Climate Change Impact and Resilience Study – Phase II

An Assessment of Climate Change Impacts on Power System Reliability in New York State

FINAL REPORT

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Acknowledgments

This report has been prepared at the request of the New York Independent System Operator (NYISO), and presents an assessment of the potential impacts on power system reliability in 2040 associated with system changes due to climate change and policies to mitigate its effects. Our work benefitted significantly from input and comment from the NYISO and its market participants and stakeholders.

About the Authors

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About Analysis Group

Analysis Group is one of the largest international economic consulting firms, with more than 1,000 professionals across 14 offices in North America, Europe, and Asia. Since 1981, Analysis Group has provided expertise in economics, finance, health care analytics, and strategy to top law firms, Fortune Global 500 companies, government agencies, and other clients worldwide.

Analysis Group's energy and environment practice area is distinguished by expertise in economics, finance, market modeling and analysis, regulatory issues, and public policy, as well as deep experience in environmental economics and energy infrastructure development. Analysis Group has worked for a wide variety of clients including (among others) energy producers, suppliers and consumers, utilities, regulatory commissions and other federal and state agencies, tribal governments, power-system operators, foundations, financial institutions, and start-up companies.

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I.Executive Summary

A. Background and Approach

In 2020, NYISO contracted with Analysis Group (AG) to complete Phase II of the *Climate Change Impact and Resilience Study* ("Phase II Study"). This Phase II Study is designed to review the potential impacts on power system reliability of the (1) the electricity demand projections for 2040 developed in the preceding *Climate Change Phase I Study*,[1] and (2) potential impacts on system load and resource availability associated with the impact of climate change on the power system in New York ("climate disruptions"). The climate disruptions considered include items that could potentially occur or intensify with a changing climate and that affect power system reliability, such as more frequent and severe storms, extended extreme temperature events (*e.g.,* heat waves and cold snaps), and other meteorological events (*e.g.,* wind lulls, droughts, and ice storms).

Notably, the 2019 New York State Climate Leadership and Community Protection Act (CLCPA) requires "…reducing 100% of the electricity sector's greenhouse gas emissions by 2040."[2] This means that step one in our analysis was the development of a "starting point" Climate Change Phase II resource set (the "CCP2 resource set") for the year 2040, one that starts with the 2019 Congestion Assessment and Resource Integration Study (CARIS) 70x30 resources, but by 2040 meets the requirements of the CLCPA. Given the extensive reliance today on generators that burn fossil fuels (primarily natural gas), a key input to the analysis was the establishment of a resource set that does not include the operation of existing fossil-fueled thermal power plants, yet has sufficient resources available to meet electricity demand in the year 2040 without emissions of greenhouse gases (GHG).

With these key parameters in mind, over the past nine months Analysis Group has carried out its analysis of climate change-related impacts to system reliability. This report summarizes the results of our analysis, and presents the purpose, analytic method, and observations drawn from Analysis Group's review. The project was completed with assistance from NYISO with respect to system data and analyses, and with input from stakeholders at the NYISO Electric System Planning Working Group (ESPWG) and the Transmission Planning Advisory Subcommittee (TPAS).

Ultimately, the purpose of this Phase II study is to simulate the potential impacts of climate change and climate policy on the reliable operation of the New York power system, and to present observations to enable the NYISO, market participants, policy makers and other stakeholders an opportunity to consider whether the potential impacts warrant changes to planning, operational practices, and/or market designs. Analysis Group's approach to the analysis is presented in detail in Section II. In summary, it consists of the following steps (depicted in Figure ES-1):

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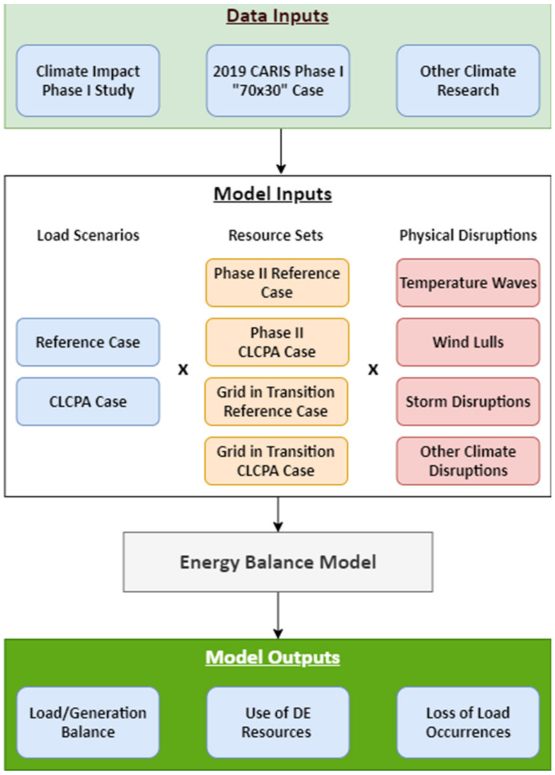
[1] In 2019, the New York Independent System Operator (NYISO) contracted with Itron to complete long-term energy, peak, and hourly load projections for the New York Control Area through the year 2050. The projections capture the impact of climate change on average temperatures and electricity demand, as well as the potential impact on demand of increased energy efficiency and electrification of the building and transportation sectors. That project - termed the Climate Change Phase I Study ("Phase I Study") - was completed in 2019, and included long-term energy, peak, and hourly load projections (for the NYISO system as a whole and each of the eleven NYISO load zones) that reflect the potential demand impacts of climate change and climate policy in New York. Itron, *New York ISO Climate Change Impact Study; Phase 1: Long-Term Load Impact*, December 2019.

[2] New York Climate Leadership and Community Protection Act (CLCPA), NY State Senate Bill S6599, 2019-06-18. The New York Department of Environmental Conservation (DEC) proposes to define GHGs as the following: GHGs are "[g]aseous constituents of the atmosphere that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. For the purposes of the Part, this includes carbon dioxide, methane, nitrous oxide, perfluorocarbons, hydrofluorocarbons, and sulfur hexafluoride." https://www.dec.ny.gov/regulations/121059.html.

- Configure Analysis Group's Energy Balance Model (EBM) to simulate power system operations in 2040, with separate balancing across and within 11 NYISO load zones;
- Review and input the ITRON Phase I hourly load forecasts for 2040, and extract data from the Phase I analysis to enable the modeling of changes in electricity demand with changes in meteorological conditions (*e.g.*, temperature); From each Phase I forecast we evaluate the peak-demand month in the winter (January) and summer (July), and the low-demand month in the shoulder season (April);
- Review state requirements encoded in the CLCPA, and consider potential scenarios for resource development consistent with state requirements and current technology trends;
- Based on this review, identify principles for constructing resource sets with sufficient resources to reliably meet NYISO seasonal peak demand, building on the 2019 CARIS Phase I 70X30 Case;
- Develop **four cases** to analyze, incorporating two Phase I Itron 2040 load forecasts (the "Reference Case" and the "CLCPA Case") and 2040 resource sets that reliably meet demand for each forecast: two that were developed for this Phase II Study, and two that were developed as part of the Grid in Transition (GIT) study.[3] Thus, the four cases analyzed are:
  - **CCP2-Reference**
  - **CCP2-CLCPA**
  - **GIT-Reference**
  - **GIT-CLCPA**
- Include in the resource sets a generic resource, the role of which is to identify the attributes of any additional resources that may be needed to avoid or reduce Loss of Load Occurrences (LOLO).[4] These resources - identified as dispatchable and emissions-free resources ("DE Resources") - are described in more detail below;

Figure ES-1: Energy Balance Model (EBM) Inputs and Outputs



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[3] The review of resource sets from both studies is intended to highlight differences in potential resource development pathways. The CCP2 resource sets are focused on achieving the CLCPA 2040 requirements with a primary focus on expansion of renewable resources and associated transmission. The GIT resource sets reflect less infrastructure development, and a stronger focus on resources like existing thermal generating resources operating on zero carbon fuels. See Section II for a more detailed description of the resource sets.

[4] Loss of Load Occurrences are not meant to be equivalent to Loss of Load Expectation in a resource adequacy context.

- Identify the potential impacts of a changing climate on the power system, including conditions or events that alter electricity demand, generating resource availability and operations, and inter-zonal transmission transfer capability. This research is used to construct "climate disruption scenarios";
- Run the climate disruption scenarios through Analysis Group's EBM for each of the four cases analyzed (the CCP2-Reference, CCP2-CLCPA, GIT-Reference, and GIT-CLCPA), for each seasonal month (where relevant);[5] and
- Generate results with respect to potential loss of load occurrences (LOLO) and reliance on DE resources, and draw observations related to power system operations based on the comparison of results across cases.

Section II contains a detailed summary of our analytic method, and of the structure and mechanics of the Analysis Group Energy Balance Model. Section III describes the cases we analyze, which include the climate change-induced physical disruptions layered on the four different cases. In Section IV we provide an overview of the metrics we evaluate through the EBM, and the form of model outputs for each case. Finally, in Section V we present the results of the analysis and our observations based on the results. The Appendices contain additional modeling details and a comprehensive set of results across all relevant cases and climate disruption scenarios.

B. Results and Observations

The context for our analysis includes both the impact of a changing climate on power system operations, and the energy and environmental policy response to the threat of climate change. In recent years, many states have moved towards establishing significant and progressive GHG emission reduction requirements that are directionally consistent with dramatically reducing GHGs from energy supply and use by the middle of the century, across all sectors of the economy. With the passage of the CLCPA, New York positioned itself at the forefront of these efforts to address climate change and initiated a fundamental transition in energy supply and use in general, and in the electric system in particular.

It is difficult to envision the specific pathway New York will take to achieve the required GHG emission reductions from the economy over just the next three decades, and from the electric sector over the next two decades. The scope of changes that will be needed to the state's building, transportation and electric sectors is unprecedented. Meeting this level of emission reductions will not only require rapid advancement of existing advanced energy technologies, but will also likely require technologies, policies, and programs that have not yet been conceived of or developed. This introduces significant uncertainty in modeling what the economy and power system look like in 2040, when the power system will operate under a very different set of resources, infrastructure, and end-use consumption patterns.

With these uncertainties in mind, we develop a model of the New York power system in 2040 that starts from the present, and is focused on the resources and policies that are taking shape at this time. We begin with the load forecasts developed in the Phase I Study, and the resources assumed in the most recent CARIS report for the 70X30 scenario. However, the load forecasts for 2040 result in electricity demand levels well in excess of the CARIS starting point resources, particularly in the CLCPA case, due to the assumed level of electrification of other sectors

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[5] Some combinations of cases, climate disruption scenarios, and months are not relevant. For example, severe heat wave cases are only modeled for the summer month.

in the economy. Moreover, all of the existing fossil-fueled generating resources are removed from the resource set to be consistent with the requirements of the CLCPA. As a result, we must construct starting point resource sets by assuming a vast buildout of carbon-free resources sufficient to meet electricity demand in the peak hour of the year.

To develop the 2040 starting point CCP2 resource sets,[6] we prioritize the addition of wind, solar, demand response, and storage technologies alongside substantial build out of the state's transmission system. The reliance in the CCP2 resource sets on renewable resources[7] -- the potential of which is largely located in the upstate region -- requires significant increases in inter-zonal transfer capability across all NYISO zones.

Finally, both the CCP2 and GIT resource sets include undefined "backstop resources" to cover any circumstances where the resource sets are insufficient to meet identified demand, and to evaluate what attributes such a resource must have to help meet reliability needs. Since the resource generally needs to be *dispatchable* and compliant with *emission* requirements, we designate this the "DE Resource." As described in more detail below, the DE Resource is not tied to any particular technology. Table ES-1 summarizes the generation resources assumed in the CCP2-CLCPA resource set.

Table ES-1: Generation Capacity, CCP2-CLCPA Resource Set

Nameplate Capacity by Zone, MW	A	B	C	D	E	F	G	H	I	J	K	Total
Land-based Wind	10,815.9	1,566.9	7,726.2	7,774.5	7,316.4	-	-	-	-	-	-	**35,200.0**
Offshore Wind	-	-	-	-	-	-	-	-	-	14,957.8	6,105.2	**21,063.0**
Solar (Behind-the-meter)	1,408.5	436.4	1,192.8	138.2	1,345.5	1,653.4	1,367.3	121.2	179.4	1,343.1	1,692.2	**10,877.8**
Solar (Grid Connected)	11,496.0	1,312.0	7,170.0	-	4,536.0	9,322.0	5,272.0	-	-	-	154.0	**39,262.0**
Hydro Pondage	2,675.0	-	-	856.0	-	-	41.6	-	-	-	-	**3,572.6**
Hydro Pumped Storage	-	-	-	-	-	1,170.0	-	-	-	-	-	**1,170.0**
Hydro Run-of-River	4.7	63.7	70.4	58.8	376.2	282.5	57.1	-	-	-	-	**913.4**
Nuclear	-	581.7	2,782.5	-	-	-	-	-	-	-	-	**3,364.2**
Imports	-	-	-	1,500.0	-	-	-	-	-	1,310.0	-	**2,810.0**
Storage	4,232.0	20.0	3,160.0	4,168.0	2,296.0	292.0	84.0	-	-	1,096.0	252.0	**15,600.0**
Price Responsive Demand (Summer)	949.9	205.2	510.1	357.7	211.1	433.9	246.3	58.6	134.9	1,940.8	187.6	**5,236.0**
Price Responsive Demand (Winter)	619.0	133.7	332.4	233.1	137.5	282.7	160.5	38.2	87.9	1,264.7	122.3	**3,412.0**
DE Resources	465.4	674.2	1,513.4	370.0	312.7	3,390.4	6,887.2	79.8	-	11,848.1	6,595.4	**32,136.6**

With this model arrangement, we evaluate a range of climate disruption scenarios. These represent episodic circumstance and events driven by meteorological conditions that could become more frequent and/or more severe in a changing climate. The disruption scenarios are focused on those weather conditions known to disrupt power system operations, specifically coastal and inland storms, heat and cold spells, drought and icing events. And their effects on power system infrastructure and operations are modeled based on historical experience with similar events.

Based on our review of modeling results and the context for our analysis, we come to the following observations:

Climate disruption scenarios involving storms and/or reductions in renewable resource output (e.g., due to wind lulls) can lead to loss of load occurrences. Electrification, particularly in the building sector, transforms New York into a winter-peaking system. Thus loss of load occurrences due to climate disruptions in the winter are deeper and occur across more scenarios than in the summer. *See* Table ES-2. Specifically, in the winter severe wind storms, lulls in wind resource output (upstate or downstate), and icing events all lead to loss of load, as well as

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[6] The GIT resource sets were developed as part of a separate NYISO Study.

[7] In this report we use the term "renewable resource" to refer to on-shore and off-shore wind, and grid-connected and behind-the-meter solar resources. In the EBM, renewable resource hourly output is modeled based on state-specific and resource-specific generation profiles from the National Renewable Energy Lab ("NREL"). For more detail on the modeling of renewable resources, see Section II.D below.

elevated reliance on the DE resource. In the summer, these events increase the system's reliance on the DE resource, but LOLOs are only triggered in the severe coastal (hurricane) and upstate wind storm events.

The variability of meteorological conditions that govern the output from wind and solar resources presents a fundamental challenge to relying on those resources to meet electricity demand. In scenarios involving LOLOs, or requiring substantial contributions from DE resources, periods of reduced output from wind and solar resources are the primary driver of challenging system reliability conditions, particularly during extended wind lull events. *See* Figure ES-2, showing results for the CCP2-CLCPA Case in the winter, including an extended wind lull. During the wind lull,[8] the state realizes losses of load in at least one zone for thirteen hours, with a total loss of over 14 gigawatt-hours (GWh). Moreover, during the wind lull the system relies *primarily* on the DE generating resource to avoid more severe LOLOs. Even outside the specific seven-day climate disruption wind lull period, one can see that base case reductions in wind output create periods of significant reliance on the DE resource to avoid losses of load.[9] Importantly, further increasing the nameplate capacity of such resources is of limited value, since when output is low, it is low for all similar resources across regions or the whole state.[10] As can also be seen across the full winter month, periods of solar output are not able to contribute during the early evening winter peak hours.

Table ES-2: Case Result Summaries, CCP2-CLCPA Case

	Loss of Load		DE Resource Generation				
	Total Hours with LOLO in at least one Load Zone	Aggregate LOLO (MWh)	Max Consecutive Hours with DE Resource Gen.	Total Hours with DE Resource Gen.	Aggregate DE Resource Gen. (MWh)	Max DE Resource Gen. (MW)	Max 1-hr. DE Resource Gen. Ramp (MW)
CLCPA Summer Scenario - Climate Impact Phase II Resource Set							
Baseline Summer	0	0	36	145	847,589	22,081	9,170
Heat Wave	0	0	36	147	964,668	22,081	8,642
Wind Lull - Upstate	0	0	37	179	1,171,656	23,361	9,447
Wind Lull - Off-Shore	0	0	40	196	1,116,165	23,170	9,170
Wind Lull - State-Wide	0	0	40	235	1,697,161	24,440	11,605
Hurricane/Coastal Wind Storm	26	20,168	171	322	1,892,046	22,081	8,642
Severe Wind Storm – Upstate	8	1,620	87	283	2,002,682	22,081	8,642
Severe Wind Storm – Offshore	0	0	36	167	1,079,462	22,163	10,015
Drought	0	0	36	166	1,148,649	23,595	10,610

	Loss of Load		DE Resource Generation				
	Total Hours with LOLO in at least one Load Zone	Aggregate LOLO (MWh)	Max Consecutive Hours with DE Resource Gen.	Total Hours with DE Resource Gen.	Aggregate DE Resource Gen. (MWh)	Max DE Resource Gen. (MW)	Max 1-hr. DE Resource Gen. Ramp (MW)
CLCPA Winter Scenario - Climate Impact Phase II Resource Set							
Baseline Winter	0	0	62	255	2,866,203	32,135	11,716
Cold Wave	0	0	62	259	2,879,947	32,135	11,716
Wind Lull - Upstate	5	2,373	62	259	3,076,530	32,135	12,707
Wind Lull - Off-Shore	10	7,184	104	274	3,350,666	32,135	11,715
Wind Lull - State-Wide	13	14,404	105	278	3,653,404	32,135	12,403
Severe Wind Storm – Upstate	45	22,146	81	369	3,822,059	31,419	12,850
Severe Wind Storm – Offshore	9	4,203	103	304	3,609,785	32,135	11,715
Icing Event	2	88	62	273	2,909,437	32,135	11,716

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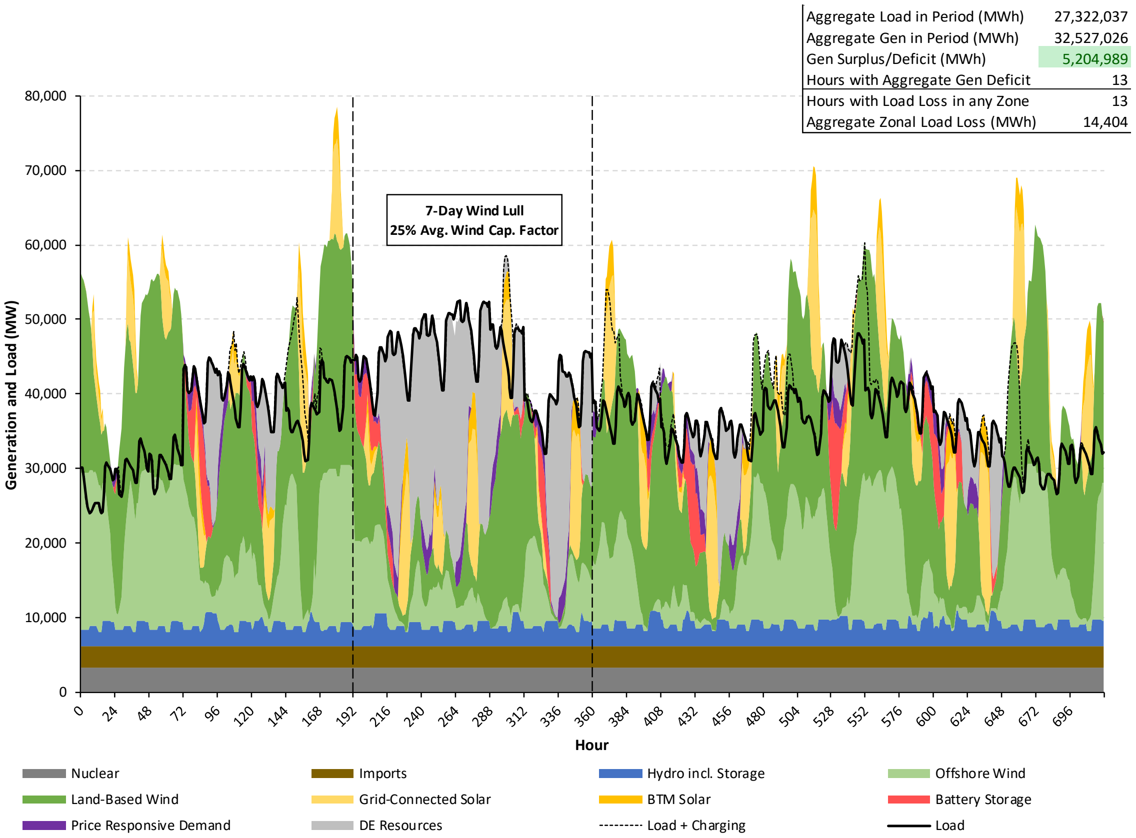
[8] The wind lull is a seven-day period from hours 192-360 in Figure ES-2.

[9] *See* hours 72-144, and hours 408-480.

[10] As noted, the generation profiles used for the wind and solar resources are taken from NREL state-specific generation profiles, based on historical meteorological data. The resulting renewable resource output profile across each season's month affects both the amount of renewable capacity needed to meet 2040 peak demand, and the reliance on the DE Resource and occurrence of LOLOs across all hours of the month. Renewable generation technology development and/or the realization of meteorological conditions that are different than the underlying historical NREL profiles could result in fundamentally different contributions from such resources in 2040, and different levels and types of system impacts than those reported here. The significance of the modeled renewable generation technologies and profiles thus represents a key uncertainty in the analysis, and this should be considered in interpreting results.

Figure ES-2: Hourly Load/Generation Balance, CCP2-CLCPA Winter Wind Lull Case



Aggregate Load in Period (MWh)	27,322,037
Aggregate Gen in Period (MWh)	32,527,026
Gen Surplus/Deficit (MWh)	5,204,989
Hours with Aggregate Gen Deficit	13
Hours with Load Loss in any Zone	13
Aggregate Zonal Load Loss (MWh)	14,404

Battery storage resources help to fill in voids created by reduced output from renewable resources, but periods of reduced renewable generation rapidly deplete battery storage resource capabilities. As described in Section II, the CCP2-CLCPA resource set includes the development and operation of over 15,600 MW (124.8 GWh) of new storage resources, configured as eight-hour batteries, and distributed throughout the state to maximize their ability to time shift excess generation from renewable resources.[11] At this level of development, battery storage makes significant contributions to avoiding loss of load and reliance on backstop generation for the immediate period following sharp declines in renewable resource output due to climate disruptions (and also due to normal wind/solar resource variability).[12] While this represents a substantial level of assumed growth in battery storage within New York, the contribution of storage is quickly overwhelmed by the depth of the gap left during periods of time with a drop off in renewable generating output over periods of a day or more. This is revealed by the fill in of the DE Resource (in grey) following depletion of the storage resources (in red) during various periods in Figure ES-2.

The DE resources needed to balance the system in many months must be significant in capacity, be able to come on line quickly, and be flexible enough to meet rapid, steep ramping needs. Our generic DE resource generates energy as needed to meet demand and avoid loss of load occurrences. This study does not make any assumptions

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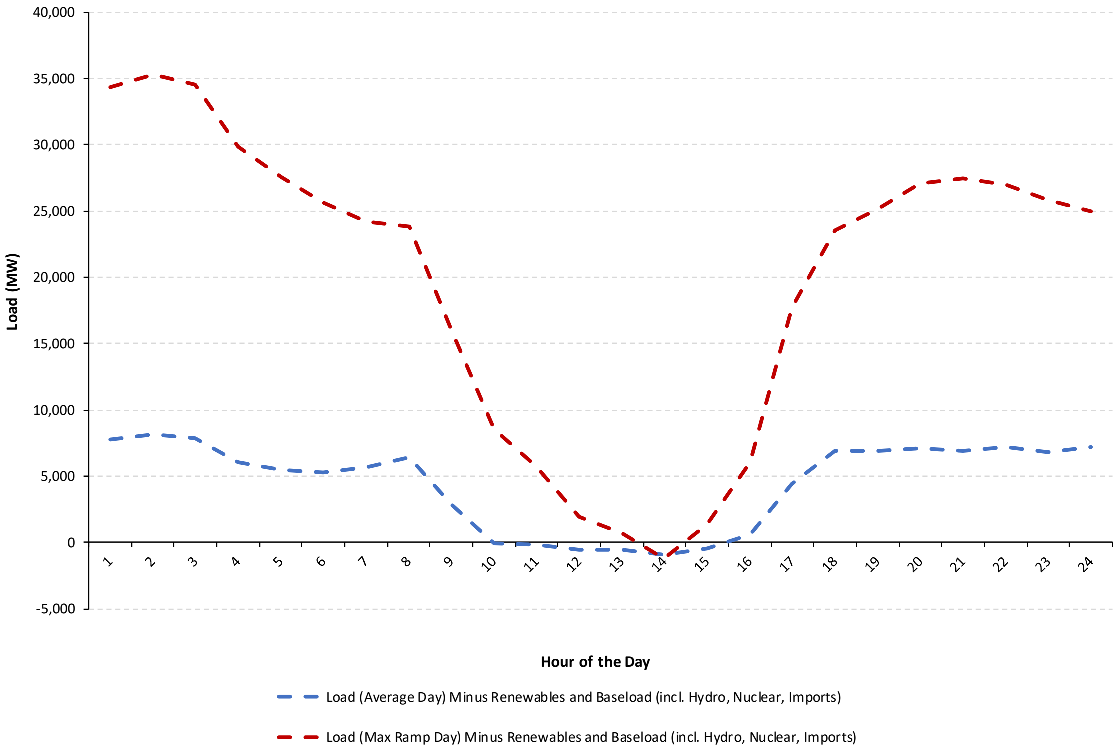
[11] As noted earlier, the development of the CCP2 resource sets requires a vast buildout of carbon-free resources to meet elevated electricity demand and the absence of existing fossil-fueled generating resources. This need drives the assumed amount of battery storage resources included in the resource sets; that is, the amount of battery storage assumed reflects an assumption of continuous and significant growth in storage technology over the next twenty years, and is well in excess of any existing mandates or near-term development expectations.

[12] *See*, e.g., Figure ES-2, hours 72-96, 192-216, and 410-440.

about what technology or fuel source can fill this role twenty years hence. Instead, the model includes the DE Resource to identify the attributes required of whatever resource (or resources) emerges to fill this role. Based on a review of the frequency and circumstances of reliance on the DE Resource to maintain reliability in the model, we can identify the characteristics required of the resource. In this, certain observations stand out. First, even in the baseline cases (*i.e.,* before layering in climate disruption events), there are periods of very low output from the renewable resources during periods of demand when resources need to be available to meet the bulk of the system's annual energy requirements. During such periods, the need for the DE Resource climbs very high - at times more than 30,000 MW. This is true even though the DE Resource is not significantly utilized on an annual energy basis, and has a very low capacity factor, at or less than ten percent. Second, the DE Resource needs to be highly flexible - it needs to be able to come on quickly, and be able to meet rapid and sustained ramps in demand. The results in Table ES-2 show that the minimum one-hour ramp requirement, even in the baseline CCP2-CLCPA case, approaches 12 GW, and climbs to nearly 13 GW in multiple CLCPA climate disruption cases. Moreover, as can be seen in Figure ES-3, the ramping capability of the DE Resource is even larger when viewed across multiple hours. For example, the four-hour period of greatest ramp in the CCP2-CLCPA case in the winter exceeds 20,000 MW.

Figure ES-3: Maximum Hourly Ramping Requirement, CCP2-CLCPA Winter Case



The assumed increase in inter-zonal transfer capability in the CCP2 resource sets enables a renewables-heavy resource mix and improves reliability, but also increases vulnerability to certain climate disruption scenarios. The CCP2 resource sets are designed to maximize the contribution of renewable resources which, due to available land area and ease of siting, are heavily weighted towards the upstate region. As a result, it is necessary to assume a major build out of the transmission system in New York, to enable the upstate renewable resources to contribute to meeting load in the downstate region. Across the climate disruption cases, the increased transfer capability improves the resilience of the power system to all events that are localized, such as offshore storms or wind lulls that only affect the upstate or downstate regions, as well as to some disruptions that affect load and generation across the state, such as heat waves and cold snaps. Conversely, the increased reliance on transmission increases the vulnerability of the system to climate disruption events that specifically impact transmission capability, including icing events or major storms that disable transmission capacity.

Cross-seasonal differences in load and renewable generation could provide opportunities for renewable fuel production. The CCP2 resource sets are constructed to be able to meet peak demand in the winter and summer seasons based primarily on production from renewable resources. However, this means that there is a substantial amount of renewable generation that is excess, or "spilled," in off-peak seasons and hours. This introduces the potential for a seasonal storage technology to help meet the needs represented in the analysis by DE Resource generation during the summer and winter. Such potential assumes the emergence of economic technologies capable of converting excess renewable energy to a fuel and storing it for later use, or the development of other long term storage technologies. For example, as seen in Table ES-3, the excess renewable generation in the shoulder season modeling period under the CCP2-CLCPA case totaled roughly 23,204 GWh, while the DE Resource use in the winter modeling period was just 4,401 GWh. This raises the possibility that, should such technologies or capabilities emerge, excess off-peak renewable generation could help meet the peak-month energy requirements represented in the model by generation from the DE Resource.

Table ES-3: Excess Renewable Generation

Season	Aggregate Excess Renewable Generation (GWh)	Average Hourly Excess Renewable Generation (MW)	Average Hourly Percentage of Excess Renewable Generation (%)
Winter	4,401	6,112	13.66%
Summer	3,926	5,453	13.95%
Shoulder	23,204	32,227	75.80%

The current system is heavily dependent on existing fossil-fueled resources to maintain reliability, and eliminating these resources from the mix will require an unprecedented level of investment in new and replacement infrastructure, and/or the emergence of a zero-carbon fuel source for thermal generating resources. A power system that is effectively free of GHG emissions in 2040 cannot include the continued operation of thermal units fueled by well-based natural gas. However, these are the very units that are currently vital to maintain power system reliability throughout the year. This is the fundamental challenge of the power system transition that will take place over the next two decades. Indeed, this transition must take place at the same time that electricity demand in the state will grow significantly if electrification of other economic sectors, such as transportation and heating, is needed to meet the economy-wide GHG emission reduction requirements. In all four cases studied, the required investment in and development of renewable resources is substantial, and far greater than anything previously experienced in New York. Table ES-4 shows the pace of development required for each case and resource set, compared to the historical capacity growth rate in New York.

Table ES-4: Required Rate of New Resource Development

	Nameplate Capacity (MW)		Required 2020-2040 Nameplate Capacity Growth Rate (MW/yr)	
	Wind (Land-based and Offshore)	Grid-Connected Solar	Wind (Land-based and Offshore)	Grid-Connected Solar
Existing Resources (2020)	1,985	57		
Climate Phase II Reference Case Resource Set (2040)	39,962	34,354	1,899	1,715
Climate Phase II CLCPA Scenario Resource Set (2040)	56,263	39,262	2,714	1,960
Grid in Transition Reference Case Resource Set (2040)	23,522	30,043	1,077	1,499
Grid in Transition CLCPA Scenario Resource Set (2040)	48,357	31,669	2,319	1,581
Historical Nameplate Capacity Growth Rate (2012-2020, MW/yr)			**71.4**	**3.1**

Overall, the key reliability challenges identified in this study are associated with <u>both</u> how the resource mix evolves between now and 2040 in compliance with the CLCPA, and the impact of climate change on meteorological conditions and events that introduce additional reliability risks. The climate disruption events modeled in the EBM may be more frequent and/or more severe than in the past, and this increases NYISO's challenges in managing reliability risks over time. Nevertheless, such events do not appear to be *qualitatively* different than similar events experienced in the past, and present reliability challenges that may be considered similar to those faced today. With sufficient planning and preparation such events could be managed to maintain reliability in much the same way current weather-based disruptions are managed. However, on top of this the analysis demonstrates that, based on current information and technologies, the evolution of the system to one focused on zero-carbon resources and the infrastructure needed to support such a resource mix could introduce a number of key vulnerabilities to system reliability. These challenges include the variability of the meteorological conditions affecting renewable generation, the temporal limitations of existing battery storage technologies, and the increased dependence on resources distant from load centers. Based on our analysis, managing this transition seems to introduce reliability challenges that may be more difficult than those arising from the conditions of a changing climate. *Most importantly, this analysis suggests that establishing electricity market designs and energy policies to encourage innovation and accelerate advanced energy resource development will be key to reliably and economically managing the transition in the electric sector in New York*.

Comparing the CCP2 resource sets to the GIT resource sets reveals key differences in how the system makeup in 2040 can affect reliability outcomes. There are key differences between the Climate Change Phase II resource sets and those developed for the Grid in Transition study. First, given the different mixes of resources, the proportion of load met by DE Resources in the CLCPA winter load scenario is roughly nine percent for the CCP2-CLCPA resource set, but about 20 percent for the GIT-CLCPA resource set. In addition, given differences in the assumed level of transmission on the system (the GIT resource set does not include any expansion of the current transmission system), constraints on the Total East and Total South interfaces are binding in a larger percentage of hours under the GIT resource set, which means that DE Resources downstate are dispatched to provide electricity in more hours. The differences also lead to changes in vulnerability to climate disruptions. There are more hours with loss of load occurrences in the state-wide and offshore wind lull cases under the CCP2 resource sets, given the smaller overall quantity of DE Resources and greater reliance on wind resources. Conversely, the lower level of inter-zonal transfer capability in the Grid-in-Transition study resource set leads to more severe load losses during scenarios that affect upstate resources, such as severe windstorm and icing events.

In this study, we provide results for two very different visions for the evolution of the power system - one that relies on renewables and transmission (the CCP2 resource sets), and one that places greater emphasis on the backstop resource - that is, the potential emergence of a zero-carbon generation or fuel source (the GIT resource sets). These are only two of a wide range of potential outcomes as the system and technologies change over the next two decades, but they represent in some sense two bookends to potential system changes - one focused on aggressive system infrastructure development, and one that looks more like the current system, but is dependent on the development of zero-GHG fuel sources. The key differences between them are the relative levels of investment in system infrastructure, and the degree of reliance on the DE Resource.

For example, if there is skepticism that an economic fuel or technology will emerge and be widely available, and that can deliver reliable capacity, energy, reserves, and flexible operating attributes with little or no emissions of GHGs, then the pathway may be more heavily tilted towards aggressive investment in and development of renewable and transmission infrastructure, such as in the CCP2 resource sets. This approach would allow the system to operate with relatively low annual generation from the DE Resource. Conversely, if such a fuel or technology were to emerge, be technologically and economically viable, and be widely available, then there is less need to invest the significant capital needed to build out renewable and transmission infrastructure to meet the CLCPA requirements. These differences provide useful insight into the challenges New York State will face in guiding and managing what will likely be a rapid transition over the next two decades.

II.Analytic Method

A. Overview of Analytic Method

Analysis Group developed and applied a multi-step energy balance analysis to assess the risks to the reliability of the NYISO power system posed by changes in system conditions and infrastructure due to climate change in New York State. The analysis is completed for 2040 based upon the state's CLCPA requirements for that year. It reflects both the Climate Change Phase I results with respect to climate-induced changes to system demand, and assumptions described further in this report with respect to system infrastructure available in 2040. Figure 4 presents the structure of the analysis used to generate results for all cases, and Figure 5 summarizes the inputs and logic of the energy balance model. Section II provides a more detailed description of the analytic method, model components, and data and information sources used in the analysis.

Figure 4: Structure of Analysis

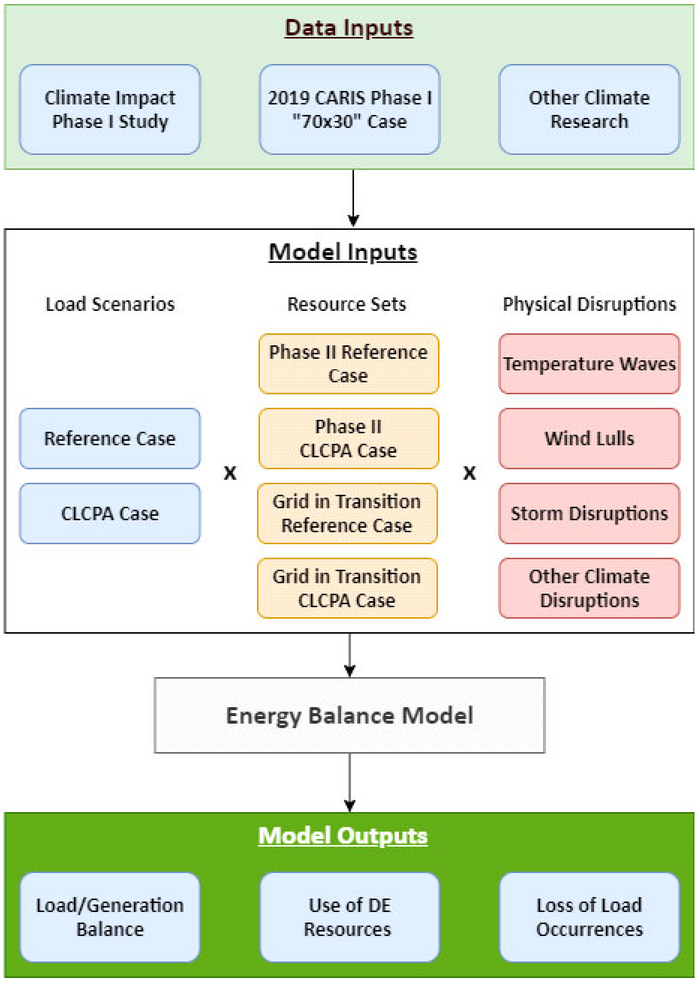
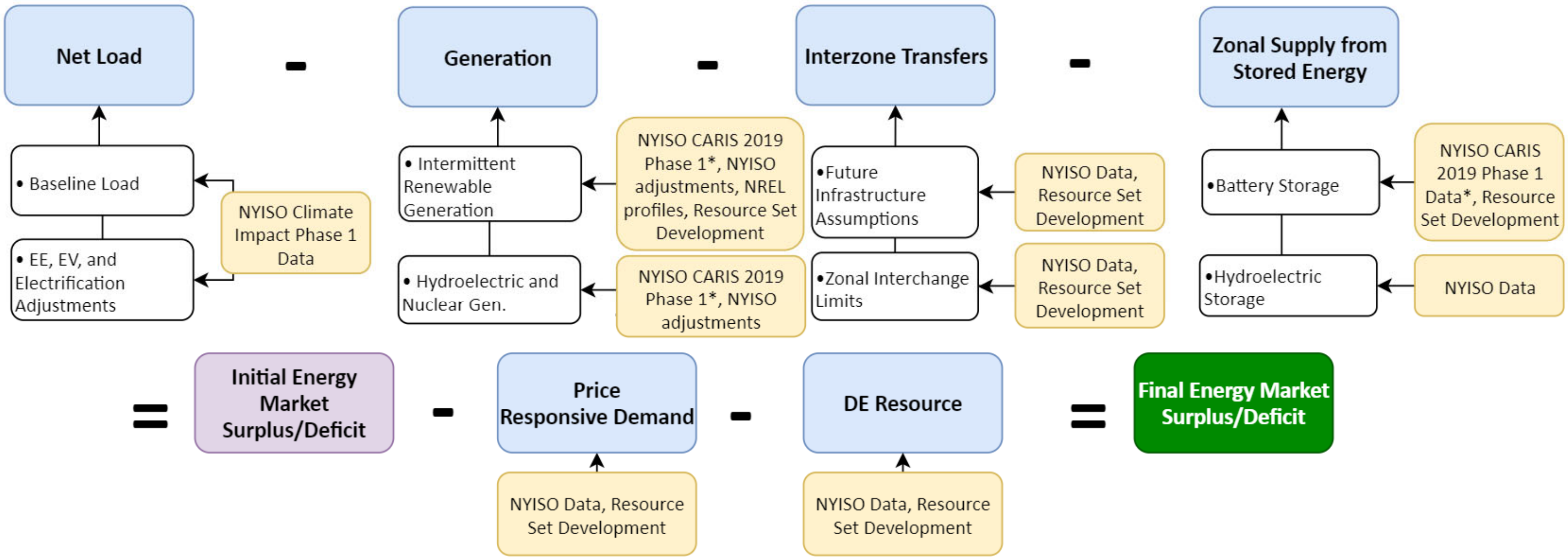


Figure 5: Energy Balance Model Steps and Data Sources



*CARIS 2019 is being leveraged as a starting point in the initial base case assumption

B. Framework for Energy Balance Analysis

Analysis Group's energy balance model is a deterministic, scenario-based assessment of system operations in a future year - 2040. The model evaluates system reliability under different combinations of load including assumptions regarding future loads and hourly shapes based on weather. It analyzes different resource sets and variations in future system resource mix and transmission topology. The model examines various climate disruptions under which altered climate conditions affect load, resource availability/generation, and transmission availability. Given that the load levels and the output of renewable generating capacity vary widely over the course of the year, we evaluate three representative seasonal modeling periods: summer, winter, and shoulder season. For each season we model a single month.

There are three core elements to the modeling framework - (1) Load, (2) Resources, and (3) Climate Disruptions:

(1) Load: The starting point for the analysis is expected system conditions for the future year of 2040, based on load scenarios developed by Itron in the NYISO Climate Impact Phase I study ("Phase I Study").[13] The Phase I load scenarios reflect the impact of climate change and state policy on electricity demand in New York State. We focus on two of the Phase I scenarios: 1) the Reference Case, which assumes average New York State temperatures will increase at 0.7 degrees F per decade without significant load impact from state policy; and 2) the CLCPA Case, which assumes the same temperature trend, but reflects load impacts from electrification of the transportation and building sectors in the state, and enhanced implementation of energy efficiency. These factors are described in more detail in Section II.C.1 below.

(2) Resources: The next step involves development of resource sets for each of the two load scenarios, based on the Analysis Group Climate Change Phase II (CCP2) set and the NYISO Grid in Transition (GIT) Study set. This leads to four resource sets: CCP2-reference, CCP2-CLCPA, GIT-reference, and GIT-CLCPA. The purpose of this step is to position the power system to reliably meet the Phase I 2040 demand levels. The resource sets are developed to maintain reliable system operations in the season with the highest peak load, which is summer for the Reference Case and winter for the CLCPA Case. For the CCP2 resource sets, the starting point for each resource set is the 2019 CARIS Phase I "70x30" case, which assumes specific quantities of renewable and nonrenewable resources by load zone. This resource set alone is insufficient to meet demand; thus, the analysis adds renewable generating capacity, storage capacity, transmission capability, and DE resource capacity in quantities sufficient to meet the seasonal peak demand.[14] The resource sets are described in more detail in Section II.D below.

(3) Climate Disruption Scenarios: With the Phase I load scenarios and reliable starting point resource sets in hand, we then identify a range of impacts on loads and resources associated with the impacts of a changing climate. These climate disruptions are used to define seasonal "cases," which are run through the energy balance model to identify any reliability risks associated with operations under those conditions. The results of the model identify the magnitude, frequency and duration of any periods where available generation was potentially insufficient to

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[13] Itron, "New York ISO Climate Impact Study; Phase 1: Long-Term Load Impact," (hereafter "Phase I Study"), December 2019.

[14] Analysis Group developed the reliable resource sets for use in this study. As described in Section II.F below, we also evaluate system outcomes using the resource set assumed in the Grid in Transition study, which varies in the location and quantities of both renewable and DE resources across zones.

meet load over the duration of the seasonal modeling period, or where significant storage or DE resource output is needed to supplement renewable generation.[15]

The sections that follow describe the methods and data used in the model and analyses. Section II.C addresses the development of the load scenarios and seasonal modeling periods. Section II.D details the construction of resource sets by load scenario, which includes generation, storage resources, and transmission. Section II.E reviews the "dispatch" and intrastate power transfer logic that is applied across all cases, and finally Section II.F compares the resource sets developed for this study with those used in the *Grid in Transition* study.

C. Construction of Seasonal Modeling Periods and Load Scenarios

The model represents three 30-day seasonal modeling periods during 2040, under two load scenarios. The selection of these modeling periods was designed to represent normal winter peak, summer peak, and shoulder season weather conditions, and to reflect the associated electricity demand and load shapes, and the seasonal generation profiles of renewable resources. The analysis is a review of reliability under normal conditions; it is not meant to represent a severe or worst case scenario. This section describes (1) the load scenarios used to represent electrical demand and (2) the selection of the modeling periods.

1. Load Scenarios

The load profiles used in the energy balance model are derived from the NYISO Climate Impact Phase I study conducted by Itron in 2019.[16,17] For each day of the years from 2020 to 2050, the Phase I Study estimated daily peak loads and total energy based on historical average daily temperatures after adjustments for the temperature impacts of climate change, using a nonlinear model of load-temperature response.[18] In each scenario, hourly loads were further modified with adjustments to account for predicted energy efficiency and electrification of the transportation and building sectors. The daily peak and energy forecasts were then combined with a forecasted system hourly load shape to create an 8,760 hour baseline load forecast for each year.[19] The Phase I Study modeled four load scenarios: the Reference Case, the Reference Case with accelerated weather trend, the Policy Case, and the CLCPA case.

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[15] We do not explicitly model operating reserves in this framework. In nearly all hours, there are sufficient DE resources available in the model to cover reserve needs in all zones across the state, and we do not model the degree of reserve drawdown as a metric in this analysis. This means that during the limited number of hours when the energy balance model predicts loss of load in one of the combination cases modeled, additional DE resources above those assumed would be needed to meet load and/or maintain reserves.

[16] Itron, "New York ISO Climate Impact Study; Phase 1: Long-Term Load Impact," December 2019.

[17] We note that other work is being performed toward forecasting future demand, such as the NYSERDA study "Pathways to Deep Decarbonization in New York State." NYSERDA, "Pathways to Deep Decarbonization in New York State," June 24, 2020, available at https://climate.ny.gov/-/media/CLCPA/Files/2020-06-24-NYS-Decarbonization-Pathways-Report.pdf.

[18] Phase I Study, pp. 29-41.

[19] Phase I Study, pp. 38-41.

This study focuses on two of the Phase I load scenarios, with the following underlying assumptions:

1) Reference Case
    a) 0.7 degrees F per decade increase in average New York state temperatures[20]
    b) Increases in energy efficiency over 2019 levels[21]
    c) Increases in electric vehicle charging load over 2019 levels[22]
2) CLCPA Case
    a) 0.7 degrees F per decade increase in average New York state temperatures
    b) Increases in energy efficiency (more extensive than Reference Case)[23]
    c) Increases in electric vehicle charging load (more extensive than Reference Case)[24]
    d) Increases in residential and commercial building electrification

The CLCPA Case in the Phase I study assumed significant electrification of both the residential and commercial building sectors.[25] This electrification load comprises three components: 1) base-use electrification, which includes replacement of existing gas-powered household appliances with electric-powered models; 2) cooling electrification, with additional summer load from cooling heat pumps and A/C units; and 3) heating electrification, with additional winter load from electric heat pumps. In the residential sector, the Phase I study assumed "fossil fuel heating is converted to cold climate heat pumps with resistance heat backup, gas water heaters are converted to electric water heaters, gas dryers are converted to electric dryers, and gas stoves are converted to electric stoves."[26] In the commercial sector, the Phase I study assumed "electric sales gains from commercial gas conversions are similar in proportion to residential electrification, based on similar size in total energy usage in the two sectors, and similar proportions of heating and cooling end uses."[27] Cooling and heating electrification are based on historical hourly profiles of loads, and vary with daily temperature. The additional heating electrification load is sufficient in the CLCPA Case to move the system as a whole from summer-peaking to winter-peaking, with highest loads in January. Total load impacts for each Phase I load scenario are provided in Appendix A.

The Phase I study load scenarios also account for expected growth in behind-the-meter solar generation, but this study removes that impact from loads and instead treats behind-the meter solar as a generating resource.

2. Seasonal Modeling Periods

Both loads and renewable generation vary considerably across the course of the year, and present different types of challenges for reliability during different seasons. For example, wind capacity factors are on average highest in winter, when solar capacity factors are lowest, and vice versa. In addition, the modeling periods needed to be long enough to capture multi-day or multi-week trends in generation resource availability and output, which are affected by natural variance in meteorological conditions over the course of a day, week, month, and season.

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[20] 0.7 degrees F per decade is the historical trend based on weather station data from 1950 through 2018. Phase I Study, pp. 9, 16.

[21] According to the Phase I Study, "End-use efficiency projections include the expected impact of standards, naturally occurring efficiency gains, and utility efficiency (EE) programs such rebates and thermal shell improvement programs." Phase I Study, p. 30.

[22] EV charging load assumes that electric vehicles (both Battery Electric Vehicles and Plug-in Hybrid Electric Vehicles) account for 40% of passenger vehicles and light duty trucks by 2040. Additional penetration of commercial electric vehicles (medium and heavy duty trucks and buses) are also assumed, for total EV electric sales of 13,174 GWh in 2040. Phase I Study, p.37.

[23] The CLCPA Case assumes an additional 2,200 GWh per year in energy efficiency savings over the Reference Case. Phase I Study, p. 43.

[24] The CLCPA Case assumes "Stronger electric vehicle market penetration than the Reference Case." Phase I Study, p. 43.

[25] Phase I Study, pp. 46-50.

[26] Phase I Study, p. 46.

[27] Phase I Study, p. 48.

As a result, this study analyzes three 30-day representative modeling periods in 2040, one for the summer season, one for the winter season, and one for the shoulder season. The Phase I Study provided 8,760 hourly loads for all of 2040. The Phase II Study uses the first 30 days of the months of July, January, and April for the summer, winter and shoulder seasons. These months were selected because for each load scenario, July 2040 included the day with the forecasted summer peak load, January 2040 included the day with the forecasted winter peak load, and April 2040 had the lowest total energy consumed. Table 5 summarizes the load scenarios by peak and total energy.

Table 5: Summary of Load by Seasonal Modeling Period

		Summer	**Winter**	**Shoulder**
	Dates	7/1/2040 - 7/30/2040	1/1/2040 - 1/30/2040	4/1/2040 - 4/30/2040
Reference Case	Peak Load (MW)	38,666	28,010	23,507
	Total Energy (GWh)	19,013	14,111	11,385
CLCPA Case	Peak Load (MW)	48,589	57,144	27,060
	Total Energy (GWh)	22,476	27,322	12,497

D. Construction of Resource Sets by Load Case

This section describes the construction of the CCP2 resource sets underlying the analytic model, which are the generation and transmission inputs making up the supply side of the electrical system. Each resource set is specifically designed to establish a reliable starting point for the analysis, given the load forecasts from the Phase I report. With a reliable starting point, we then run scenarios that incorporate the physical disruptions associated with climate change impacts on load and system resources.

As a starting point, the CCP2 resource set is based on the 2019 CARIS 1 Phase 1 "70X30" Case for generation inputs, and assumes a transmission topology provided by NYISO that reflects current inter-zonal transfer limits. Intra-zonal and/or local transmission limitations were not assessed in this study. The CARIS generation inputs are designed to meet the CLCPA mandate that New York consumers be served by 70 percent renewable energy by 2030, and include significant additional development of renewable resources above current levels.

Two factors influence the resources added to get to a reliable system starting point. First, the Phase I CLCPA case requires additional resources to meet incremental load due to both temperature-induced demand increases and the assumed electrification of the transportation and building sectors. Second, the CLCPA establishes certain requirements that may affect the resources available to meet demand in 2040. Specifically, the Act requires 100 percent of the state's electricity supply to be emissions free by 2040,[28] and the state must reach at least 85% reduction on the way to net zero greenhouse gas emissions by 2050 across all economic sectors. This will require a significant transformation of the existing system in ways that are not easy to anticipate at this time.

In consideration of these factors, we constructed a set of additional resources to reliably meet system demand in 2040. In doing so, we recognize that there is a vast array of different resource types and pathways to meeting the CLCPA requirements, which potentially include resources, technologies, and fuels that are currently not commercially available. Further, even the resource options that we consider based on current information will evolve significantly in the coming decades, and each has different properties in terms of availability and generation profiles, maximum capacity potential, total energy potential, and cost. Thus our starting point resource set should be viewed as but one among a vast number of potential resource combinations, technologies or pathways that could reliably meet electricity demand in 2040.

Given the unique circumstances and focus of state law and policy in New York, the analysis developed a resource set prioritizing the development and operation of zero-carbon renewable resources and the expansion of high-voltage transmission capacity as needed to move generation to load within the state. Specifically, in order to identify a combination that fully met load in all hours of the modeling periods, the resource set was built from the following resources, in the following order:

1) **Assume the retention of existing zero-carbon resources**
   Maintain in 2040 the availability and operation of existing hydroelectric and nuclear capacity as baseload system resources.
2) **Maximize the development of renewable generating resources in New York state**
   Build out solar and land-based and offshore wind generating capability to the maximum feasible extent, based on an evaluation of need and a review of technical potential. Steps one and two are key to addressing aggregate incremental energy demand.
3) **Increase zero carbon resources imported from neighboring regions**

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[28] NY Senate Bill S6599, pp. 4, June 18, 2019.

The analysis assumes that it is possible to increase the transfer of zero-emission capacity and generation from Canada through the addition of new transmission lines to the north. This resource provides assistance with both incremental energy needs and the ability to instantaneously balance system load.

4) **Mitigate the impact of electrification through demand modulation by the "shaping" of EV load**
The analysis assumes that with electrification of the transportation sector, electricity markets and pricing in New York will provide incentives for the management of demand associated with electric vehicle charging. Such incentives will assist with managing peak demand and instantaneous power needs, but they will not address aggregate energy deficits.
5) **Enable the efficient movement of diverse generation sources across the state through additional transmission**
The vast majority of land-based renewable resource potential is in upstate New York. A renewables-focused resource set will need significant increases in inter-zonal transfer capability, helping to reduce zonal bottlenecks.
6) **Maximize the participation in markets of price responsive demand**
The combination of wholesale market designs and new distributed resource initiatives and technologies will provide incentives for significant expansion of price responsive demand, helping meet instantaneous power needs.
7) **Continue the aggressive development of energy storage technologies**
The analysis assumes that current initiatives and changing economics will continue growth in the development of storage within the state, helping address instantaneous power needs
8) **Dispatchable and emissions-free resource**
Even with the substantial infrastructure and resource growth in steps 1-7, there will likely need to be a dispatchable resource with attributes needed to help balance the system under certain conditions, such as high loads, loss of resources, inter-zonal transfer limits, or limited output from variable resources. This report focuses on the attributes needed from such resources, without assuming we can anticipate what form they will take in 2040 as technologies continue to evolve.

As noted, the starting point CCP2 resource set represents only one possible pathway or outcome. The Grid in Transition resource set, reviewed in Section II.F., presents another, and very different, potential pathway for the development of resources to reliably meet 2040 system needs, one focused more on a DE resource, and less on renewables and transmission. In reality, it is likely that the manner in which the system evolves to meet the changing nature of electricity demand and resource requirements will involve some elements of both resource sets, but will not look exactly like either. Nonetheless, the results, and how they differ across these two resource sets, offer interesting insights into the challenges that will need to be addressed through market design, resource/technological development, and policy in the coming decades.

In the following sections, we describe in more detail our assumptions with respect to each of the categories of resources described above for the CCP2 resource sets.

1. Retention of Baseload Resources

The generation fleet used in the energy balance model assumes the continued operation of a number of baseload hydroelectric and nuclear units. Resource retirements are guided by 2019 CARIS Phase 1 "70X30" Case. CARIS performs a sensitivity to examine the impact of upstate nuclear operations beyond the currently regulated Zero Emission Credits ("ZECs") eligibility criteria.[29] This resource set assumes the operation of Nine Mile Point 1 & 2,

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[29] NYISO, "2019 CARIS 1 70X30 Scenario Development", pp. 12, September 6, 2019.

James A. Fitzpatrick 1 and R.E. Ginna 1. We assume the plants will operate at a 100 percent capacity factor for all hours of the thirty day modeling period. Actual resource operations across the full year will be lower, based upon the dependable maximum net capability and forced outage rates of the nuclear resources in the future.

CARIS assumes that the majority of the existing hydro resources will continue in operation. Each resource set maintains 913 MW of run of river hydro and 3,573 MW of pondage hydro. The hourly capacity factor of run-of-river hydro units is based on historical 2018 generation data.[30] The Niagara units (Robert Moses and Lewiston) operate on a daily cycle that depends on season and load case. Niagara operations obey water levels set by an international water treaty and are synchronized with solar generation to generate in hours when need is greatest. The other hydro pondage units, including the St. Lawrence-Franklin D. Roosevelt unit, are assumed to operate at a 100 percent capacity factor for all hours of the modeling period. The Gilboa pumped storage unit behaves as a storage resource and is described in Section II.C.7. Additional baseload nuclear and hydroelectric resources are not included in the resource set.

2. Renewable Resources (CARIS Starting Point)

The model includes four types of renewable resources: land-based wind, offshore wind, utility-scale solar, and behind-the-meter solar. The starting point for the amount of wind and solar resources modeled is the nameplate capacity of these resources assumed in the 2019 CARIS Phase I study as of February 2020.[31] The 2019 CARIS Phase I CLCPA case starting point assumes an approximately an additional 17,500 MW of wind and 25,000 MW of solar, and aligns with renewable targets established in state policies, including 9,000 MW of offshore wind by 2035 and 6,000 MW of behind the meter solar capacity by 2025.[32] Solar and wind resources are distributed according to capacity shares by zone from the 2017 and 2018 CES REC solicitation awards and the interconnection queue.[33] The study does not assume any utility solar in Zones G, H, I, and J, in consideration of potential siting challenges and land costs. Similarly, no land-based wind is assumed in Zones F through K.

The generation profile assumed for the solar units, in terms of hourly capacity factors, are based on 2006 data from the NREL Solar Power database using 62 simulated solar farm sites across New York State, which provide separate estimates for BTM and grid-connected solar.[34] Two Zones did not have solar farm data. For Zone D BTM solar, a simple average of bordering Zones F and E was used. For Zone K grid-connected solar, the BTM solar data from Zone K was scaled up by the average ratio of utility to BTM solar capacity factors NYCA-wide. The hourly capacity factors assumed for the wind units are based on 2009 data at simulated 100 meter turbine height from the NREL's Wind Toolkit Database, using 721 weather sites in NY.[35] A summary of renewable resource capacity factors by season is listed in Table 6. As shown, solar capacity factors are higher on average in the summer modeling period than in the winter, and wind capacity factors are higher on average in the winter than in the summer.

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[30] Aggregated Run of River Hydro Production Data collected from NYISO's Decision Support System.

[31] The 2019 CARIS Phase I study was ongoing at the time this study was conducted, and certain assumptions in the CARIS Phase I Study have been altered since February 2020.

[32] The CARIS starting point assumes 6,750 DC MW in behind-the-meter solar capacity in 2040 in the CLCPA case, which translates to 5,439 AC MW. For the purposes of this study, we use the AC MW as the basis for nameplate capacity of solar resources. This is a larger nameplate capacity for behind-the-meter solar in the CLCPA case as compared to the Reference case (3,629 AC MW).

[33] NYISO, "2019 CARIS 1 70X30 Scenario Development," pp. 15, September 6, 2019.

[34] NREL Solar Power Database, https://www.nrel.gov/grid/solar-power-data.html.

[35] NREL Wind Toolkit Database, https://www.nrel.gov/grid/wind-toolkit.html.

Table 6: Renewable Capacity Factor by Season

	Average Capacity Factor by Season		
Resource Type	**Summer**	**Winter**	**Shoulder**
Wind (Land-based)	27.31%	46.22%	51.72%
Wind (Offshore)	30.14%	47.81%	58.42%
Solar (Behind-the-meter)	17.98%	8.02%	18.20%
Solar (Grid-Connected)	20.23%	8.61%	20.25%

Notes:
[1] Wind capacity factors are based on 2009 historical data; solar capacity factors are based on 2006 historical data
Sources:
[1] NREL Solar Power Database, https://www.nrel.gov/grid/solar-power-data.html.
[2] NREL Wind Toolkit Database, https://www.nrel.gov/grid/wind-toolkit.html.

3. Renewable Resource: Additions to 2040

As noted, the approach used in developing the resource set assumes that renewable resources will be prioritized for development to help meet the CLCPA 100 percent emission-free resources requirement for 2040. This means that a significant quantity of new renewable resources needs to be added in the model, above and beyond the 2019 CARIS starting point resources, in order to meet electrical loads in that year.[36] Due to seasonal differences in capacity factors among renewable resource types, the optimal mix of renewable resources depends in part on characteristics of the load scenarios. For example, wind resources are more productive in winter months and therefore can generate more than solar resources of the same nameplate capacity, to ensure reliability in a winter-load-peaking scenario. On the other hand, in a summer-load-peaking scenario, additional solar resources may be more useful in meeting energy needs.

To capture these seasonal effects, additional renewable resources were added to the resource sets using an iterative marginal benefit analysis targeted at the seasonal modeling period with the greatest load for each scenario. These are the summer period for the Reference Case, and the winter period for the CLCPA Case. Starting from the CARIS starting point resource set, the nameplate capacity of wind and solar resources were each increased in specific increments of 25 percent of the CARIS starting point quantities. In each iteration, we added whichever technology type (either wind or solar) reduced the aggregate energy deficit the most. This process continued iteratively until the total energy deficit for the peak month was met. In addition, the total nameplate capacity for each resource type was not allowed to exceed an estimate of its technical potential in New York State.[37] This technical potential upper limit was reached in the CLCPA case for both land-based and offshore wind. The results of the marginal benefit analysis for each resource set can be found in Table 7.

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[36] The CCP2 resource sets was constructed so that intermittent resources provide the bulk of energy through the peak modeling periods and then treated DE resources as backstops, similar to peaking resources. Resource sets developed using a preference for use of DE resources as baseload resources would result in less Intermittent resources needed to meet load.

[37] Technical Potential for land-based wind in New York is estimated by NREL to be 35,200 MW. Technical Potential for offshore wind is calculated at 21,063 MW from BOEM and DOE data, assuming maximum 3 MW/km^2 wind capacity is installed in the 7,021 km^2 New York Bight Lease Areas. NREL, Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results, August 2016, Appendices A and F. Bureau of Ocean Energy Management, New York Bight, available at https://www.boem.gov/renewable-energy/state-activities/new-york-bight. Department of Energy, Computing America's Offshore Wind Energy Potential, September 9, 2016.

Table 7: Renewable Capacity by Resource Set

	Zone												
Technology Type	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total**	**% Increase**
CARIS Starting Point													
Land-Based Wind	2,692	390	1,923	1,935	1,821	-	-	-	-	-	-	**8,761**	-
Offshore Wind	-	-	-	-	-	-	-	-	-	6,391	2,609	**9,000**	-
BTM Solar (CLCPA)	704	218	596	69	673	827	684	61	90	672	846	**5,439**	-
BTM Solar (Reference)	470	146	398	46	449	552	456	40	60	448	565	**3,629**	-
Grid-Connected Solar	5,748	656	3,585	-	2,268	4,661	2,636	-	-	-	77	**19,631**	-
CCP2 - Reference Case													
Land-Based Wind	6,057	878	4,327	4,354	4,097	-	-	-	-	-	-	**19,712**	125%
Offshore Wind	-	-	-	-	-	-	-	-	-	14,380	5,870	**20,250**	125%
BTM Solar	822	255	696	81	786	965	798	71	105	784	988	**6,351**	75%
Grid-Connected Solar	10,059	1,148	6,274	-	3,969	8,157	4,613	-	-	-	135	**34,354**	75%
CCP2 - CLCPA Case													
Land-Based Wind	10,816	1,567	7,726	7,774	7,316	-	-	-	-	-	-	**35,200**	302%
Offshore Wind	-	-	-	-	-	-	-	-	-	14,958	6,105	**21,063**	134%
BTM Solar	1,409	436	1,193	138	1,345	1,653	1,367	121	179	1,343	1,692	**10,878**	100%
Grid-Connected Solar	11,496	1,312	7,170	-	4,536	9,322	5,272	-	-	-	154	**39,262**	100%

Notes:
[1] Technical Potential for land-based wind in New York is estimated by NREL to be 35,200 MW.
[2] Technical Potential for offshore wind is 21,063 MW calculated from BOEM and DOE data, assuming maximum 3 MW/km^2 wind capacity is installed in the 7,021 km^2 New York Bight Lease Areas.
Sources:
[1] NREL, Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results, August 2016, Appendices A and F.
[2] Bureau of Ocean Energy Management, New York Bight, available at https://www.boem.gov/renewable-energy/state-activities/new-york-bight.
[3] Department of Energy, Computing America’s Offshore Wind Energy Potential, September 9, 2016.

4. Imports from Neighboring Areas

Our analysis assumes fixed quantities of zero-carbon imports during the modeling period, but no other imports or exports into or out of New York.[38] Based on NYISO data on current import flows, a baseline level of 1,500 MW of imports into Zone D were assumed in each hour, and an additional 1,310 MW of imports in 2040 associated with a potential increase in imports through the development of additional transmission infrastructure. The assumed flows for imports are represented in Figure 6.

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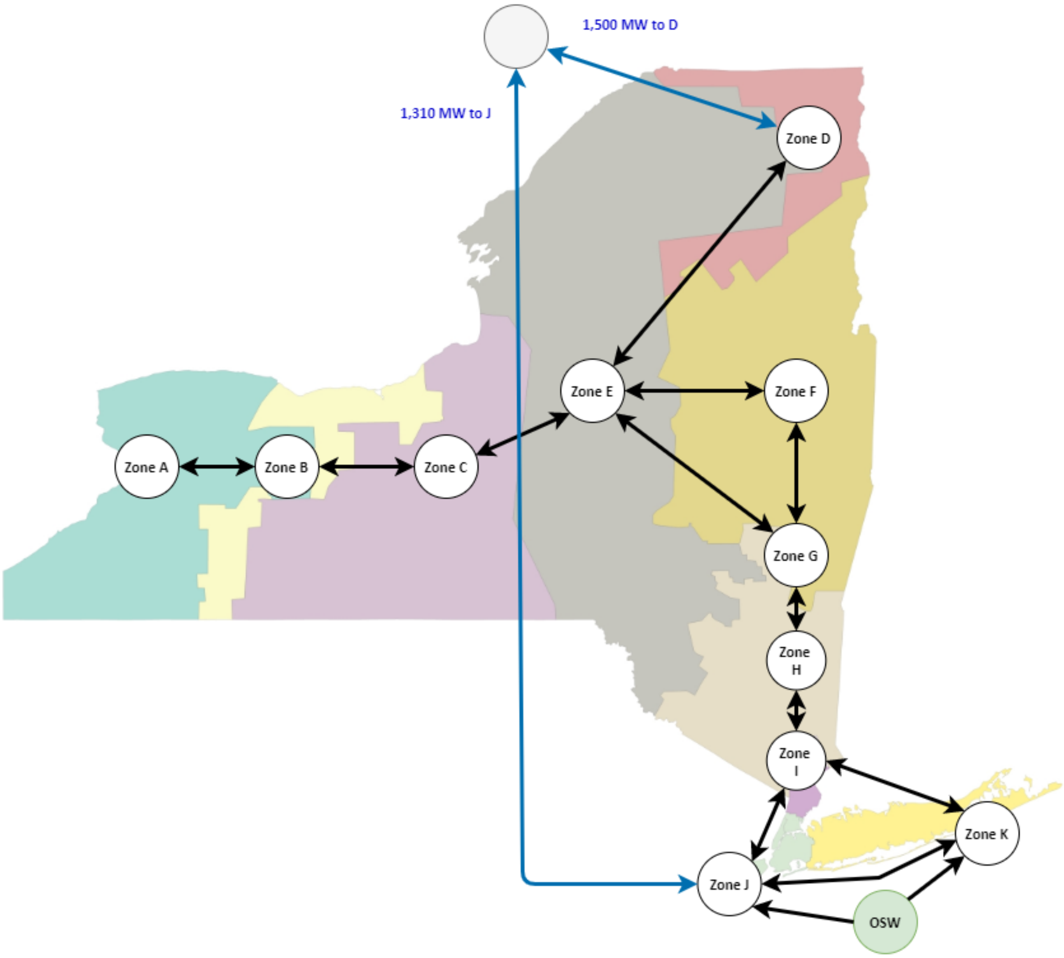
[38] The analysis assumes that New York’s requirement for a GHG-emission free electric system in 2040 extends to imported power, and does not assume that neighboring U.S. regions will meet these requirements. Thus, for the purpose of this modeling exercise, the study does not assume any imports/exports between New York and neighboring U.S. regions. However, there are zero-emission resources available and potentially available in neighboring Canada, and there is interest in importing certifiable zero-carbon hydro resources if or as available. Thus, for the model assumes the availability in 2040 of energy and capacity imports from Canada.

Figure 6: Imports During Modeling Period



5. Modulation of EV Load Shape

The potential increase in electric vehicles and the transition of the electric generation sector to heavy reliance on renewable resources provides incentives and opportunities for efficient shifts in load over the course of a day. In particular, the daily load shape for electric vehicle charging demand set in the Phase I Study assumes a charging peak in the evening, around hour 20 (see Figure 7 below). However, a shift to a "flatter" load shape that is more equal across evening hours and/or all hours of the day could help reduce peak demand and better tailor the timing of demand to the pattern of generation from renewable resources.

The study models load management based on the NYSERDA report, *Electricity Pricing Strategies to Reduce Grid Impacts from Plug-in Electric Vehicle Charging in New York State.* That report shows that use of a time of use (TOU) rate could significantly shift the timing of daily peak EV load from evening hours to early morning hours.[39] A TOU rate varies the cost of electricity depending on the time of day, with higher rates during peak load hours and lower rates during off-peak hours. A TOU rate acts as an incentive for an EV owner to delay the start of charging to

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[39] NYSERDA, "Electricity Pricing Strategies to Reduce Grid Impacts from Plug-in Electric Vehicle Charging in New York State", June 2015 https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Transportation/EV-Pricing.pdf

periods of lower load. The reshaping of the EV load profile shows the shift from peak hours to off-peak hours. The total energy demanded for EV charging is unchanged, but the timing is altered to be highest overnight instead of during the peak evening hours. From a modeling perspective, we adjust the EV charging profile used in the Phase I Itron analysis to shift EV charging demand towards a profile consistent with that found in the NYSERDA study.

Figure 7: Electric Vehicle Daily Load Shape from Phase I Study

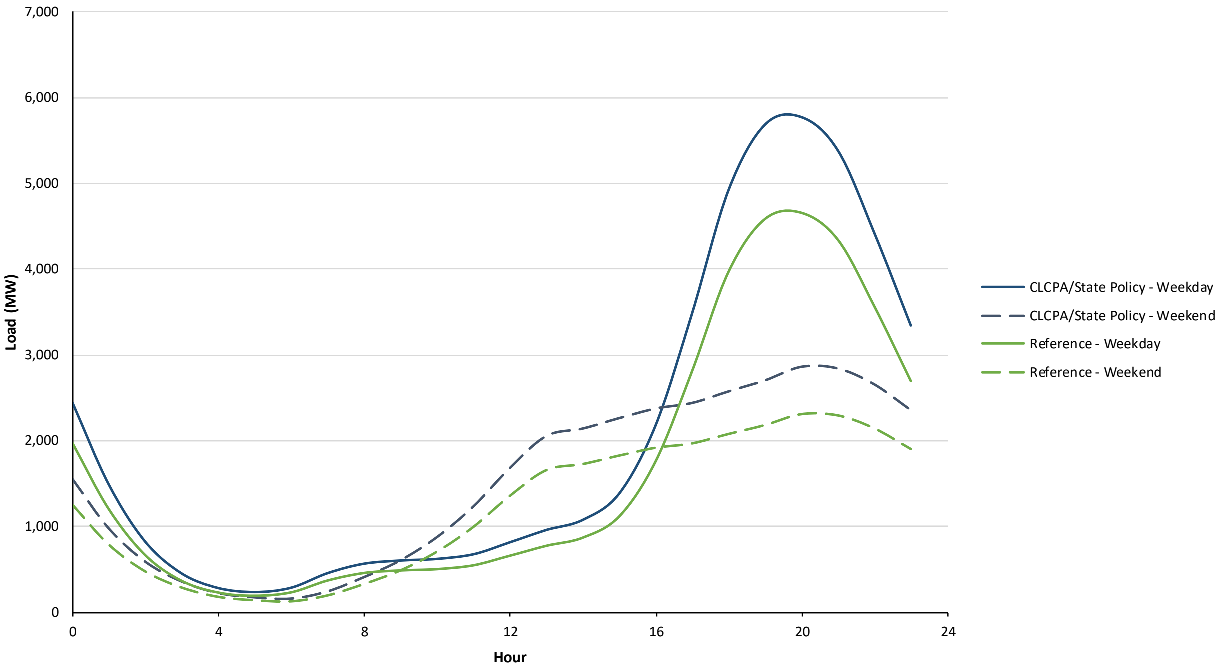
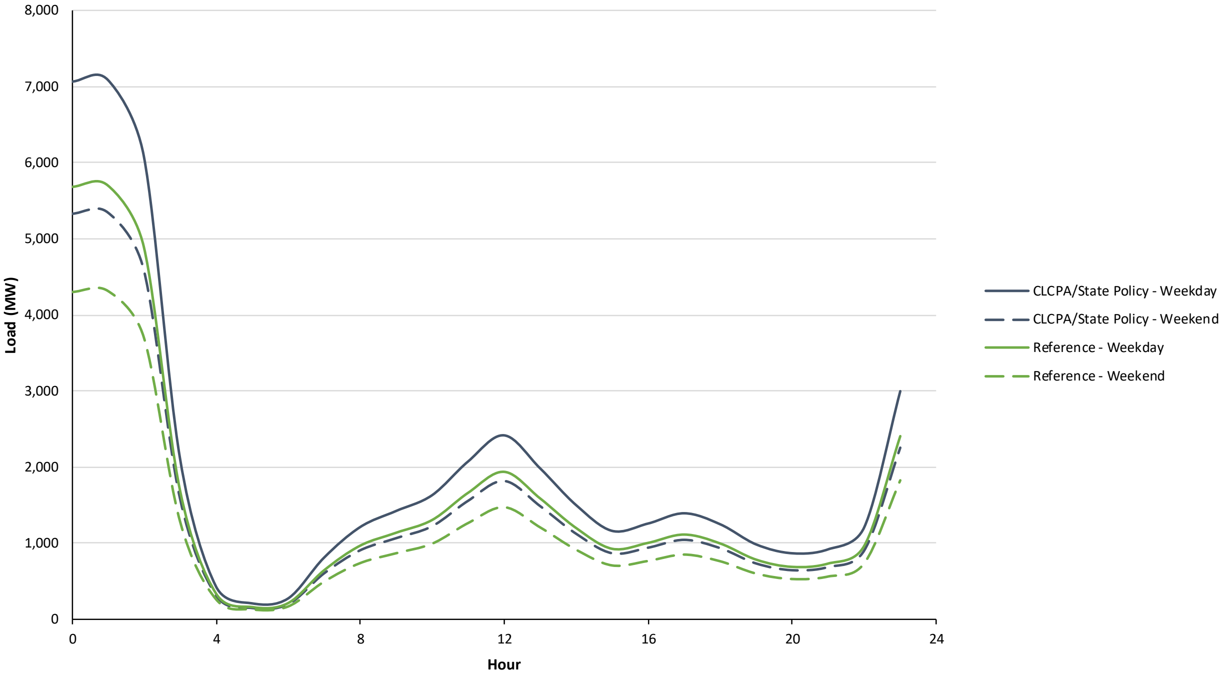


Figure 8: Electric Vehicle Daily Load Shape Adjusted for Off-peak Charging



6. Increase in Inter-zonal Transfer Capability

In order to capture geographic constraints on electrical generation and transmission, the model applies a simplified version of the NYISO transmission network. NYISO divides the state into 11 geographic load zones, A through K, which are individually modeled in this study. The energy balance model uses a set of transmission transfer limits for each interface between load zones. The starting point for these limits is based on an N-1 contingency analysis, as provided by NYISO (see Figure 9). The Western New York and AC Public Policy Transmission upgrades are assumed to be in-service.

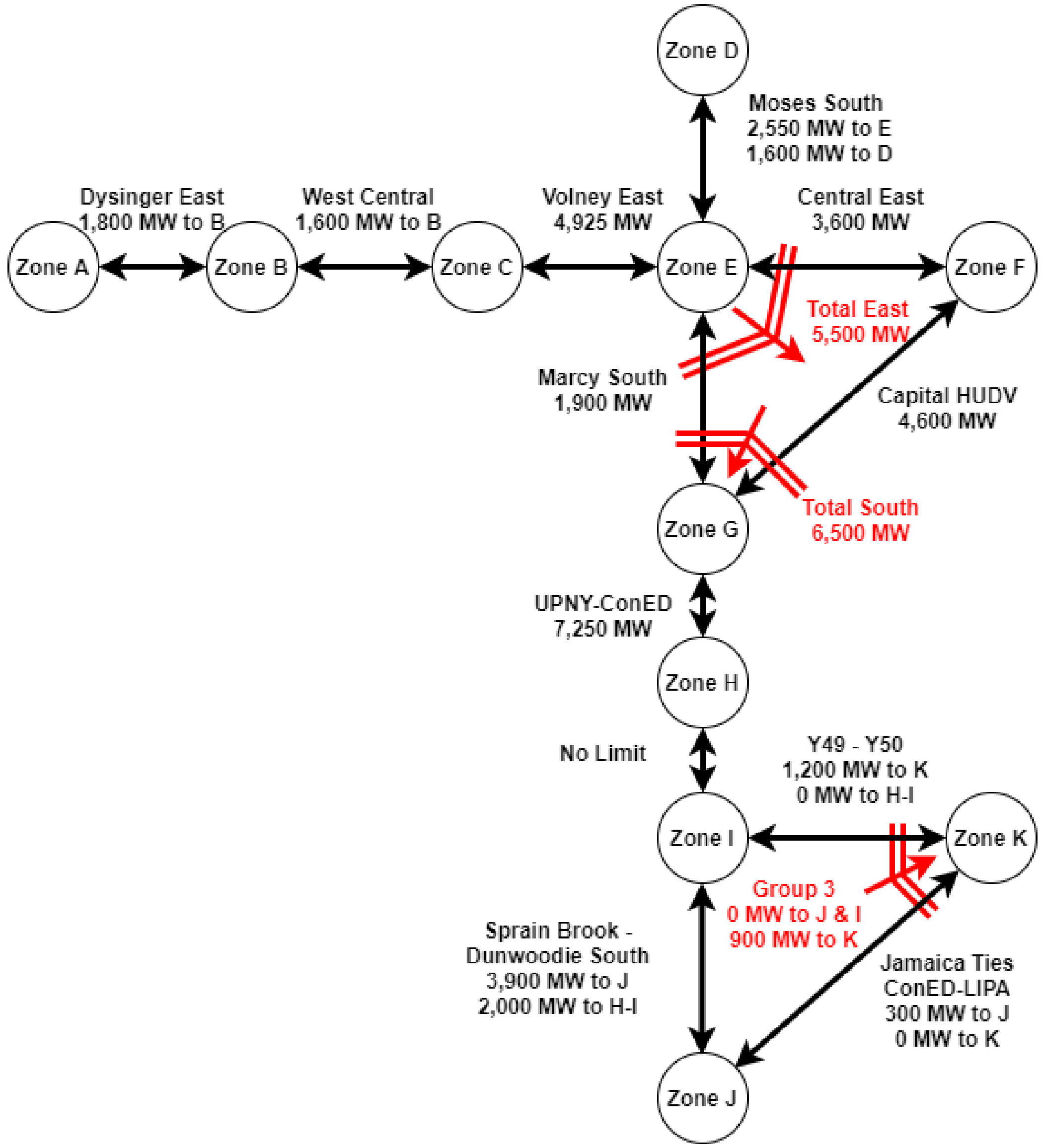
Importantly, the distribution of renewable resources across New York is heavily weighted to the upstate region, given the constraints on land availability and cost discussed previously. As a result, the addition of renewable resources across New York in the amounts we assume requires substantial increases in inter-zonal transfer capability to allow for sufficient flows to meet zonal demand. The starting point transfer limits restrict renewable resources' ability to help address zonal hourly load deficits due to congestion. In the CLCPA Winter modeling period, current transfer limits would result in an average of 3,565 MW of renewable power in each hour unable to help meet load requirements (this is equivalent to 9.4 percent of total NYCA load).

For each transmission interface between Zones, the model assumes an increase in transfer capability by calculating the transmission limits required to alleviate load losses in 90 percent of transmission-constrained hours. The results of the transmission analysis for each resource set can be found in Table 8.

Table 8: Transmission Limits by Resource Set

Interface	NYISO Limits (Starting Point)	90% Limits (CCP2 - Reference)	90% Limits (CCP2 - CLCPA)
A to B	1,800 MW	5,133 MW	7,149 MW
C to B	1,600 MW	1,600 MW	3,319 MW
C to E	4,925 MW	8,432 MW	11,357 MW
D to E	2,550 MW	4,161 MW	6,448 MW
E to G	1,900 MW	9,279 MW	13,932 MW
G to H	7,250 MW	14,713 MW	15,791 MW
I to J	3,900 MW	8,675 MW	10,585 MW
I to K	1,200 MW	4,520 MW	5,137 MW

Figure 9: Simplified Transmission Map and Limits, Starting Point



7. Energy Storage Resources

Renewable resources are dependent on variable meteorological conditions, and thus their generating output does not always coincide with load. Energy storage allows for time shifting of generation to meet the timing of demand. The starting point for storage resources used in our model is based on the 2019 CARIS Phase I "70x30" case. The starting point assumes 3,900 MW of battery energy storage and aligns with the specific CLCPA target of 3,000 MW by 2030.[40] The battery energy storage units are assumed to have eight hours of storage duration and operate with an 85 percent round trip efficiency.[41] It also assumes that the Gilboa hydro pumped storage unit is operating effectively as a single large battery contributing an additional 1,170 MW of storage capacity. The Gilboa unit assumes 12 hours of storage duration and operates with a 75 percent round trip efficiency.[42] The storage units only charge when there is excess renewable generation.[43]

For the Reference and CLCPA cases, additional battery energy storage resources above the amounts modeled in CARIS were added to meet instantaneous power needs. The analysis assumes a doubling of the 2019 CARIS capacity for the Reference case (adding 3,900 MW), and quadrupling of the CARIS capacity for the CLCPA case (adding 11,700 MW). The additional capacity is distributed geographically proportional to the total quantity of "excess" renewable generation in the peak month. That is, batteries were distributed across zones based on the potential to reduce the curtailment or "spilling" of renewable generation in each zone.

From a practical standpoint, the location of energy storage based on the available level of renewable generation improves the use of transmission over the course of a day. On days with high renewable generation upstate, solar and wind power is transmitted over lines from upstate to downstate during the daytime, while simultaneously charging energy storage devices upstate with "excess" energy - that is, energy produced in excess of available transfer capability. In the evening and night, once solar power has dropped to zero, the storage discharges and moves power from upstate to downstate over the same transmission lines. The location of the battery resources for each case is shown in Figure 10 and Figure 11.

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[40] NY Senate Bill S6599S, pp. 9, June 18, 2019.

[41] Roundtrip efficiency of less than 100 percent implies that the units do not receive their full capacity of energy inflow when charging; therefore a battery with 8 hours of stored energy takes longer than 8 hours to charge.

[42] Dames and Moore, "An Assessment of Hydroelectric Pumped Storage", November 1981, pp.99.

[43] In effect, this means that the model does not allow the DE generating technology to charge energy storage devices. As described below, we position the DE resource to operate if and only if it is needed to avoid loss of load.

Figure 10: Battery and Renewables Location, CCP2 - CLCPA

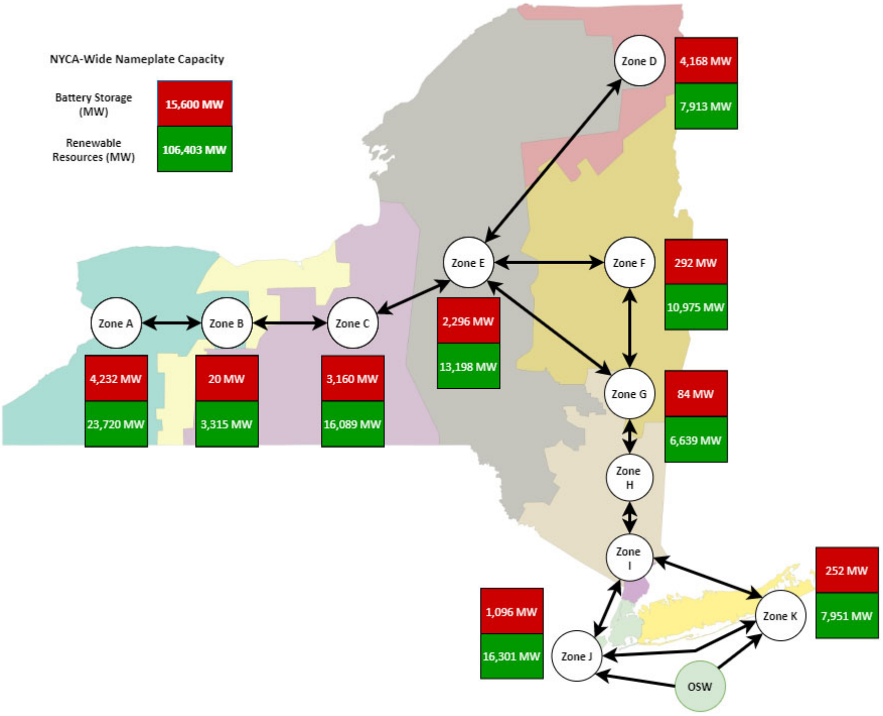
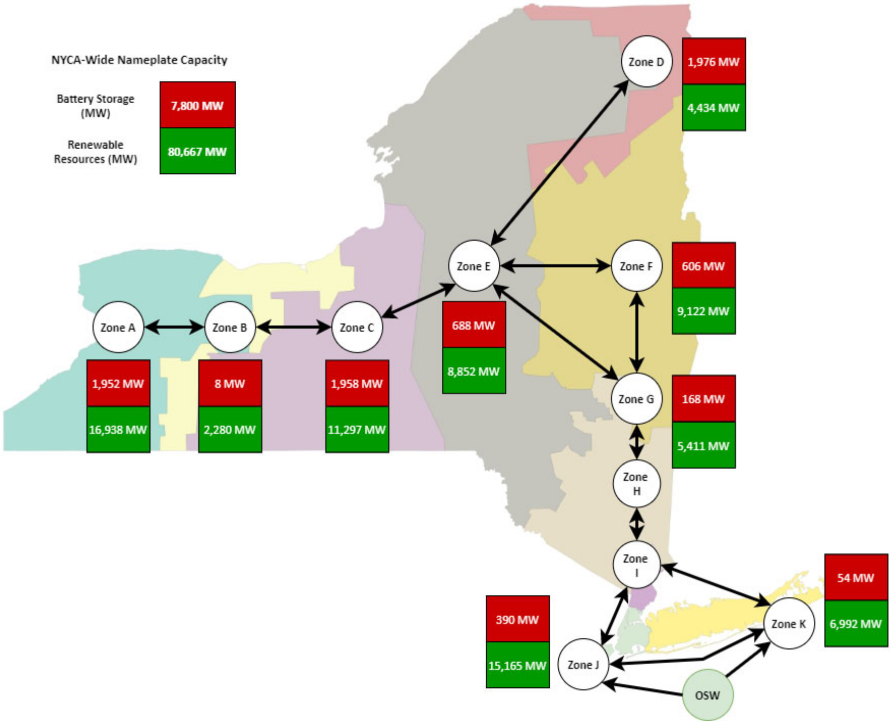


Figure 11: Battery and Renewables Location, CCP2 - Reference



8. Price Responsive Demand

Given the nature of the transition in energy supply and use in New York over the coming decades, the study assumes a significant expansion of price responsive demand (PRD) resources by the modeling year, 2040. The PRD resources used in the energy balance model are based on NYISO's Special Case Resource (SCR) Program and are assumed to be dispatchable by NYISO.[44] The starting point aligns with the 2019 summer and winter capacities from the 2019 NYISO Gold Book, 1,309 MW in the summer capability period and 853 in the winter for NYCA.[45]

Specifically, the study projects a quadrupling of the current levels by 2040 for the CLCPA case, and doubling the current levels by 2040 for the Reference Case. This results in 5,236 MW in the summer for the CLCPA case and 2,618 MW for the Reference Case, and, for the winter, 1,706 MW for the CLCPA case and 3,412 MW for the Reference Case.

9. Dispatchable and Emissions-Free Resource

The primary focus of our analysis is an evaluation of the potential impacts of a changing climate on power system operations, through (1) broad-based changes in load and supply/delivery infrastructure operations from changes in average temperature; and (2) episodic severe weather events that are expected to increase in probability or severity with the changing climate. Thus, our starting point in 2040 incorporates the Phase I impacts to electricity demand of average annual changes in temperature. The study further starts with a system load and resource mix that is consistent with current technology and policy trends. In this respect, the CLPCA has two major influences: First, the economy-wide focus of the Act means that the starting point should include load adjustments for electrification of the building and transportation sectors. In the CLCPA case, this adjustment is built into the 2040 load forecast. Second, to comply with the CLCPA, the study assumes that no fossil fuels that have positive net GHG emissions in operation may be included in the resource set.

This latter point raises a number of challenges for the development of a "starting point" resource set. As highlighted in Analysis Group's Fuel Security Study, New York is highly dependent on the availability and operation of thermal, dual-fuel (*e.g.,* natural gas and oil) generating resources in the downstate region to maintain reliability generally, and in particular in cold weather conditions.[46] In order to eliminate the need for generation from these carbon-emitting generators, the study removes them from the resource mix and supplant them with renewables, storage, demand response, and transmission, as described above. In particular, there is substantial "overbuild" of renewable resource capacity and increases in transfer capability in order to start with a system where peak annual demand in the Reference and CLCPA cases is met with zero-carbon resources. However, even with all these additions, the variability of renewable resource output leads to circumstances where, for both the Reference and CLCPA cases, there are periods of time that our resource mix is insufficient to meet load in all Zones. For these reasons, a DE resource is included to fill in the gap.

The analysis does not identify exactly what the resource is. It could be thermal generating resources that looks like the combustion turbines in operation today, but operating on a fuel that is at least net zero from a GHG emission perspective, such as turbines running on renewable natural gas or hydrogen. It could be some form of demand response. It could represent the emergence of a long-term economic storage technology. Or, of course, some

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[44] SCRs are interruptible load customers whose load curtailments are activated by NYISO, and are part of NYISO's Reliability-Based Programs. NYISO, "Demand Response," https://www.nyiso.com/demand-response

[45] NYISO, "2019 Load & Capacity Data Gold Book," https://www.nyiso.com/documents/20142/2226333/2019-Gold-Book-Final-Public.pdf/

[46] Paul J. Hibbard and Charles Wu, *Fuel and Energy Security in New York State*, November 2019.

combination of all of the above. There is no way to know how advances in power system technologies, costs, policies, and consumer behavior can change the way the system meets demand twenty years hence.

Thus, the purpose of the DE resource is twofold. First, by seeing when the DE resource is relied on, this study helps identify the magnitude of the resource gap created by relying primarily on variable renewable generating resources to meet annual, state-wide energy needs. Second, the "operation" of the DE resource in the model defines *the attributes* needed from resources that meet this gap, in terms of when it is needed, in what zones, under what conditions, and with which system reliability attributes, such as cycling and ramping capabilities.

The DE resources are assumed to meet any remaining instantaneous power needs in the modeling period. They are modeled as able to dispatch on demand without any operational or duration restrictions. The quantity of capacity assumed in each resource set is calibrated to meet all remaining zonal load losses in the peak seasonal modeling period after all other resources have been exhausted. In the Reference Case, 17,059 MW is assumed to be available and operational in order to meet zonal load need in every hour of the summer modeling period. From a modeling perspective, the DE resource is zonally distributed proportional to the 2017 existing thermal capacity that fills a similar need. In the CLCPA case, 32,137 MW of DE resource availability is required to meet load in every hour of the winter modeling period. Of this quantity, 22,471 MW is placed in the same Zones as currently existing thermal capacity. The remaining DE capability is located strategically based on observed transmission bottlenecks and zonal load loss outcomes: 539 MW is located in Zone B, 3,409 MW in Zone G, 29 MW in Zone H, 4,258 MW in Zone J, and 1,431 MW in Zone K.

The climate disruption cases, described in Section III, involve circumstances and events that increase demand and/or reduce or eliminate the availability of renewable resources and transmission infrastructure. These cases, in some instances, did result in loss of load occurrences.

10. Resource Set Summaries for CCP2

Table 9: Generation Capacity, CCP2-CLCPA

Nameplate Capacity by Zone, MW	A	B	C	D	E	F	G	H	I	J	K	Total
Land-based Wind	10,815.9	1,566.9	7,726.2	7,774.5	7,316.4	-	-	-	-	-	-	**35,200.0**
Offshore Wind	-	-	-	-	-	-	-	-	-	14,957.8	6,105.2	**21,063.0**
Solar (Behind-the-meter)	1,408.5	436.4	1,192.8	138.2	1,345.5	1,653.4	1,367.3	121.2	179.4	1,343.1	1,692.2	**10,877.8**
Solar (Grid Connected)	11,496.0	1,312.0	7,170.0	-	4,536.0	9,322.0	5,272.0	-	-	-	154.0	**39,262.0**
Hydro Pondage	2,675.0	-	-	856.0	-	-	41.6	-	-	-	-	**3,572.6**
Hydro Pumped Storage	-	-	-	-	-	1,170.0	-	-	-	-	-	**1,170.0**
Hydro Run-of-River	4.7	63.7	70.4	58.8	376.2	282.5	57.1	-	-	-	-	**913.4**
Nuclear	-	581.7	2,782.5	-	-	-	-	-	-	-	-	**3,364.2**
Imports	-	-	-	1,500.0	-	-	-	-	-	1,310.0	-	**2,810.0**
Storage	4,232.0	20.0	3,160.0	4,168.0	2,296.0	292.0	84.0	-	-	1,096.0	252.0	**15,600.0**
Price Responsive Demand (Summer)	949.9	205.2	510.1	357.7	211.1	433.9	246.3	58.6	134.9	1,940.8	187.6	**5,236.0**
Price Responsive Demand (Winter)	619.0	133.7	332.4	233.1	137.5	282.7	160.5	38.2	87.9	1,264.7	122.3	**3,412.0**
DE Resources	465.4	674.2	1,513.4	370.0	312.7	3,390.4	6,887.2	79.8	-	11,848.1	6,595.4	**32,136.6**

Figure 12: Simplified Transmission Map and Limits, CCP2-CLCPA

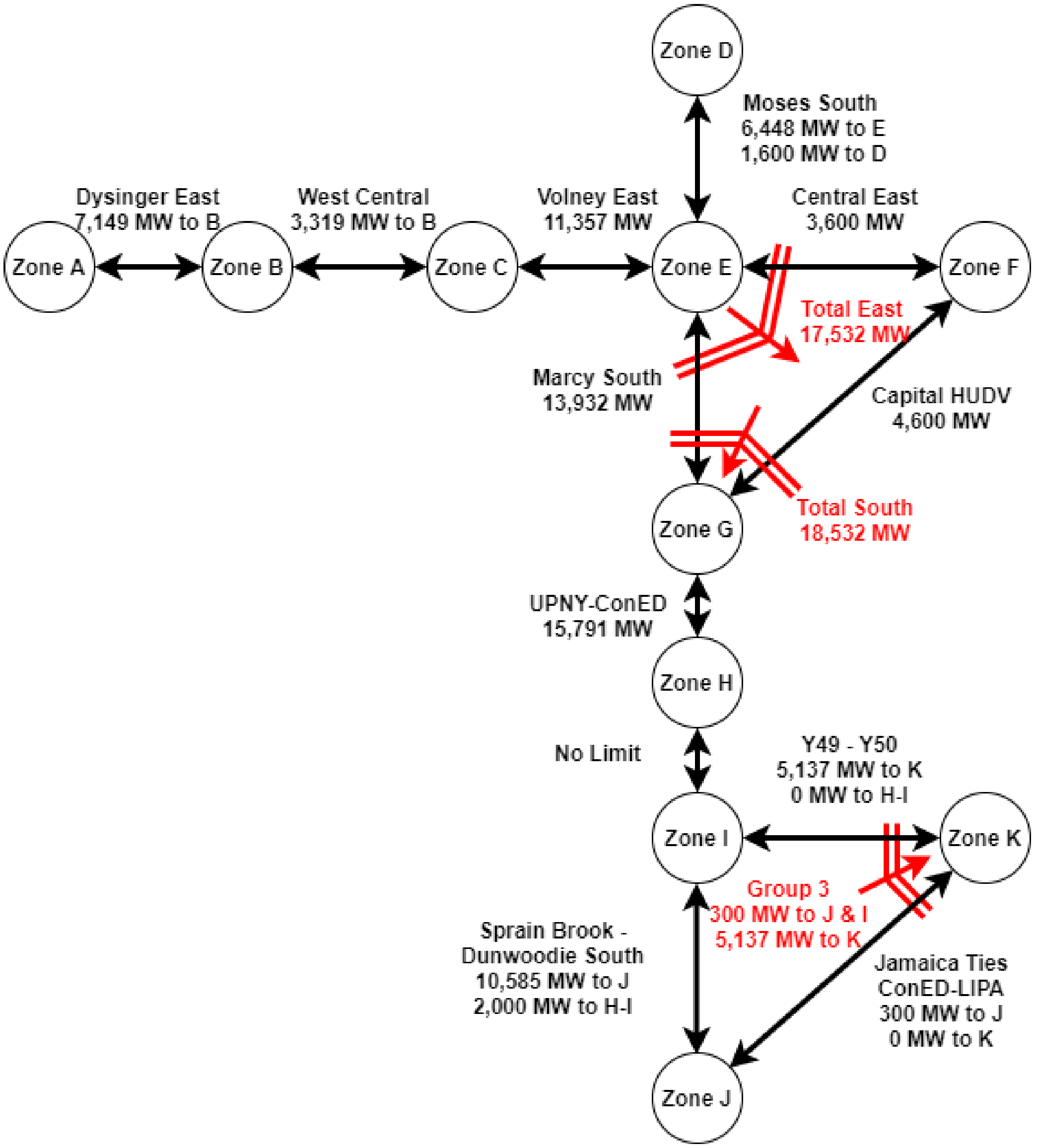
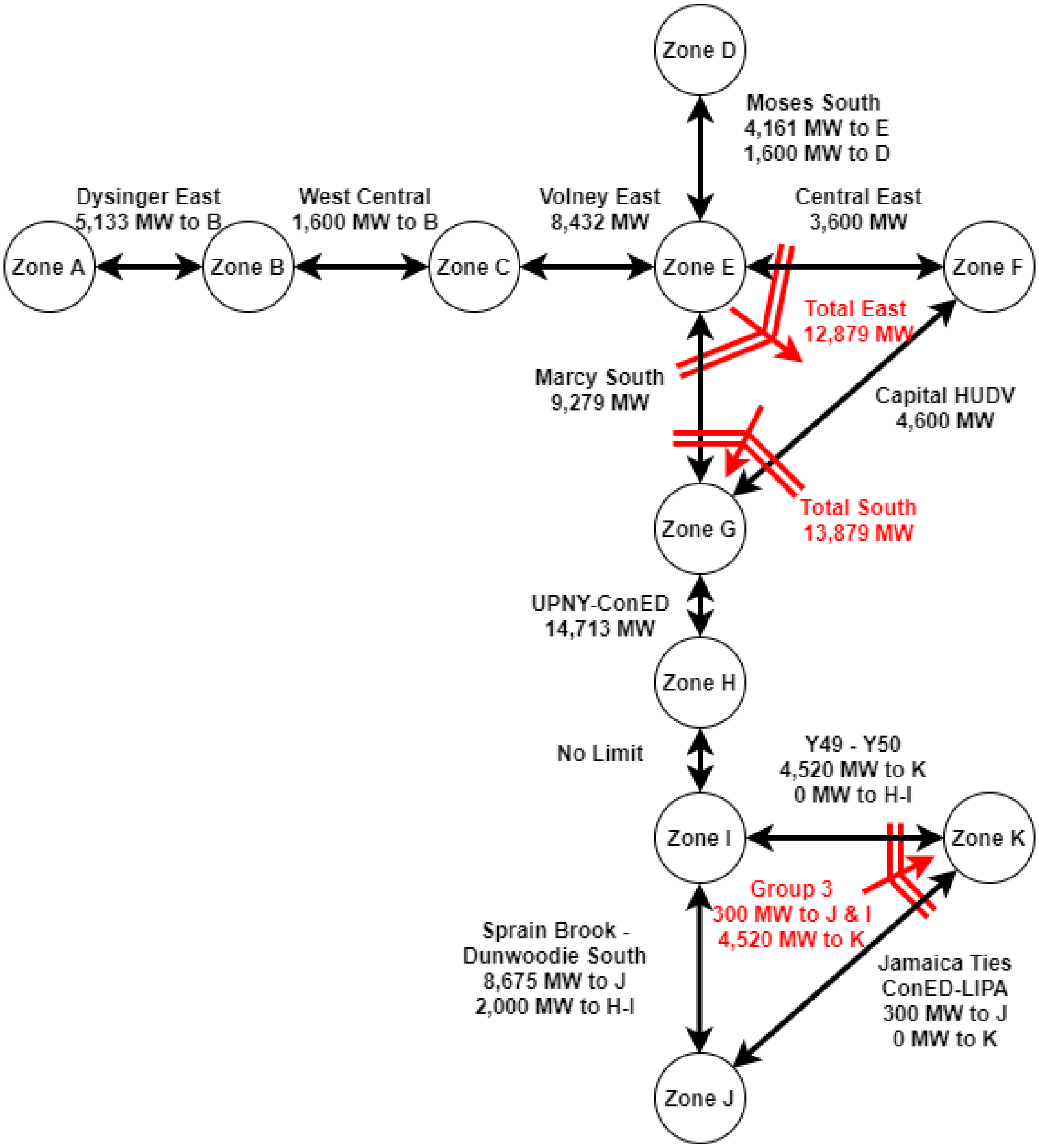


Table 10: Generation Capacity, CCP2-Reference

Nameplate Capacity by Zone, MW	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total**
Land-based Wind	6,057.0	877.5	4,326.8	4,353.8	4,097.3	-	-	-	-	-	-	**19,712.3**
Offshore Wind	-	-	-	-	-	-	-	-	-	14,380.4	5,869.6	**20,250.0**
Solar (Behind-the-meter)	822.3	254.8	696.4	80.7	785.5	965.3	798.3	70.8	104.7	784.1	987.9	**6,350.7**
Solar (Grid Connected)	10,059.0	1,148.0	6,273.8	-	3,969.0	8,156.8	4,613.0	-	-	-	134.8	**34,354.3**
Hydro Pondage	2,675.0	-	-	856.0	-	-	41.6	-	-	-	-	**3,572.6**
Hydro Pumped Storage	-	-	-	-	-	1,170.0	-	-	-	-	-	**1,170.0**
Hydro Run-of-River	4.7	63.7	70.4	58.8	376.2	282.5	57.1	-	-	-	-	**913.4**
Nuclear	-	581.7	2,782.5	-	-	-	-	-	-	-	-	**3,364.2**
Imports	-	-	-	1,500.0	-	-	-	-	-	1,310.0	-	**2,810.0**
Storage	1,952.0	8.0	1,958.0	1,976.0	688.0	606.0	168.0	-	-	390.0	54.0	**7,800.0**
Price Responsive Demand (Summer)	474.9	102.6	255.1	178.8	105.5	216.9	123.1	29.3	67.4	970.4	93.8	**2,618.0**
Price Responsive Demand (Winter)	309.5	66.9	166.2	116.5	68.8	141.4	80.2	19.1	43.9	632.3	61.1	**1,706.0**
DE Resources	353.3	102.6	1,148.9	280.9	237.4	2,573.9	2,640.7	38.8	-	5,761.7	3,920.7	**17,059.0**

Figure 13: Simplified Transmission Map and Limits, CCP2-Reference



E. Representation of Electric System Operations

1. Transfer and Dispatch Logic

Electrical transfers and generation across New York were modeled using the 11-region transmission framework discussed in Section II.C.6. The electric system model is designed to meet load needs using available resources subject to transmission and operational constraints.[47] The model operates pursuant to a sequence of resource loading steps, subject to the transfer constraints.

First, hydroelectric and nuclear units are assumed to generate at fixed capacity factors based on historical averages and do not respond to load (see Section II.C.1). Next, renewable generation is dispatched in each region and then transferred throughout the state to maximize load served through the operation of system renewable resources. Solar and land-based wind units are assumed to generate based on hourly profiles used in the 2019 CARIS Phase 1 70x30 Scenario (see Sections II.C.2 and II.C.3). Load within each region is served by renewable generation in that region first, followed by inter-region transfers to distribute regional generation surpluses across the state. Any excess renewable generation in a given hour is used to charge storage units if there is sufficient storage headroom. The backup resource is not used to charge storage.

In the next step of the model, if any zonal generation deficits remain, batteries and PRD are dispatched, and power flows between Zones as needed based on load deficit severity, transmission headroom, and available stored energy.[48] If a zonal deficit is not filled by running PRD and batteries within that zone, PRD and batteries in other Zones are transferred to the zone with a deficit, until all deficits are filled.

2. Use of Dispatchable and Emissions-Free Resources

The final mechanism relied upon to meet load is the DE resource, which is dispatched in hours when the combination of baseload resources, renewable generation, inter-zonal transfers, batteries, and PRD is insufficient to meet demand. If there is sufficient headroom on transmission lines, power generated by DE resources are transferred to Zones with generation deficits.

F. Comparisons with Grid in Transition Resource Sets

In addition to the resource sets developed as described in Section II.D, this study also modeled two resource sets developed for the NYISO Grid in Transition (GIT) study,[49] which seeks to understand the reliability and market implications of the State's plans to transition to clean energy sources.[50] The GIT resource set is based on an economic simulation of the NYISO markets through 2040, in consideration of NYISO market operations and economic retirement/additions of capacity. The simulation was run with the GIT resource set for both the Reference Case and CLCPA load scenarios, without any increase in transmission transfer capability in the base

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[47] Note, however, that the analysis is not a production cost model which takes prices into account for unit dispatch.

[48] When PRD is dispatched, the entire PRD capacity is used in each zone where there is a deficit, mimicking how the current SCR program currently functions.

[49] New York's Evolution to a Zero Emission Power System, June 22, 2020, https://www.nyiso.com/documents/20142/13245925/Brattle%20New%20York%20Electric%20Grid%20Evolution%20Study%20-%20June%202020.pdf/69397029-ffed-6fa9-cff8-c49240eb6f9d.

[50] The Brattle Group, "NYISO Grid in Transition Study: Detailed Assumptions and Modeling Description," March 30, 2020.

case.[51] The two resource sets provide bookends on the quantity of transmission buildout: the CCP2 resource set developed under this study looks at significant increases in transmission, while the Grid-in-Transition resource set has no increase in transmission. This difference in transmission capability has a significant impact on where future renewable resources would be located.

For comparison purposes, this study tests the GIT resource set under both the reference and CLCPA load scenarios as alternative inputs into the energy balance model. As seen in Table 11, the Grid in Transition resource sets includes a much larger quantity of the dispatchable renewable natural gas resource and lower quantity of renewable resources to meet total energy needs.[52] In addition, the renewable resources in the GIT resource set are located primarily in the eastern half of the state, whereas the renewables included in the resource sets used in this study are more evenly spread across the state (For example, a large amount of solar generation is assumed in Zone F in the GIT resource set). Finally, to provide a reliable starting point for the physical disruption analyses, AG added additional DE resources to the resource sets to meet load in all hours of the modeling periods.

Table 11: Resource Sets from Grid in Transition Study

Grid in Transition Reference Case

Nameplate Capacity by Zone, MW	A-E	F	G-I	J	K	Total
Land-based Wind	9,754.8	0.0	0.0	-	-	9,754.8
Offshore Wind	-	-	-	9,173.5	4,593.8	13,767.3
Solar (Behind-the-meter)	452.1	2,606.7	265.0	779.9	2,009.4	6,113.1
Solar (Grid Connected)	4,771.7	20,838.5	4,376.0	-	56.4	30,042.6
Hydro Pondage + Run-of-River	4,431.7	485.6	100.7	-	-	5,018.0
Hydro Pumped Storage	-	1,171.3	-	-	-	1,171.3
Nuclear	2,095.9	-	-	-	-	2,095.9
Imports	1,100.0	-	-	-	-	1,100.0
Storage	1,973.5	3,276.9	895.4	2,645.5	1,945.0	10,736.3
Price Responsive Demand (SCR/EDRP)	1,054.9	216.3	318.5	938.0	634.9	3,162.6
Renewable Natural Gas Dispatchable	2,333.7	3,040.7	3,847.2	6,388.1	5,008.7	20,618.4
DE Resources (added by AG)	-	-	-	1,283.0	797	2,080.0

Grid in Transition CLCPA Case

Nameplate Capacity by Zone, MW	A-E	F	G-I	J	K	Total
Land-based Wind	23,254.8	0.0	0.0	-	-	23,254.9
Offshore Wind	-	-	-	17,938.0	7,164.1	25,102.2
Solar (Behind-the-meter)	537.5	2,843.1	265.0	779.9	2,009.4	6,434.9
Solar (Grid Connected)	4,907.1	21,378.9	5,326.8	-	56.4	31,669.3
Hydro Pondage + Run-of-River	4,431.7	485.6	100.7	-	-	5,018.0
Hydro Pumped Storage	-	1,171.3	-	-	-	1,171.3
Nuclear	2,156.4	-	-	-	-	2,156.4
Imports	1,100.0	-	-	-	-	1,100.0
Storage	5,894.2	3,014.9	260.1	2,620.7	2,317.0	14,106.9
Price Responsive Demand (SCR/EDRP)	1,462.9	306.2	472.5	1,348.9	909.1	4,499.5
Renewable Natural Gas Dispatchable	2,483.6	9,048.6	5,596.7	10,187.0	6,386.5	33,702.3
DE Resources (added by AG)	219.0	-	-	3,629.0	1,988.0	5,836.0

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[51] Additional alternative scenarios were included in the NYISO Grid in Transition study but were not included in this analysis.

[52] The backup resource is described in the GIT study as renewable natural gas dispatchable capacity, which is used as a proxy for potential future zero emission technology development. The Brattle Group, "NYISO Grid in Transition Study: Detailed Assumptions and Modeling Description," March 30, 2020, slide 36.

III. Cases Analyzed: Combinations of Load Scenarios and Physical Disruptions

In order to test the resilience of the electrical system to different possible system conditions during future events, a number of potential "physical disruptions" were modeled, representing possible future effects of climate change on electricity demand and system infrastructure operations. The physical disruptions listed in Table 12 are primarily intended to simulate possible short-term adverse events with load, generation, and transmission impacts that coincide within the modeling period. The load scenarios, resource sets, and physical disruptions are combined into a series of cases, the results of which are evaluated through the AG system model. The sections that follow explain the modeled impacts for each physical disruption.

Table 12: Description of Physical Disruption Modeling

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 DE Capacity - 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 DE Capacity - 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	

A. Physical Disruptions: Interruptions of Resources and Transmission

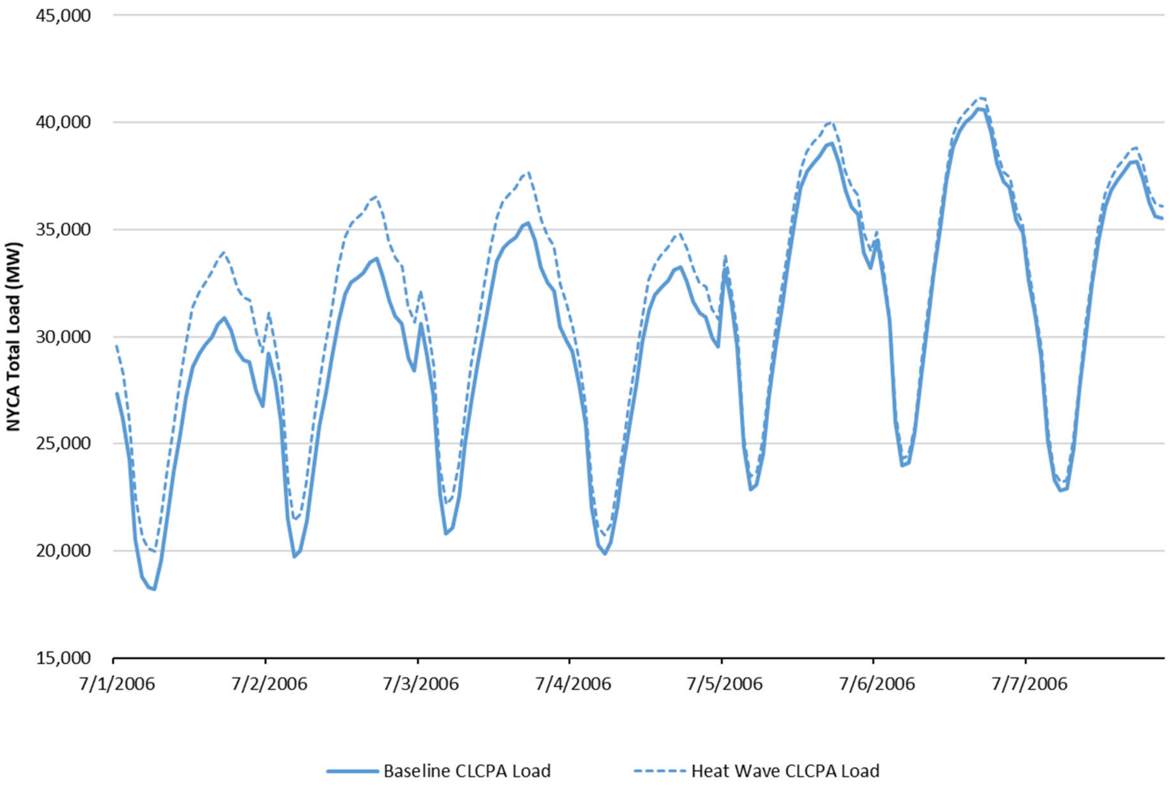
1. Temperature Waves

Periods of extreme heat or cold can have contemporaneous impacts on the bulk electric system due to increased load, changes in wind and solar generation, and impacts on transmission capacity. The temperature wave scenarios stress the power system with several days of severe temperatures across New York State.

The NYSERDA ClimAID report defines extreme temperatures for both hot and cold periods: heat waves are defined as periods of three or more consecutive days where daily high temperatures are at or above 90° Fahrenheit (F), and extreme cold days are defined as days with a minimum temperature at or below 0° F.[53] The model evaluates as a climate-change induced disruption an extended heat wave of seven days and an extended cold snap of seven days. These extreme hot/cold events are calibrated to historical heat and cold waves and adjusted for average temperature increases due to climate change using the Phase I Study modeling.

The load impacts from heat and cold temperature waves are based on zonal load-temperature sensitivities from the Phase I Study modeling. In the Phase I model, the impact of trending weather conditions are translated through the peak model heating and cooling loads to get a peak energy forecast. By adjusting the mean daily temperature across all Zones during the study period to meet the NYSERDA criteria for a period of extreme heat or cold, the analysis calculates an average load impact. The cold wave peak load impact average is about 110 percent across zones and the summer heat wave averages to about a 107 percent increase in peak load. Figure 14 shows loads in the CLCPA summer heat wave case.

Figure 14: Example of Heat Wave Increased Load: CLCPA Summer Load Scenario



Evidence from the European heat wave of 2018 showed wind resources can decrease by as much as 20 percent below long-term averages during a heat wave.[54] In order to model a similar impact, a 20 percent wind capacity factor decrease is modeled during the heat wave climate scenario. Figure 15 shows a wind decrease in the CLCPA summer heat wave case. The study does not model any impact on wind output during the cold snap.

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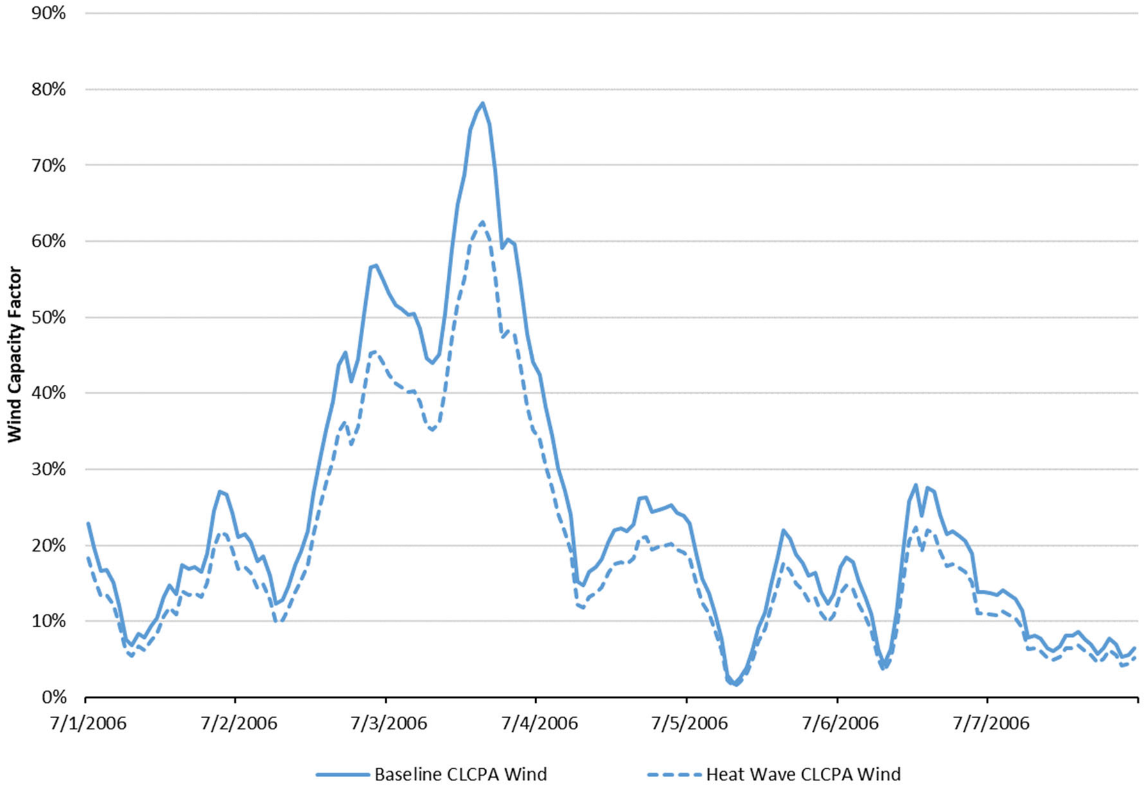
[53] NYSERDA, "Responding to Climate Change in New York State (ClimAID)," (hereafter "NYSERDA ClimAID "), pp. 2-3, 2014, https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/ClimAID/2014-ClimAid-Report.pdf

[54] Renewable Energy Magazine, "Heatwave hits European wind energy but boosts solar energy generation," , August 2018, https://www.renewableenergymagazine.com/wind/heatwave-hits-european-wind-energy-but-boosts-20180814

Figure 15: Example of Heat Wave Decreased Wind Production: CLCPA Summer Load Scenario



In heat waves solar irradiance is higher than long-term average irradiance, but PV efficiency decreases due to temperature effects.[55] During cold waves, solar irradiance can be variable but there is no impact on PV efficiency. To model the dual effect during temperature wave periods, this study uses zonal-aggregated National Renewable Energy Laboratory (NREL) PV output data from the hottest and coldest days during the summer and winter periods in 2006 as the load profiles for the model. As seen in Figure 16, using the solar generation profile from July 18, 2006 reveals that the majority of days in the seven days of the modeled heat wave experience an increase in solar generation.

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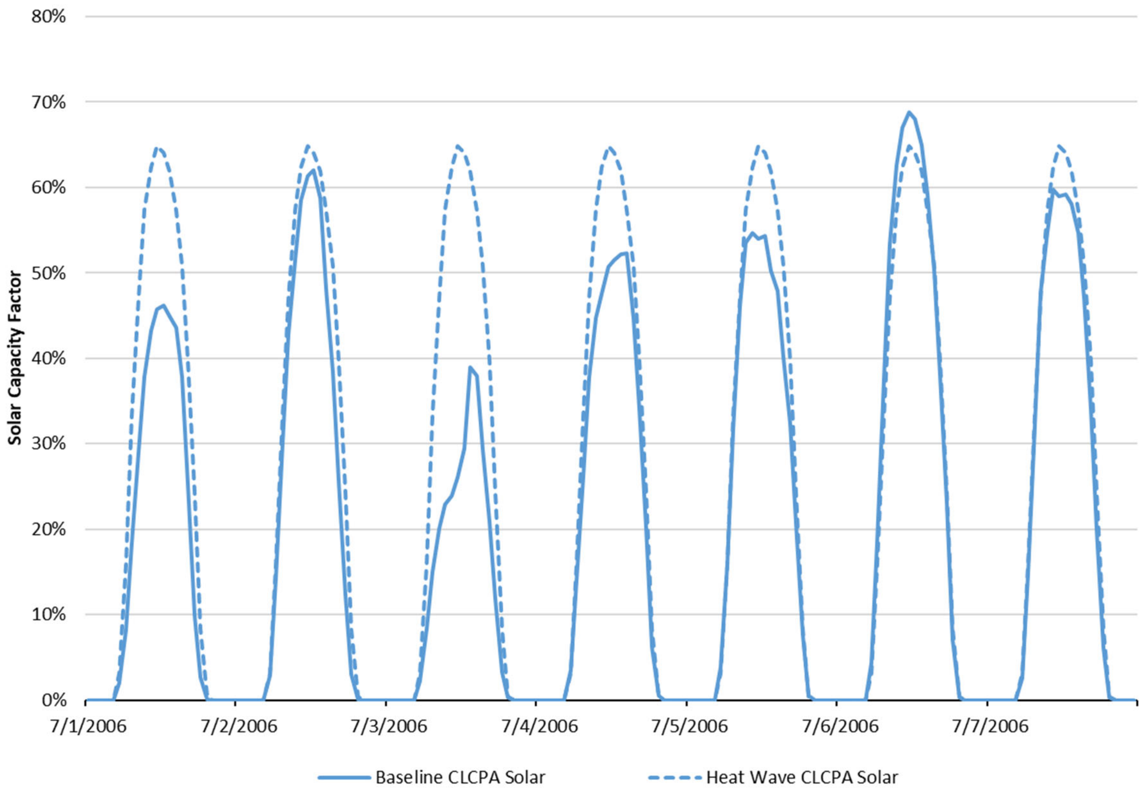
[55] EnergySage, "How hot do solar panels get? Effect of temperature on solar performance," Updated July 21, 2020, https://news.energysage.com/solar-panel-temperature-overheating/

Figure 16: Heat Wave Solar Production: CLCPA Summer Load Scenario



There is more variability in the winter due to the impact of cloud cover on solar irradiance. Using the solar generation profile from the coldest day in January 2006, which occurred on the 16th, results in an increase in solar generation for the seven days of the modeled cold wave.

Finally, heat waves decrease transmission capacity due to reduction in thermal limits and conductor sag.[56] Accordingly, a five percent transmission MW transfer capability decrease is modeled during the heat wave. There is no impact to transmission modeled during the cold wave scenario.

As a result of the above findings, heat waves are modeled using the following model adjustments:

- Load - High temp 90° F or above for seven days, with daily zonal load increase of between 0 percent and percent 18.7 percent
- Wind Generation - 20 percent decrease for seven days
- Solar Generation - use solar profile from hottest day in Y2006 for seven days
- Transmission - five percent decrease for seven days

Cold waves are modeled using the following model adjustments:

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[56] Bartos, Matthew, et. al., "Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States," *Environmental Research Letters,* Volume 11, 2016, https://iopscience.iop.org/article/10.1088/1748-9326/11/11/114008/pdf

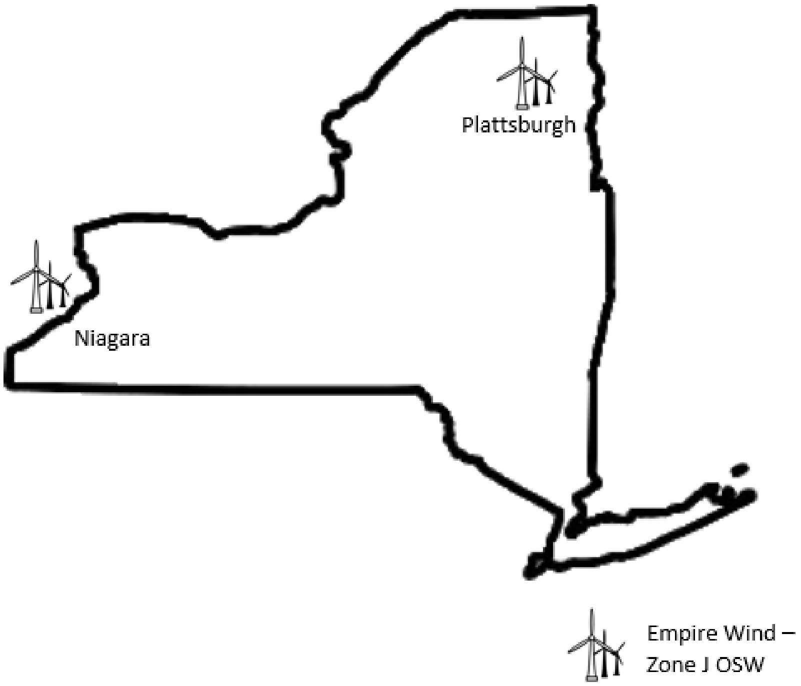
- Load - Low temp of 0° F or below for seven days, with daily zonal load increase of between 2.3 percent and percent 25.6 percent.
- Solar Generation - Use solar profile from coldest day in Y2006 for seven days

2. Wind Lulls

Although wind power provides a significant amount of aggregate generation, wind power production follows seasonal weather patterns and is variable in real time, which could include multi-day periods with relatively low capacity factors, or “wind lulls.” A state-wide wind lull that affects both upstate and offshore wind generating plants could create a large instantaneous shortfall in power that would significantly stress the electrical system. In that case, the generation deficit would need to be filled in by other forms of generation.

To evaluate this potential variability, we include analysis of wind lulls based on historical NREL daily wind data, with capacity factor at simulated 100 meter turbine height, from the WIND Toolkit covering the period from 2007 through 2012. These data were used as a guide to establish the appropriate length and severity of a state-wide wind lull. Three sites representing upstate and offshore production were used: Niagara, Plattsburgh, and Empire Wind Zones, as shown in Figure 17. The locations of these representative sites roughly correspond with the share of wind nameplate capacity assumed in the modeled resource sets.

Figure 17: Wind Farm Locations used in Wind Lull Analysis



Due to the differences in seasonal wind patterns, wind lulls in the summer and winter were defined and assessed separately. A summer wind lull is defined as four or more consecutive days of a rolling average capacity factor of less than or equal to 15 percent. Because winter is a windier season on average, the threshold was raised to a capacity factor of less than or equal to 25 percent. Table 13 and Table 14 summarizes the historic statewide wind lulls by season in the years 2007 - 2012. Summer wind lulls were both more frequent and more severe; there were 19 wind lulls during summer months but only three wind lulls in the winter, even using a higher capacity factor threshold. The observed wind lulls occur during periods with both seasonally high and low temperatures, so are not limited to "heat wave" periods.

Table 13: Historical Summer Wind Lulls from NREL data, 2007-2012, ≤15 percent Implied Capacity Factor

Wind Lull Period	Number of Days	Average Wind Capacity Factor Across Regions	Statewide Average Temperature	Statewide Average High
7/21/2007 - 8/1/2007	12	14.2%	72°	80.9°
8/10/2009 - 8/16/2009	7	14.1%	74.7°	82.5°
6/10/2009 - 6/16/2009	7	13.7%	64.5°	72.4°
8/31/2009 - 9/5/2009	6	13.3%	65°	75.2°
7/27/2012 - 8/1/2012	6	14.4%	73.9°	81.6°
8/12/2008 - 8/16/2008	5	14.9%	67.4°	75.9°
7/6/2009 - 7/10/2009	5	14.3%	66°	74.6°
7/9/2012 - 7/13/2012	5	14.4%	73.8°	84.8°
8/18/2012 - 8/22/2012	5	14.7%	67.6°	77.3°

Notes:
[1] Based on NREL Wind Toolkit wind data at 100 meter height for points in Plattsburgh (North), Niagara Falls (West), and Empire Wind Zone.
[2] A wind lull is defined as four or more consecutive days where the average daily implied capacity factor is less than or equal to 15 percent.
[3] In addition to the listed wind lulls, there were 10 wind lulls of 4 days between 2007 - 2012.
Sources:
[1] NREL Wind Toolkit Database, https://www.nrel.gov/grid/wind-toolkit.html.

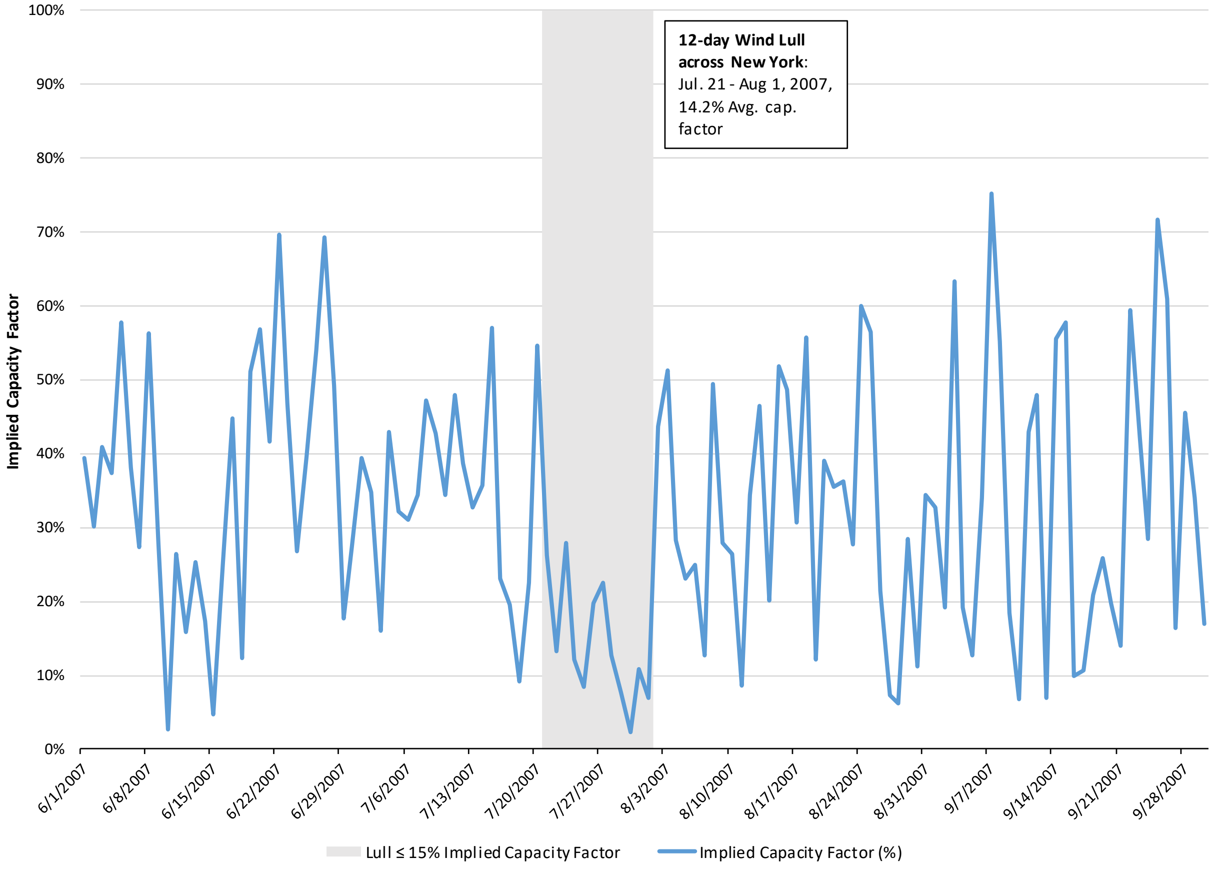
Table 14: Historical Winter Wind Lulls from NREL data, 2007-2012, ≤25 percent Implied Capacity Factor

Wind Lull Period	Number of Days	Average Wind Capacity Factor Across Regions	Statewide Average Temperature	Statewide Average High
2/25/2007 - 3/1/2007	5	21.7%	25.6°	33.6°
1/28/2011 - 2/1/2011	5	22.5%	22.2°	28.4°
2/2/2012 - 2/5/2012	4	24.3%	33.1°	40.2°

Notes:
[1] Based on NREL Wind Toolkit wind data at 100 meter height for points in Plattsburgh (North), Niagara Falls (West), and Empire Wind Zone.
[2] A wind lull is defined as four or more consecutive days where the average daily implied capacity factor is less than or equal to 25 percent.
Sources:
[1] NREL Wind Toolkit Database, https://www.nrel.gov/grid/wind-toolkit.html.

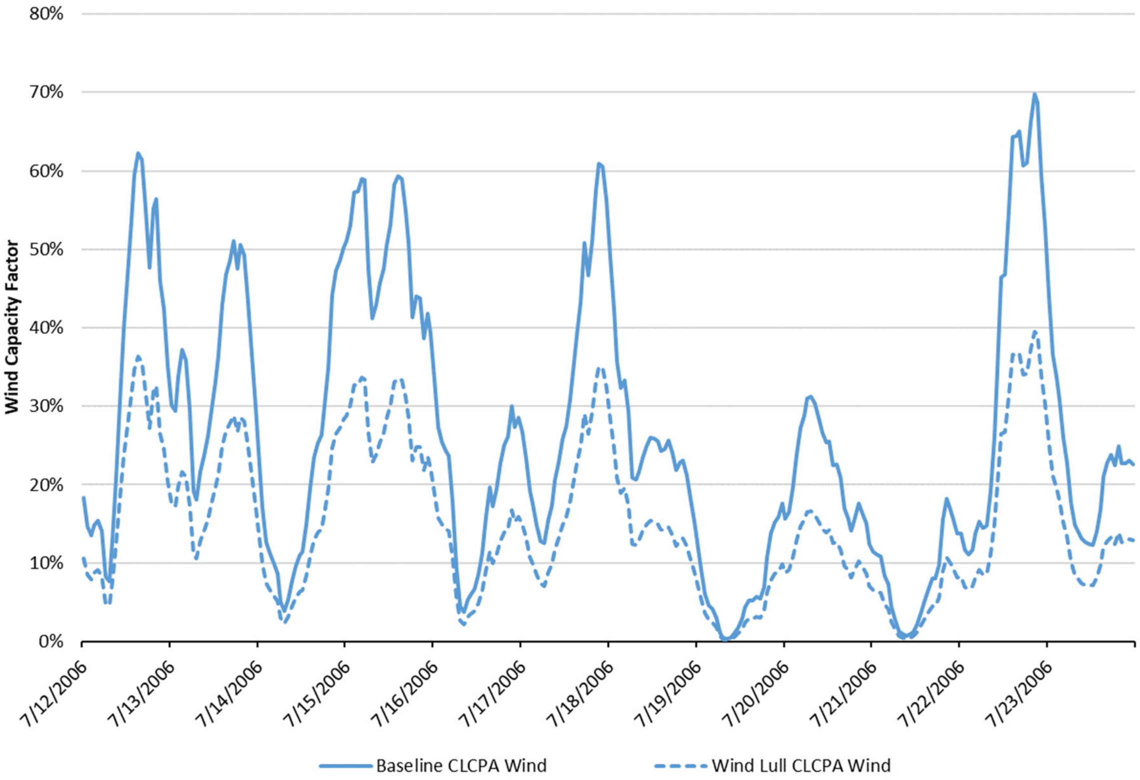
Figure 18 shows the daily capacity factor over the entire summer period in 2007, highlighting the capacity factor during the 12-day wind lull in July of 2007.

Figure 18: Summer Wind Lull Example - Summer 2007 Average Daily Wind Shape



The NREL data is a snapshot of six years of wind speeds. We recognize that while the trends are consistent over this six-year period, it is possible that there have been more severe wind lulls than in the time span we analyzed, and that there could be more severe wind lulls going forward, particularly if such outcomes are made more likely by climate change. Thus, in order to evaluate impacts associated with extended wind lulls, we set the winter wind lull used in the model to 7 days and set the summer wind lull in the model to the longest lull observed in the NREL data, 12 days. In order to evaluate potential impacts at times of high electricity demand, the wind lulls are timed to overlap with the 12- and 7-day periods of highest load for each month, (including the peak load day). Based on the historical wind lull data, we set the average capacity factors in a wind lull at 15 percent for 12 days in the summer, and 25 percent for seven days in the winter. In both seasons, the capacity for each day in the wind lull period was reduced by the same scaling factor so that the average capacity factor over the entire period was equal to 15 or 25 percent.

Figure 19: Example of Wind Lull Decreased Wind Production: CLCPA Summer Load Scenario



As a result of the above findings, summer wind lulls are modeled using the following model adjustments:

- Wind Generation - 15 percent Average Capacity Factor in all Zones for 12 days
- Wind Lull overlaps the 12-day period with highest load

Winter wind lulls are modeled using the following model adjustments:

- Wind Generation - 25 percent Average Capacity Factor in all Zones for seven days
- Wind Lull overlaps the seven-day period with highest load

3. Storm Scenarios

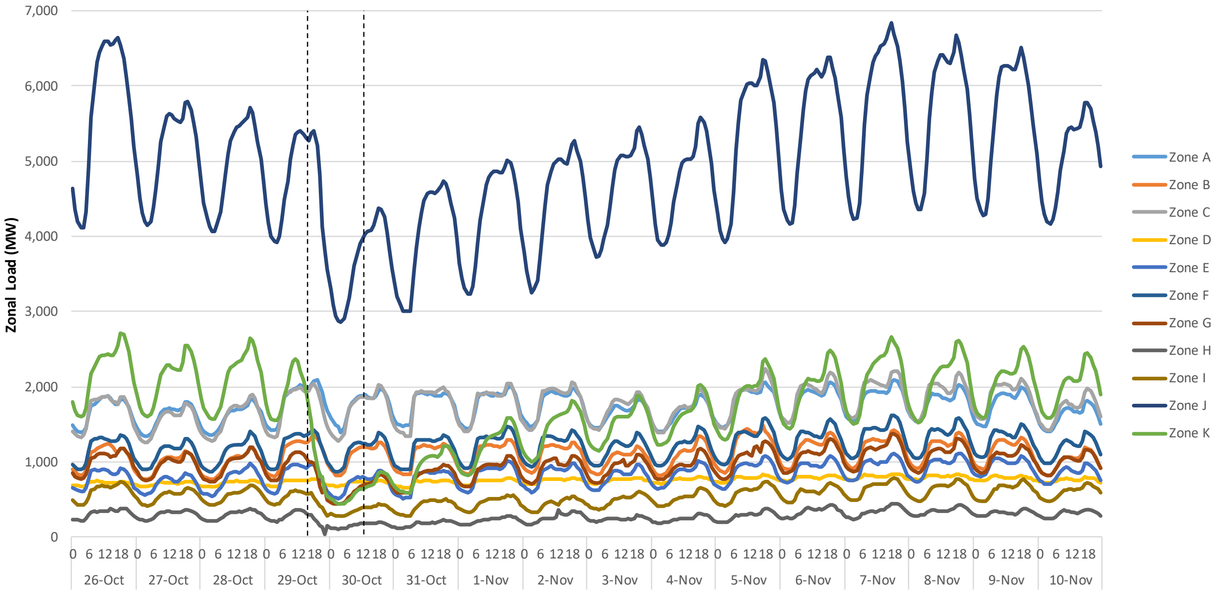
Severe storms stress the electrical system due to contemporaneous impacts on transmission, generation, transmission, and load. This analysis modeled scenarios cover severe storm impacts with sustained recovery periods of multiple days and weeks, and evaluated the potential for reliability impacts across the entire state, not just the area most directly affected by the storm event.

Hurricane Sandy, which made landfall in New York on October 29, 2012, affected load, fossil generation, and transmission assets. The storm scenarios in this study were developed based on historical observations from the

2013 NYISO Hurricane Sandy report[57] and NYISO-metered load data from the period of Hurricane Sandy and its immediate aftermath.

Large storms often cause local losses of load at the distribution system level due to physical damage from downed trees, flooding, or lightning. These distribution-level losses show up as reduced load that must be met by the electrical grid. During outages caused by Hurricane Sandy, NYISO-metered load decreased significantly in New York City and Long Island during the course of the storm (10/29/12 - 10/30/12, shown in Figure 20 with dashed line, with a nearly linear recovery. There was a nearly complete recovery of load levels by the weekend of Nov. 10. In the upstate zone, where there were fewer outages caused by the hurricane, there was a marginal decrease in load during the storm, but overall, upstate load remained consistent. [58]

Figure 20: NYISO-Metered Load during Hurricane Sandy and Recovery Period



The impact of the hurricane on generation was primarily centered on nuclear and fossil units downstate. On the first day after the storm, about 20 percent of NYCA nameplate capacity was offline, and about 40 percent of New York City and Long Island capacity was offline. By day 11, the last day in the NYISO Hurricane Sandy study, approximately 30 percent of capacity was still offline. Based on the average pace of recovery, full capacity would have been back online on or about Day 15. See Figure 21 below. We apply these trends as a 40 percent reduction in DE resource capacity in the affected area with a linear recovery of generation over two weeks.

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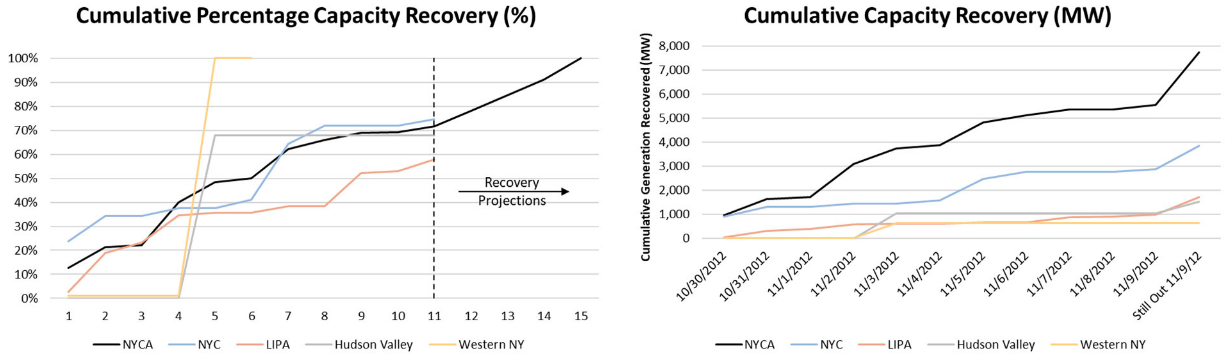
[57] NYISO, "Hurricane Sandy - A report from the New York Independent System Operator," March 27, 2013, http://www.nysrc.org/pdf/MeetingMaterial/RCMSMeetingMaterial/RCMS%20Agenda%20159/Sandy_Report___3_27_133.pdf

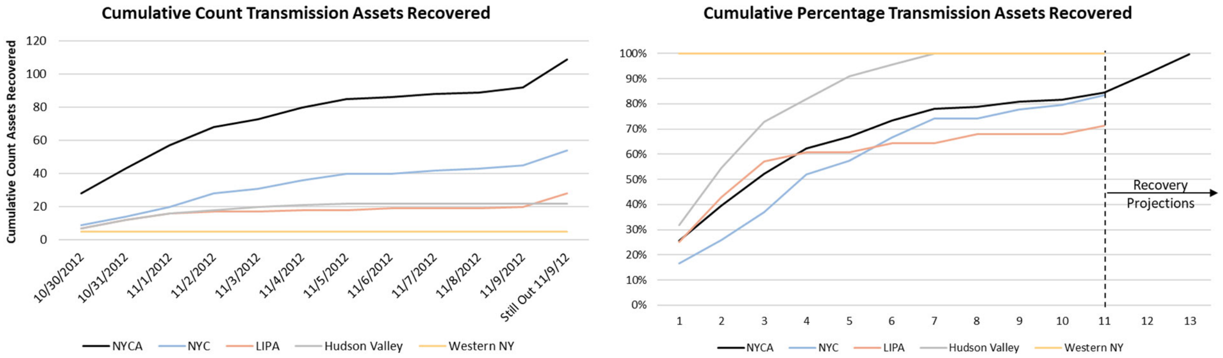
[58] NYISO, Load Data, https://www.nyiso.com/load-data

Figure 21: Cumulative Generating Capacity Recovery during Hurricane Sandy Recovery Period



The 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." [59] By Day 11, approximately 15 percent of transmission assets were still offline. Based on the average pace of recovery, full capacity would have been back online on or about Day 13. See Figure 22 below. Thus, the study models transmission as being completely off line in the area affected by the storm, with a two week linear recovery period.

Figure 22: Cumulative Transmission Recovery during Hurricane Sandy Recovery Period



There is limited evidence of effects on renewable generation, in part because there were so few installations in Zones J and K in 2012. Sandy hit New York as a Category 1 hurricane, with max wind gusts under 100 mph during the storm.[60] Some wind generation damage would be expected given current turbine storm ratings, but future installations may be hardened to withstand Sandy-level wind speeds.[61] Solar panels are generally rated for 110-145 mph winds, and damage to both rooftop solar and grid-connected solar during Hurricane Sandy was limited.[62]

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[59] Hurricane Sandy A report from the New York Independent System Operator, http://www.nysrc.org/pdf/MeetingMaterial/RCMSMeetingMaterial/RCMS percent20Agenda percent20159/Sandy_Report___3_27_133.pdf

[60] National Weather Service, "Hurricane Sandy," https://www.weather.gov/okx/HurricaneSandy

[61] General Electric, "Riders On The Storm: GE Is Building A Wind Turbine That Can Weather Violent Typhoons, Hurricanes," June 17, 2018, https://www.ge.com/news/reports/riders-storm-ge-building-wind-turbine-can-weather-violent-typhoons-hurricanes?utm_source=feedburner

[62] IEEE Spectrum, "Rooftop Solar Stood Up to Sandy," November 16, 2012, https://spectrum.ieee.org/green-tech/solar/rooftop-solar-stood-up-to-sandy and Christian Science Monitor, "Are renewables stormproof? Hurricane Sandy tests solar, wind," November 19, 2012, https://www.csmonitor.com/Environment/Energy-Voices/2012/1119/Are-renewables-stormproof-Hurricane-Sandy-tests-solar-wind

Based on this information, wind generation is modeled as being off during the storm and then as having a two week linear recovery period for repairs. Solar generation is modeled at a 50 percent reduction due to cloud cover impacts during Day 1 of the storm, with a full next-day recovery after the storm ends.

The most recent historical experience is from Hurricane Sandy, but future storms may not necessarily be geographically centered on downstate zones. As a result, the study models upstate and offshore storm scenarios using the same level of impact as the downstate scenario, but with shifts in the geographic center of storm damage. For the upstate storm scenarios, the analysis models the same magnitude of effects, but focused on Zones A-F instead of G-K. For the offshore storm scenario, we similarly apply the same magnitude of effects, but only to impact offshore wind generation in Zones J and K.

As a result of the findings described above, the model setup for Hurricane/Coastal wind storm scenario is calibrated using the Hurricane Sandy data, as follows:

- Load: 30 percent reduction in load in Zones G-K; 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 J-K during one-day storm; 14 day linear recovery period.
    - Solar Generation - 50 percent decrease in Zones G-K during one day storm; next day recovery.
    - DE Generation - 40 percent decrease in Zones G-K; 14 day linear recovery period.

Severe Wind Storm – Upstate is calibrated using the downstate Hurricane Sandy effects:

- Load: 30 percent reduction in load in Zones A-F; 11 day linear recovery period.
- Transmission: cut off transmission lines to upstate Zones A-F; 14 day linear recovery period.
- Generation:
    - Wind Generation - Off in Zones A-F during 1-day storm; 14 day linear recovery period.
    - Solar Generation - 50 percent Decrease in Zones A-F during one day storm; next day recovery.
    - DE Generation - 40 percent Decrease in Zones A-F; 14 day linear recovery period.

Severe Wind Storm - Offshore

- Wind Generation - Off in Zones J-K during one-day storm; 14 day linear recovery period.

4. Other Climate Impacts

In addition to the disruptions discussed above, we modeled two season-specific climate impacts: summer droughts and winter icing events.

A potential impact of climate change and rising average temperatures is the increased probability of a drought in New York, which would affect hydroelectric production during summer months. According to the NYSERDA ClimAID report, "[s]hort-duration warm season droughts will more likely than not become more common."[63] Based on NYISO operations information on historical low water periods, we assume a 50 percent reduction in hydroelectric production during the entire 30 day modeling period in the drought disruption:

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[63] NYSERDA ClimAID, p.16

Summer drought

- Hydroelectric Generation - 50 percent of baseline production across all of New York State

Finally, NYISO historical experience with severe winter conditions has shown the potential for short-term icing events that would damage upstate transmission lines and would reduce wind production. Historical evidence is not fully available for the effect of icing in upstate New York on wind production, but one engineering study has shown the potential for up to 50 percent reduction in wind production at wind farms due to ice accretion on turbine blades.[64]

Icing Event (winter only)

- Load: 25 percent reduction in load in Zones A-C; seven day linear recovery period.
- Transmission: cut off transmission lines to upstate Zones A-C; seven day linear recovery period.
- Wind Generation - 50 percent reduction in Zones A-C during one-day event; seven day linear recovery period.

B. Construction of Combination Cases

Finally, to test the joint impact of differences in season, load scenarios, resource sets, and short-term physical disruptions, combination "cases" of each were modeled. All combination cases are presented in Table 15. The results from these cases are presented in Section V.

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[64] Iowa State University News Service, "Engineers study icing/de-icing of wind turbine blades to improve winter power production," September 23, 2019.

Table 15: List of Modeled Combination Cases

		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		

IV. Output Metrics

A. Model Output

The energy balance model is run for each case identified for analysis. As described in Section III, each case is a combination of a load scenario, resource set, and physical disruption. The model proceeds through an electricity transfer and dispatch sequence based on the data inputs described above, including physical constraints on unit operations and the flow of power between locations within New York. Results are presented along several metrics indicating system reliability performance, including the identification of potential loss of load occurrences. The results are assessed both individually for each case, and across all combination cases. This section describes the model output metrics and graphics, followed by the process used to distill case results into a set of key observations.

For each model run, the energy balance model estimates or tracks:

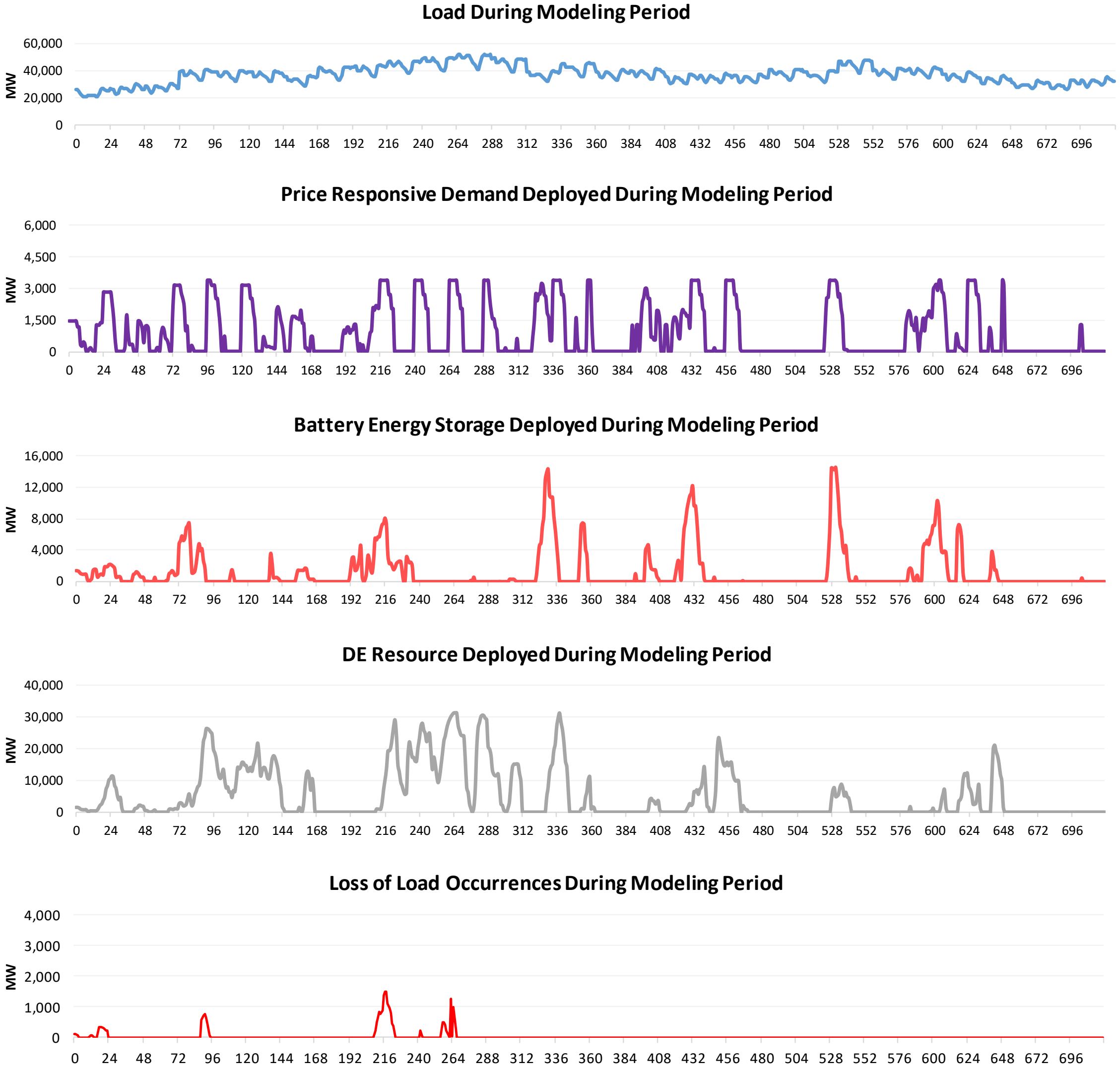
a. Hourly demand for electricity;
b. Hourly generation from renewable resources;
c. Hourly dispatch and stored energy for battery and pumped storage units;
d. Total hourly zonal generation relative to electrical demand;
e. Hourly capacity imports and transfers of power between Zones;
f. Hourly activation of price-responsive demand resources, when needed to avoid loss of load;
g. Hourly dispatch of DE resources, when needed to avoid loss of load;
h. Magnitude of potential loss of load on an hourly basis, in each zone, over the thirty-day modeling period.

The central focus of the model outputs are the magnitudes, duration and frequency of use of DE resources, and potential loss of load occurrences. In order to assist in the detailed analysis of each case, and for comparison of potential LOLO drivers across cases, the model generates a consistent set of tables and graphics for each case. For illustration of the reporting outputs on case outcomes, Figure 23 through Figure 28**Error! Reference source not found.** present an example of the full set of metrics generated in graphical and tabular form for one case - namely the case run with the most observed loss of load occurrences (CLCPA Winter Severe Wind Storm - Upstate).

Figure 23: Example of Hourly Results Summary

Hourly Results Summary

Case Name: CLCPA Case - Winter - Climate Change Phase II Resource Set - Severe Wind Storm - Upstate



Load	
Total Hrs.	720
Total MWh	26,633,154
Avg. MW	36,990.5

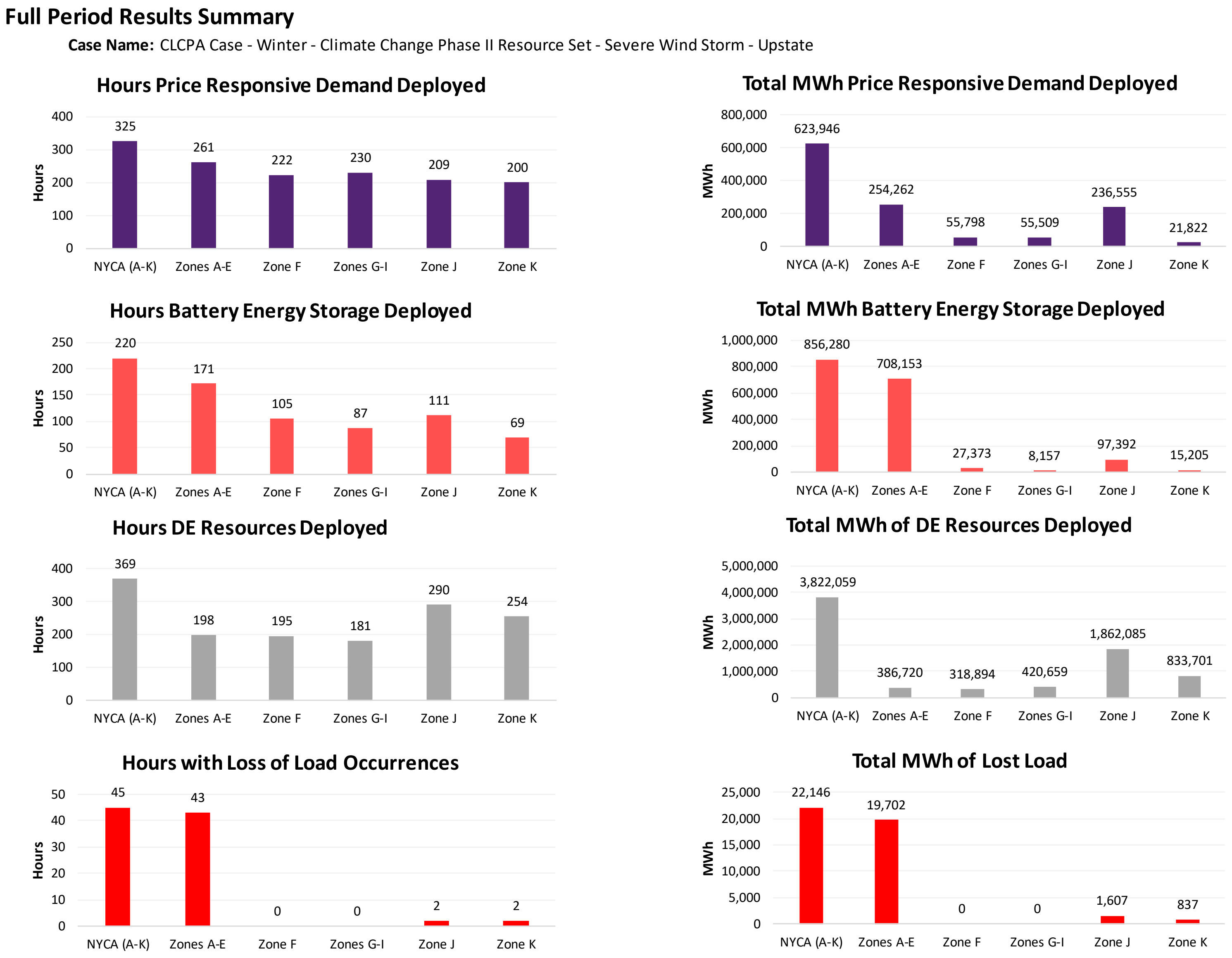
PRD Deployment	
Total Hrs.	325
Total MWh	623,946
Avg. MW	1,919.8

Battery Deployment	
Total Hrs.	262
Total MWh	856,262
Avg. MW	3,268.2

DE Resource Deployment	
Total Hrs.	369
Total MWh	3,822,059
Avg. MW	10,357.9

Loss of Load Occurrences	
Total Hrs.	45
Total MWh	22,150
Avg. MW	492.2

Figure 24: Example of Full Period Results Summary



Full Period Results Summary

Case Name: CLCPA Case - Winter - Climate Change Phase II Resource Set - Severe Wind Storm - Upstate

Hours Price Responsive Demand Deployed

Total MWh Price Responsive Demand Deployed

Hours Battery Energy Storage Deployed

Total MWh Battery Energy Storage Deployed

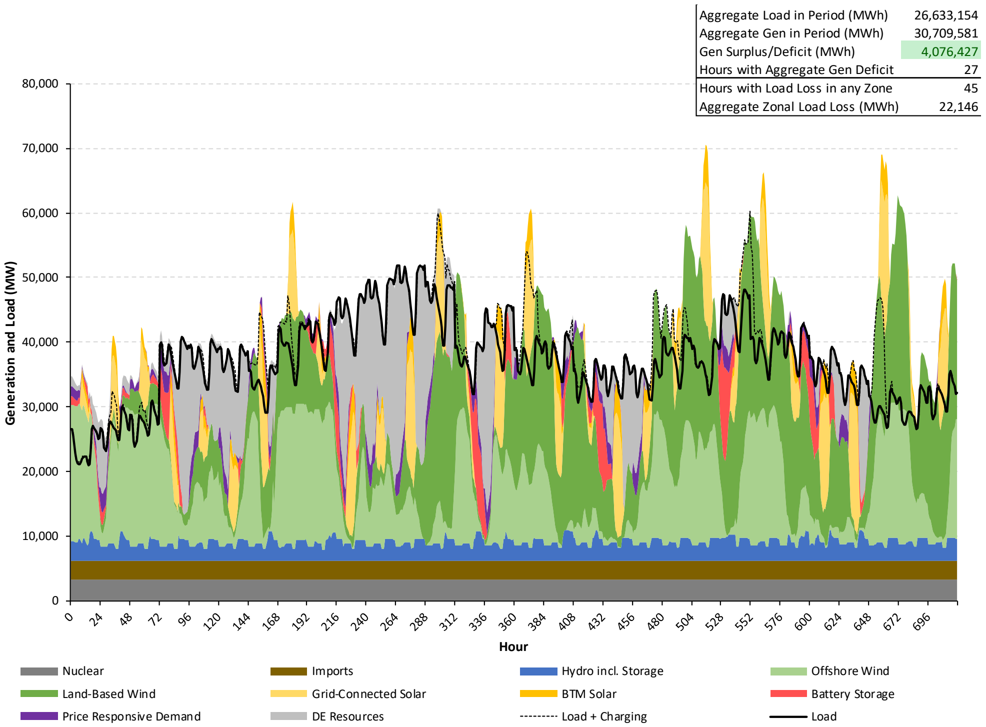
Hours DE Resources Deployed

Total MWh of DE Resources Deployed

Hours with Loss of Load Occurrences

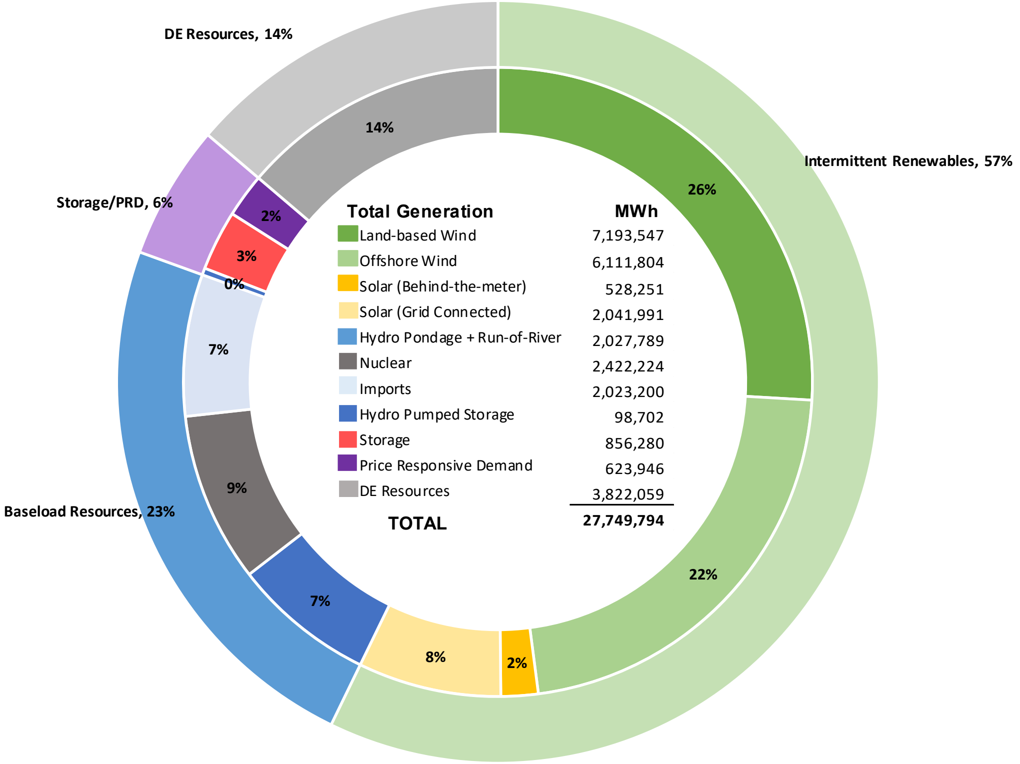
Total MWh of Lost Load

Figure 25: Example of NYCA Hourly Generation by Fuel Group



Aggregate Load in Period (MWh)	26,633,154
Aggregate Gen in Period (MWh)	30,709,581
Gen Surplus/Deficit (MWh)	4,076,427
Hours with Aggregate Gen Deficit	27
Hours with Load Loss in any Zone	45
Aggregate Zonal Load Loss (MWh)	22,146

Figure 26: Example of Generation by Resource Type over Modeling Period



Total Generation	MWh
Land-based Wind	7,193,547
Offshore Wind	6,111,804
Solar (Behind-the-meter)	528,251
Solar (Grid Connected)	2,041,991
Hydro Pondage + Run-of-River	2,027,789
Nuclear	2,422,224
Imports	2,023,200
Hydro Pumped Storage	98,702
Storage	856,280
Price Responsive Demand	623,946
DE Resources	3,822,059
TOTAL	27,749,794

Figure 27: Example of NYCA DE Resources Generation Duration

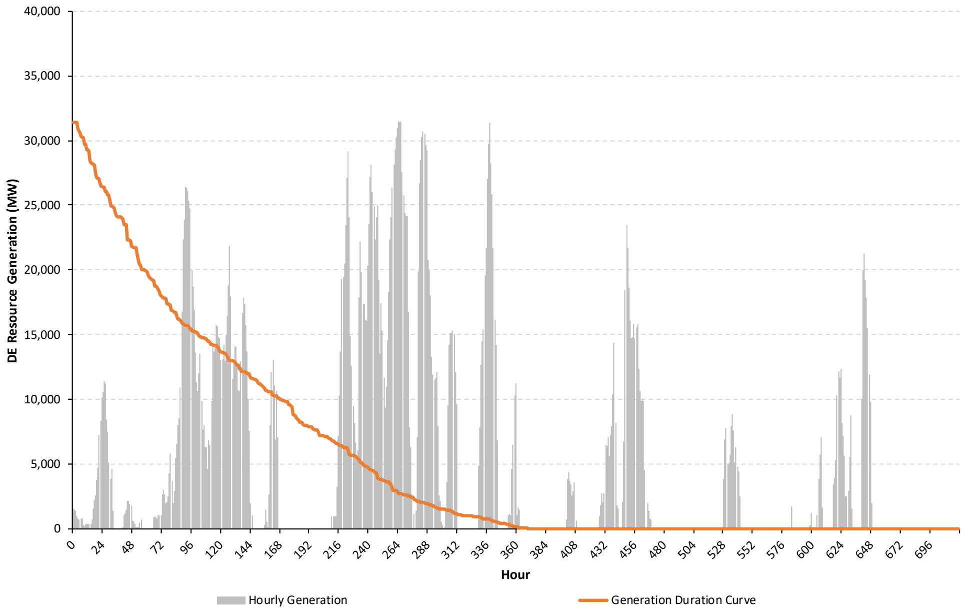
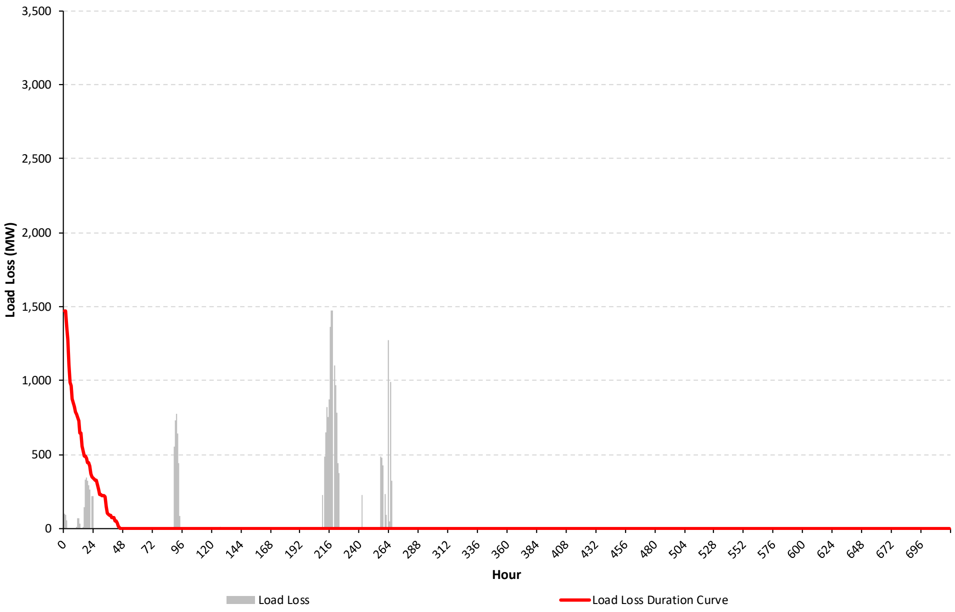


Figure 28: Example of NYCA Loss of Load Occurrences Duration



B. Analysis of Outcomes

The key focus of the analysis is on cases where there is a potential loss of load occurrence, or where leading indicators (PRD activations and/or use of DE resources) point to tight conditions and heighted reliability risks. Each combination case based on an initial load scenario and resource set is first reviewed and analyzed as a "baseline" case without additional physical disruptions factors that might influence system operations. Cases are analyzed based on usage of price responsive demand and DE resource activation, and potential load deficits. The severity of impact, meaning the magnitude, duration, and frequency of DE resource usage or loss of load, is informative to the properties of the DE resource needed to maintain system reliability. Aggregate energy balance patterns, peak hour patterns, and resource ramping requirements are all reviewed. Following the "baseline" cases, the physical disruption cases are analyzed using the same metrics to measure level of impact.

The model does not take into account other emergency actions such as voltage reduction, public appeals, or targeted load shedding, nor does it automatically consider that there may be other steps that could be taken to resolve any transient or minor potential outage (e.g., allowing assets to move to emergency operation ratings). In addition, the model does not take into account the probability that the combination of scenario definition and the physical disruptions identified in a particular case will come to fruition. The model output metrics quantify the potential reliability *consequences* of each case - that is, the magnitude and duration of potential LOLO (or for leading indicators) under the modeled combinations of system scenarios and physical disruptions, but it is not intended to replicate a probabilistic assessment of whether the conditions in question will or will not meet a standard such as loss of load no more frequent than once in ten years.[65] That type of assessment is not within the scope of this report.

The analysis of cases is summarized in Section V below, and Appendix B and Appendix C provide exhibits that show detailed diagnostic results across all combination cases run.

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[65] NYISO is obligated to plan for a system that has the "probability (or risk) of disconnecting any firm load due to resource deficiencies, on average, not more than once in ten years." New York State Reliability Council, "Reliability Rules and Compliance Manual," February 9, 2018, page. 13, available at http://www.nysrc.org/pdf/Reliability%20Rules%20Manuals/RRC%20Manual%20V42_Final.pdf.

V.Results and Observations

A. Overview

The purpose of this report is to evaluate whether and how a changing climate and policies to mitigate its effects may place additional stresses on reliable power system operations in New York State. These stresses may range from changes to load due to increasing average temperatures to more frequent and/or severe storms and other weather events. The Phase I climate study identified the impact of increasing temperature on load. This analysis carries that review one step further, and postulates how the changing climate depicted in the Phase I study may affect power system operations and reliability.

Our analysis is complicated by the fact that in response to the realities and risks of climate change, New York State is embarking, through the CLCPA, on an ambitious and challenging period of transition -- one that will require an unprecedented level and pace of change in energy supply and use to achieve steep reductions in GHG emissions across all sectors of the economy. The electricity sector is expected to play an outsized role in this transition - both to enable reductions in other sectors through electrification, and through a rapid decarbonization of the power infrastructure relied on to reliably meet electricity demand. As a result, the electric system of 2040, which is the required year for no GHG emissions from the electric sector, will look fundamentally different from the current system. That system will need to meet growing electricity demand without any of the fossil-fueled resources relied upon to maintain reliability today.

Thus the context for our analysis is both an altered climate, with new and different challenges to system operations, and a completely altered set of demand, generating, fuel and transmission resources to reliably meet the system demand 8,760 hours each year.

In this section we review the results of our modeling of potential climate disruption scenarios in the year 2040. We discuss the results of our model in the context of the transition to a decarbonized economy and power system that meets the requirements of the CLCPA.

B. Baseline Scenario Results

1. A Note About Starting Point Resource Sets

As noted earlier, before evaluating the climate disruption scenarios we must establish a system that; (1) has demand consistent with the Climate Change Phase I Study, (2) has a set of resources that comply with the requirements of the CLCPA, and (3) that meets electricity demand in every hour all year.

Constructing a set of “starting point” resources is highly uncertain at this point, for a variety of reasons:

- The New York power system is currently heavily dependent on natural gas fired generating units to provide energy, to be available during high load hours, to provide critical reserves on the system, and to be able to ramp up and downs on timescales of seconds, minutes, hours, and days to manage net load[66] variability. At least as currently configured and fueled, these resources cannot operate in 2040;

- Even retaining existing zero-carbon (nuclear, hydro) resources, there is an enormous amount of energy and capacity needed to meet projected demand in 2040;
- Currently-available and reasonably economic resources available to make up the zonal and system-wide energy deficits include solar and wind resources, yet their availability is uncertain and somewhat unpredictable. In fact, data reviewed for this report reveal that there would be long (multi-day) “lulls” in production from these resources. This means that almost no quantity of nameplate capacity from these resources is sufficient to meet demand in all hours of the year;
- Energy storage resources that are currently and expected to be available can fill part, but not all of the gap needed to maintain system reliability;
- There is a void that will need to be filled with technologies and/or fuels that - at the scales that would be required - will need to developed, proven, and economic; and
- There is no doubt a major amount of technological change that will happen over the next twenty years, rendering it very difficult to forecast a future resource set with reasonable confidence.

Thus constructing a “starting point” resource set on which to model system reliability in 2040 is highly subjective. There are innumerable potential combinations of generating resources (current and future), storage resources, transmission expansions, distributed resources, and demand management practices that could evolve to meet future demand. Therefore, we construct a starting point resource set with a few core principles in mind:

(1) The state of New York has embarked on an aggressive path to facilitate the rapid development and siting of zero-carbon renewable energy resources to ensure reasonable progress towards the ultimate CLCPA requirements. Based on this, we focus as a first step on constructing a resource set that relies on the build out of solar and wind resources in all zones.

(2) The potential for development of substantial renewable resources exists somewhat distant - upstate and offshore - from the downstate region where load is concentrated in the state. Thus, relying on renewable resources to facilitate the transition of energy supply and demand in New York will require substantial increases in inter-zonal transfer capability through the development and construction of new high-voltage transmission capacity.

(3) Based on current technologies and the Phase I study assumptions about the shape of electricity demand in 2040, there could be periods of time when all of the retained resources and renewable generating output are not sufficient on their own to meet demand. While we cannot know what or which technologies may emerge to fill any gaps, we do include the DE resource to identify the nature and magnitude of residual need.

One point is worth repeating - this is but one approach to constructing a starting point resource set. The GIT resource set - which we also evaluate in the model - may be viewed as an alternative approach to the CCP2 resource set. The GIT resource set does not have increases to the transmission system and therefore results in a smaller set of renewable generation which is located closer to the downstate load and also results in relying more on the DE resource. Thus while there are many other ways in which the grid will evolve in the coming decades, the two resource sets we evaluate in this study may be viewed to some extent as bookends on potential outcomes.

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[66] “Net load” is used to represent the varying second-by-second level of demand on the bulk power system, net of the impact of energy efficiency, demand response, and behind-the-meter generating resources (primarily solar photovoltaic).

Since the CCP2 resource set was designed to have sufficient capacity and transfer capability to meet peak demand in each case (reference and CLCPA), it is worth reviewing results of running the system for all hours in the modeling periods with this resource set in place. Primarily, this gives us a view into how much and how often the system requires the operation of the DE resource, but it also demonstrates quantitatively the challenges of reliable system operations with a system configured with existing zero-carbon resource and storage technologies.

While from an annual energy standpoint the DE resources provide only minor contributions, in both the summer and winter modeling periods, the DE resources are critical to maintaining system reliability during hours when the system is stressed, either from high loads, low renewable capacity factors, or both. This section will summarize the aggregate load/generation balance across the seasonal modeling periods, then discuss specific observations about DE resource generation in various cases.

2. Aggregate Load/Generation Balance

By construction, the total amount of baseload and renewable generation in each modeling period is sufficient to meet all load in that period if there were no deliverability or storage constraints. For example, in the CLCPA winter load scenario (as shown in Figure 30), in the peak load month, aggregate baseload and renewable generation is 28,493 GWh, more than the total load of 27,322 GWh. However, due to the existence of limits on inter-zonal transfer capability in certain hours (even with some expansion of the transmission system) and finite storage quantities, the realized resource mix used to meet load includes 12 percent DE resources and price responsive demand, meaning that renewables, either in terms of concurrent generation or stored energy), are not able to be used to provide 12 percent of load (see Figure 31).

Even assuming large increases in both transmission and storage capacity (as defined in Section II.D), sizable variance in renewable output and load means that there will not always be enough storage capacity to meet short-term load/generation deficits. For example, as seen in Figure 29, in the winter CLCPA Case, the wind capacity factor from hours 150-200 is 74.1 percent, which allows all storage units across the state to be charged to full capacity (138,840 MWh) by hour 173. During hours 174-200, an average of 18,121 MW per hour of excess renewable capacity is effectively curtailed due to lack of storage. This period is immediately followed by the hours of 200-288, where the wind capacity factor is 28.5 percent and load simultaneously increases. As a result, storage capability is completely used up by hour 226, and DE resource generation is needed to run. In other words, even though there is enough renewable generation to meet loads in winter, due to its intermittent nature, the energy is not always deliverable during the times and to the locations it is needed.

The CLCPA load scenario is winter-peaking, so the summer and shoulder modeling periods require less DE resource generation and PRD to fulfill demand. The summer modeling period has more than enough aggregate baseload and renewables generation of 27,760 GWh to meet load of 22,475 GWh (see Figure 32). Again, due to transmission and storage restrictions, the analysis finds that DE resource and PRD resources are needed to provide six percent of load (see Figure 33). The shoulder modeling period has even more surplus generation compared to load, with aggregate baseload and renewables generation of 35,688 GWh and load of only 12,496 GWh (see Figure 34). In this modeling period, no DE resource generation is needed at all to supply load (see Figure 35).

Figure 29: Battery and Pumped Storage Energy Level, CCP2-CLCPA Winter

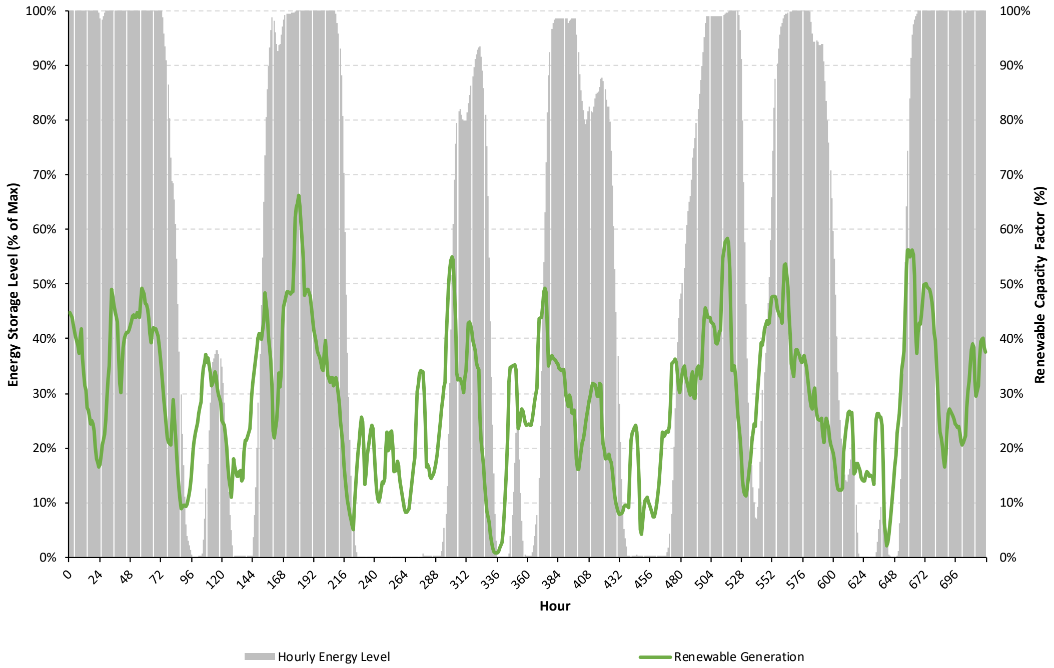
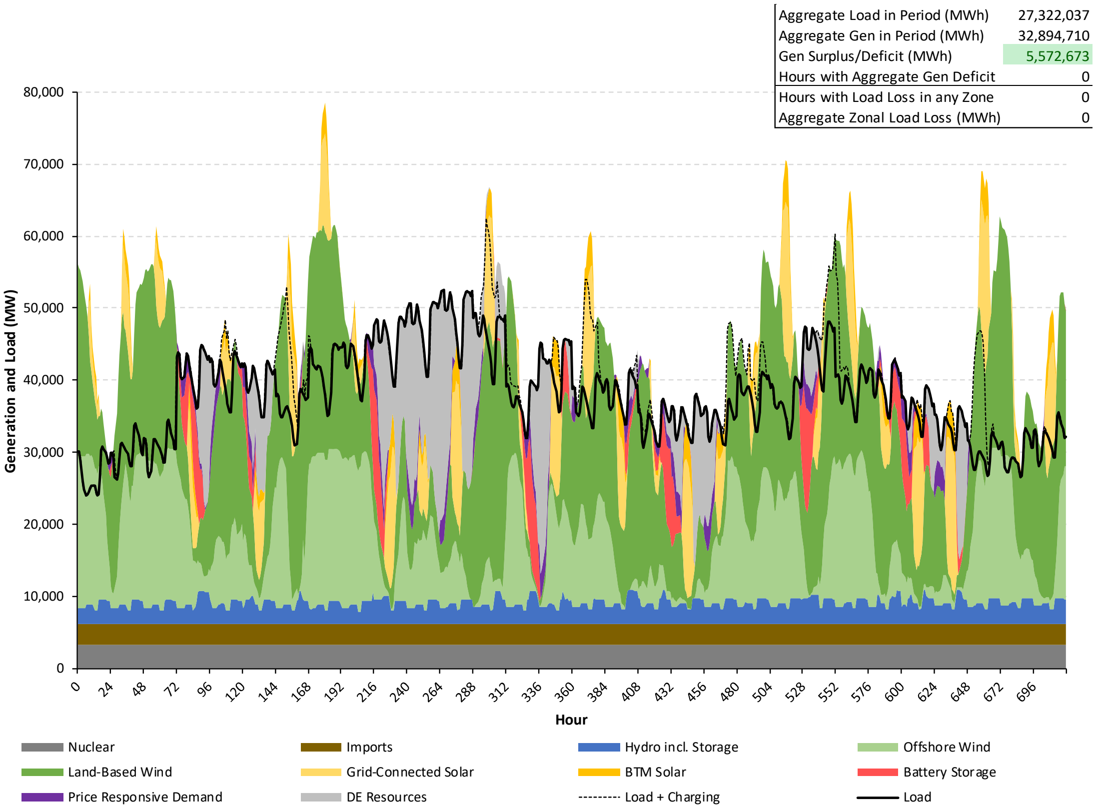
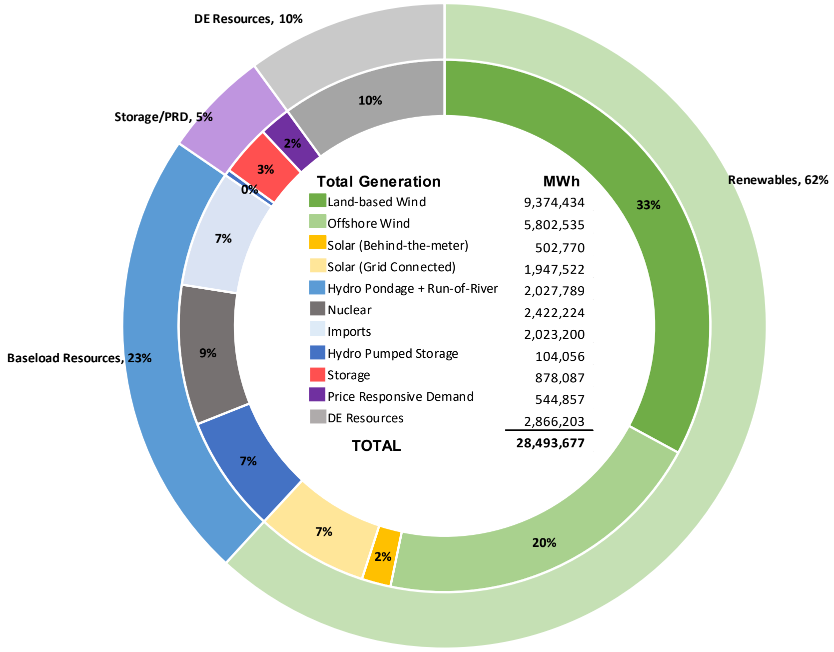


Figure 30: Hourly Load/Generation Balance, CCP2-CLCPA Winter



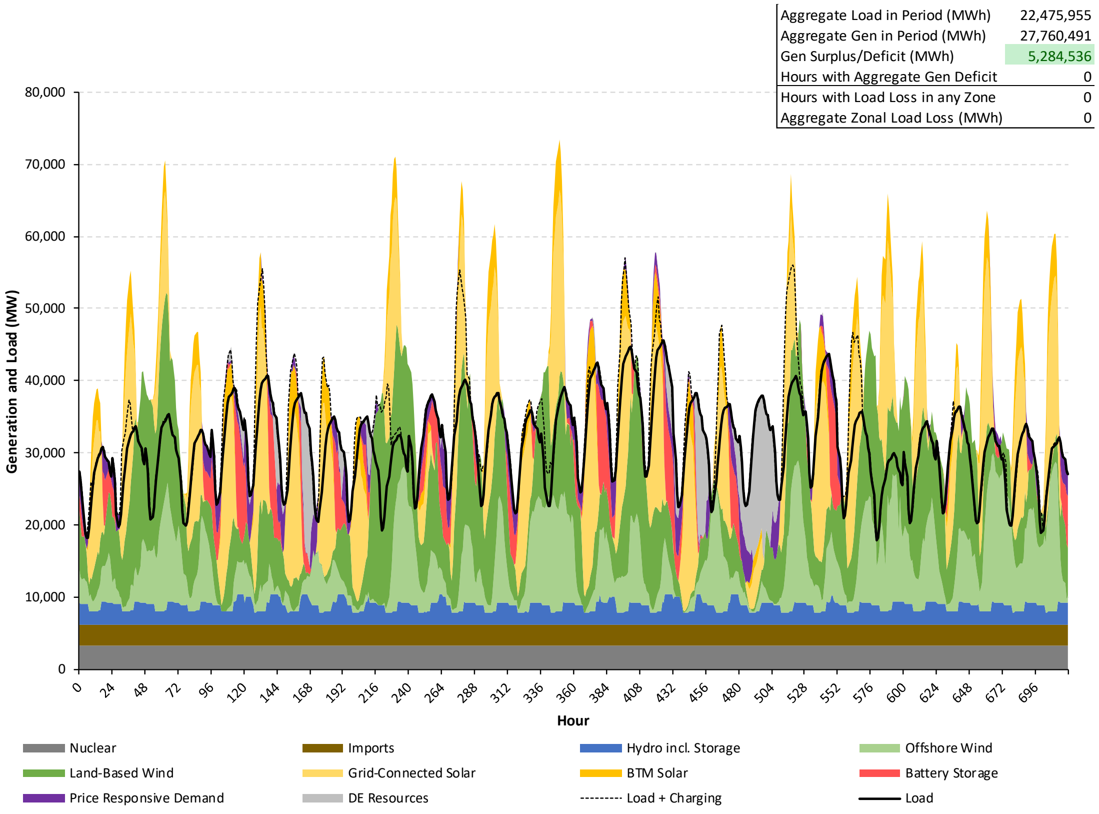
Aggregate Load in Period (MWh)	27,322,037
Aggregate Gen in Period (MWh)	32,894,710
Gen Surplus/Deficit (MWh)	5,572,673
Hours with Aggregate Gen Deficit	0
Hours with Load Loss in any Zone	0
Aggregate Zonal Load Loss (MWh)	0

Figure 31: Generation by Resource Type, CCP2-CLCPA Winter



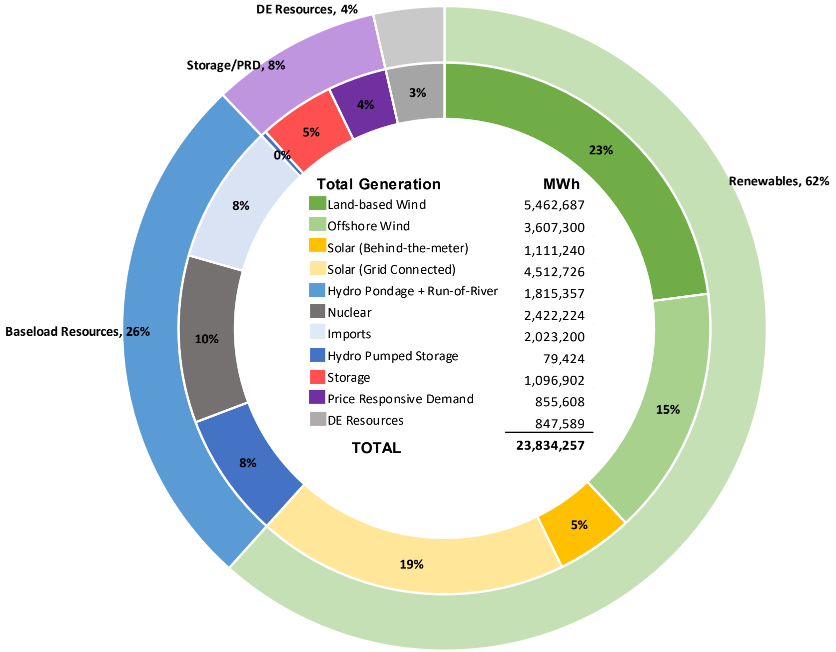
Total Generation	MWh
🟩 Land-based Wind	9,374,434
🟩 Offshore Wind	5,802,535
🟨 Solar (Behind-the-meter)	502,770
🟨 Solar (Grid Connected)	1,947,522
🟦 Hydro Pondage + Run-of-River	2,027,789
■ Nuclear	2,422,224
■ Imports	2,023,200
🟦 Hydro Pumped Storage	104,056
🟥 Storage	878,087
🟪 Price Responsive Demand	544,857
■ DE Resources	2,866,203
TOTAL	**28,493,677**

Figure 32: Hourly Load/Generation Balance, CCP2-CLCPA Summer



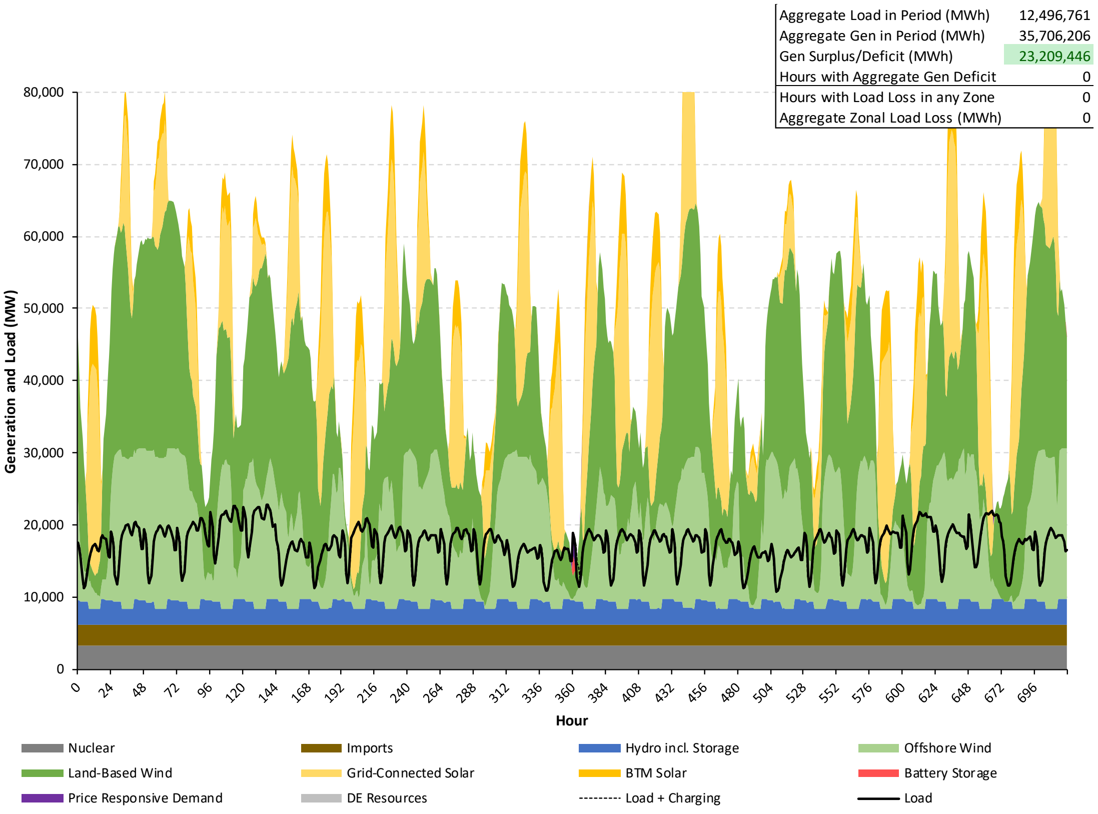
Aggregate Load in Period (MWh)	22,475,955
Aggregate Gen in Period (MWh)	27,760,491
Gen Surplus/Deficit (MWh)	5,284,536
Hours with Aggregate Gen Deficit	0
Hours with Load Loss in any Zone	0
Aggregate Zonal Load Loss (MWh)	0

Figure 33: Generation by Resource Type, CCP2-CLCPA Summer



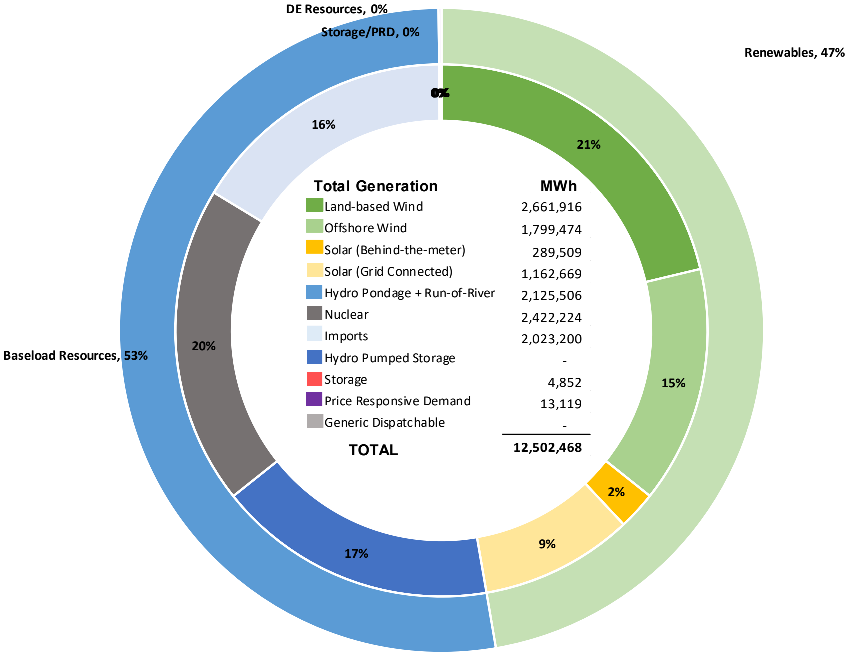
Total Generation	MWh
Land-based Wind	5,462,687
Offshore Wind	3,607,300
Solar (Behind-the-meter)	1,111,240
Solar (Grid Connected)	4,512,726
Hydro Pondage + Run-of-River	1,815,357
Nuclear	2,422,224
Imports	2,023,200
Hydro Pumped Storage	79,424
Storage	1,096,902
Price Responsive Demand	855,608
DE Resources	847,589
TOTAL	23,834,257

Figure 34: Hourly Load/Generation Balance, CCP2-CLCPA Shoulder



Aggregate Load in Period (MWh)	12,496,761
Aggregate Gen in Period (MWh)	35,706,206
Gen Surplus/Deficit (MWh)	23,209,446
Hours with Aggregate Gen Deficit	0
Hours with Load Loss in any Zone	0
Aggregate Zonal Load Loss (MWh)	0

Figure 35: Generation by Resource Type, CCP2-CLCPA Shoulder



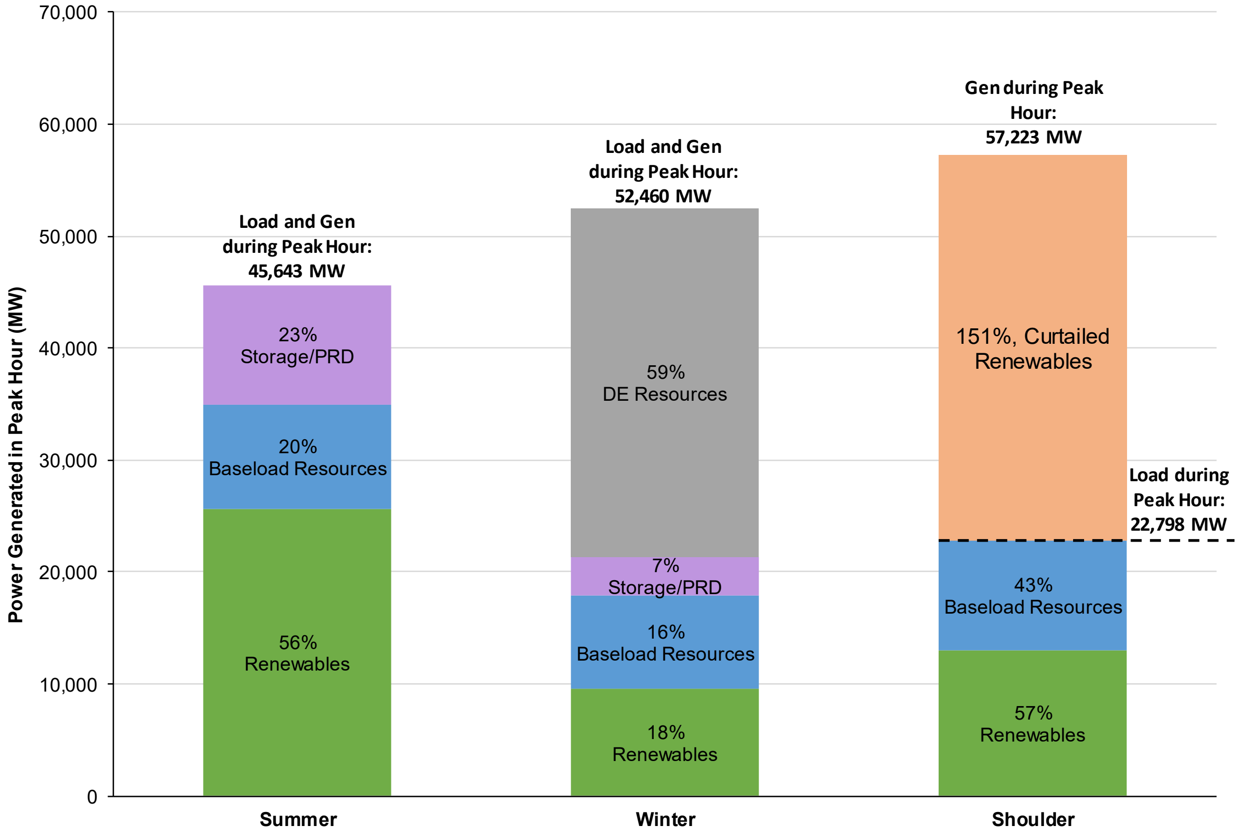
Total Generation	MWh
🟩 Land-based Wind	2,661,916
🟩 Offshore Wind	1,799,474
🟨 Solar (Behind-the-meter)	289,509
🟨 Solar (Grid Connected)	1,162,669
🟦 Hydro Pondage + Run-of-River	2,125,506
⬛ Nuclear	2,422,224
⬜ Imports	2,023,200
🟦 Hydro Pumped Storage	-
🟥 Storage	4,852
🟪 Price Responsive Demand	13,119
⬜ Generic Dispatchable	-
TOTAL	**12,502,468**

3. Peak Hour Patterns

DE resources have a particular role to play during the peak load hours of each modeling period. Figure 36 shows that during the peak hour in the winter CLCPA Case (Hour 2 of January 12, 2040), DE resources provide 59 percent of demand. It happens that in the winter peak hour, solar generators on aggregate have a 0 percent capacity factor, and wind generators have on aggregate a 17 percent capacity factor. As a result, DE resources provide the majority of energy on the peak winter hour.

By contrast, Figure 36 shows that during the peak load hour during the summer CLCPA Case (Hour 17 of July 18, 2040), the entirety of load is met by the ample amount of renewable resources, baseload resources, storage, and PRD, and no DE resource generation is required. In the summer peak hour, solar generators on aggregate have a 24.0 percent capacity factor, and wind generators have on aggregate a 24.2 percent capacity factor, enough to meet load needs. However, there are several hours in the summer that, due to reduced renewable output, that significant amounts of DE resources are required to serve load. Additionally, even though the results from this analysis did not show the need for DE resources during the shoulder season load levels, there is always the potential, given the nature of renewable resources, for the need for DE resources.

Figure 36: Resource Mix during Seasonal Peak Load Hours, CCP2-CLCPA Case



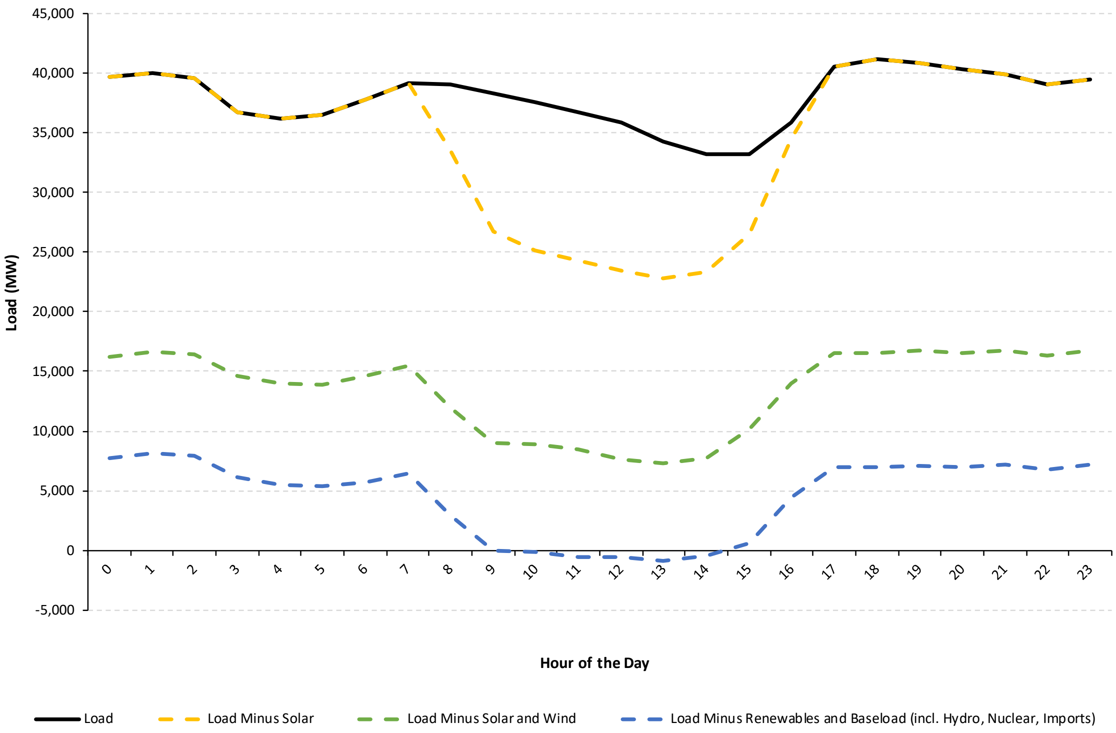
4. Ramping Patterns

Another important requirement for the DE resource is the ability to “ramp up” quickly, or increase generation over a short period of time during the course of an operating day. Due to the large reliance on renewable generation throughout each modeling period, there are certain hours and certain days in the modeling periods where a large quantity of DE resource output is needed to meet load needs.

Figure 37 shows the quantity of load that is needed to be met on average by hour for each day of the Winter CLCPA baseline case. The top black solid line shows average load over the course of the day. This load is met first by solar and wind resources, shown by the load reductions in the dashed yellow and green lines. The final average quantity to be met by storage, PRD, or DE resource generation is the quantity shown by the blue dashed line.

On average during the day, there is more generation than load, which means that storage capacity can be filled from generation and DE resources are not needed to operate. Even on days when there are short lulls in resource generation, if storage resources are filled to capacity in advance of the evening peak, storage output is sufficient to meet load needs without dispatch of DE resources.

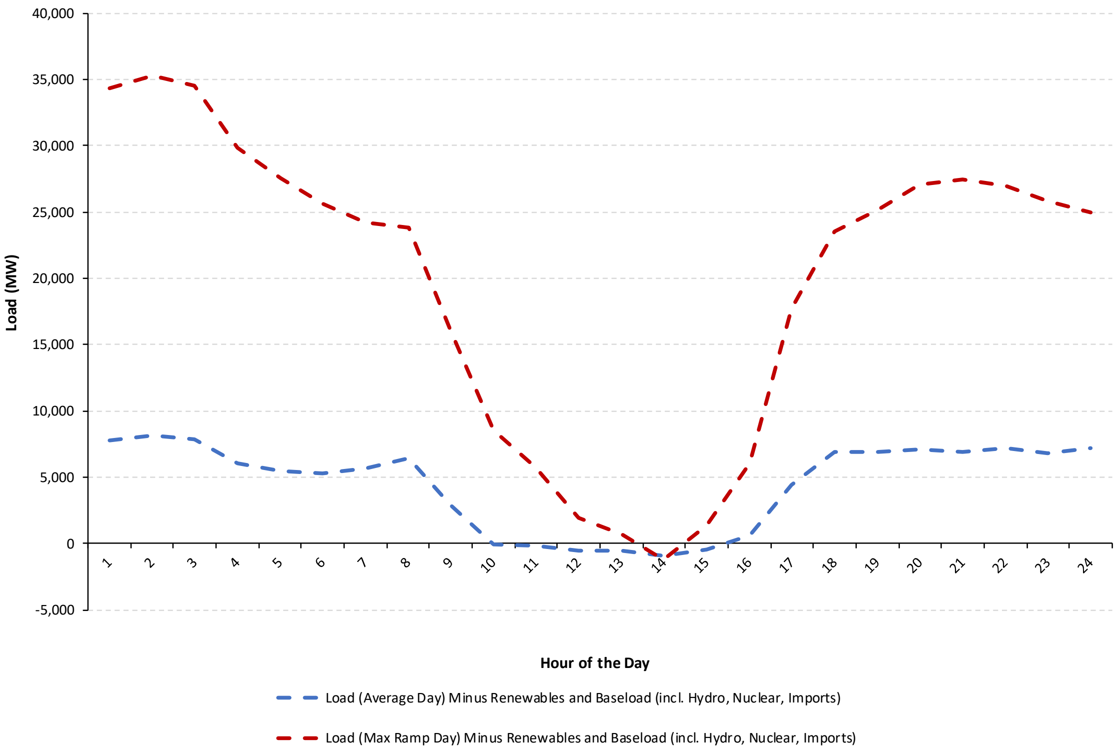
Figure 37: Average Load and Generation Requirements, CCP2-CLCPA Winter



Note:
[1] Renewable generation quantities offset from load do not include curtailed renewable generation.

However, there is also great variance between days within the modeling period. Based on model results, there also are short periods of less than 6 hours where output from the DE resource must be ramped from almost nothing to almost full capacity. Figure 38 shows an example of the single day in the CLCPA Winter baseline case where the most ramping capability is required. Between hours 14 and 20, DE resource output across the state must increase from 362 MW (or 1.1% of DE resource nameplate capacity) to 27,434 MW (or 85.4% of nameplate capacity). In the single hour between 15 and 16, DE resource output must increase 11,716 MW, which is the largest single-hour increase across the entire winter modeling period. Given the rapidity of decrease in solar generation when the sun sets, the DE resource must have fast ramping capability in order to meet requirements on days when other resources are not available to meet load.

Figure 38: Maximum Hourly Ramping Requirement, CCP2-CLCPA Winter



Note:

[1] Renewable generation quantities offset from load do not include curtailed renewable generation.

5. Aggregate Use of Dispatchable and Emissions-free Resources

Though DE resources provide an important function during peak hours, on average, they are rarely called upon to supply energy. As shown in Table 16, DE resource capacity factor is only 12.4 percent in winter, 3.7 percent in summer, and zero percent in the shoulder month for the CLCPA Case. In addition, as shown in Figure 39, the need for DE resources is most acute in a limited number of hours. In winter, when the system is most stressed, over 10,000 MW of DE resources are needed for 126 hours (or 17.5 percent of the 720 hour modeling period), but no DE resources are called upon for 465 hours (or 64.6 percent of modeled hours).

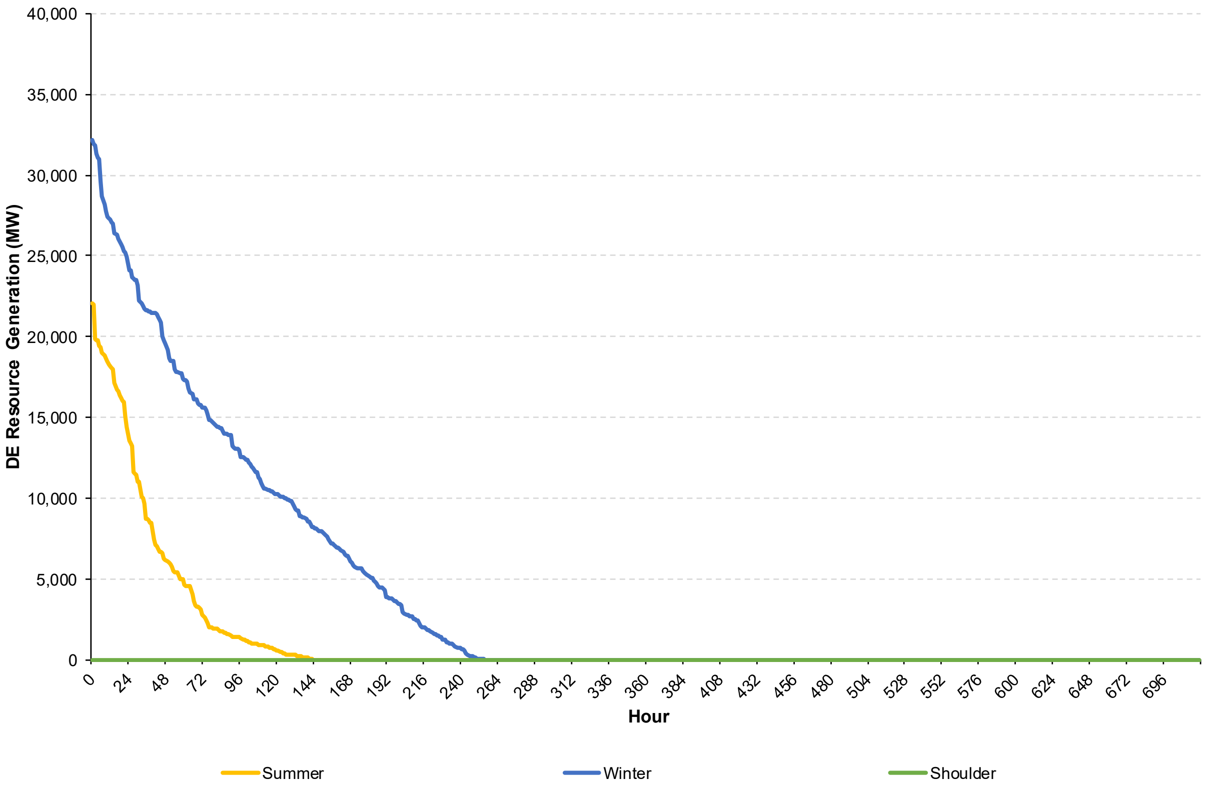
In this study, we provide results for two very different visions for the evolution of the power system - one that relies on renewables and transmission (the CCP2-CLCPA resource set), and one that places greater emphasis on the DE resource - that is, the potential emergence of a zero-carbon generation or fuel source (the GIT resource set). A key difference between them is that since the GIT resource sets do not include any transmission expansion, it results in a higher degree of reliance on the DE resource. This provides insight into the challenges New York State will face in guiding and managing what will likely be a rapid transition over the next two decades.

For example, if there is skepticism that an economic fuel or technology will emerge and be widely available, and that can deliver reliable capacity, energy, reserves, and flexible operating attributes with no emissions of GHGs, then the pathway may be more heavily tilted towards aggressive investment in and development of renewable and transmission infrastructure, such as in the CCP2 resource set. This approach would allow the system to operate with relatively low annual generation from the DE resource. Conversely, if such a fuel or technology were to emerge, be technologically and economically viable, and be widely available, then there is little need to invest the significant capital needed to build out renewable and transmission infrastructure to meet the CLCPA requirements. Thus, the degree of reliance on a DE resources under different scenarios and resource sets is evaluated in this report as an indication of the challenges New York will face to manage its energy systems transition in the coming decades.

Table 16: DE Resource Capacity Factor by Season

Season	Average Capacity Factor
Winter	12.39%
Summer	3.66%
Shoulder	0.00%

Figure 39**: Duration Curve of DE Resource Generation by Modeling Period**



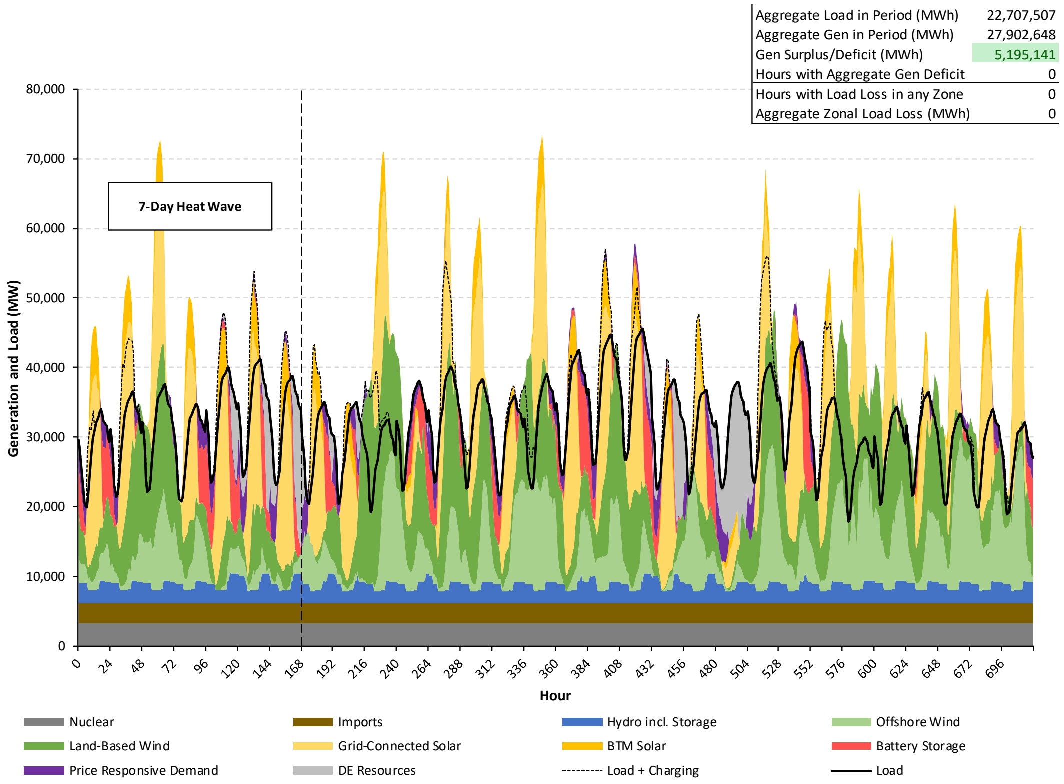
C. Key Observations by Physical Disruption

1. Temperature Waves

For both the summer heat wave and winter cold wave scenarios, model results show no losses of load based on increased reliance on DE resources, as discussed below. The combination of transmission, PRD, and DE resource generation is sufficient to meet load in all hours. In the summer modeling period in particular, increases in solar output partially offset declines in wind production.

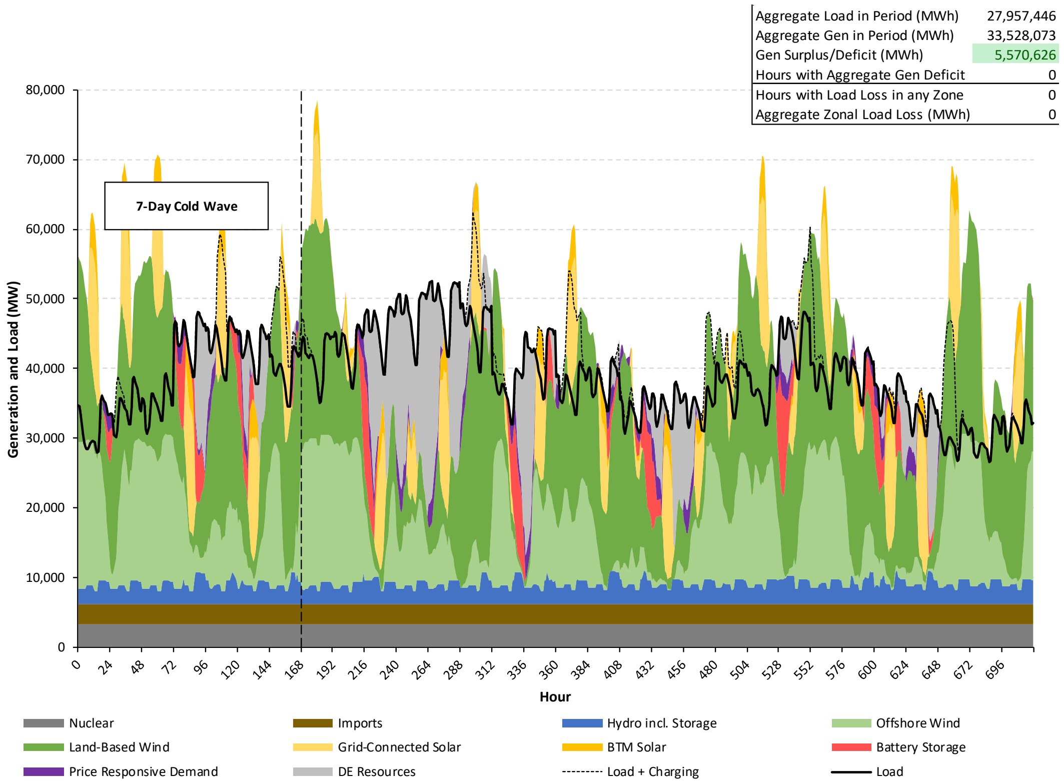
In both cases, there is an increase of the use of DE resources over the baseline case. This increase is more pronounced in the summer modeling period as compared to the winter. Based on the Phase I study temperature-load modeling, across all zones, higher temperatures during heat waves lead to steeper increases in load compared to lower temperatures during cold waves. That is, a one degree increase in temperature during a summer heat wave will lead to more *additional* MWs of load during the daily peak than a one degree decrease in temperature during a winter cold wave. As a result, the summer heat wave scenario requires more DE resource generation over the baseline scenario as compared to the winter cold wave.

Figure 40: Hourly Load/Generation Balance, CCP2-CLCPA Summer Heat Wave Case



Aggregate Load in Period (MWh)	22,707,507
Aggregate Gen in Period (MWh)	27,902,648
Gen Surplus/Deficit (MWh)	5,195,141
Hours with Aggregate Gen Deficit	0
Hours with Load Loss in any Zone	0
Aggregate Zonal Load Loss (MWh)	0

Figure 41: Hourly Load/Generation Balance, CCP2-CLCPA Winter Cold Wave Case



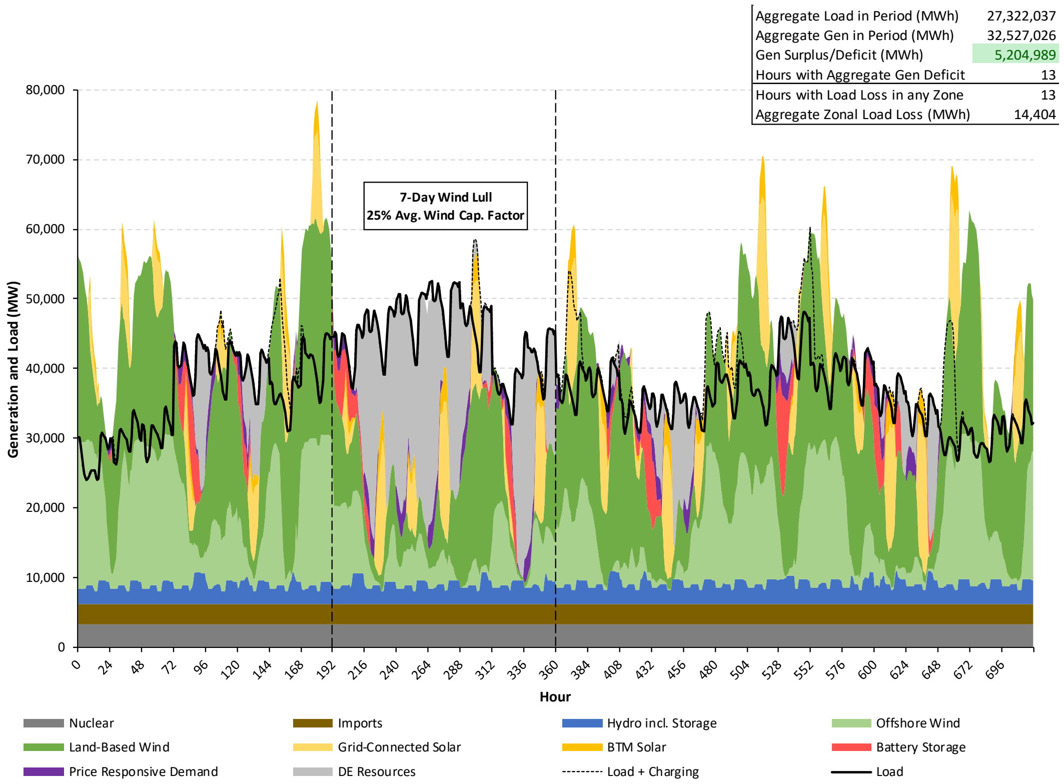
The heat and cold waves modeled in this study are meant to represent temperature waves that are consistent with historical record in terms of severity and duration. More severe modeled temperature waves, as may occur more frequently in a future with climate change, could result in increased stresses on the power system and/or greater reliance on the DE resource.

2. Wind Lulls

According to model results, multi-day wind lulls coincident with peak load hours can lead to significant increased use of DE generation and loss of load. This is particularly pronounced in the most stressed month for each load scenario, winter for the CLCPA Case, summer for the CCP2 Reference Case.

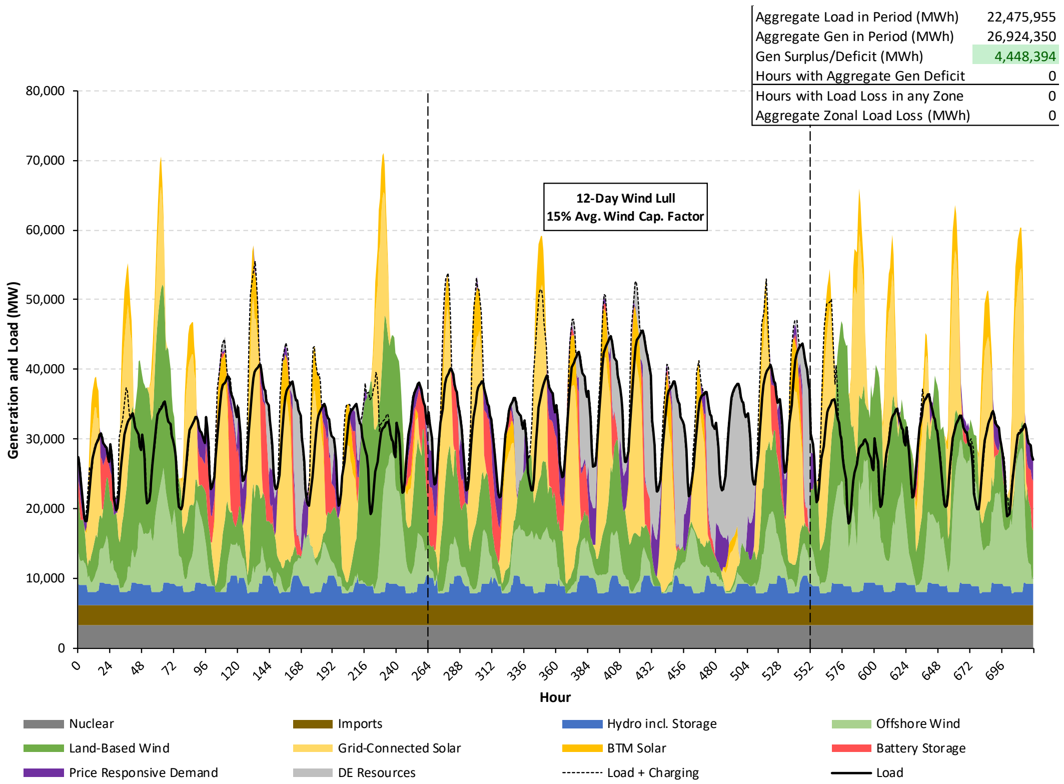
As shown in Figure 42, a winter wind lull that overlaps with the peak load period in the CLCPA load scenario would lead to a reliance on DE generation in order to meet demand, and 13 hours with some loss of load across all Zones. In Figure 43, solar generation during the 12-day summer wind lull offsets a significant portion of generation losses from wind, with the remaining demand met by price responsive demand and an increased amount of DE resource generation. Ultimately, there is no load loss in the summer load scenario even with the more severe wind lull than in winter.

Figure 42: Hourly Load/Generation Balance, CCP2-CLCPA Winter Wind Lull Case



Aggregate Load in Period (MWh)	27,322,037
Aggregate Gen in Period (MWh)	32,527,026
Gen Surplus/Deficit (MWh)	5,204,989
Hours with Aggregate Gen Deficit	13
Hours with Load Loss in any Zone	13
Aggregate Zonal Load Loss (MWh)	14,404

Figure 43: Hourly Load/Generation Balance, CCP2-CLCPA Summer Wind Lull Case



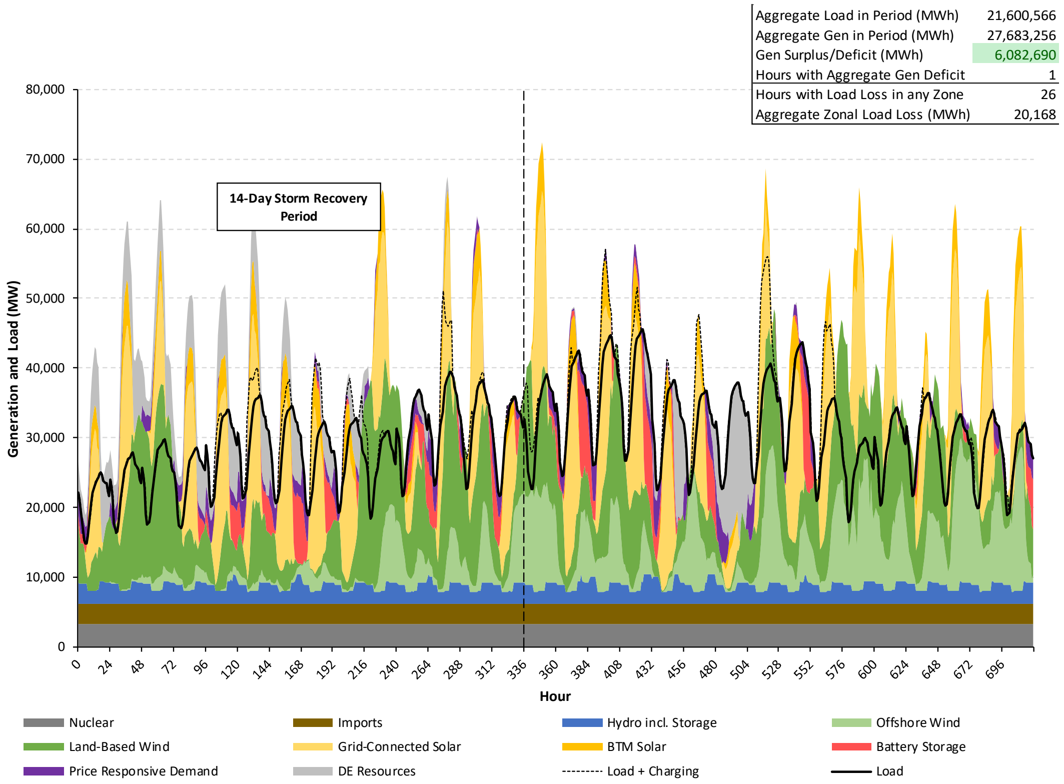
Aggregate Load in Period (MWh)	22,475,955
Aggregate Gen in Period (MWh)	26,924,350
Gen Surplus/Deficit (MWh)	4,448,394
Hours with Aggregate Gen Deficit	0
Hours with Load Loss in any Zone	0
Aggregate Zonal Load Loss (MWh)	0

3. Storm Scenarios

The storm disruptions caused the most severe impacts to system reliability of all the cases run in the model. Based on model results, hurricane/major wind storms can cause loss of load at the transmission system level during the storm itself and the 14-day recovery period, but losses ease significantly once transmission is partially restored. Based on historical experience in Hurricane Sandy, generation, transmission, and load recover at similar paces, which means that generators would be back online to meet increased demand when storm damage is repaired and power is restored to end users. Quick recovery of transmission assets is vital to limiting load losses. Any loss of transmission in downstate zones prevents batteries, renewable resources, and DE resource generation in upstate Zones from relieving loss of load downstate.

The storm cases cause the greatest system disruption in seasons when load is highest; the winter upstate storm case under the CLCPA load scenario shows more losses of load than the summer hurricane case. In both seasons, the storm scenario affecting offshore wind availability shows only modest system impact - there are a handful of hours with potential for loss of load in winter and none in summer.

Figure 44: Hourly Load/Generation Balance, CCP2-CLCPA Summer Hurricane Case



Aggregate Load in Period (MWh)	21,600,566
Aggregate Gen in Period (MWh)	27,683,256
Gen Surplus/Deficit (MWh)	6,082,690
Hours with Aggregate Gen Deficit	1
Hours with Load Loss in any Zone	26
Aggregate Zonal Load Loss (MWh)	20,168

The storm scenarios were all based on historical experience with Hurricane Sandy. While the impact of that storm was significant, the results here may understate system reliability challenges to the extent that climate change leads to more severe or more frequent storms, especially if multiple storms occur in rapid succession.

4. Other Climate Impacts

The drought event has a limited impact on DE resource generation usage during the CLCPA Case and no loss of load. The lower summer loads as compared to winter means that there is enough renewable and DE resource generation to compensate for the loss of hydroelectric capacity. The icing event leads to two hours with very small loss of load occurrences in the CLCPA winter load scenario. For the most part, other resources are able to compensate for losses of transmission and generation during the event.

5. Case Result Summaries:

	Loss of Load		DE Resource Generation				
	Total Hours with LOLO in at least one Load Zone	**Aggregate LOLO (MWh)**	**Max Consecutive Hours with DE Resource Gen.**	**Total Hours with DE Resource Gen.**	**Aggregate DE Resource Gen. (MWh)**	**Max DE Resource Gen. (MW)**	**Max 1-hr. DE Resource Gen. Ramp (MW)**
CLCPA Summer Scenario - Climate Impact Phase II Resource Set							
Baseline Summer	0	0	36	145	847,589	22,081	9,170
Heat Wave	0	0	36	147	964,668	22,081	8,642
Wind Lull - Upstate	0	0	37	179	1,171,656	23,361	9,447
Wind Lull - Off-Shore	0	0	40	196	1,116,165	23,170	9,170
Wind Lull - State-Wide	0	0	40	235	1,697,161	24,440	11,605
Hurricane/Coastal Wind Storm	26	20,168	171	322	1,892,046	22,081	8,642
Severe Wind Storm – Upstate	8	1,620	87	283	2,002,682	22,081	8,642
Severe Wind Storm – Offshore	0	0	36	167	1,079,462	22,163	10,015
Drought	0	0	36	166	1,148,649	23,595	10,610

	Loss of Load		DE Resource Generation				
	Total Hours with LOLO in at least one Load Zone	**Aggregate LOLO (MWh)**	**Max Consecutive Hours with DE Resource Gen.**	**Total Hours with DE Resource Gen.**	**Aggregate DE Resource Gen. (MWh)**	**Max DE Resource Gen. (MW)**	**Max 1-hr. DE Resource Gen. Ramp (MW)**
CLCPA Winter Scenario - Climate Impact Phase II Resource Set							
Baseline Winter	0	0	62	255	2,866,203	32,135	11,716
Cold Wave	0	0	62	259	2,879,947	32,135	11,716
Wind Lull - Upstate	5	2,373	62	259	3,076,530	32,135	12,707
Wind Lull - Off-Shore	10	7,184	104	274	3,350,666	32,135	11,715
Wind Lull - State-Wide	13	14,404	105	278	3,653,404	32,135	12,403
Severe Wind Storm – Upstate	45	22,146	81	369	3,822,059	31,419	12,850
Severe Wind Storm – Offshore	9	4,203	103	304	3,609,785	32,135	11,715
Icing Event	2	88	62	273	2,909,437	32,135	11,716

	Loss of Load		DE Resource Generation				
	Total Hours with LOLO in at least one Load Zone	**Aggregate LOLO (MWh)**	**Max Consecutive Hours with DE Resource Gen.**	**Total Hours with DE Resource Gen.**	**Aggregate DE Resource Gen. (MWh)**	**Max DE Resource Gen. (MW)**	**Max 1-hr. DE Resource Gen. Ramp (MW)**
Reference Summer Scenario - Climate Impact Phase II Resource Set							
Baseline Summer	0	0	36	183	972,444	17,059	6,520
Heat Wave	0	0	36	199	1,067,892	17,059	6,520
Wind Lull - Upstate	2	729	38	209	1,175,961	17,059	5,655
Wind Lull - Off-Shore	2	1,797	41	243	1,307,211	17,059	6,380
Wind Lull - State-Wide	4	3,149	42	283	1,697,728	17,059	10,929
Hurricane/Coastal Wind Storm	76	96,295	173	349	1,637,221	17,059	6,520
Severe Wind Storm – Upstate	18	4,470	106	330	1,975,003	17,059	6,520
Severe Wind Storm – Offshore	0	0	36	241	1,249,958	17,059	7,489
Drought	11	6,383	38	209	1,305,698	17,059	5,755

	Loss of Load		DE Resource Generation				
	Total Hours with LOLO in at least one Load Zone	**Aggregate LOLO (MWh)**	**Max Consecutive Hours with DE Resource Gen.**	**Total Hours with DE Resource Gen.**	**Aggregate DE Resource Gen. (MWh)**	**Max DE Resource Gen. (MW)**	**Max 1-hr. DE Resource Gen. Ramp (MW)**
Reference Winter Scenario - Climate Impact Phase II Resource Set							
Baseline Winter	0	0	4	6	9,316	3,762	2,479
Cold Wave	0	0	4	6	9,316	3,762	2,479
Wind Lull - Upstate	0	0	4	6	10,646	4,213	2,400
Wind Lull - Off-Shore	0	0	9	15	48,055	6,386	3,819
Wind Lull - State-Wide	0	0	13	32	90,238	8,219	4,127
Severe Wind Storm – Upstate	10	1,146	14	56	119,192	5,809	2,283
Severe Wind Storm – Offshore	0	0	8	20	31,311	4,677	3,809
Icing Event	3	157	6	14	9,886	3,762	2,479

D. Cross-Seasonal Effects

The resource sets evaluated in this study are designed to maintain sufficient resource availability to meet peak seasonal demand for electricity. Thus, due to the large differences in load and renewable generation across seasons, the modeled results show large surpluses of renewable generation during the shoulder seasons of spring and fall. As discussed in Section II.C.2 and Table 6 earlier, wind capacity factors are highest during the shoulder season modeling, with over 50 percent capacity factor for both land-based and offshore wind generation. At the same time, aggregate load is lowest in the shoulder month, with total energy demanded over the 30-day modeling period 54.3 percent lower than demand during the winter modeling period and 44.4 percent lower than demand during the summer modeling period for the CLCPA load scenario (see Table 5). As a result, during the shoulder month, there is on average 32,227 MW of "excess" potential renewable generation that is curtailed - or "spilled" - due to a lack of load or short-term storage capacity (see Table 17). In fact, for each of the resource sets and load scenarios developed for this study,[67] the majority of renewable generation during the shoulder month is excess, and is not needed to meet load or fill storage (see Table 18). The quantity of excess renewables is particularly pronounced when looking at peak load hours. For the hour with the highest load in the shoulder season modeling period, there is enough renewable generation to meet 208 percent of demand (see Figure 45).

Table 17: Curtailed "Excess" Renewable Generation by Seasonal Modeling Period, CLCPA Load Scenario, CCP2-CLCPA Resource Set

Season	Aggregate Excess Renewable Generation (GWh)	Average Hourly Excess Renewable Generation (MW)	Average Hourly Percentage of Excess Renewable Generation (%)
Winter	4,401	6,112	13.66%
Summer	3,926	5,453	13.95%
Shoulder	23,204	32,227	75.80%

Table 18: Curtailed "Excess" Shoulder Month Renewable Generation by Load Scenario and Resource Set

Resource Set - Load Case	Aggregate Excess Renewable Generation (GWh)	Average Hourly Excess Renewable Generation (MW)	Average Percentage of Hourly Excess of Total Renewable Generation (%)
Climate Impact Phase II			
CLCPA	23,204	32,227	75.80%
Reference	16,900	23,472	73.40%
Grid In Transition			
CLCPA	17,153	23,823	64.51%
Reference	8,162	11,336	47.30%

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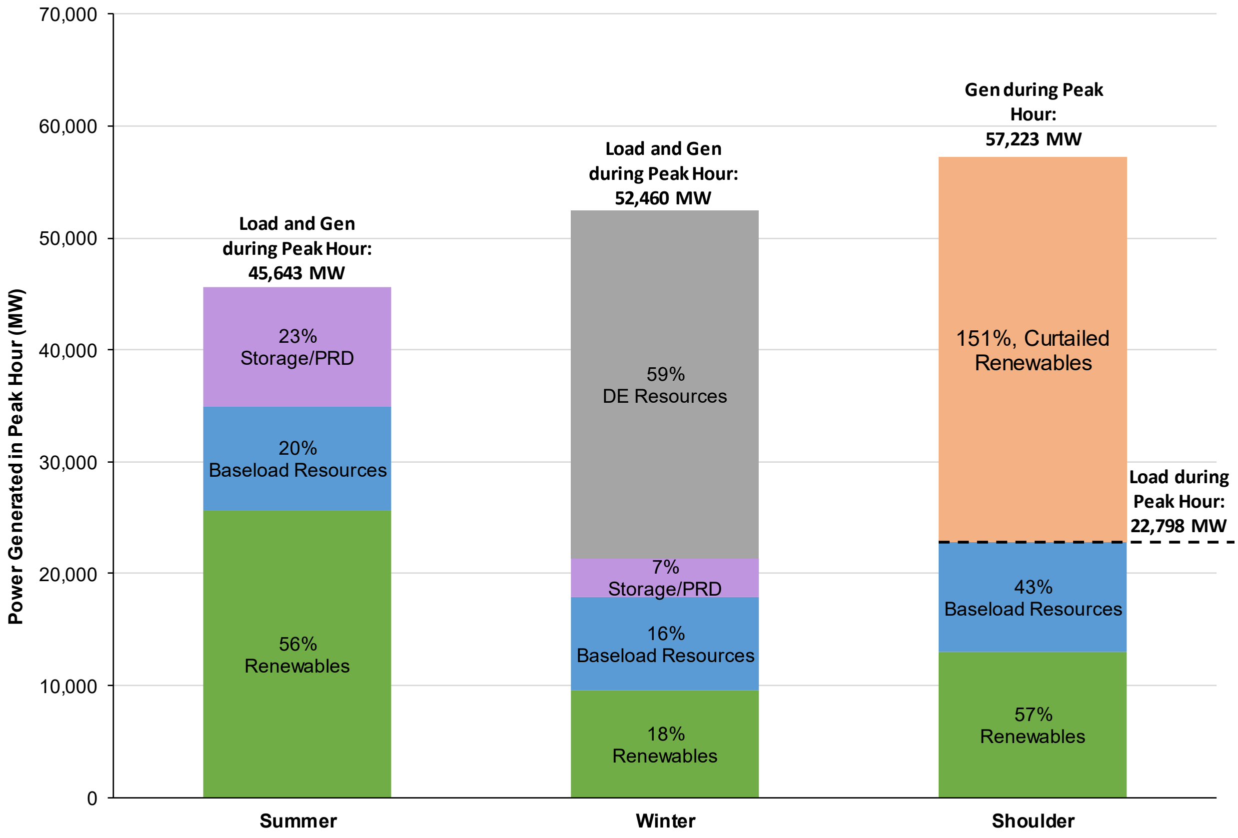
[67] As noted, this is a key difference between the renewables/transmission-focused resource set, and the GIT resource set. Since the GIT resource set relies far less on renewables to meet seasonal peak loads, there is less renewable generation spilled in shoulder season months (and across the year).

Figure 45: Resource Mix during Seasonal Peak Load Hours, CCP2-CLCPA



Given the large quantity of excess generation during the shoulder month, there is a potential for a seasonal storage technology to meet the energy needs of DE resource generation during the summer and winter. For example, as seen in Table 19, the excess renewable generation in the shoulder season modeling period under the CLCPA load scenario totaled to 23,204 GWh, and the DE resource use in the winter modeling period was just 4,401 MWh. Therefore, if a technology existed that allowed 12.4 percent of the excess renewable generation in the shoulder month to be stored until winter - e.g., through the production, processing and/or storing of renewable natural gas or hydrogen fuel for use in generation technology - then all of the winter DE resource fuel need could be met by excess renewable energy from the shoulder season.

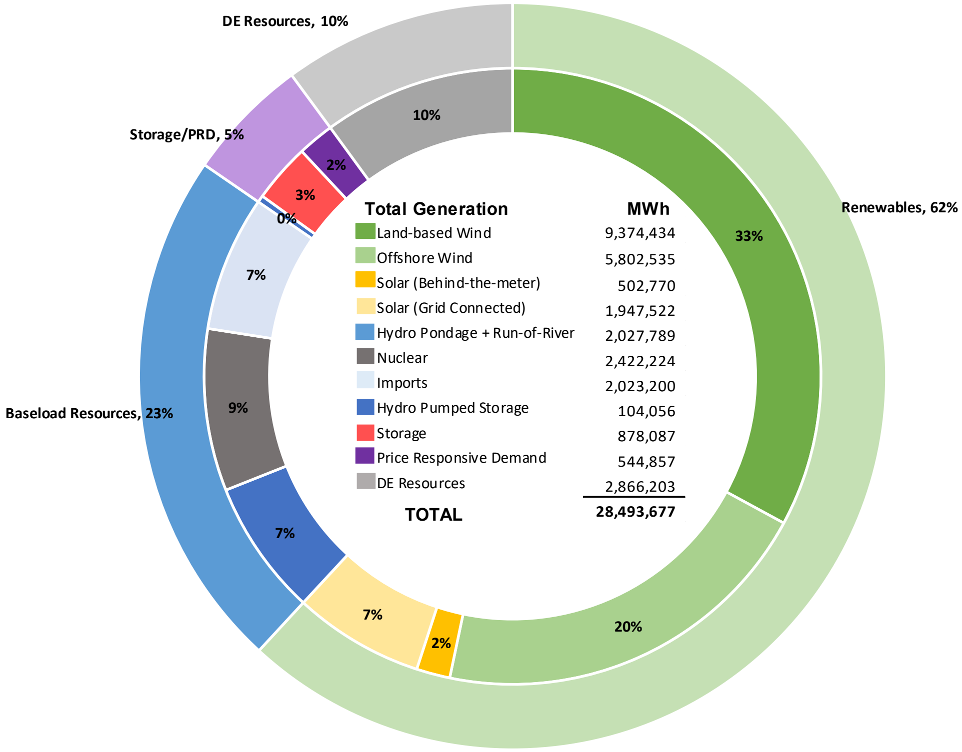
Table 19: Shoulder Month Energy Potential as Compared to DE Resource Use, CCP2 Resource Set

		Shoulder	Summer	Winter
	Dates	4/1/2040 -4/30/2040	7/1/2040 -7/30/2040	1/1/2040 -1/30/2040
CLCPA Case	Total DE Resource Energy Used (GWh)	0 GWh	848 GWh	2,866 GWh
	Total Intermittent Renewable Energy Curtailed (GWh)	23,204 GWh	3,926 GWh	4,401 GWh
	Seasonal Storage Efficiency Needed to Meet DE Resource Energy Need with Shoulder Season Curtailed Energy	-	3.65%	12.35%
Reference Case	Total DE Resource Energy Used (GWh)	0 GWh	972 GWh	9 GWh
	Total Intermittent Renewable Energy Curtailed (GWh)	16,900 GWh	2,660 GWh	8,467 GWh
	Seasonal Storage Efficiency Needed to Meet DE Resource Energy Need with Shoulder Season Curtailed Energy	-	5.75%	0.06%

E. Comparisons of Results with Grid in Transition Resource Set

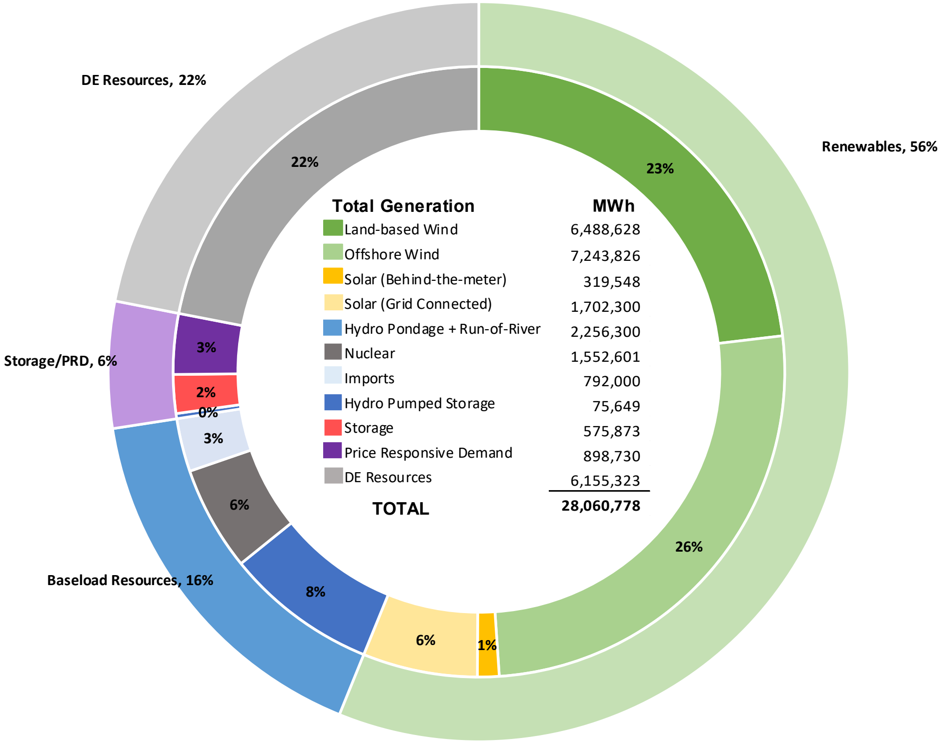
As described in Section II.F, the Grid in Transition study resource set includes considerably more DE resource capacity than in the resource sets developed for this study, which include more renewables and transmission. The differences in resource mix also lead to considerable differences in results. As seen in Figure 46 and Figure 47, in the baseline cases, the proportion of load met by DE resources in the CLCPA winter load scenario is roughly nine percent for the AG resource set but about 20 percent for the Grid in Transition resource set. One of the main difference between the two resource sets is the level of available transmission capacity, especially on the Total East and Total South interfaces constraints. As shown on Table 20, those constraints are binding in a larger percentage of hours under the Grid in Transition resource set, which means that DE resources downstate are dispatched to produce electricity in more hours.

Figure 46: Winter Generation by Resource Type – CCP2-CLCPA



Total Generation	MWh
Land-based Wind	9,374,434
Offshore Wind	5,802,535
Solar (Behind-the-meter)	502,770
Solar (Grid Connected)	1,947,522
Hydro Pondage + Run-of-River	2,027,789
Nuclear	2,422,224
Imports	2,023,200
Hydro Pumped Storage	104,056
Storage	878,087
Price Responsive Demand	544,857
DE Resources	2,866,203
TOTAL	28,493,677

Figure 47: Winter Generation by Resource Type – GIT-CLCPA



Total Generation	MWh
Land-based Wind	6,488,628
Offshore Wind	7,243,826
Solar (Behind-the-meter)	319,548
Solar (Grid Connected)	1,702,300
Hydro Pondage + Run-of-River	2,256,300
Nuclear	1,552,601
Imports	792,000
Hydro Pumped Storage	75,649
Storage	575,873
Price Responsive Demand	898,730
DE Resources	6,155,323
TOTAL	28,060,778

Table 20: Transmission Constrained Hours, CCP2-CLCPA Winter Baseline Case

	Total East		Total South	
Resource Set	**N**	**%**	**N**	**%**
Climate Impact Phase II	81	11%	1	0%
Grid In Transition	310	43%	82	11%

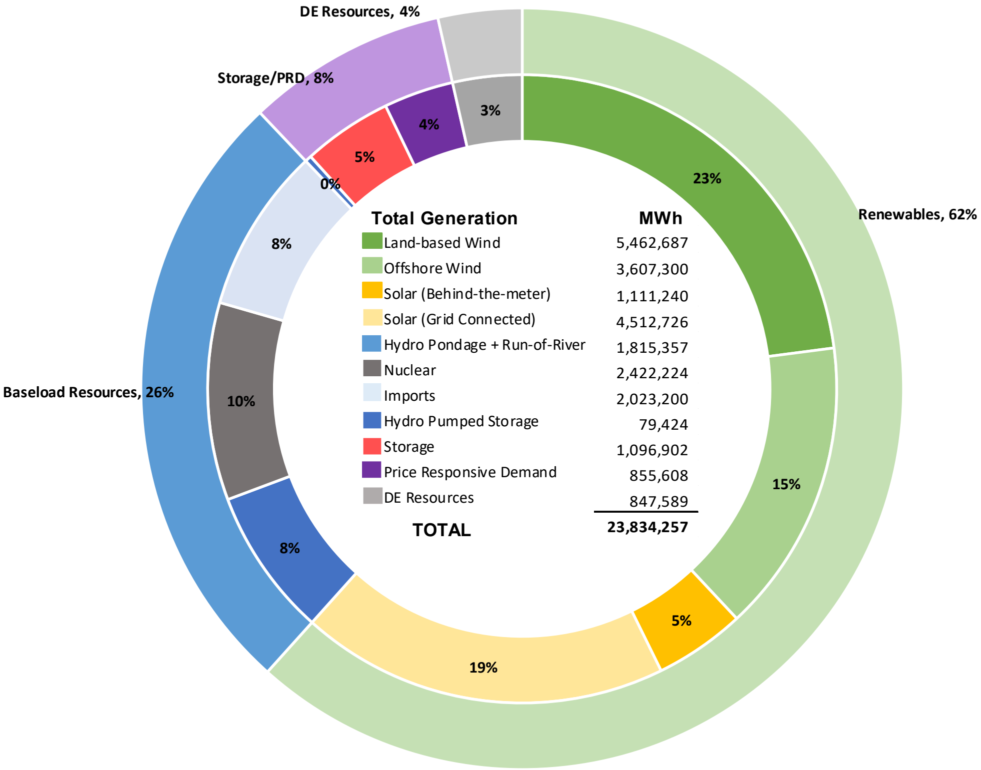
The differences in the baseline cases also produce changes in the physical disruption cases. As seen in Table 21, there are more hours with loss of load occurrences in the state-wide and offshore wind lull cases under the Climate Change Phase II resource set, given the smaller overall quantity of DE resources, and the far greater reliance on wind resources. On the other hand, reduced transmission under Grid in Transition resource set leads to more severe load losses during scenarios that affect upstate resources (Severe Wind Storm – Upstate and Icing Event).

Table 21: Comparison of Case Results by Resource Set, Winter CLCPA

	Climate Impact Phase II Resource Set					Grid in Transition Resource Set				
	Total Hours with LOLO in at least one Load Zone	Aggregate LOLO (MWh)	Total Hours with DE Resource Gen.	Aggregate DE Resource Gen. (MWh)	Diff. in DE Resource Gen. from Baseline (MWh)	Total Hours with LOLO in at least one Load Zone	Aggregate LOLO (MWh)	Total Hours with DE Resource Gen.	Aggregate DE Resource Gen. (MWh)	Diff. in DE Resource Gen. from Baseline (MWh)
CLCPA Winter Scenario										
Baseline Winter	0	0	255	2,866,203	+0	0	0	460	6,155,321	+0
Cold Wave	0	0	259	2,879,947	+13,744	0	0	466	6,272,961	+117,640
Wind Lull - Upstate	5	2,373	259	3,076,530	+210,327	8	7,090	469	6,309,711	+154,390
Wind Lull - Off-Shore	10	7,184	274	3,350,666	+484,463	6	1,378	487	6,836,558	+681,237
Wind Lull - State-Wide	13	14,404	278	3,653,404	+787,201	9	10,757	486	6,988,838	+833,517
Severe Wind Storm – Upstate	45	22,146	369	3,822,059	+955,856	51	57,457	551	6,707,765	+552,444
Severe Wind Storm – Offshore	9	4,203	304	3,609,785	+743,582	2	327	561	7,916,575	+1,761,254
Icing Event	2	88	273	2,909,437	+43,234	24	11,242	480	6,145,568	-9,753

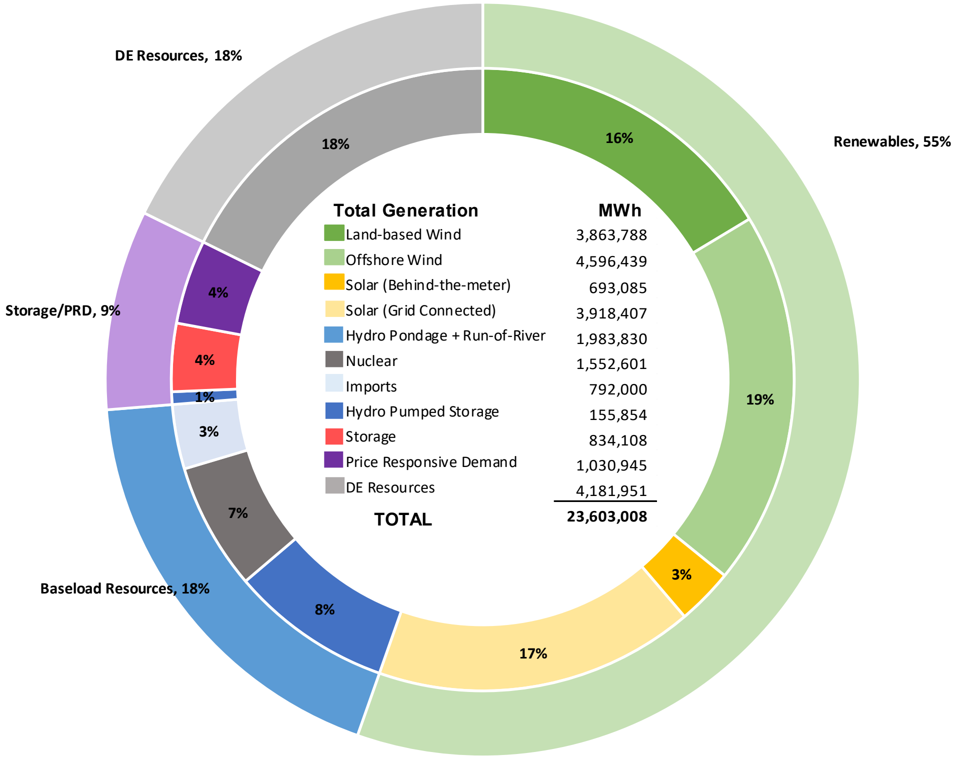
The patterns of differences in DE resource generation between resources are repeated in the summer modeling period. As seen in Figure 48 and Figure 49, in the baseline cases, the proportion of load met by DE resource generation in the CLCPA winter load scenario is approximately three percent for the CCP2 resource set but about 16 percent for the Grid in Transition resource set. Again, the differences in transmission is one of the main contributing factors to differences in generation outcomes; Table 22 shows that the number of hours with constrained transmission under the Grid in Transition resource set is greater than that under the AG resource set.

Figure 48: Summer Generation by Resource Type – CCP2-CLCPA



Total Generation	MWh
Land-based Wind	5,462,687
Offshore Wind	3,607,300
Solar (Behind-the-meter)	1,111,240
Solar (Grid Connected)	4,512,726
Hydro Pondage + Run-of-River	1,815,357
Nuclear	2,422,224
Imports	2,023,200
Hydro Pumped Storage	79,424
Storage	1,096,902
Price Responsive Demand	855,608
DE Resources	847,589
TOTAL	**23,834,257**

Figure 49: Summer Generation by Resource Type – GIT-CLCPA



Total Generation	MWh
Land-based Wind	3,863,788
Offshore Wind	4,596,439
Solar (Behind-the-meter)	693,085
Solar (Grid Connected)	3,918,407
Hydro Pondage + Run-of-River	1,983,830
Nuclear	1,552,601
Imports	792,000
Hydro Pumped Storage	155,854
Storage	834,108
Price Responsive Demand	1,030,945
DE Resources	4,181,951
TOTAL	**23,603,008**

Table 22: Transmission Constrained Hours - Summer CLCPA Baseline Case

	Total East		Total South	
Resource Set	**N**	**%**	**N**	**%**
Climate Impact Phase II	12	2%	0	0%
Grid In Transition	229	32%	179	25%

The Severe Wind Storm - Upstate case also has greater losses of load under Grid in Transition resource set, due to more limited transmission during the storm recovery period.

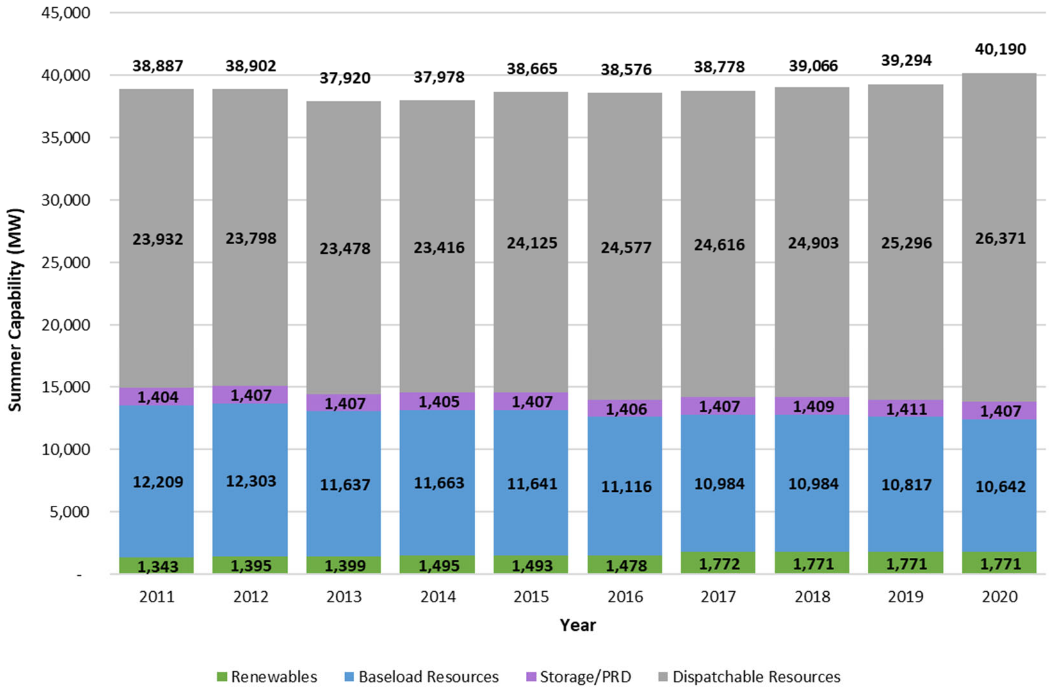
Table 23: Comparison of Case Results by Resource Set - Summer CLCPA

	Climate Impact Phase II Resource Set					Grid in Transition Resource Set				
	Total Hours with LOLO in at least one Load Zone	Aggregate LOLO (MWh)	Total Hours with DE Resource Gen.	Aggregate DE Resource Gen. (MWh)	Diff. in DE Resource Gen. from Baseline (MWh)	Total Hours with LOLO in at least one Load Zone	Aggregate LOLO (MWh)	Total Hours with DE Resource Gen.	Aggregate DE Resource Gen. (MWh)	Diff. in DE Resource Gen. from Baseline (MWh)
CLCPA Summer Scenario										
Baseline Summer	0	0	145	847,589	+0	0	0	512	4,181,951	+0
Heat Wave	0	0	147	964,668	+117,079	0	0	523	4,404,209	+222,258
Wind Lull - Upstate	0	0	179	1,171,656	+324,067	0	0	516	4,501,251	+319,300
Wind Lull - Off-Shore	0	0	196	1,116,165	+268,576	0	0	543	4,983,818	+801,867
Wind Lull - State-Wide	0	0	235	1,697,161	+849,572	0	0	543	5,322,997	+1,141,046
Hurricane/Coastal Wind Storm	26	20,168	322	1,892,046	+1,044,457	25	20,488	559	4,832,633	+650,682
Severe Wind Storm – Upstate	8	1,620	283	2,002,682	+1,155,093	24	18,963	549	4,998,149	+816,198
Severe Wind Storm – Offshore	0	0	167	1,079,462	+231,873	0	0	556	5,126,163	+944,212
Drought	0	0	166	1,148,649	+301,060	0	0	520	4,616,646	+434,695

F. Pace of Resource Change

The pace of development required to meet the capacity requirements for each resource set is historically unprecedented in New York. As seen in Figure 50, the resource mix within New York has not changed much from 2011 through 2020. According to the NYISO Gold Books, between 2011 and 2020, the total summer capability of grid-connected renewable generation increased from 1,342.5 MW to 1,770.5 MW (an increase of 47.6 MW/year on average). The only grid-connected Solar PV power plants in New York are the Long Island Solar and Shoreham Solar Farms, and wind generation has modestly increased from 2011 to 2020.

Figure 50: Historical Resource Mix in New York, 2011-2020



Notes:
[1] Dispatchable Resources include "Gas," "Oil," and "Gas & Oil."
[2] Baseload Resources include "Coal," "Nuclear," "Hydro," and "Other", with the exception of 31.5MW of grid-connected solar.
[3] Renewable Resources include "Wind."
[4] Storage/PRD Resources include "Pumped Storage."

Sources:
[1] 2012-2020 NYISO Gold Books.

As shown in Table 24, in order for the system to have the quantities of renewable generation in nameplate capacity developed for the CLCPA resource set (56,263 MW), wind nameplate capacity will need to grow by 2,714 MW per year for the next 20 years. This would be a thirty-fold increase in wind capacity. Solar capacity will need to grow by 1,960 MW per year to reach the CLCPA resource set quantity of 39,262 MW, for a more than thousand-fold increase in solar capacity. The pace of development is much the same for the other resource sets presented in this study, and each will require large sustained increases in renewable capacity through 2040.

Table 24: Required Pace of Development to Meet 2040 Resource Set Quantities

	Nameplate Capacity (MW)		Required 2020-2040 Nameplate Capacity Growth Rate (MW/yr)	
	Wind (Land-based and Offshore)	**Grid-Connected Solar**	**Wind (Land-based and Offshore)**	**Grid-Connected Solar**
Existing Resources (2020)	1,985	57		
Climate Phase II Reference Case Resource Set (2040)	39,962	34,354	1,899	1,715
Climate Phase II CLCPA Scenario Resource Set (2040)	56,263	39,262	2,714	1,960
Grid in Transition Reference Case Resource Set (2040)	23,522	30,043	1,077	1,499
Grid in Transition CLCPA Scenario Resource Set (2040)	48,357	31,669	2,319	1,581
Historical Nameplate Capacity Growth Rate (2012-2020, MW/yr)			**71.4**	**3.1**

G. Observations

In this report, we have evaluated a range of climate disruption scenarios in the year 2040, and under assumptions about the resources in place in that year. Based on our review of modeling results and the context for our analysis, we come to the following observations:

Climate disruption scenarios involving storms and/or reductions in renewable resource output (e.g., due to wind lulls) can lead to loss of load occurrences. Electrification, particularly in the building sector, transforms New York into a winter-peaking system. Thus loss of load occurrences due to climate disruptions in the winter are deeper and occur across more scenarios than in the summer (*See* Table ES-2). Specifically, in the winter severe wind storms, lulls in wind resource output (upstate or downstate), and icing events all lead to loss of load, as well as elevated reliance on the DE resource. In the summer, these events increase the system's reliance on the DE resource, but LOLOs are only triggered in the severe coastal (hurricane) and upstate wind storm events.

The variability of meteorological conditions that govern the output from wind and solar resources presents a fundamental challenge to relying on those resources to meet electricity demand. In scenarios involving LOLOs, or requiring substantial contributions from DE resources, periods of reduced output from wind and solar resources are the primary driver of challenging system reliability conditions, particularly during extended wind lull events. *See* Figure ES-2, showing results for the CCP2-CLCPA Case in the winter, including an extended wind lull. During the wind lull,[68] the state realizes losses of load in at least one zone for thirteen hours, with a total loss of over 14 gigawatt-hours (GWh). Moreover, during the wind lull the system relies *primarily* on the DE generating resource to avoid more severe LOLOs. Even outside the specific seven-day climate disruption wind lull period, one can see that base case reductions in wind output create periods of significant reliance on the DE resource to avoid losses of load.[69] Importantly, further increasing the nameplate capacity of such resources is of limited value, since when output is low, it is low for all similar resources across regions or the whole state.[70] As can also be seen across the full winter month, periods of solar output are not able to contribute during the early evening winter peak hours.

Battery storage resources help to fill in voids created by reduced output from renewable resources, but periods of reduced renewable generation rapidly deplete battery storage resource capabilities. As described in Section II, the CCP2-CLCPA resource set includes the development and operation of over 15,600 MW (124.8 GWh) of new storage resources, configured as eight-hour batteries, and distributed throughout the state to maximize their ability to time shift excess generation from renewable resources.[71] At this level of development, battery storage

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[68] The wind lull is a seven-day period from hours 192-360 in Figure ES-2.

[69] *See* hours 72-144, and hours 408-480.

[70] As noted, the generation profiles used for the wind and solar resources are taken from NREL state-specific generation profiles, based on historical meteorological data. The resulting renewable resource output profile across each season's month affects both the amount of renewable capacity needed to meet 2040 peak demand, and the reliance on the DE Resource and occurrence of LOLOs across all hours of the month. Renewable generation technology development and/or the realization of meteorological conditions that are different than the underlying historical NREL profiles could result in fundamentally different contributions from such resources in 2040, and different levels and types of system impacts than those reported here. The significance of the modeled renewable generation technologies and profiles thus represents a key uncertainty in the analysis, and this should be considered in interpreting results.

[71] As noted earlier, the development of the CCP2 resource sets requires a vast buildout of carbon-free resources to meet elevated electricity demand and the absence of existing fossil-fueled generating resources. This need drives the assumed amount of battery storage resources included in the resource sets; that is, the amount of battery storage assumed reflects an assumption of continuous and significant growth in storage technology over the next twenty years, and is well in excess of any existing mandates or near-term development expectations.

makes significant contributions to avoiding loss of load and reliance on backstop generation for the immediate period following sharp declines in renewable resource output due to climate disruptions (and also due to normal wind/solar resource variability).[72] While this represents a substantial level of assumed growth in battery storage within New York, the contribution of storage is quickly overwhelmed by the depth of the gap left during periods of time with a drop off in renewable generating output over periods of a day or more. This is revealed by the fill in of the DE Resource (in grey) following depletion of the storage resources (in red) during various periods in Figure ES-2.

The DE resources needed to balance the system in many months must be significant in capacity, be able to come on line quickly, and be flexible enough to meet rapid, steep ramping needs. Our generic DE resource generates energy as needed to meet demand and avoid loss of load occurrences. This study does not make any assumptions about what technology or fuel source can fill this role twenty years hence. Instead, the model includes the DE Resource to identify the attributes required of whatever resource (or resources) emerges to fill this role. Based on a review of the frequency and circumstances of reliance on the DE Resource to maintain reliability in the model, we can identify the characteristics required of the resource. In this, certain observations stand out. First, even in the baseline cases (*i.e.,* before layering in climate disruption events), there are periods of very low output from the renewable resources during periods of demand when resources need to be available to meet the bulk of the system's annual energy requirements. During such periods, the need for the DE Resource climbs very high - at times more than 30,000 MW. This is true even though the DE Resource is not significantly utilized on an annual energy basis, and has a very low capacity factor, at or less than ten percent. Second, the DE Resource needs to be highly flexible - it needs to be able to come on quickly, and be able to meet rapid and sustained ramps in demand. The results in Table ES-2 show that the minimum one-hour ramp requirement, even in the baseline CCP2-CLCPA case, approaches 12 GW, and climbs to nearly 13 GW in multiple CLCPA climate disruption cases. Moreover, as can be seen in Figure ES-3, the ramping capability of the DE Resource is even larger when viewed across multiple hours. For example, the four-hour period of greatest ramp in the CCP2-CLCPA case in the winter exceeds 20,000 MW.

The assumed increase in inter-zonal transfer capability in the CCP2 resource sets enables a renewables-heavy resource mix and improves reliability, but also increases vulnerability to certain climate disruption scenarios. The CCP2 resource sets are designed to maximize the contribution of renewable resources which, due to available land area and ease of siting, are heavily weighted towards the upstate region. As a result, it is necessary to assume a major build out of the transmission system in New York, to enable the upstate renewable resources to contribute to meeting load in the downstate region. Across the climate disruption cases, the increased transfer capability improves the resilience of the power system to all events that are localized, such as offshore storms or wind lulls that only affect the upstate or downstate regions, as well as to some disruptions that affect load and generation across the state, such as heat waves and cold snaps. Conversely, the increased reliance on transmission increases the vulnerability of the system to climate disruption events that specifically impact transmission capability, including icing events or major storms that disable transmission capacity.

Cross-seasonal differences in load and renewable generation could provide opportunities for renewable fuel production. The CCP2 resource sets are constructed to be able to meet peak demand in the winter and summer seasons based primarily on production from renewable resources. However, this means that there is a substantial amount of renewable generation that is excess, or "spilled," in off-peak seasons and hours. This introduces the potential for a seasonal storage technology to help meet the needs represented in the analysis by DE Resource

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[72] *See*, e.g., Figure ES-3, hours 72-96, 192-216, and 410-440.

generation during the summer and winter. Such potential assumes the emergence of economic technologies capable of converting excess renewable energy to a fuel and storing it for later use, or the development of other long term storage technologies. For example, as seen in Table ES-3, the excess renewable generation in the shoulder season modeling period under the CCP2-CLCPA case totaled roughly 23,204 GWh, while the DE Resource use in the winter modeling period was just 4,401 GWh. This raises the possibility that, should such technologies or capabilities emerge, excess off-peak renewable generation could help meet the peak-month energy requirements represented in the model by generation from the DE Resource.

The current system is heavily dependent on existing fossil-fueled resources to maintain reliability, and eliminating these resources from the mix will require an unprecedented level of investment in new and replacement infrastructure, and/or the emergence of a zero-carbon fuel source for thermal generating resources. A power system that is effectively free of GHG emissions in 2040 cannot include the continued operation of thermal units fueled by well-based natural gas. However, these are the very units that are currently vital to maintain power system reliability throughout the year. This is the fundamental challenge of the power system transition that will take place over the next two decades. Indeed, this transition must take place at the same time that electricity demand in the state will grow significantly if electrification of other economic sectors, such as transportation and heating, is needed to meet the economy-wide GHG emission reduction requirements. In all four cases studied, the required investment in and development of renewable resources is substantial, and far greater than anything previously experienced in New York. Table ES-4 shows the pace of development required for each case and resource set, compared to the historical capacity growth rate in New York.

Overall, the key reliability challenges identified in this study are associated with both how the resource mix evolves between now and 2040 in compliance with the CLCPA, and the impact of climate change on meteorological conditions and events that introduce additional reliability risks. The climate disruption events modeled in the EBM may be more frequent and/or more severe than in the past, and this increases NYISO's challenges in managing reliability risks over time. Nevertheless, such events do not appear to be *qualitatively* different than similar events experienced in the past, and present reliability challenges that may be considered similar to those faced today. With sufficient planning and preparation such events could be managed to maintain reliability in much the same way current weather-based disruptions are managed. However, on top of this the analysis demonstrates that, based on current information and technologies, the evolution of the system to one focused on zero-carbon resources and the infrastructure needed to support such a resource mix could introduce a number of key vulnerabilities to system reliability. These challenges include the variability of the meteorological conditions affecting renewable generation, the temporal limitations of existing battery storage technologies, and the increased dependence on resources distant from load centers. Based on our analysis, managing this transition seems to introduce reliability challenges that may be more difficult than those arising from the conditions of a changing climate. *Most importantly, this analysis suggests that establishing electricity market designs and energy policies to encourage innovation and accelerate advanced energy resource development will be key to reliably and economically managing the transition in the electric sector in New York*.

Comparing the CCP2 resource sets to the GIT resource sets reveals key differences in how the system makeup in 2040 can affect reliability outcomes. There are key differences between the Climate Change Phase II resource sets and those developed for the Grid in Transition study. First, given the different mixes of resources, the proportion of load met by DE Resources in the CLCPA winter load scenario is roughly nine percent for the CCP2-CLCPA resource set, but about 20 percent for the GIT-CLCPA resource set. In addition, given differences in the assumed level of transmission on the system (the GIT resource set does not include any expansion of the current transmission system), constraints on the Total East and Total South interfaces are binding in a larger percentage of hours under the GIT resource set, which means that DE Resources downstate are dispatched to provide electricity in more hours. The differences also lead to changes in vulnerability to climate disruptions. There are more hours with loss of load occurrences in the state-wide and offshore wind lull cases under the CCP2 resource sets, given the smaller overall quantity of DE Resources and greater reliance on wind resources. Conversely, the lower level of inter-zonal transfer capability in the Grid-in-Transition study resource set leads to more severe load losses during scenarios that affect upstate resources, such as severe windstorm and icing events.

In this study, we provide results for two very different visions for the evolution of the power system - one that relies on renewables and transmission (the CCP2 resource sets), and one that places greater emphasis on the backstop resource - that is, the potential emergence of a zero-carbon generation or fuel source (the GIT resource sets). These are only two of a wide range of potential outcomes as the system and technologies change over the next two decades, but they represent in some sense two bookends to potential system changes - one focused on aggressive system infrastructure development, and one that looks more like the current system, but is dependent on the development of zero-GHG fuel sources. The key differences between them are the relative levels of investment in system infrastructure, and the degree of reliance on the DE Resource.

For example, if there is skepticism that an economic fuel or technology will emerge and be widely available, and that can deliver reliable capacity, energy, reserves, and flexible operating attributes with little or no emissions of GHGs, then the pathway may be more heavily tilted towards aggressive investment in and development of renewable and transmission infrastructure, such as in the CCP2 resource sets. This approach would allow the system to operate with relatively low annual generation from the DE Resource. Conversely, if such a fuel or technology were to emerge, be technologically and economically viable, and be widely available, then there is less need to invest the significant capital needed to build out renewable and transmission infrastructure to meet the CLCPA requirements. These differences provide useful insight into the challenges New York State will face in guiding and managing what will likely be a rapid transition over the next two decades.

VI.References

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VII. Glossary

C&I	Commercial and industrial
CARIS	Congestion Assessment and Resource Integration Study
CLCPA	Climate Leadership and Community Protection Act
EDD	Effective degree day
EDRP	Emergency Demand Response Program
EE	Energy efficiency
EFORd	Equivalent Forced Outage Rate on Demand
EIA	US Energy Information Administration
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse gas
HQ	Hydro-Québec
ICAP	Installed capacity
ISO	Independent System Operator
ISO-NE	ISO New England Inc.
LI	Long Island (Zone K)
LOLO	Loss of load occurrences
MW	Megawatts
MWh	Megawatt hour
NYC	New York City (Zone J)
NYCA	New York Control Area
NYISO	New York Independent System Operator, Inc.
NYSERDA	New York State Energy Research and Development Authority
OSW	Offshore wind
PS	Pumped storage
PV	Photovoltaic
RTO	Regional Transmission Organization
SCR	Special Case Resource
SENY	Southeastern New York (Zones G-K)
SUN	Solar
UPNY	Upstate New York (Zones A-F)
WND	Wind
WT	Wind turbine