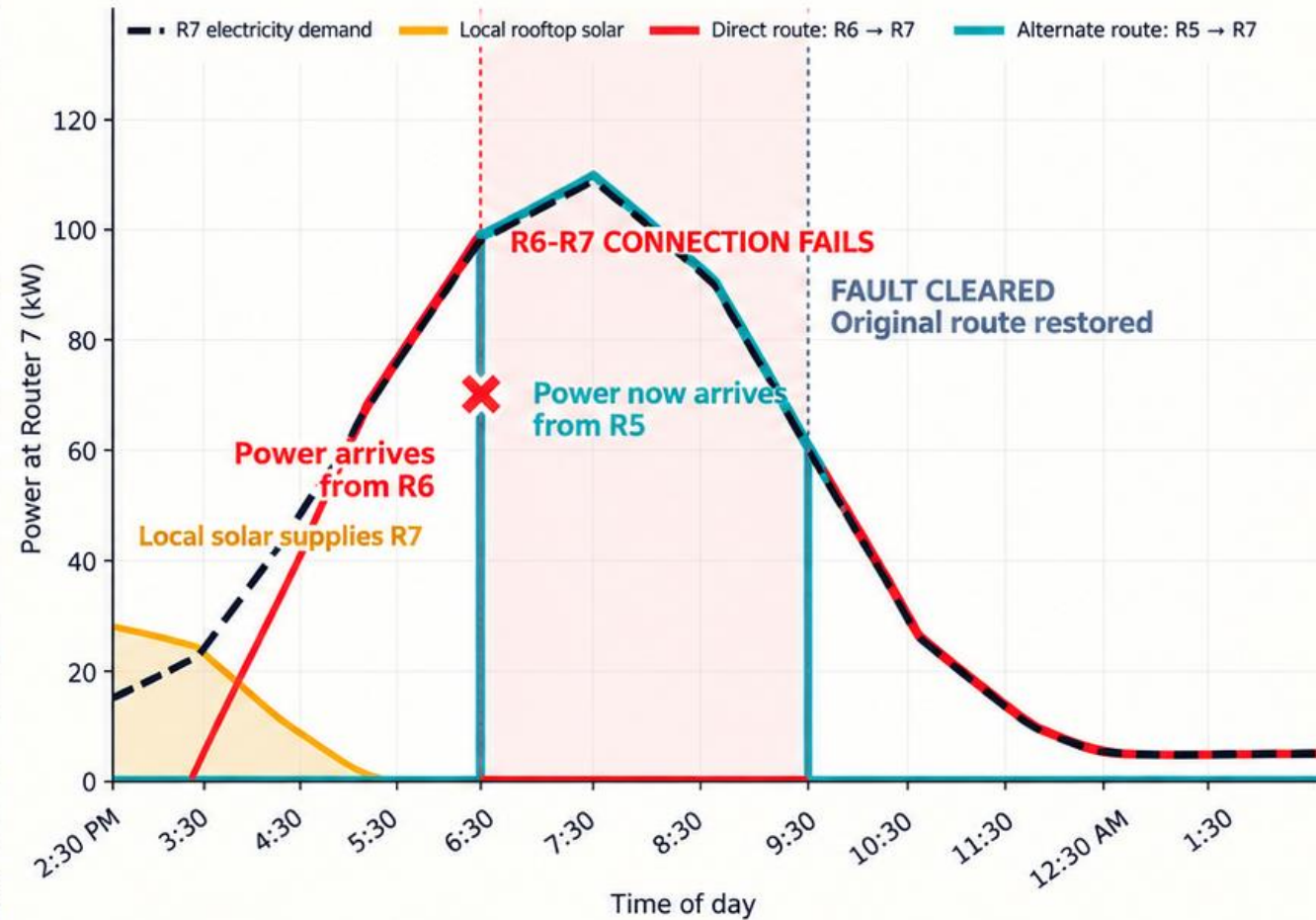
~50%
less grid electricity

Solar generated in the middle of the day is stored and used when residents need it in the evening.

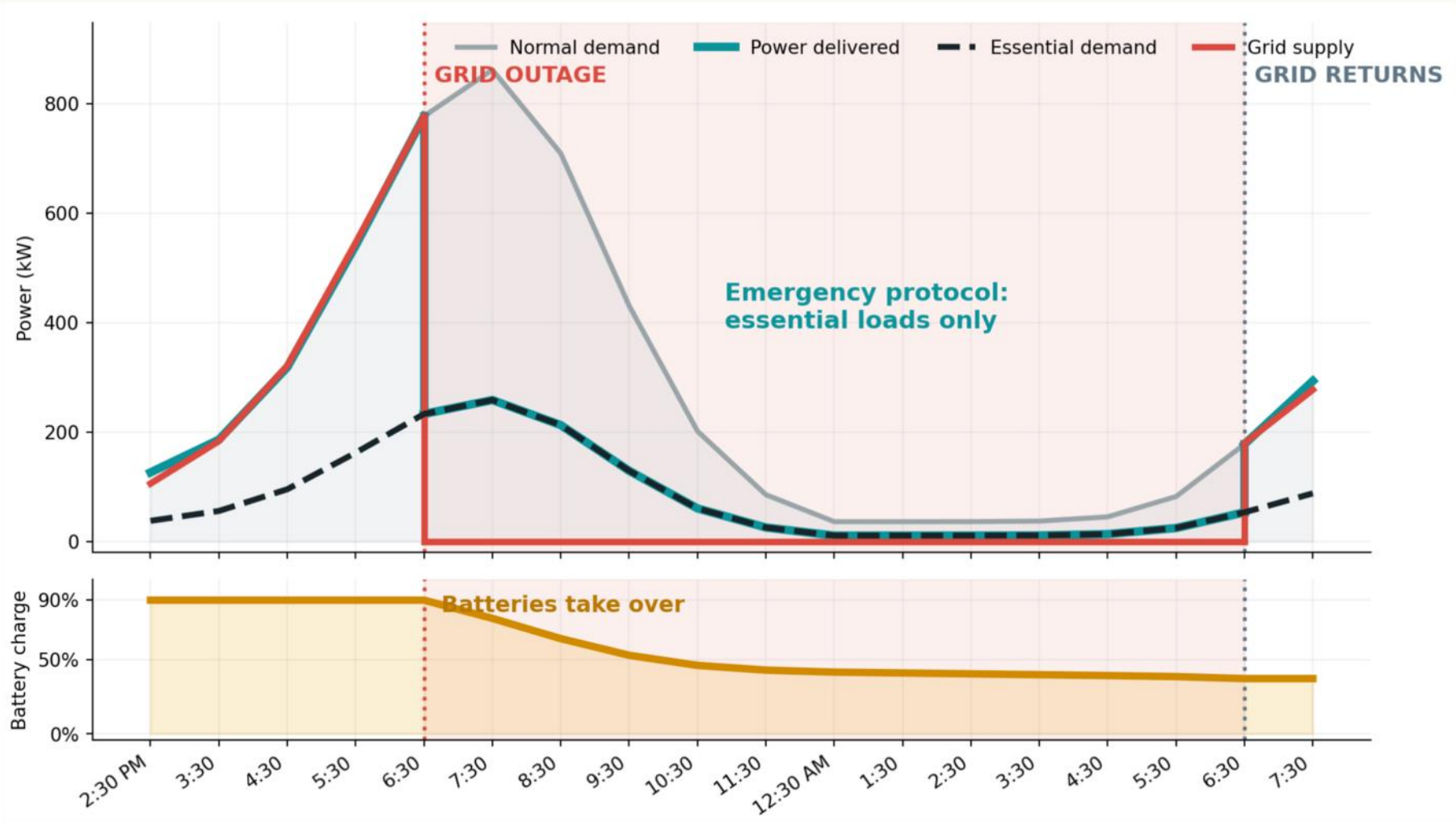
NYCHA Ocean Bay Apartments (Oceanside) – router link outage



The connection fails. Router 7 receives power from the other direction.



NYCHA Ocean Bay Apartments (Oceanside) – complete grid outage



100%

critical demand served

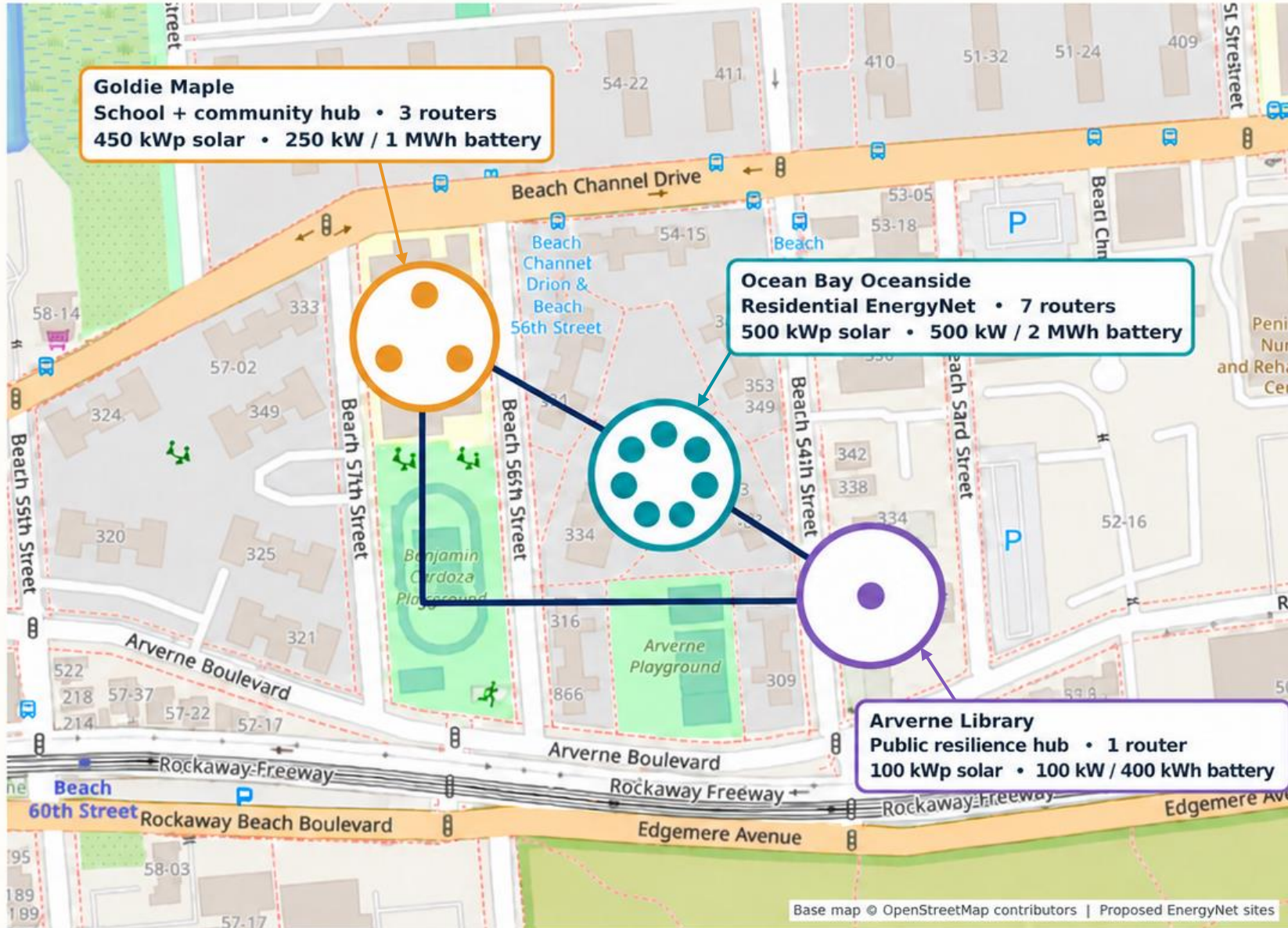
12 hours

without grid connection

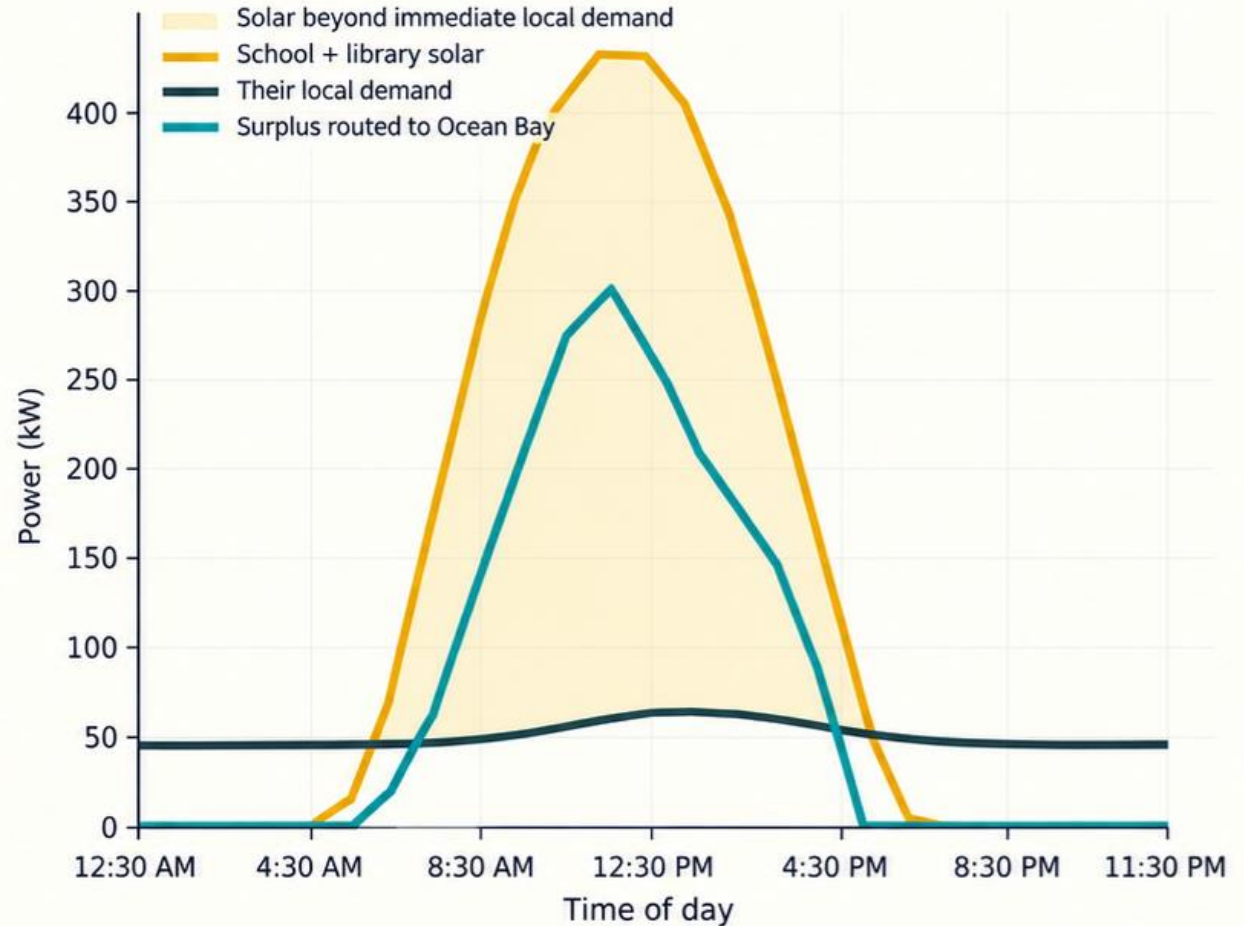
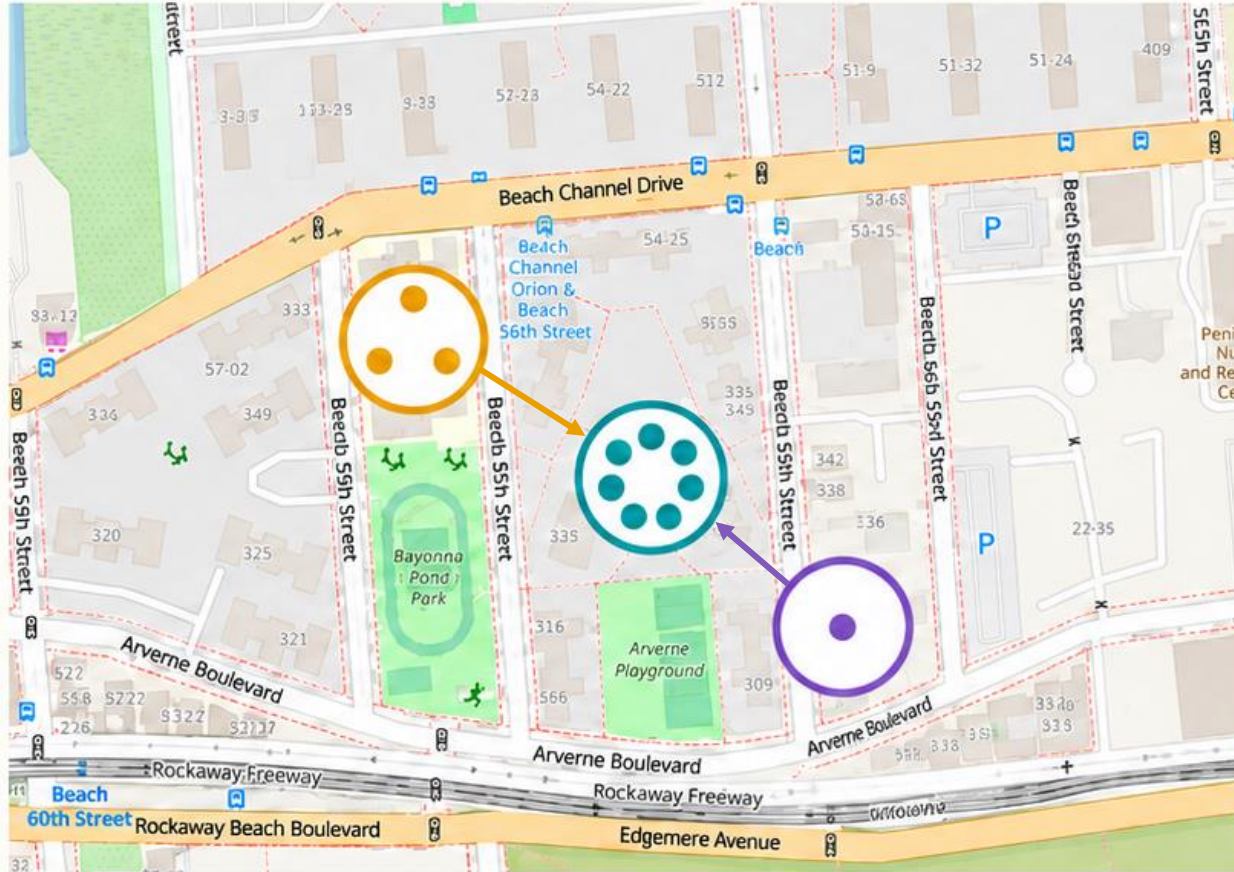
37%

battery state-of-charge remaining

Study Connecting three EnergyNets



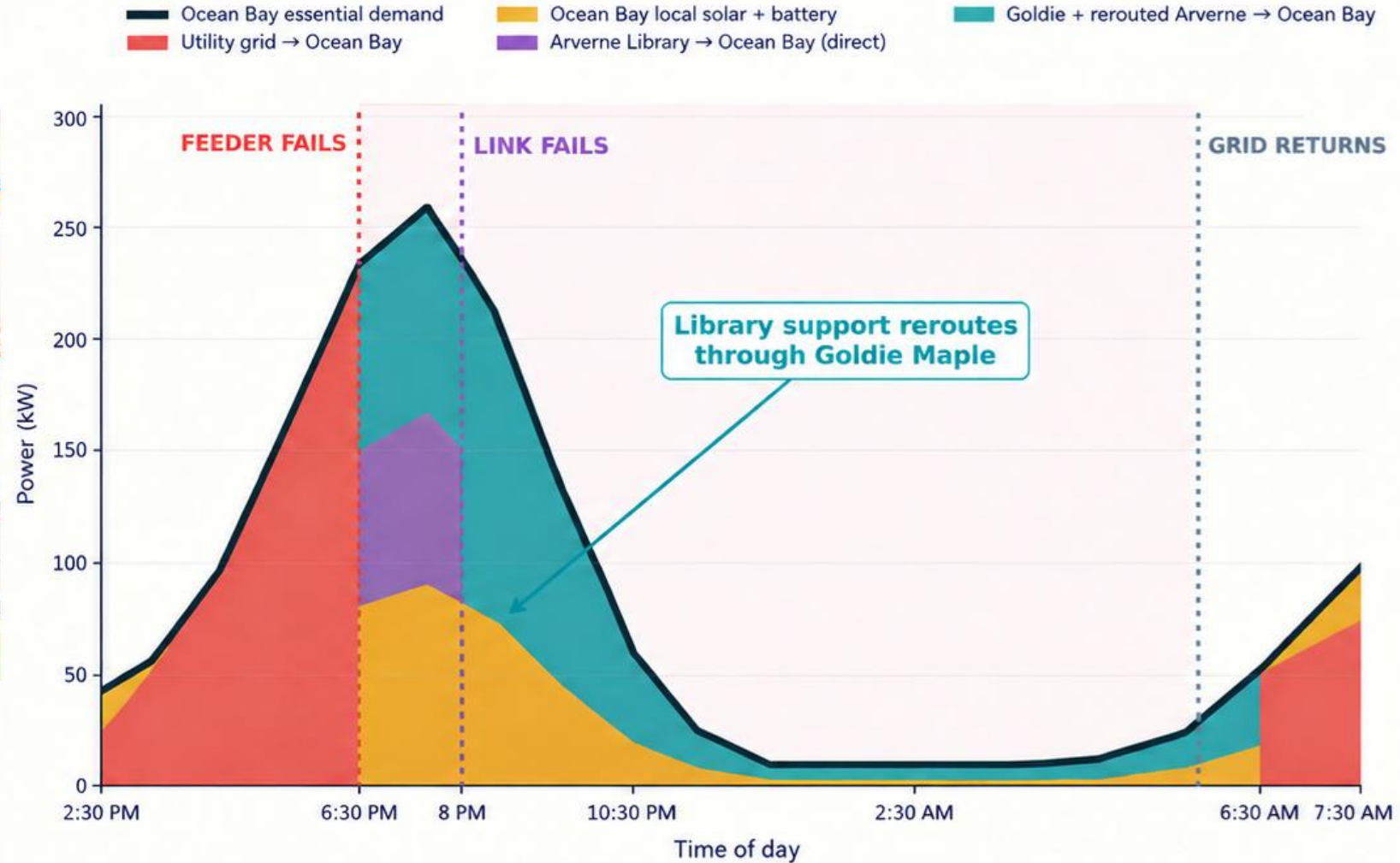
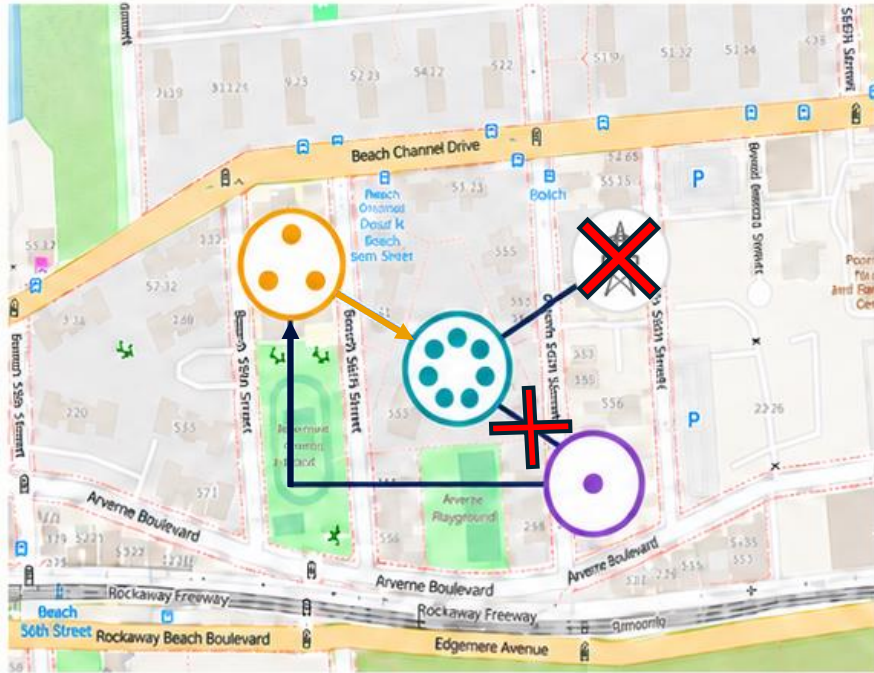
Three EnergyNets Routing and utilizing solar surplus



Some buildings have high solar generation but low demand (school building during weekend...)

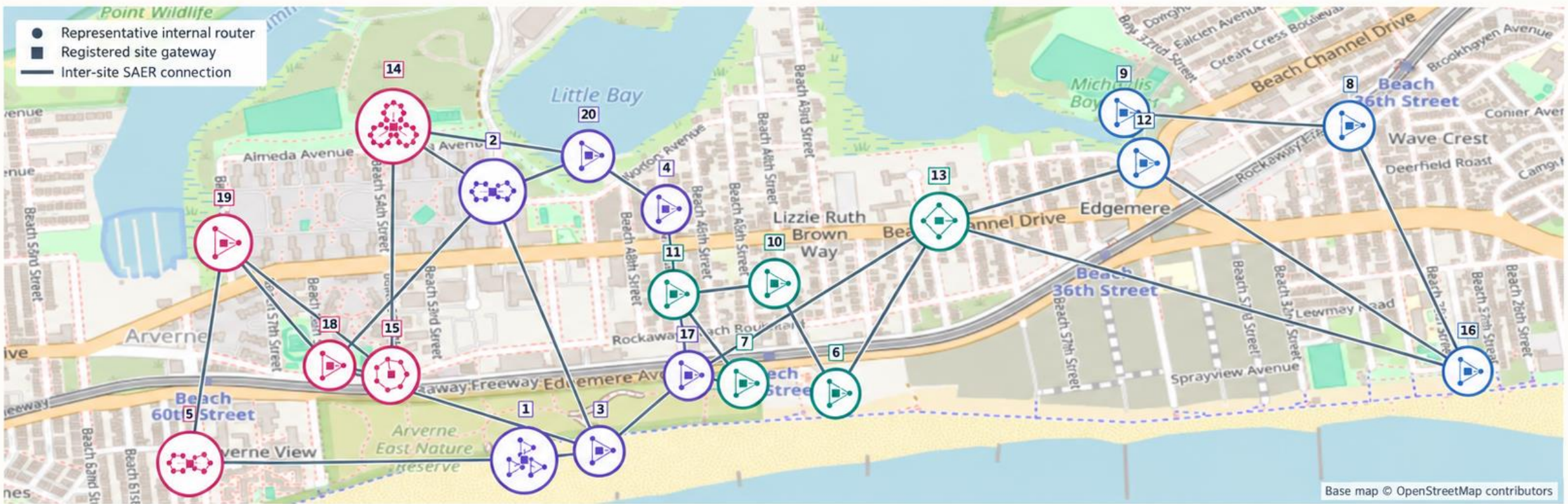
EnergyNet permits energy sharing: 3.4 MWh less grid energy required/week

Three EnergyNets Resiliency by re-routing during grid outages



Ocean Bay essential demand remains 100% served

SAER from local EnergyNets to Rockaway-wide energy system



WEST RESIDENTIAL

- 5 Arverne View
- 14 Ocean Bay Bayside
- 15 Ocean Bay Oceanside
- 18 Arverne Library
- 19 Goldie Maple

CENTRAL DEVELOPMENT & CRITICAL

- 1 Arverne East
- 2 Edgemere Commons
- 3 50-01 RBB
- 4 Rockaway Care
- 17 EMS 47
- 20 PS 105

MID-CORRIDOR

- 6 La Quinta
- 7 Seaview Manor
- 10 BGD I
- 11 BGD II
- 13 Beach 41st

EAST

- 8 Seaview Towers
- 9 Seagirt Senior
- 12 BGD III
- 16 PS/MS 43

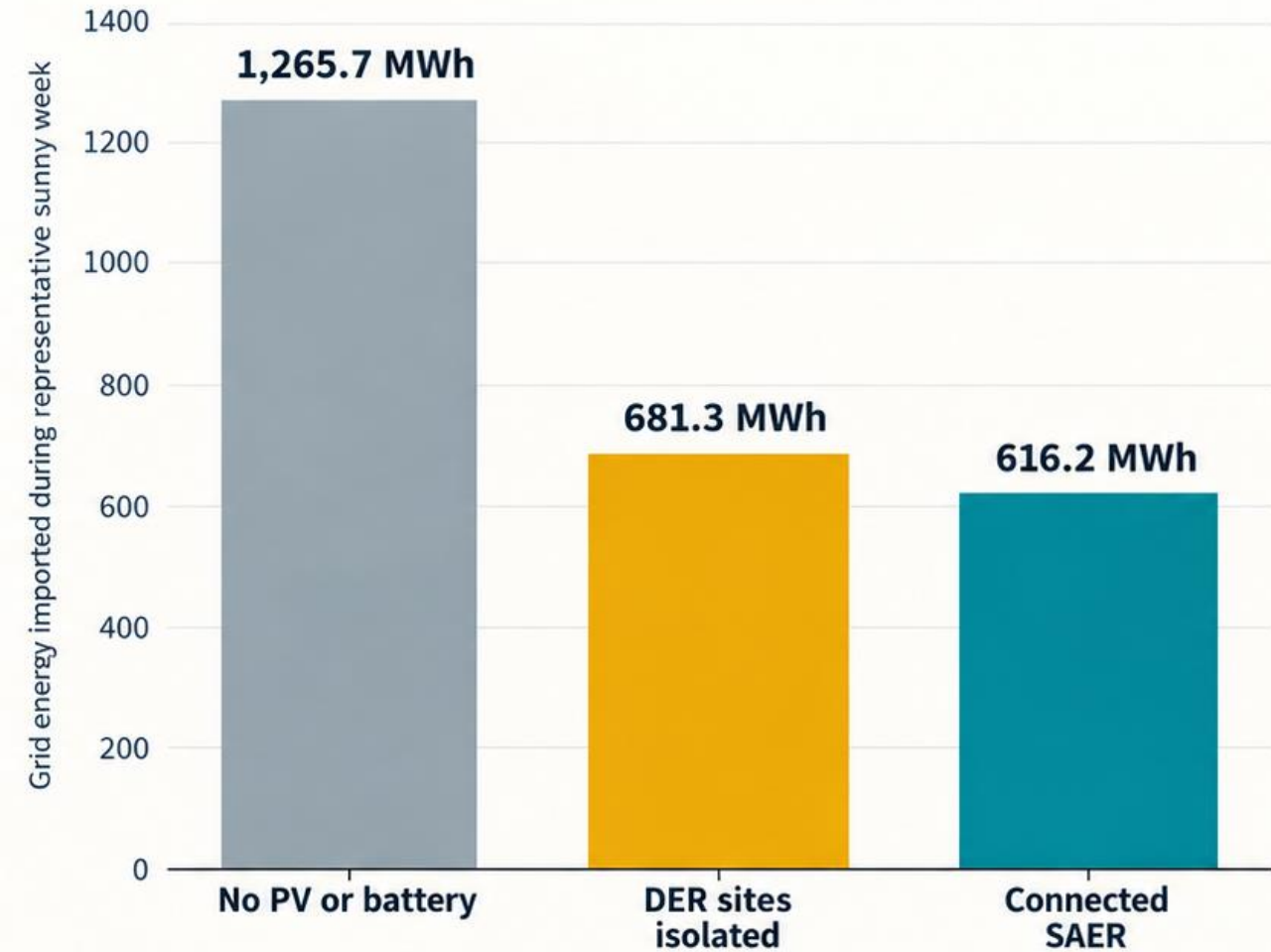
20 EnergyNets

83 Energy Routers

28 Inter-site connections

Internal diagrams illustrate the site EnergyNet architecture.

SAER from local EnergyNets to Rockaway-wide energy system



51.3%

lower grid energy imports

1,265.7 → 616.2 MWh

12.9%

lower peak grid draw

18.89 → 16.45 MW
2.44 MW reduction

99.5%

of available solar used

95.3% less curtailment

+9.5%

additional import reduction
through inter-site energy
sharing

versus the same DER sites
operating independently

Across the full network, SAER reduces grid energy and peak demand while making use of almost all available solar.

How EnergyNet responds to a prolonged regional outage

Stress test: prolonged winter outage with the regional grid unavailable

Share



Prioritize



Reinforce

1. Stationary EnergyNet



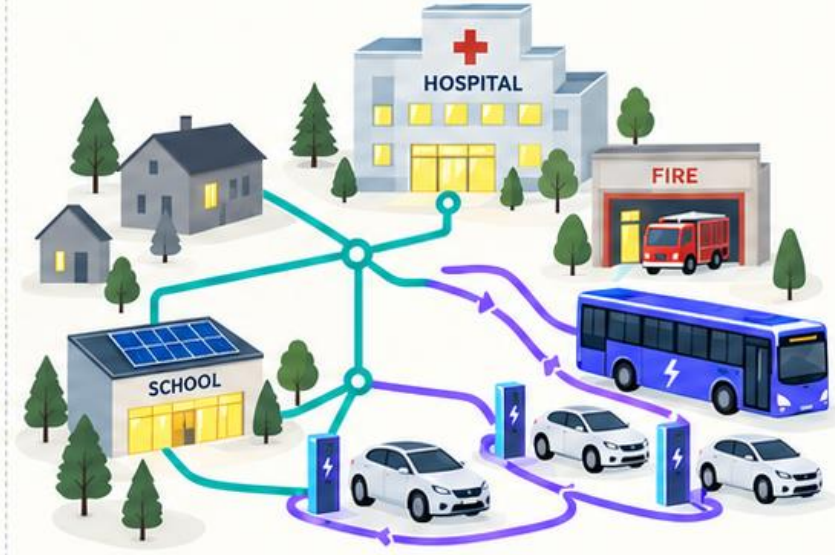
Share available solar and stored energy across the network

2. Emergency operation



Protect priority services and reduce non-essential demand

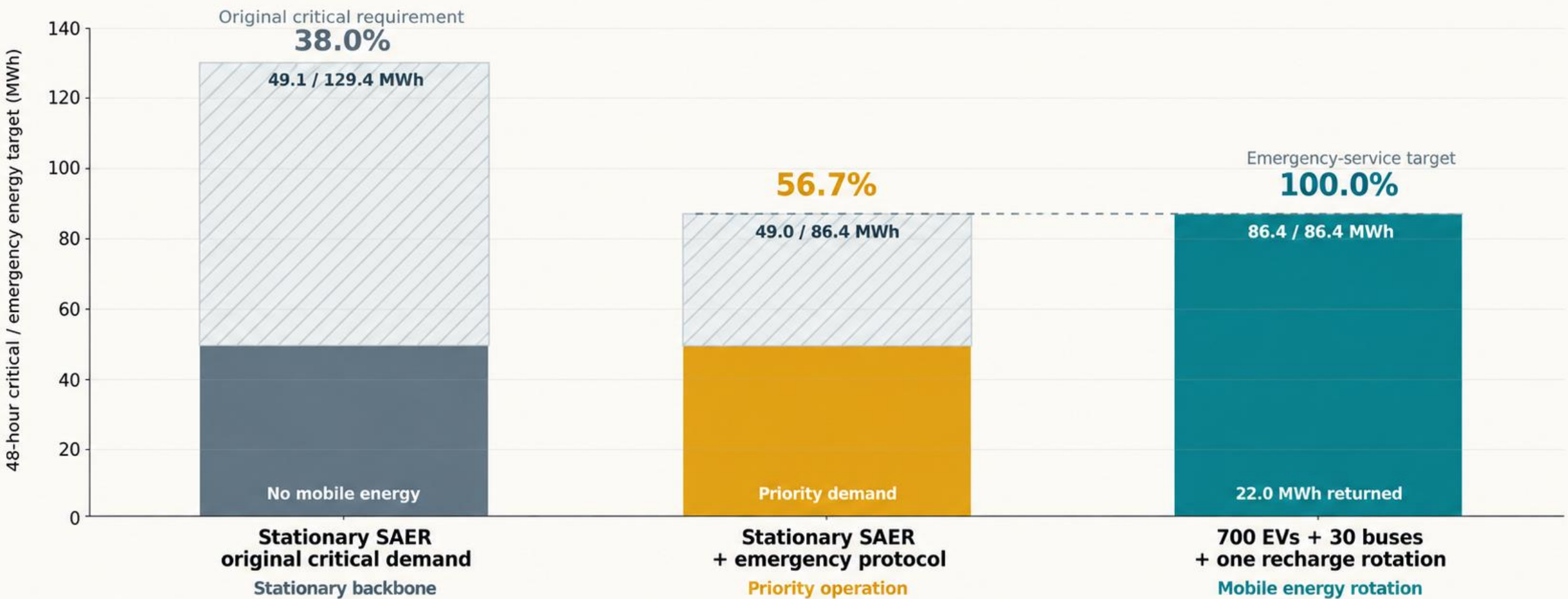
3. Mobile Energy Peering



Use EVs and buses to close the remaining winter energy gap

The stationary EnergyNet establishes the resilience backbone. Emergency operation protects essential services, and mobile storage supplies the remaining energy.

48-hour regional outage mobile energy closes the resilience gap



The stationary SAER provides the backbone, emergency operation protects priority services, and a rotating mobile fleet supplies the remaining winter energy.

Tack!

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