ANALYSIS GROUP

NYISO Climate Change Phase II Study

Internal Update on Climate Cases

July 23, 2020

Climate Disruption Case Discussion

Climate Disruption Case Modeling

- Climate impacts will be analyzed using a set of climate cases that model impacts to the bulk power system during 30-day modeling periods
- Climate impacts analyzed for winter, summer, and shoulder seasons for the CLCPA and Reference load scenarios from the Climate Change Phase I study
- Impacts analyzed under both Climate Change Phase II and Grid in Transition resource sets
  - Climate Change Phase II resource set includes significant increase in transmission capacity across NY State along with increases in renewable resources
  - Grid in Transition does not add transmission capacity, but increases both dispatchable generation and renewable resources

Types of Modeled Climate Disruptions

1. Temperature Waves
   - Coordinated impact to load, generation, and transmission due to severe temperatures across New York State
   - Calibrated to historical heat and cold waves, adjusted for average temperature increases due to climate change (from Phase I study modeling)
2. Wind Lulls
   - Multi-day reductions in wind output without effects on other resource types
   - Calibrated to historical periods of low wind production across state
3. Severe Storms
   - Combined load, generation, and transmission effects, requiring repair/recovery over multiple weeks
4. Other Impacts
   - Reduction in water availability for hydro units due to droughts

Climate Disruption Revised Case List

- Cases were run based on relevance to each season and resource set

		Climate Change Phase II Resource Set						Grid in Transition Resource Set			
		CLCPA			Reference			CLCPA		Reference	
ID	**Event**	**Summer**	**Winter**	**Shoulder**	**Summer**	**Winter**	**Shoulder**	**Summer**	**Winter**	**Summer**	**Winter**
Baseline	None	X	X	X	X	X	X	X	X	X	X
A	Heat Wave	X			X			X			
B	Cold Wave		X			X			X		
C	Wind Lull - Upstate	X	X		X	X		X	X		
D	Wind Lull - Off-Shore	X	X		X	X		X	X		
E	Wind Lull - State-Wide	X	X		X	X		X	X		
F	Hurricane/Coastal Wind Storm	X			X			X			
G	Severe Wind Storm – Upstate	X	X		X	X		X	X		
H	Severe Wind Storm – Offshore	X	X	X	X	X		X	X		
I	Drought	X			X			X			
J	Icing Event		X			X			X		

Climate Disruption Revised Case Details

ID	Event	Model Toggles Adjusted	
Baseline	None		
A	Heat Wave	Wind Generation - 20% decrease for 7 days Solar Generation - Use solar profile from hottest day in Y2006 for 7 days Load - High temp 90° F or above for days 1-7, with daily zonal load increase of between 0% to 18.7% Transmission - 5% decrease for 7 days	
B	Cold Wave	Solar Generation - Use solar profile from coldest day in Y2006 for 7 days Load - Low temp of 0° F or below for days 1-7, with daily zonal load increase of between 2.3% to 25.6%	
		Summer	Winter
C	Wind Lull - Upstate	Wind Generation - 15% Average Capacity Factor in Zones A-E for 12 days	Wind Generation - 25% Average Capacity Factor in Zones A-E for 7 days
D	Wind Lull - Off-Shore	Wind Generation - 15% Average Capacity Factor in Zones J-K for 12 days	Wind Generation - 25% Average Capacity Factor in Zones J-K for 7 days
E	Wind Lull - State-wide	Wind Generation - 15% Average Capacity Factor in Zones A-K for 12 days	Wind Generation - 25% Average Capacity Factor in Zones A-K for 7 days
F	Hurricane/Coastal Wind Storm	Calibrated using Hurricane Sandy data Load - 30% decrease in Zones G-K for 1 day with 11 day recovery Transmission - Off in Zones G-K for 1 day with 14 day recovery Wind Generation - Off in Zones J-K for 1 day with 14 day recovery Solar Generation - 50% decrease in Zones G-K for 1 day with next day recovery Dispatchable - 40% decrease in Zones G-K for 1 day with 14 day recovery	
G	Severe Wind Storm – Upstate	Calibrated using Hurricane Sandy data Load - 30% decrease in Zones A-F for 1 day with 11 day recovery Transmission - Off in Zones A-F for 1 day with 14 day recovery Wind Generation - Off in Zones A-F for 1 day with 14 day recovery Solar Generation - 50% decrease in Zones A-F for 1 day with next day recovery Dispatchable - 40% decrease in Zones A-F for 1 day with 14 day recovery	
H	Severe Wind Storm – Offshore	Wind Generation - Off in Zones J-K for 1 day with 14 day recovery	
I	Drought	Hydro Generation - 50% decrease for 30 days	
J	Icing Event	Transmission - Off in Zones A-C for 1 day with 7 day recovery Load - 25% decrease in Zones A-C for 1 day with 7 day recovery Wind Generation - 50% decrease in Zones A-C for 1 day with 7 day recovery	

Historical Calibration: Temperature Waves

Definitions of Temperature Waves

- Periods of extreme heat or cold can have coordinated impacts on system due to:
  - Increased Load
  - Changes in Wind Generation
  - Changes in Solar Generation
  - Changes in Transmission Capacity
- Heat waves defined as periods of 3 or more consecutive days where daily high temperatures are ≥90° F
- Cold waves defined as 3 or more consecutive days where daily low temperatures are ≤0° F

System Effects of Temperature Waves

- Increased Load
  - Load impacts from temperature waves (both heat and cold) based on zonal load-temperature sensitivities from Climate Impact Phase I modeling
- Wind Generation
  - Evidence from European heat wave of 2018 showed wind resource 20% below long-term averages; 20% wind capacity factor decrease modeled
- Solar Generation
  - In heat waves, solar irradiance increases relative to long-term averages but PV efficiency decreases
  - In cold waves, solar irradiance variable but there is no impact on PV efficiency
  - To model dual effect during temperature wave periods, study uses zonal-aggregated National Renewable Energy Laboratory (NREL) PV output data from the hottest and coldest days in 2006
- Transmission Capacity
  - Heat waves decrease transmission capacity due to conductor sag; 5% transmission MW transfer capability decrease modeled

Historical Calibration: Severe Wind Lulls

Summer Wind Lulls

- Extremely low wind production over multiple days can present reliability concerns during peak load periods
- Study reviewed NREL implied turbine capacity factor data for 100m height in 4 representative regions for NY State from 2007-2012
- Summer lulls are not uncommon; 19 lulls of more than 4 consecutive days with less than 20% state-wide average wind capacity in 2007-2012 data

NREL Wind Profile Summer Lulls, 2007-2012
≤15% Implied Capacity Factor

Wind Lull Period	Number of Days	Average Wind Capacity Factor Across Regions
7/21/2007 - 8/1/2007	12	14.2%
8/10/2009 - 8/16/2009	7	14.1%
6/10/2009 - 6/16/2009	7	13.7%
8/31/2009 - 9/5/2009	6	13.3%
7/27/2012 - 8/1/2012	6	14.4%
8/12/2008 - 8/16/2008	5	14.9%
7/6/2009 - 7/10/2009	5	14.3%
7/9/2012 - 7/13/2012	5	14.4%
8/18/2012 - 8/22/2012	5	14.7%

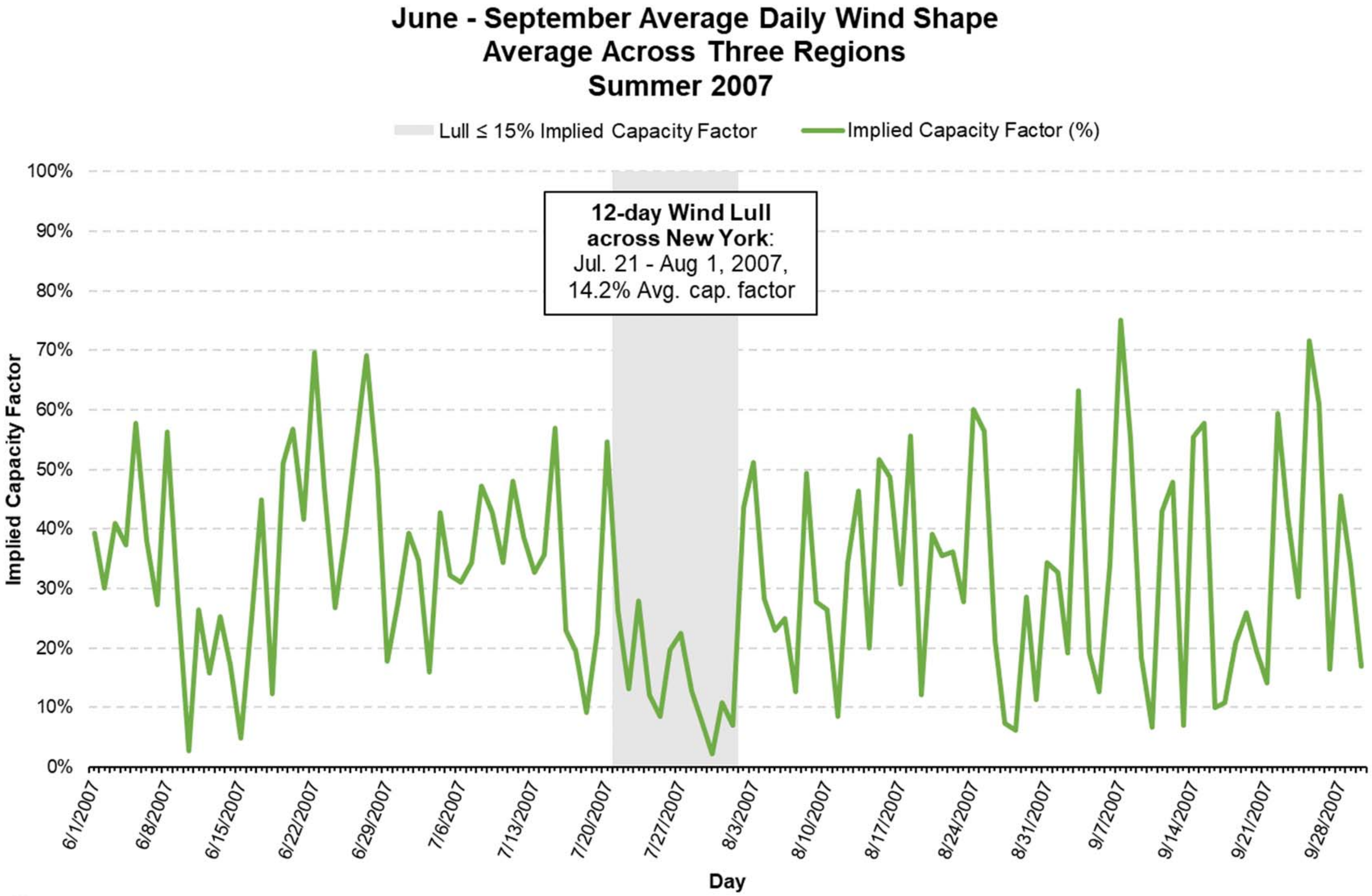
Notes:

[1] Based on NREL Wind Toolkit wind data at 100m height for points in Plattsburgh (North), Niagara Falls (West), and Empire Wind Zone.

[2] A wind lull is defined as 4 or more consecutive days where the average daily implied capacity factor is less than or equal to 15%.

[3] In addition to the listed wind lulls, there were 10 wind lulls of 4 days between 2007 - 2012.

Summer Wind Lull Example



Notes:
[1] Based on NREL Wind Toolkit wind data at 100m height for points in Plattsburgh (North), Niagara Falls (West), and Empire Wind Zone.
[2] A wind lull is defined as 4 or more consecutive days where the average daily implied capacity factor is less than or equal to 15%.

Winter Wind Lulls

- Winter coordinated wind lulls less common but more important due to increased reliance on wind in 2040 scenarios
- CLCPA load scenarios are winter-peaking, so wind lulls have outsized impact

NREL Wind Profile Winter Lulls, 2007-2012
≤25% Implied Capacity Factor

Wind Lull Period	Number of Days	Average Wind Capacity Factor Across Regions
2/25/2007 - 3/1/2007	5	21.7%
1/28/2011 - 2/1/2011	5	22.5%
2/2/2012 - 2/5/2012	4	24.3%

Notes:

[1] Based on NREL Wind Toolkit wind data at 100m height for points in Plattsburgh (North), Niagara Falls (West), and Empire Wind Zone.

[2] A wind lull is defined as 4 or more consecutive days where the average daily implied capacity factor is less than or equal to 25%.

Localized Wind Lulls

- In addition to state-wide wind lulls, land-based and offshore wind capacity may experience unsynchronized low wind conditions
- Between 2007-2012, there were 35 days (occurring in all season) where upstate implied wind capacity factor was >75% and offshore implied capacity factor was <25% or vice versa

Extreme Wind Differences Between Upstate and Offshore Wind, 2007 - 2012

Month	Days with High Upstate Capacity Factor, Low Offshore Capacity Factor	Days with High Upstate Offshore Factor, Low Upstate Capacity Factor
Jan	3	0
May	3	2
Jun	2	0
Jul	1	0
Aug	2	1
Sep	1	3
Oct	3	8
Nov	3	2
Dec	1	0
Total	19	16

Notes:
[1] Based on NREL Wind Toolkit wind data at 100m height for points in Plattsburgh (North), Niagara Falls (West), and Empire Wind Zone.
[2] "High capacity factor" is defined as greater than or equal to 75% capacity factor, while "low capacity factor" is defined as less than or equal to 25% capacity factor.

Wind Lulls in Climate Disruption Cases

- Modeled wind lulls are calibrated to historical values
  - Summer wind lulls modeled as 15% average wind capacity factor for 12 days
  - Winter wind lulls modeled as 25% average wind capacity factor for 7 days
- Wind lulls are constructed to overlap with the 12- and 7-day periods of highest load for each season (including the peak load day)
- Study models statewide wind lulls and localized wind lulls in upstate and offshore regions

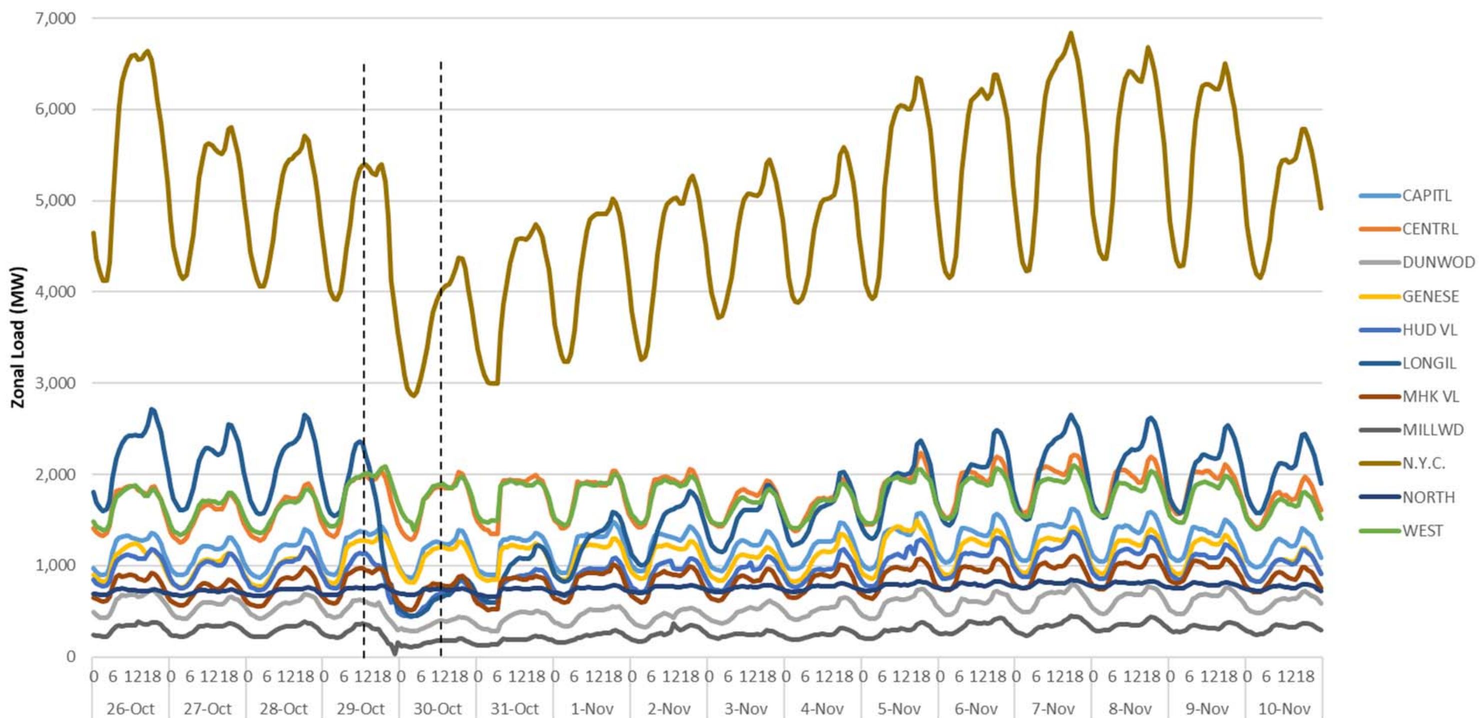
Historical Calibration: Hurricane Impact

Historical Coastal Storm Impact (Hurricane Sandy)

- Severe storm impacts with sustained recovery period of multiple days/weeks could lead to reliability concerns across entire state, not just directly impacted area
- Storm scenarios based on historical observations from 2013 NYISO Hurricane Sandy report and load data from period of Hurricane Sandy and immediate aftermath
- Hurricane Sandy caused impacts on:
  - Load
  - Fossil Generation
  - Transmission

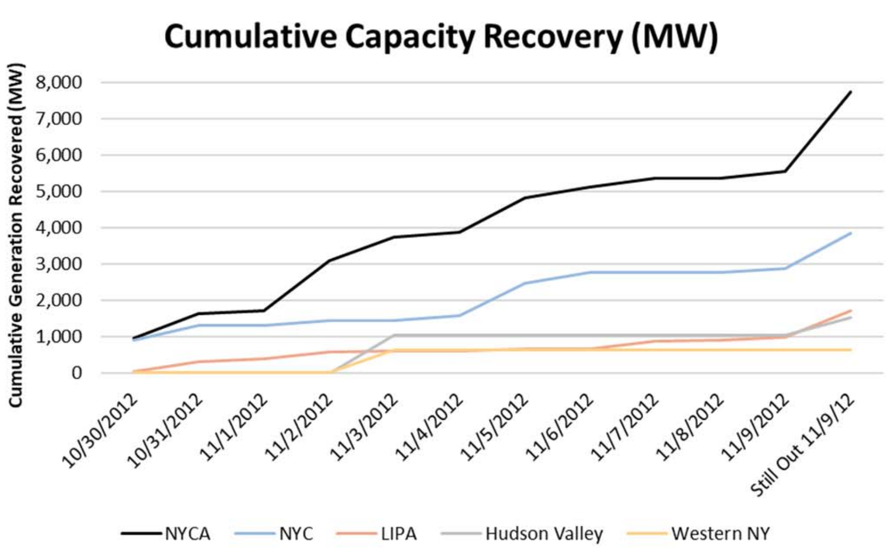
Historical Coastal Storm Load Impact

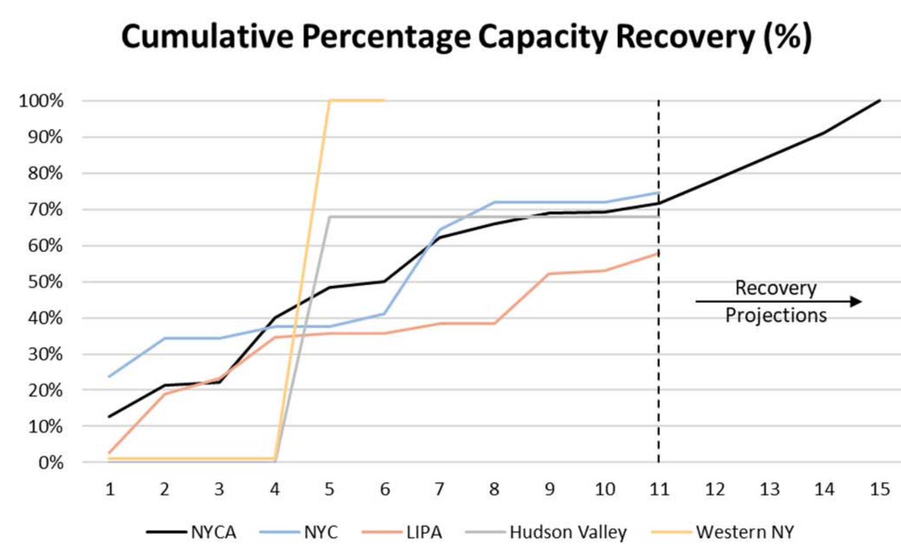
- Large load impact on NYC and Long Island during the course of storm (10/29/12 - 10/30/12, shown below with dashed line) with a nearly linear recovery
- Nearly complete load recovery the weekend by Nov. 10 (a period of 11 days)
- Marginal decrease in load in upstate zones during the storm, but overall upstate load remained consistent



Historical Coastal Storm Generation Impact

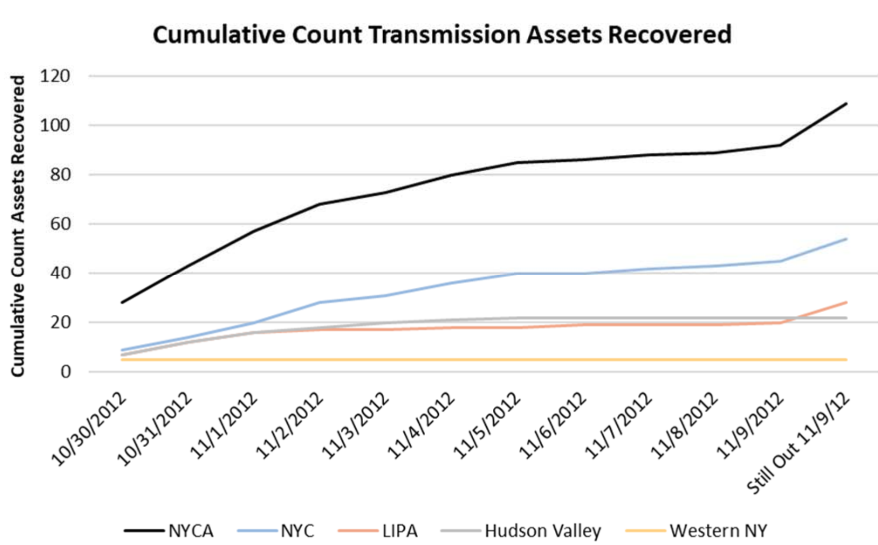
- Generation impact was primarily on nuclear and fossil units downstate
- On the first day after the storm, ~20% of NYCA nameplate capacity was offline, and ~40% of Zone J/K capacity was offline
- By day 11 (last day in study), ~30% of capacity was still offline; based on average pace of recovery, full capacity would have been online around Day 15
- Limited evidence of effects on renewable generation given fewer installations in 2012
  - Some wind generation damage would be expected given current turbine storm ratings
  - Solar panels generally rated for ~140 mph winds; max gusts ~100 mph in Sandy

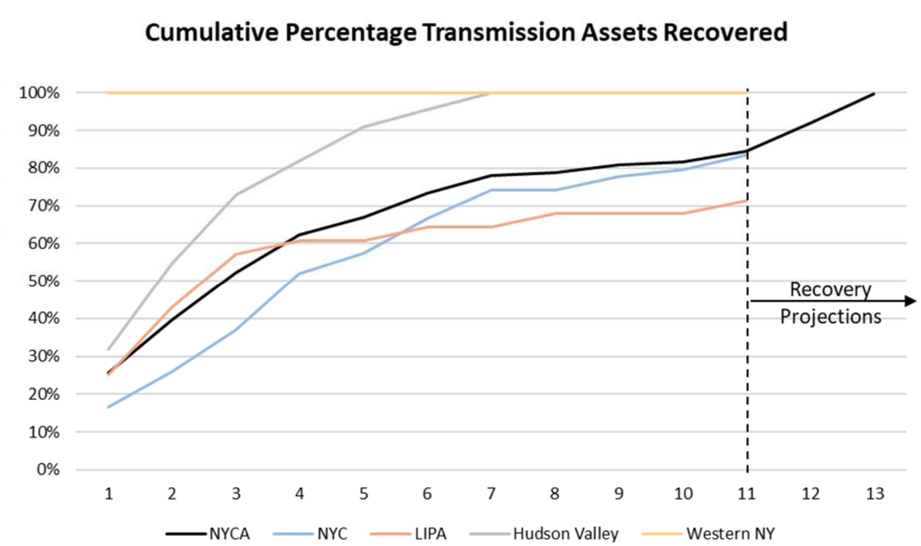




Historical Coastal Storm Transmission Impact

- Transmission impact was severe downstate and affected both interstate and intrastate transmission lines
- According to the NYISO report, “Essentially, the seven southernmost interconnections to southeastern New York were disconnected, leaving Long Island and New York City only connected to the Eastern Interconnection via the Lower Hudson Valley 345 kV transmission lines.”
- By Day 11 (last day in study), ~15% of transmission assets still offline; based on average pace of recovery, full capacity would have been online around Day 13





Historical Coastal Storm Impact (Hurricane Sandy)

- Model setup for coastal storm scenario:
  - Load: 30% reduction in load in zones impacted; 11 day linear recovery period
  - Transmission: cut off transmission lines to downstate zones (G-K); 14 day linear recovery period
  - Generation:
    - Wind generation off in zones impacted (offshore and onshore) during 1-day storm; 14 day linear recovery period
    - Solar generation at 50% in zones impacted during 1-day storm; next day recovery
    - Reduction of dispatchable generation downstate (Zones G-K) by 40% based on the generation capacity losses from the NYISO report; linear recovery of 14 days
- Upstate storm scenarios use same magnitude of effects, with change in geographic center of storm damage

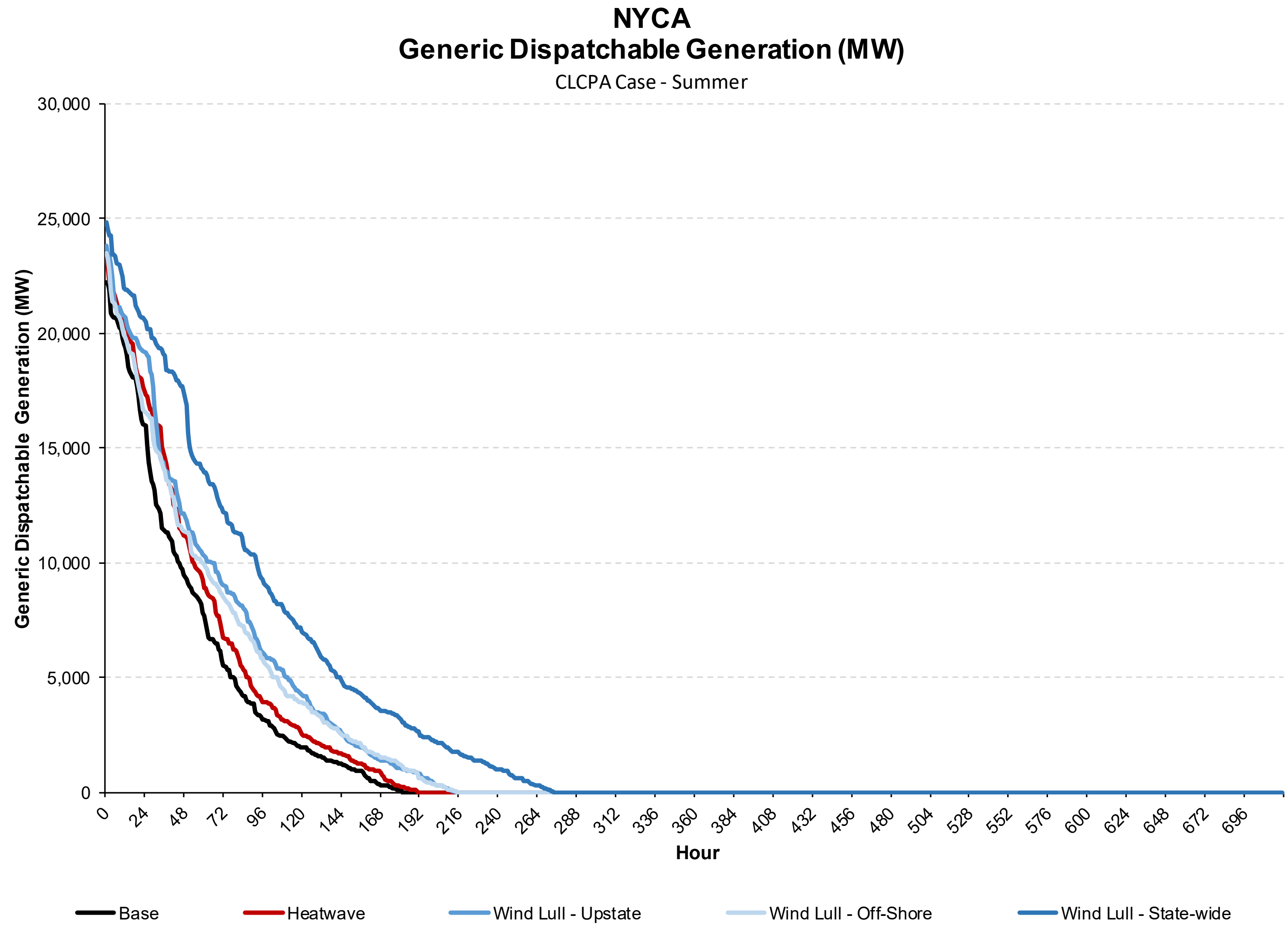
Preliminary Results with Climate Change Phase II Resource Set

Preliminary Findings using CLCPA Summer Cases

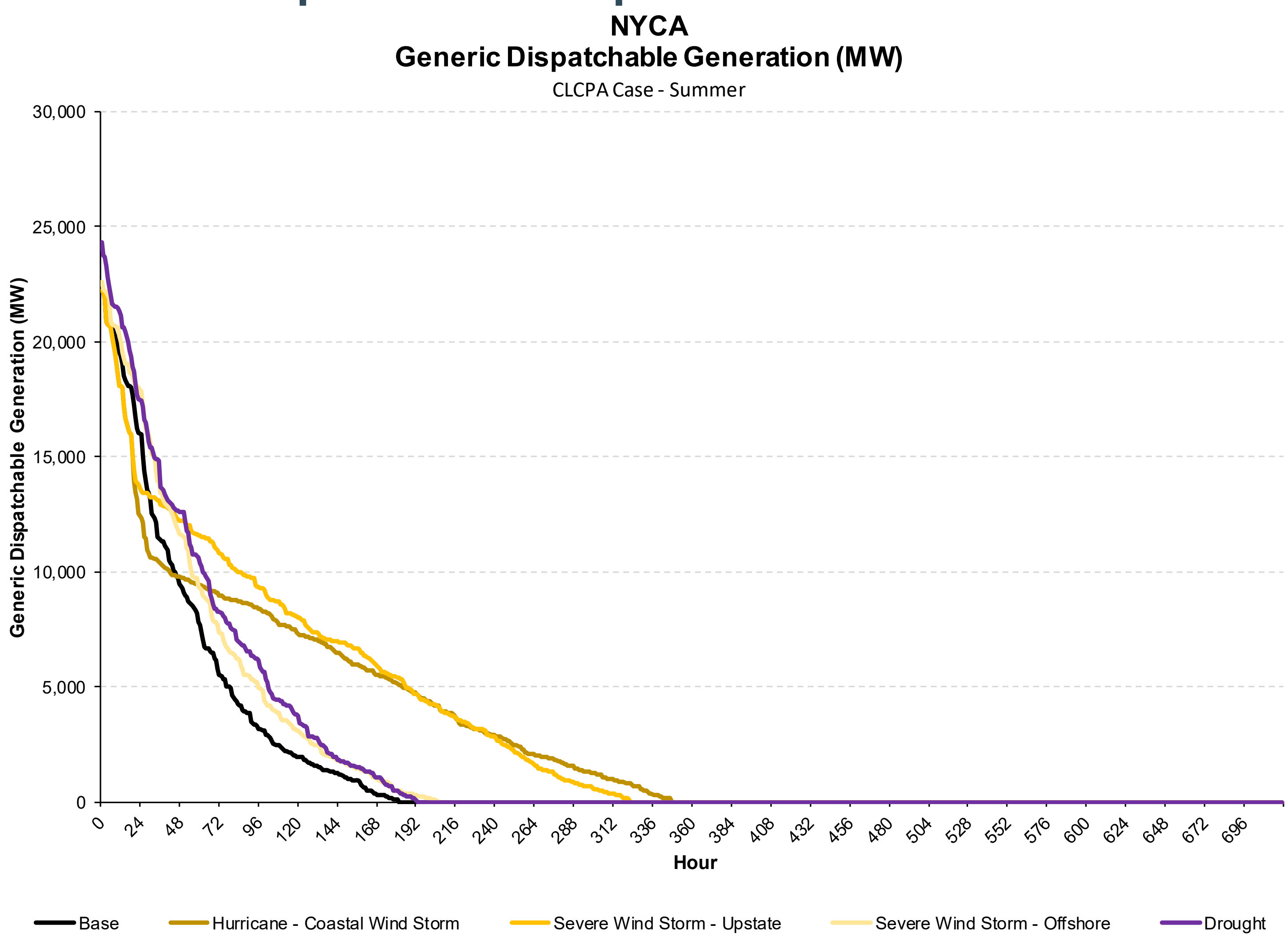
- Loss of load rare because resource set is built to meet winter peak
- Losses of load at transmission system level and required dispatchable generation occur in storm cases with transmission disruptions

	Loss of Load		Dispatchable Generation				
	Total Hours with LOL in at least one Load Zone	Aggregate LOL (MWh)	Max Consecutive Hours with Dispatchable Gen.	Total Hours with Dispatchable Gen.	Aggregate Dispatchable Gen. (MWh)	Max Dispatchable Gen. (MW)	Max 1-hr. Dispatchable Gen. Ramp (MW)
CLCPA Summer Scenario - Climate Impact Phase II Resource Set							
Baseline Summer	0	0	36	181	1,159,404	22,245	10,117
Heat Wave	0	0	36	191	1,354,972	23,225	8,072
Wind Lull - Upstate	0	0	38	214	1,592,818	23,782	10,117
Wind Lull - Off-Shore	0	0	40	216	1,502,020	23,469	10,117
Wind Lull - State-Wide	0	0	41	274	2,210,826	24,821	10,117
Hurricane/Coastal Wind Storm	28	20,279	171	349	2,072,911	22,245	6,222
Severe Wind Storm – Upstate	8	1,721	87	322	2,213,628	22,245	6,222
Severe Wind Storm – Offshore	0	0	36	205	1,400,864	22,570	8,202
Drought	0	0	37	193	1,495,695	24,304	7,282

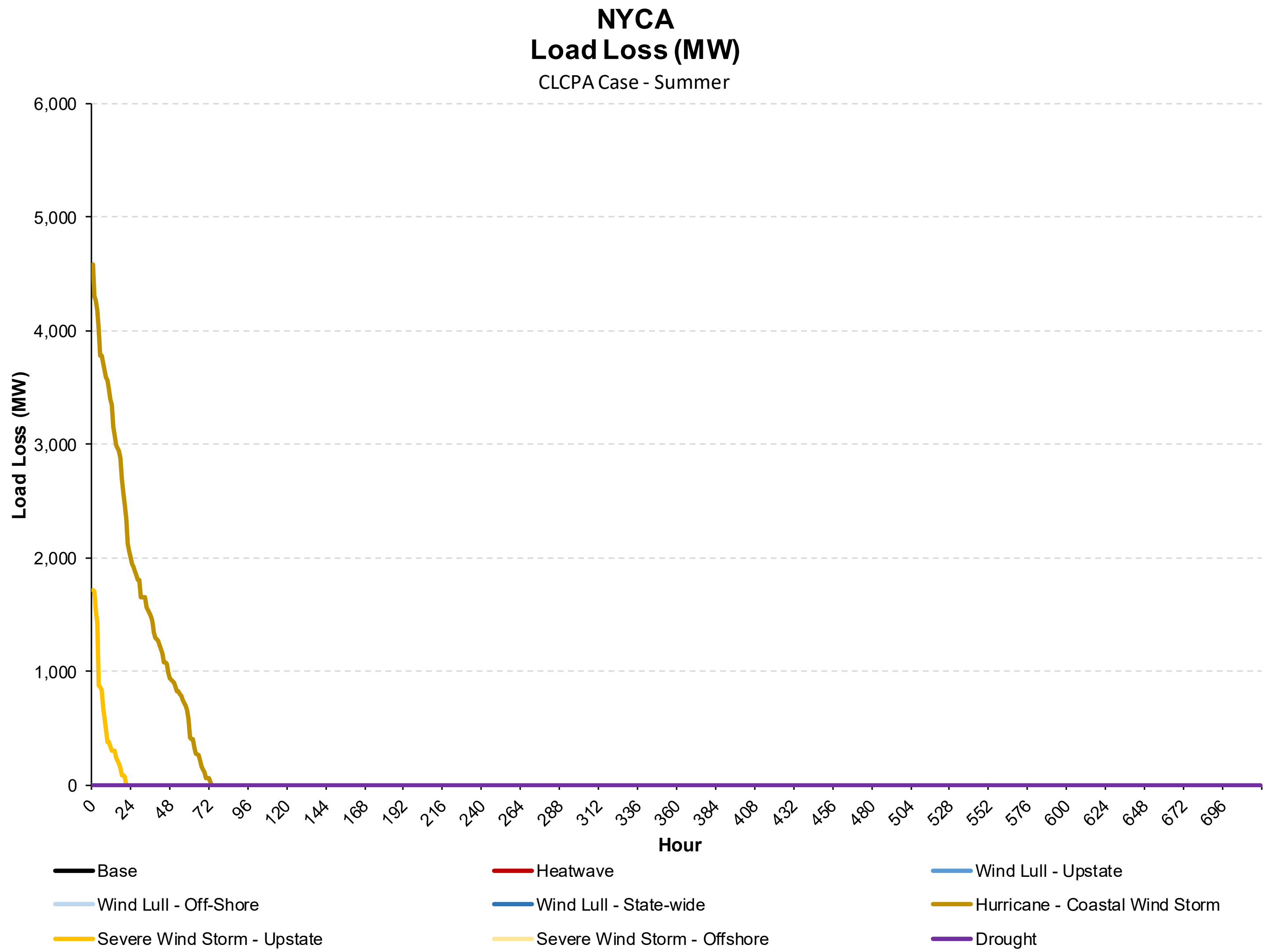
Cross-Case Comparison of Dispatchable Generation: Summer



Cross-Case Comparison of Dispatchable Generation: Summer



Cross-Case Comparison of Zonal Load Loss: Summer



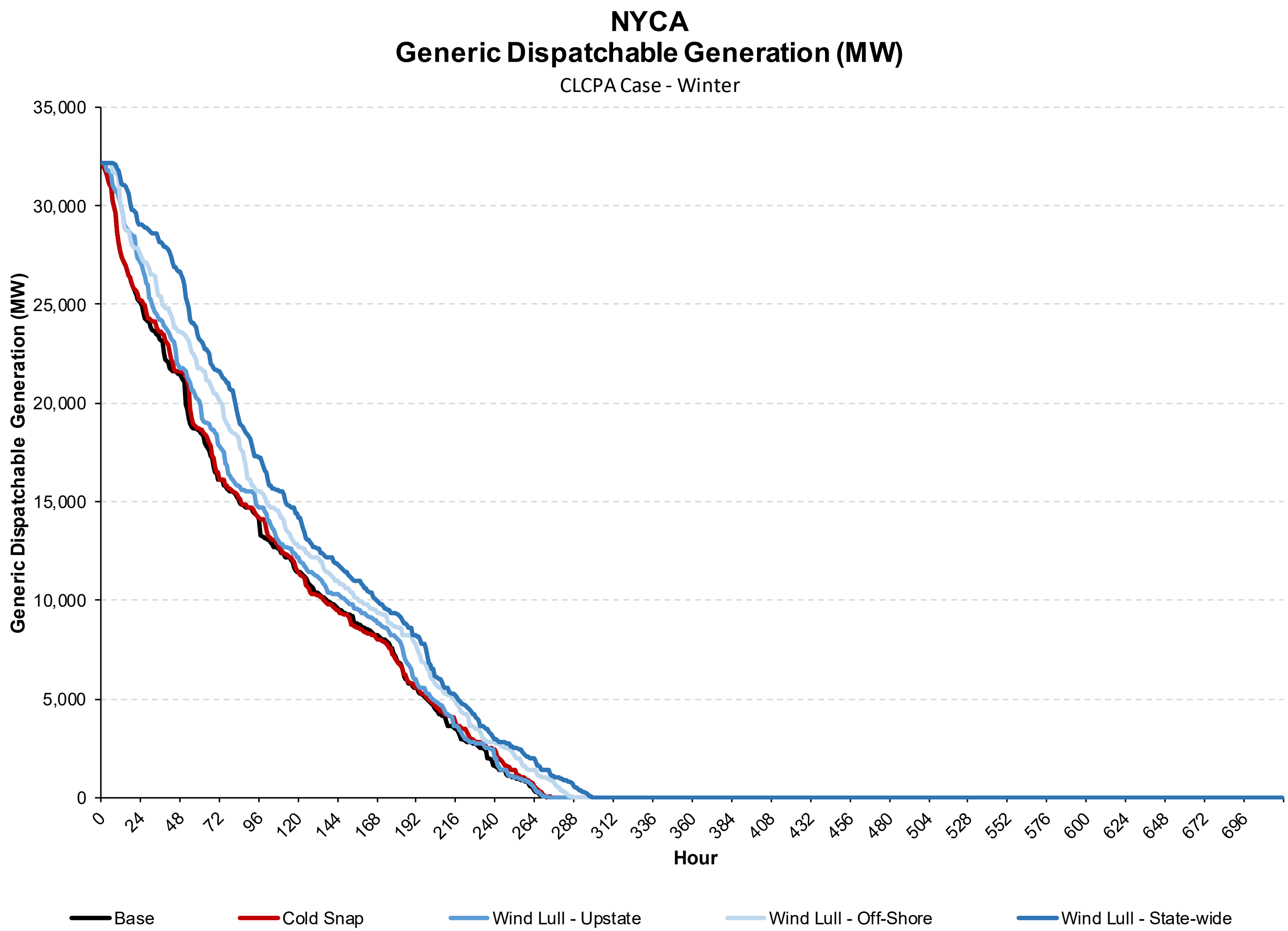
Preliminary Findings using CLCPA Winter Cases

- Wind lull scenarios cause some losses of load, even without transmission impacts
- Acute losses of load and required dispatchable generation occur in storm cases with transmission disruptions
- Almost all scenarios require at least one hour with max output of 32,136 MW from dispatchable generation, by definition of resource set (dispatchable generation is amount required to exactly meet load in all hours in baseline CLCPA winter scenario)

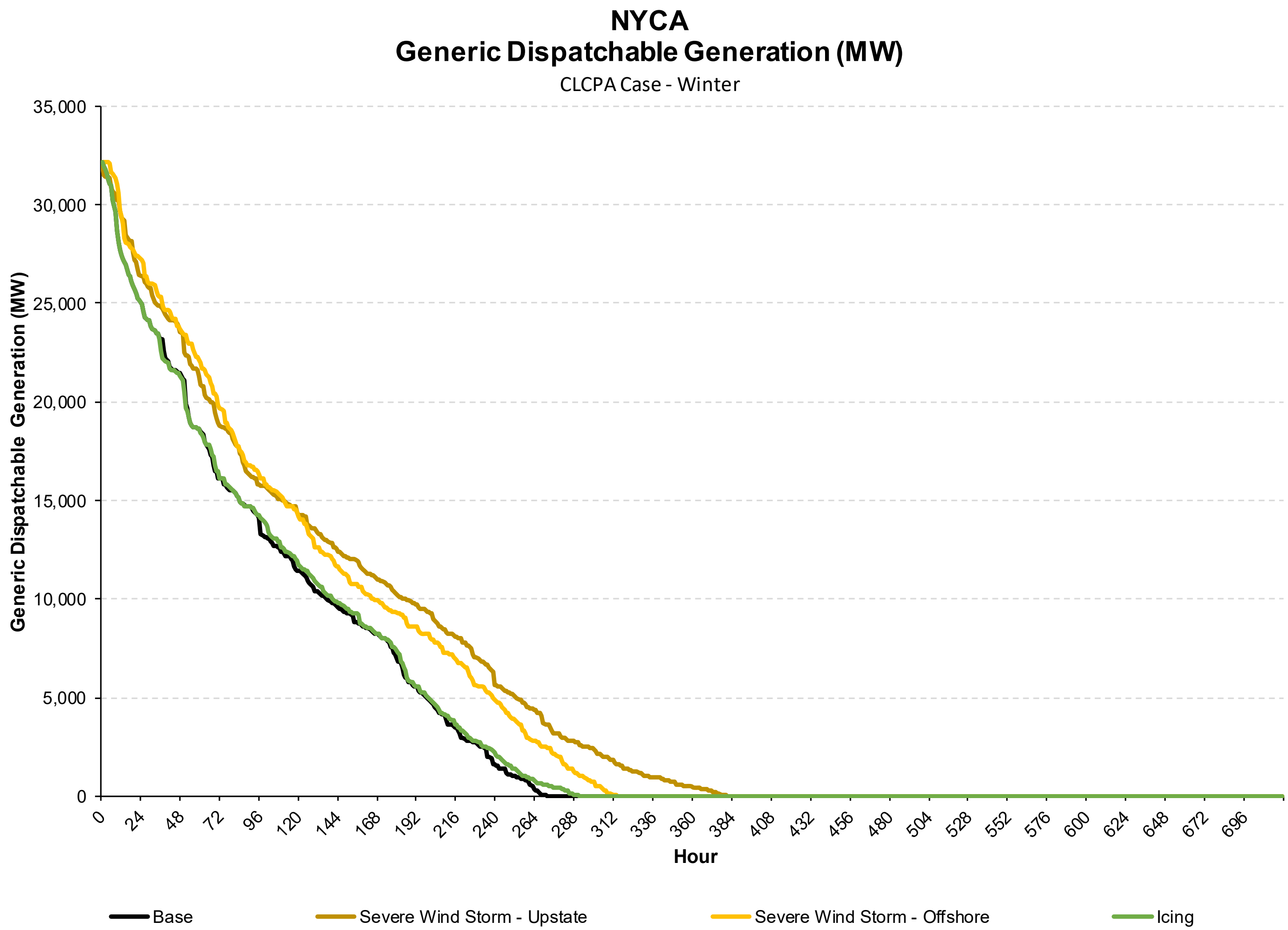
	Loss of Load		Dispatchable Generation				
	Total Hours with LOL in at least one Load Zone	Aggregate LOL (MWh)	Max Consecutive Hours with Dispatchable Gen.	Total Hours with Dispatchable Gen.	Aggregate Dispatchable Gen. (MWh)	Max Dispatchable Gen. (MW)	Max 1-hr. Dispatchable Gen. Ramp (MW)
CLCPA Winter Scenario - Climate Impact Phase II Resource Set							
Baseline Winter	0	0	85	272	3,167,828	32,136	12,583
Cold Wave	0	0	85	275	3,210,585	32,136	12,583
Wind Lull - Upstate	6	2,805	85	273	3,379,007	32,136	12,583
Wind Lull - Off-Shore	10	7,112	104	288	3,658,990	32,136	12,583
Wind Lull - State-Wide	13	14,317	110	300	3,953,931	32,136	12,583
Severe Wind Storm – Upstate	50	28,601	103	382	4,142,431	31,957	12,583
Severe Wind Storm – Offshore	8	4,117	103	315	3,913,116	32,136	12,583
Icing Event	2	106	85	293	3,217,483	32,136	12,583

- In all cases, peak dispatchable ramp occurs on day 27 of the modeling period due to a short-term wind lull

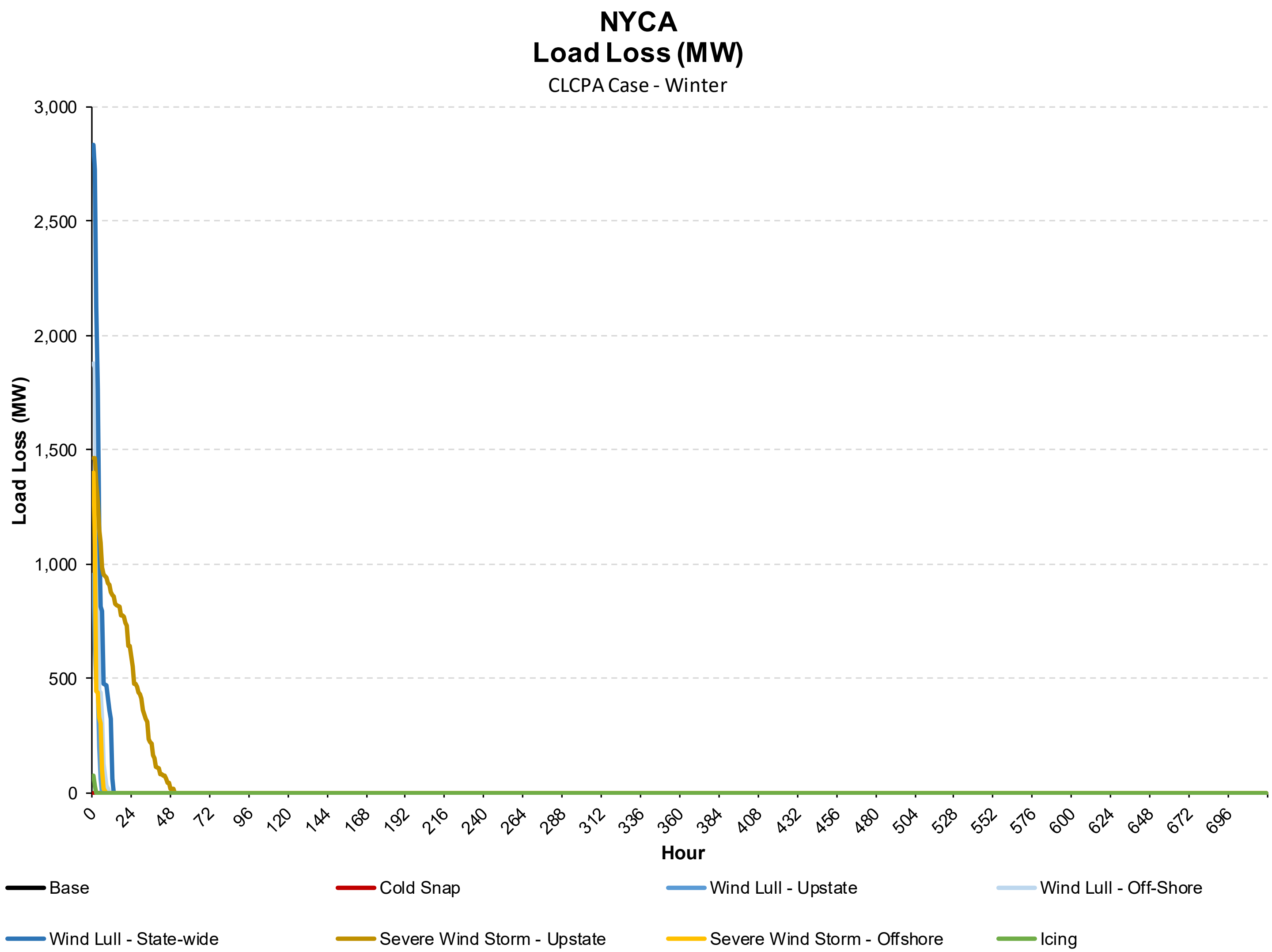
Cross-Case Comparison of Dispatchable Generation: Winter



Cross-Case Comparison of Dispatchable Generation: Winter

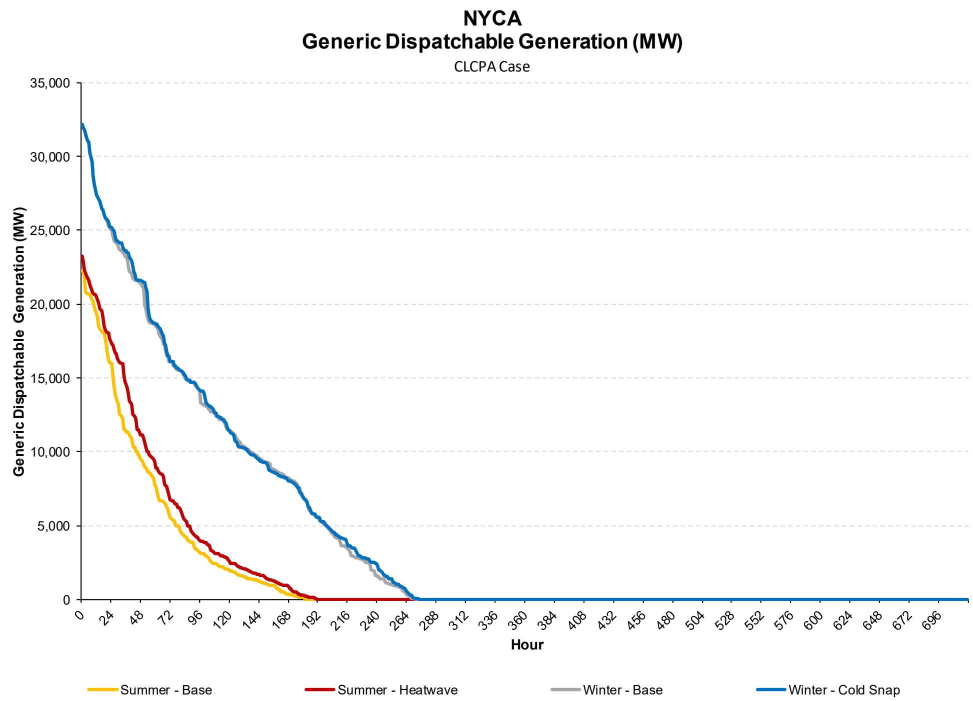


Cross-Case Comparison of Zonal Load Loss: Winter



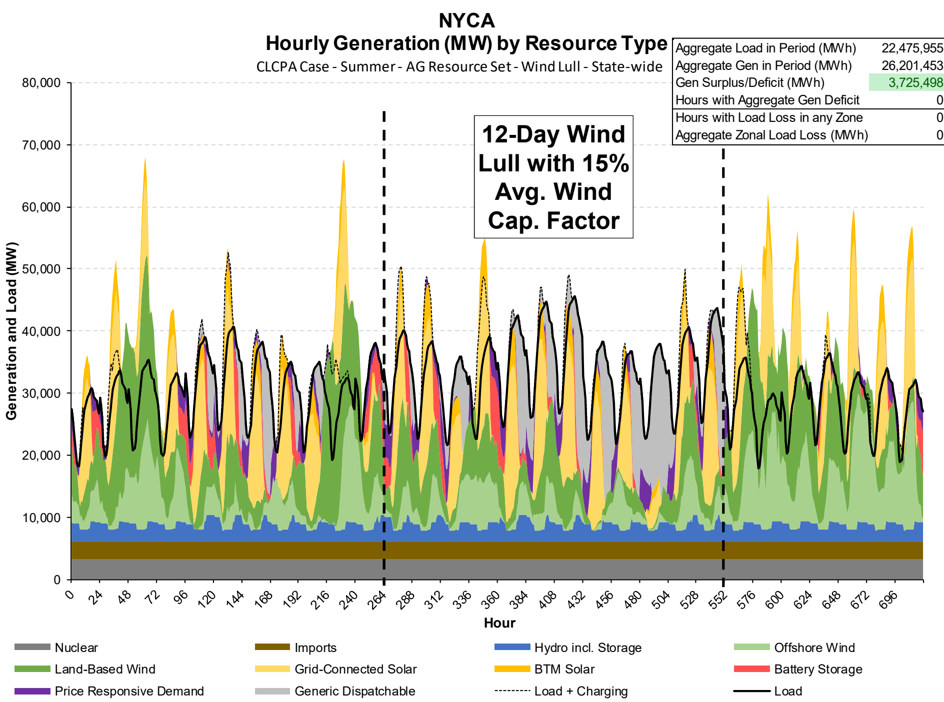
Trends Across Temperature Wave Cases

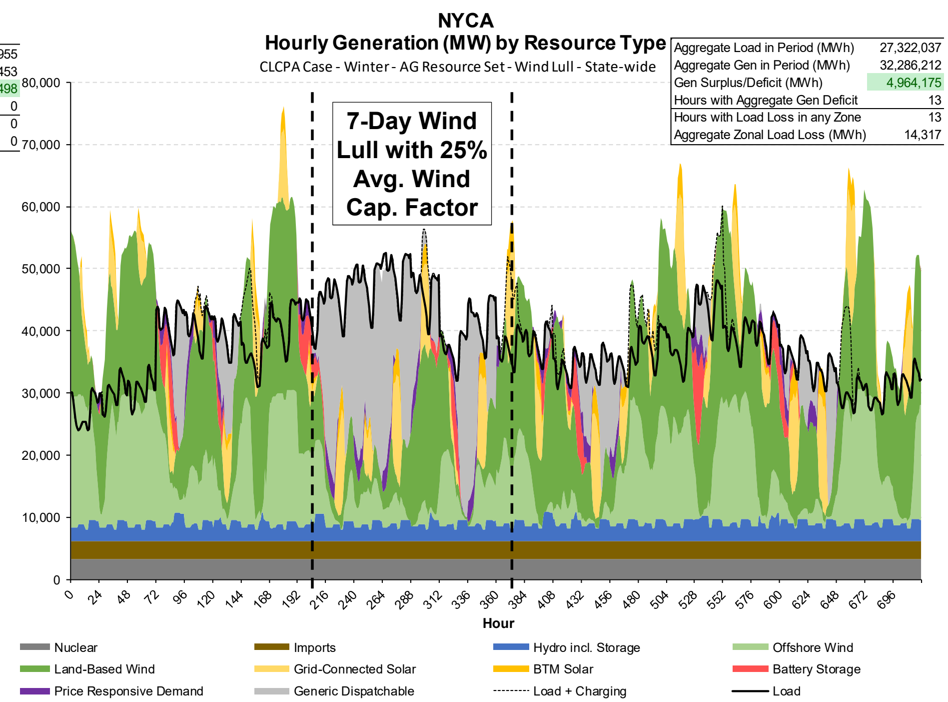
- Heat/cold waves show no losses of load; dispatchable generation and transmission are sufficient to meet load in all hours
- Increased load response to high temperatures mean heat waves have greater impact on loads than cold waves
- More severe modeled temperature waves may lead to increased stresses on system



Trends Across Wind Lull Cases

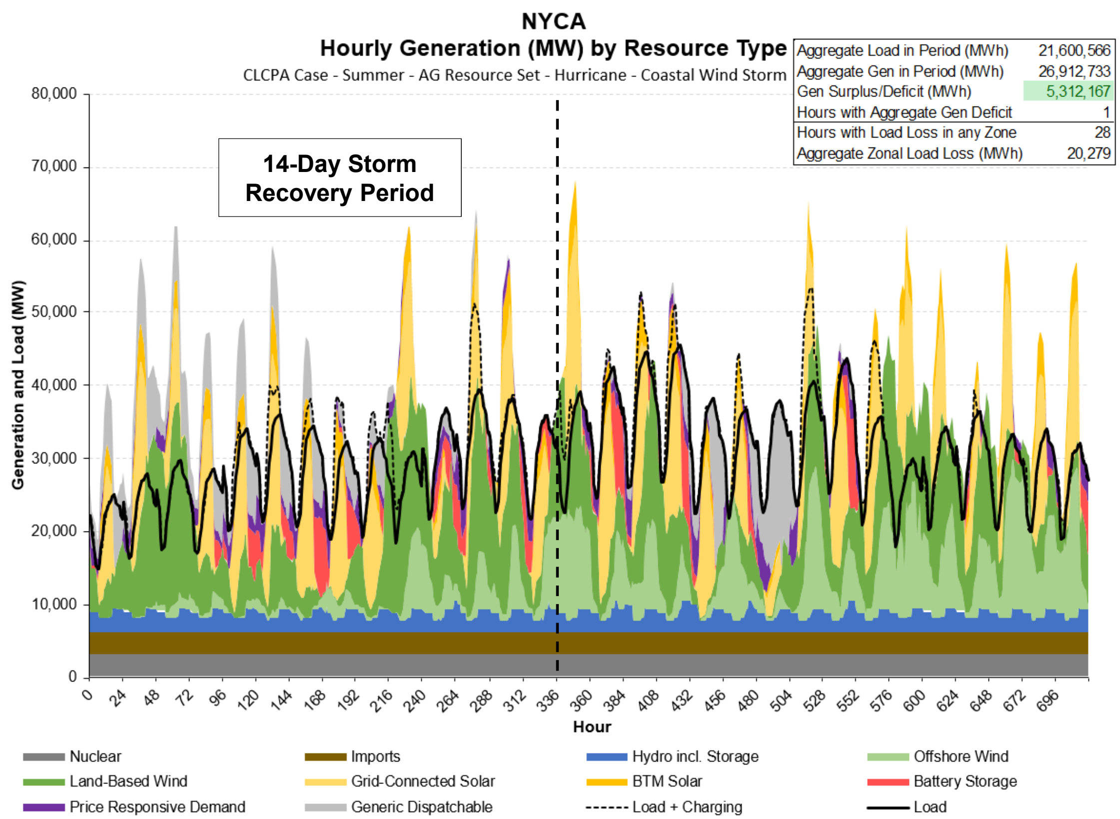
- Increased solar generation during summer wind lulls offset losses of wind output, and result in no summer loss of load events
- Winter wind lulls lead to reliance on dispatchable generation during lull periods and small loss of load events





Trends Across Storm Cases: Summer

- Hurricane/major wind storms cause loss of load (at transmission system level) during storm and 14-day recovery period, but ease significantly once transmission is partially restored
- Loss of transmission in downstate zones prevents batteries and dispatchable generation in upstate zones from relieving loss of load downstate during early recovery period



Preliminary Results with Grid in Transition Resource Set

Preliminary Findings using CLCPA Summer Cases

- Significant reliance on dispatchable generation across all cases (>70% of hours have some dispatchable generation used in baseline case)
- Losses of load occur in storm cases with transmission and dispatchable generation disruptions

	Loss of Load		Dispatchable Generation				
	Total Hours with LOL in at least one Load Zone	Aggregate LOL (MWh)	Max Consecutive Hours with Dispatchable Gen.	Total Hours with Dispatchable Gen.	Aggregate Dispatchable Gen. (MWh)	Max Dispatchable Gen. (MW)	Max 1-hr. Dispatchable Gen. Ramp (MW)
CLCPA Summer Scenario - Grid in Transition Resource Set							
Baseline Summer	0	0	98	512	4,198,131	27,075	5,938
Heat Wave	0	0	98	523	4,498,791	28,100	5,938
Wind Lull - Upstate	0	0	98	516	4,517,346	28,807	6,382
Wind Lull - Off-Shore	0	0	227	544	5,001,691	28,360	6,007
Wind Lull - State-Wide	0	0	227	544	5,339,716	30,794	7,569
Hurricane/Coastal Wind Storm	24	20,463	240	560	4,849,592	27,075	5,938
Severe Wind Storm – Upstate	24	19,741	172	549	5,016,534	27,075	5,938
Severe Wind Storm – Offshore	0	0	171	556	5,142,130	27,932	5,938
Drought	0	0	102	519	4,630,408	28,992	7,170

- In all cases, peak dispatchable ramp occurs on the peak hour of day 19 of the modeling period

Comparison of CLCPA Summer Results between Resource Sets

- Greater amounts of dispatchable generation used across all CLCPA climate disruption cases under Grid in Transition resource set
- Upstate storm scenario has greater losses of load under Grid in Transition resource set, due to more limited transmission during storm recovery period

	Climate Impact Phase II Resource Set					Grid in Transition Resource Set				
CLCPA Summer Scenario	Total Hours with LOL in at least one Load Zone	Aggregate LOL (MWh)	Total Hours with Dispatchable Gen.	Aggregate Dispatchable Gen. (MWh)	Diff. in Dispatchable Gen. from Baseline (MWh)	Total Hours with LOL in at least one Load Zone	Aggregate LOL (MWh)	Total Hours with Dispatchable Gen.	Aggregate Dispatchable Gen. (MWh)	Diff. in Dispatchable Gen. from Baseline (MWh)
Baseline Summer	0	0	181	1,159,404	+0	0	0	512	4,198,131	+0
Heat Wave	0	0	191	1,354,972	+195,568	0	0	523	4,498,791	+300,660
Wind Lull - Upstate	0	0	214	1,592,818	+433,414	0	0	516	4,517,346	+319,215
Wind Lull - Off-Shore	0	0	216	1,502,020	+342,616	0	0	544	5,001,691	+803,560
Wind Lull - State-Wide	0	0	274	2,210,826	+1,051,422	0	0	544	5,339,716	+1,141,585
Hurricane/Coastal Wind Storm	28	20,279	349	2,072,911	+913,507	24	20,463	560	4,849,592	+651,461
Severe Wind Storm – Upstate	8	1,721	322	2,213,628	+1,054,224	24	19,741	549	5,016,534	+818,403
Severe Wind Storm – Offshore	0	0	205	1,400,864	+241,460	0	0	556	5,142,130	+943,999
Drought	0	0	193	1,495,695	+336,291	0	0	519	4,630,408	+432,277

Preliminary Findings using CLCPA Winter Cases

- >60% of hours have some dispatchable generation used in all cases
- Wind lull scenarios cause no loss of load, due to available dispatchable generation

	Loss of Load		Dispatchable Generation				
	Total Hours with LOL in at least one Load Zone	Aggregate LOL (MWh)	Max Consecutive Hours with Dispatchable Gen.	Total Hours with Dispatchable Gen.	Aggregate Dispatchable Gen. (MWh)	Max Dispatchable Gen. (MW)	Max 1-hr. Dispatchable Gen. Ramp (MW)
CLCPA Winter Scenario - Grid in Transition Resource Set							
Baseline Winter	0	0	104	461	6,162,565	39,539	11,645
Cold Wave	0	0	104	467	6,281,603	39,539	11,645
Wind Lull - Upstate	7	6,367	110	470	6,317,654	39,758	12,061
Wind Lull - Off-Shore	5	1,092	168	488	6,844,813	39,758	11,540
Wind Lull - State-Wide	8	10,000	124	487	6,997,633	39,758	11,693
Severe Wind Storm – Upstate	51	57,658	111	554	6,715,584	38,503	11,540
Severe Wind Storm – Offshore	2	108	120	562	7,925,848	39,758	11,540
Icing Event	24	11,247	104	481	6,154,836	39,539	11,645

- In all cases, peak dispatchable ramp occurs on day 12 of the modeling period, the peak day of winter load

Comparison of CLCPA Winter Results between Resource Sets

- Greater amounts of dispatchable generation in Grid in Transition resource set during wind lull cases but similar or reduced number of loss of load events
- Reduced transmission under Grid in Transition resource set leads to additional load losses during scenarios that affect upstate resources (Severe Wind Storm – Upstate and Icing Event)

	Climate Impact Phase II Resource Set					Grid in Transition Resource Set				
CLCPA Winter Scenario	Total Hours with LOL in at least one Load Zone	Aggregate LOL (MWh)	Total Hours with Dispatchable Gen.	Aggregate Dispatchable Gen. (MWh)	Diff. in Dispatchable Gen. from Baseline (MWh)	Total Hours with LOL in at least one Load Zone	Aggregate LOL (MWh)	Total Hours with Dispatchable Gen.	Aggregate Dispatchable Gen. (MWh)	Diff. in Dispatchable Gen. from Baseline (MWh)
Baseline Winter	0	0	272	3,167,828	+0	0	0	461	6,162,565	+0
Cold Wave	0	0	275	3,210,585	+42,757	0	0	467	6,281,603	+119,038
Wind Lull - Upstate	6	2,805	273	3,379,007	+211,179	7	6,367	470	6,317,654	+155,089
Wind Lull - Off-Shore	10	7,112	288	3,658,990	+491,162	5	1,092	488	6,844,813	+682,248
Wind Lull - State-Wide	13	14,317	300	3,953,931	+786,103	8	10,000	487	6,997,633	+835,068
Severe Wind Storm – Upstate	50	28,601	382	4,142,431	+974,603	51	57,658	554	6,715,584	+553,019
Severe Wind Storm – Offshore	8	4,117	315	3,913,116	+745,288	2	108	562	7,925,848	+1,763,283
Icing Event	2	106	293	3,217,483	+49,655	24	11,247	481	6,154,836	-7,729

Preliminary Findings

Cross-Scenario Trends

- Temperature Waves
  - Periods of extreme temperature lead to additional usage of generic dispatchable generation but not losses of load
- Wind Lulls
  - Even assuming large amounts of new renewables and transmission, coordinated multi-zone lulls in wind production will place stress on system that will need to be met with generic dispatchable capacity
  - Wind lulls have greatest impact in winter, when loads are highest in the CLCPA load scenario
- Severe Storms
  - Load losses are localized given sufficient storage and generic dispatchable generation, and ease once transmission is partially restored
  - Quick recovery of damaged transmission is key to limiting load losses by allowing resources in unaffected zones to offset lost generation in affected zones

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