Integrated Strategic System Planning Initiative

Modeling Framework, Demonstration Study Results, and Key Insights

Anish Gaikwad, Sr. Program Manager

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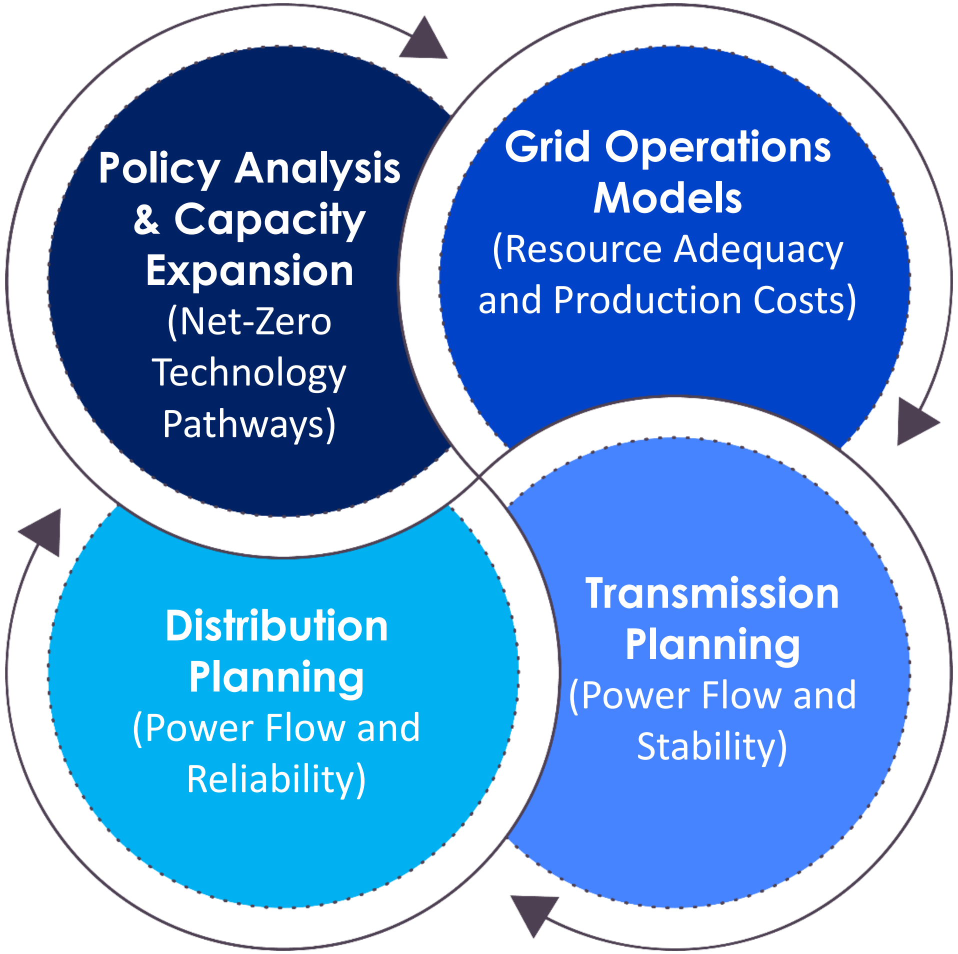
EPRI's Integrated Strategic System Planning (ISSP) Initiative

Integrated Planning for Strategic Questions

Least-cost pathway to electric sector decarbonization?

Sufficient capacity, energy, and flexibility to reliably balance supply and demand?

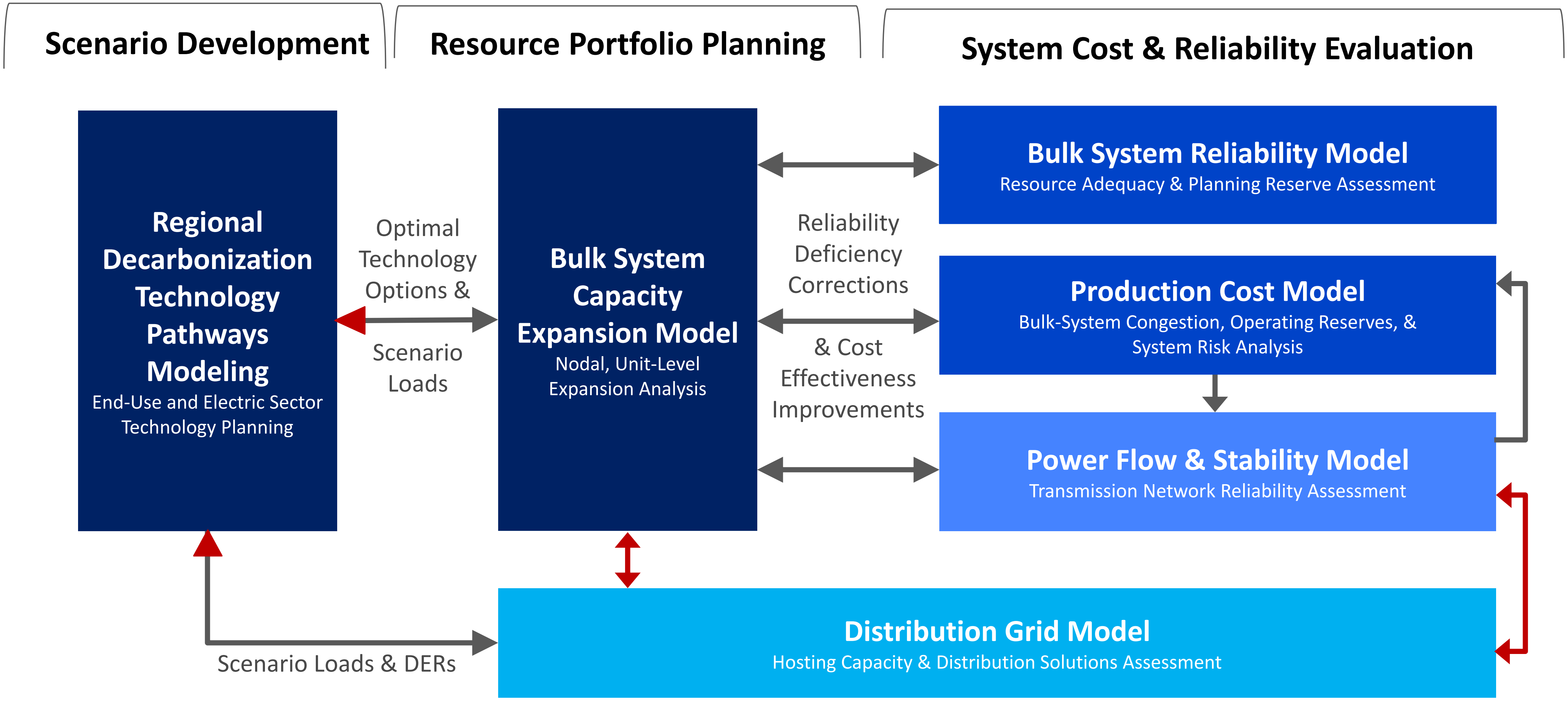
T&D investments for reliability/resiliency for a distributed, inverter-based supply mix?



Develops a generalizable analytical framework to assess future expansion plans across supply and delivery (T&D) that incorporates distributed energy resources & ensures reliability

ISSP NY Demonstration Study Modeling Process

NY Study Links
Future Links



One Toolbox* & a Range of Coordinated Modeling Tools

Model Type	Tool	Primary Objective(s) in ISSP Demonstration Study	Generation Scope	Transmission Scope	Distribution & DER Scope	Temporal Resolution
Regional Technology Pathways Model	US-REGEN	Regional End-Use and Electric Sector Technology Planning	Aggregate resources	Zonal "pipe and bubble network"	Aggregated end-use technologies & DERs explicitly modeled	110 representative time slices per year
Power System Capacity Expansion Planning Tool	PLEXOS	System-specific G&T Expansion Analysis	Individual existing and new generators	Nodal	End-Use & DERs modeled via load adjustments	48 time slices per year, using statistical fitting to the load duration curve
System Reliability Assessment Tool	PLEXOS	Resource Adequacy & Planning Reserve Assessment	Individual existing and new generators	Zonal	End-Use & DERs modeled via load adjustments	1 year, 8760 hours
Production Costing Tool	PLEXOS + **EPRI Scheduling & Dispatch Tool**	Bulk-System Network Congestion, Operating Reserve, & System Risk Analysis	Individual existing and new generators	Nodal	End-Use & DERs modeled via load adjustments	1 year, 8760 hours & snapshots
Power Flow Model	PSS®E	Transmission Network Reliability Assessment	Individual existing and new generators	Nodal	DERs modeled via load adjustments	1 year, snapshots
Distribution Grid Model	EPRI DRIVE	Hosting Capacity & Distribution Solutions Assessment	No bulk-system	124 feeders 11 substations	End-use technologies and DERs explicitly modeled	1 year, 8760 hours

*** This toolbox shows specific models used for the ISSP demonstration study; it is one example of many**

NY Demonstration Study Scenarios

Assumptions	Reference	Decarbonization + Accelerated Electrification
	"Business-as-usual" with no additional decarbonization technology or policy drivers	Rapid U.S.-wide decarbonization, driven by policy and high electrification

Environmental and CO_2 Policies	All major "on the books" federal, regional, and state environmental and climate policies
	• Includes New York's SB6599 (CLCPA)
		Reference, plus
		• U.S. electric sector is zero carbon by 2035
		  • No negative emissions or offsets permitted
		  • Interim 80% carbon-free by 2030 target
		• U.S.-wide carbon pricing over the rest of the economy, consistent with a U.S. 50x2030 goal

Technology	Default EPRI inputs for technology cost and performance	Reference, plus • Faster diffusion of electrified consumer technologies: • Accelerated heat pump adoption • Accelerated turnover of existing end-use equipment • Lower cost and higher performance electric vehicles and heat pumps

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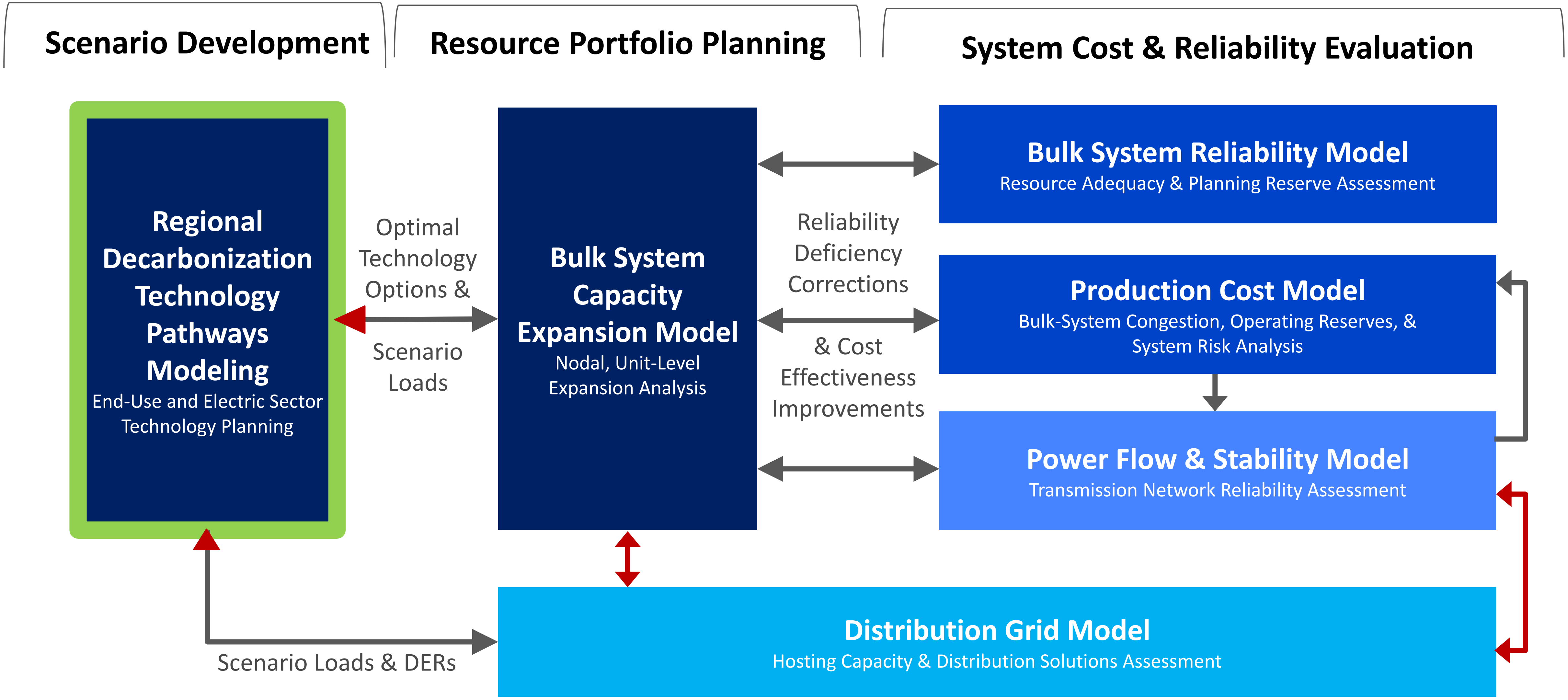
Determining the Role of Emerging Technologies and Other Resources in Future Energy Systems

Scenario Development for Long-Range Planning

ISSP NY Demonstration Study Modeling Process

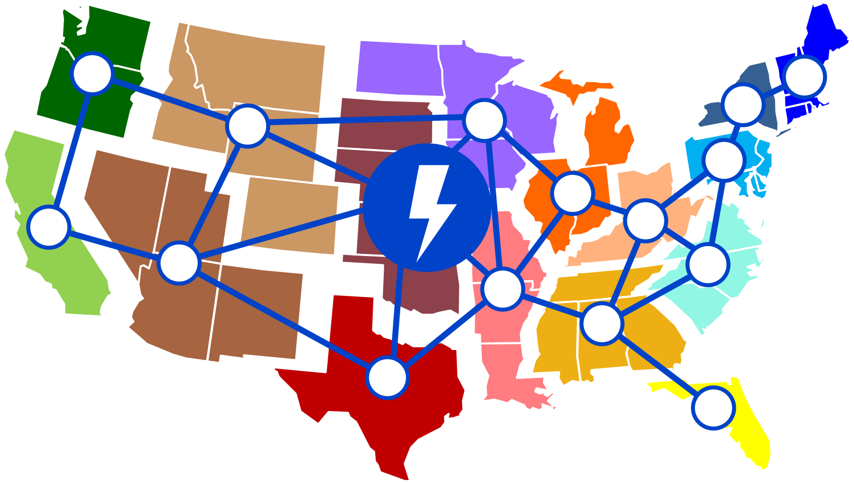
NY Study Links
Future Links



Regional Decarbonization Technology Pathways Modeling

US-REGEN
Regional Economy, GHG, and Energy

Electric Generation



Detailed representation of:

- Energy and capacity requirements
- Renewable integration, transmission, storage
- Federal, regional, and state-level policies and constraints

Synchronized

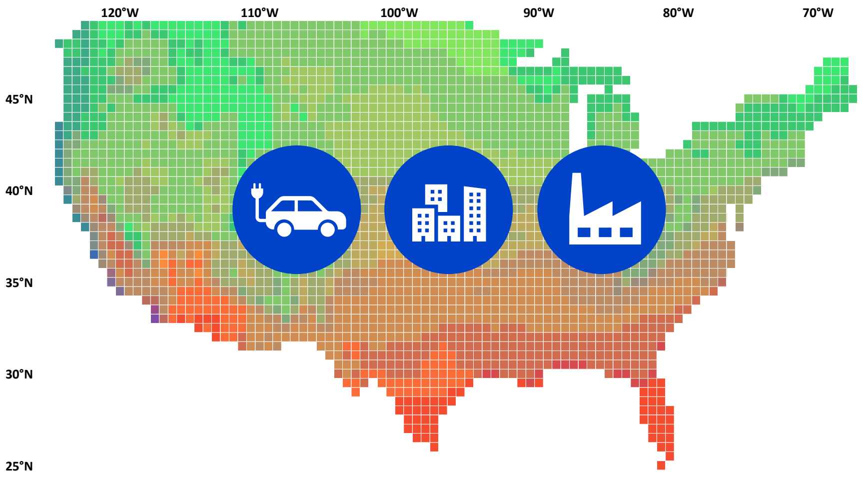
Hourly Load, Renewables, and Prices

Model Outputs:

Economic equilibrium for generation, capacity, and end-use mix

Emissions, air quality, and water

Energy Use



Detailed representation of:

- Customer heterogeneity across end-use sectors
- End-use technology trade-offs
- Electrification and efficiency opportunities

Documentation, articles, and reports available at https://esca.epri.com

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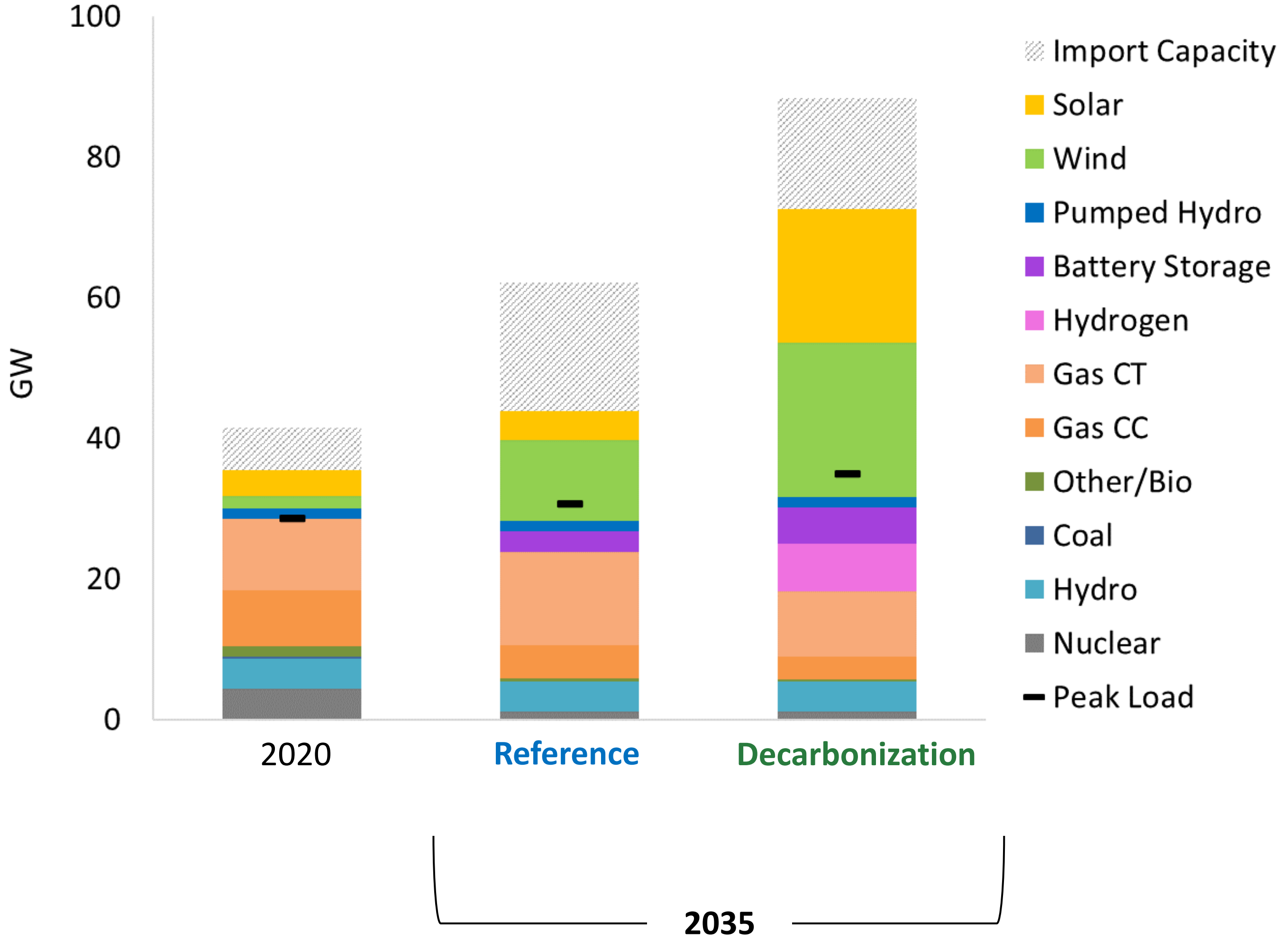
US-REGEN NY Installed Generation Capacity by Scenario



The modeled **Reference Scenario** portfolio shows:

- Continued strong economics for gas
- Economic deployments for renewables (mostly wind)
- Modest role for short-duration batteries

Compared to Reference, the modeled **Decarbonization Scenario** drives:

- Significantly higher wind
- Significantly higher utility-scale solar
- Electrolytic hydrogen-fired generation
- Additional and longer duration batteries (~20 hr)
- Earlier retirement of carbon emitting natural gas-fired generation

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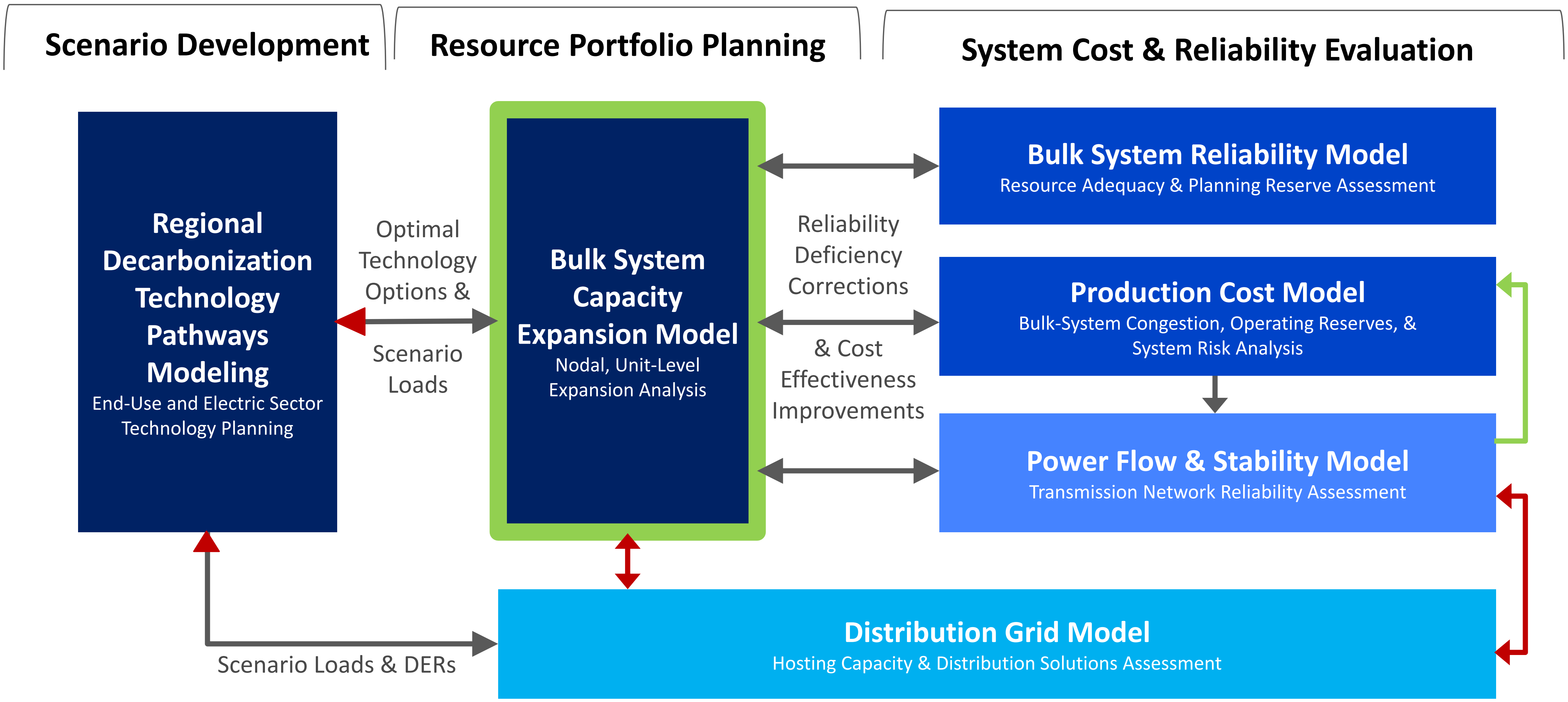
Identifying Long-Term Resource Expansion Portfolios

System Resource Portfolio Planning

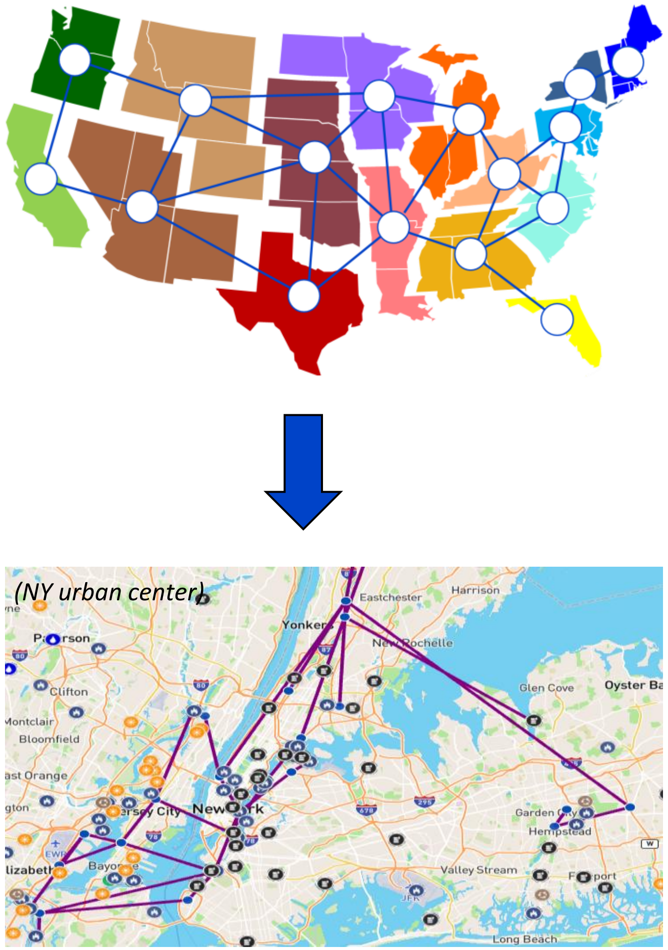
ISSP NY Demonstration Study Modeling Process

NY Study Links
Future Links



Nodal Capacity Expansion Modeling Objectives

- Detailed power system reliability studies benefit from each generating unit in a system being represented by its physical location and engineering/operating characteristics, and the transmission network lines between them and localized loads.
- We use Energy Exemplar's long-term capacity expansion planning model (PLEXOS-LT Plan) and inform it with US-REGEN scenarios to develop a power system model with the unit-level detail and system topology required for the system cost and reliability evaluations in this study.
- For this study, PLEXOS-LT Plan is configured as a nodal model, optimizing the generating capacity portfolio as a mixed integer program to site discrete units across nodes.
- PLEXOS-LT Plan is run several times throughout the study; the next slides show the initial portfolio used for further reliability study.



Regional technology planning models provide a critical starting point for detailed unit-level capacity expansion and operations analyses

US-REGEN Data Transferred to PLEXOS LT Plan

	US-REGEN Data
Inputs	Candidate Generator Technologies
	Technology-Based Capital Costs
	Technology-Based FOM & VOM Costs
	Fuel Costs
	Wind and Solar Profiles
	RPS, CO_2 constraints
Outputs	Optimal Generation Capacity (GW) by Technology
	Electricity Demand (8760 Load) by Region/Zone
	Reserve Margin (calculated endogenously)

Schematic of Data Transfer Process

Transfer selected US-REGEN inputs & outputs to common working directory

↓

Reformat & restructure data using Python scripts customized to CapEx model (e.g., PLEXOS-LT) input requirements

↓

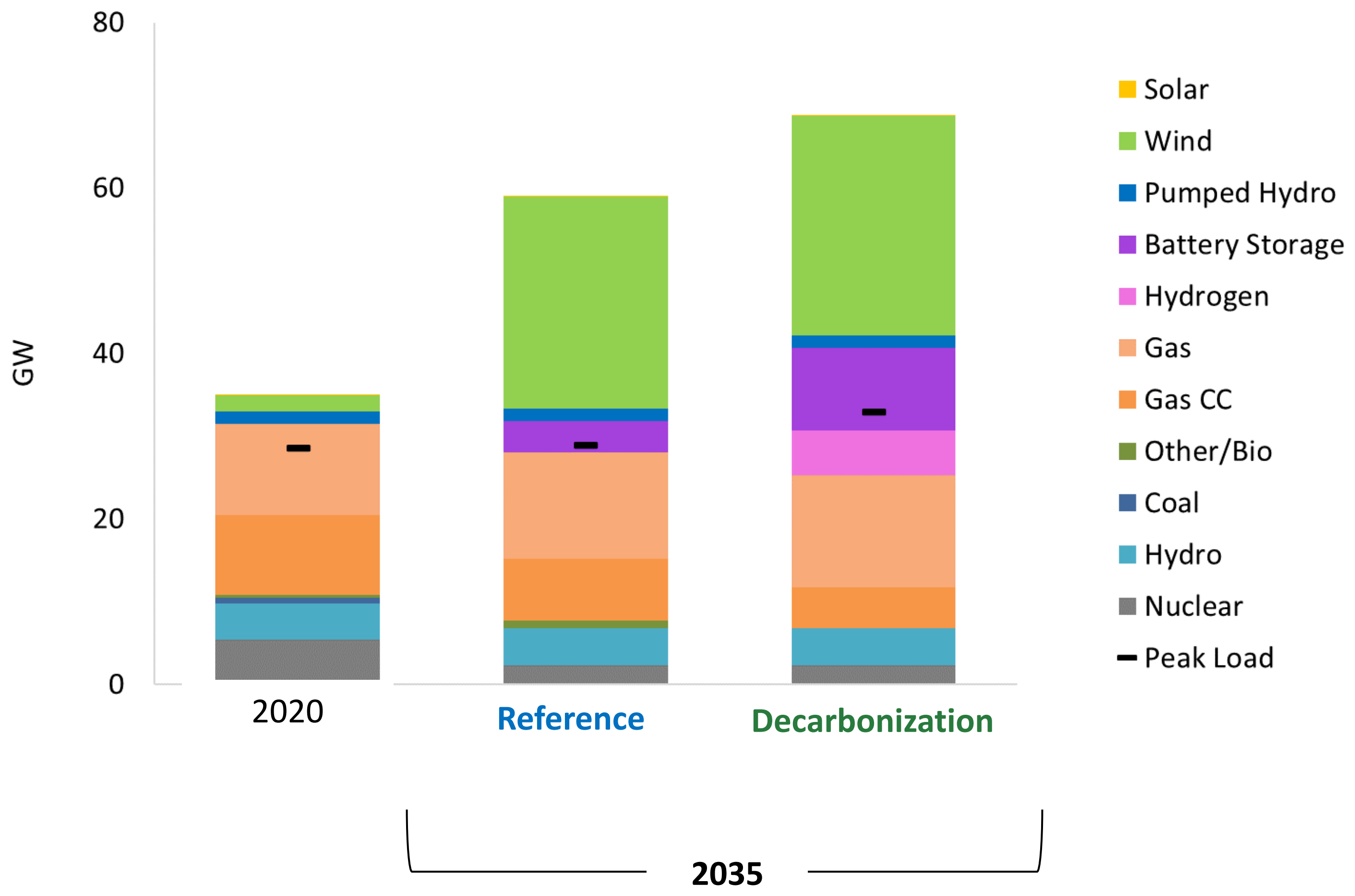
Call PLEXOS API to input the data into PLEXOS

↓

Initiate PLEXOS LT Plan Model

PLEXOS LT Plan NY Installed Capacity* by Scenario

*These portfolios represents the initial resource expansion plan, prior to information feedback from reliability analyses



Re-optimizing the resource portfolio at the unit-level and across a nodal transmission network drives:

A **Reference portfolio** with
- Significant new on and off-shore wind
- New short-duration batteries
- Continued reliance on natural gas

A **Decarbonization portfolio** with
- Significant new on and off-shore wind
- Significant *long-duration* batteries
- New electrolytic H_2-fired generation
- Natural gas (slightly lower than Reference)

There is significantly more wind and less solar in the PLEXOS portfolios than in the US-REGEN scenarios used as a starting point. Key drivers:
- Demonstration study PLEXOS scenarios represent NY as an "island," and net-import capacity is replaced by new wind
- Nodal buses support significantly more offshore wind, reducing need for less economic solar

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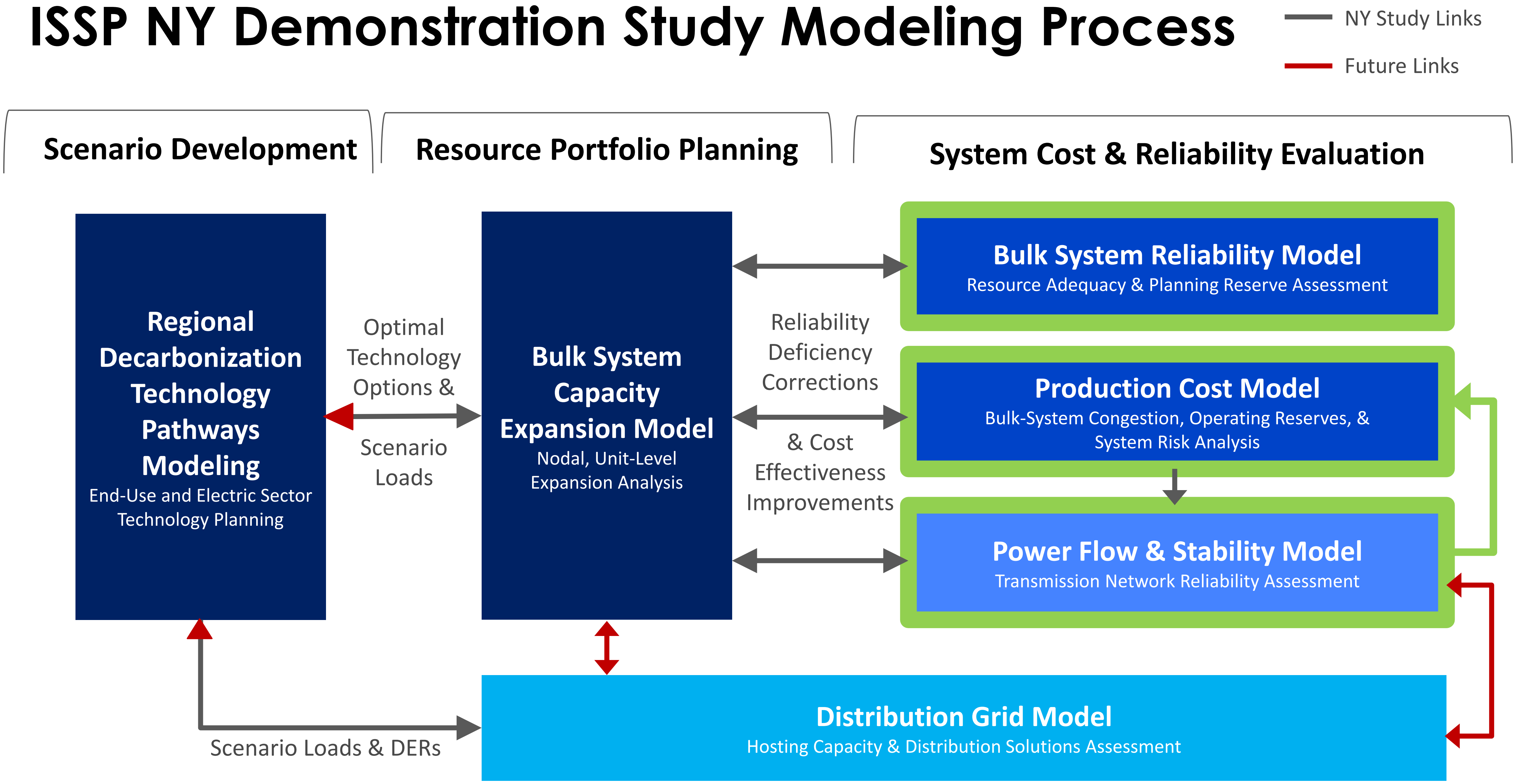
Assessing the Capability of the System to Meet Grid Operational Requirements

System Cost & Reliability Evaluations

ISSP NY Demonstration Study Modeling Process



Summary of Integrated Cost & Reliability Evaluations and Recommended Planning Actions: Decarbonization Scenario

Green text highlights key differences from Reference

Evaluation	Description	Key NY Study Finding(s)	Recommended Planning Actions
1	Resource Adequacy—Planning Reserve Assessment	• Resource portfolio failed minimum LOLE target of 0.1 days/year • High risk periods of unserved energy (e.g., high load due to heating on winter nights)	• Start with higher (16%) PRM from Reference Scenario final portfolio and check sufficiency; explore other solutions (e.g., storage) to complement PRM needs
2	Resource Adequacy—Storage Assessment	• Significant LOLE benefits of longer duration storage	• Increase duration of candidate batteries available in CapEx by 30%
3	PCM—Transmission Network Congestion Assessment	• Notable lines with significant congestion and overloading • High variation in system wide prices	• Allow CapEx model to consider economic transmission upgrades for all congested lines (37 new line candidates)
4	Operations Reserves & Risk Assessment	• Reference scenario passed key flexibility and contingency requirement tests	• None (Note, performed a sensitivity analysis to show a case where the CapEx would need to be re-run)
5	Transmission Network Reliability Assessment	• 17 extra circuits *in addition to those required under Reference* for N-1 required to secure the Decarbonization portfolio	• Reliability-driven candidate transmission reinforcements are recommended for CapEx

Production Cost Module – Transmission Planning Linkage

5. Scenario Selection

- ❖ ***Step 1***: ***Group operating hours*** based on similarities in load levels, generation dispatch, renewable output, tie line flows etc. into ***clusters***.
- ❖ ***Step 2***: ***Select cases from each cluster*** based on engineering judgement and system knowledge

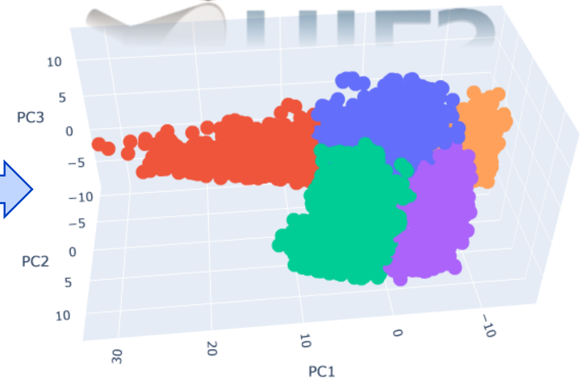
PCM Runs

8760 data points

NYISO total Gen	NYISO natural gas output
NYISO wind output	NYISO storage output
NYISO solar output	NYISO total export/import
NYISO total load	NYISO- Canada flow
NYISO hydro output	NYISO- ISO-NE flow
NYISO nuclear output	NYISO PJM flow

Multidimensional variability assessment

HiLS



Clustered operating conditions

Dc 8760 snapshots → ***Few representative hours***

- ❖ **The ISSP approach allows TPs a greater visibility into possible operating conditions by linking to PCM results**
- ❖ **The HiLS process allows TPs to identify critical operating conditions by making the data manageable**

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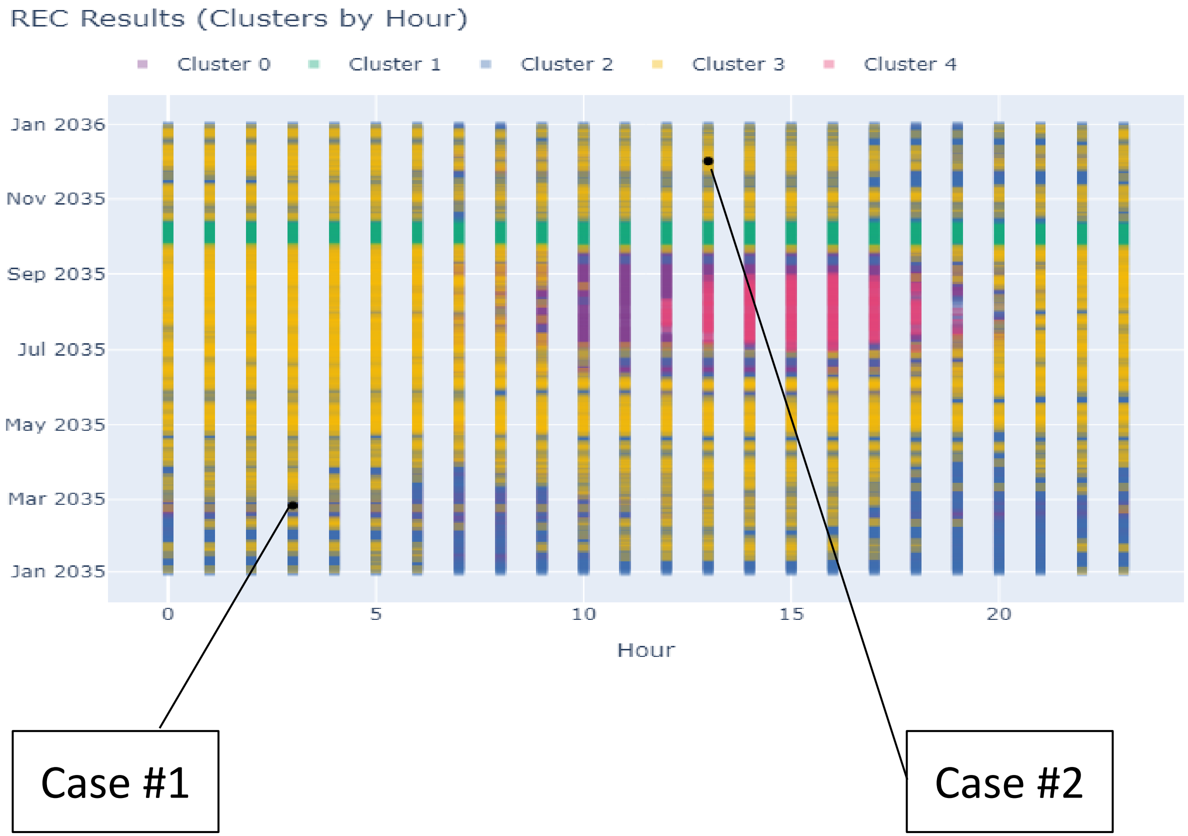
5. Example: HiLS Clustering Analysis Results



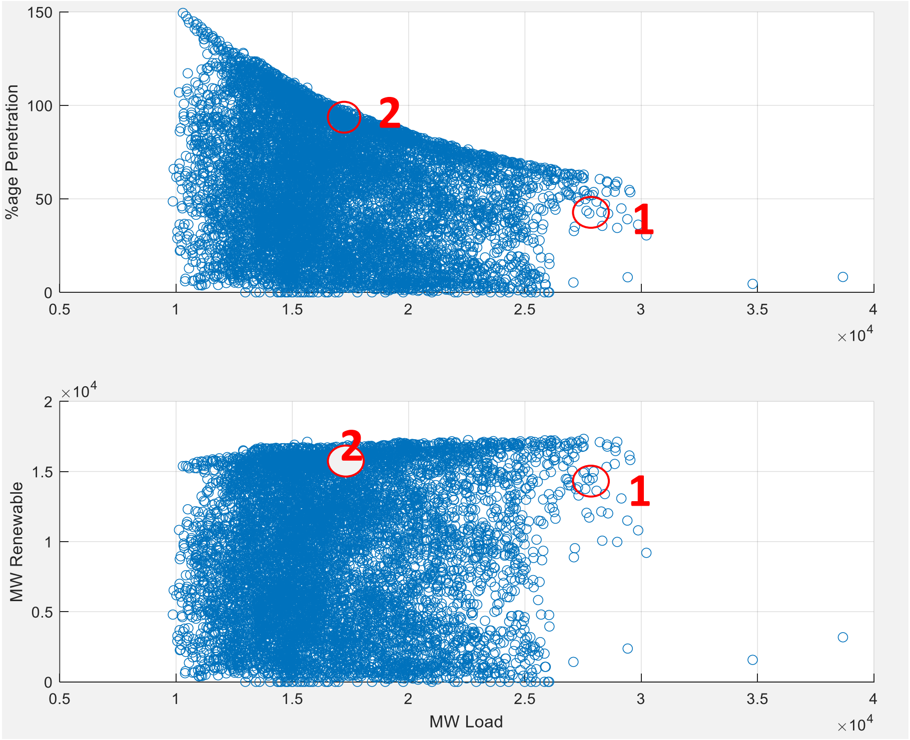
The HiLS tool clustered the operating hours into 5 clusters

- ❑ ***Cluster 0*** – Shoulder load, low % renewables
- ❑ ***Cluster 1*** – Low fall load with Nuclear units out for service
- ❑ ***Cluster 2 – High winter load, high % renewables***
- ❑ ***Cluster 3 – Low winter/fall load, high % renewables***
- ❑ ***Cluster 4*** – Summer peak load, low % renewables

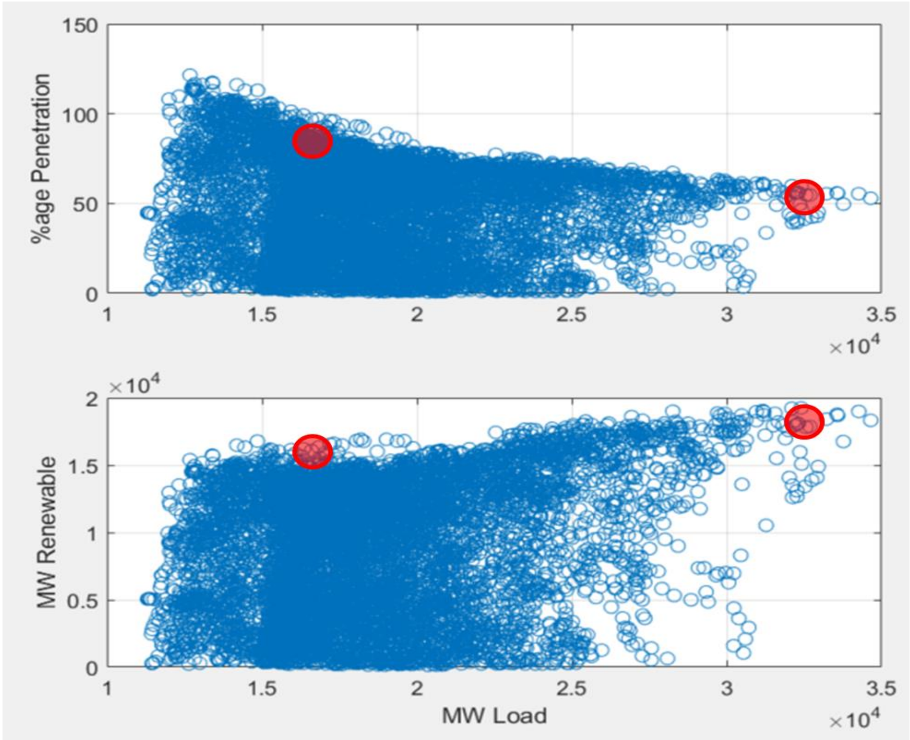
Two cases were investigated from cluster 2 and 3 to demonstrate the remaining process

5. Selected Snapshots

Reference Scenario



Decarbonization Scenario



Metric	Case 1	Case 2
Total Generation	30935 MW	23570 MW
Total Onshore Wind	10768 MW	11558 MW
Total Offshore Wind	4000 MW	4250 MW
Total Solar/PV	0 MW	0 MW
Total Renewables	14768 MW	15808 MW
Total Load	29636 MW	16100 MW
Percentage renewable	49.8%	98.18%

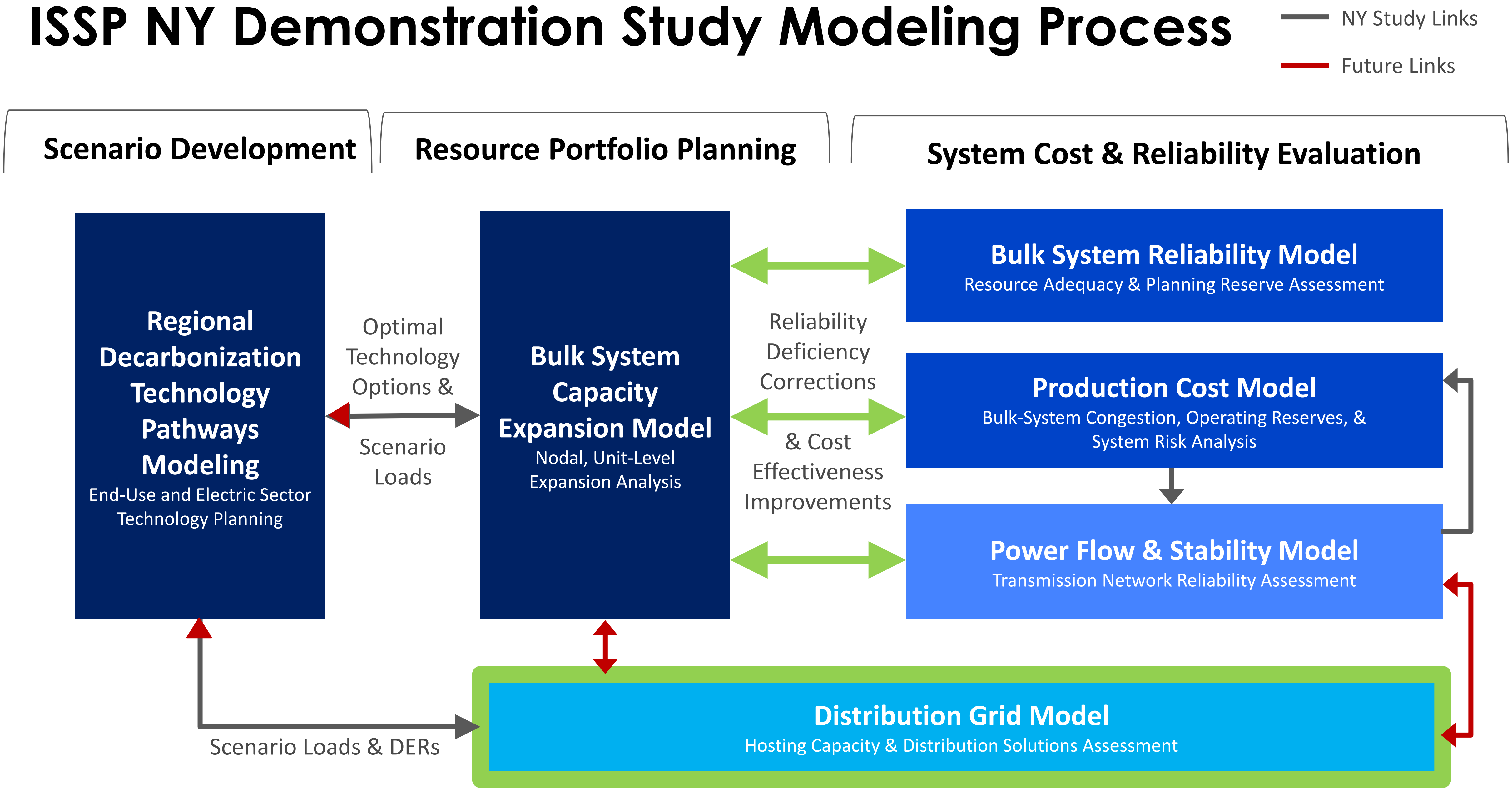
Metric	Case 1	Case 2
Total Generation	*29505 MW*	*20317 MW*
Total Onshore Wind	14184 MW	11558 MW
Total Offshore Wind	4240 MW	4250 MW
Total Solar/PV	0 MW	0 MW
Total Renewables	*18424 MW*	*16058 MW*
Total Load	*33223 MW*	*16620 MW*
Percentage renewable	*55.5%*	*96.2%*

5

Developing Robust Long-Term Resource Plans Capability of the System to Meet Grid Operational Requirements

Correcting Reliability Deficiencies and Evaluating Distribution Solutions

ISSP NY Demonstration Study Modeling Process



Planning Actions to Create a More Robust Resource Portfolio

- This study performs two main "corrective" actions for modifying the initial resource portfolio to address identified and potential future reliability deficiencies.

1. Correcting Identified Reliability Deficiencies in Bulk-System Resource Plan

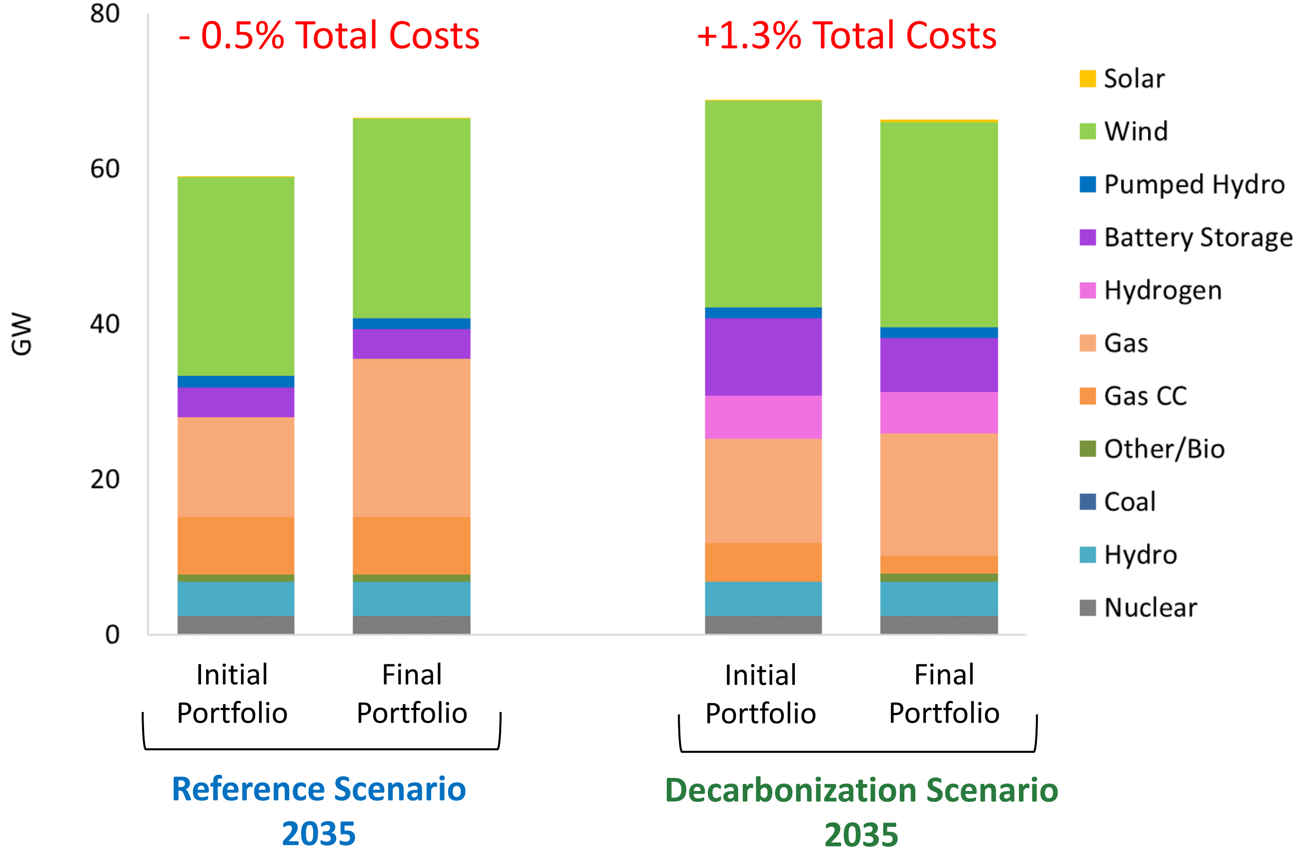
- PLEXOS LT Plan iteratively incorporates recommended planning actions identified in the system cost & reliability evaluations
- PLEXOS RA and PCM is re-run to verify benefits and calculate costs.
- Corrective actions focus on increasing the planning reserve margin, increasing the duration of candidate battery storage installations, and both economic and reliability-driven transmission reinforcements.

2. Coordinated DER & Wide Area Distribution System Planning Analysis

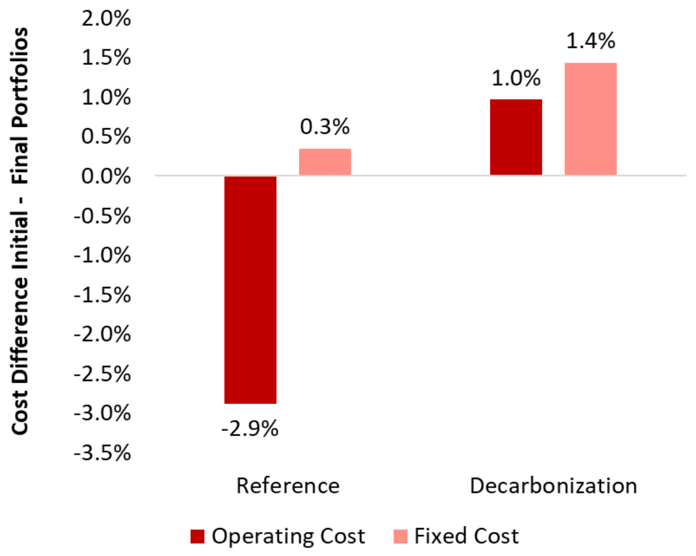
- A baseline distribution system grid model, US-REGEN scenario load and DER/end-use technology outputs, and potential Dx solutions and costs are to calculate the ability of the distribution system to accommodate future planned resources.
- Potential violations are assessed, and opportunities to modify the system with Dx solutions including non-wires alternatives are identified.

Incorporating Feedback Improves the Reliability of Final Portfolios, with changes in portfolios and costs of the system

All Reported Costs are Cumulative (2020-2035)



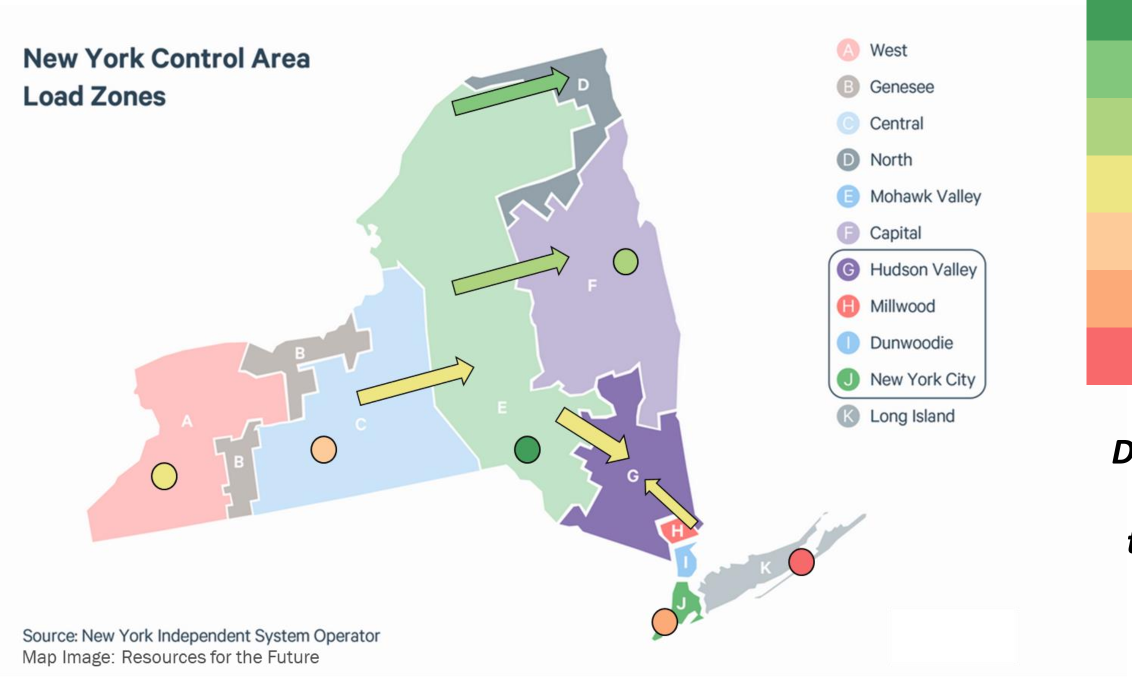
Several factors, including final generator siting and access to Tx, new Tx investments, and sizing of energy storage drive cost differentials between initial and final portfolios.



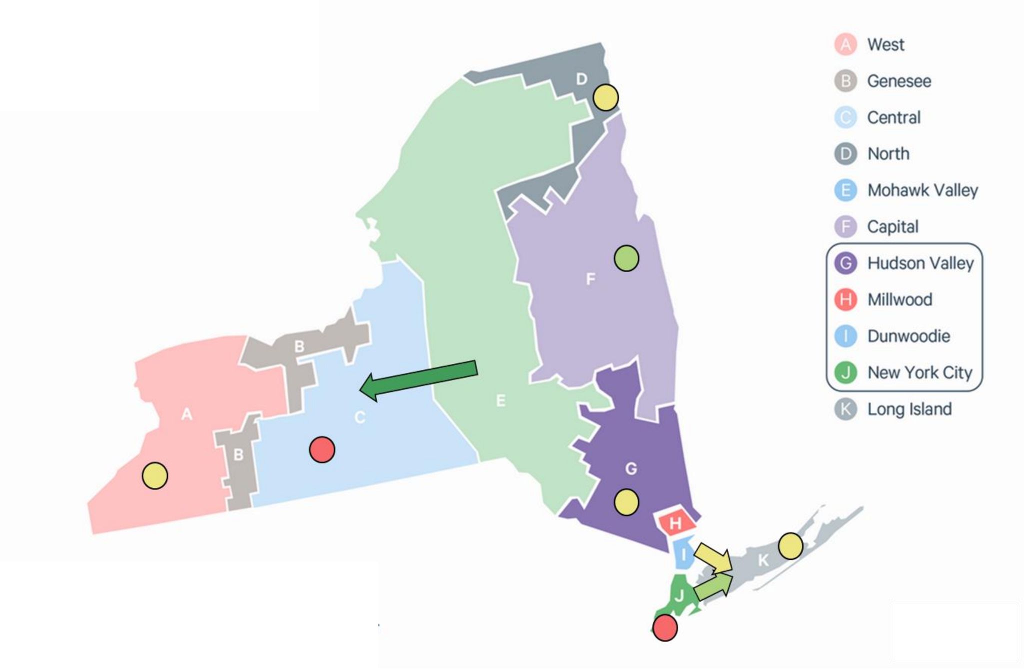
Incorporating new economic and reliability-driven system upgrade options in the capacity expansion planning step can align final resource portfolios with expected system conditions more closely

Final Portfolio Transmission Upgrades

Reference Scenario



Decarbonization Scenario



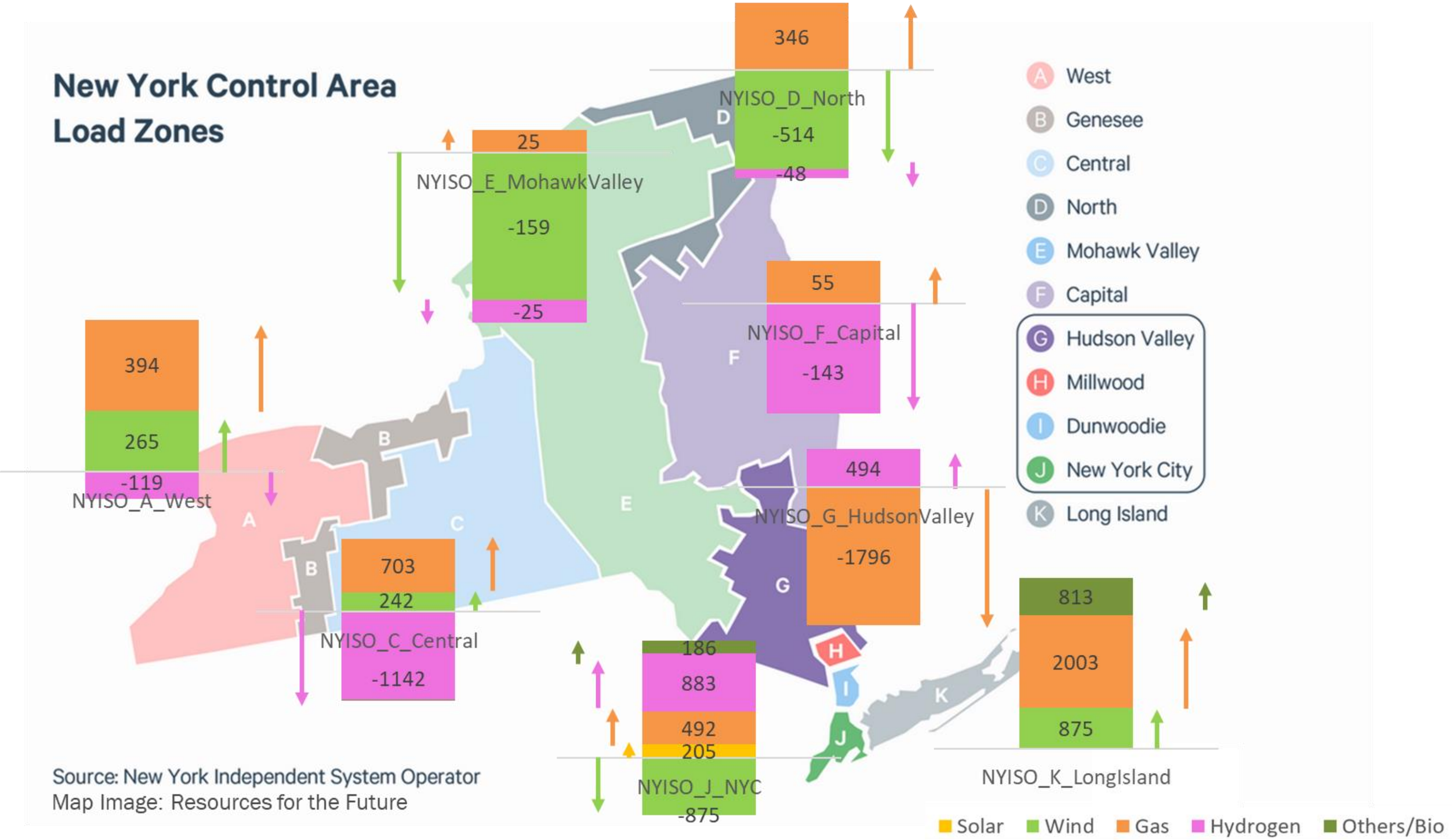
Capacity (MW)

- <100
- 100-400
- 400-800
- 800-1200
- 2400-2800
- 2800-3200
- >3200

Dots represent intra-zone transmission capacity

Transmission upgrades under the Decarbonization scenario are slightly lower than under the Reference Scenario (16.4 vs. 15.6 GW, respectively) and concentrated between fewer zones—primarily due to the widespread deployment of storage.

Decarbonization Scenario Generation Capacity Changes With and Without Tx Upgrades



In the Decarbonization Scenario, new transmission drives additional regional variation in optimal generation capacities across a wider range of technologies and NY zones.

Baseline Hosting Capacity

- Proxy system used for distribution analysis
- Baseline distribution grid
  - 124 feeders
  - 11 substations
  - 1.25 GW peak load
- Scaled to approximate New York study area

HC Results - Schematic

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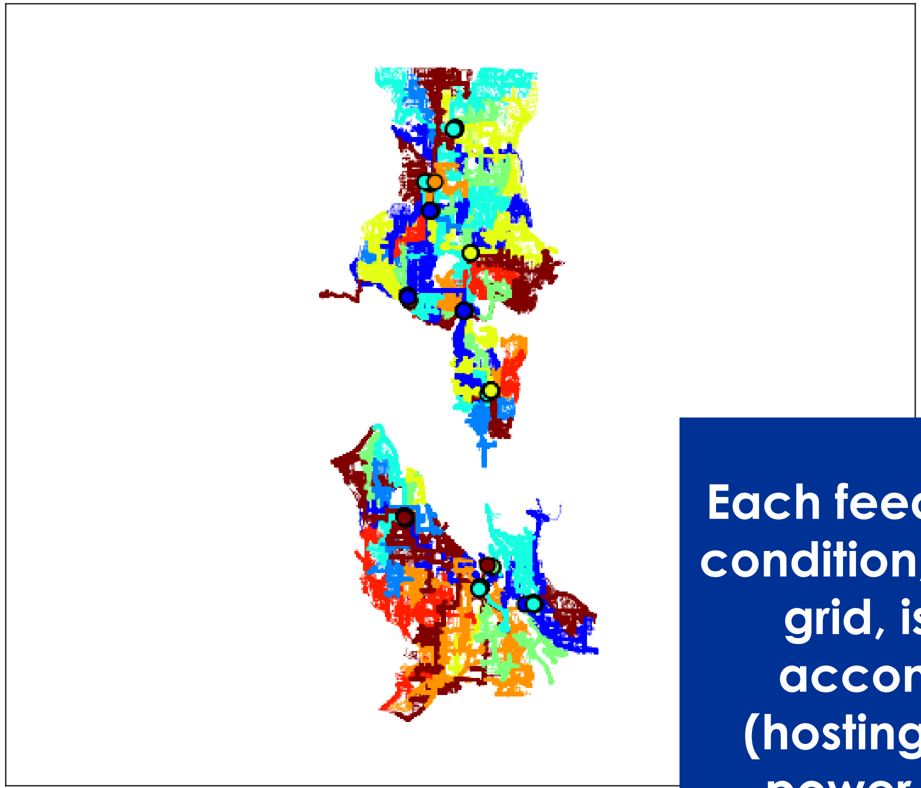
Show Details for Selected Substation

System View of Substation-level Hosting Capacity
124 Substations
Distributed



< 1.25 MW
1.25-2.5 MW
2.5-3.75 MW
3.75-5.0 MW
5.0-6.25 MW
6.25-7.5 MW
7.5-8.75 MW
> 8.75 MW

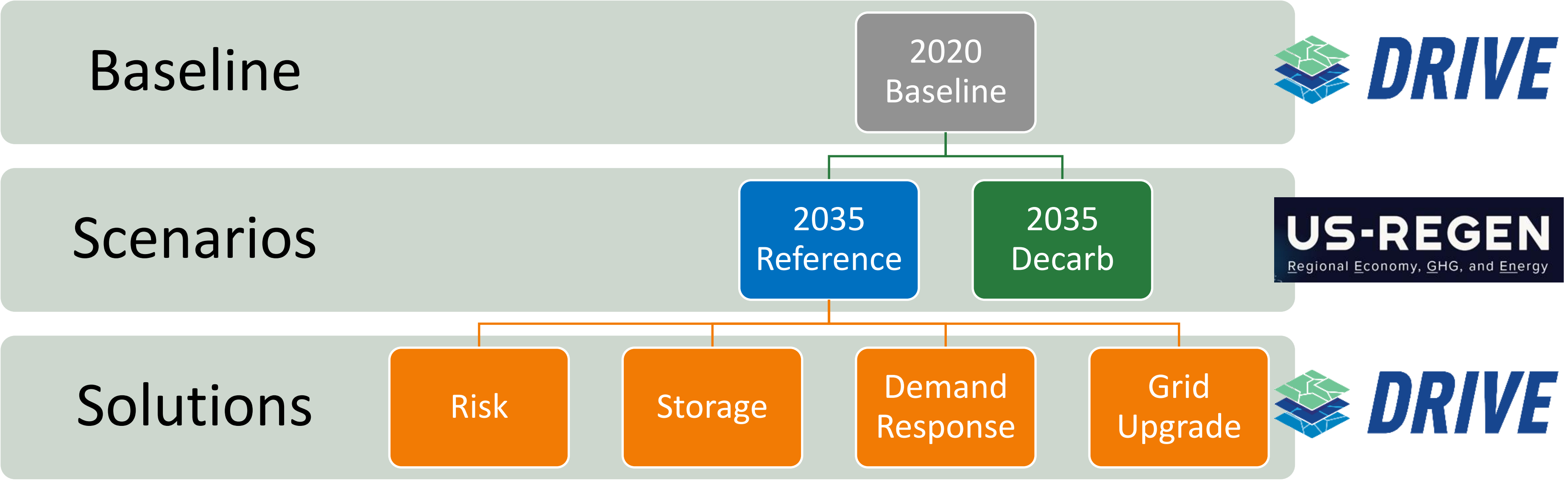
Issue	High	Mean	Low
Primary Over-Voltage	10.0	9.15	0.0
Primary Under-Voltage for Load	10.0	8.32	0.0
Thermal for Load	10.0	6.91	0.0
Thermal for Gen	10.0	9.77	2.2

Each feeder, in their current operating condition, across the entire distribution grid, is analyzed for its ability to accommodate future resources (hosting capacity) without causing power quality or reliability issues.

Distribution Analysis Design

Wide-Area Distribution Assessment (WADA)

- Baseline hosting capacity assessment – *Identify distribution grid's ability to accommodate future load/generation*
- Scenario development – *Leverage regional forecast and apply appropriately to the distribution grid to identify which feeders are constrained to projected growth*
- Integration solutions – *Identify valid mitigation options and costs for currently constrained feeders*
- **Iterate via ISSP Process**



Inputs: Baseline Dx grid model, ISSP scenario forecasts, ISSP study plan solutions to examine

Outputs: Optimal Dx solutions, Iterate across ISSP

Summary of Distribution Analysis

Reference Scenario

- Violations
  - 16% of feeders with violations from reference load/gen growth
- Solutions
  - Grid solutions are the costliest[1] on Dx
  - Risk is the cheapest analyzed solution
  - Further iteration across ISSP is necessary to optimize solutions across the entire grid

[1]Grid costs do not account for stacked benefits from additional substation capacity.
[2]Decarbonization scenario costs to not account for added environmental value.
[3]Communication and control management costs not considered.

	Risk	Storage[2]		Demand Response[2]		Grid Upgrade
	Capital	Capital	Annual	Capital	Annual	Capital
Total $	$ 10 M	$ 12 M	$ 303 k per year	$ 40 M	$ 9.5 M per year	$ 126 M

Decarbonization Scenario

- Violations
  - 23% of feeders with violations from reference load/gen growth
- Solutions
  - All solutions are costlier[3] in this scenario when not considering upstream value.
  - Risk is the cheapest analyzed solution
  - Further iteration across ISSP is necessary to optimize solutions across the entire grid
  - Optimizing across the entire grid will likely require a combination of solutions at the distribution level.

	Risk	Storage[2]		Demand Response[2]		Grid Upgrade
	Capital	Capital	Annual	Capital	Annual	Capital
Total $	$ 10 M	$ 48.4 M	$ 1.2 M per year	$ 61 M	$ 65.0 M per year	$ 196 M

Breadth and depth of solutions increase for the decarbonization scenario and creates impacts that further warrant iterative examination through the ISSP process.

Top 5 Lessons Learned from the NY Demonstration Study

- Regional technology planning provides an informed "starting point" for detailed unit-level capacity expansion and grid operations analyses. It reduces potential to miss key technology solutions that may be beneficial for a specific system.
- Nodal capacity expansion planning (vs. zonal) is important for integrated system planning; having site-specific generators and co-optimized nodal transmission reinforcements allows a direct follow-on system cost and reliability evaluation.
- Different methods for system cost & reliability analyses can lead to different, but complementary insights; a multi-step approach to testing potential deficiency of candidate resource portfolios can find robust solutions.
- The link between production cost modeling scenarios and ac feasible power flow solutions is critical to identify potential network reliability issues when planning future resource portfolios.
- Improving reliability does not de facto come at a higher cost. Economic transmission upgrades can offset higher fixed and other costs under certain conditions, and in cases result in lower total costs.

Publicly Available Deliverables Coming Soon – www.epri.com/issp

- ISSP Framework, Case Study & Key Insights
- Existing Approaches for Integrated Planning: A Review of Recent Studies
- A Brief Review of Select Existing Tools for Integrated Planning
- Linking Capacity Expansion, Resource Adequacy, & Production Cost Modeling Tools
- Linking Power Flow Analysis Tools with Production Cost Modeling Tools
- Distribution Planning Perspective in Integrated Planning
- Integrated Planning Framework: A Distribution Perspective of Process, Capabilities, & Data

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