2021 Economic Study: Future Grid Reliability Study Phase 1

Preliminary Production Cost Results – Part 2

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SPECIAL STUDIES AND INTERREGIONAL PLANNING

Introduction

- On March 12, 2021, NEPOOL submitted the Future Grid Reliability Study Phase 1 as a 2021 Economic Study Request
- On April 1, 2021, ISO New England accepted the request and will perform the FGRS as the 2021 Economic Study
- Part one of study assumptions were presented by the ISO at the April 2021 PAC meeting; part two at the May 2021 PAC meeting; part three at the June 2021 PAC meeting
- Today's presentation will cover the second round of initial production cost simulation results. Part one of the preliminary results were presented at the June PAC meeting

Introduction, cont.

- “It’s tough to make predictions, especially about the future.” – Yogi Berra
- The FGRS will provide directional results and trends to help guide discussion on how to prepare for the future grid

2021 Economic Study Past Presentations & Materials

Presentation & Materials	Date (Link)
ISO-NE's Economic Studies Reference Guide	
Production Cost Simulations Preliminary Results (Part 1)	June 17, 2021
High-level draft scope of work and assumptions (Part 3)	June 17, 2021
High-level draft scope of work and assumptions (Part 2)	May 14, 2021
High-level draft scope of work and assumptions (Part 1)	April 14, 2021
FGRS Assumptions Table Submitted to ISO-NE	March 31, 2021
FGRS Framework Document Submitted to ISO-NE	March 31, 2021

- Further historical presentations made at the joint MC/RC meetings in 2020 and 2021 can be found on the ISO website
- Acronyms used in this presentation can be found in Appendix II

MATRIX SCENARIOS

Assumption Refresher

How to Read the Matrix Table & Scenario Names

There are three types of assumptions in FGRS that are paired together in different combinations to create the matrix scenarios:

- *Scenario (S) Assumptions* – Retirements, Onshore Wind Additions, Threshold Price Order, Transmission Topology, and Load Profiles
  - Note: there are other assumptions, but they are in common amongst Scenarios 1-3
- *Load (L) Assumptions* – Gross Load, Energy Efficiency, Heating and Transportation Electrification Magnitudes
- *Resource (R) Assumptions* – Solar, Offshore Wind, and Energy Storage Additions
- **Example:** Scenario 1, Load 2, Resource 3 (S1_L2R3) has:
  - Scenario 1's Retirements, Onshore Wind Additions, Threshold Price Order, Transmission Topology, Load Profile
  - Scenario 2's Gross Load, Energy Efficiency, Heating and Transportation Electrification Magnitudes
  - Scenario 3's Solar, Offshore Wind, and Energy Storage Magnitudes

GridView Matrix

Describes 40 Scenarios Reading "Down and Across"*

	(Resource 1) OSW 8,000 MW PV 16,000 MW** BESS 2,000 MW**	(Resource 2) OSW 8,000 MW PV 22,000 MW** BESS 3,940 MW**	(Resource 3) OSW 17,000 MW PV 28,000 MW** BESS 600 MW**
(Load 1) Buildings 9,600 GWh Transport 7,300 GWh	**(5 Scenarios)** **Matrix Scenario 1 plus** **Alternatives A, C, D and E** Scenario 2 (Resource 1 and Load 1)* Scenario 3 (Resource 1 and Load 1)*	(3 Sensitivity Scenarios) Scenario 1 (Resource 2 and Load 1) Scenario 2 (Resource 2 and Load 1) Scenario 3 (Resource 2 and Load 1)	(3 Sensitivity Scenarios) Scenario 1 (Resource 3 and Load 1) Scenario 2 (Resource 3 and Load 1) Scenario 3 (Resource 3 and Load 1)
(Load 2) Buildings 6,600 GWh Transport 18,500 GWh	(3 Sensitivity Scenarios) Scenario 1 (Resource 1 and Load 2) Scenario 2 (Resource 1 and Load 2) Scenario 3 (Resource 1 and Load 2)	**(5 Scenarios)** **Matrix Scenario 2 plus** **Alternatives A, C, D and E** Scenario 1 (Resource 2 and Load 2)* Scenario 3 (Resource 2 and Load 2)*	(3 Sensitivity Scenarios) Scenario 1 (Resource 3 and Load 2) Scenario 2 (Resource 3 and Load 2) Scenario 3 (Resource 3 and Load 2)
(Load 3) Buildings 38,900 GWh Transport 40,000 GWh	(3 Sensitivity Scenarios) Scenario 1 (Resource 1 and Load 3) Scenario 2 (Resource 1 and Load 3) Scenario 3 (Resource 1 and Load 3)	(3 Sensitivity Scenarios) Scenario 1 (Resource 2 and Load 3) Scenario 2 (Resource 2 and Load 3) Scenario 3 (Resource 2 and Load 3)	**(6 Scenarios)** **Scenario 3 plus** **Alternatives A, B, C, D and E** Scenario 1 (Resource 3 and Load 3)* Scenario 2 (Resource 3 and Load 3)*

* Additional matrix scenarios

** "DER" values in previous presentations were split to better reflect assumptions spreadsheet

Naming Convention for Cases

	R1 OSW 8,000 MW PV 16,000 MW BESS 2,000 MW	R2 OSW 8,000 MW PV 22,000 MW BESS 3,940 MW	R3 OSW 17,000 MW PV 28,000 MW BESS 600 MW
L1 Buildings 9,600 GWh Transport 7,300 GWh	S1_L1R1, S2_L1R1*, S3_L1R1* S1_L1R1_A S1_L1R1_C S1_L1R1_D S1_L1R1_E	S1_L1R2 S2_L1R2 S3_L1R2	S1_L1R3 S2_L1R3 S3_L1R3
L2 Buildings 6,600 GWh Transport 18,500 GWh	S1_L2R1 S2_L2R1 S3_L2R1	S1_L2R2*, S2_L2R2, S3_L2R2* S2_L2R2_A S2_L2R2_C S2_L2R2_D S2_L2R2_E	S1_L2R3 S2_L2R3 S3_L2R3
L3 Buildings 38,900 GWh Transport 40,000 GWh	S1_L3R1 S2_L3R1 S3_L3R1	S1_L3R2 S2_L3R2 S3_L3R2	S1_L3R3*, S2_L2R2*, S3_L3R3 S3_L3R3_A S3_L3R3_B S3_L3R3_C S3_L3R3_D S3_L3R3_E

* Additional matrix scenarios

Import Priority Threshold Prices

Threshold Prices Prioritizing Imports:

- Triggers exports, curtail renewables when export capability is exhausted
- Referred to as "Import Priority"
- Used in S1
- Note: only Alternative A will have an additional tie-line to facilitate energy banking

Price-Taking Resource	Threshold Price ($/MWh)	Priority
Imports on New Tie Line	-5	First Curtailed
Trigger for Exports on New Line	-25	↓
Onshore Wind	-35	
Offshore Wind	-40	
FCM and Energy-only PV	-45	
Imports from Canada over Existing Lines	-50	
NECEC	-99	
Behind-the-Meter PV	-100	Last Curtailed

Threshold prices are used to facilitate the analysis of load levels where the amount of $0/MWh resources exceeds the system load

- They are not indicative of "true" cost, expected bidding behavior or the preference for one type of resource over another
- Use of a different order for threshold prices than indicated will produce different outcomes, particularly curtailment by resource

Load Assumptions

*Total Peak load is the max coincident peak value for summer and winter after profiles are combined
**Net Peak load is the total load after the BTM profile is added to the load profile
† BTM PV is a resource assumption but added to this slide to show 'net' load profile effect
†† BTM PV could be curtailed during simulation, so final Net Min Load could be higher

Item	Resource	S1_L1R1 (Peak, MW)	S1_L1R1 (Energy, TWh)	S1_L2R2 (Peak, MW)	S1_L2R2 (Energy, TWh)	S1_L3R3 (Peak, MW)	S1_L3R3 (Energy, TWh)
A	Gross Summer Peak	33,707	172.6	33,707	172.6	33,707	172.6
B	Gross Winter Peak	27,970		27,970		27,970	
C	Energy Efficiency	6,777	37.7	6,777	37.7	6,777	37.7
D	Transportation Electrification	1,817	7.3	3,578	17.9	9,956	40.0
E	Heating Electrification	5,214	9.6	2,991	5.4	22,250	38.9
F (=A – C + D + E)	Total Summer Peak*	28,060	151.3	30,316	158.2	35,711	213.8
G (=B – C + D + E)	Total Winter Peak*	25,767		26,971		43,816	
H (=A – C + D + E)	Total Minimum Load*	11,202		11,863		14,102	
J	BTM Solar†	7,681	10.3	11,899	15.6	12,671	16.9
K (=F – J)	Net Summer Peak**	26,555	141.1	28,317	142.7	33,162	196.9
L (=G – J)	Net Winter Peak **	25,767		26,971		43,814	
M (=H – J)	Net Minimum Load**††	8,562		6,745		8,427	

Resource Assumptions

	R1 Nameplate MW	R1 Energy TWh**	R2 Nameplate MW	R2 Energy TWh**	R3 Nameplate MW	R3 Energy TWh**
Onshore Wind*	2,585	8.56	2,585	8.56	2,585	8.56
Offshore Wind	8,029	32.67	8,029	32.41	16,662	69.95
PV (BTM)	7,681	10.29	11,899	15.56	12,671	16.90
PV (Utility)	8,091	10.84	10,650	11.55	15,467	20.65

*Onshore wind is considered a scenario assumption, and does not change between S1 runs
**Energy values are all pre-curtailment

	R1 (Capacity, MW)	R1 (Capacity, GWh)	R2 (Capacity, MW)	R2 (Capacity, GWh)	R3 (Capacity, MW)	R3 (Capacity, GWh)
Battery Storage	2,000	7.5	3940	12.5	600	2.3
Pumped Storage	1,763	11.5	1,763	11.5	1,763	11.5

LMPs during an Energy Shortfall

- In FGRS, some scenarios will have a shortfall of resources to serve load. During these times an LMP of $5,455/MWh is applied
- $5,455/MWh is the Capacity Performance Payment Rate June 1, 2025 and thereafter under the Tariff (III.13.7.2.5). The Capacity Performance Payment Rate is imposed if a Capacity Scarcity Condition occurs. This is analogous to an energy shortfall is a Production Cost Simulation

FOLLOW-UP FROM JUNE PAC

Responses to stakeholder comments/questions and other updates from June results presentation

Dispatchable Generation During Curtailment

- During the June PAC presentation ISO presented a series of graphs that showed the impact of “profiled” resources (wind, solar, hydro) and demand (gross load, energy efficiency, electric vehicles, etc.). These profiles showed dispatchable units still producing during times of curtailment (when “zero-cost” resources are available)
  - ISO investigated this and there was a graphing issue causing some of these results
  - However, sometimes dispatchable units are on during curtailment of resources due to unit commitment constraints

Definition of LSEEE

- LSEEE is calculated by summing, at each location, the load multiplied by the corresponding LMP in each hour
  - Note: Negative LMPs will lower annual LSEEE
- LSEEE is a metric that was historically intended to represent the cost of energy to customers. This metric now doesn't account for many costs to consumers outside the wholesale LMP
- This metric may have less relevance during the 2021 economic study since the total cost to consumers is not fully represented

Revision to Reflect 2019 Weather Year

- Since the June PAC meeting presentation on preliminary results, it was discovered the 2015 weather year load shape had continued to be used
- Updated results in today's presentation fully reflect the 2019 weather year

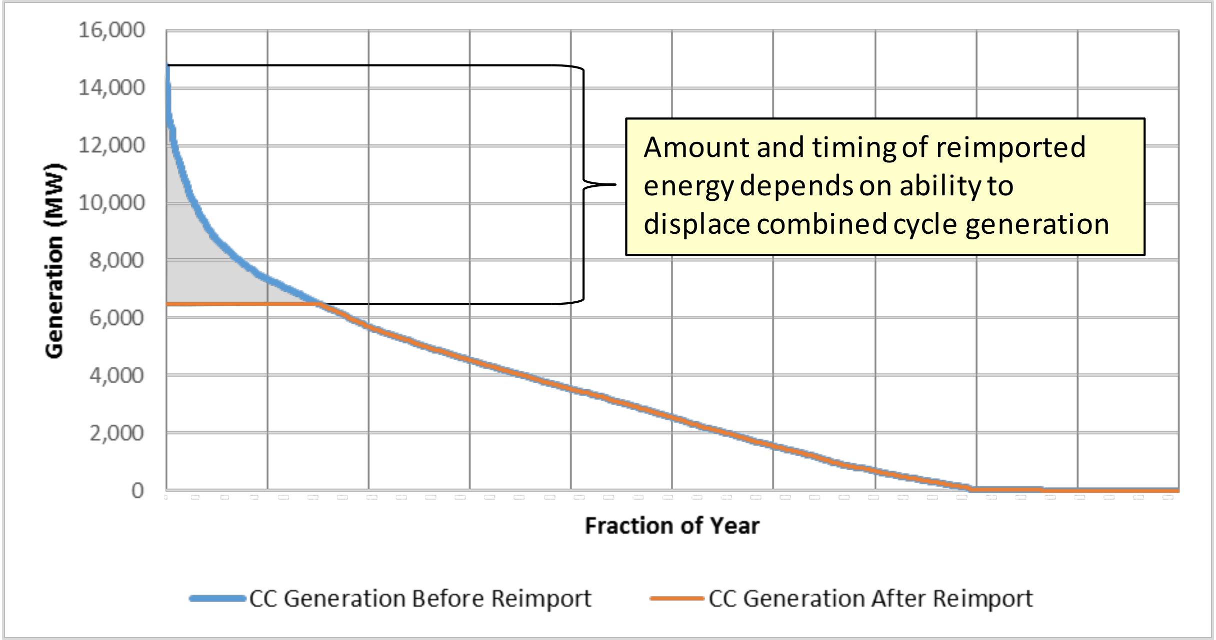
The Distribution of Photovoltaics in Resource 3

- The solar PV resources as part of resource set 3 (R3) are distributed as follows by RSP zone:
  - For states where there is a single RSP zone PV is allotted as it was in the MA Decarbonization Roadmap study for the year 2040
  - For states where there is more than one RSP zone PV is allotted by RSP zone following the distribution of queue projects as of April 1, 2021
- PV distributions for each resource set is detailed in the Appendix I

Alternative Scenario A: Energy Banking and Return

- Investigate banking of carbon free energy via Québec
  - One new tie line to the CMA/NEMA RSP zone
    - Function is only to facilitate bi-directional transmission for banking
    - Unconstrained capability in both directions
- In the first iteration exports to Québec on the new tie line
- In the second iteration, banked energy is made available
  - Banked energy made available at times of highest combined cycle dispatch in first iteration
  - Expectation is all the banked energy can be absorbed in New England

Banked Energy Returned
Displaces Least Efficient Combined Cycle Generation



LOAD & RESOURCE PROFILES

Monthly Profiles

Scenario 1 Load and Resource Profiles

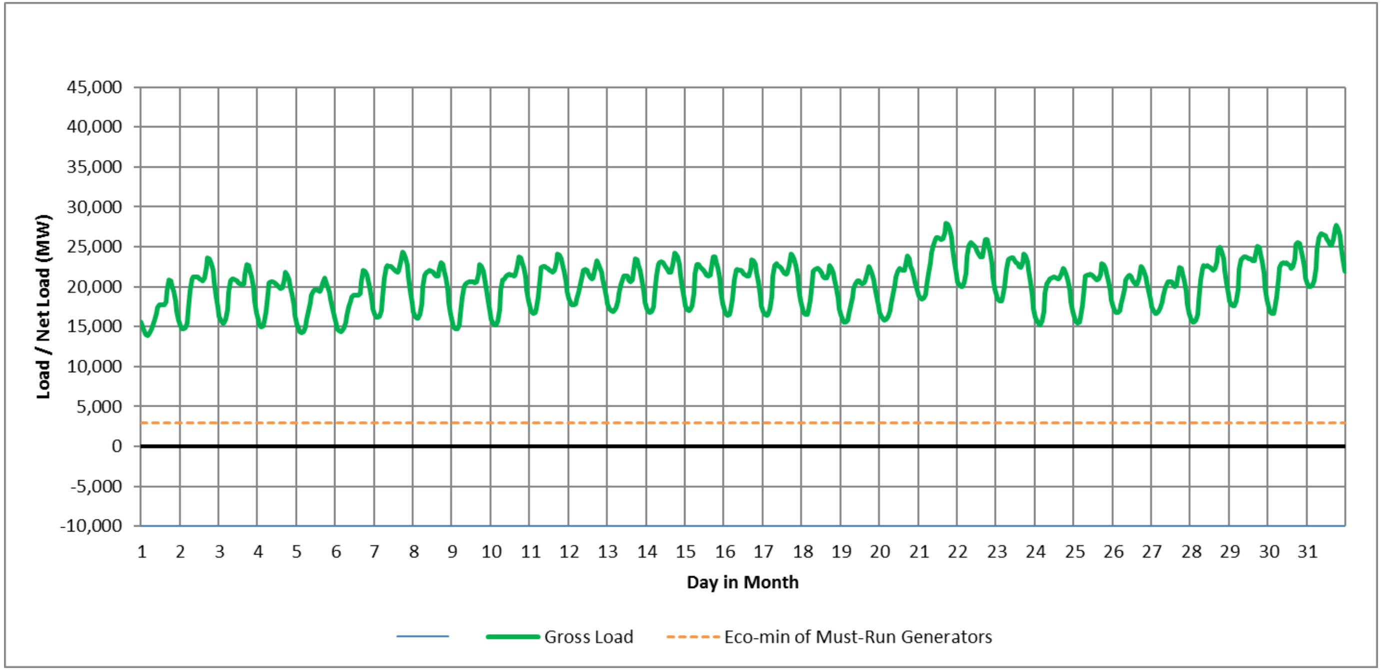
- The following slides for January and April illustrate:
  - In scoping this study, proponents requested various amounts of resources and loads and these profiles
    - Provide a visual indication of their magnitudes
    - How much customer load energy is served by dispatchable generation
  - The impact of energy storage
  - The amount of curtailment and or unserved energy
  - S1_L3R1 – January: Selected to show unserved energy
  - S1_L1R3 – April: Selected to show curtailment
- Note: The titles on the following slides describe the change in remaining load for dispatchable resources going from the previous blue line to a new green line with latest profile

S1_L3R1 JANUARY 2040 PROFILE

High Electrification Loads, Lower Renewables, Winter Peak

Scenario 1 L3R1 – January 2040

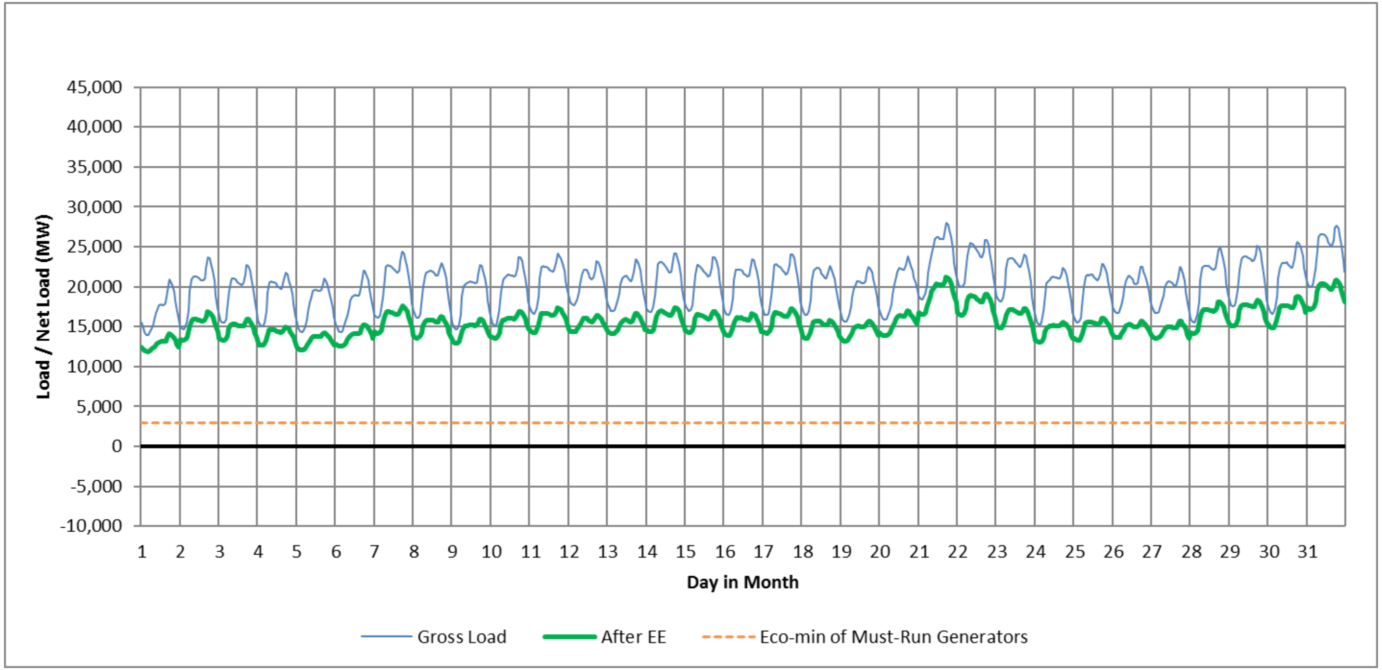
Gross Load



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

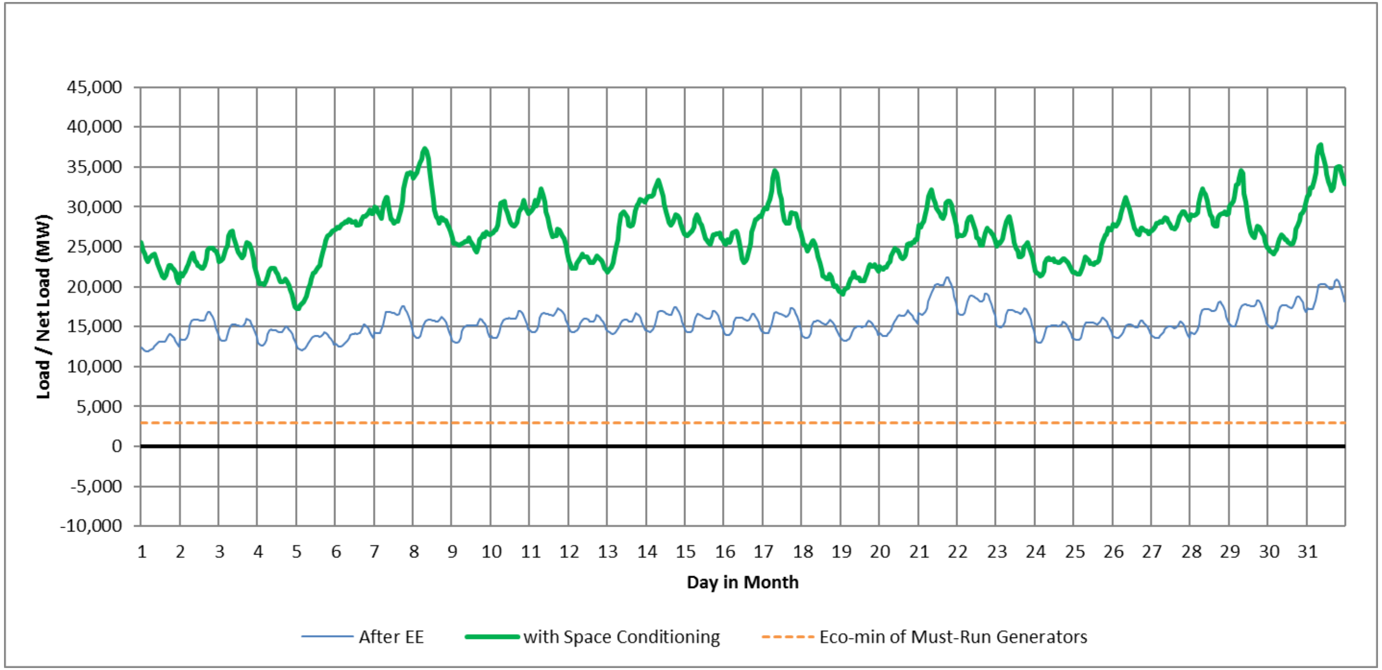
Gross Load to After Energy Efficiency (EE)



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

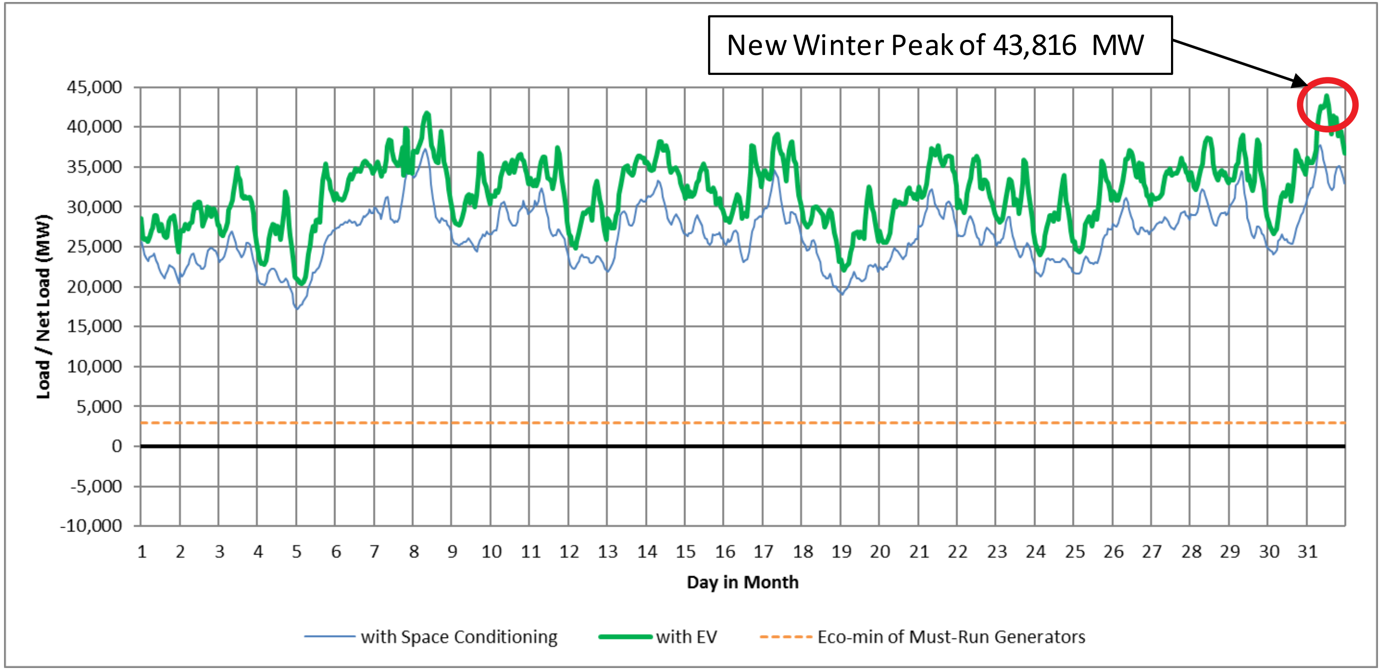
After EE to After Space Conditioning Electrification



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

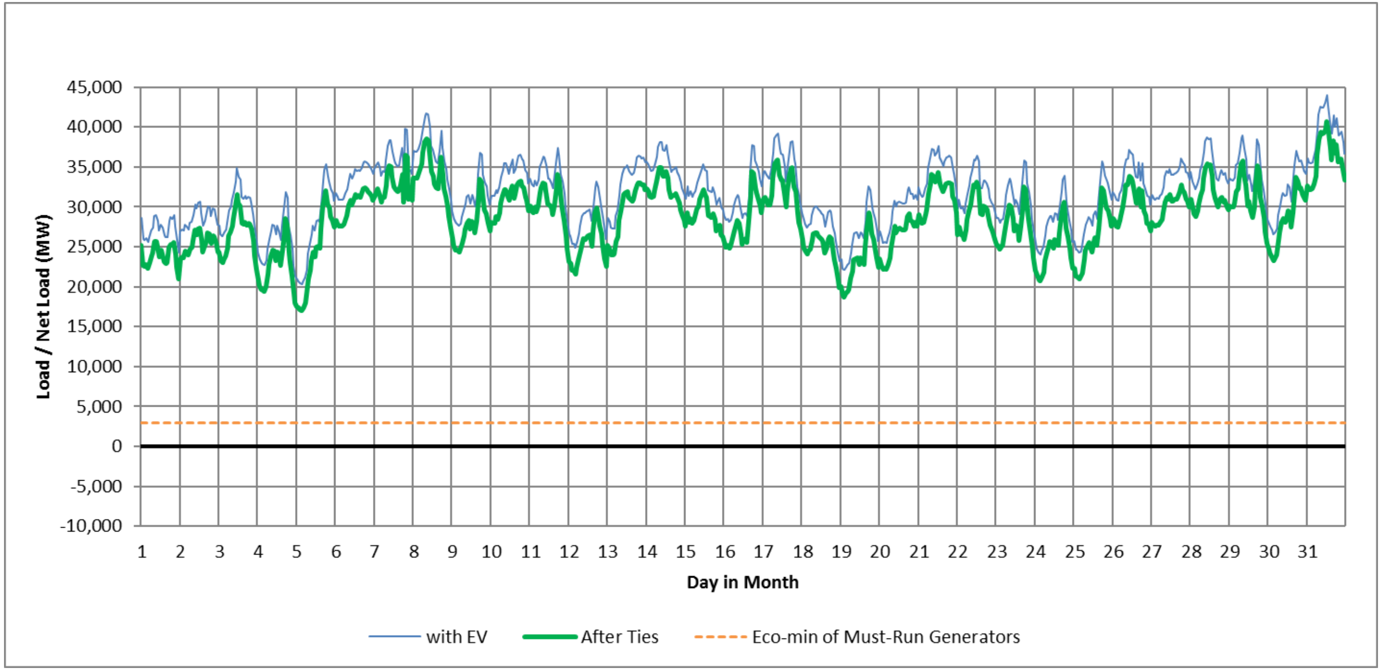
After Space Conditioning Electrification to After EVs



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

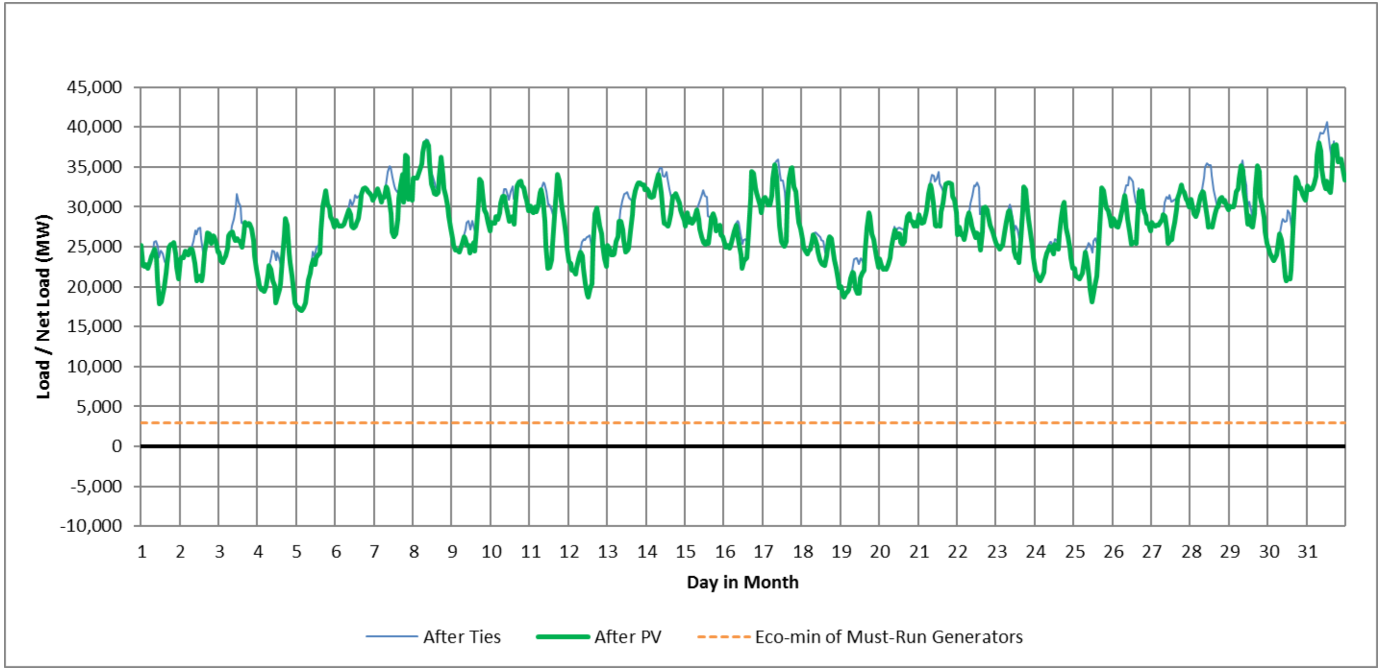
After EVs to After All Imports



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

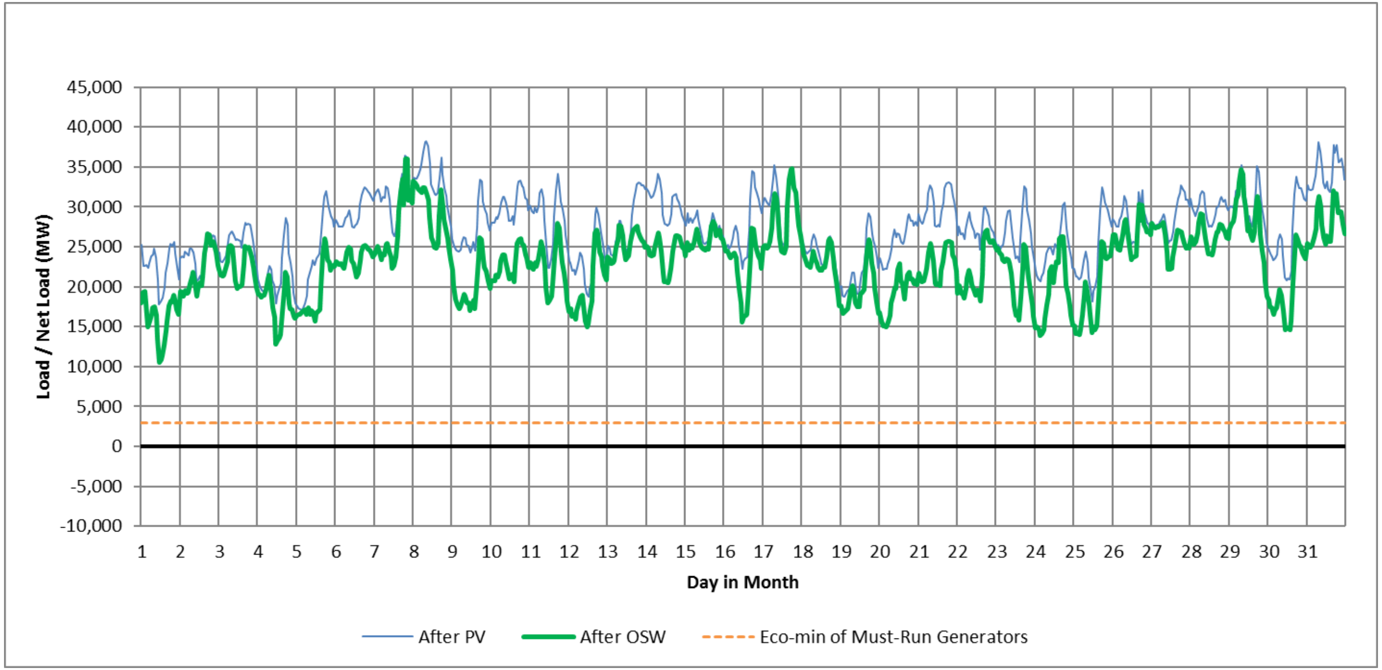
After All Imports to After PV



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

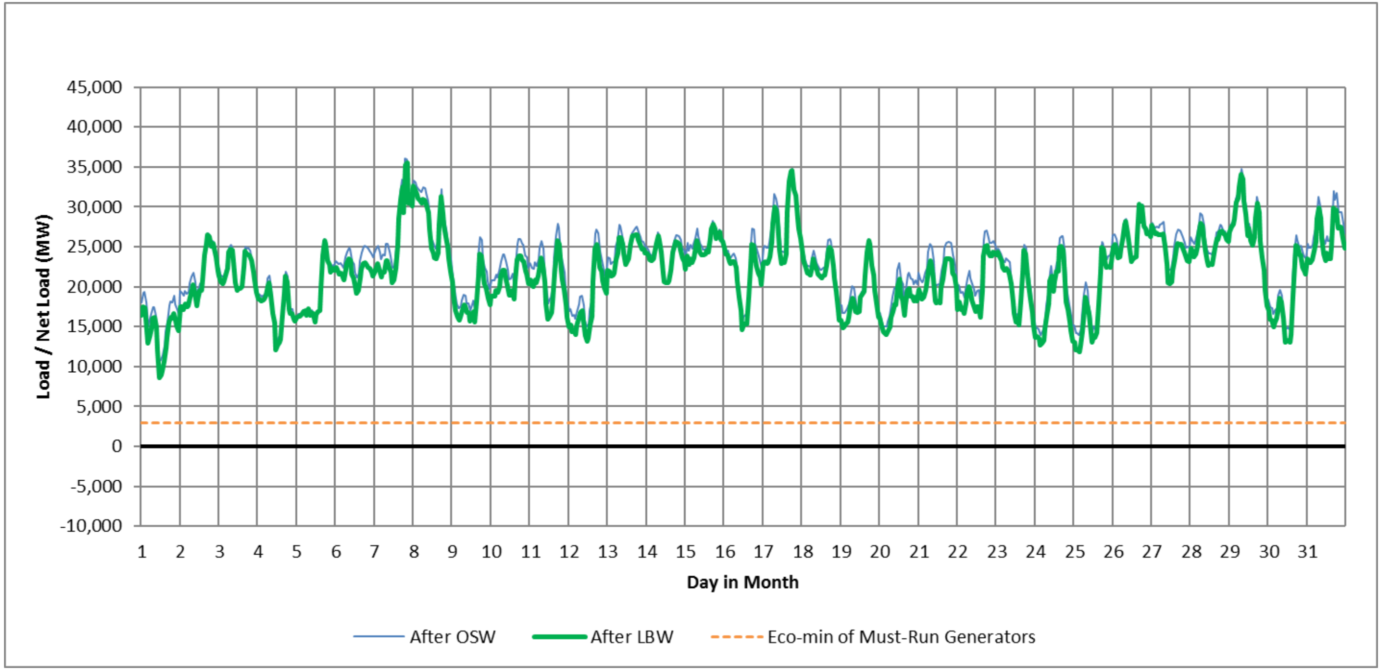
After PV to After OSW



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

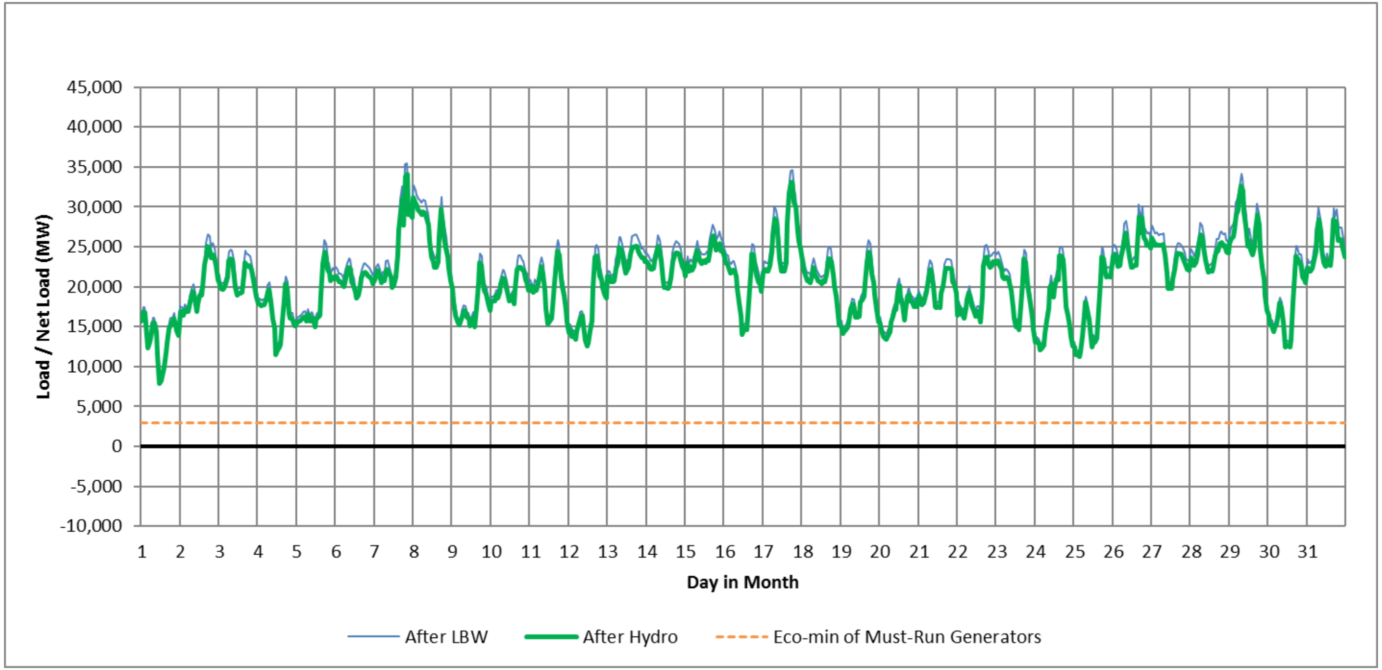
After OSW to After LBW



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

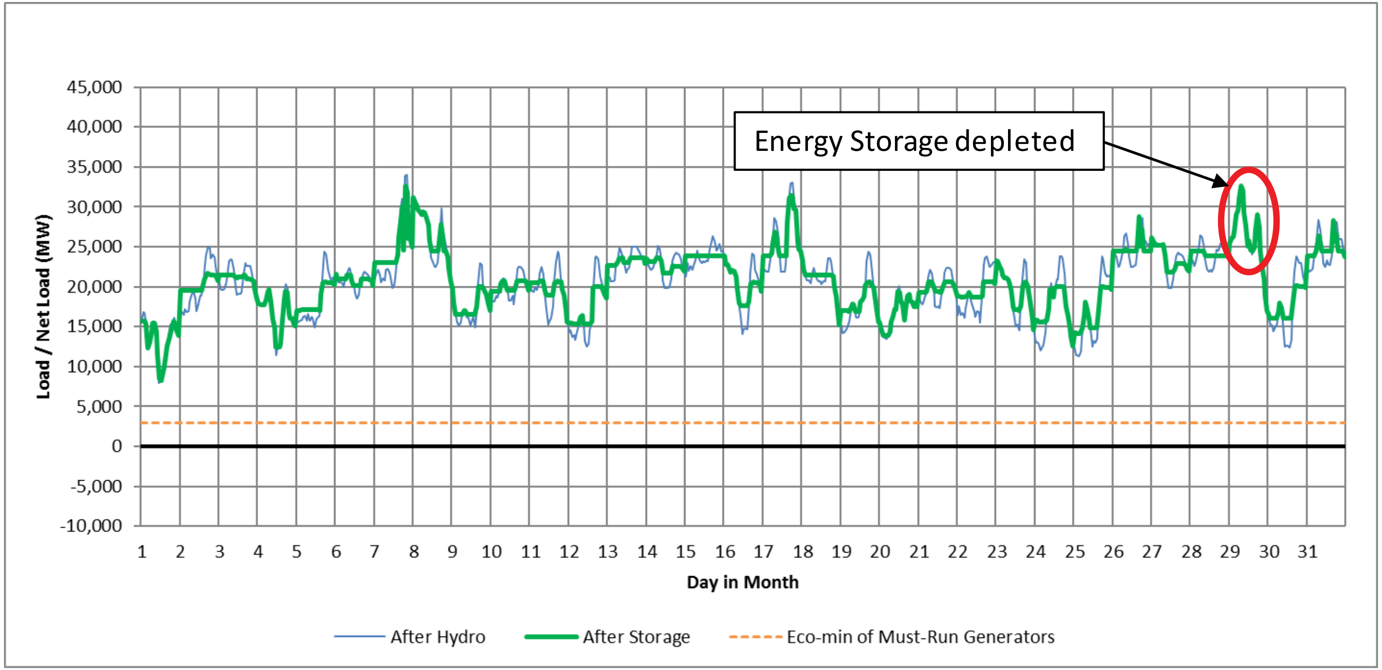
After LBW to After Hydro



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

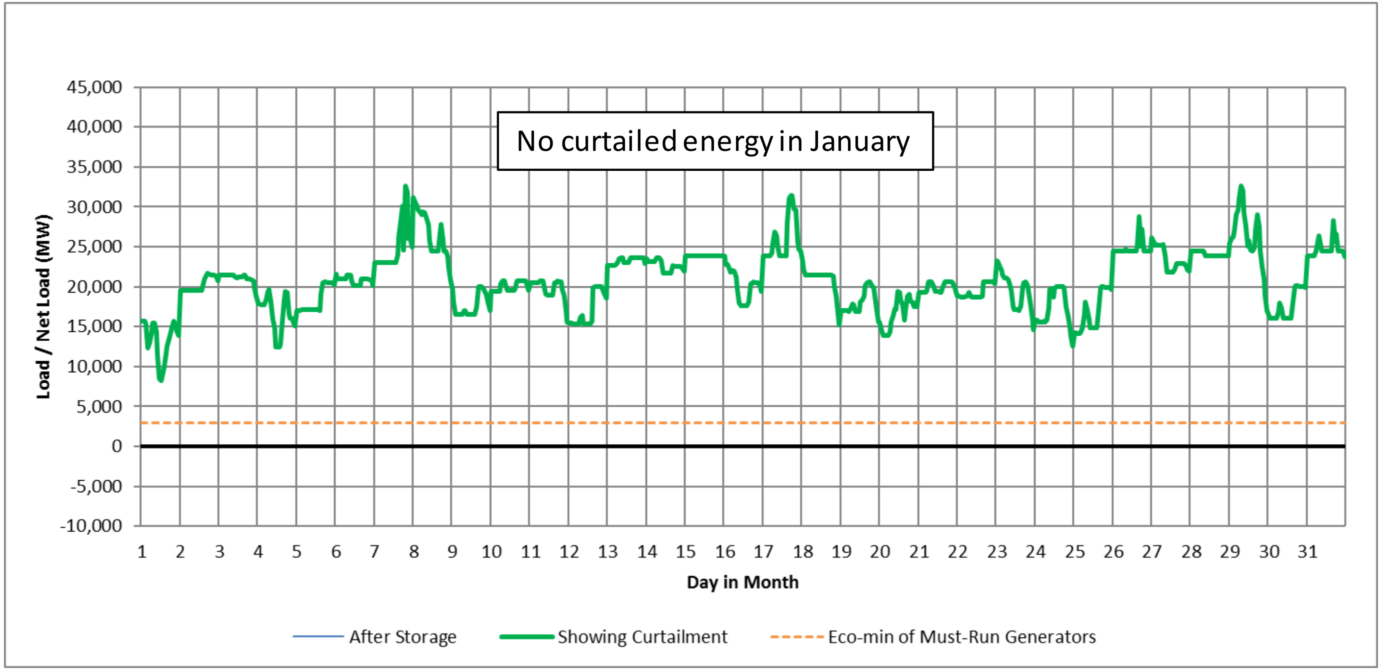
After Hydro to After Energy Storage



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

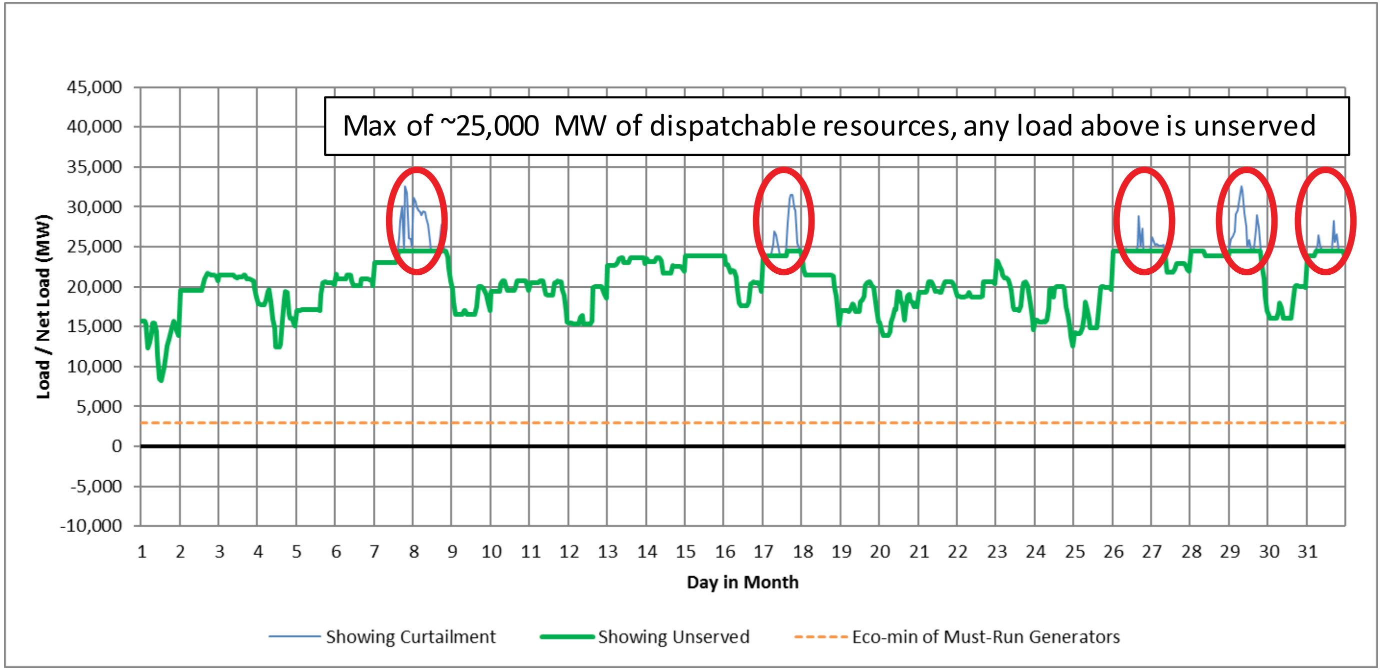
After Energy Storage to Showing Curtailments



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

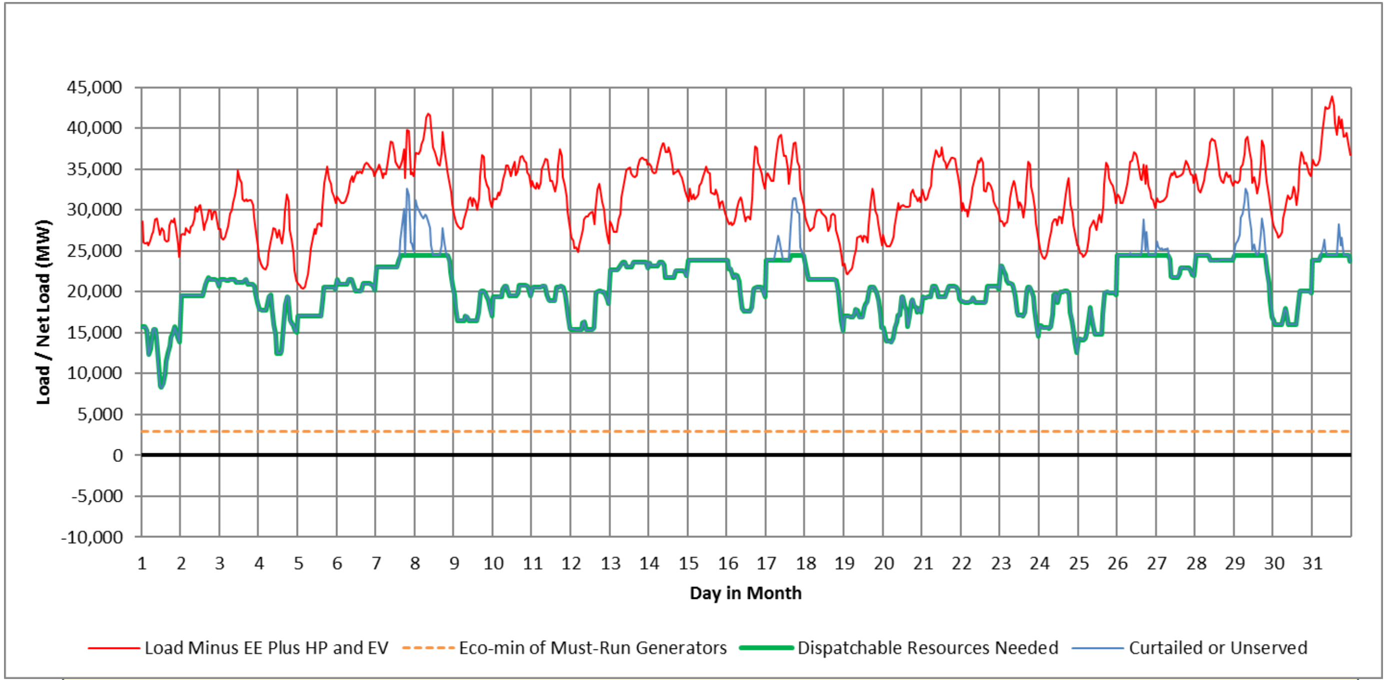
Showing Curtailments to Showing Unserved Energy



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L3R1 – January 2040, cont.

Total Load, Dispatchable Resources, Curtailments, and Must-Run



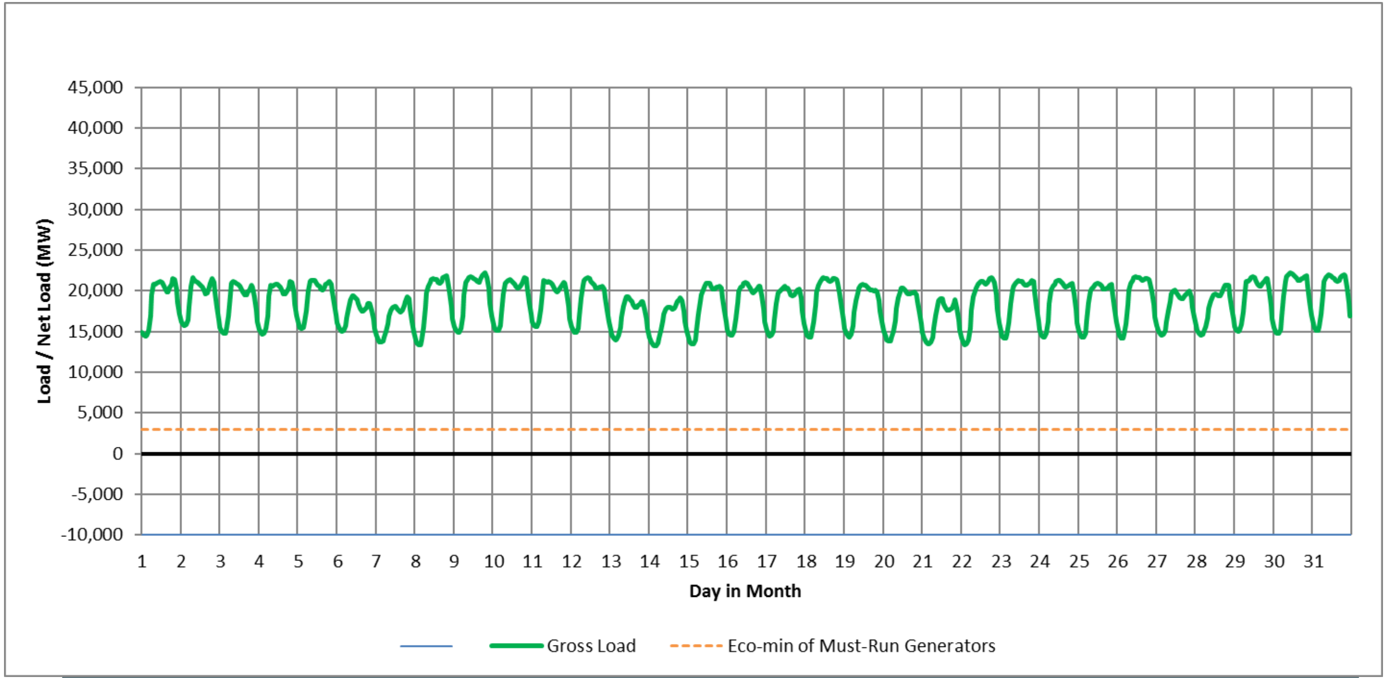
Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

S1_L1R3 APRIL 2040 PROFILE

Lower Electrification Loads, High Renewables, Shoulder Season

Scenario 1 L1R3 – April 2040

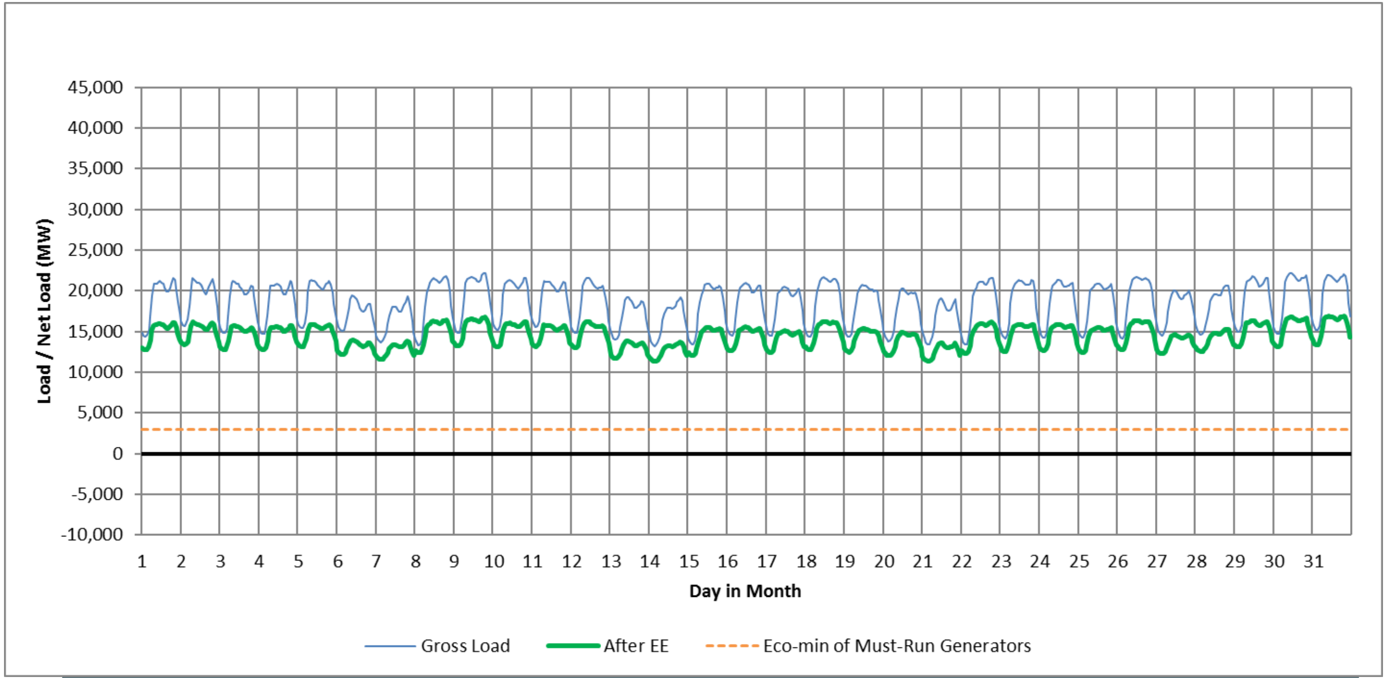
Gross Load



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

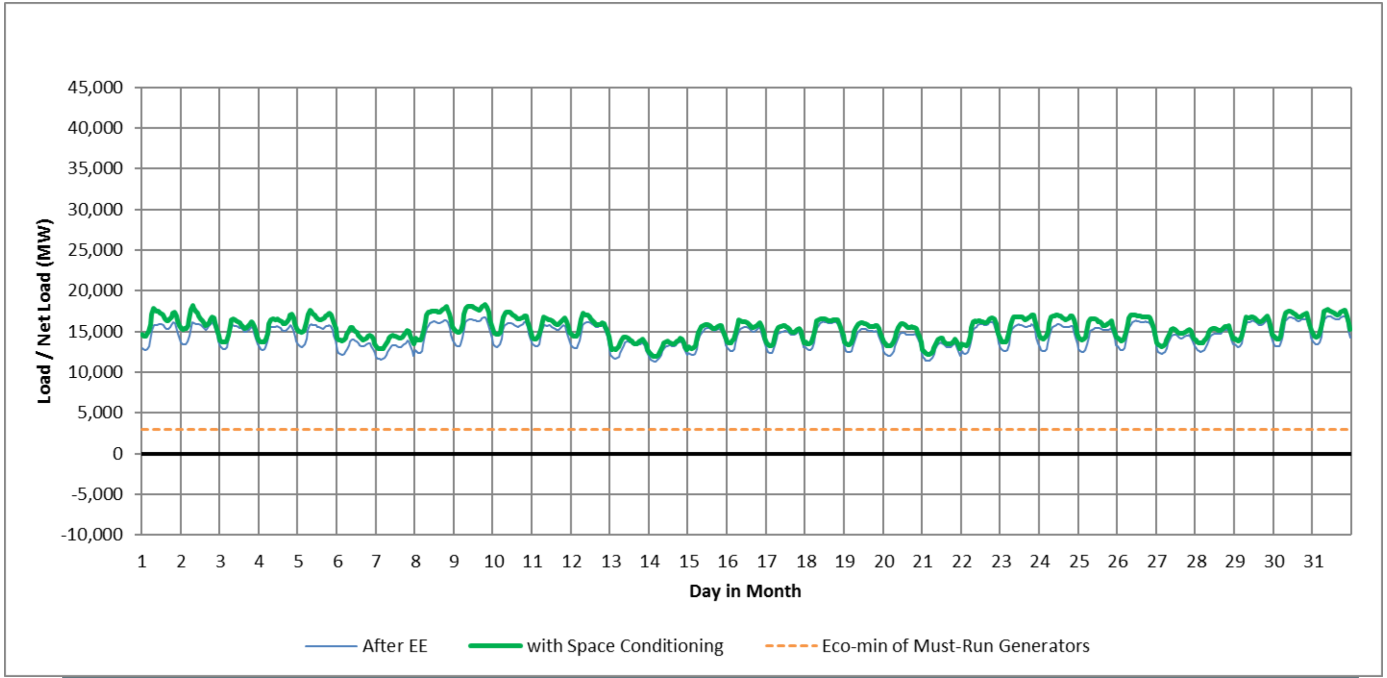
Gross Load to After EE



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

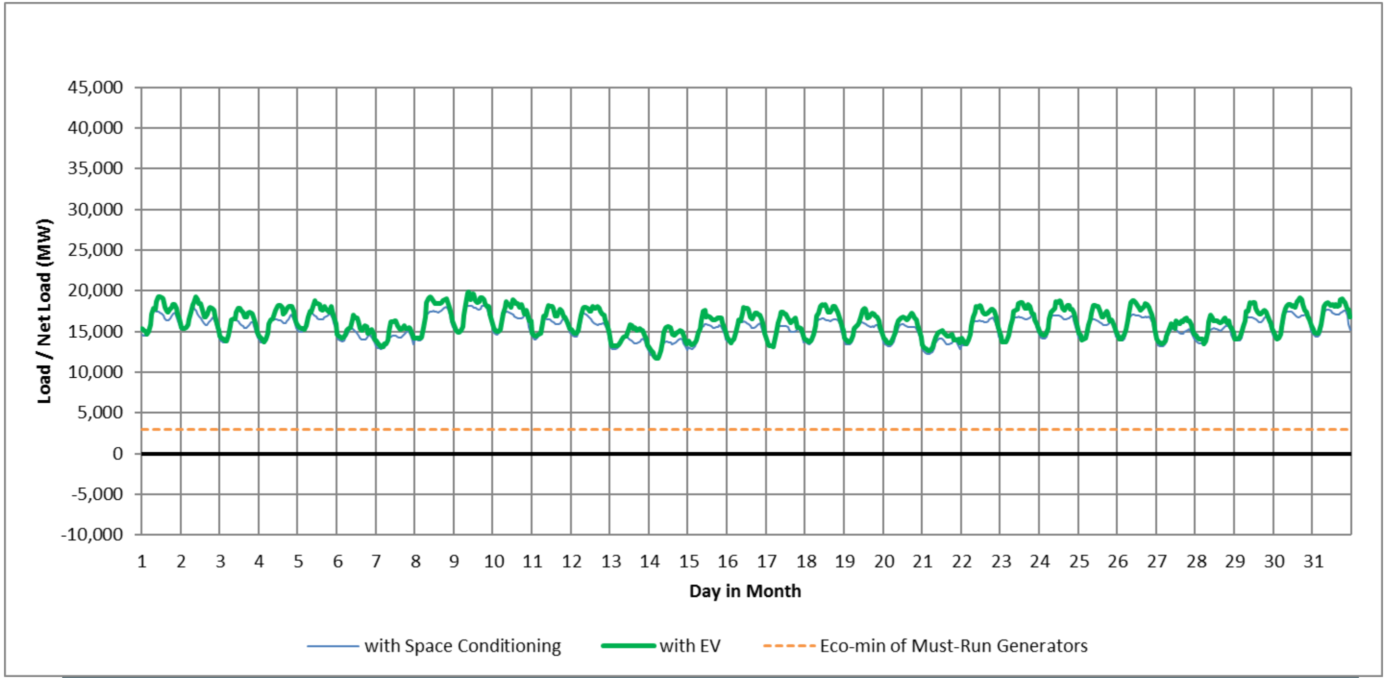
After EE to After Space Conditioning Electrification



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

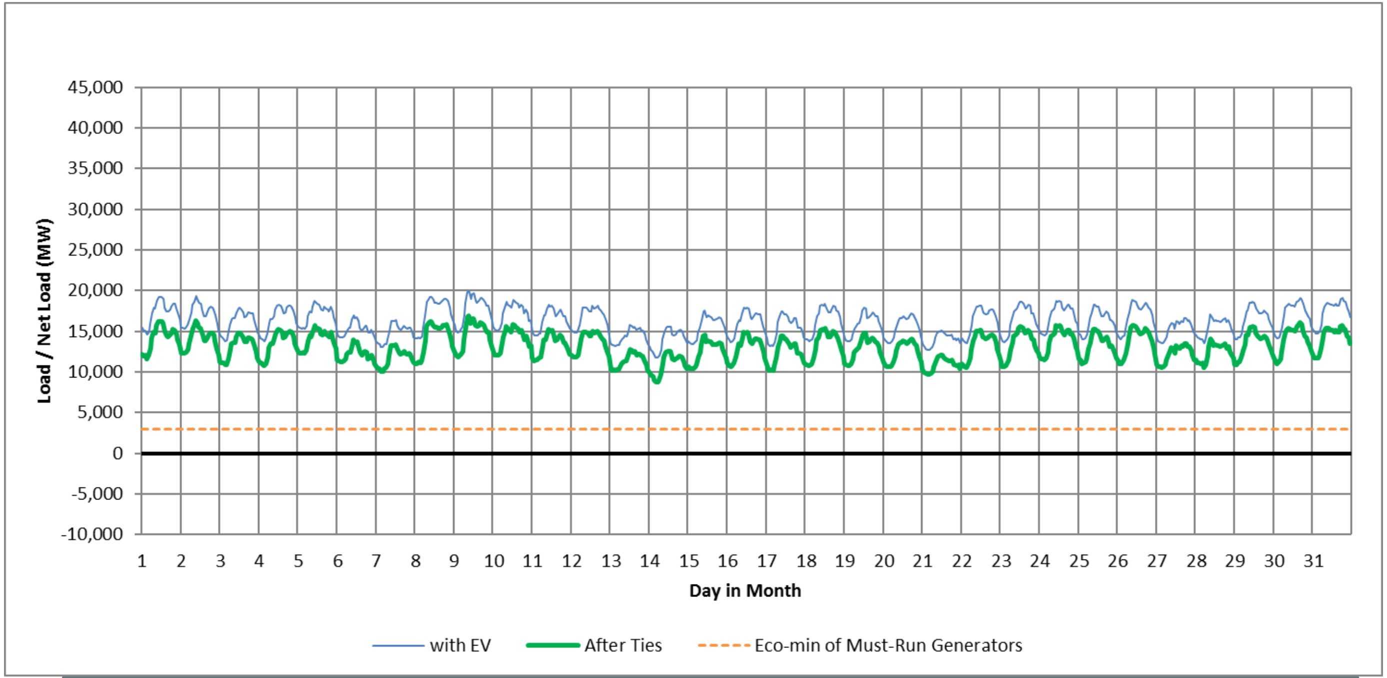
After Space Conditioning Electrification to After EVs



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

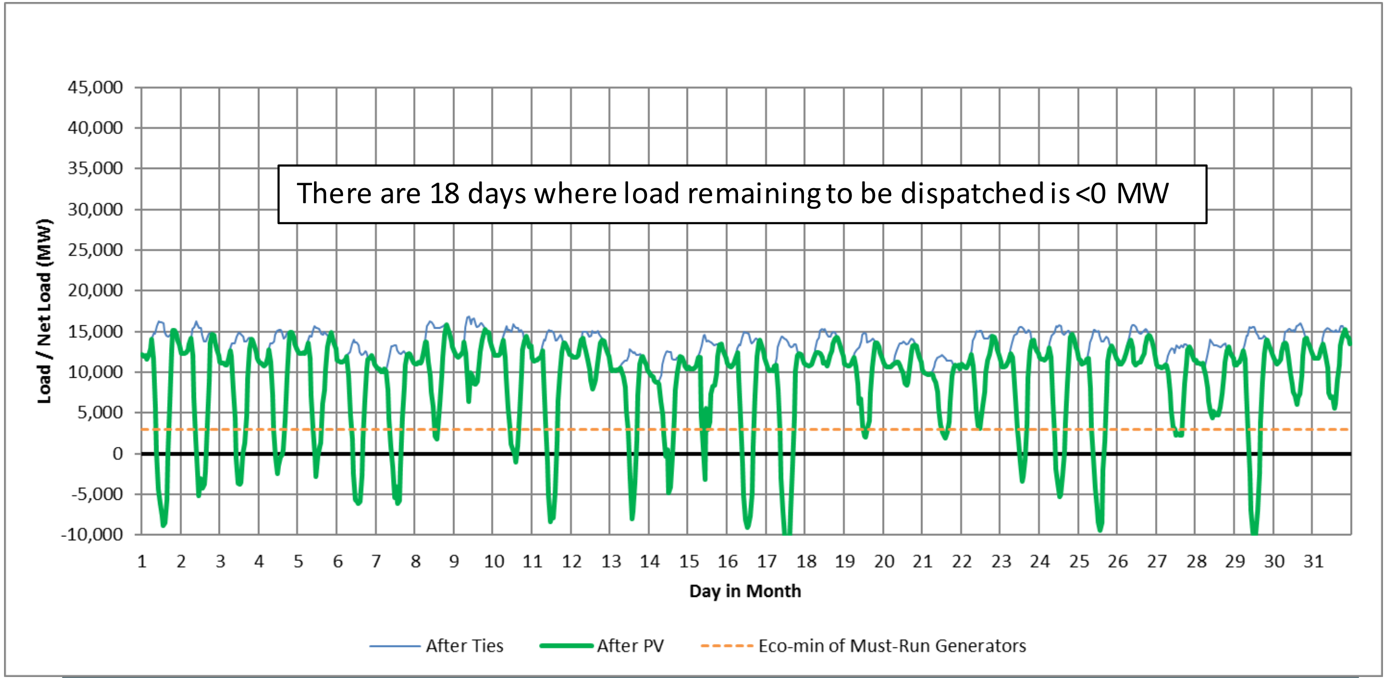
After EVs to After All Imports



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

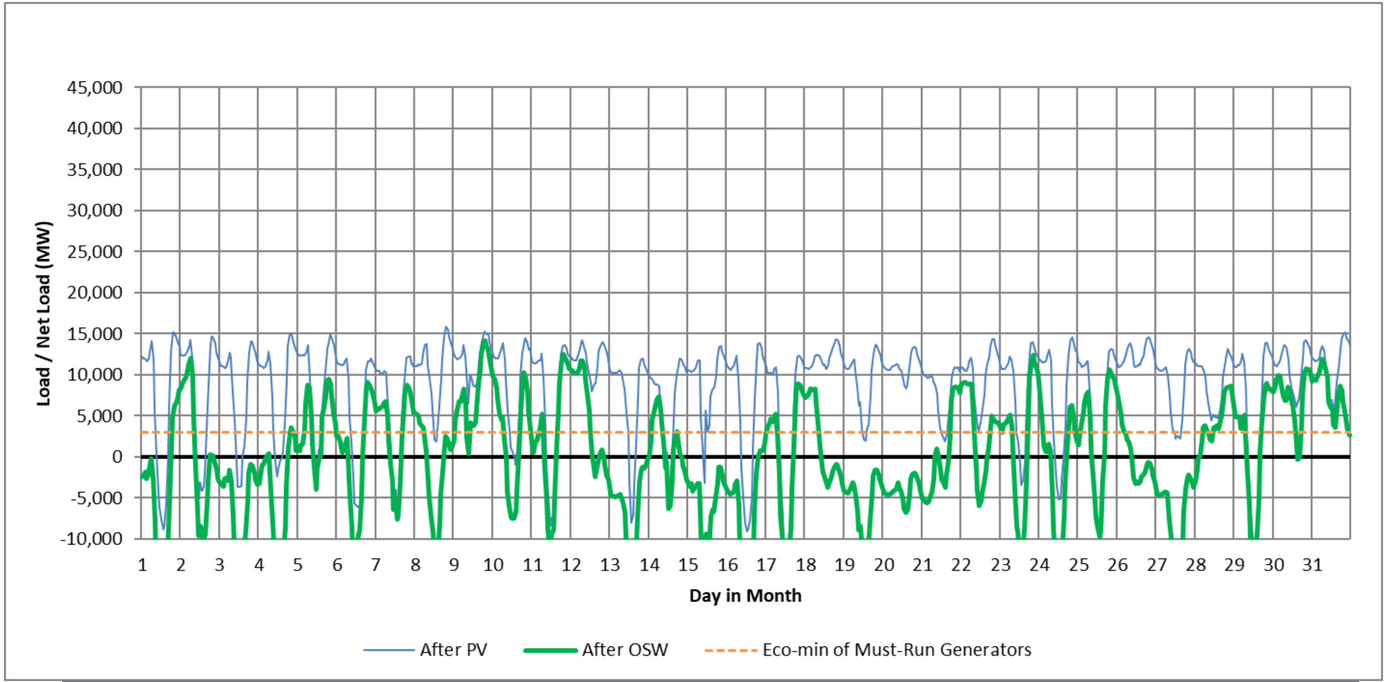
After All Imports to After Solar Photovoltaics (PV)



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

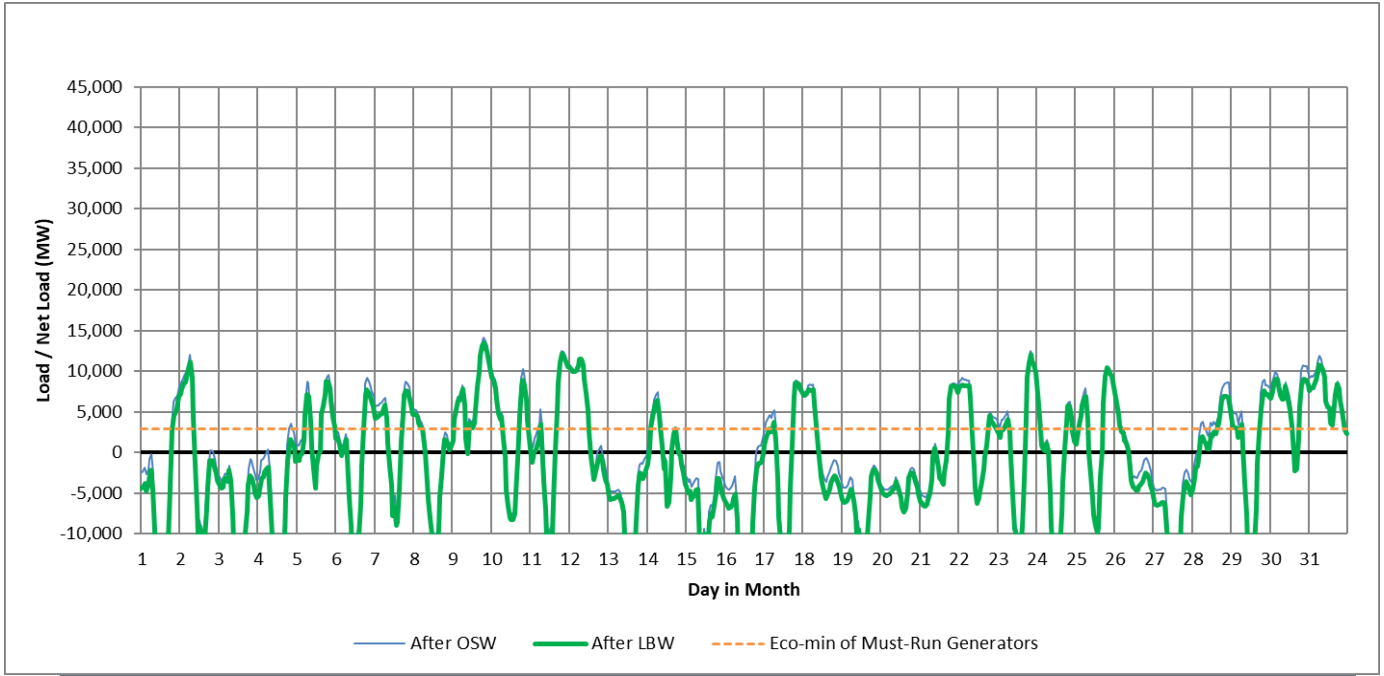
After PV to After OSW



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

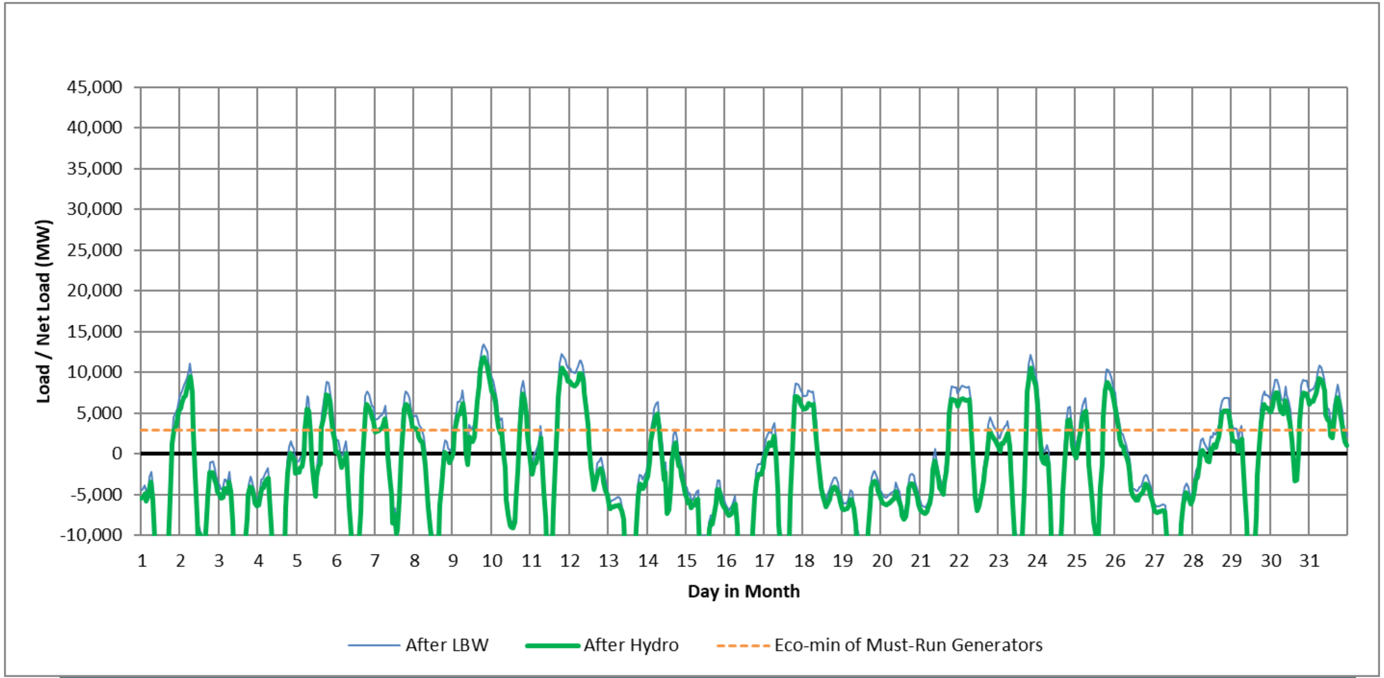
After OSW to After LBW



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

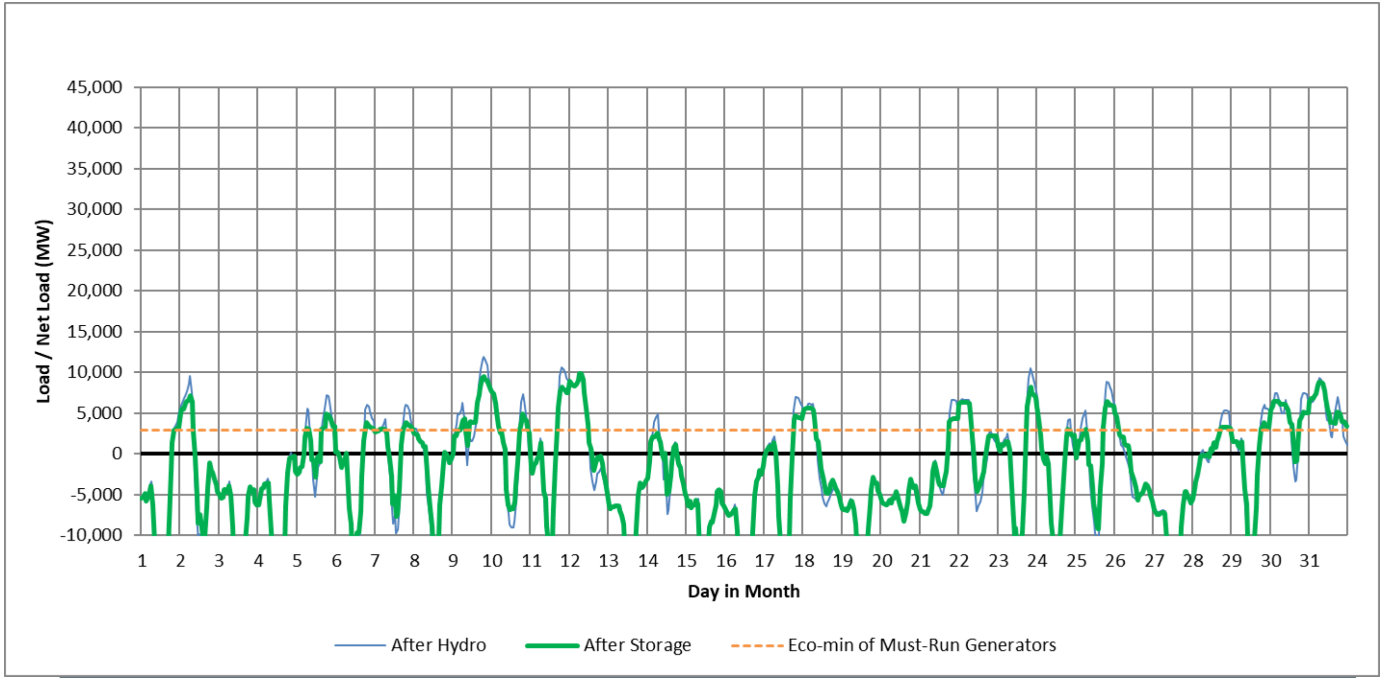
After LBW to After Hydro



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

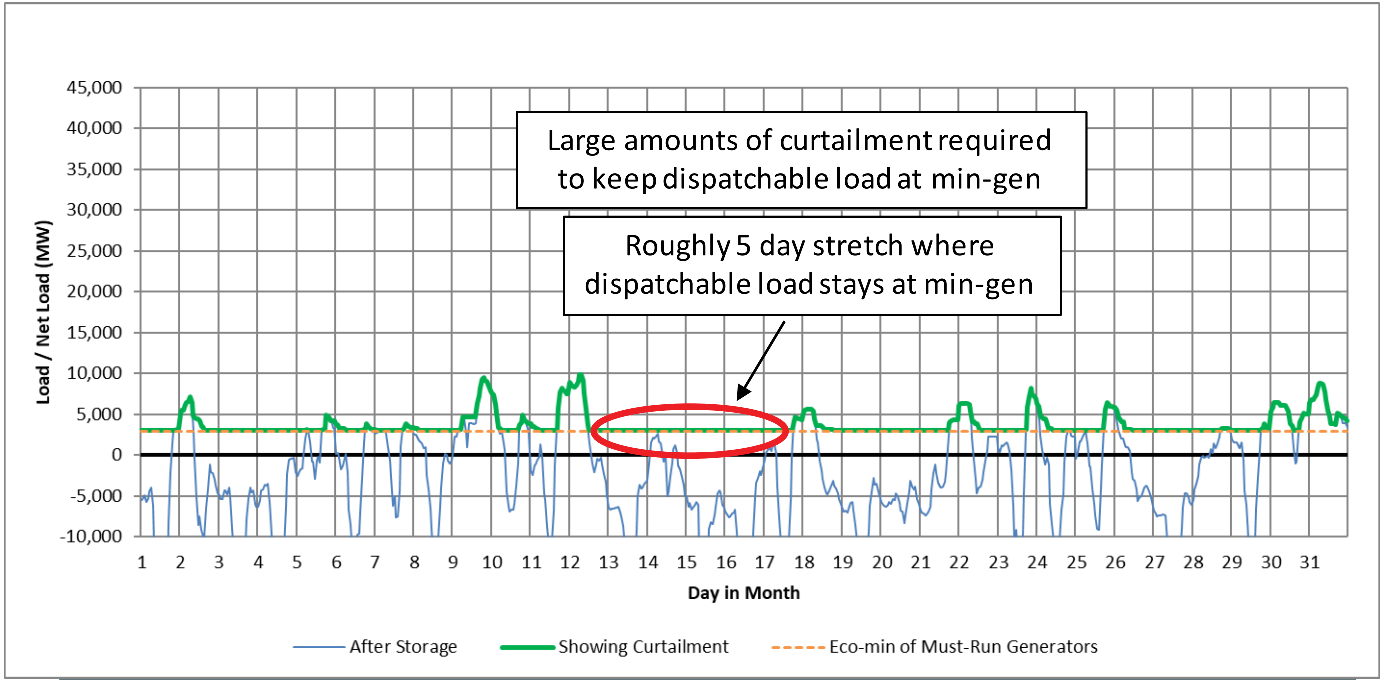
After Hydro to After Energy Storage



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

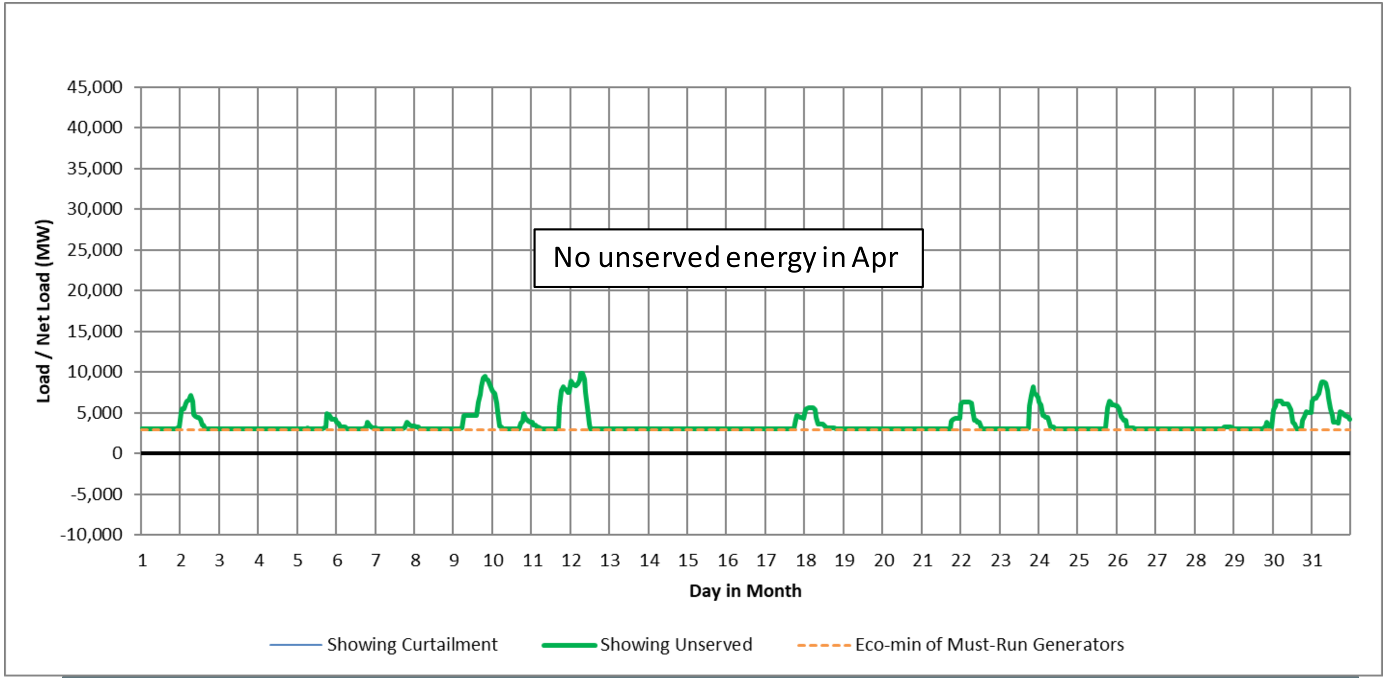
After Energy Storage to Showing Curtailments



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

Scenario 1 L1R3 – April 2040, cont.

Showing Curtailments to Showing Unserved Energy



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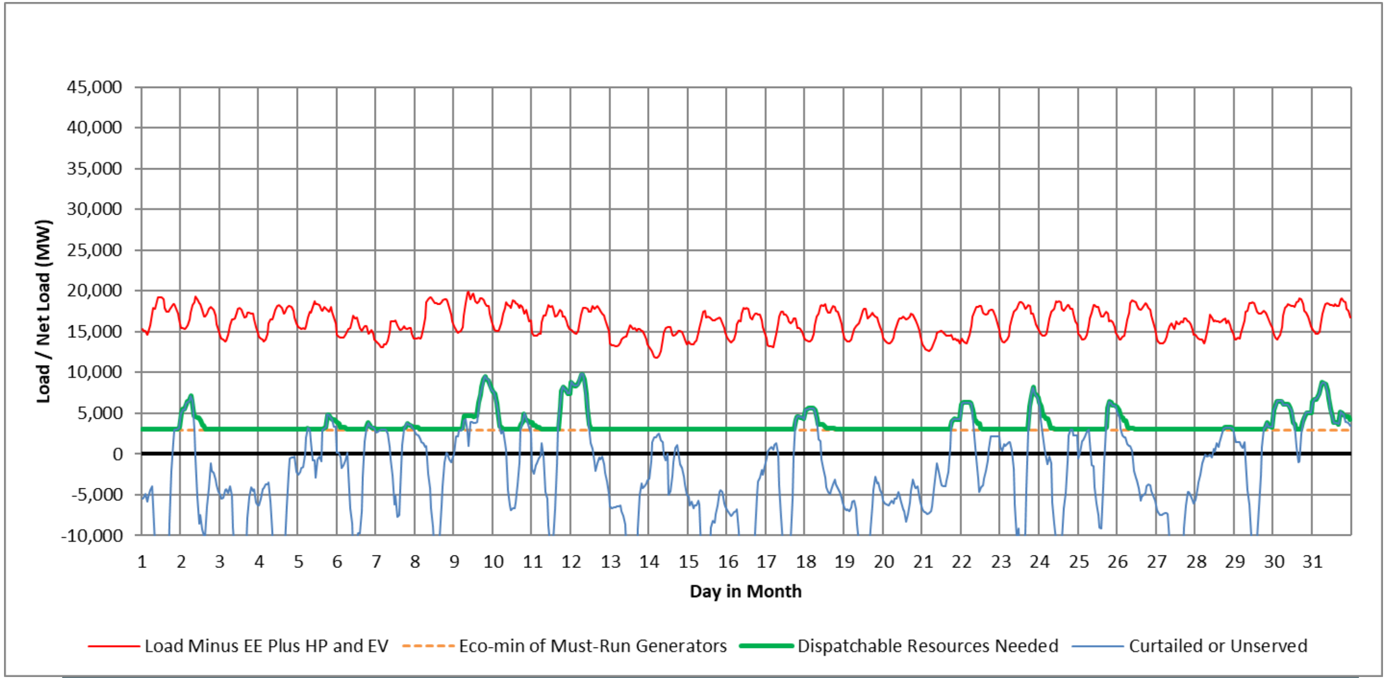
Scenario 1 L1R3 – April 2040, cont.

Total Load, Dispatchable Resources, Curtailments, and Must-Run



Sequences presented only to illustrate relative amounts of resources and electrification in requested scenario

PRELIMINARY RESULTS

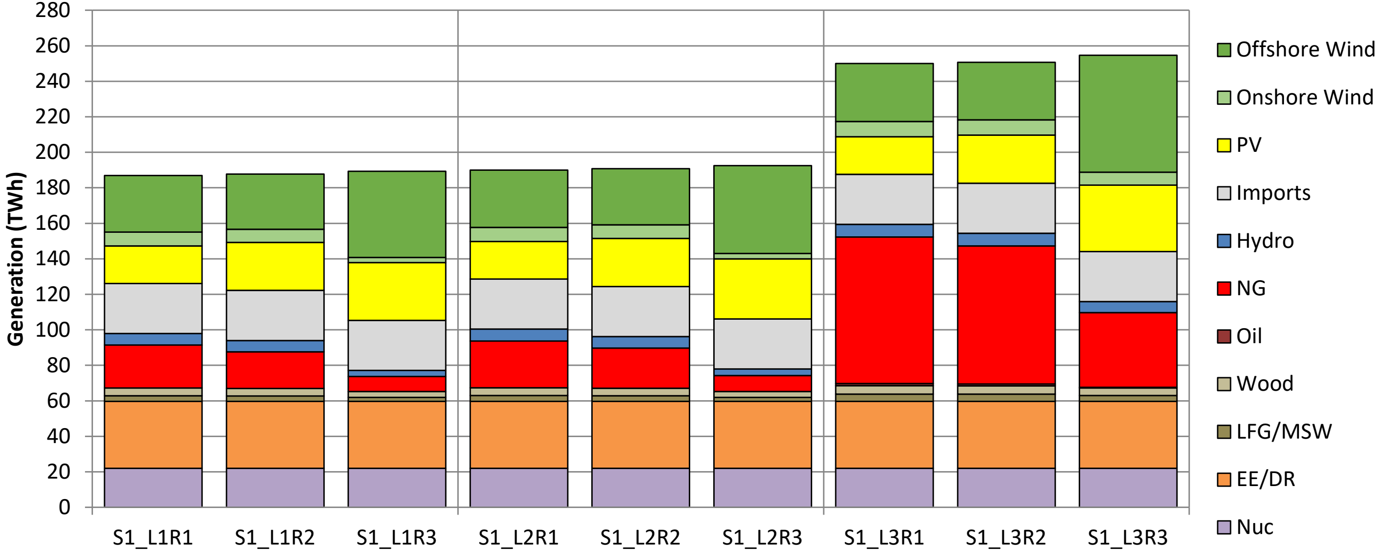
Production Cost Simulations – Scenario 1 Matrix Cases

Summary of Preliminary Results

- In Scenario 1 with Load 1 or Load 2 and Resource 3 had significant oversupply
  - Oversupply is curtailed by threshold prices which results in annual average negative LMPs
  - There was minimal difference between the results of Load 1 and Load 2
- Meanwhile, Scenario 1 with Load 3 had unserved energy resulting in capacity shortfall penalty prices
  - There was insufficient storage in these scenarios to store energy during times of oversupply for use later
  - S1_L3R3 had the closest balance of resources of the L3 cases, but still had both unserved energy and periods of curtailment

Total System-Wide Energy Production by Fuel Type (TWh)

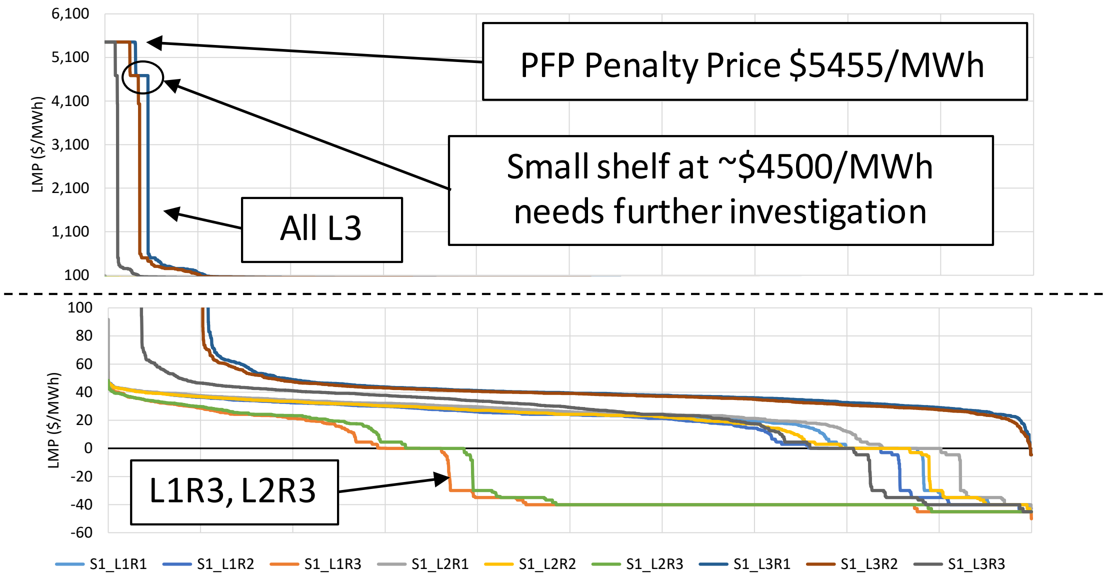
Comparison of Scenario 1 Matrix Cases



- Relatively small increases in load from L1 to L2 lead to similar results between scenarios
  - L3 saw a much more significant increase in load leading to much higher natural gas production primarily
- Increasing OSW and PV from R1 to R2 and then R2 to R3 led to decreased natural gas production between cases

Locational Marginal Price Duration Curve ($/MWh)

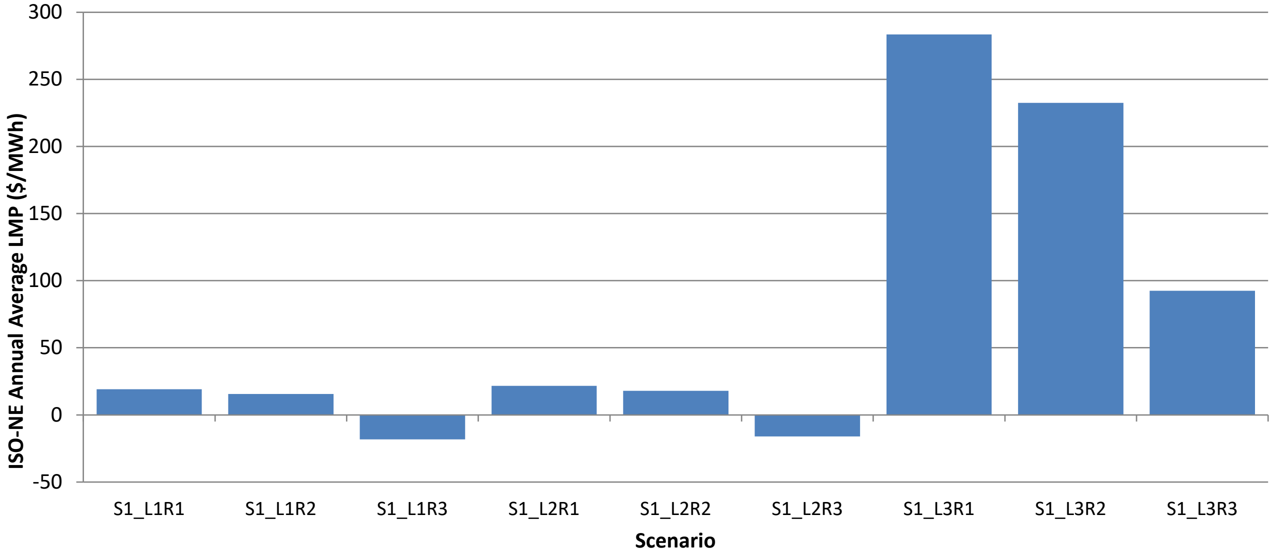
Comparison of Scenario 1 Matrix Cases



- L3 scenarios saw significant amounts of unserved energy
  - S1_L3R3 had both curtailment and unserved energy throughout the year
- L1R3 and L2R3 experienced negative LMPs due to oversupply and threshold pricing 66% and 63% of the year, respectively

Annual Average Locational Marginal Price ISO-NE ($/MWh)

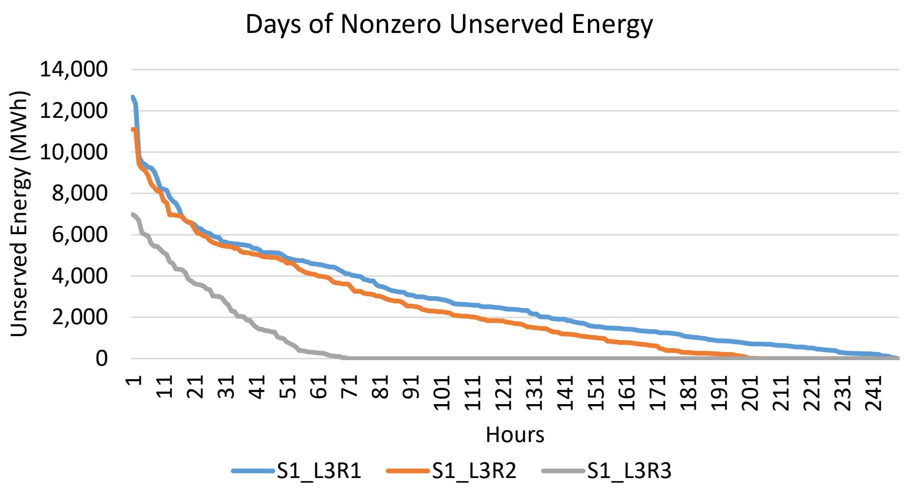
Comparison of Scenario 1 Matrix Cases



- Due to a large oversupply seen in S1_L1R3 and S1_L2R3, average LMP was negative
- For the L3 cases, the PFP penalty price of $5455/MWh significantly raised the annual average LMPs

Unserved Energy for L3 Scenarios

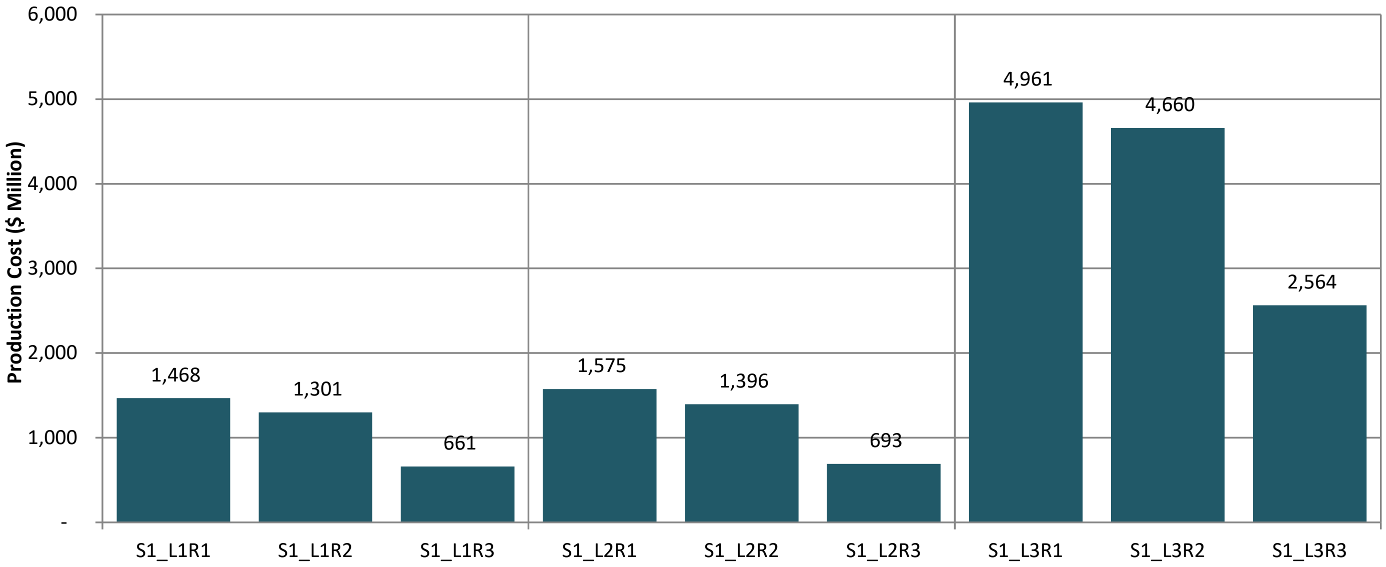
Scenario	S1_L3R1	S1_L3R2	S1_L3R3
Hours with Unserved Energy	249 Hours	204 Hours	70 Hours
Unserved Energy	725 GWh	594 GWh	178 GWh
Peak Unserved Energy	12,664 MW	11,108 MW	6,975 MW



- There were insufficient resources to meet load for all of the scenarios with the L3 assumption
  - Even with the highest assumed resource mix for Scenario 1 (S1_L3R3), there was an unbalance between load and resources due insufficient energy storage to shift the production to times of consumption
- L1 and L2 assumptions did not have any unserved energy

Production Costs ($ Million)

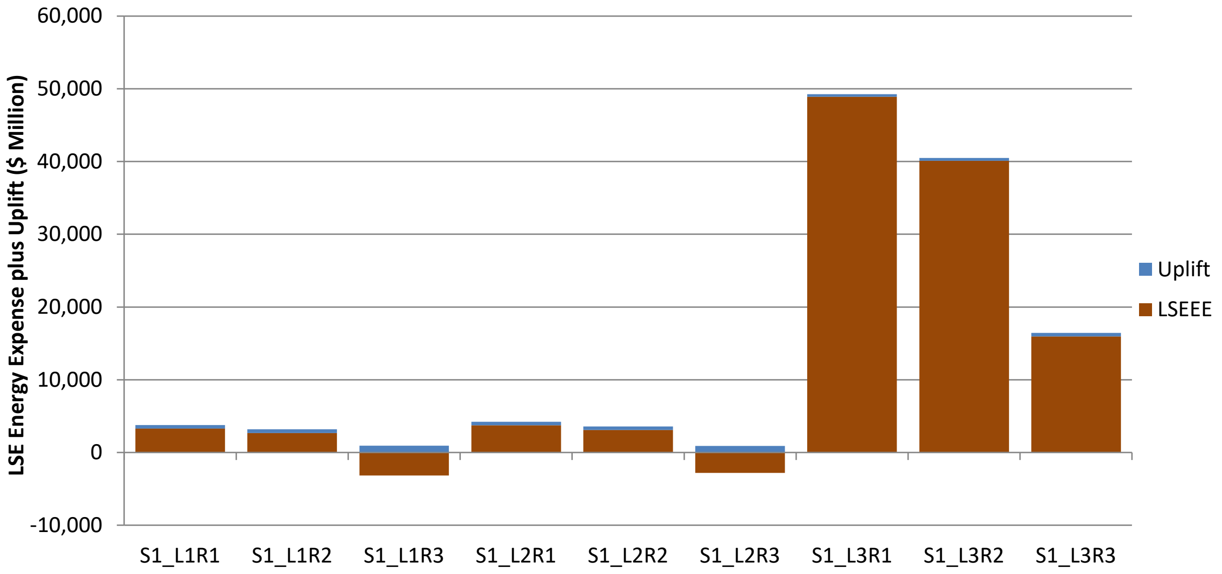
Comparison of Scenario 1 Matrix Cases



- Dispatching generators for many more hours drove production costs higher in the L3 cases
  - Note: The PFP penalty price for unserved energy does not factor into the production cost

LSEEE and Uplift

Comparison of Scenario 1 Matrix Cases



- Significant oversupply in S1_L1R3 and S1_L2R3 drove LSEEE negative due to threshold prices
- L1 and L2 results were very similar despite some differences in electrification load assumptions
- LSEEE was drastically increased with R3 due to hours of the PFP penalty rate being enforced

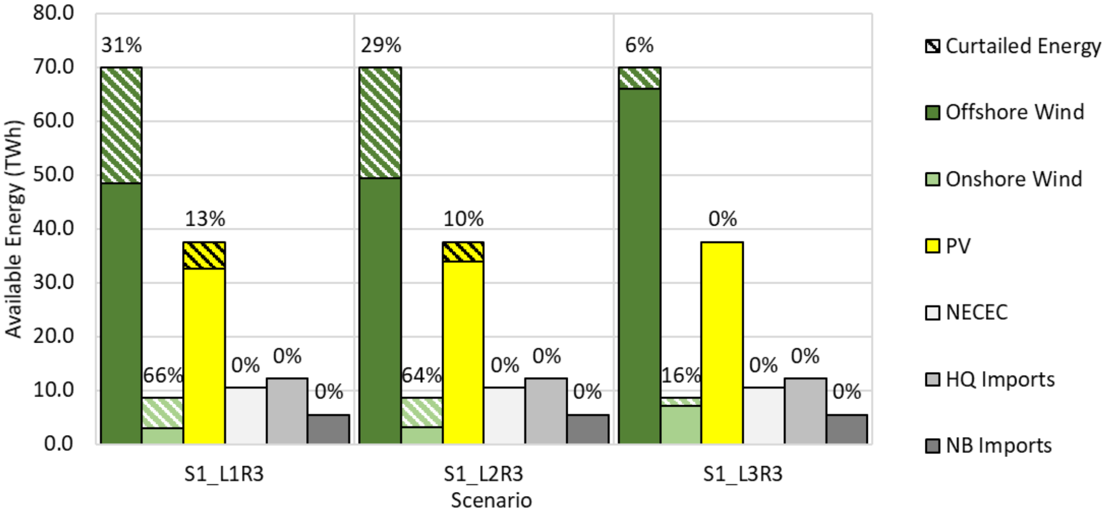
Curtailment by Resource (TWh)

Comparison of Scenario 1 Matrix Cases

- The combination of a significant imbalance of load and resources in the S1_L1R3 and S1_L2R3 cases and the insufficient energy storage led to immense curtailments
  - Relative amounts of curtailments shown are based on the assumed threshold price order and may not reflect bidding behavior or the preference for one type of resource over another
- In L3 cases with unserved energy:
  - S1_L3R1 and S1_R3L2 have no curtailed energy since all resources are used to serve load
  - S1_L3R3 has both curtailment and unserved energy in the first three months of the year

Available Energy and Curtailment

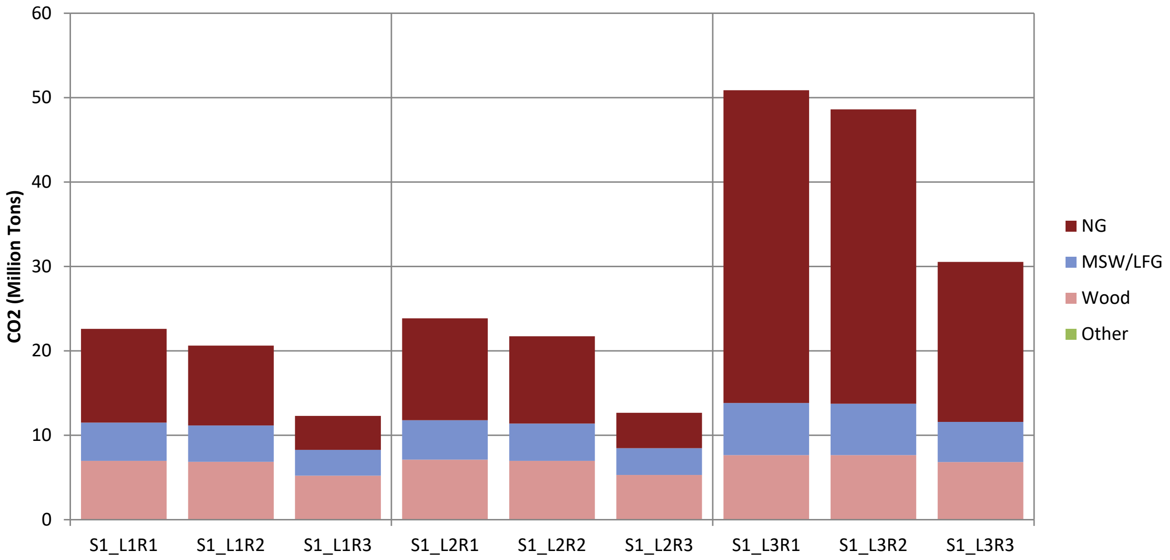
Comparison of R3 Scenarios



- A large portion of onshore wind, offshore wind, and some PV were curtailed in S1_L1R3 and S1_L2R3
- Even with unserved energy, a portion of onshore and offshore wind were curtailed in S1_L3R3

CO_2 Emissions (Millions of Tons)

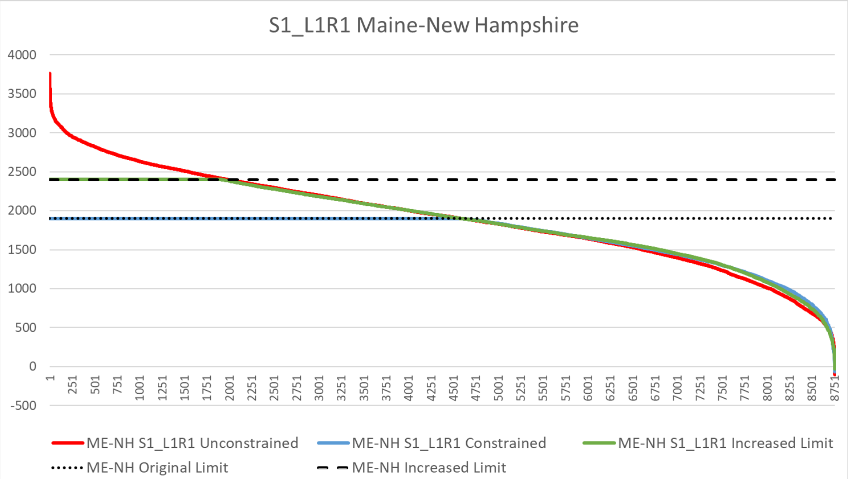
Comparison of Scenario 1 Matrix Cases

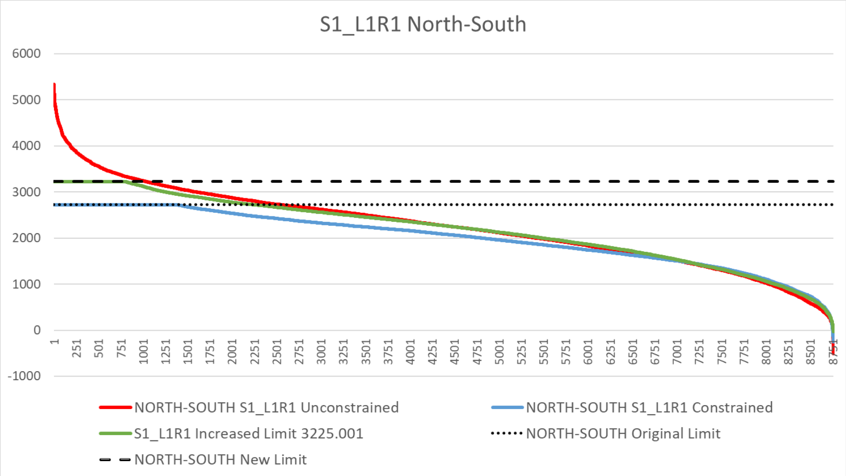


- Natural gas emissions were minimal in cases with large oversupply and maximum in cases with unserved energy
- Wood, MSW, and LFG units followed a similar trend to natural gas
  - These must run units were allowed to be dispatched between their eco-min and eco-max ratings

High-Level Transmission Analysis

Scenario 1 L1R1





- Running constrained case, three interfaces had significant congestion:
  - ME-NH (52%, 2.19 TWh, 4,592 Hrs), North-South (29%, 1.31 TWh, 2,552 Hrs), Surowiec-South (28%, 0.82 TWh, 2,463 Hrs)
- Based on historical proposals and realistic increases in transfer limits, a 500 MW increase was applied to those three transfer limits to represent a new 345 kV line from the ME subarea down to the Boston subarea
- This limit increase significantly reduced the constrained energy and hours as compared to the unconstrained case:
  - Energy: Surowiec-South (-90%, -0.74 TWh), ME-NH (-74%, -1.62 TWh), North-South (-65%, -0.86 TWh)
  - Hours: Surowiec-South (-76%, -1,871 Hrs), ME-NH (-57%, -2,611 Hrs), North-South (-59%, -1,510 Hrs)

PRELIMINARY ALTERNATIVE RESULTS

Production Cost Simulations – Scenario 1 Alternatives A & C

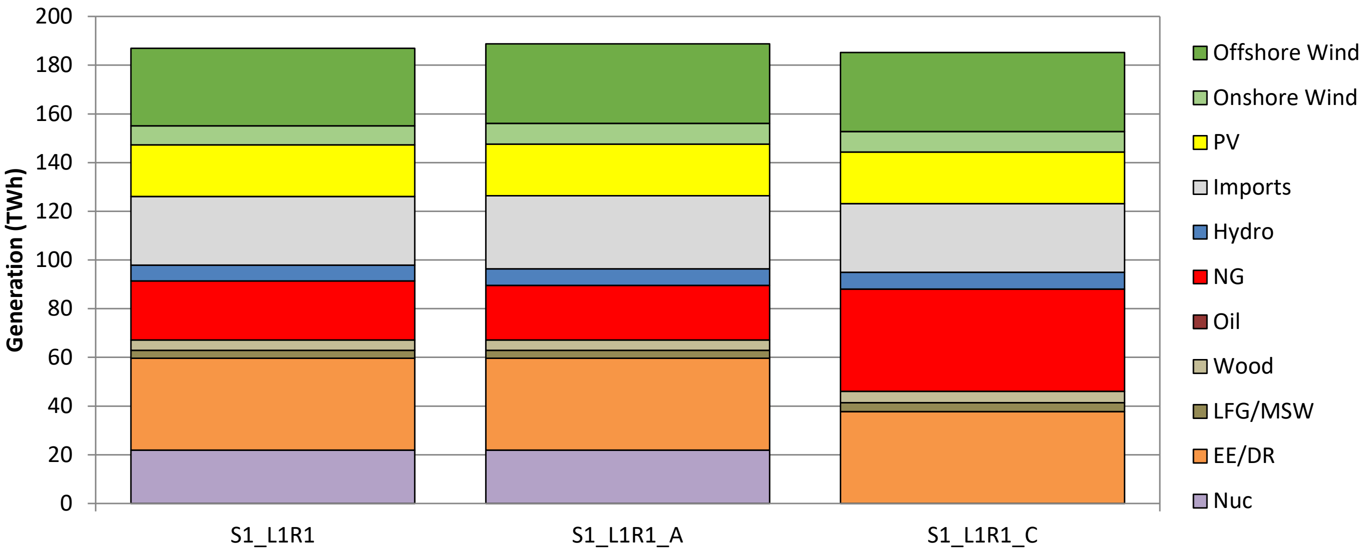
Summary of Preliminary Alternative Results

- In Alternative A, using an unconstrained tie line to Québec for energy banking* led to the elimination of all curtailment in New England
  - By reimporting energy during times of high natural gas production, total natural gas production is significantly decreased
  - A maximum flow of 12,448 MW was seen on the new tie line
- In Alternative C, the retirement of nuclear units led to a slightly higher utilization of renewables and a significant increase in natural gas production

* Energy Banking utilizes existing and new ties to lower renewable build-out spillage by utilizing "energy banking". Energy banking was discussed in detail at the February 17, 2021 PAC meeting (slides 10-14). The intent was to us bi-directional external tielines with negative threshold prices to simulate incentives of Renewable Energy Credits (RECs). The study explored the addition of two new tielines & seasonal storage with Hydro Quebec.

Total System-Wide Energy Production by Fuel Type (TWh)

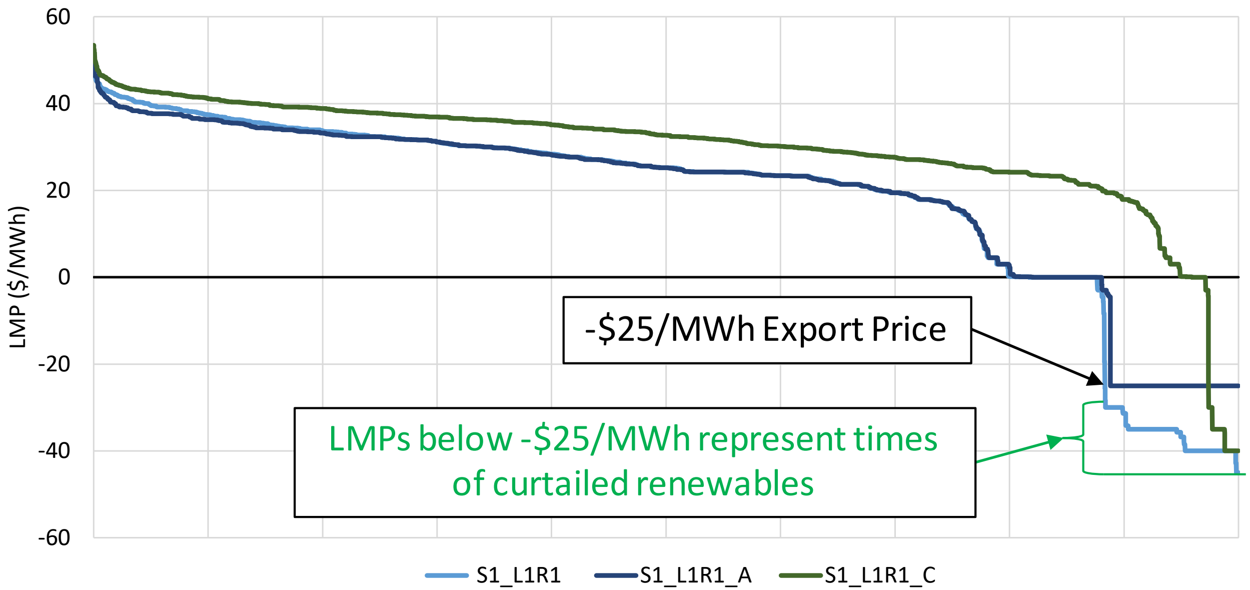
Comparison of S1_L1R1, S1_L1R1_A, and S1_L1R1_C



- Due to minimal need of the new tie line for export of curtailed renewable energy, there was only a slight difference in unit commitment is seen between S1_L1R1 and S1_L1R1_A
- In S1_L1R1_C, nuclear generation was primarily replaced by natural gas resources

Locational Marginal Price Duration Curve ($/MWh)

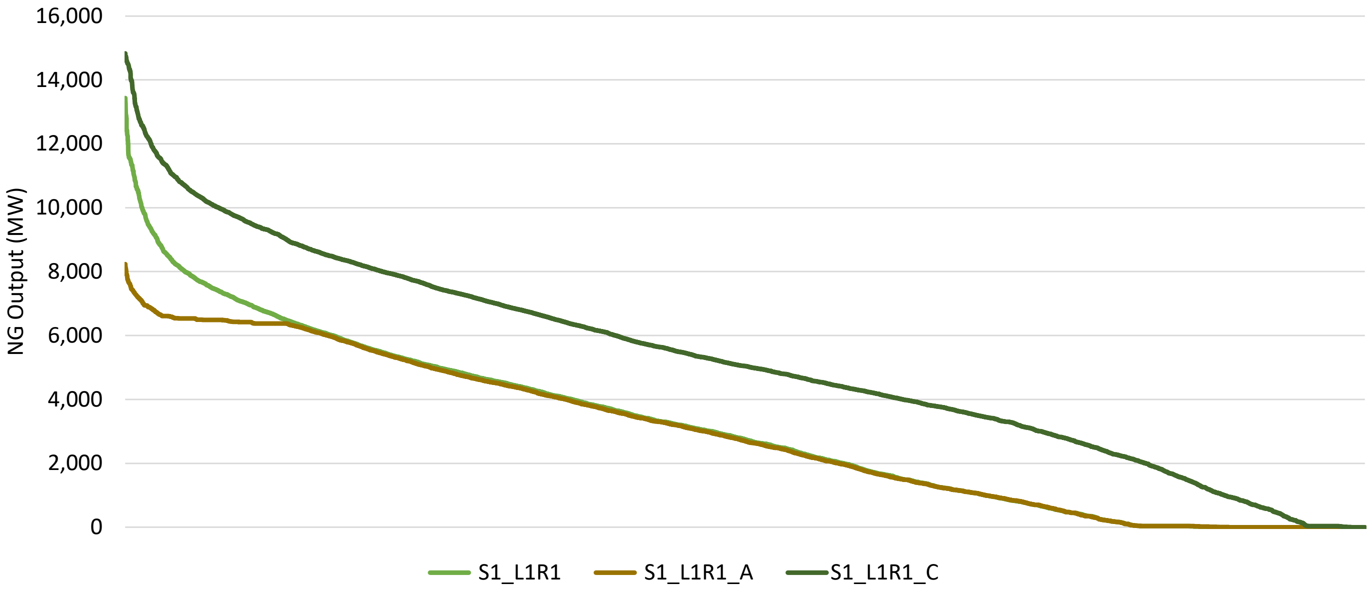
Comparison of S1_L1R1, S1_L1R1_A, and S1_L1R1_C



- Unconstrained energy banking led to elimination of curtailments
- The average LMP for S1_L1R1 was $19.05, S1_L1R1_A was $19.32, and S1_L1R1_C was $29.94

Natural Gas Generation Duration Curve (MW)

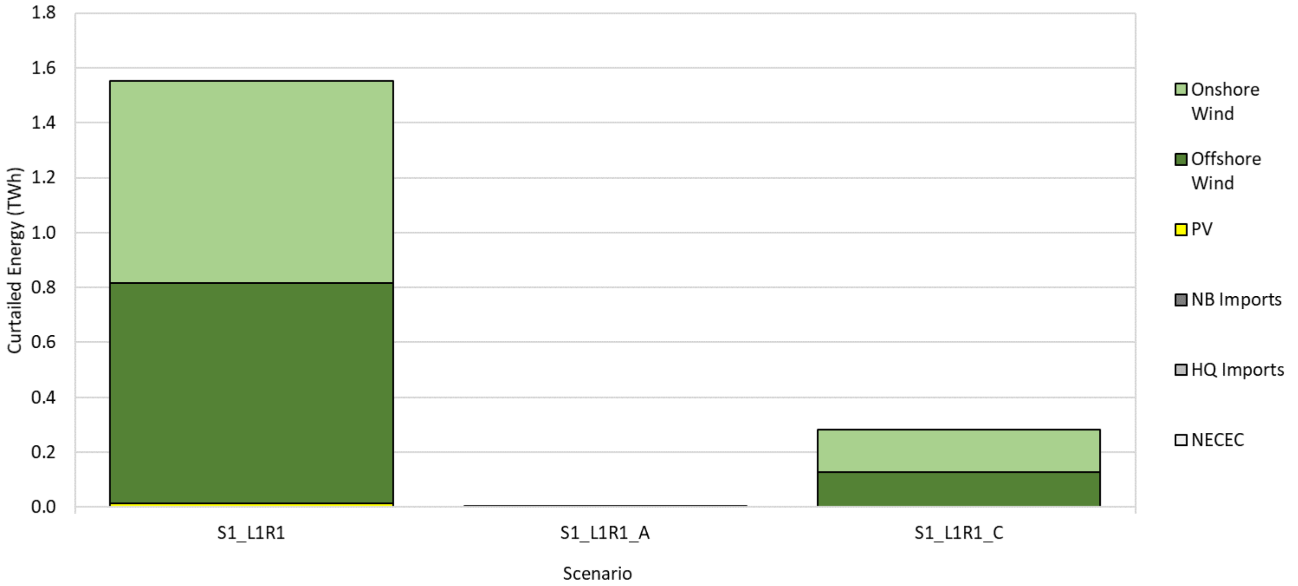
Comparison of S1_L1R1, S1_L1R1_A, and S1_L1R1_C



- Natural gas production was reduced by 1.9 TWh (8%) during peak hours due to the return of banked energy
- The retirement of nuclear units led to an increase of 17.9 TWh (73%) usage of NG

Curtailment by Resource (TWh)

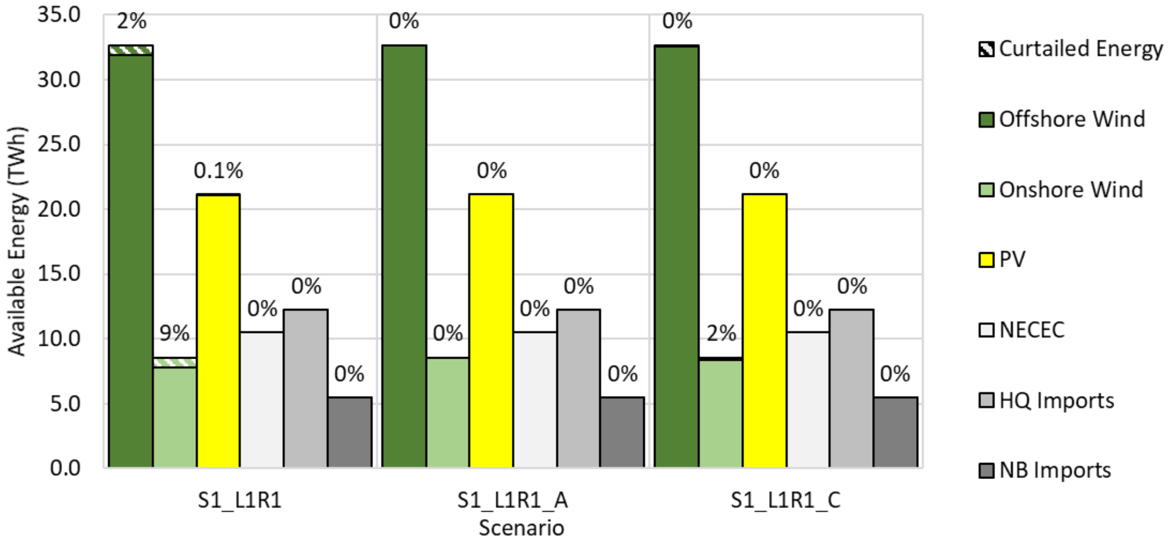
Comparison of S1_L1R1, S1_L1R1_A, and S1_L1R1_C



- No resources were curtailed in Alternative A
- There was an 82% reduction in curtailment with the retirement of nuclear units in Alternative C
- Relative amounts of curtailments shown were based on the assumed 'import priority' threshold price order and may not reflect bidding behavior or the preference for one type of resource over another

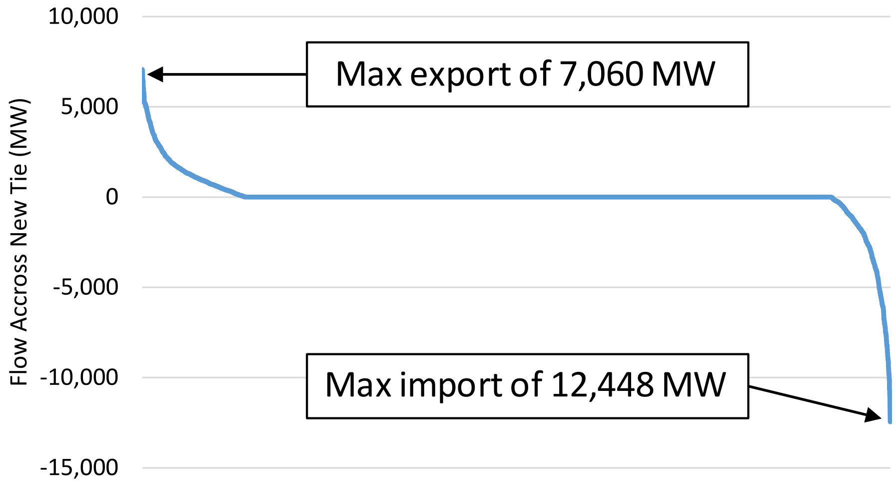
Available Energy and Curtailment

Comparison of S1_L1R1, S1_L1R1_A, and S1_L1R1_C



- S1_L1R1 had minimal curtailment, but curtailment was eliminated with energy banking in Alternative A
- The retirement of nuclear units (S1_L1R1_C) led to slightly higher utilization of renewables

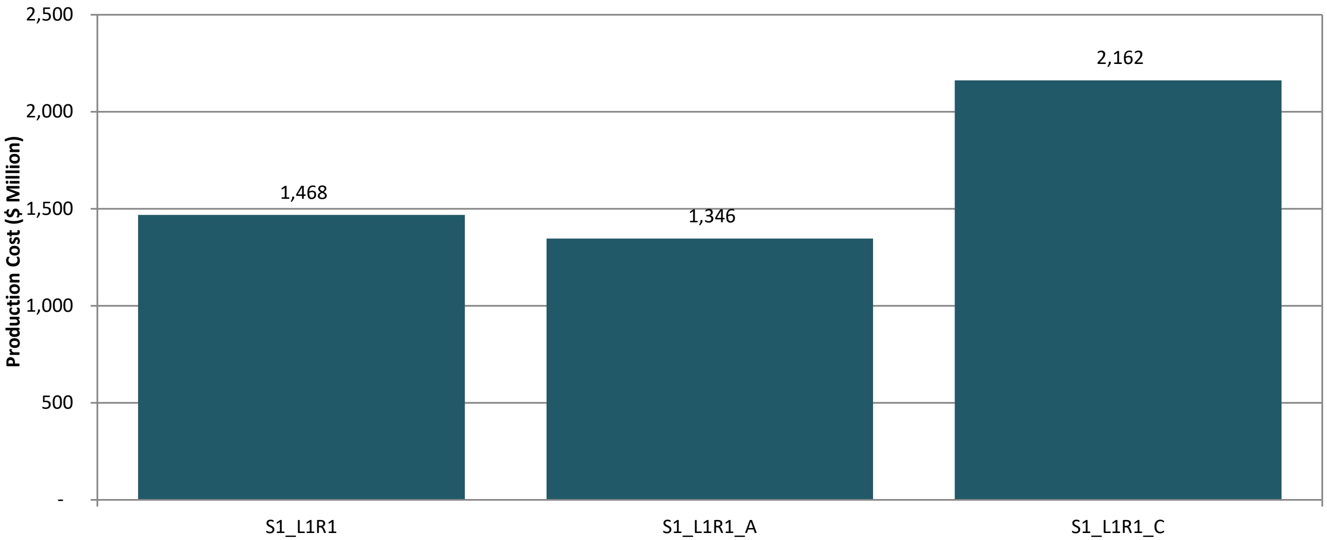
Flow Duration Curve Across Unconstrained Tie from ISO-NE to HQ
S1_L1R1_A



- Minimal curtailment in S1_L1R1 led to low utilization of the new tie line in Alternative A
- The new tie line imported/exported 1.88 TWh of energy
  - Since existing imports were not curtailed, all banked energy was from exported energy from New England
  - The new tie line was not curtailed while importing banked energy

Production Costs ($ Million)

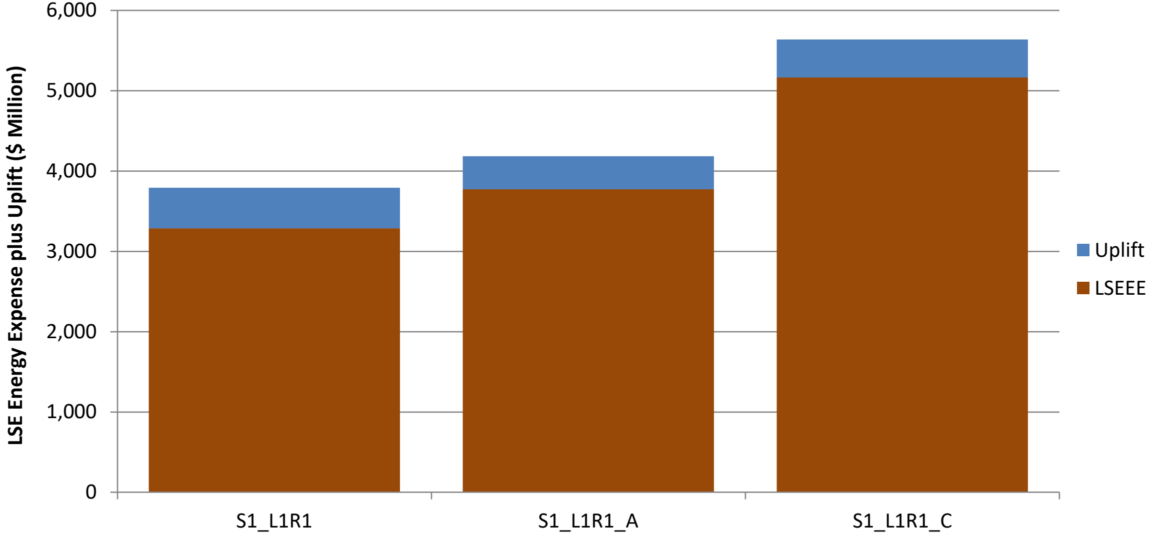
Comparison of S1_L1R1, S1_L1R1_A, and S1_L1R1_C



- In Alternative A, the return of banked energy primarily replaced natural gas and led to a reduced production cost
- In Alternative C, the retirement of nuclear units and increased production from primarily natural gas led to increased production cost

LSEEE and Uplift

Comparison of S1_L1R1, S1_L1R1_A, and S1_L1R1_C



- Since no resources were curtailed in S1_L1R1_A, negative prices didn’t fall as low as S1_L1R1 which led to a higher LSEEE
- Increased natural gas production with the retirement of nuclear units led to increased LSEEE

NEXT STEPS

Next Steps

- The remaining preliminary production cost results for other scenarios will be presented in August 2021
  - Scenario 1 Alternatives D & E
  - Scenarios 2 and 3 with Alternatives and matrix sensitivities
- Preliminary ancillary services analysis results for Scenario 1 are expected in September 2021
- Preliminary probabilistic (MARS) analyses to be presented starting in October 2021
- Stakeholders will have an opportunity to discuss assumption modifications in November/December 2021
- Results for probabilistic analyses and final round of production cost and ancillary services are expected in Q3/Q4 2021

Questions

APPENDIX I

Results in Table Form

BESS Characteristics

Assumption	Matrix Scenario 1	Matrix Scenario 2	Matrix Scenario 3	A Bi-Directional Transmission	B Vehicle to Grid	C Nuclear Retirement	D 100% Clean Electricity	E On/Offshore Grids
Capacity (MW)	Existing 600 + 1,400	Existing 600 + 3,340	Existing 600*	Same as Parent	Add 100,000	Same as Parent	77,700	77,700
Energy (MWh)	7,500	12,525	2,250	Same as Parent	Add 200,000	Same as Parent	2,393,000	2,393,000

Note: "Parent" refers to the scenario to which the alternative is applied. For example when, Alternative Scenario C ("Nuclear Retirement") is applied to Matrix Scenario 1, Matrix Scenario 2 and Matrix Scenario 3 the amount of batteries will be determined by the assumptions for batteries in Matrix Scenario 1, Matrix Scenario 2 and Matrix Scenario 3, respectively.

* Significant energy storage capability assumed via flexible EV charging.

Reference: Modeling of Battery Storage in Economic Studies, December 16, 2020
https://www.iso-ne.com/static-assets/documents/2020/12/a9_modeling_of_battery_storage_in_economic_studies.pdf

Range in Economic Output of Units by Fuel Type

Scenario 1

Fuel Type	Collective Eco. Min.	Collective Eco. Max.	Difference Between Minimum and Maximum
ADR1	0	100	100
ADR2	0	586	586
DFO	254	1,118	864
JF	5	22	17
KER	445	1233	788
LFG	54	95	41
MSW	164	452	288
NG	5,018	17,251	12,233
NUC	2,502	2,502	0
RFO	200	573	373
WDS	302	539	237

Annual Average Locational Marginal Price ISO-NE ($/MWh)

Comparison of Scenario 1 Matrix Cases

Scenario	ISO-NE Annual Average LMP
S1_L1R1	19.05
S1_L1R2	15.60
S1_L1R3	-18.20
S1_L2R1	21.64
S1_L2R2	17.95
S1_L2R3	-16.14
S1_L3R1	283.38
S1_L3R2	232.46
S1_L3R3	92.54
S1_L1R1_A	22.18
S1_L1R1_C	29.94

Production Costs by Fuel Type ($ Million)

Resource	S1_L1R1	S1_L1R2	S1_L1R3	S1_L2R1	S1_L2R2	S1_L2R3	S1_L3R1	S1_L3R2	S1_L3R3	S1_L1R1_A	S1_L1R1_C
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NG	1,142.4	978.1	411.4	1,241.8	1,066.1	429.6	3,888.7	3,667.3	2,002.2	1,056.3	1,952.1
Oil	0.0	0.0	0.0	0.0	0.0	0.0	275.7	242.3	81.1	0.0	0.0
Wood	0.6	0.6	0.4	0.6	0.6	0.4	0.6	0.6	0.6	0.6	0.6
EE/DR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nuc	160.8	160.8	160.8	160.8	160.8	160.8	160.8	160.8	160.8	160.8	0.0
PV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Renew	61.4	58.4	43.5	63.1	59.8	44.4	85.8	84.4	65.7	61.3	72.1
Wind	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tie	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	1,365.1	1,197.9	616.0	1,466.3	1,287.3	635.3	4,411.6	4,155.4	2,310.4	1,279.0	2,024.8

Load Serving Entity Energy Expenses (LSEEE) and Uplift ($ Million)

Scenario	S1_L1R1	S1_L1R2	S1_L1R3	S1_L2R1	S1_L2R2	S1_L2R3	S1_L3R1	S1_L3R2	S1_L3R3	S1_L1R1_A	S1_L1R1_C
LSEEE	3,287	2,692	-3,142	3,734	3,097	-2,785	48,903	40,116	15,969	3,828	5,166
Uplift	506	504	934	497	497	895	368	370	479	412	470
Total	3,793	3,196	-2,208	4,231	3,594	-1,890	49,271	40,486	16,448	4,240	5,636

Total System-Wide Energy Production by Fuel Type (TWh)

Resource	S1 L1R1	S1 L1R2	S1 L1R3	S1 L2R1	S1 L2R2	S1 L2R3	S1 L3R1	S1 L3R2	S1 L3R3	S1 L1R1 A	S1 L1R1 C
NG	24.2	20.7	8.5	26.4	22.6	8.9	82.6	77.8	42.1	22.3	41.9
Oil	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.0	0.4	0.0	0.0
Wood	4.3	4.2	3.3	4.4	4.3	3.3	4.7	4.7	4.2	4.3	4.6
EE/DR	37.7	37.7	37.7	37.7	37.7	37.7	37.7	37.7	37.7	37.7	37.7
Nuc	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	0.0
PV	21.1	27.0	32.5	21.1	27.1	33.9	21.1	27.1	37.5	21.1	21.1
LFG/MSW	3.2	3.1	2.3	3.3	3.2	2.3	4.2	4.1	3.3	3.2	3.7
Onshore Wind	7.8	7.5	2.9	8.0	7.7	3.1	8.6	8.6	7.2	8.6	8.4
Offshore Wind	31.9	31.0	48.5	32.2	31.5	49.4	32.7	32.4	65.9	32.7	32.5
Hydro	6.5	6.3	3.5	6.7	6.5	3.6	7.1	7.0	6.2	6.8	7.0
Imports	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	30.1	28.2
Total	186.9	187.7	189.3	190.0	190.7	192.5	250.0	250.7	254.7	186.9	185.3

Annual Curtailed Energy (TWh)

Scenario	Offshore Wind	Onshore Wind	PV	NECEC	HQ Imports	NB Imports	Total
S1_L1R1	0.8	0.7	0.0	0.0	0.0	0.0	**0.7**
S1_L1R2	1.4	1.1	0.1	0.0	0.0	0.0	**2.6**
S1_L1R3	21.5	5.7	5.0	0.0	0.0	0.0	**32.2**
S1_L2R1	0.5	0.5	0.0	0.0	0.0	0.0	**1.0**
S1_L2R2	0.9	0.8	0.0	0.0	0.0	0.0	**1.7**
S1_L2R3	20.5	5.5	3.7	0.0	0.0	0.0	**29.7**
S1_L3R1	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
S1_L3R2	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
S1_L3R3	4.0	1.4	0.1	0.0	0.0	0.0	**5.5**
S1_L1R1_A	0.0	0.0	0.0	0.0	0.7	0.0	**0.7**
S1_L1R1_C	0.1	0.2	0.0	0.0	0.0	0.0	**0.3**

Monthly Curtailment S1_L1R1 (TWh)

Month	PV	NECEC	Offshore Wind	Onshore Wind	HQ Imports	NB Imports	Total
1 – Jan	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**
2 – Feb	0.000	0.000	0.000	0.001	0.000	0.000	**0.001**
3 – Mar	0.000	0.000	0.067	0.110	0.000	0.000	**0.177**
4 – Apr	0.023	0.000	0.284	0.242	0.000	0.000	**0.549**
5 – May	0.033	0.000	0.245	0.129	0.000	0.000	**0.407**
6 – Jun	0.014	0.000	0.133	0.048	0.000	0.000	**0.196**
7 – Jul	0.000	0.000	0.001	0.002	0.000	0.000	**0.003**
8 – Aug	0.000	0.000	0.001	0.008	0.000	0.000	**0.009**
9 – Sep	0.030	0.000	0.225	0.125	0.000	0.000	**0.380**
10 – Oct	0.000	0.000	0.137	0.142	0.000	0.000	**0.279**
11 – Nov	0.000	0.000	0.051	0.114	0.000	0.000	**0.165**
12 – Dec	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**

Native New England Resource CO_2 Emissions by Fuel Type (Millions of Short Tons)

Scenario	NG	MSW/LFG	Wood	Other Emitting Resources	Total
S1_L1R1	11.1	4.5	7.0	0.0	11.5
S1_L1R2	9.5	4.3	6.9	0.0	20.7
S1_L1R3	4.0	3.1	5.2	0.0	12.3
S1_L2R1	12.1	4.7	7.1	0.0	23.9
S1_L2R2	10.4	4.4	7.0	0.0	21.8
S1_L2R3	4.2	3.2	5.3	0.0	12.7
S1_L3R1	37.0	6.2	7.6	0.0	50.8
S1_L3R2	34.9	6.1	7.6	0.0	48.6
S1_L3R3	18.9	4.8	6.8	0.0	30.5
S1_L1R1_A	10.0	4.5	7.0	0.0	21.5
S1_L1R1_C	18.9	5.4	7.5	0.0	31.8

R3 PV by RSP Zone

RSP Zone	R3 PV Allocation (MW)
BHE	165
BOS	668
CMA/NEMA	1,091
CT	5,487
ME	626
NH	6,132
NOR	232
RI	852
SEMA	2,756
SME	427
SWCT	1,738
VT	2,246
WMA	5,719
Total	**28,139**

APPENDIX II

Acronyms

Acronyms

ACDR	Active Demand Capacity Resource	EE	Energy Efficiency
ACP	Alternative Compliance Payments	EFORd	Equivalent Forced Outage Rate demand
AGC	Automatic Generator Control	EIA	U.S. Energy Information Administration
BESS	Battery Energy Storage Systems	EPECS	Electric Power Enterprise Control System
BTM PV	Behind the Meter Photovoltaic	EV	Electric Vehicle
BOEM	Bureau of Ocean Energy Management	FCA	Forward Capacity Auction
CCP	Capacity Commitment Period	FCM	Forward Capacity Market
CELT	Capacity, Energy, Load, and Transmission Report	FGRS	Future Grid Reliability Study
CSO	Capacity Supply Obligation	FOM	Fixed Operation and Maintenance Costs
Cstr.	Constrained	HDR	Hydro Daily, Run of River
DER	Distributed Energy Resource	HDP	Hydro Daily, Pondage
DR	Demand-Response	HQ	Hydro-Québec

Acronyms, cont.

HY	Hydro Weekly Cycle	OSW	Offshore Wind
LBW	Land Based Wind	O&M	Operation and Maintenance
LFG	Landfill Gas	PHII	Phase II line between Radisson and Sandy Pond
LFR	Load Following Reserve	PV	Photovoltaic
LMP	Locational Marginal Price	RECs	Renewable Energy Credits
LSEEE	Load-Serving Entity Energy Expenses	RFP	Request for Proposals
MSW	Municipal Solid Waste	RGGI	Regional Greenhouse Gas Initiative
NECEC	New England Clean Energy Connect	RPS	Renewables Portfolio Standards
NESCOE	New England States Committee on Electricity	SCC	Seasonal Claimed Capability
NG	Natural Gas	Uncstr.	Unconstrained
NICR	Net Installed Capacity Requirement	VER	Variable Energy Resource
NREL	National Renewable Energy Laboratory		