Battery Energy Storage Sizing and Placement in Hybrid Renewable Systems

Han Kun Ren

UNIVERSITY OF OXFORD

E-ei Energy and Environmental Informatics

UNIVERSITY OF BIRMINGHAM

Method Comparison

Meta-Heuristic Optimization

- Can handle any model
- Cannot guarantee optimal
- Slow calculation speed

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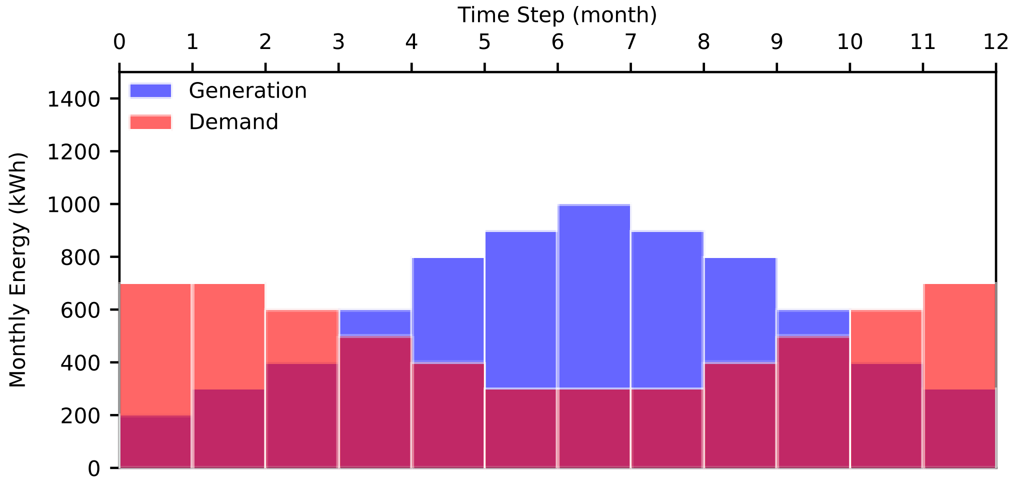
Analytical Optimization

- Can handle most models
- Good convergence to optimal
- Faster than Meta-Heuristic
- Provide good understanding

Storage Sizing



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$$P(t) = G(t) - D(t),$$

Where storage power $P(t)$ makes up the difference between generation $G(t)$ and demand $D(t)$ power.

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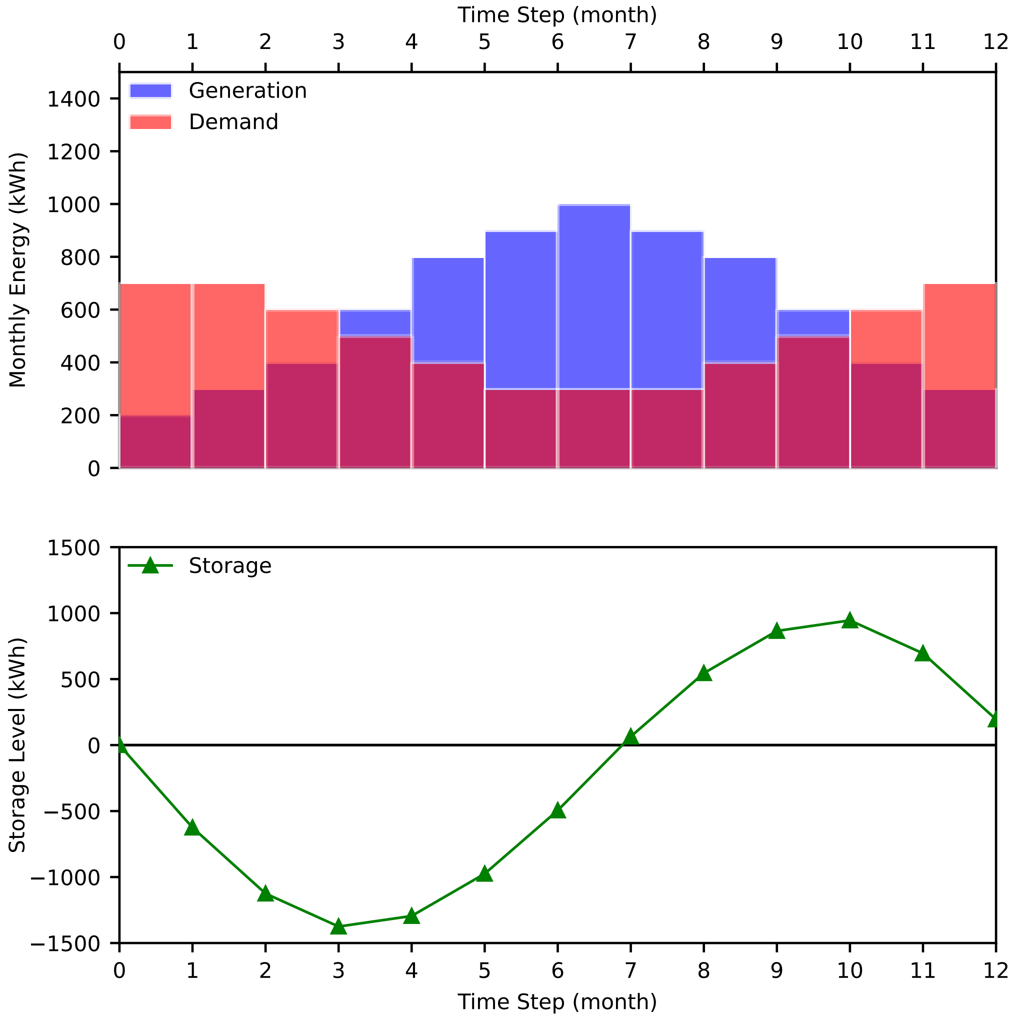

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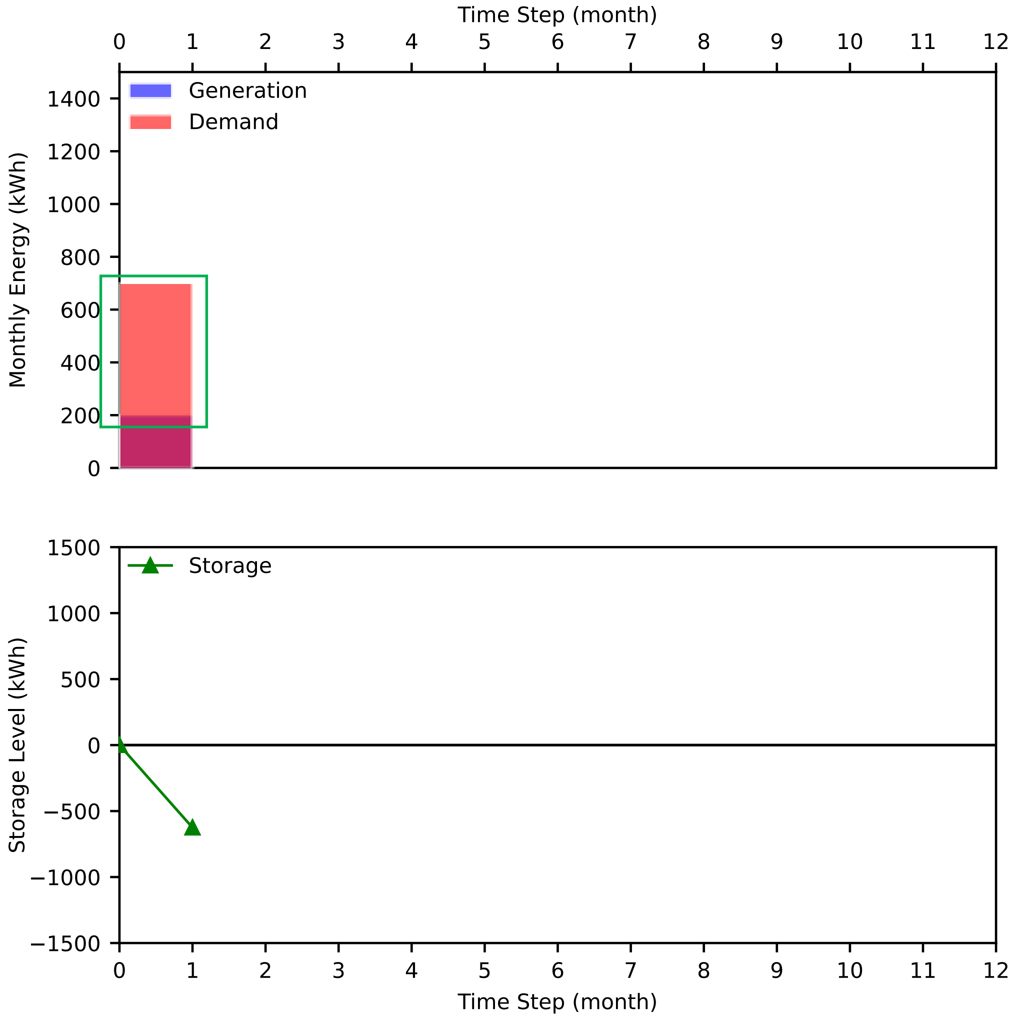

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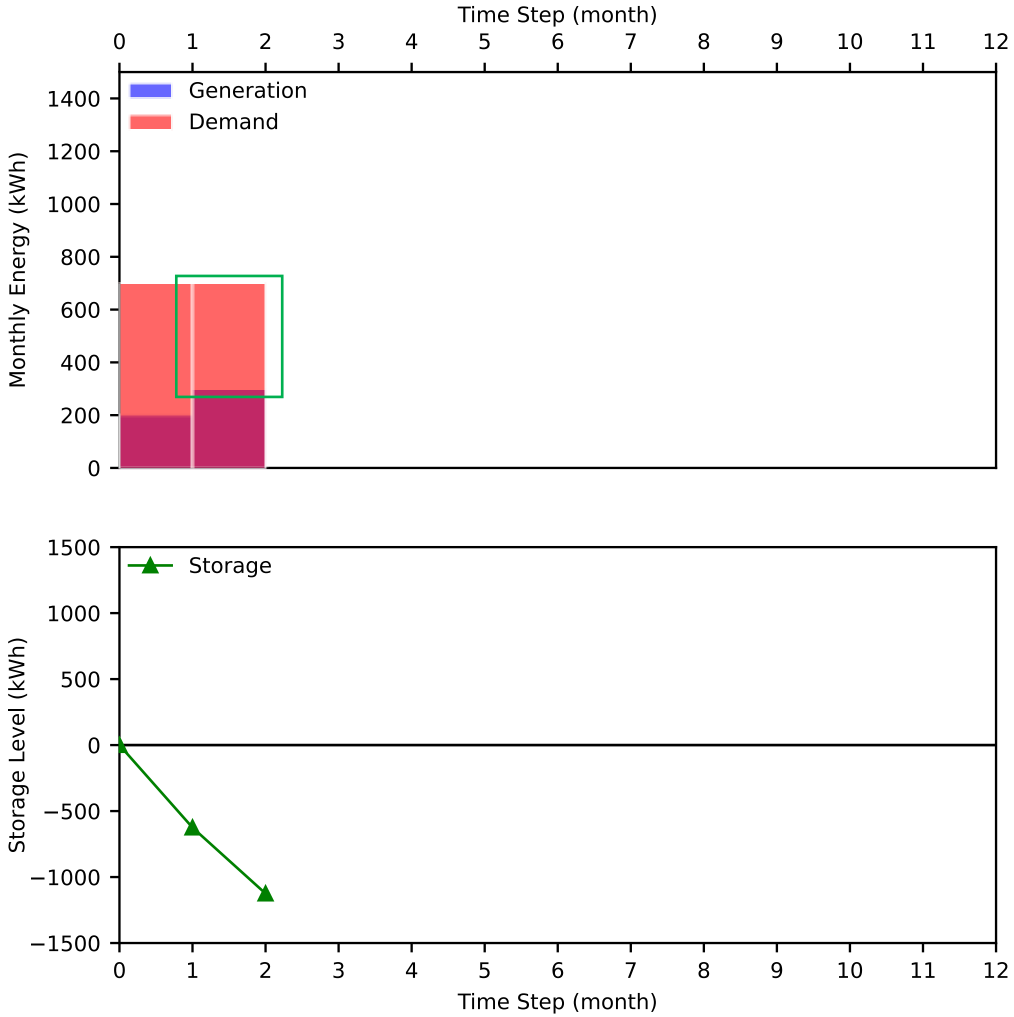

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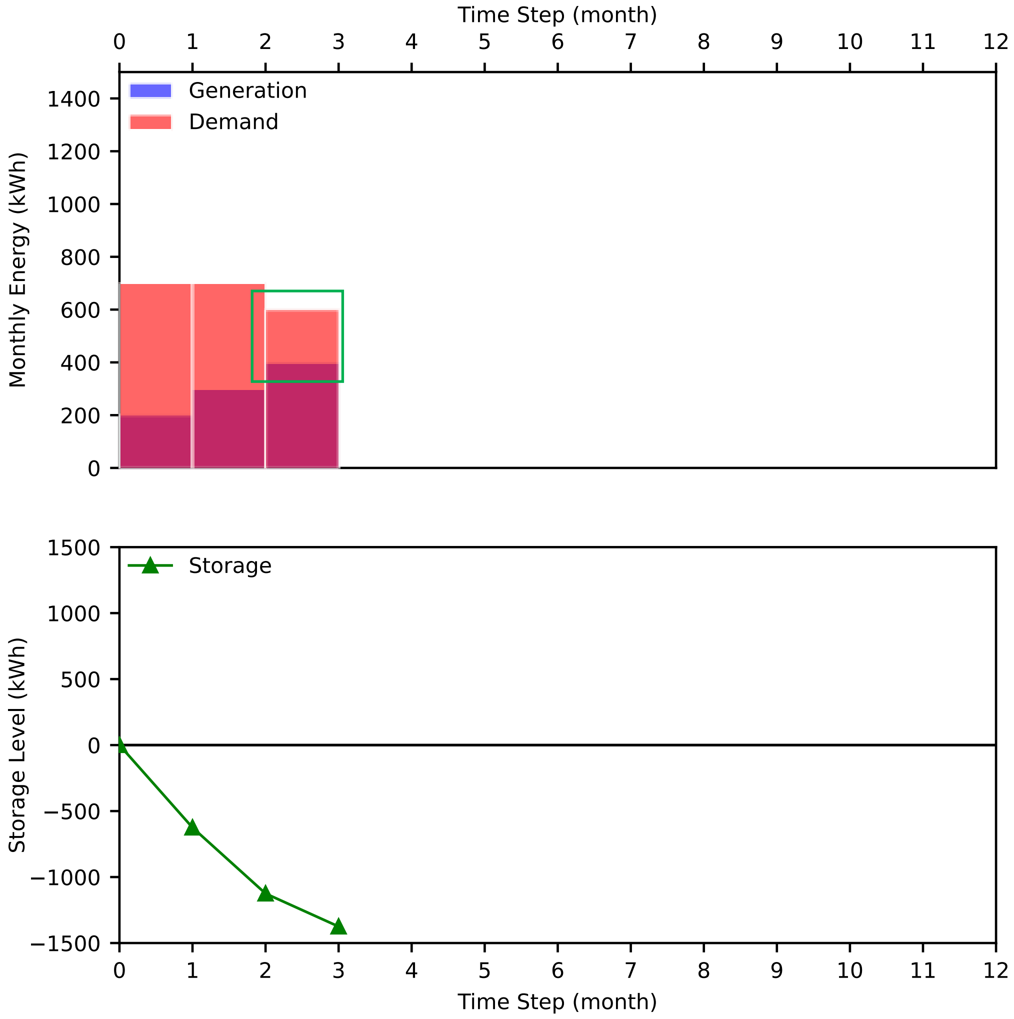

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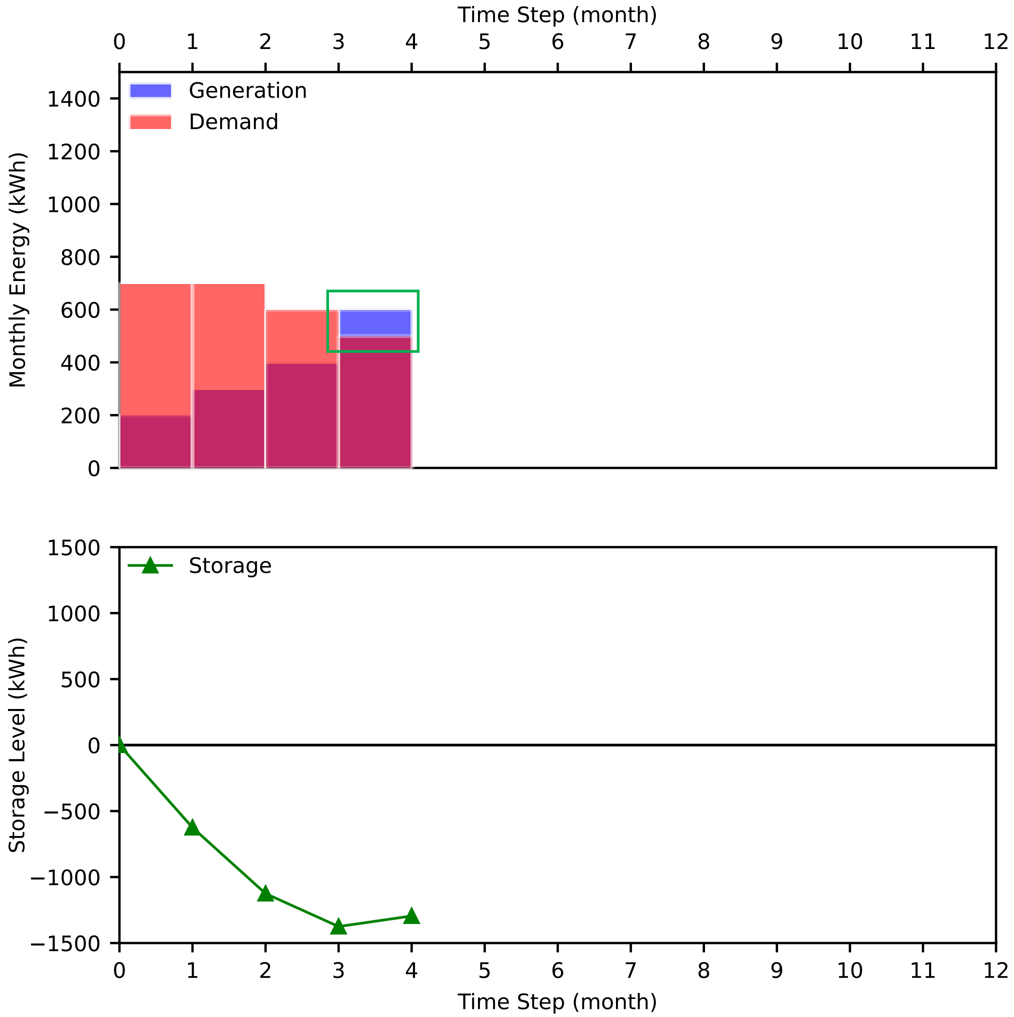

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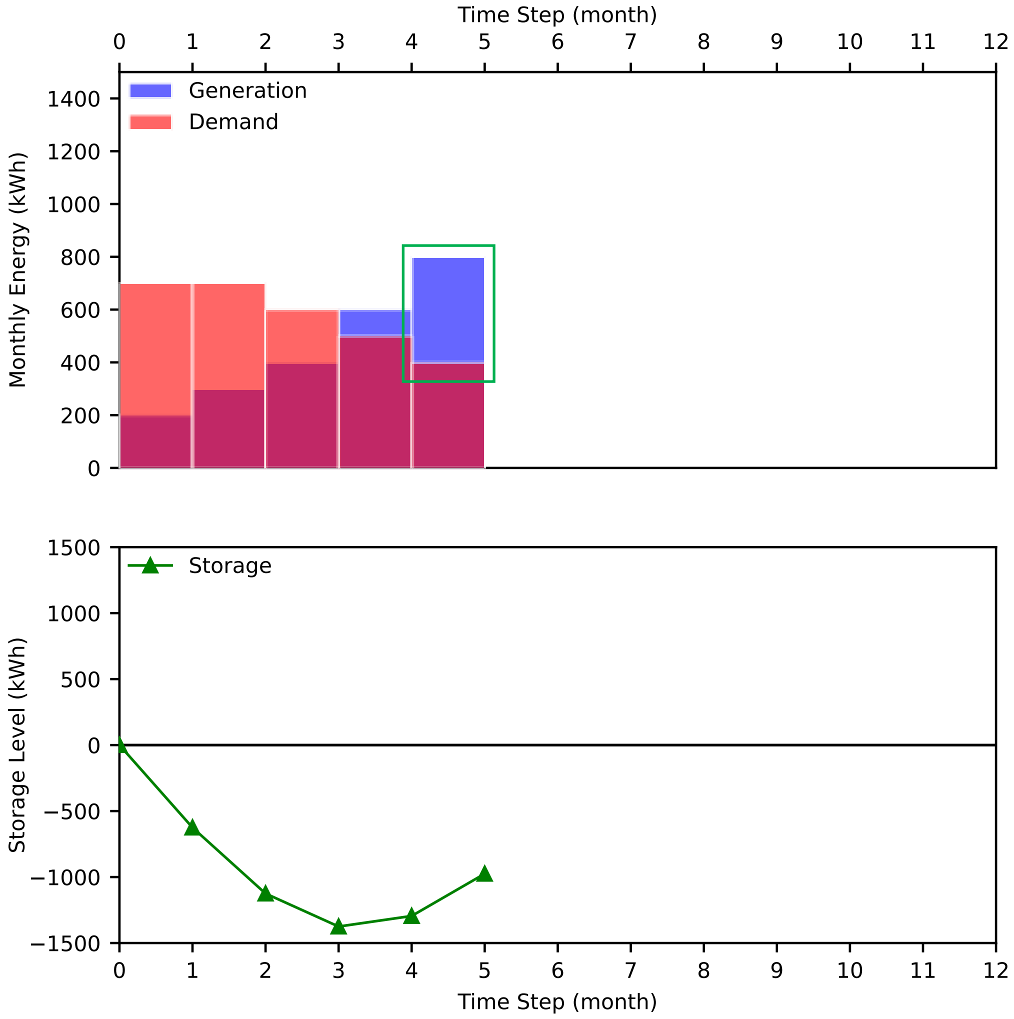

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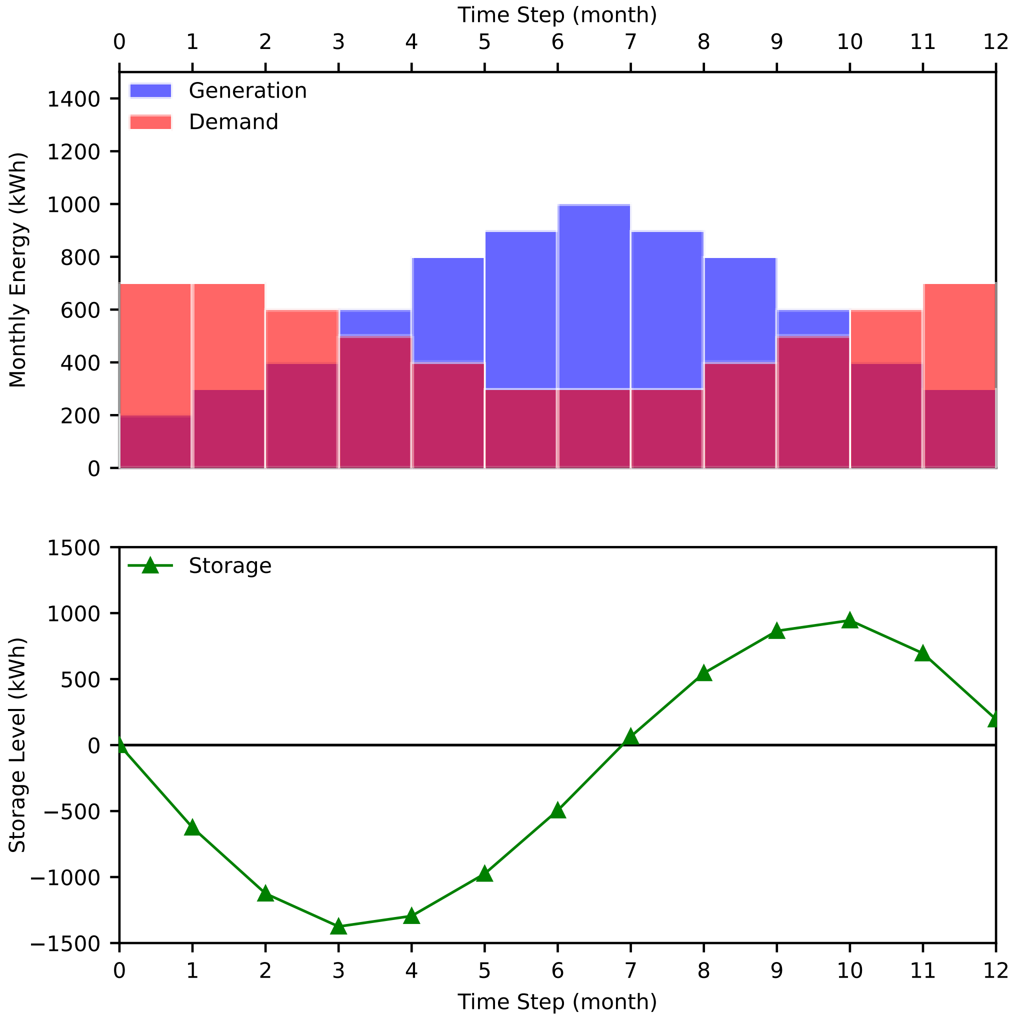

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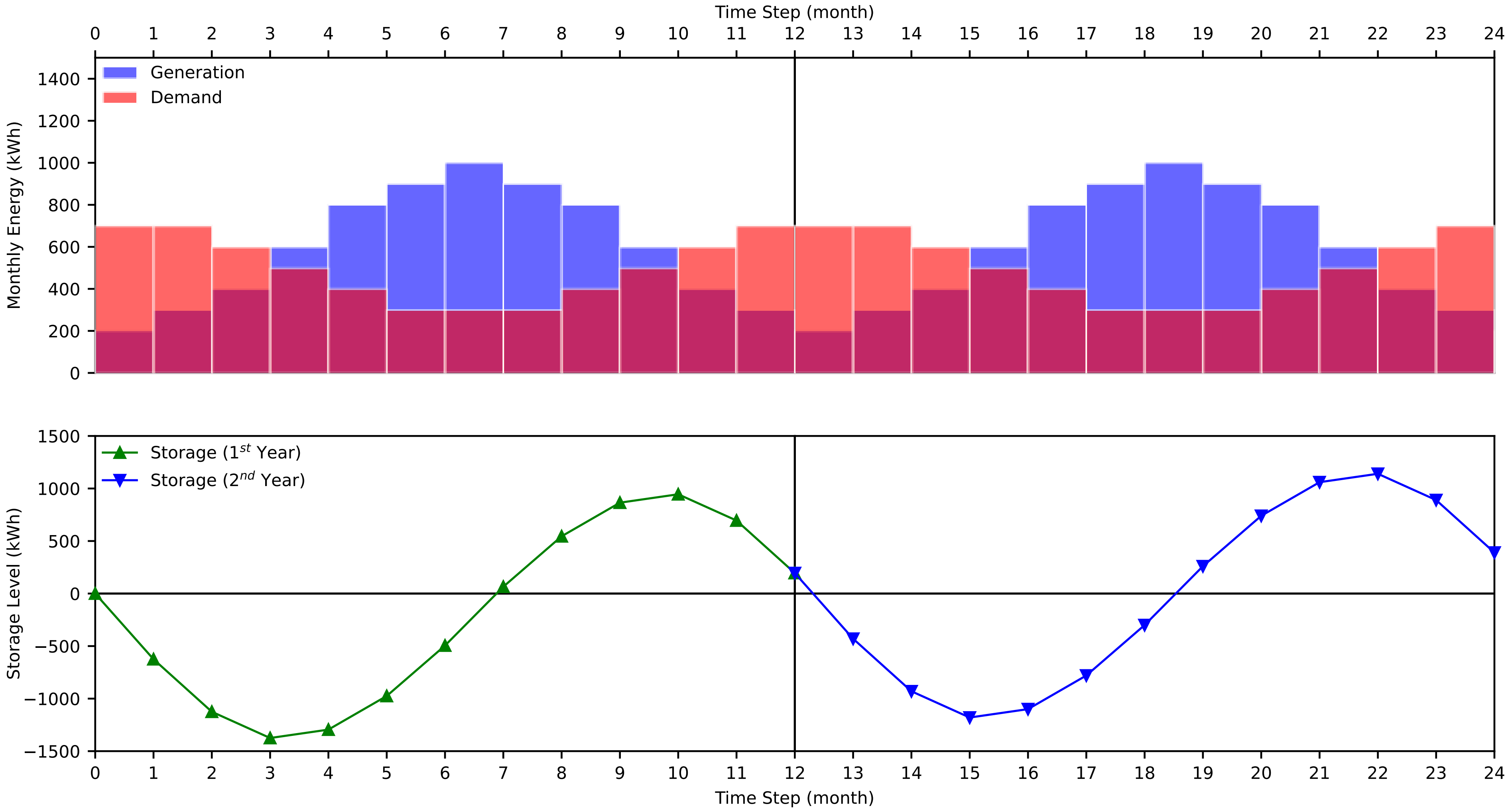
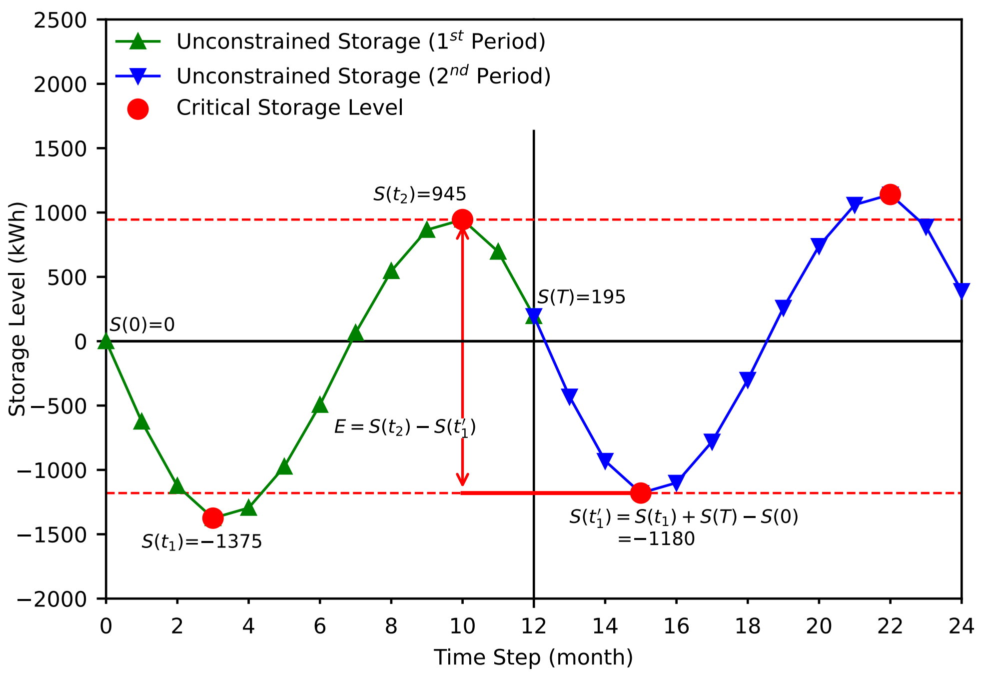


Extend to two years (design time horizon) for sizing.

Storage Sizing

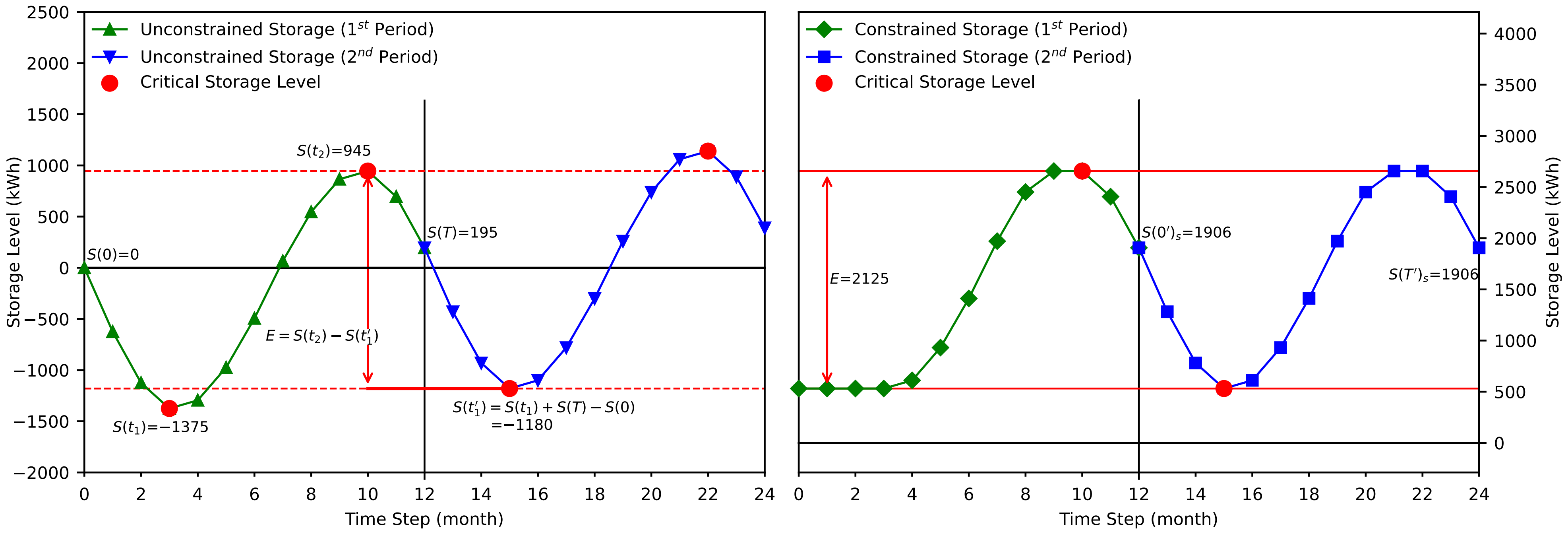
When the storage is accumulating energy, size according to the largest cumulative discharge.



Storage Sizing

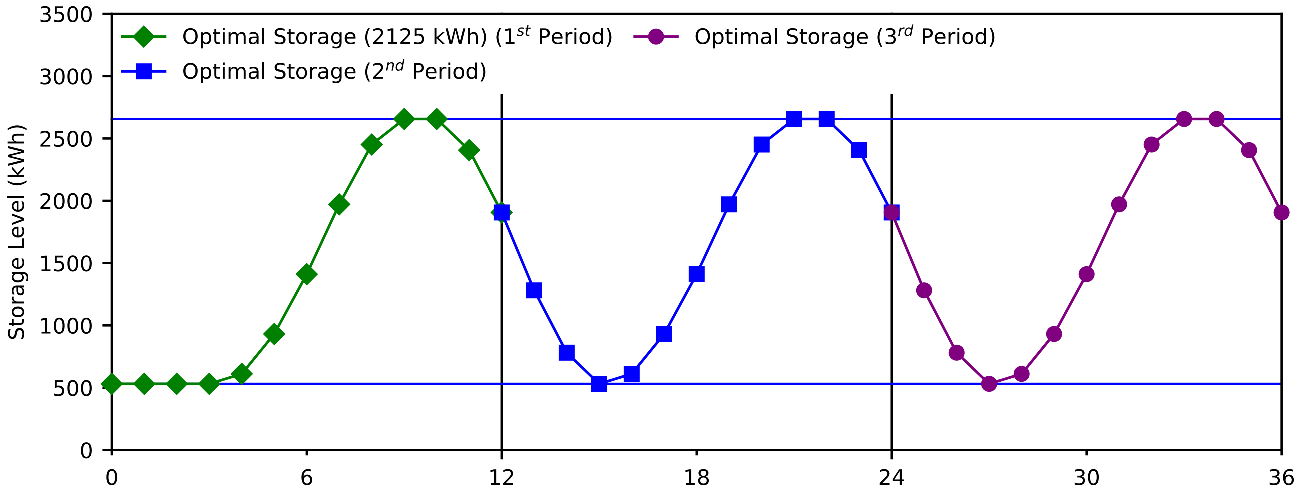
When the storage is accumulating energy, size according to the largest cumulative discharge.

The storage is sized for the largest cumulative discharge during winter, ensuring it has enough stored energy to last through the winter.



Storage Sizing

Optimally-sized storage neither causes energy deficit due to under-sizing, nor has wasted capacity due to over-sizing.



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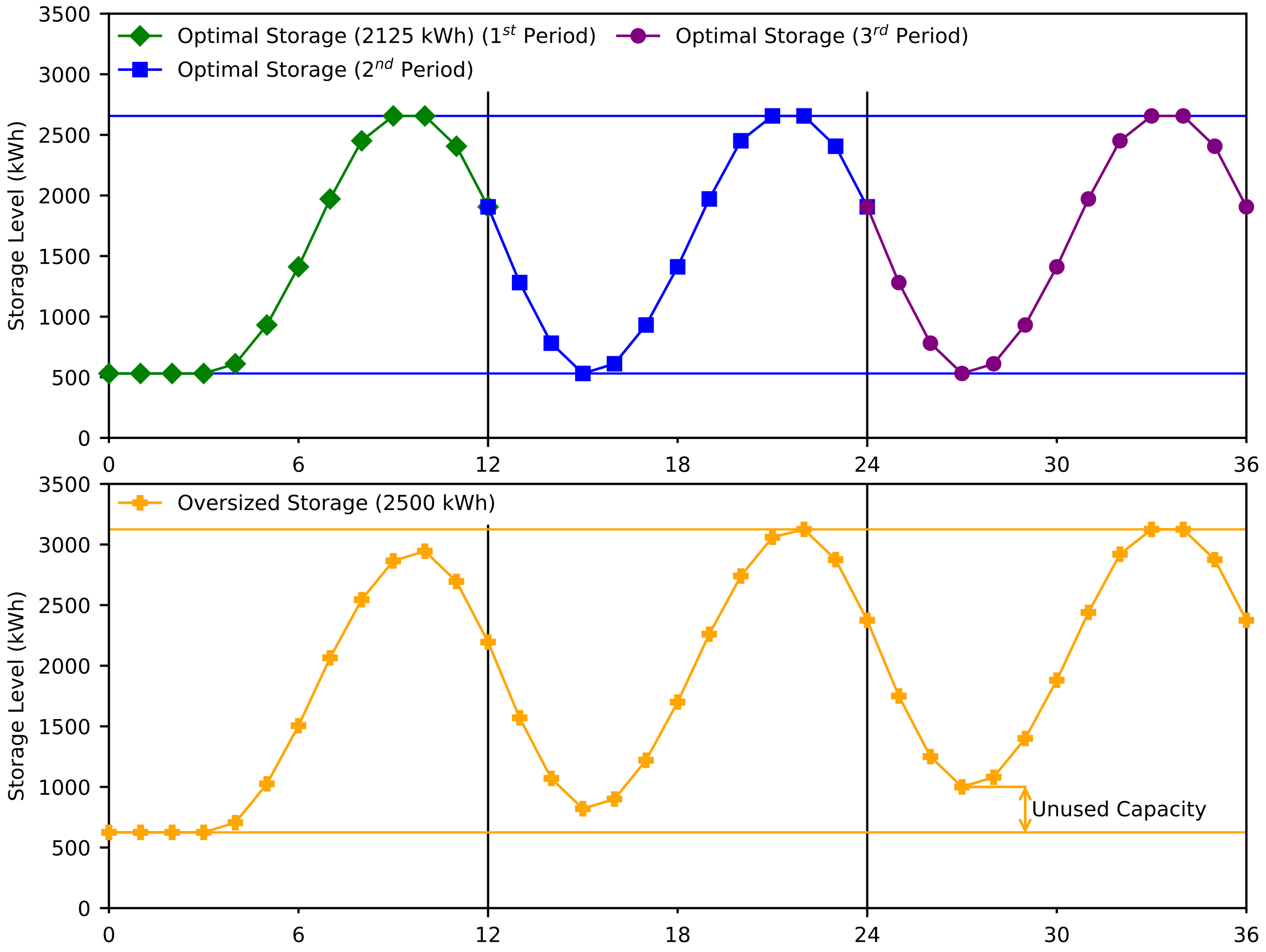

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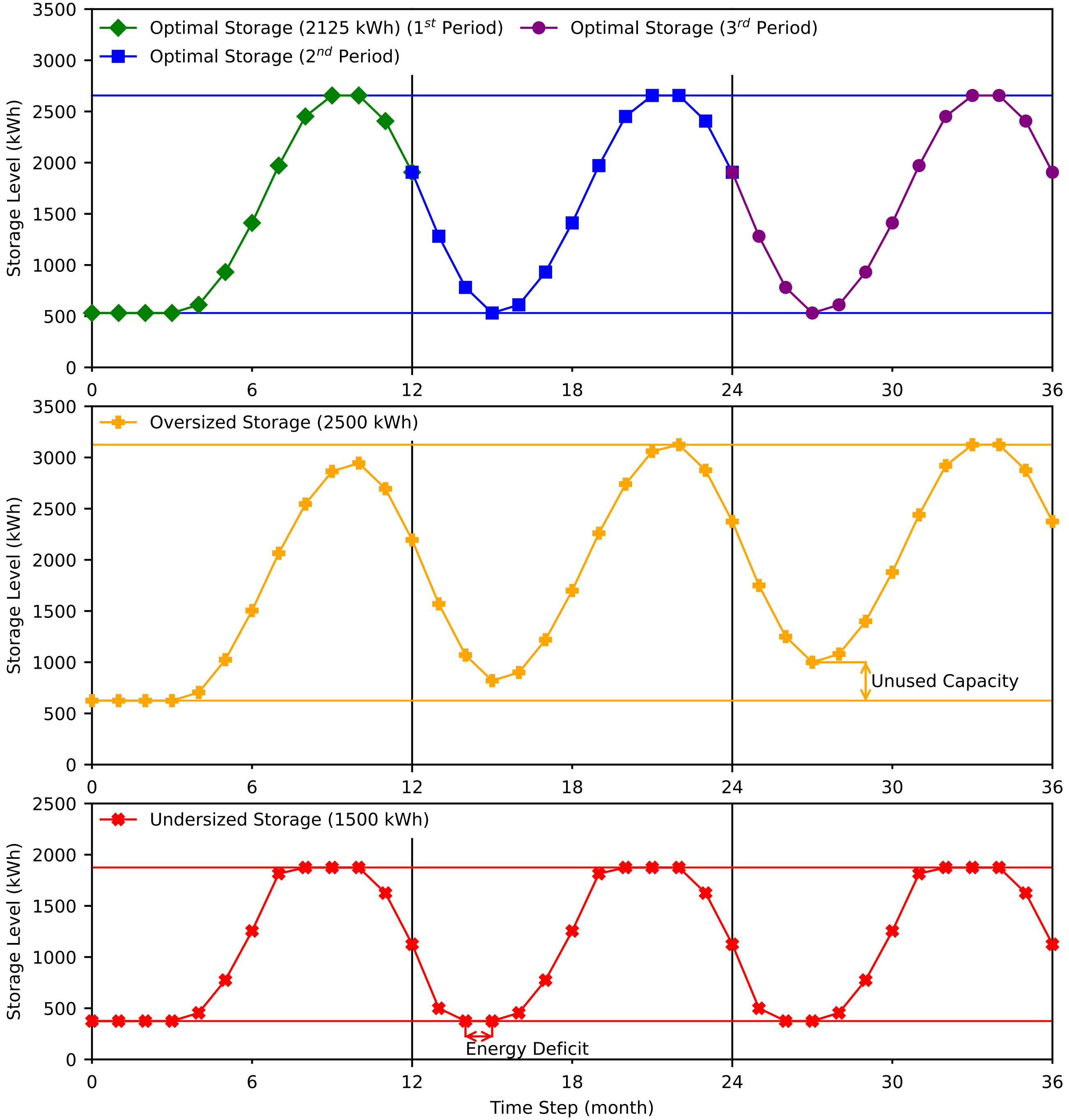
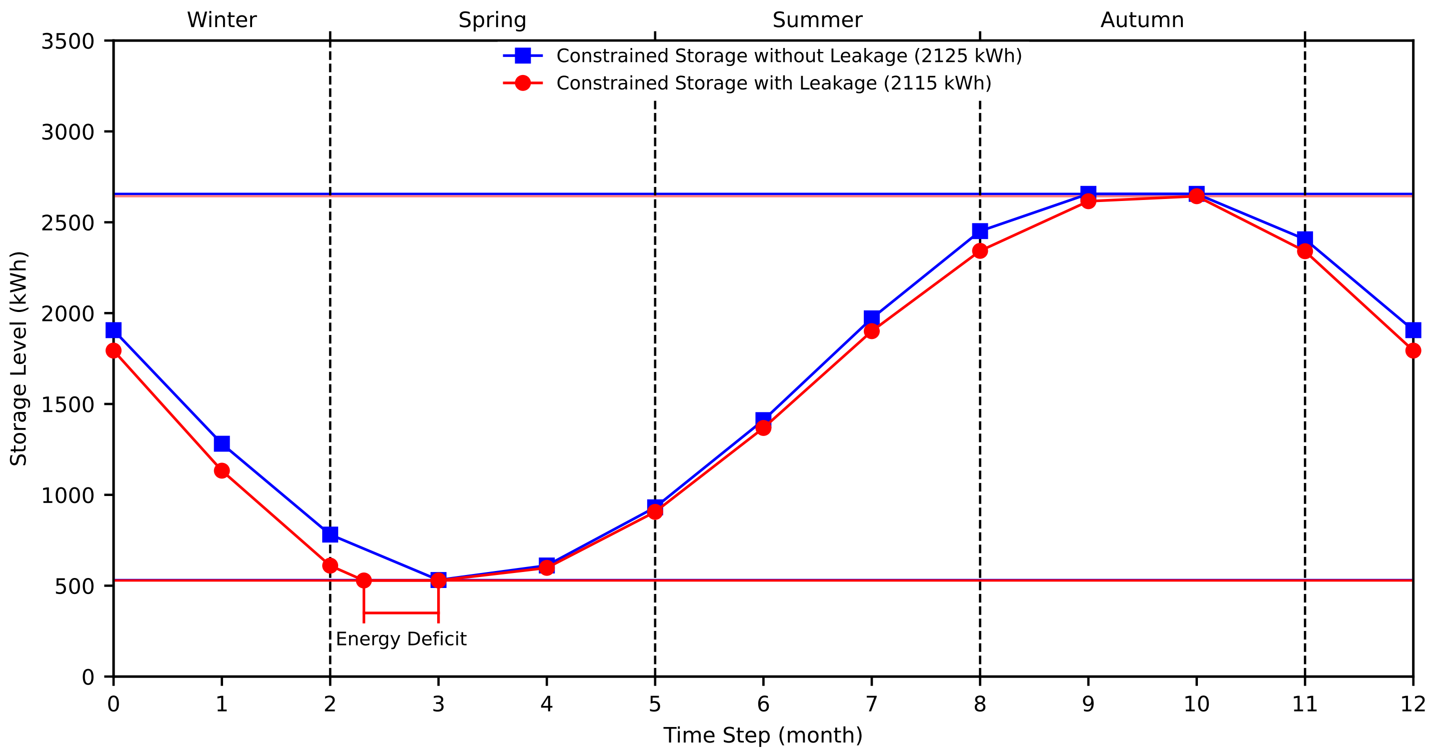
Under-sized storage causes energy deficit in the system.



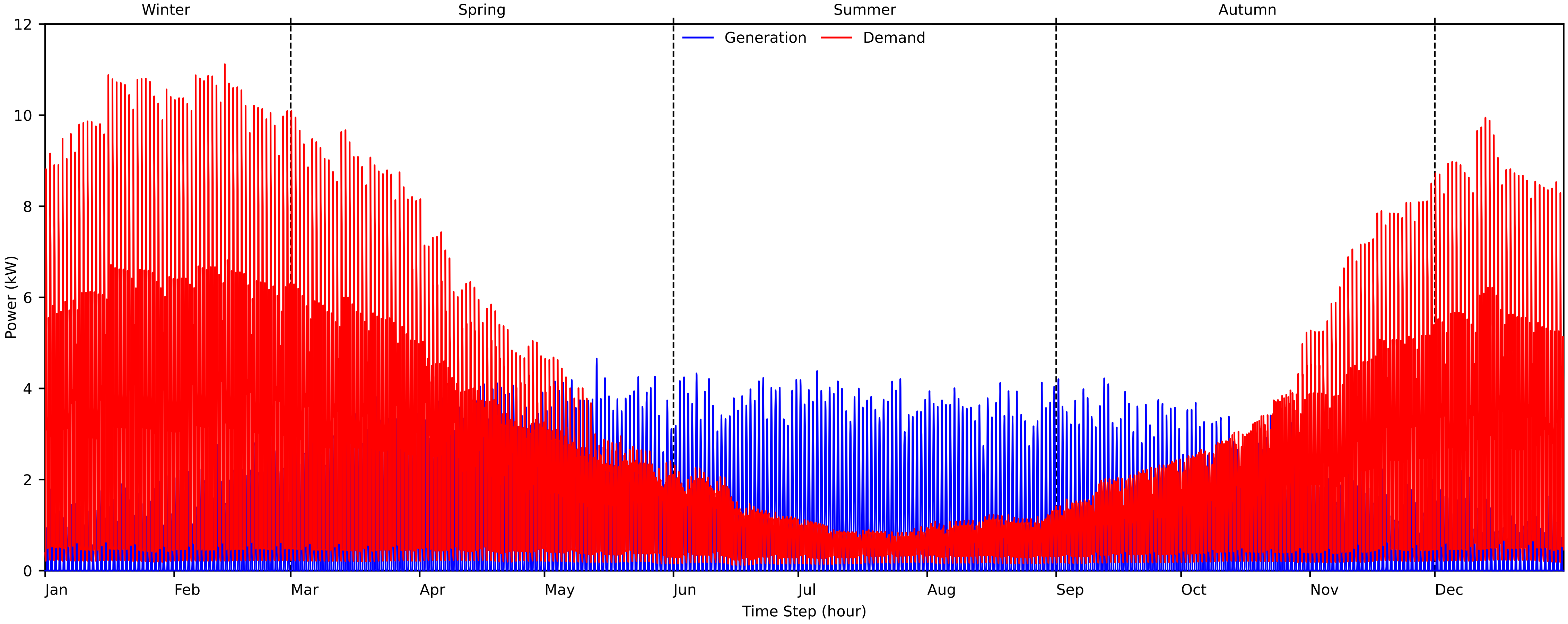
Storage Sizing

Long-term storage requires low energy leakage, as leakage can cause energy deficit to the system.



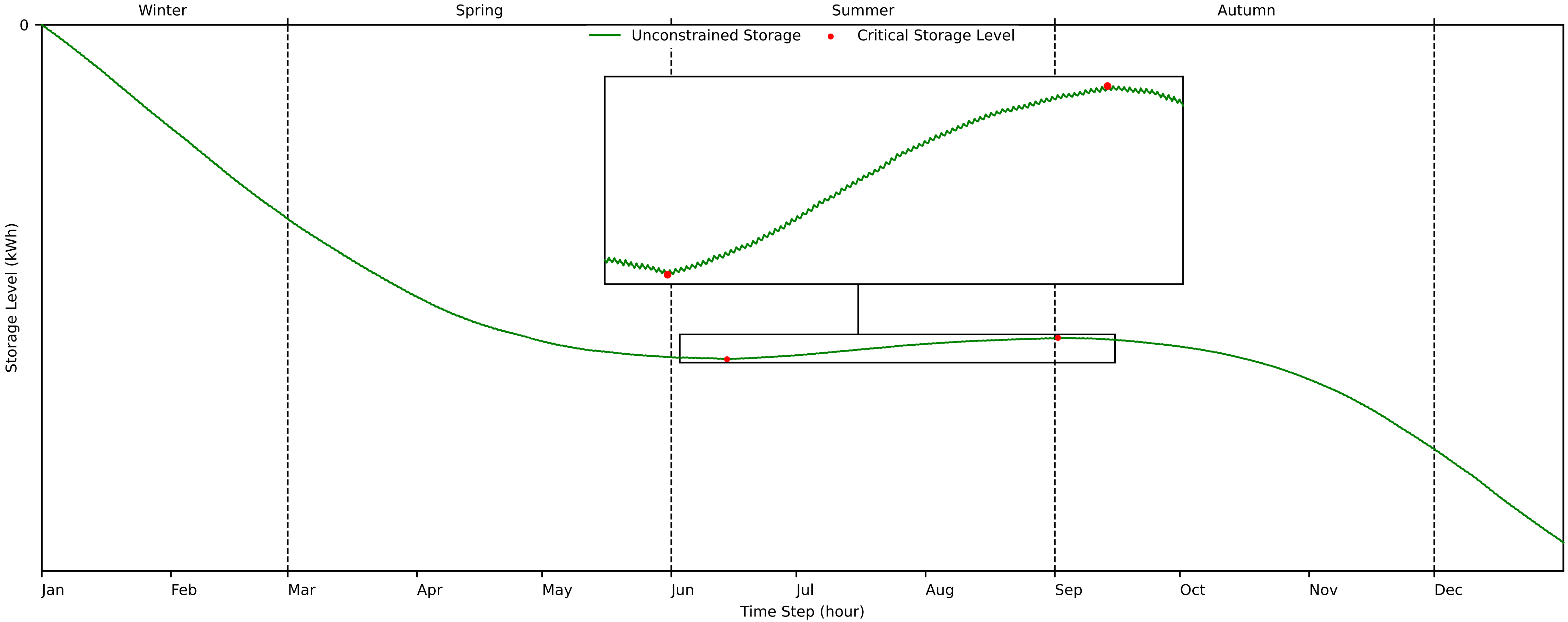
Storage Sizing

Case Study: Solar-battery home near Oxford.



Storage Sizing

When the storage is decumulating energy, size according to the largest cumulative charge.



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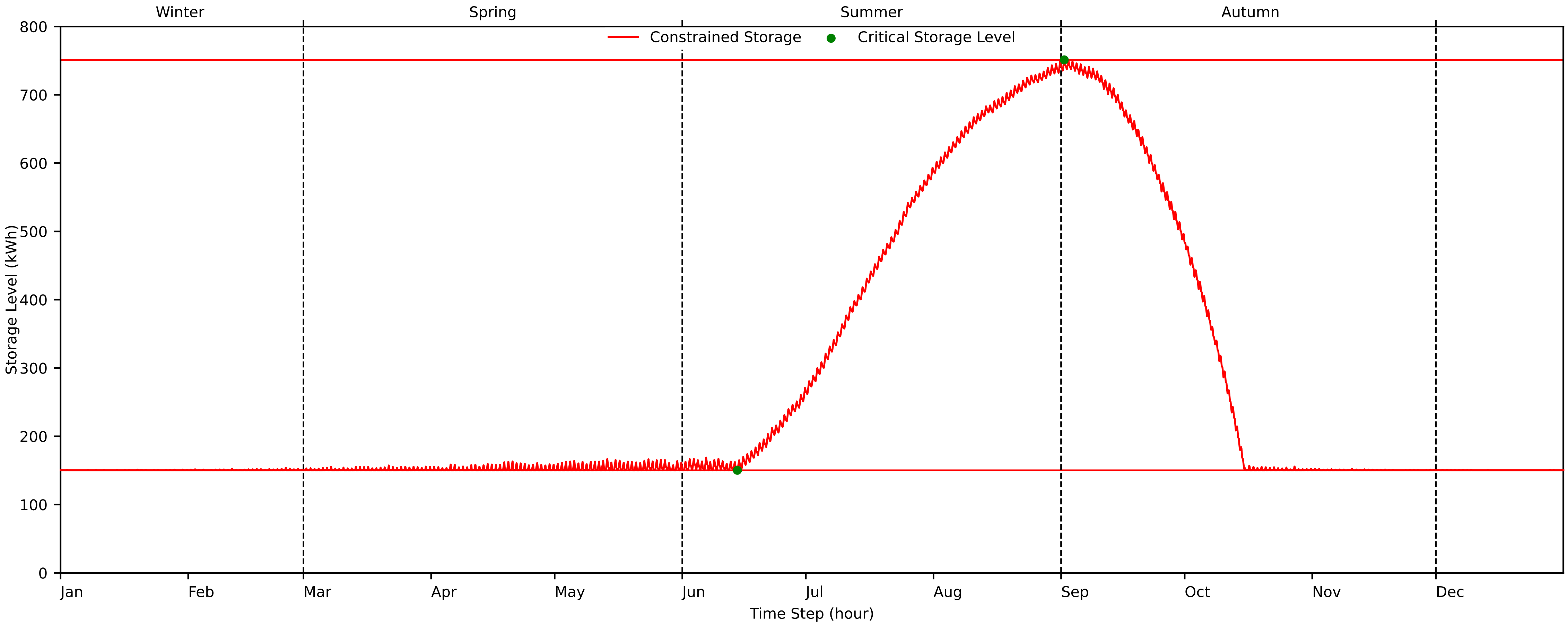
Long-term storage requires incredible amount of capacity (e.g. 600 kWh for a solar-battery home near Oxford).



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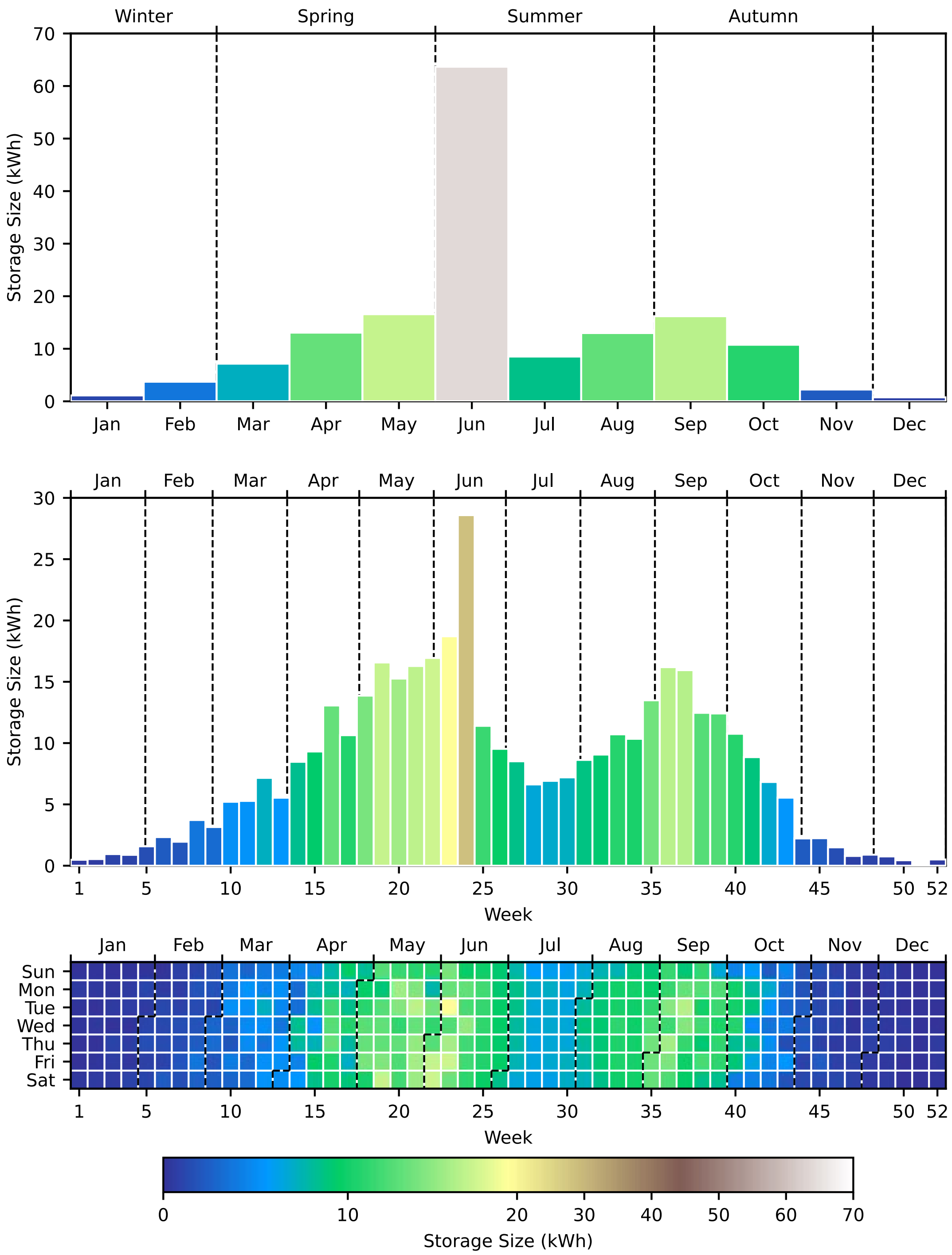
Storage Sizing

For solar-storage system in northern temperate climate, summer and winter require smaller storage, while spring and autumn require larger storage.

Summer has low demand, which do not need large storage, while winter has low generation, which cannot charge large storage.

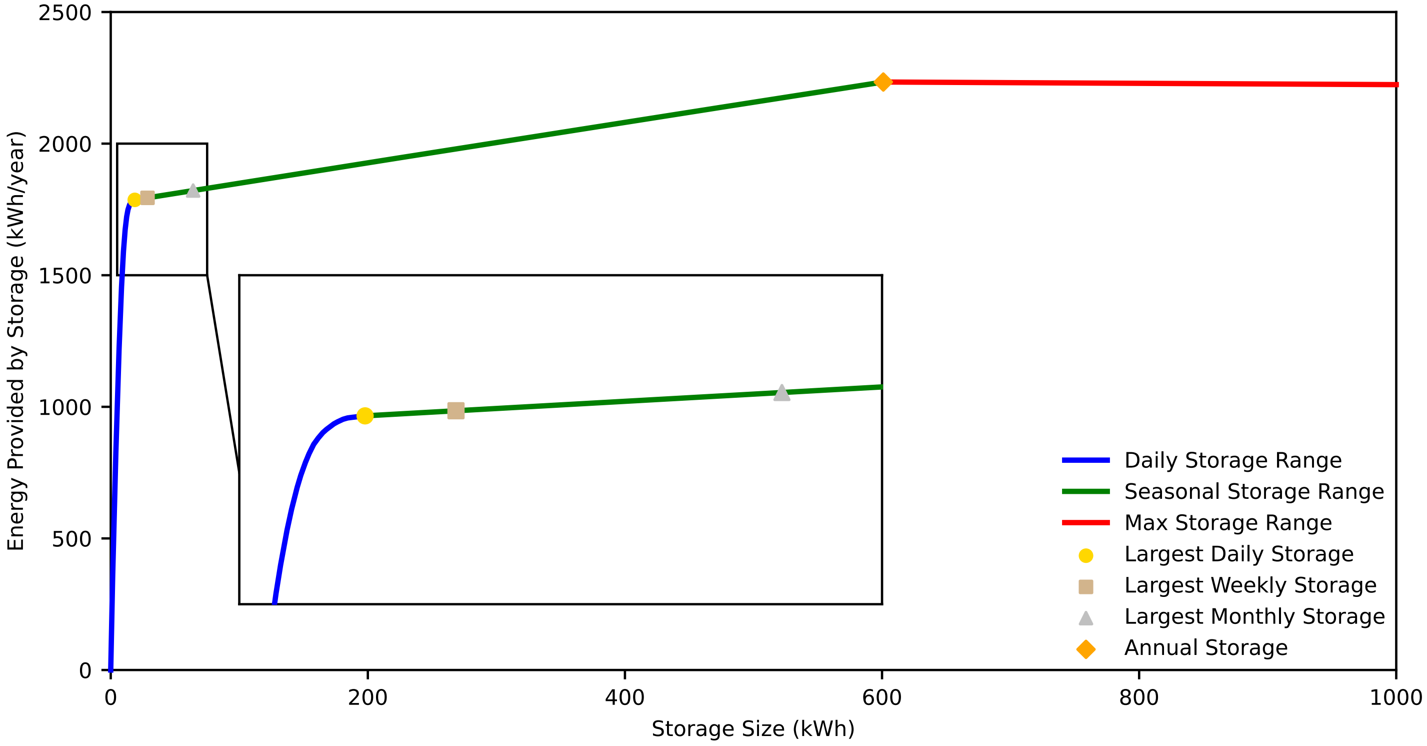
Spring and autumn have both high demand and high generation, giving generation to charge the storage, and demand for storage to discharge.

High demand and generation require larger storage, while either low demand or low generation will result in smaller storage requirement.



Storage Sizing

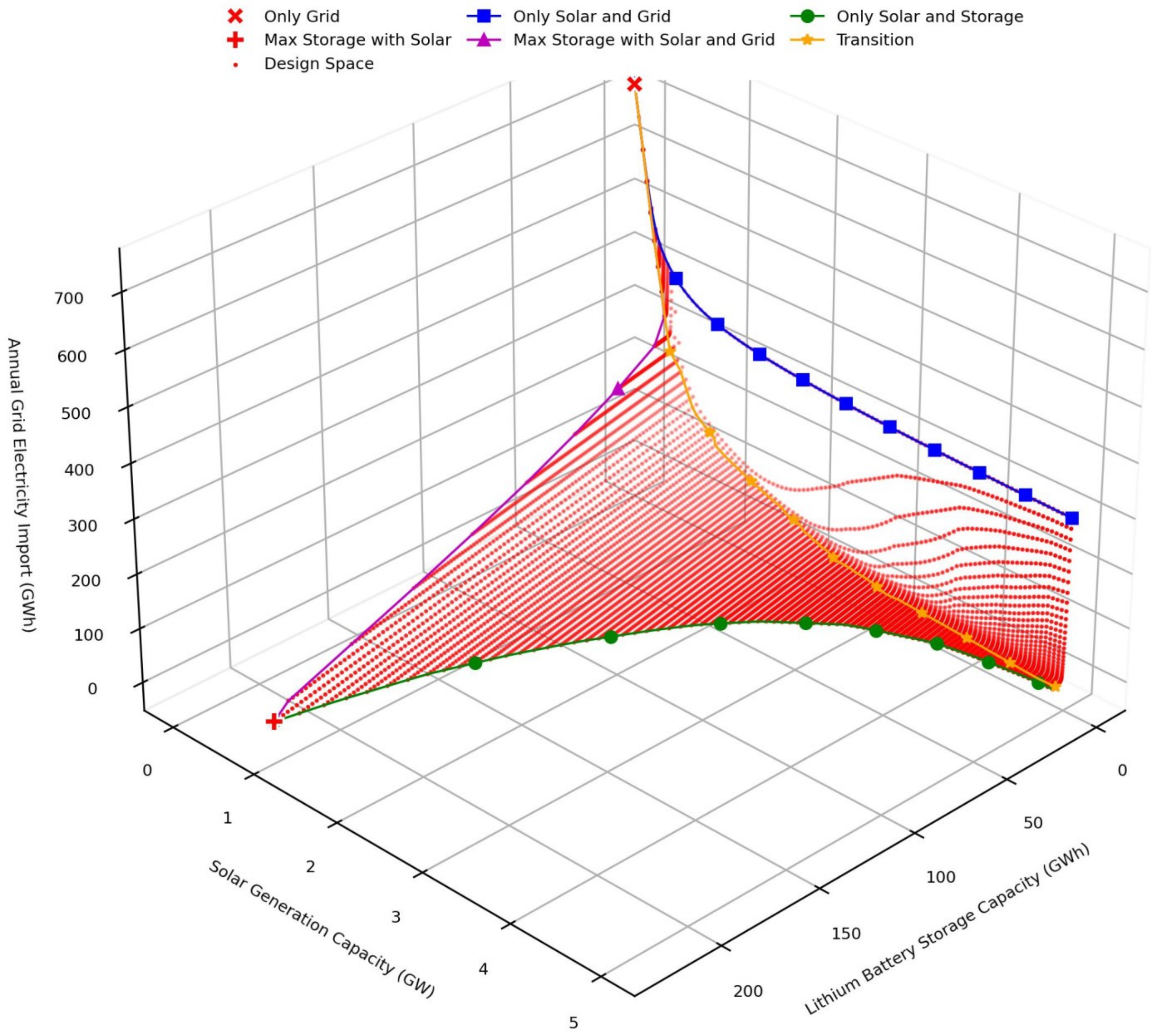
Increasing storage size has a diminishing return on the additional storage energy provided. The diminishing return thresholds are defined by the largest daily design and the annual design.



In this case study on a solar-battery home near Oxford, the largest daily design only requires 3% the storage size of annual design, but provides 80% of the energy of annual design.

Storage Sizing

Using the max storage size to define the size search range, and then systematically iterate through the search range.



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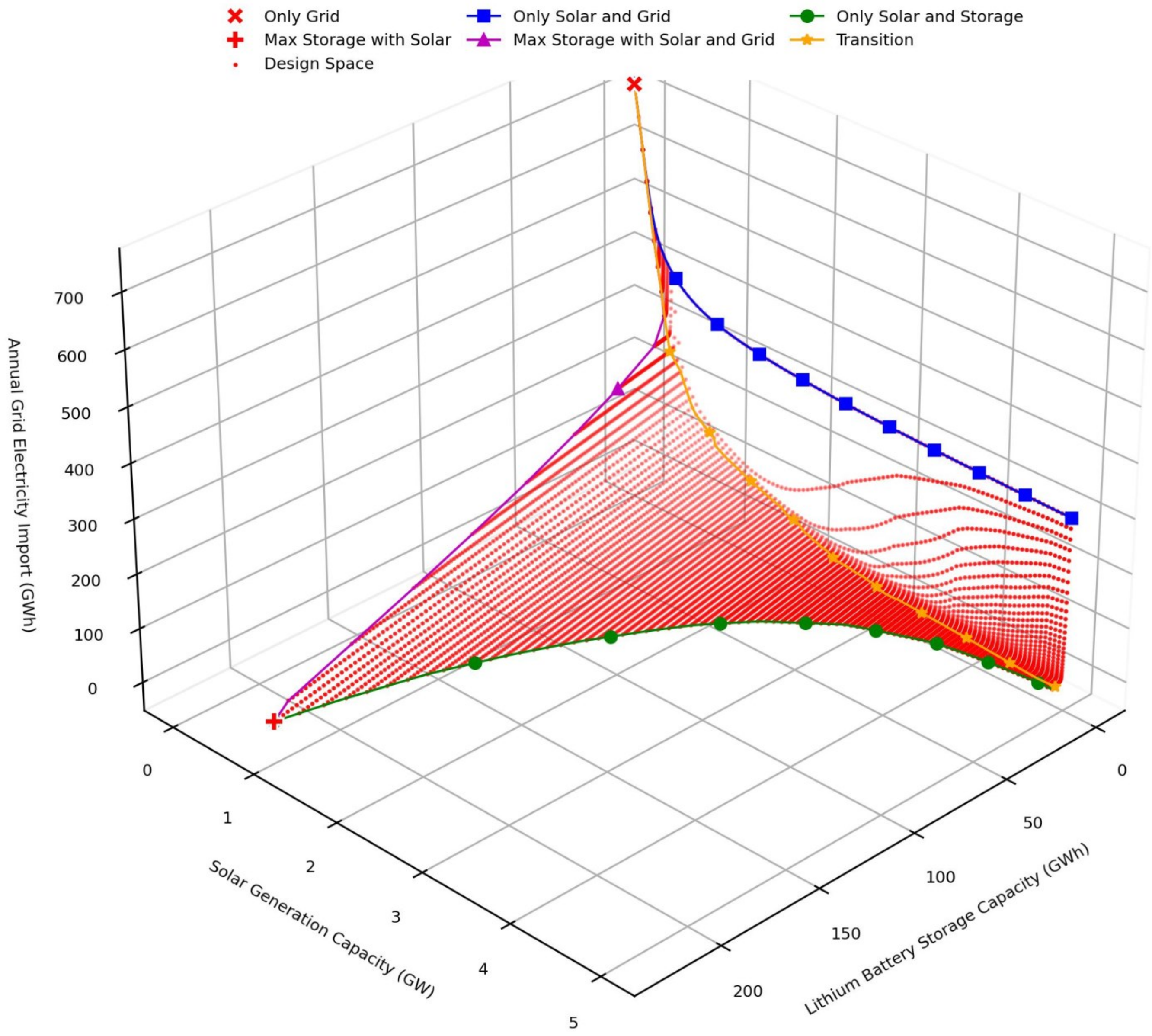

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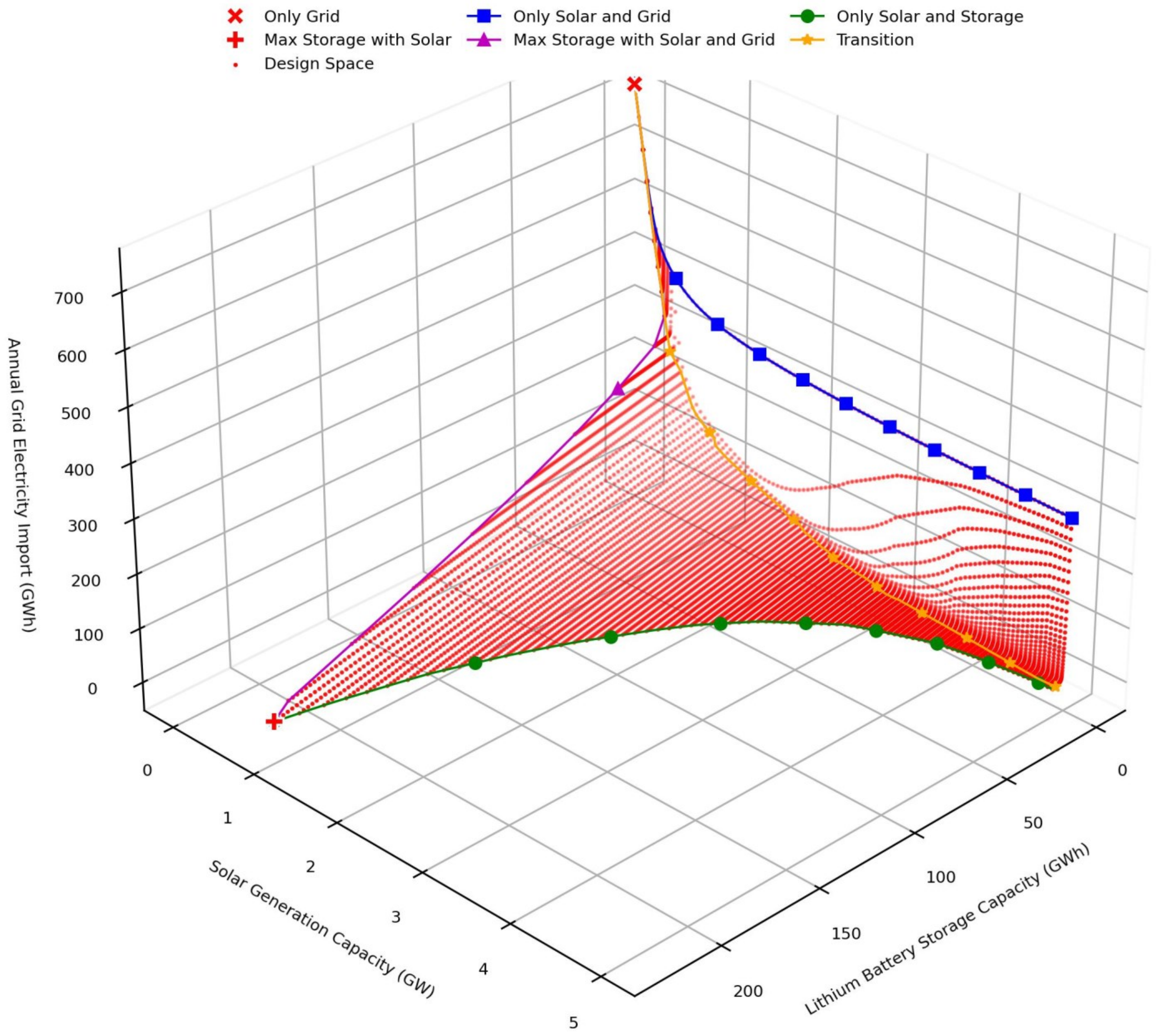
Max Storage with Solar and Grid: maximum storage capacity increases as solar capacity increases, due to more surplus generation.



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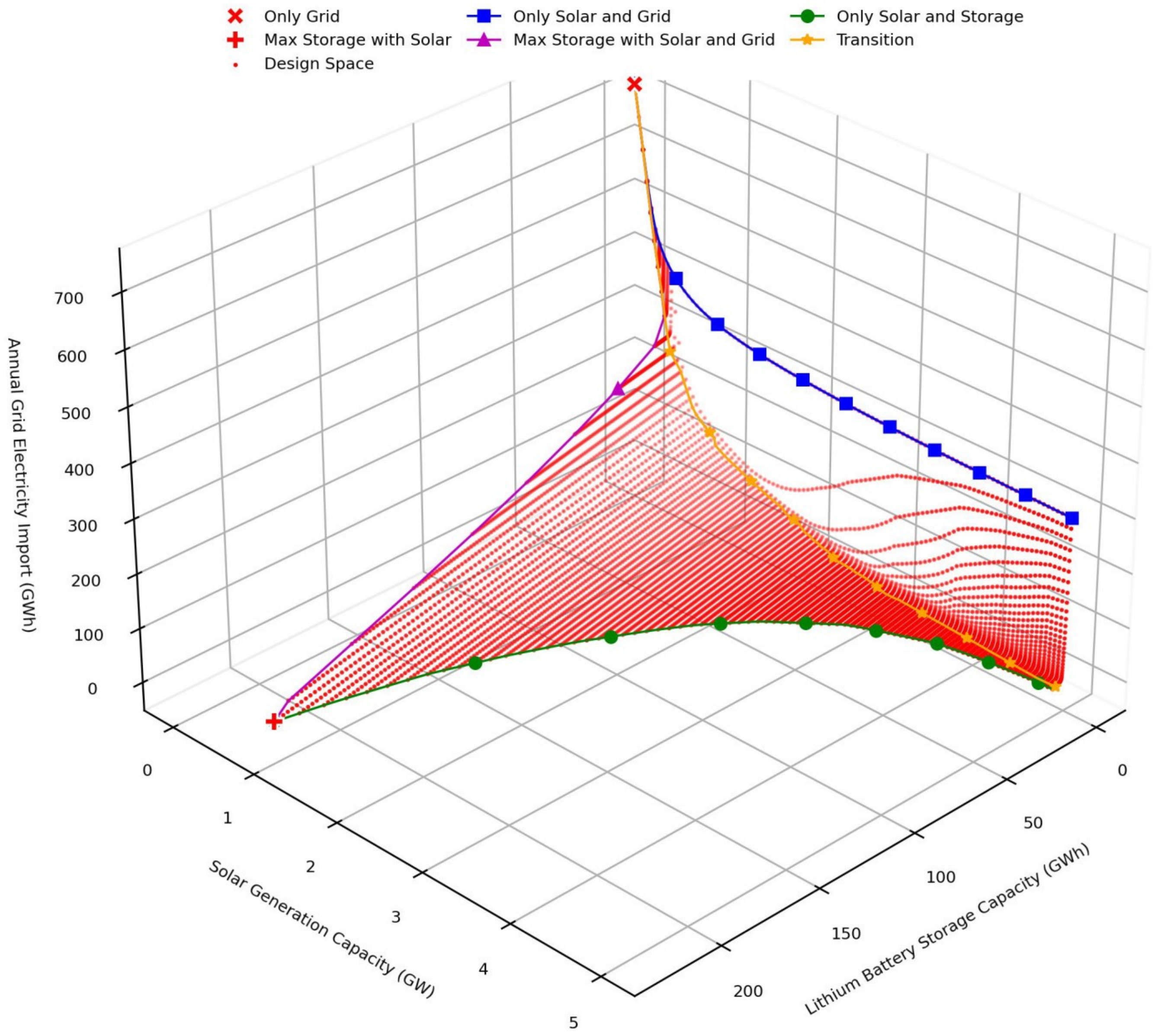
Max Storage with Solar: the first solar and storage capacities that can meet the demand without grid electricity. The storage requirement is the largest.



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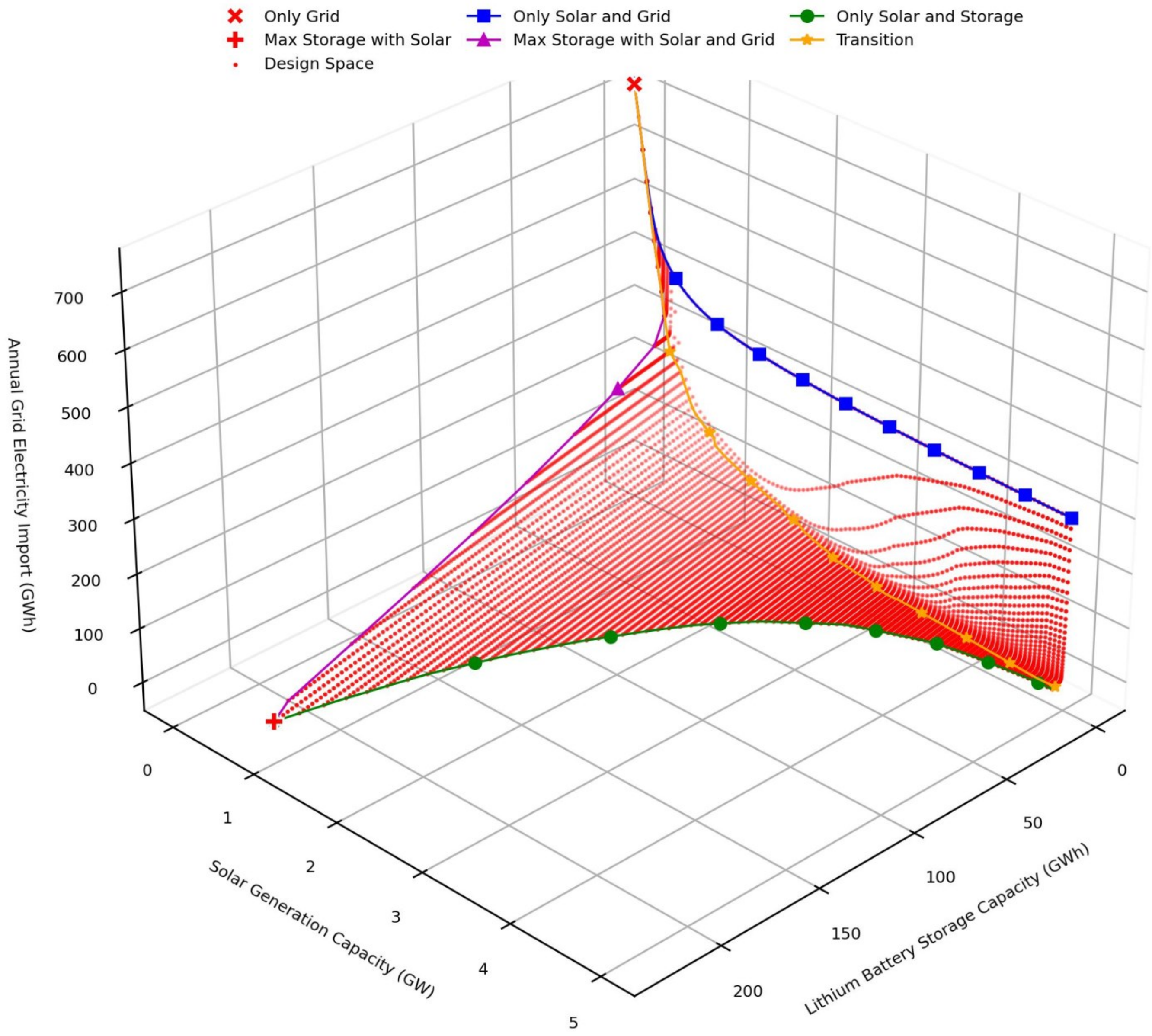
Only Solar and Storage: solar and storage capacities that can meet the demand without grid electricity. As solar capacity increases, the storage requirement decreases to an extent.



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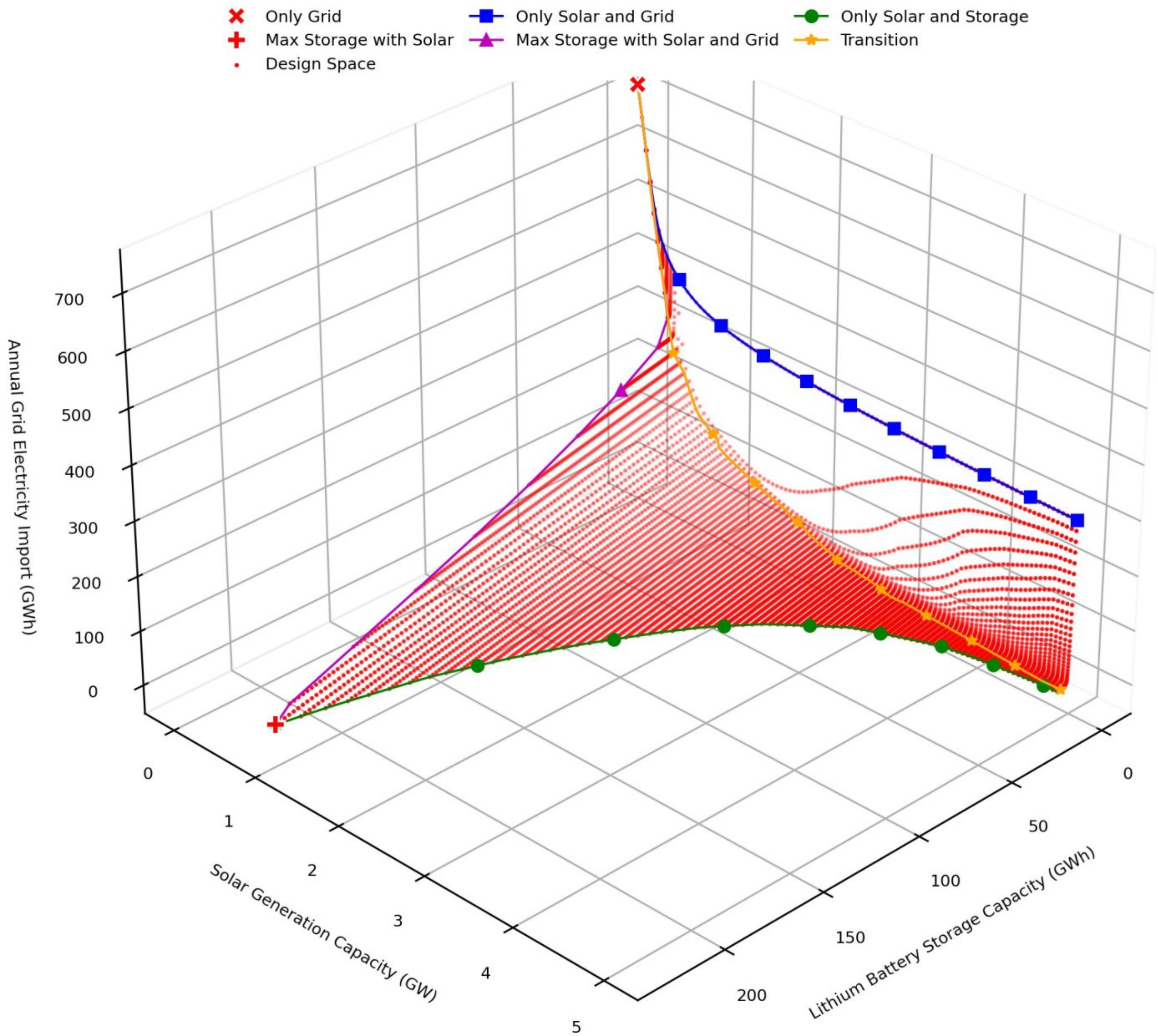
Only Grid: without solar or storage, demand solely relies on the grid, resulting in the highest grid electricity requirement.



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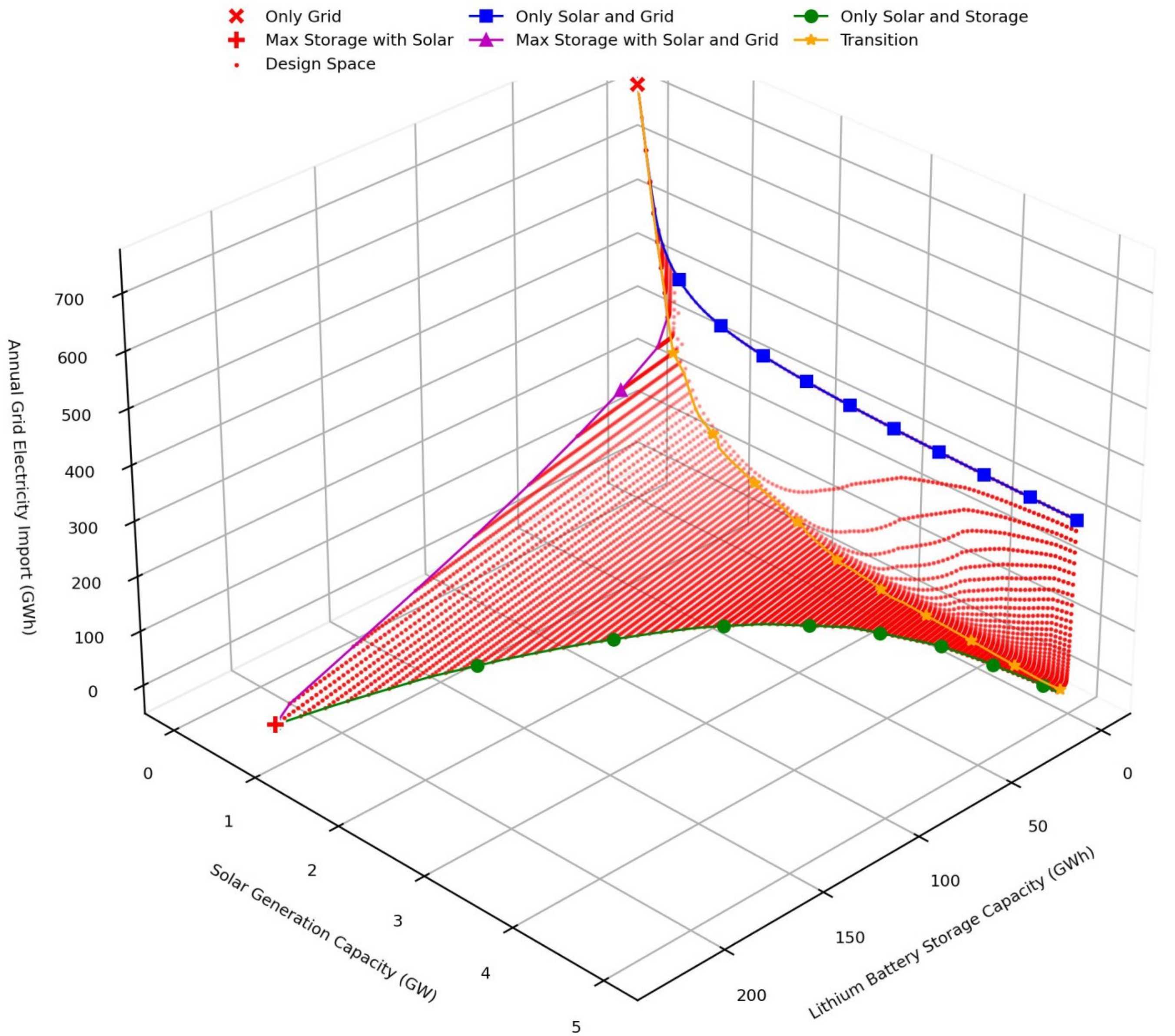
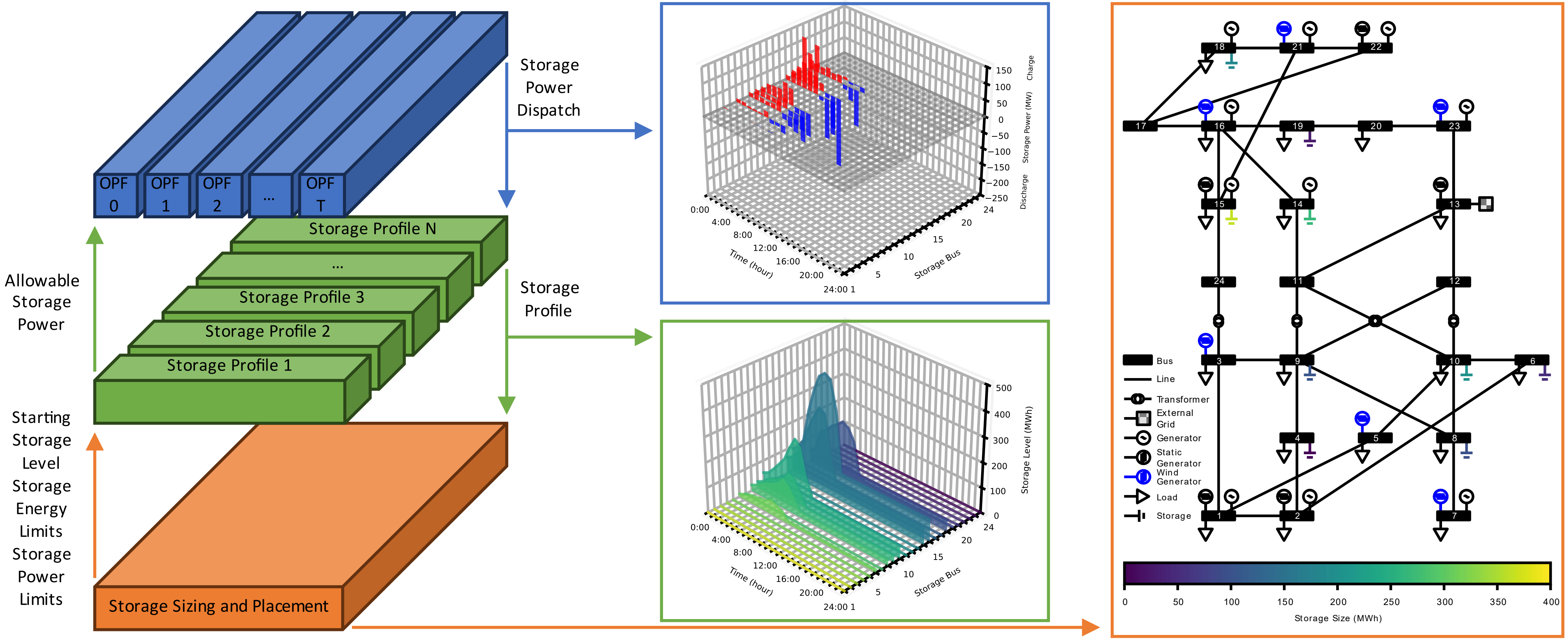


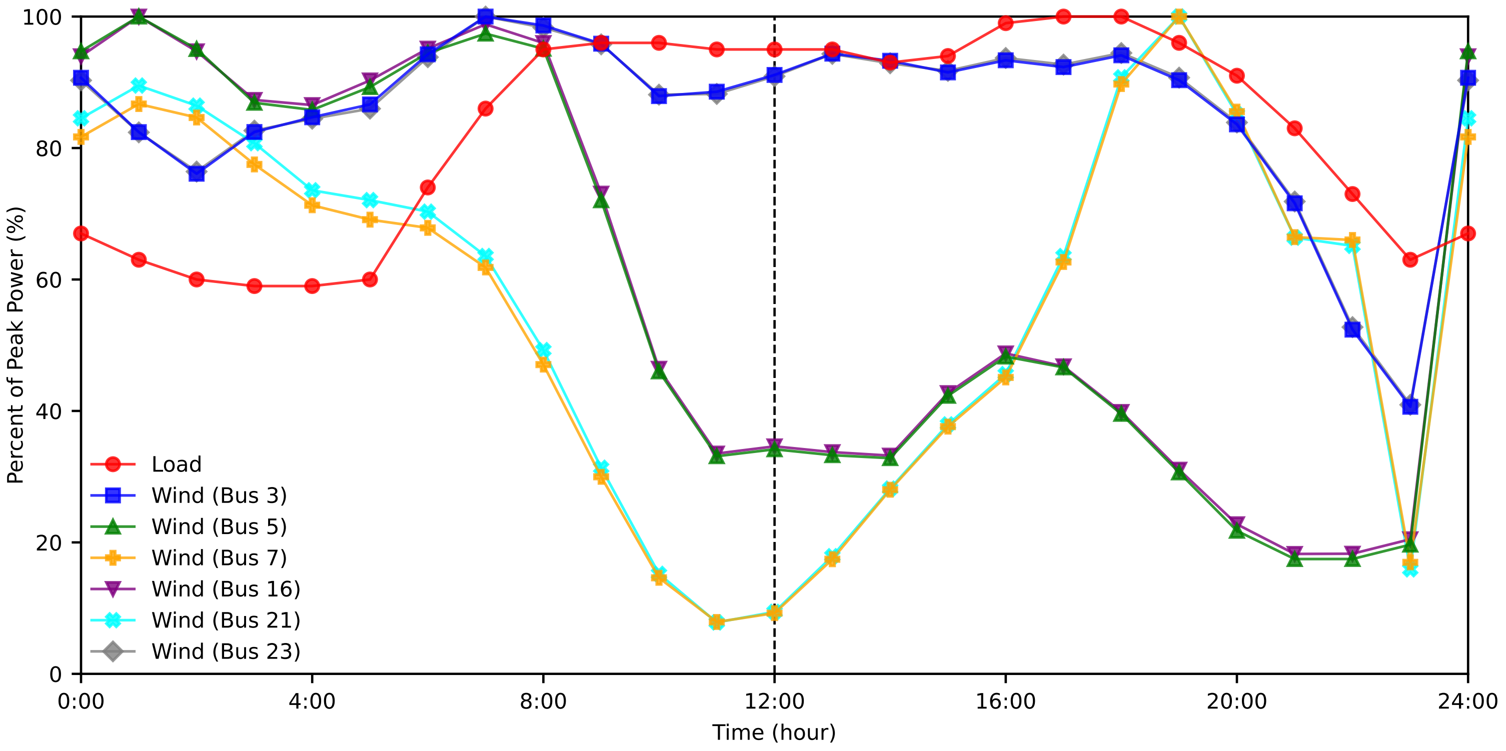
Storage Sizing and Placement

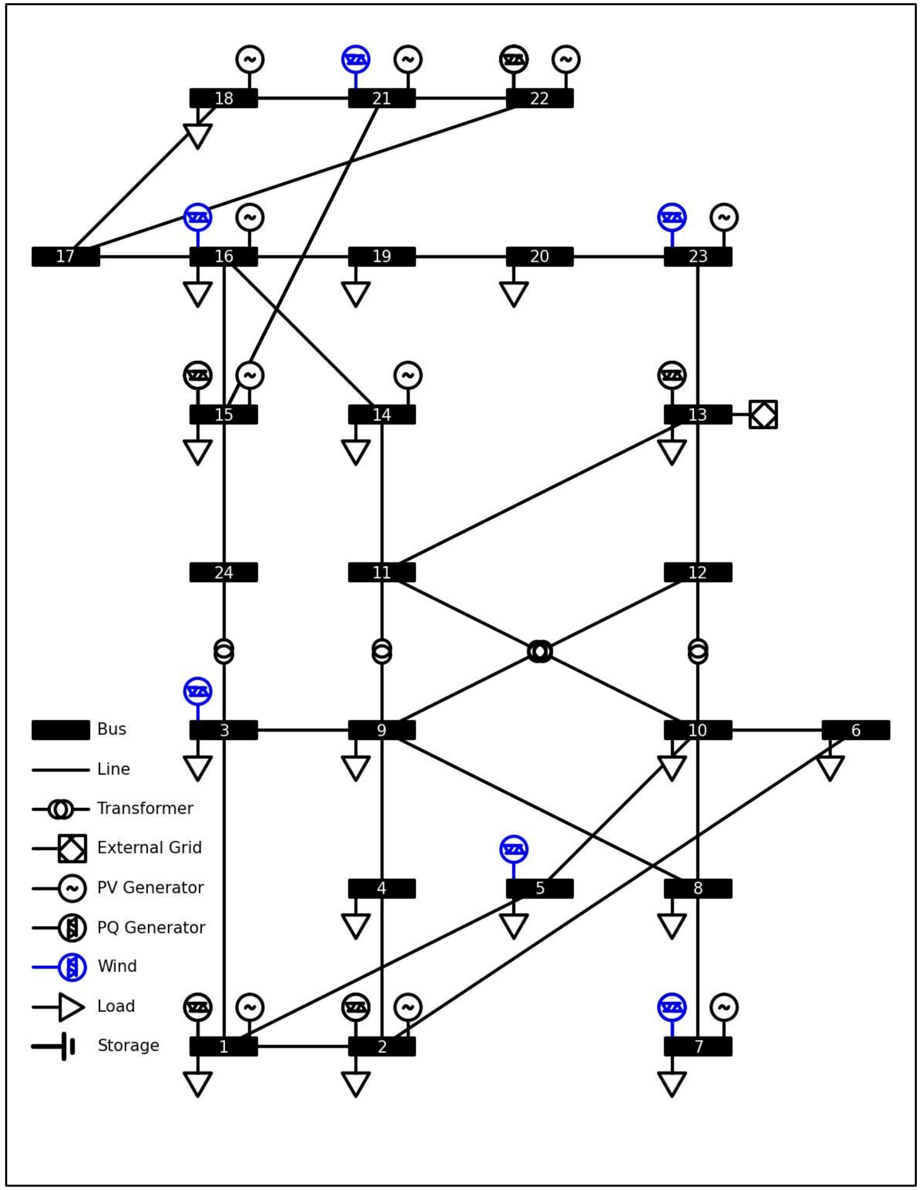
Use OPF (Optimal Power Flow) to decide the storage power dispatch at each site, then size storage at each site to obtain sizing and placement.



Storage Sizing and Placement

Case Study: IEEE Reliability Test System





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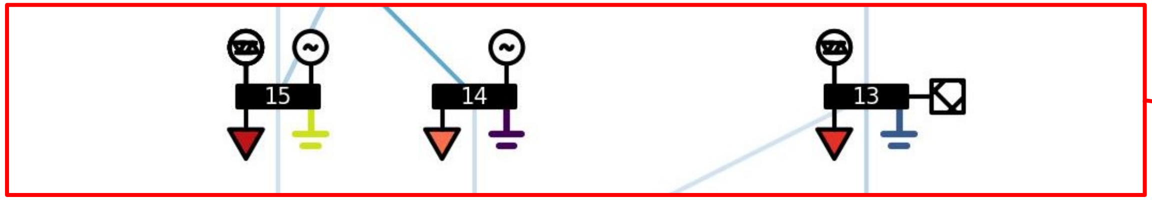
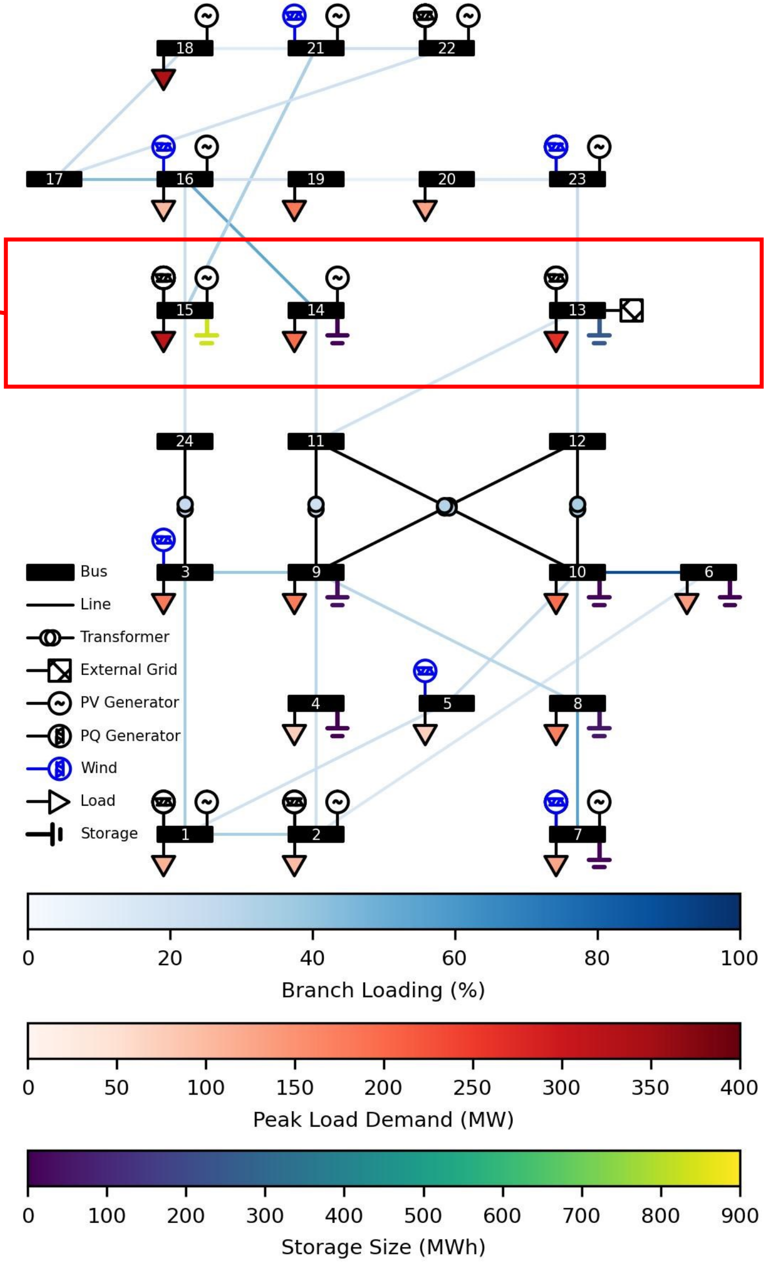


Larger storage units are placed near sites with high demand and high generation.



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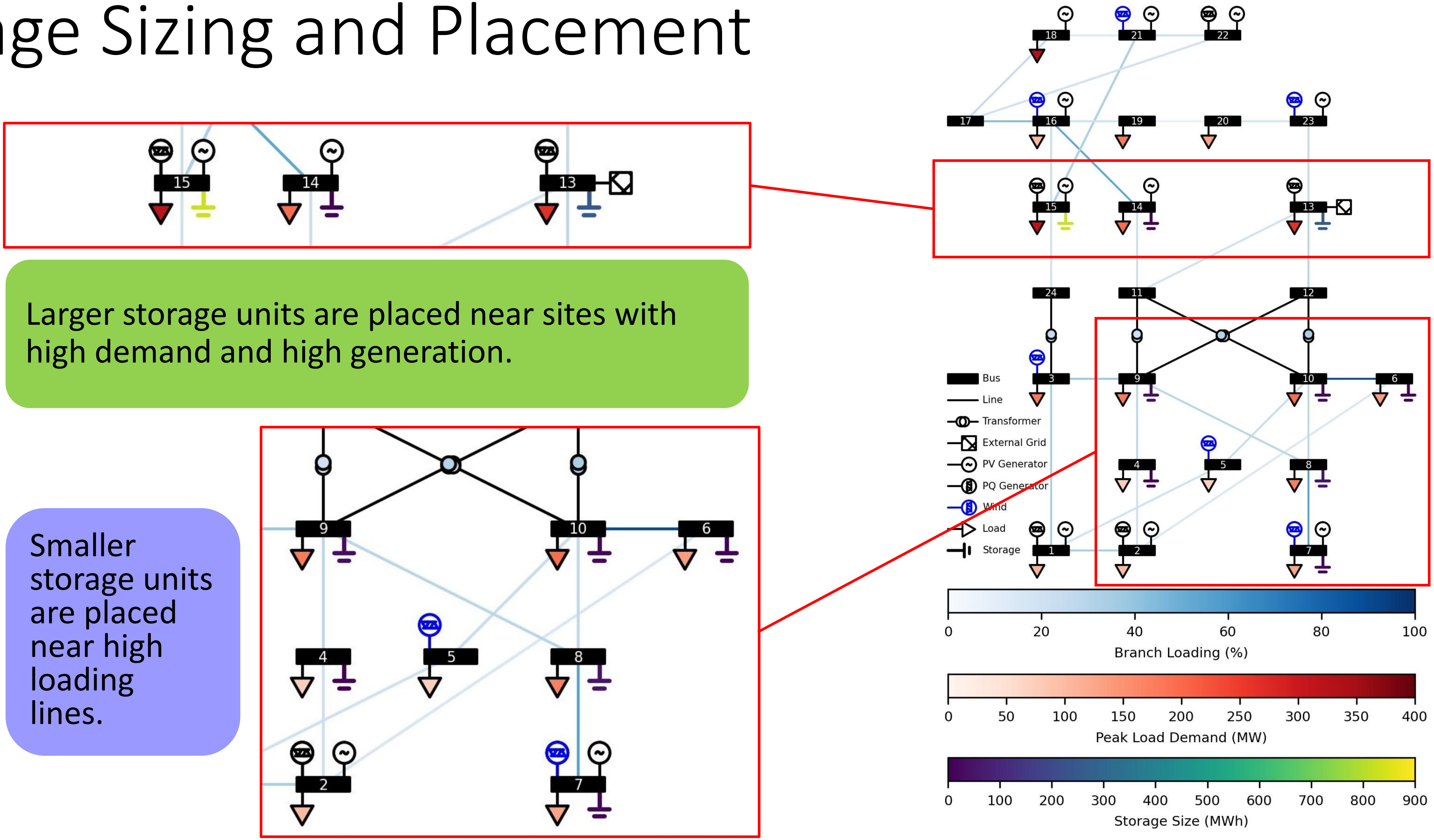


Larger storage units are placed near sites with high demand and high generation.

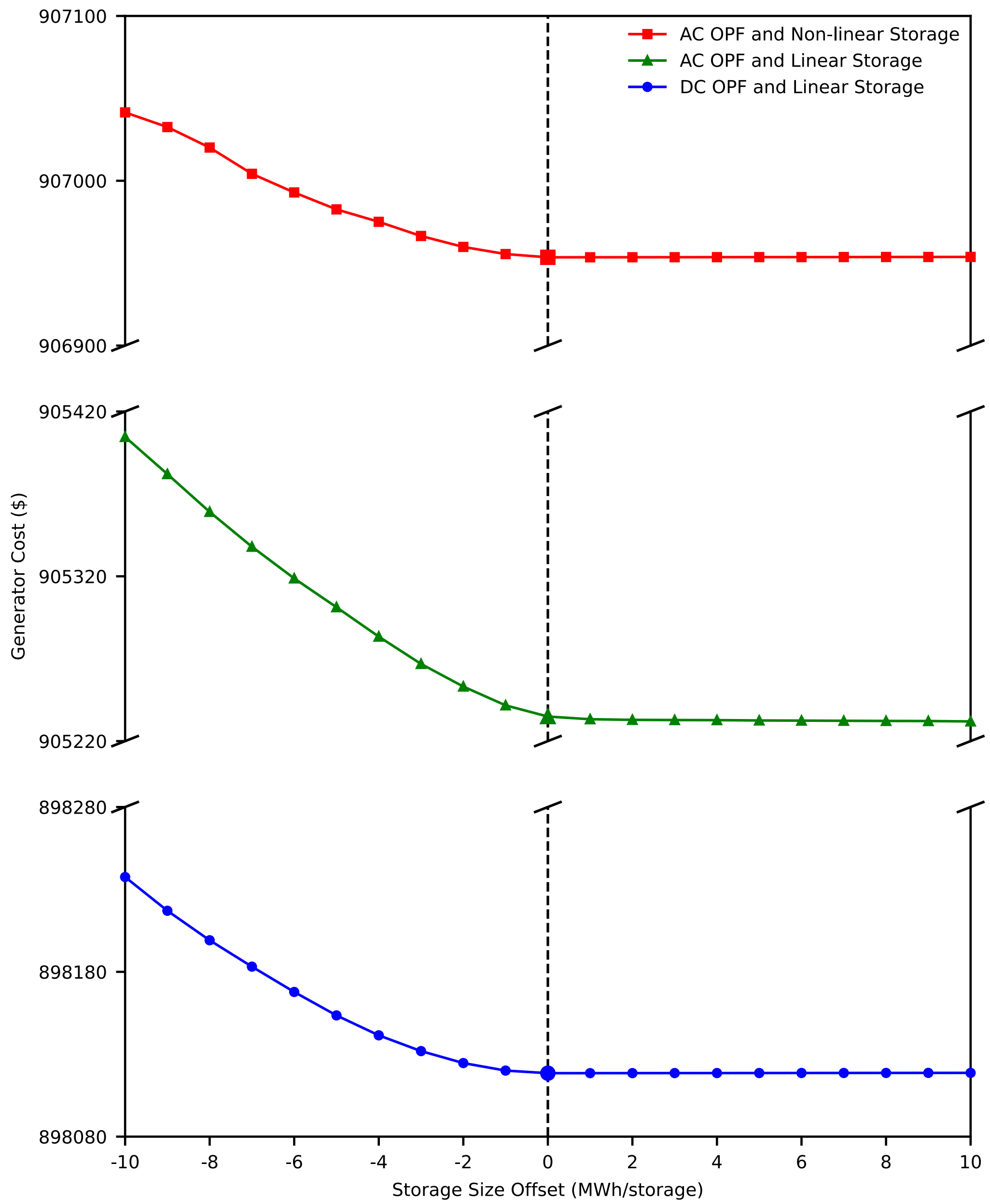
Smaller storage units are placed near high loading lines.

Storage Sizing and Placement

The method yields optimal solution when coupled with convex models (DC OPF, linear storage model).

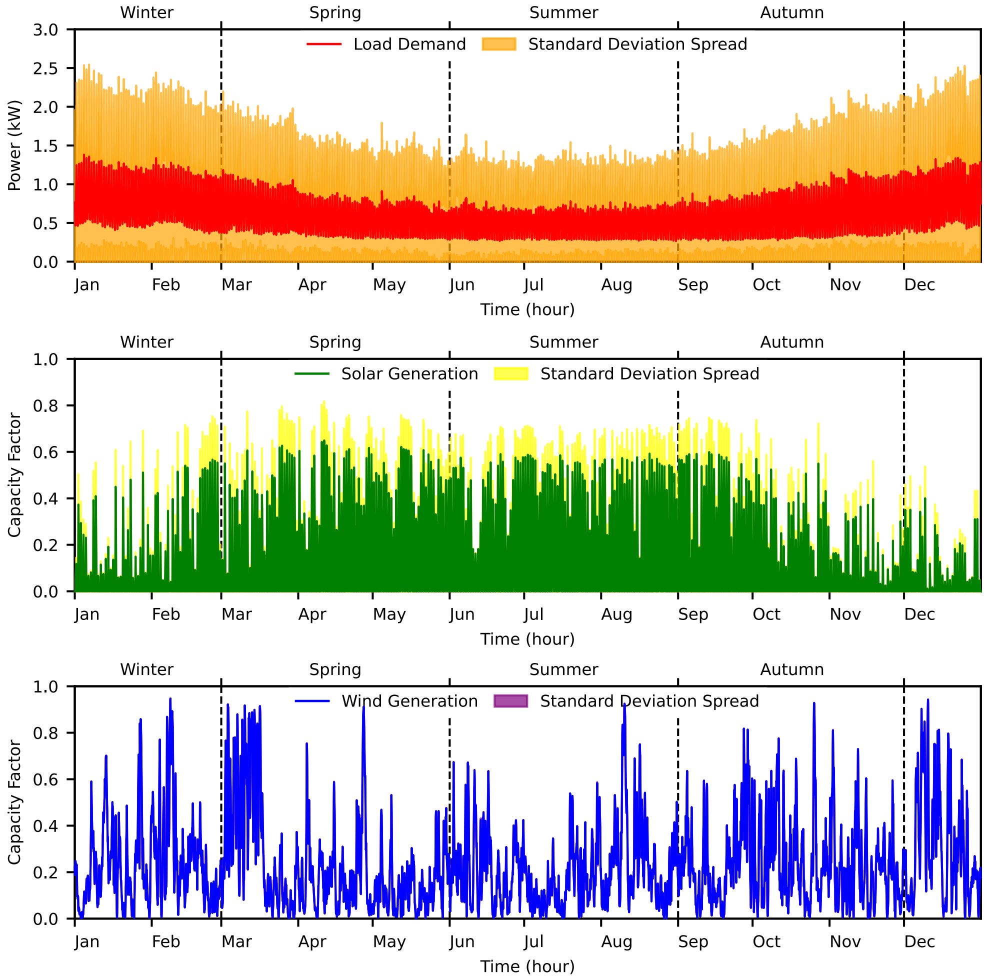
The offset shows adding storage capacity to the solution does not further reduce generator cost, while removing storage capacity from the solution increases generator cost.

The method can yield near-optimal solution when coupled with non-convex models (AC OPF, non-linear storage model).



Storage Sizing and Placement

Case Study: Carbon-neutral village



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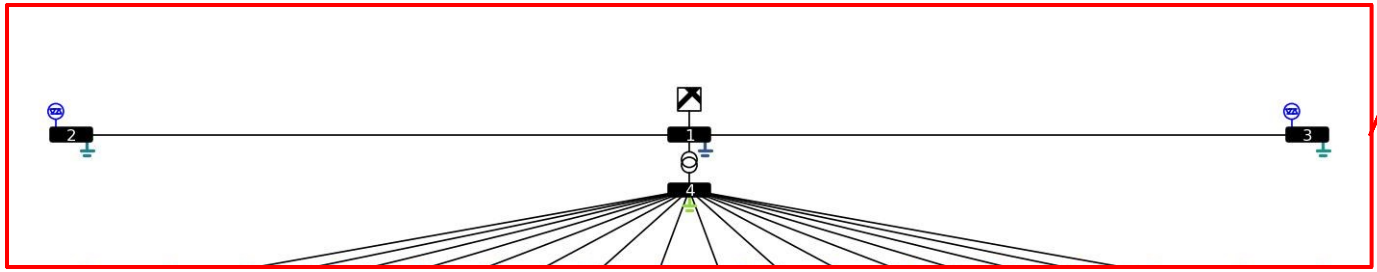
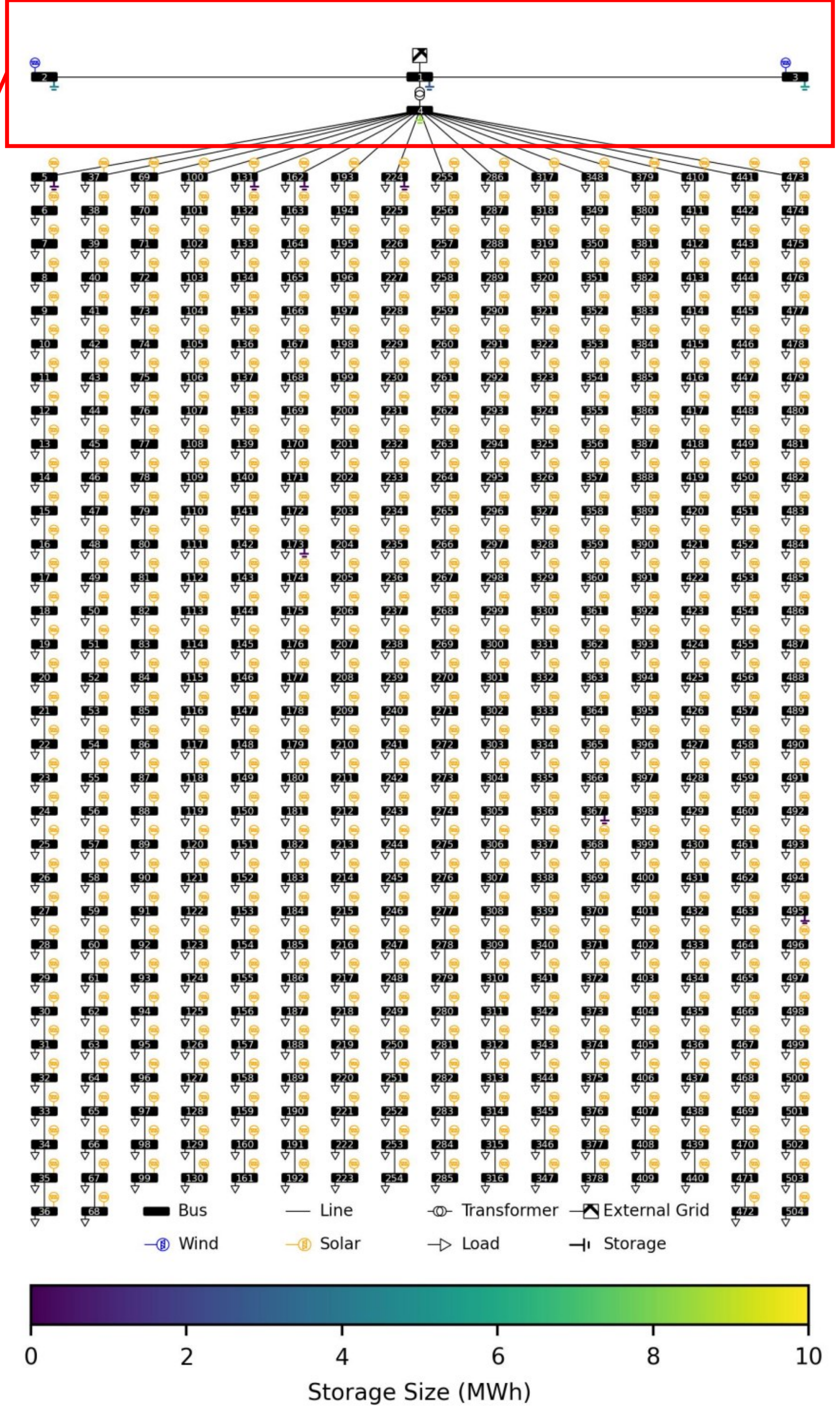


Large storage units are placed near the two wind turbines, and choke points before and after the transformer where high power flow occurs.



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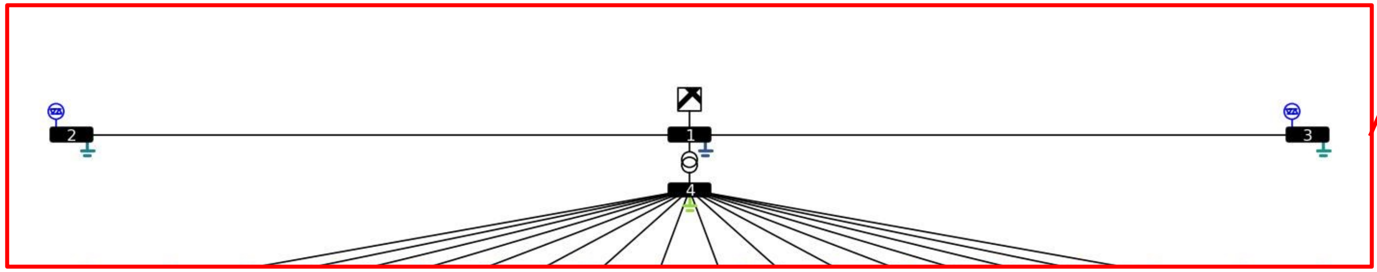

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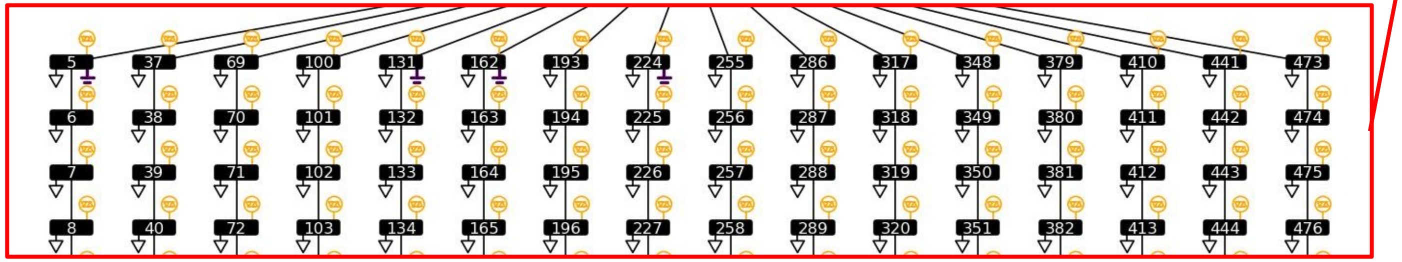
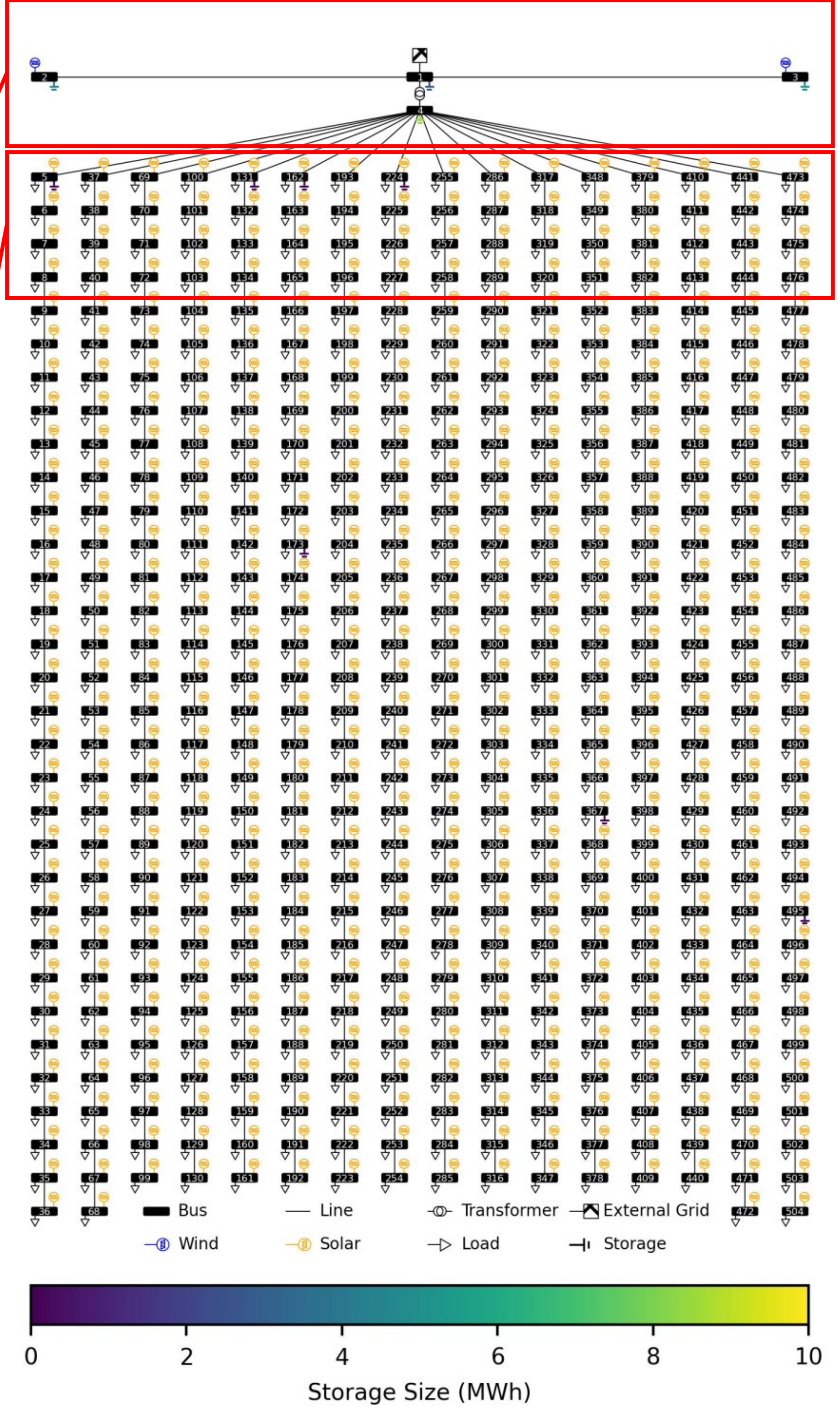


Small storage units are placed near prosumers with both high solar generation and electricity demand.



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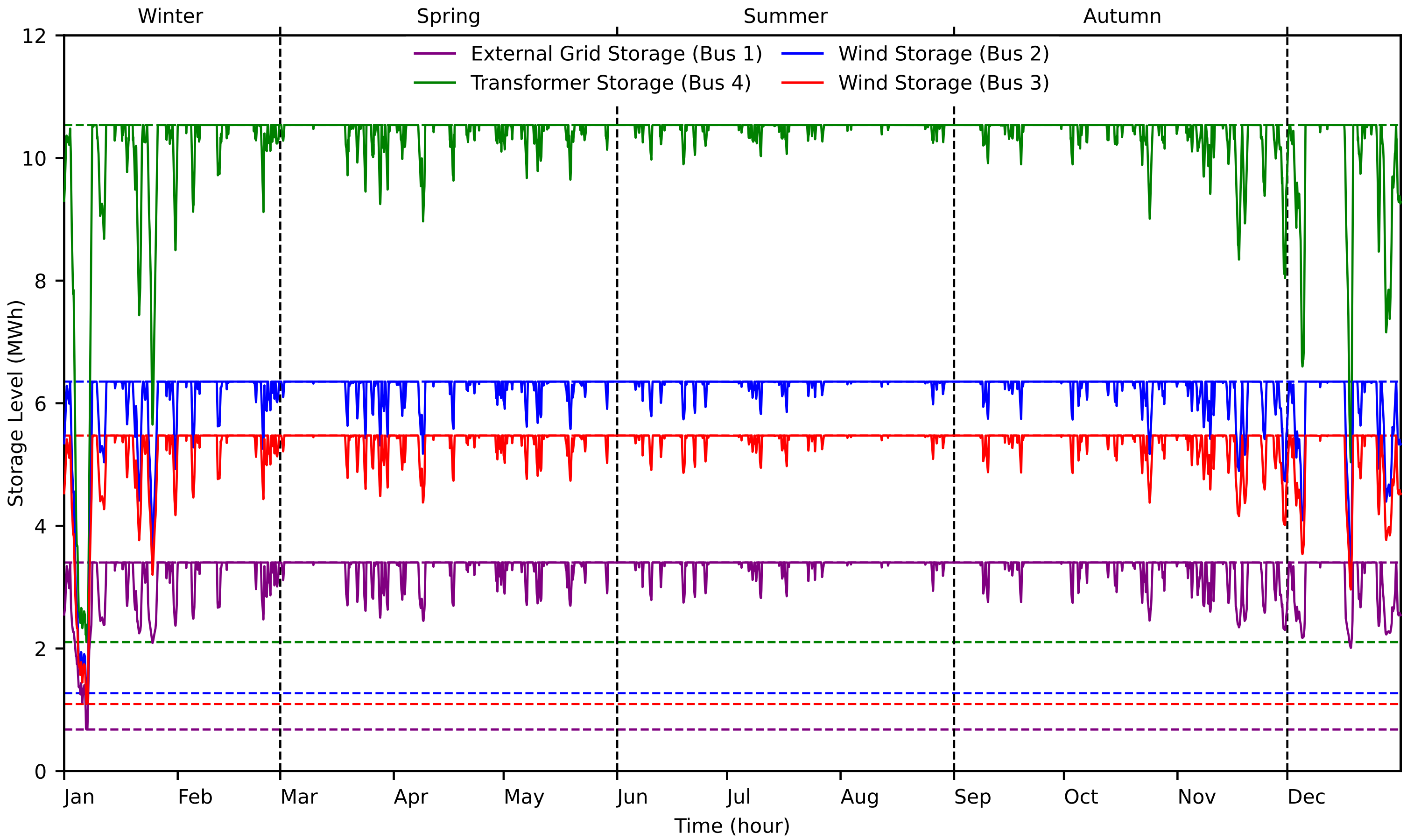
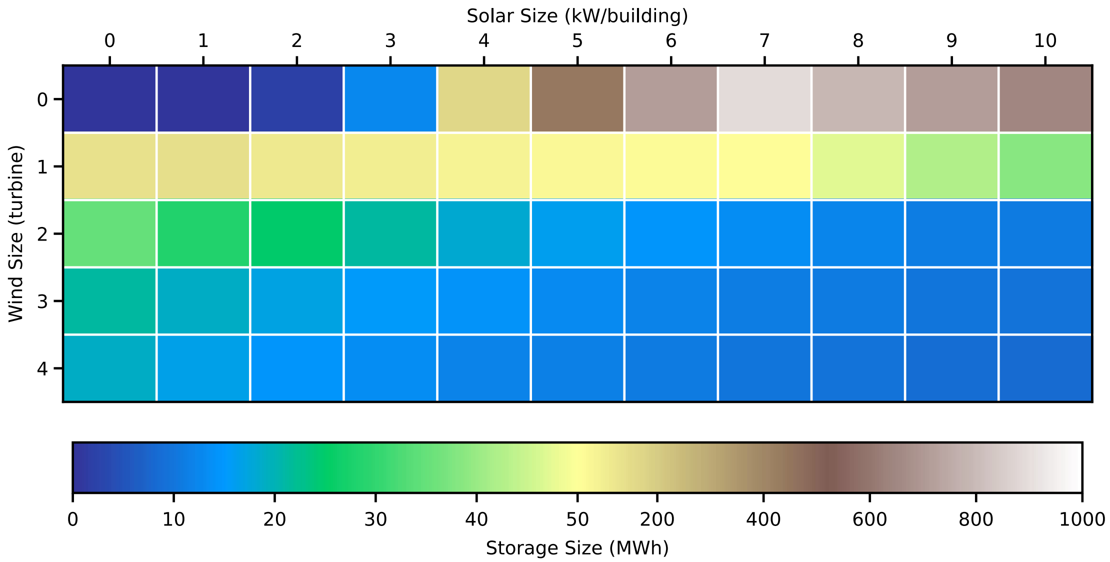


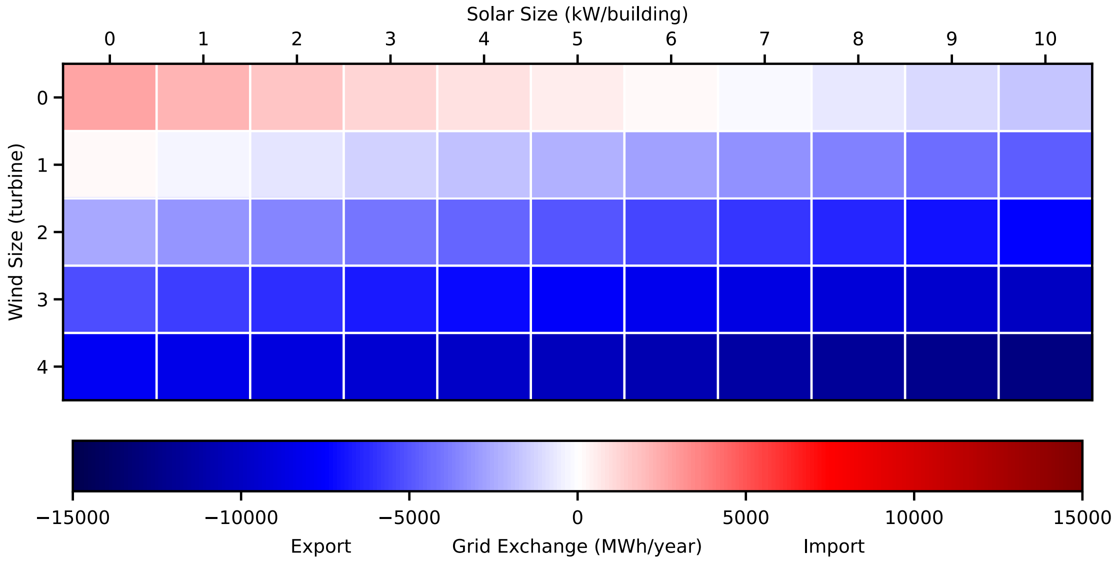
Low solar generation during winter means storage is more susceptible to variation in demand and wind generation, thus the large charge and discharge during winter.

Storage Sizing and Placement

With no solar nor wind, there is no need for storage since it cannot be charged, while grid electricity import is the highest.

Adding renewable capacity will increase storage requirement and reduce electricity import from the grid.





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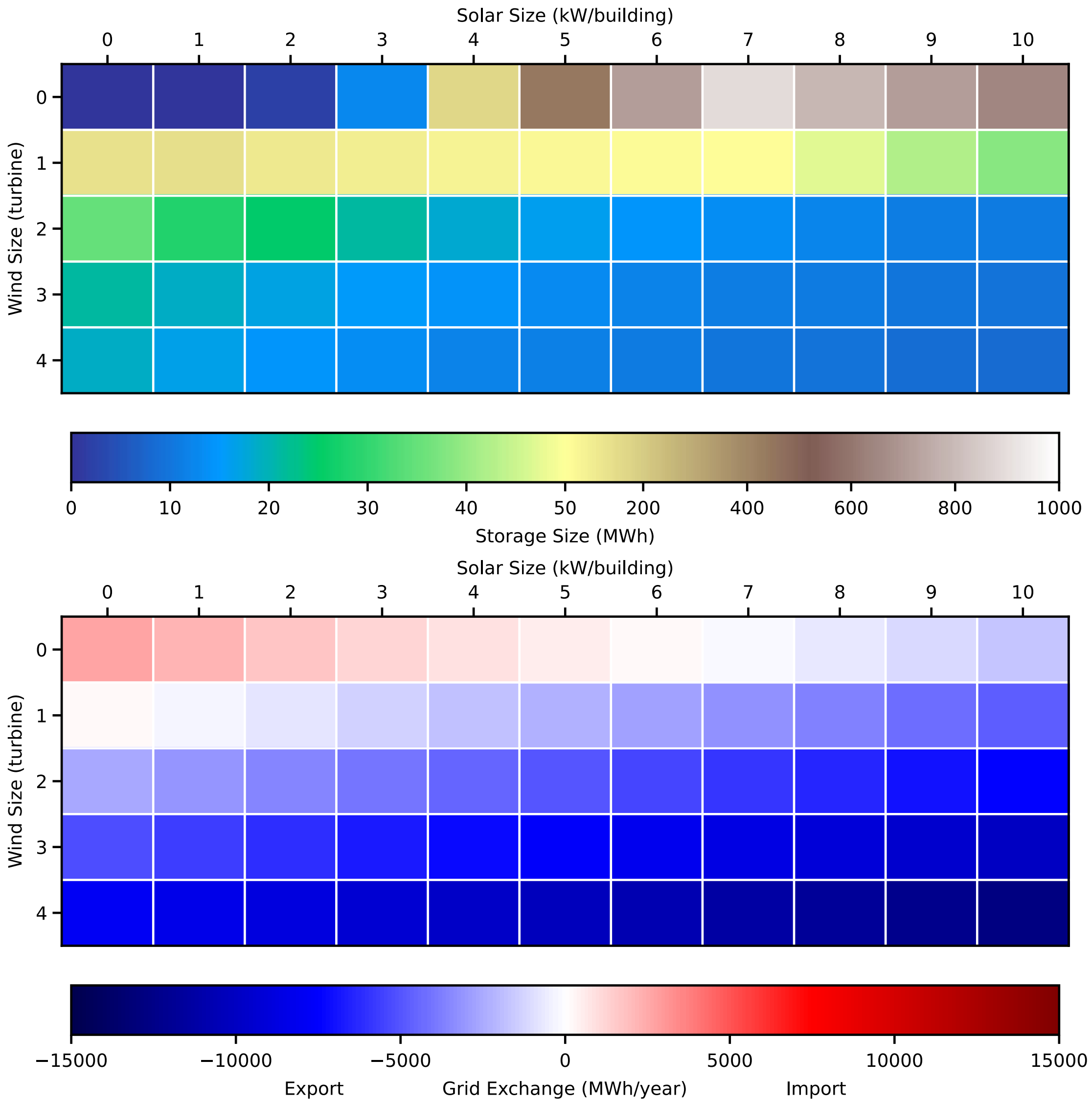

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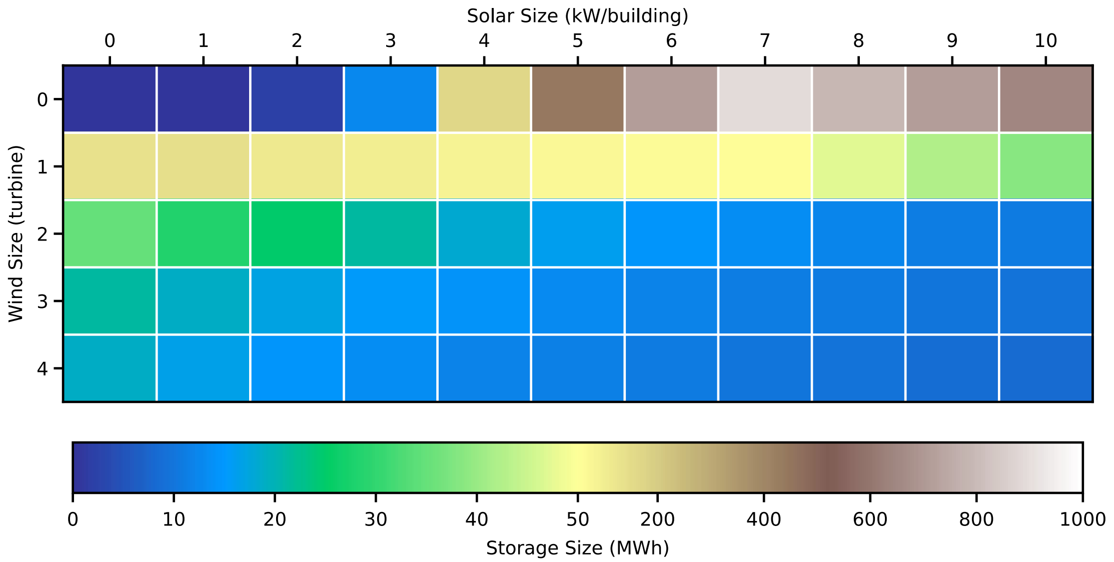
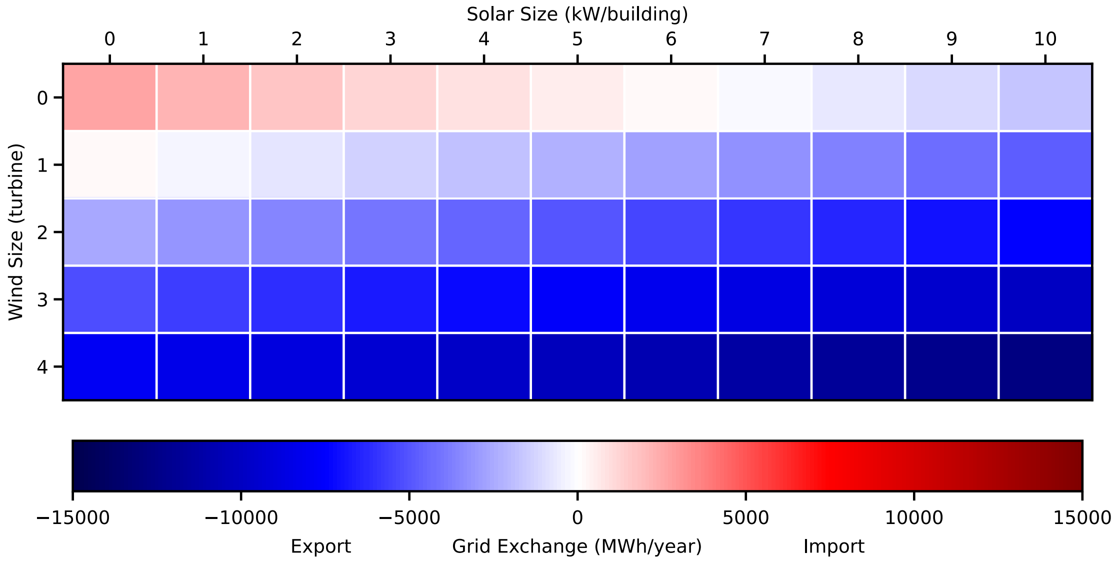
After which, continue adding renewable capacity will reduce storage requirement, and increase electricity export to the grid.

At max renewable capacity, there is still storage requirement, because some calm nights has no solar nor wind generation, which needs storage.





Key Takeaways

Storage should be sized according to the largest cumulative charge or discharge it can experience.

Long-term storage requires low energy leakage rate and capacity cost.

Storage units tend to be placed on sites with high generation, high demand, or near choke points with high power flow.

Where generation cannot fully support the system, adding generation can increase storage requirement. When generation is enough to support the system, adding generation will reduce storage requirement.

Additional Content

Han Kun Ren

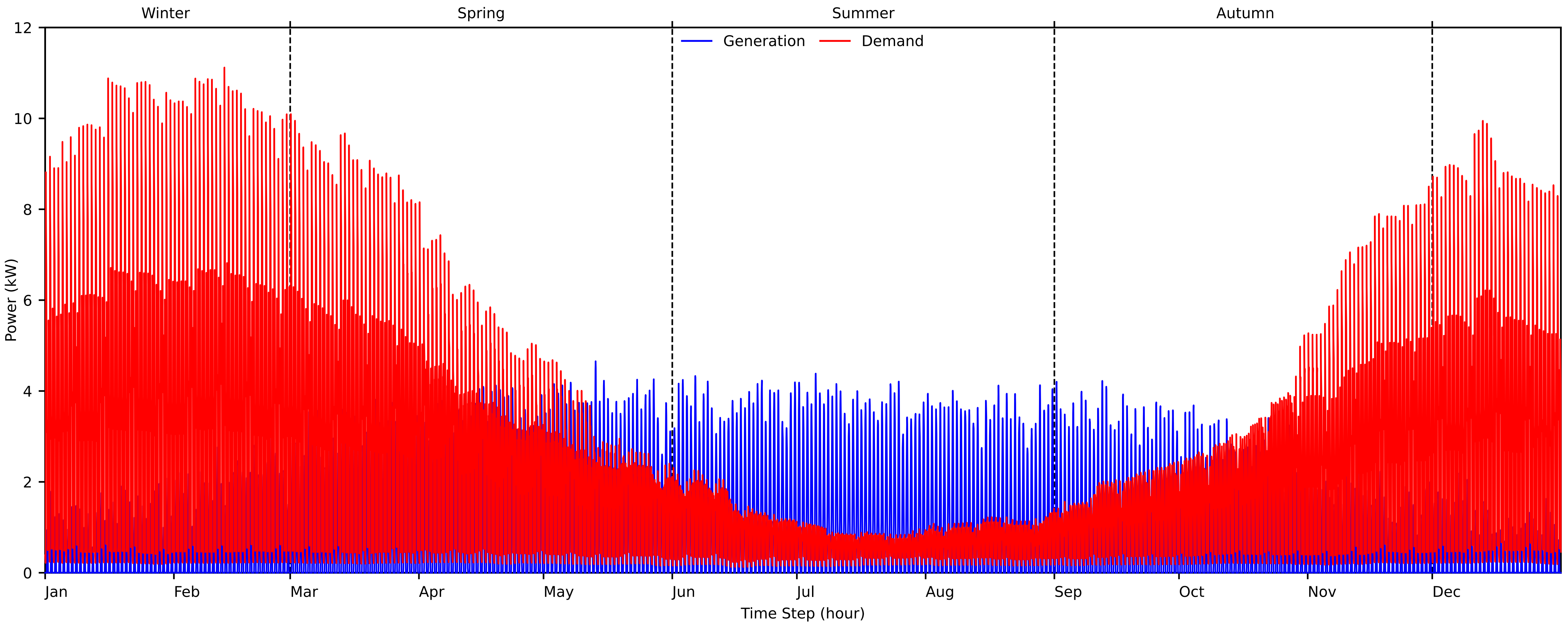
UNIVERSITY OF OXFORD

E-ei ENERGY AND ENVIRONMENTAL INFORMATICS

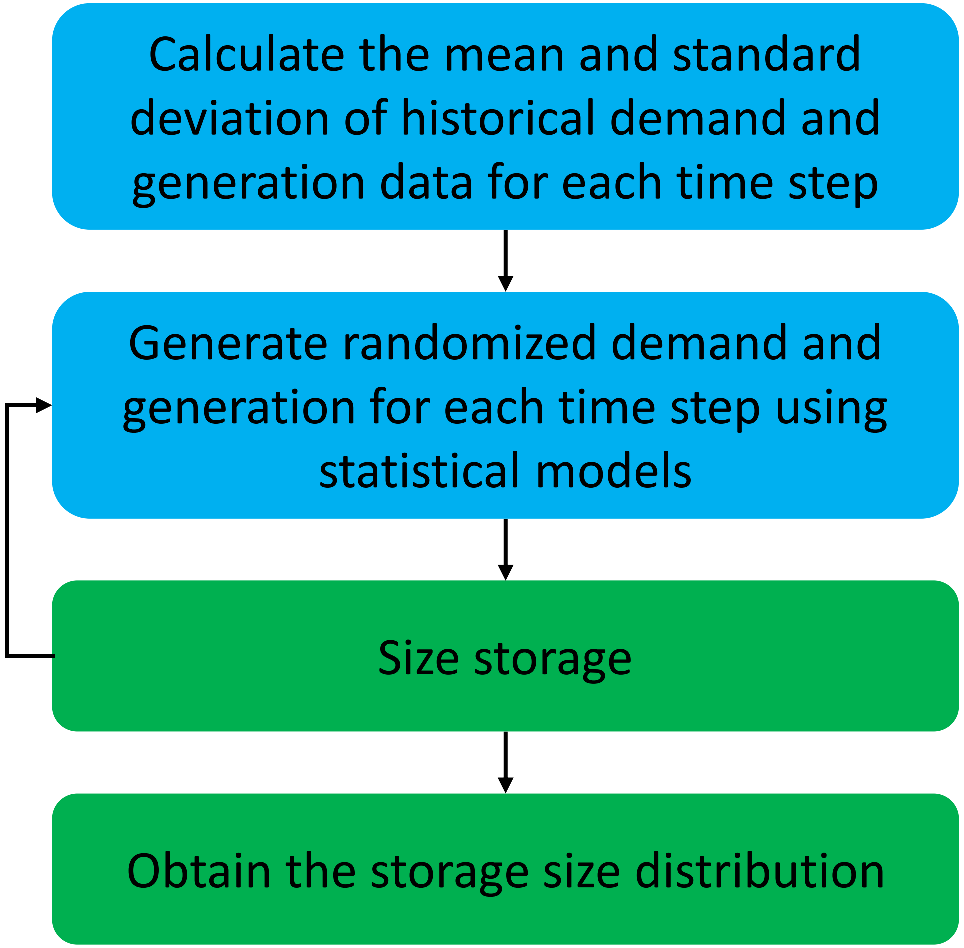
UNIVERSITY OF BIRMINGHAM

Storage Sizing

Case Study: Solar-battery home near Oxford.



Monte Carlo Method



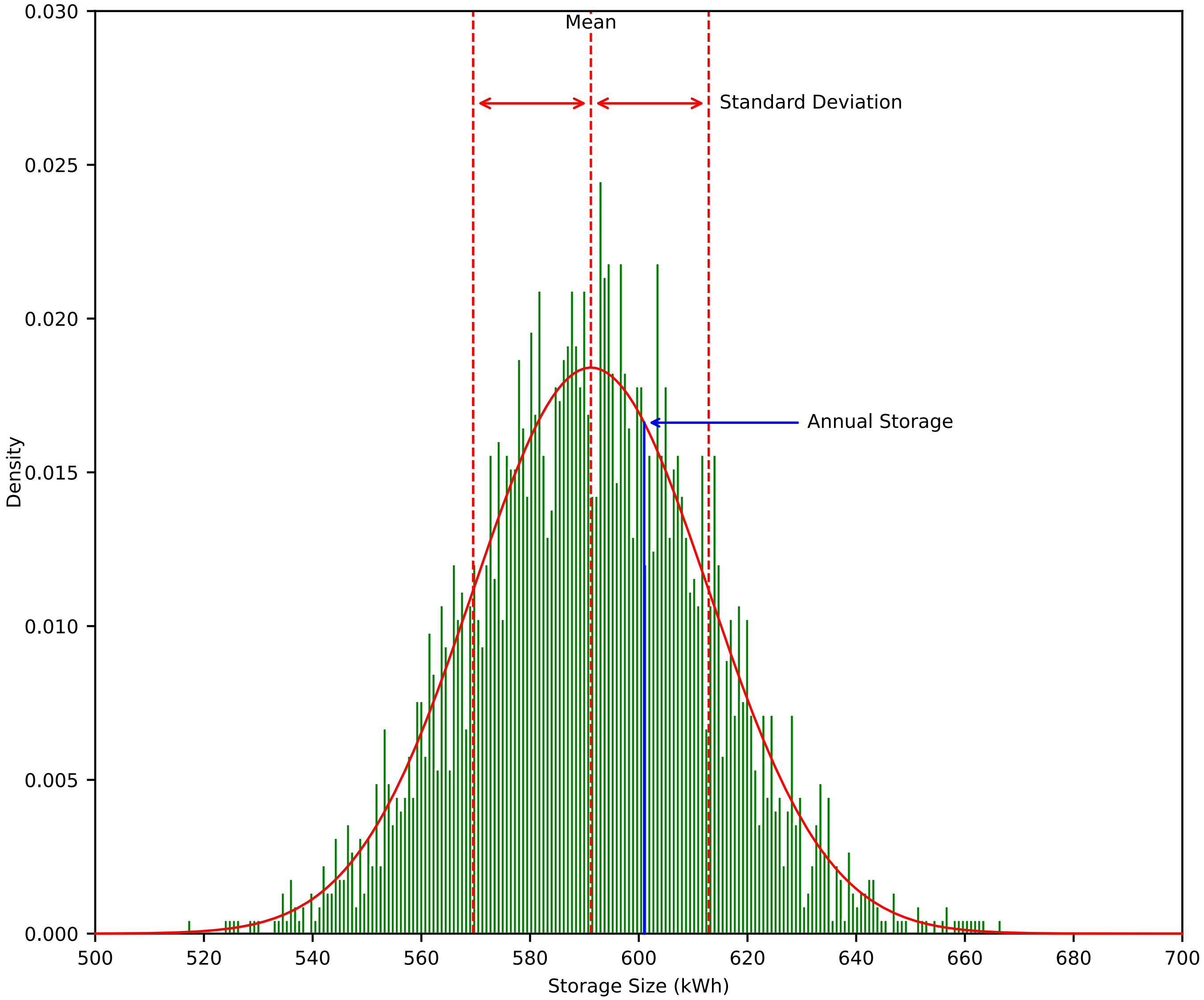
Monte Carlo Method

Calculate the mean and standard deviation of historical demand and generation data for each time step

Generate randomized demand and generation for each time step using statistical models

Size storage

Obtain the storage size distribution



Storage size makes up the 80% depth of discharge, meaning the total storage capacity is 751 kWh, which is beyond the 100th percentile.

Future System

Transition: right of transition, increasing daily storage greatly reduces grid electricity import. Left of transition, increasing seasonal storage slightly reduces electricity import.

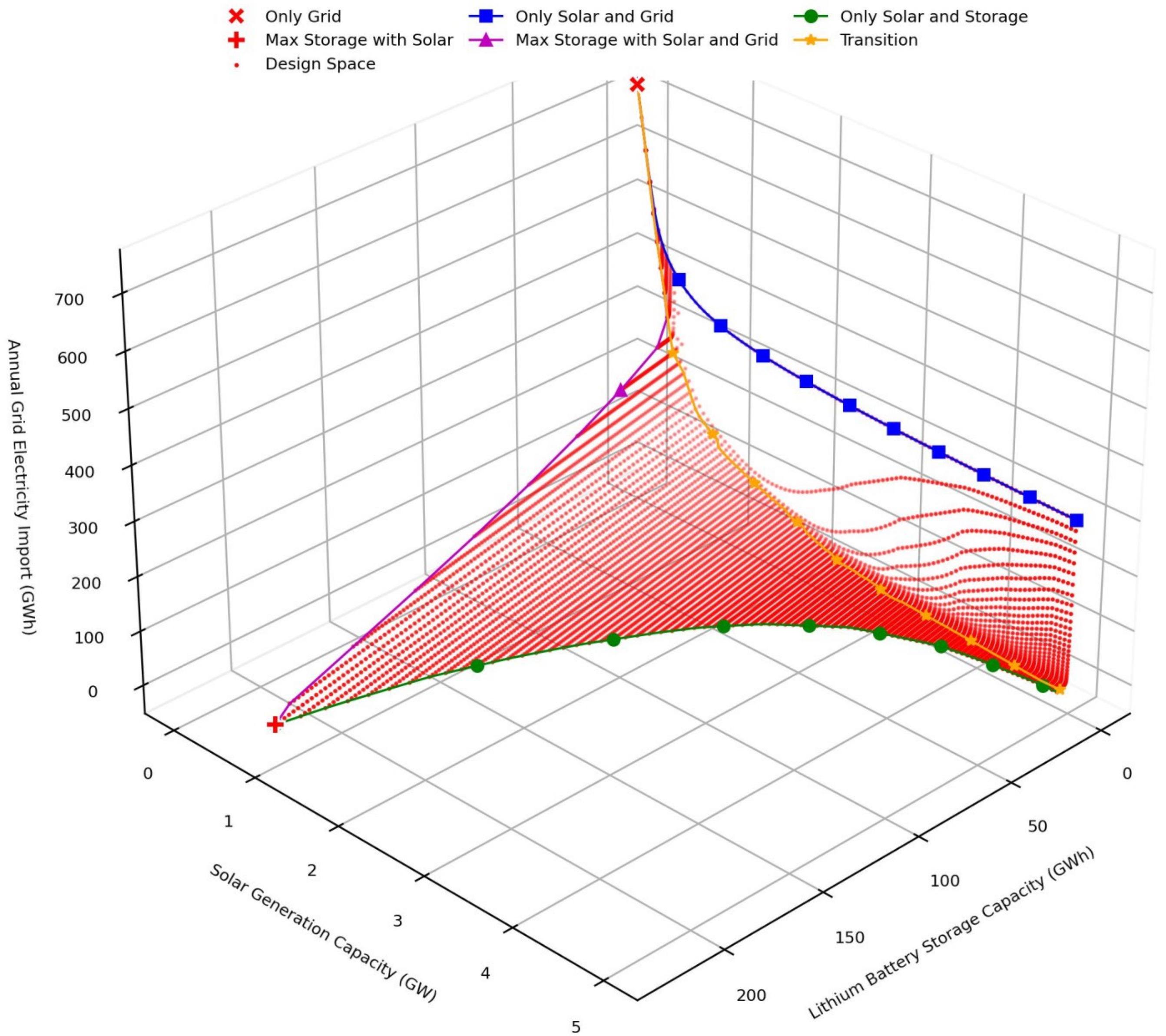
Max Storage with Solar and Grid: maximum storage capacity increases as solar capacity increases, due to more surplus generation.

Max Storage with Solar: the first solar and storage capacities that can meet the demand without grid electricity. The storage requirement is the largest.

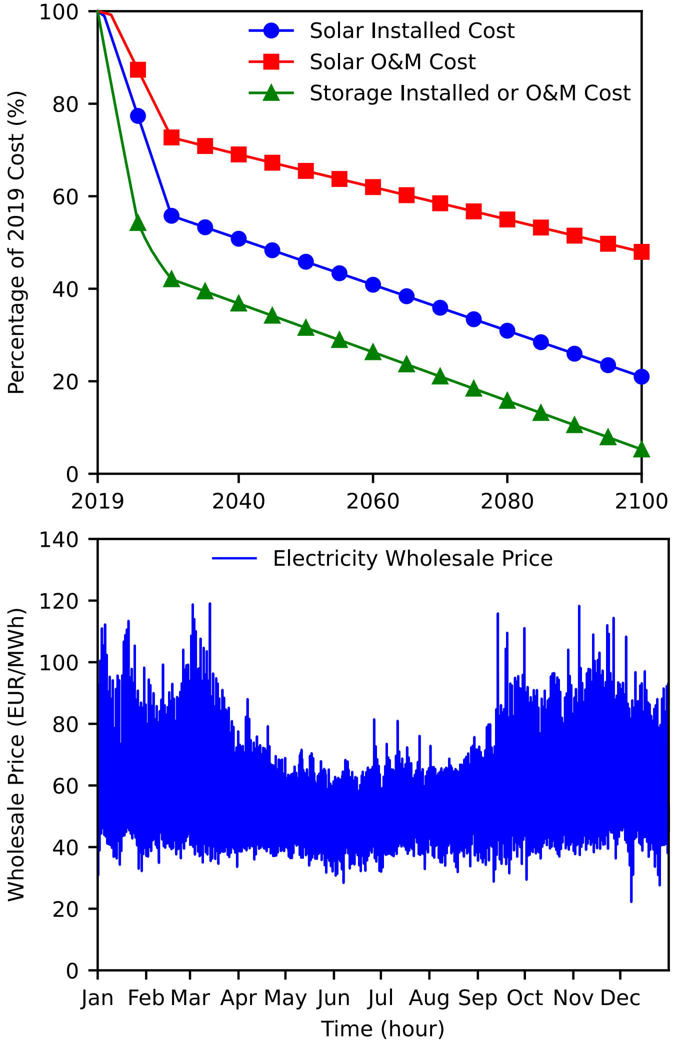
Only Solar and Storage: solar and storage capacities that can meet the demand without grid electricity. As solar capacity increases, the storage requirement decreases to an extent.

Only Grid: without solar or storage, demand solely relies on the grid, resulting in the highest grid electricity requirement.

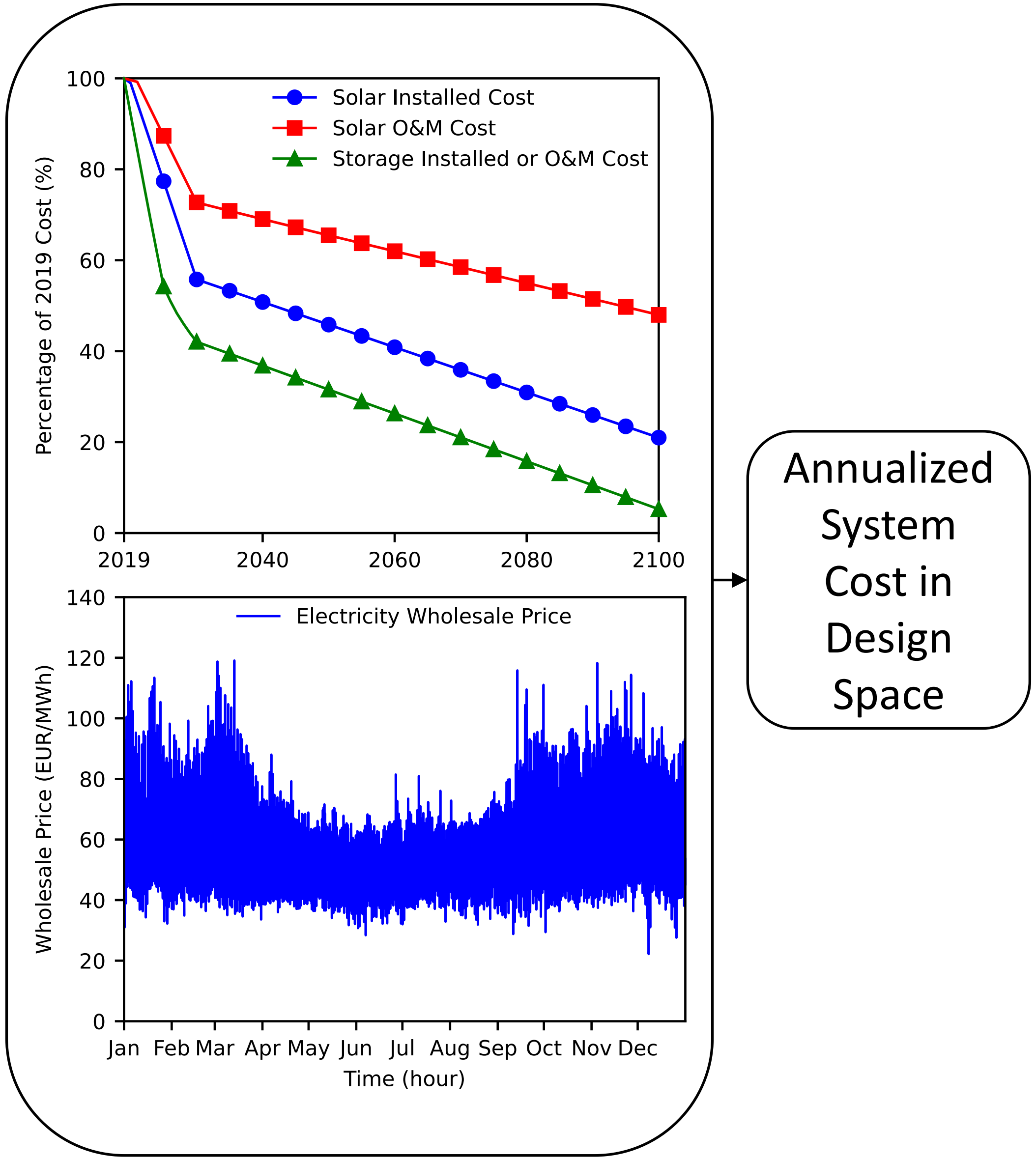
Only Solar and Grid: without storage, increasing solar capacity reduces grid electricity requirement to an extent.



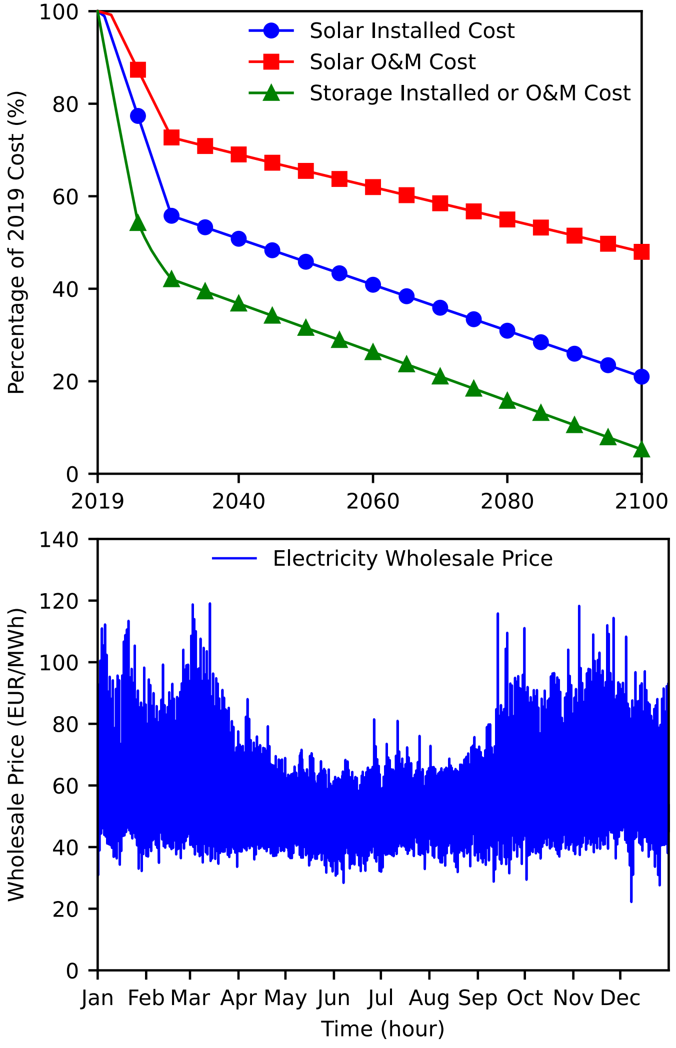
Future System



Future System

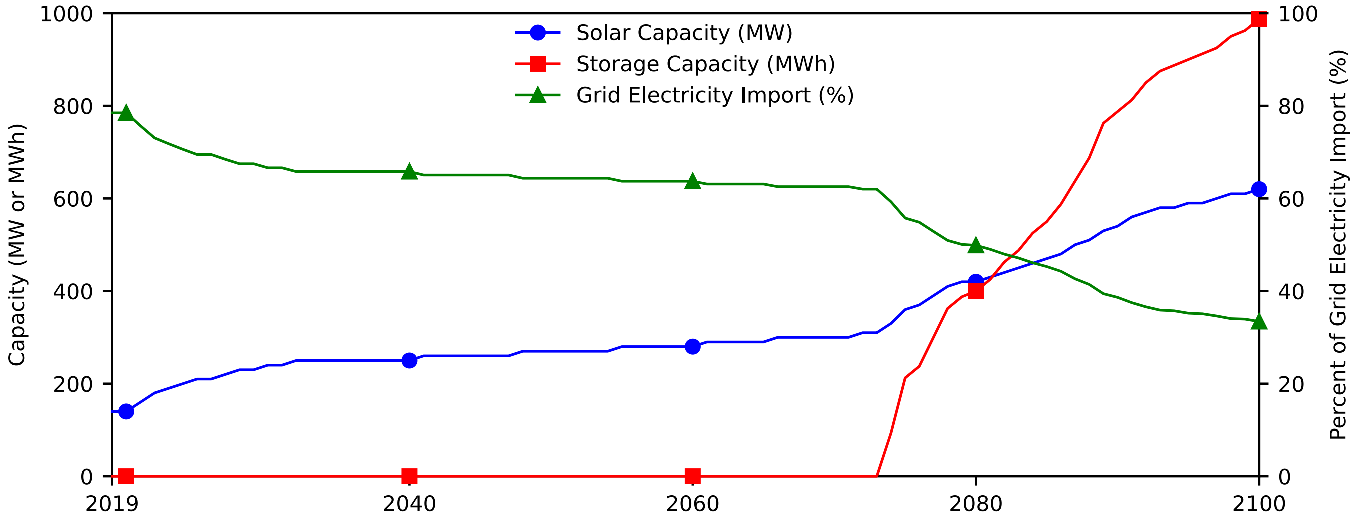


Future System



Annualized System Cost in Design Space

Optimal System Projection



- Currently, solar PV is economically competitive, but lithium storage cost is still too high.
- As solar and storage prices continue to drop, they will take up greater portions of the energy system.
- However, there will always be a need for grid electricity import. The grid provides flexibility and can meet some demands that are too costly for solar and storage alone.

Method Comparison

Meta-Heuristic Optimization

- Can handle any model
- Cannot guarantee optimal
- Slow calculation speed

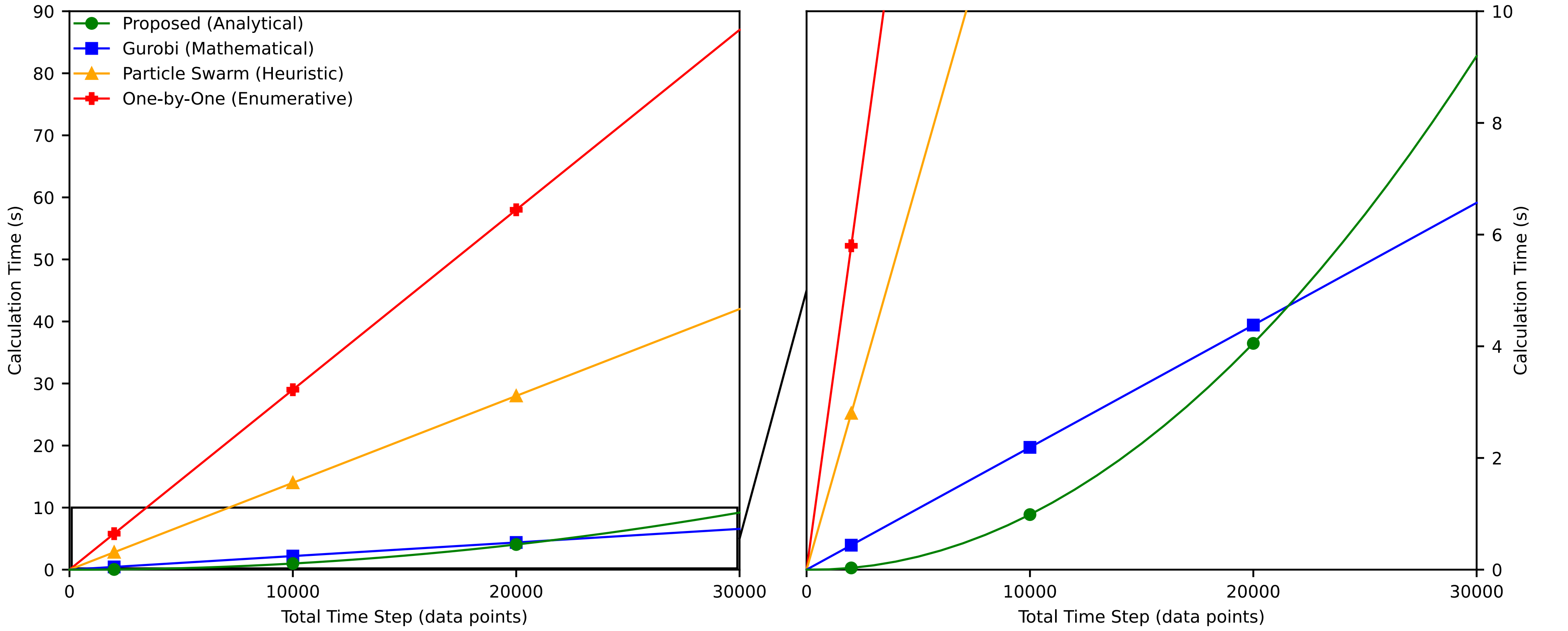
Mathematical Optimization

- Guarantees optimal
- Limited models
- Fast calculation speed

Analytical Optimization

- Can handle most models
- Good convergence to optimal
- Faster than Meta-Heuristic
- Provide good understanding

Method Comparison



The proposed method's calculation time is related to the number of critical points in the storage profile.

Other sizing methods' calculation times are related to the number of data points in the profile.

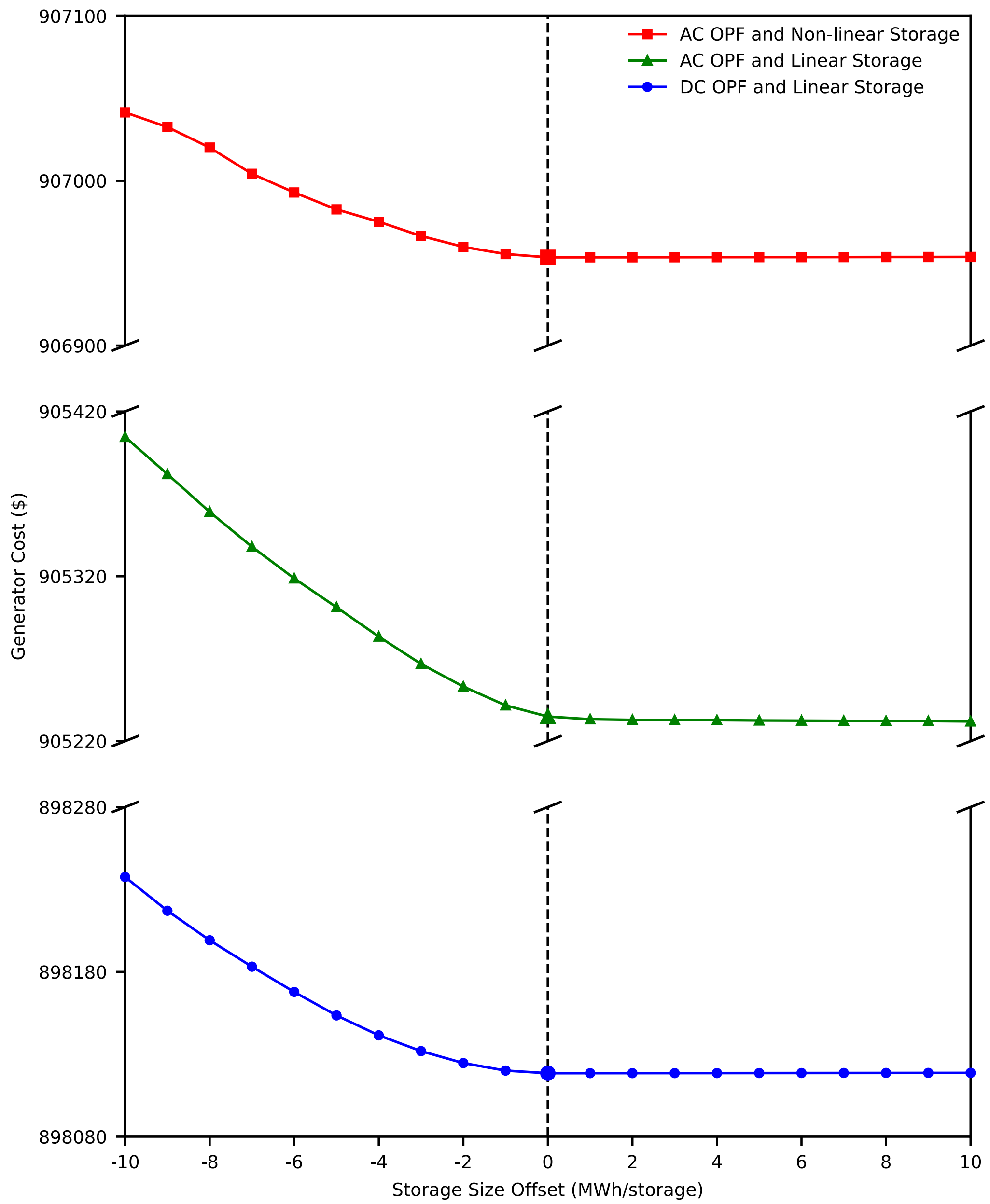
The proposed storage sizing method is faster initially but slows down with larger dataset.

Method Comparison

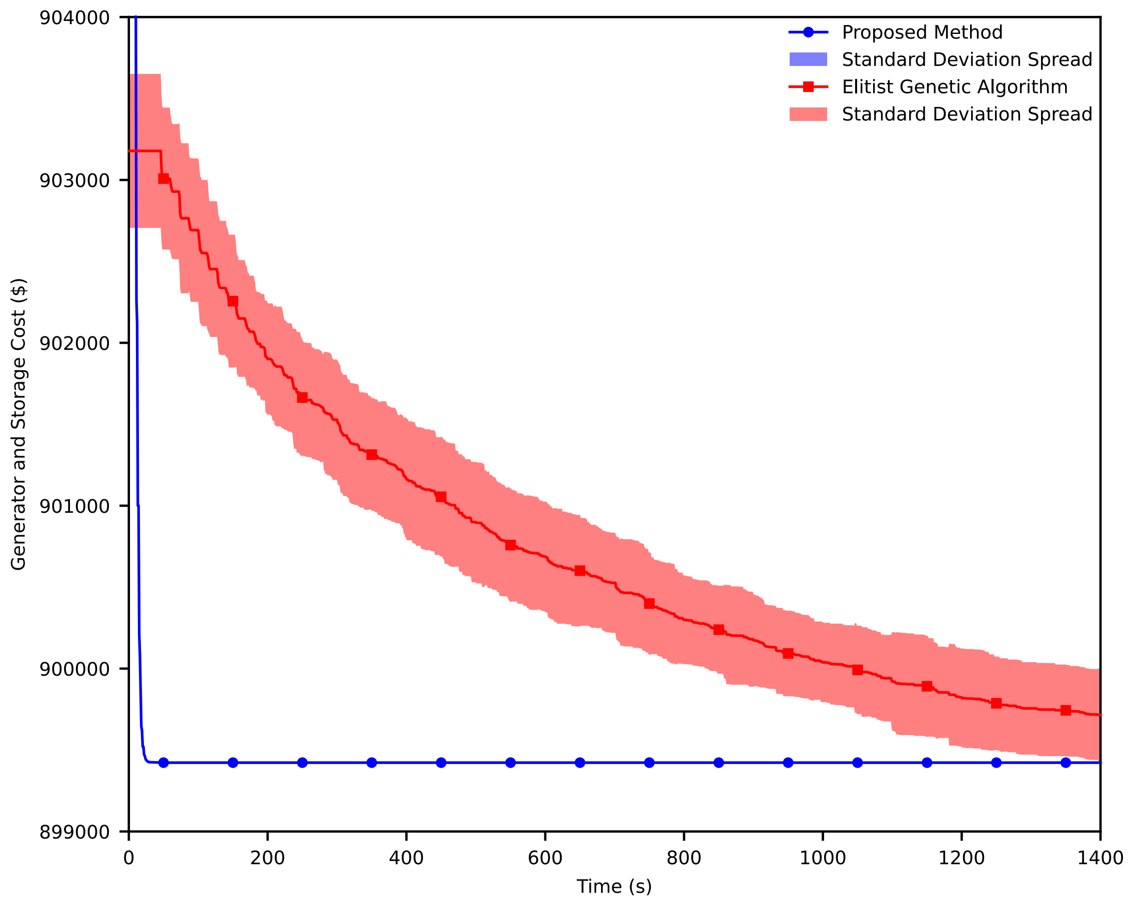
The method yields optimal solution when coupled with convex models (DC OPF, linear storage model).

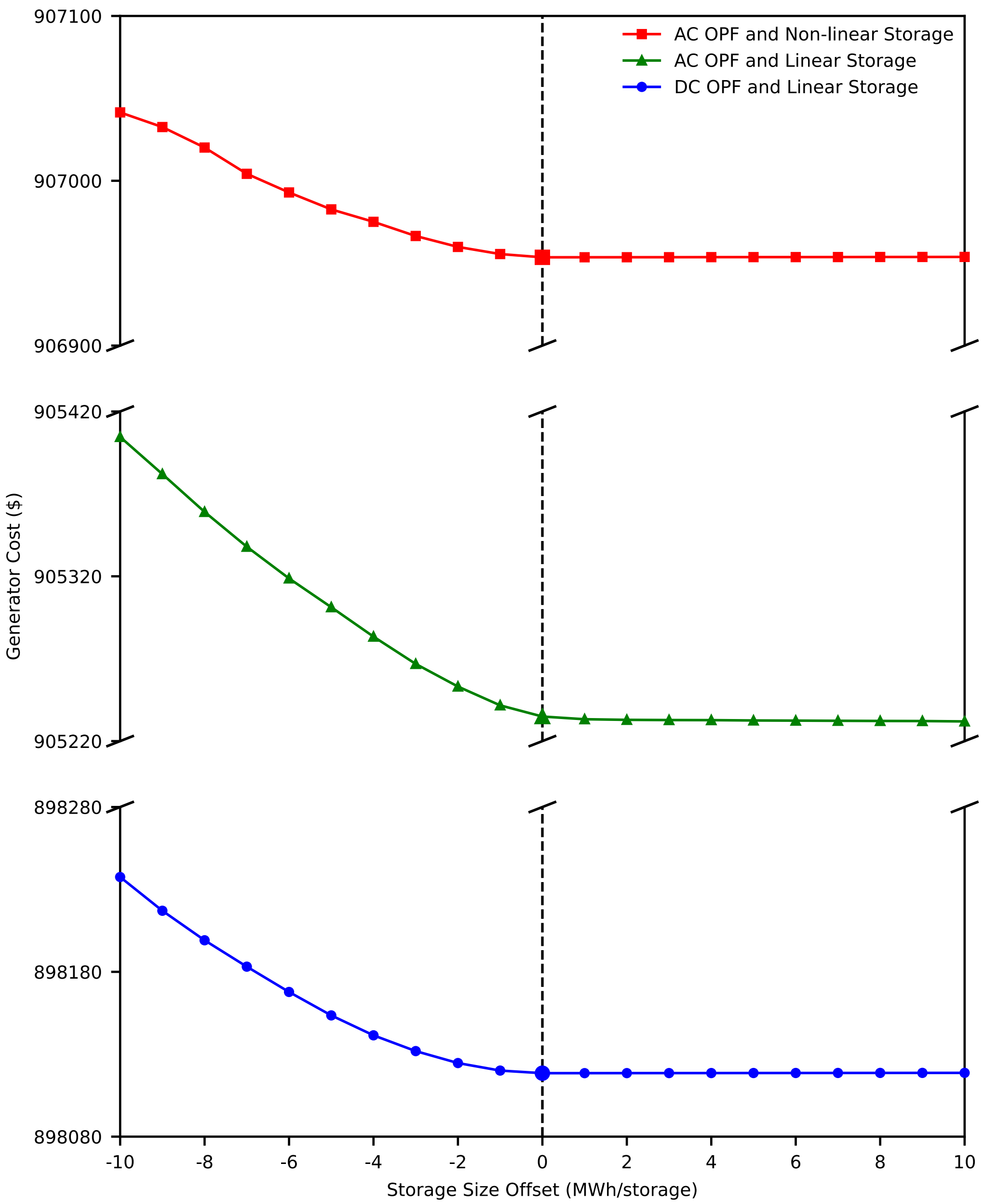
The offset shows adding storage capacity to the solution does not further reduce generator cost, while removing storage capacity from the solution increases generator cost.

The method can yield near-optimal solution when coupled with non-convex models (AC OPF, non-linear storage model).



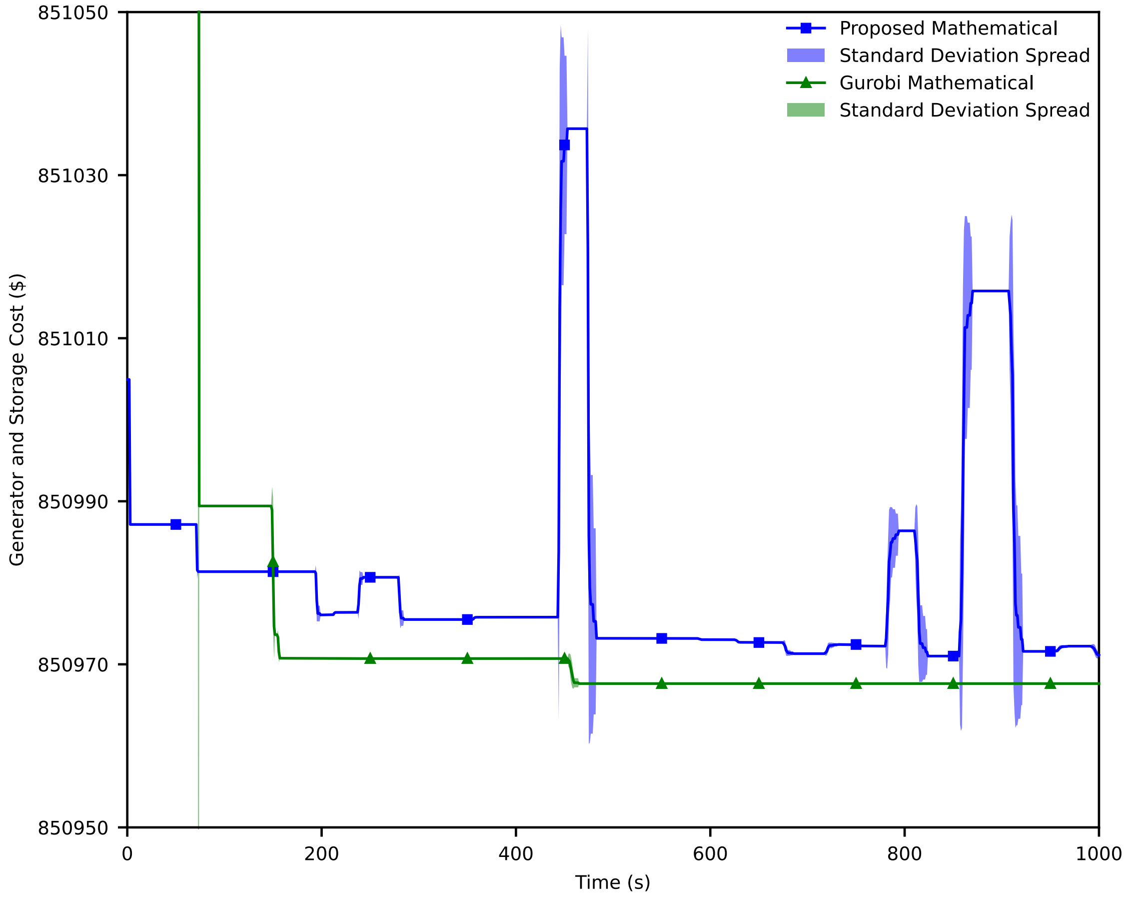
Method Comparison





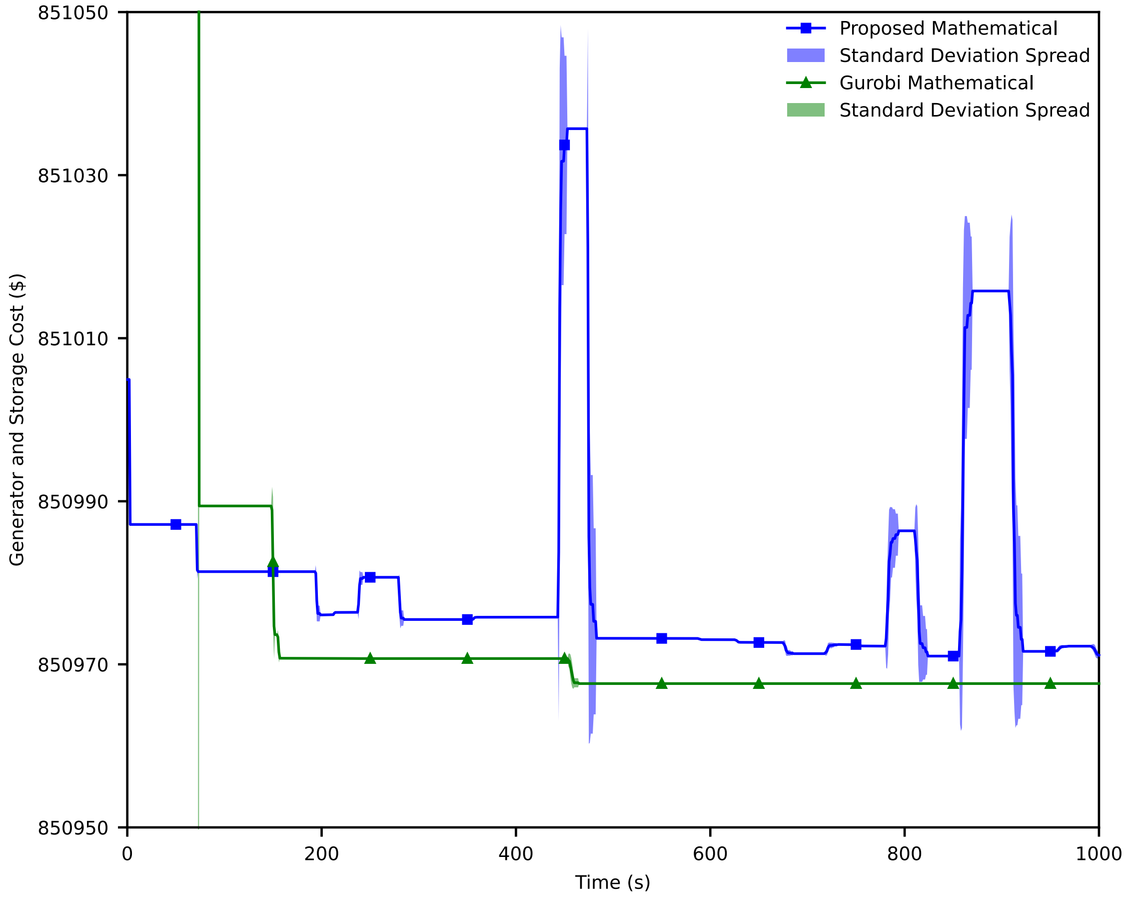
The proposed method minimized the objective cost within 40 seconds, while the elitist genetic algorithm achieved a similar objective cost after 23 minutes.

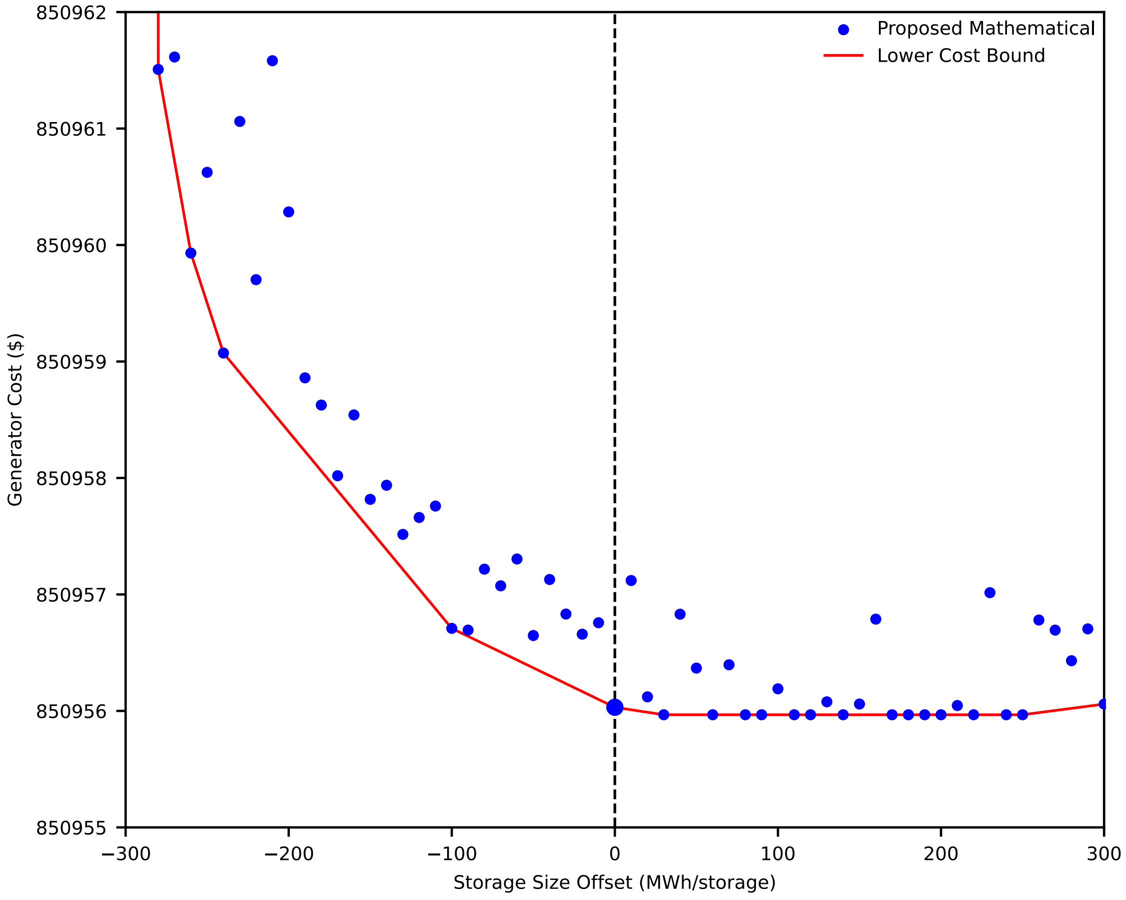
Method Comparison



The proposed mathematical method is slower but can achieve a similar objective cost as Gurobi mathematical optimization.

Method Comparison





The proposed mathematical method is slower but can achieve a similar objective cost as Gurobi mathematical optimization.

The solution is near-optimal, as adding a small amount of storage capacity can reduce the generator cost, while removing storage capacity increases cost.

Proposed Mathematical Method

The total storage size is 11 GWh, which is 9 times the storage size from the proposed method.

The larger size is due to the problem formulation, which optimizes across the entire time horizon, and implicitly optimizes generator scheduling in addition to maximizing renewable consumption.

The generators are scheduled to charge the storage during low demands, and then the storage discharges that energy to support loads during high demands. The extra energy from generators causes the larger storage size requirement.