Impacts of Climate Change on the New York Energy System

Final Report | Report Number 23-30 | December 2023

NEW YORK STATE | NYSERDA

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Our Vision:

New York is a global climate leader building a healthier future with thriving communities; homes and businesses powered by clean energy; and economic opportunities accessible to all New Yorkers.

Our Mission:

Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

Impacts of Climate Change on the New York Energy System

Prepared for:

New York State Energy Research & Development Authority (NYSERDA)

Albany, NY

Nick Patane
Amanda Stevens
Project Managers

Prepared by:

Energy and Environmental Economics (E3)

New York City, NY

Vignesh Venugopal
Managing Consultant

Kevin Steinberger
Director

With support from:

Industrial Economics (IEc)

Cambridge, MA

and

Dr. Michael Craig
Independent Consultant

NYSERDA Report 23-30 NYSERDA Contract 190918 December 2023

Notice

This report was prepared by E3 in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority (hereafter "NYSERDA"). The opinions expressed in this report do not necessarily reflect those of NYSERDA or the State of New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, NYSERDA, the State of New York, and the contractor make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. NYSERDA, the State of New York, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

NYSERDA makes every effort to provide accurate information about copyright owners and related matters in the reports we publish. Contractors are responsible for determining and satisfying copyright or other use restrictions regarding the content of reports that they write, in compliance with NYSERDA's policies and federal law. If you are the copyright owner and believe a NYSERDA report has not properly attributed your work to you or has used it without permission, please email print@nyserda.ny.gov

Information contained in this document, such as web page addresses, are current at the time of publication.

Preferred Citation

New York State Energy and Research Development Authority (NYSERDA). 2023. "Impacts of Climate Change on the New York Energy System". NYSERDA Report Number 23-30. Prepared by Energy and Environmental Economics, New York, NY. nyserda.ny.gov/publications

Abstract

This study contains a detailed analysis of the New York State's energy system under three possible climate futures and two distinct infrastructure and policy pathways. The impacts of warming temperatures on heating and cooling demand, transmission ampacity, thermal generator output, and solar output were captured. With reliability and capacity expansion modeling that followed, the impacts that these warming-adjusted variables have on electric system reliability need, resource effective load-carrying capability (ELCCs), resource portfolios and costs were calculated. Climate change will have divergent impacts on the energy system, increasing demand for cooling in the summers while decreasing demand for heating in the winters. Without broader adoption of energy efficiency and heat pumps, winter fuel savings are largely offset by increased electric system needs in warmer summers. With broader adoption of these measures and continued investment in clean energy to achieve Climate Act compliance, increased warming can both lower fuel costs and the investments needed to meet the electricity system needs while reducing emissions. Savings are modest compared to the overall energy system investment.

Keywords

Energy system modeling, climate change, capacity expansion, reliability, resource planning, demand forecasting, CLCPA, ELCC

Acknowledgements

E3 is grateful to the NYSERDA Project Managers, Nick Patane and Amanda Stevens, for their valuable insights and leadership throughout the entire study. We also thank the broader NYSERDA team for reviewing the findings from this study. We would like to acknowledge the valuable insights and contributions from Industrial Economics (IEc) and Dr. Michael Craig. They helped develop county-level temperature forecasts from downscaled General Circulation Model (GCM) outputs developed by Columbia University for the New York State Climate Impacts Assessment that formed the foundation of this study. In addition, they also helped account for the impact of warming on thermal generation performance and transmission line capacity. Core Contributors

NYSERDA:
Nick Patane
Amanda Stevens

E3:
Sharad Bharadwaj
Alexandra Gonzalez
Charles Gulian
Pedro de Vasconcellos Oporto
Kevin Steinberger
Vignesh Venugopal
Dr. Bill Wheatle

IEc:
Jim Neumann
Jason Price

Independent Consultant:
Dr. Michael Craig

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AC	Air Conditioning
ASHP	Air-Source Heat Pump
CAC	Climate Action Council
CCGT	Combined-Cycle Gas Turbine
CCS	Carbon Capture and Storage
CDD	Cooling Degree Days
CES	Clean Energy Standard
CLCPA	Climate Leadership and Community Protection Act
CO2e	Carbon Dioxide (CO2) Equivalent
CT	Combustion Turbine
DAC	Direct Air Capture
DOE	Department of Energy
DPS	Department of Public Service
E3	Energy & Environmental Economics Inc.
EPA	US. Environmental Protection Agency
ELCC	Effective Load-Carrying Capability
ER	Electric Resistance
EV	Electric Vehicle
FO	Fuel Oil
GCM	General Circulation Model
GHG	Greenhouse Gas
GSHP	Ground-Source Heat Pump
GW	Gigawatt
GWh	Gigawatt-hour
GWP	Global Warming Potential
HDD	Heating Degree Days
HDV	Heavy Duty Vehicle
HP	Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
IA	Integration Analysis
IEc	Industrial Economics Inc.
IPCC	Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act
ISC	Short-Circuit Current
ISO	Independent System Operator
ITC	Investment Tax Credit
LDAR	Leak Detection and Repair

LDV	Light Duty Vehicle
LOLE	Loss of Load Expectation
MF	Multi Family
MMT	Million Metric Ton
MW	Megawatt
MWh	Megawatt-hour
NET	Negative Emissions Technologies
NG	Natural Gas
NPV	Net Present Value
NYISO	New York Independent System Operator
NYSERDA	New York State Energy Research and Development Authority
NYSRC	New York State Reliability Council
OSW	Offshore Wind
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PSC	Public Service Commission
PRM	Planning Reserve Margin
PV	Photovoltaic
PTC	Production Tax Credit
RCP	Representative Concentration Pathway
RNG	Renewable Natural Gas
SF	Single Family
SSP	Shared Socioeconomic Pathway
ST	Steam Turbine
TWh	Terawatt-hour
UCAP	Unforced Capacity
VMT	Vehicle-Miles Traveled
VOC	Open Circuit Voltage
ZEV	Zero-Emission Vehicle

Summary

As the impacts of climate change intensify, it will become increasingly important for energy system planners to directly account for the effects that warming will have across every segment of the industry. In New York, there are multiple planning efforts underway to advance the implementation of its nation-leading Climate Leadership and Community Protection Act (Climate Act), which requires the state to achieve carbon neutrality by 2050. This study builds on those ongoing efforts by performing a detailed analysis of the impacts of climate change on the State‘s energy system under three possible climate futures and two distinct infrastructure and policy pathways. Specifically, the analytical framework for this study couples (1) temperature projections under three climate change scenarios, and (2) the impacts of changes in temperature on key components of energy supply and demand, leveraging the Integration Analysis modeling toolkit to examine a Reference case and a Climate Act-compliant Decarbonization scenario. The Integration Analysis (IA) framework was developed by Energy and Environmental Economics (E3) to support the Final Scoping Plan approved by the New York State Climate Action Council. This analysis focused solely on the impacts of climate-driven changes in temperature on the energy system; there are many other impacts of climate change that were beyond the scope of this study. Below, we highlight key findings from this work.

Climate change is projected to lead to significant warming in New York State. In addition to a “Mild” climate scenario based on original Integration Analysis assumptions, this study assessed the changes in temperatures both statewide and on a county-level basis for both a “Moderate” and “Severe” climate scenario, using hourly temperature forecasts from General Circulation Models (GCMs) with varying levels of warming, downscaled to New York State. In addition to driving significant increases in annual average temperatures relative to historical conditions, climate change is projected to impact seasonal extremes, leading to temperature increases in hot summer days while reducing the severity of extreme cold during the winter, as shown in Figure S-1 and S-2.

Figure S-1. Statewide-Averaged Winter and Summer Temperature Impacts under Moderate and Severe Climate Scenarios (Annual Minimum Temperature)

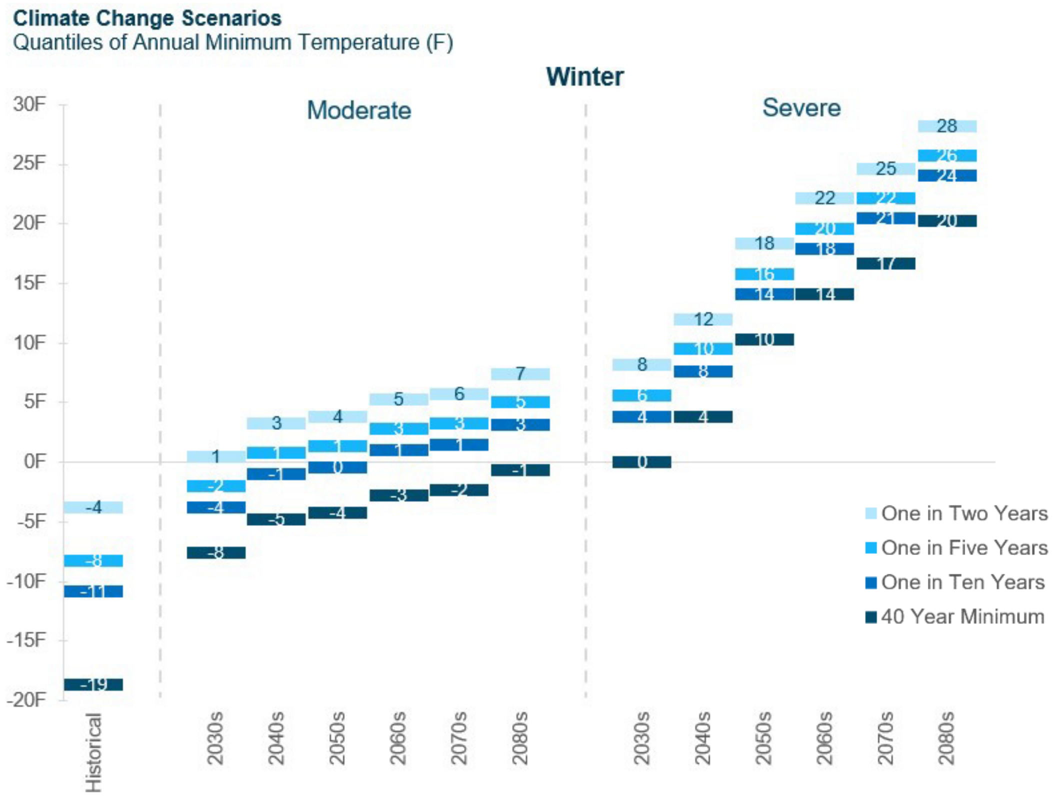
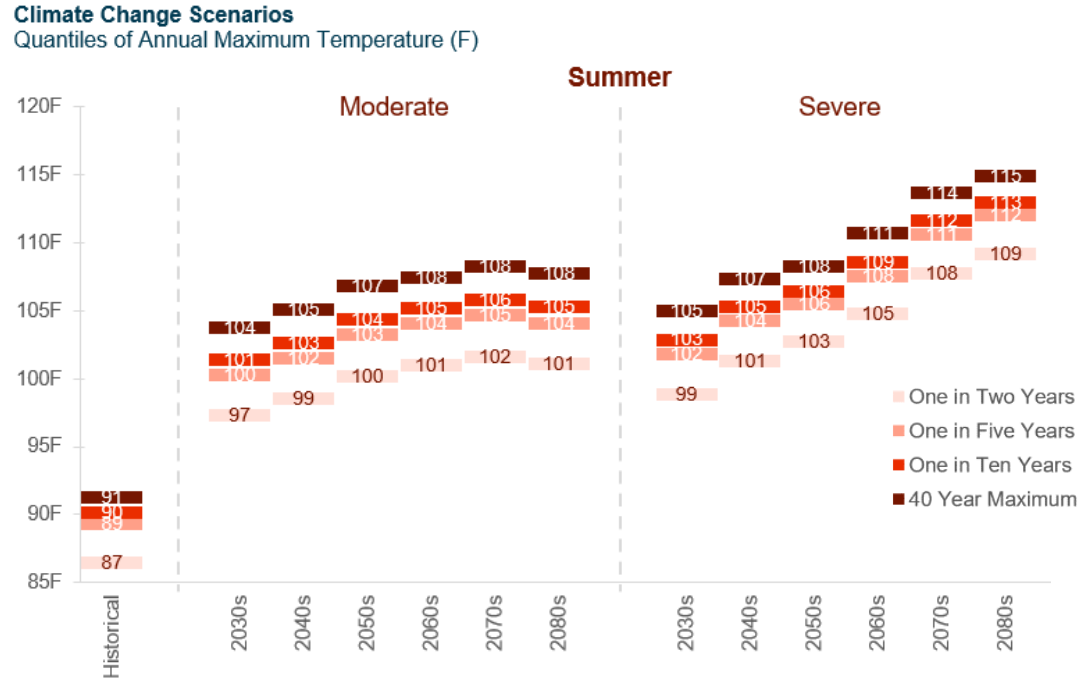


Figure S-2. Statewide-Averaged Winter and Summer Temperature Impacts under Moderate and Severe Climate Scenarios (Annual Maximum Temperature)



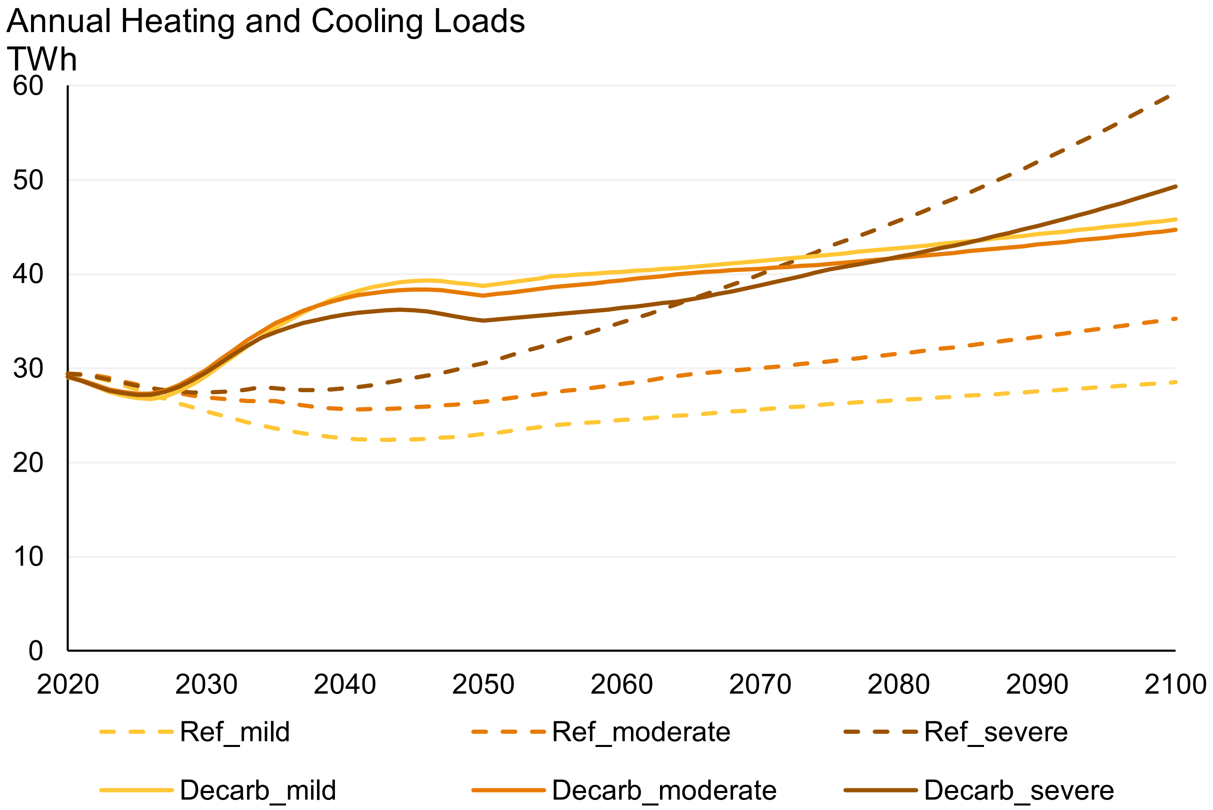
These temperature increases will have a multi-faceted impact on New York State’s energy system, affecting both infrastructure (i.e. generators and transmission lines) and customer demand. The impacts of warming temperatures on heating and cooling demand, transmission ampacity, thermal generator output, and solar output, etc. are well-documented. For other components of the electricity system, the impacts are less well-known, or the relationship has not been thoroughly studied. The modeled and non-modeled impacts of climate change in this study are summarized in Figure S-3.

Figure S-3. Matrix of Modeled and Non-Modeled Climate Impacts on New York Energy System

	Impact More Certain	Impact Less Certain
Modeled	Heating and cooling demand Transmission capacity derates Thermal generation efficiency Solar panel efficiency and output	Thermal generation outage rates
Not Modeled	Distribution capacity derates Delivery of input fuels	EV and bulk battery storage efficiency Wind Land use and resource potential Hydropower

Climate-driven warming will have divergent impacts on seasonal electricity demands, increasing cooling demand and decreasing heating demand. The resulting impacts on the energy system will be highly dependent on the extent of New York State’s investments in building decarbonization. Energy efficiency and the adoption of efficient heat pumps in addition to reducing emissions and associated health impacts will also mitigate the impacts of extreme summer warming. Without heat pumps and energy efficiency measures, cooling loads increase substantially across climate cases due to continued use of relatively inefficient air conditioning devices, and this increase in cooling demand more than offsets the decrease in electric heating demand from existing electric resistance heating. With heat pumps deployed to electrify space heating alongside other efficiency measures to meet decarbonization goals, the increase in cooling load is not as substantial. While electric heating demand does increase due to electrification, warming reduces this demand and leads to a more balanced electric system. The annual heating and cooling demand projected in the Reference and Decarbonization scenarios are shown in Figure S-4.

Figure S-4. Modeled Impacts of Climate Change on Heating + Cooling Demand



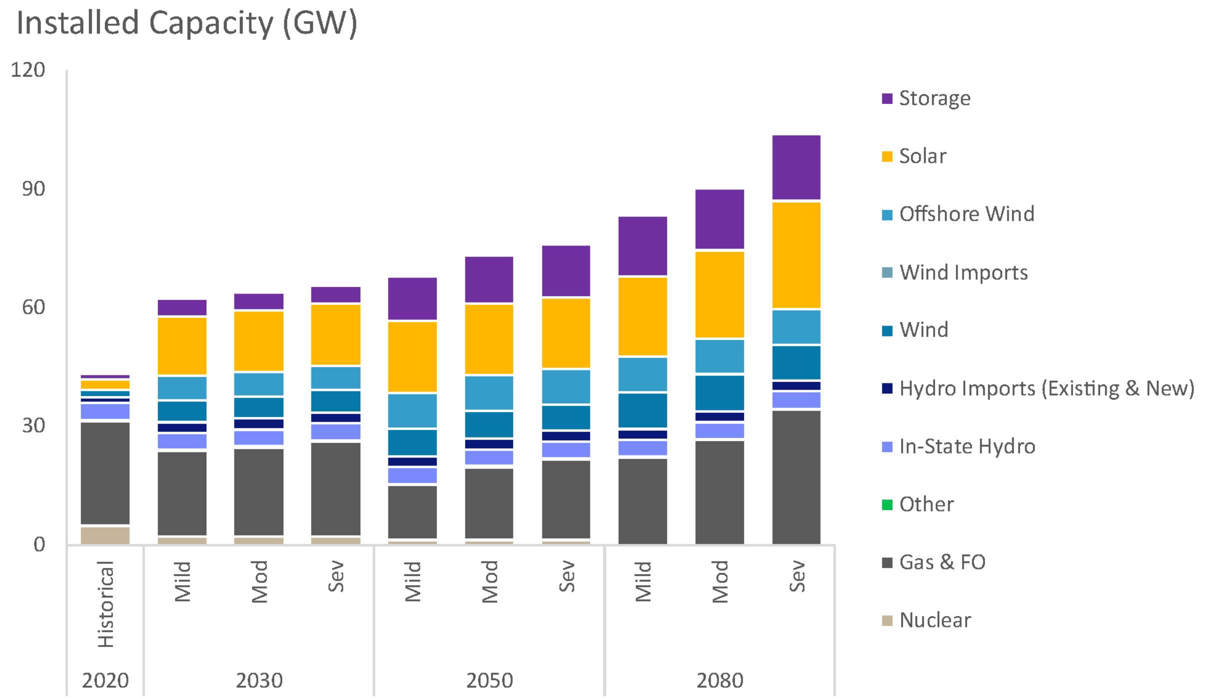
Without building decarbonization measures such as energy efficiency and heat pump adoption, the summer peak in the Reference scenario increases substantially under increased warming. In the late century, the Reference Case summer peak in fact exceeds the annual peak of the Decarbonization scenario under Severe levels of warming, despite the latter having higher levels of electrification of end uses in buildings, transportation, and industry to enable decarbonization. In the Decarbonization scenario, both the summer and winter peaks stay similar in magnitude under increased warming as shown in Figure S-5, leading to a more efficient use of the resource capacity.

Figure S-5. Impacts on Summer and Winter Peak Demand, by Infrastructure and Climate Scenario

The challenge associated with maintaining system reliability during summer peak demand periods is compounded by the impacts of rising temperatures on electric infrastructure. Warming also lowers transfer capacity across the transmission system; reduces output from solar panels due to reduced efficiency; and increases ambient temperature derates for combustion-based power plants and worsens their risk of unforced outages, subsequently resulting in a higher correlation of outage risk across the fleet.

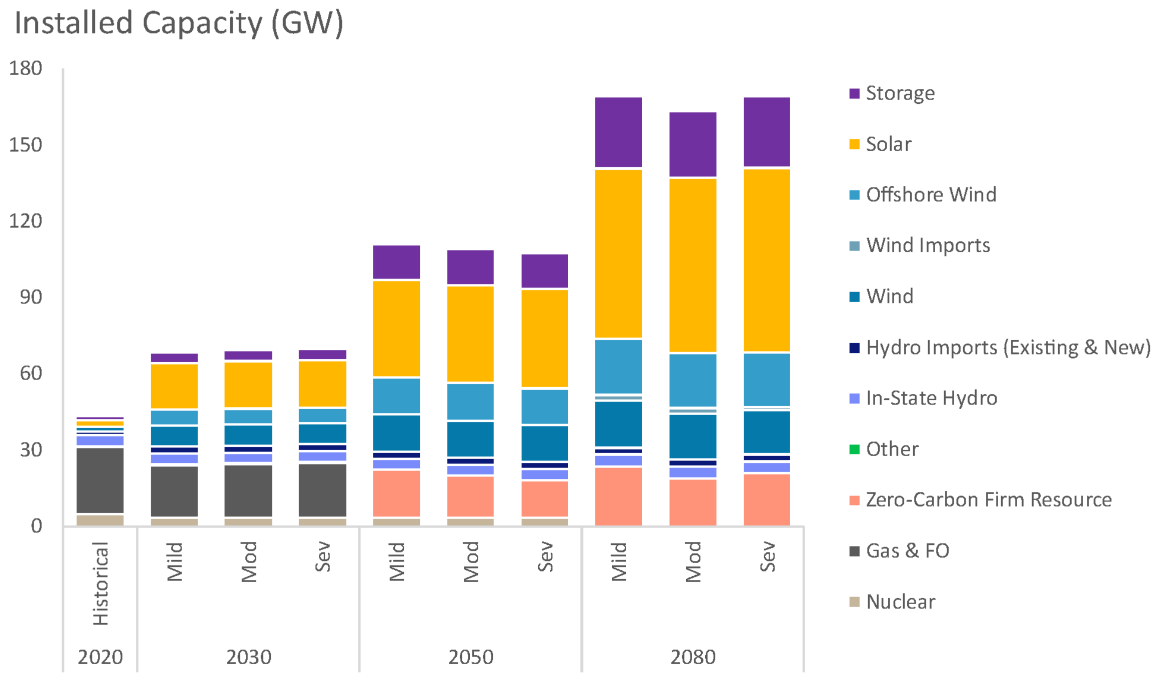
Increased resource capacity is needed to both maintain reliability and achieve the 70% Clean Energy Standard due to increased cooling demand with warming in the Reference Scenario. Increasing peak demand coupled with impacts on thermal generators lead to an increase in thermal and battery storage capacity needed to maintain reliability in the Reference scenario, as shown in Figure S-6. Increases in annual cooling demand and declines in the efficiency of solar resources also place additional pressure on the renewable infrastructure build-out required to maintain achievement of the 70% renewable electricity Clean Energy Standard throughout the forecast period.

Figure S-6. Reference Case Resource Portfolio under Each Climate Scenario



While the electric system must grow to meet newly electrified end-uses in the Decarbonization scenario, warming reduces the "peak heat" challenge of meeting winter peak demand. Although New York State can continue to expect cold weather, particularly in the short term, the severity of extreme cold snaps, as represented across GCMs, declines over the long term as winters get warmer. With increasing summer temperatures, the capacity added to meet electrification-driven winter peak demand is required to meet summer peaks as well; the resource portfolio is thus developed to meet system reliability needs across both the summer and winter seasons. Unlike the Reference case, installed capacity does not consistently grow with warming in each year, as shown in Figure S-7.

Figure S-7. Decarbonization Scenario Resource Portfolio under Each Climate Scenario



Without broader adoption of building decarbonization measures, the cost impacts of warming are unevenly distributed across sectors and largely offsetting. The electricity sector will face sharp increases in costs as a result of more extreme summers, which are largely offset by winter fuel savings. With broader investments in building decarbonization measures such as heat pumps and efficient building shells, increased warming can partially mitigate the electric infrastructure investments required by electrification-driven load growth.

As the impacts of climate change intensify, it will become increasingly important for energy system planners to directly account for the effects that warming will have across every segment of the industry, including generator and transmission impacts in addition to impacts on system demand. While average winter temperatures are projected to increase, there is still uncertainty associated with how climate change may impact extreme cold weather events, and this uncertainty may limit the ability to plan the electric system around expectations of warmer winter extremes. In other words, the system will need to remain reliable during extreme winter events even as they become less frequent or possibly less severe as a result of climate change. Additionally, it is important to note that this study focused exclusively on the impacts of temperature change on the energy system. Other climate-driven phenomena such as sea level rise and increases in the frequency or magnitude of storms will impact New York State infrastructure including the energy system but were beyond the scope of this study.

1 Introduction

As the impacts of climate change intensify, it will become increasingly important for energy system planners to directly account for the effects that warming will have across every segment of the industry. In New York State, there are multiple planning efforts underway to advance the implementation of its nation-leading climate law, the Climate Leadership and Community Protection Act (Climate Act), which requires the State to achieve 85% emission reductions and carbon neutrality by 2050. This study builds on those ongoing efforts by performing a detailed analysis of the impacts of climate change on the New York State energy system under three possible climate futures and two distinct infrastructure and policy pathways. Specifically, the analytical framework for this study couples (1) temperature projections under multiple climate change scenarios, and (2) the impacts of changes in temperature on key components of energy supply and demand, leveraging the Integration Analysis modeling toolkit to examine a Reference case and a Climate Act-compliant Decarbonization scenario.

The focus of this report is specifically on the impact of warming temperatures on both electricity demand and supply, and the impact of warming on fuel demand for non-electric end uses (primarily space heating) is also considered. While other climate-driven phenomena such as sea level rise and increases in the frequency and magnitude of storms will impact all infrastructure in New York State, including the generation and delivery of electric power, those impacts are not considered within this analysis.

1.1 Methodology

The analytical framework for this study couples (1) temperature projections under multiple climate change scenarios, and (2) the impacts of changes in temperature on key components of energy supply and demand, using the Integration Analysis modeling toolkit to examine infrastructure and policy pathways in New York State. The Integration Analysis framework is an economy-wide representation of the New York energy system with a comprehensive accounting of energy supplies and demands, coupled with a detailed reliability and capacity expansion framework in the electricity sector. The capacity expansion framework selects a resource portfolio to minimize total system cost while maintaining the New York ISO's reliability standard[1] and meeting the policy goals of each defined scenario. The framework was developed by Energy and Environmental Economics (E3) to support the Final Scoping Plan approved by the New York State Climate Action Council in 2022. A brief overview of the framework is provided below, and additional technical details of this framework can be found in Appendix G of the Final Scoping Plan.[2] The Integration Analysis framework relies on a suite of tools to assess decarbonization pathways in New York State; most relevant for this assessment are the PATHWAYS, RESHAPE, RECAP, and RESOLVE models.

PATHWAYS is a stock rollover model that contains a comprehensive accounting of energy supplies and demands across the New York State economy and is used to analyze the rate of change in each sector necessary to achieve economy-wide decarbonization goals. PATHWAYS is used to capture the impacts of changes in Cooling Degree Days (CDD) and Heating Degree Days (HDD)[3] on energy demands across the economy, including the impacts on total electricity sector demand as well as the impacts on demand for heating fuels.

Using projections for the pace and scale of electrification in buildings from PATHWAYS, E3 also leverages RESHAPE, its in-house load shaping tool, to characterize the hourly shape of electrified end uses under 40 years of weather conditions, capturing the diversity of space heating demand across the building stock. Using PATHWAYS and RESHAPE, E3 can develop an aggregate load shape that captures key changes in both the magnitude and timing of electricity demand driven by electrification of the buildings, transportation, and industrial sectors. In this analysis, both the PATHWAYS and RESHAPE tools are used to examine the impacts of changes in temperature on building heating and cooling demand, as detailed in Section 1.1.3.1.

Detailed modeling of the bulk electricity system is performed using E3's capacity expansion and resource adequacy models, RESOLVE and RECAP. RESOLVE is an electricity-sector resource investment model that optimizes long-term generation and transmission investments subject to reliability, technical, and policy constraints. RECAP is a resource adequacy model that performs loss-of-load probability simulations to determine the reliability of resource portfolios. The impacts of climate-driven changes in temperature on generator output and/or availability are examined and serve as inputs into both the RECAP and RESOLVE models, as described in Sections 1.1.3.2 and 1.1.3.3. RECAP analysis is used in this work to determine the effective load-carrying capability (ELCC)[4] of individual resources, which are input into RESOLVE to ensure that the model's economic decision-making takes into account the reliability contributions of each resource, such that the portfolio in aggregate meets NYISO reliability standards even under changing climates. With annual and hourly load projections from PATHWAYS and RESHAPE and ELCC curves from RECAP serving as inputs, RESOLVE is used to develop least-cost electricity generation portfolios that achieves New York State's policy goals while maintaining electric system reliability.

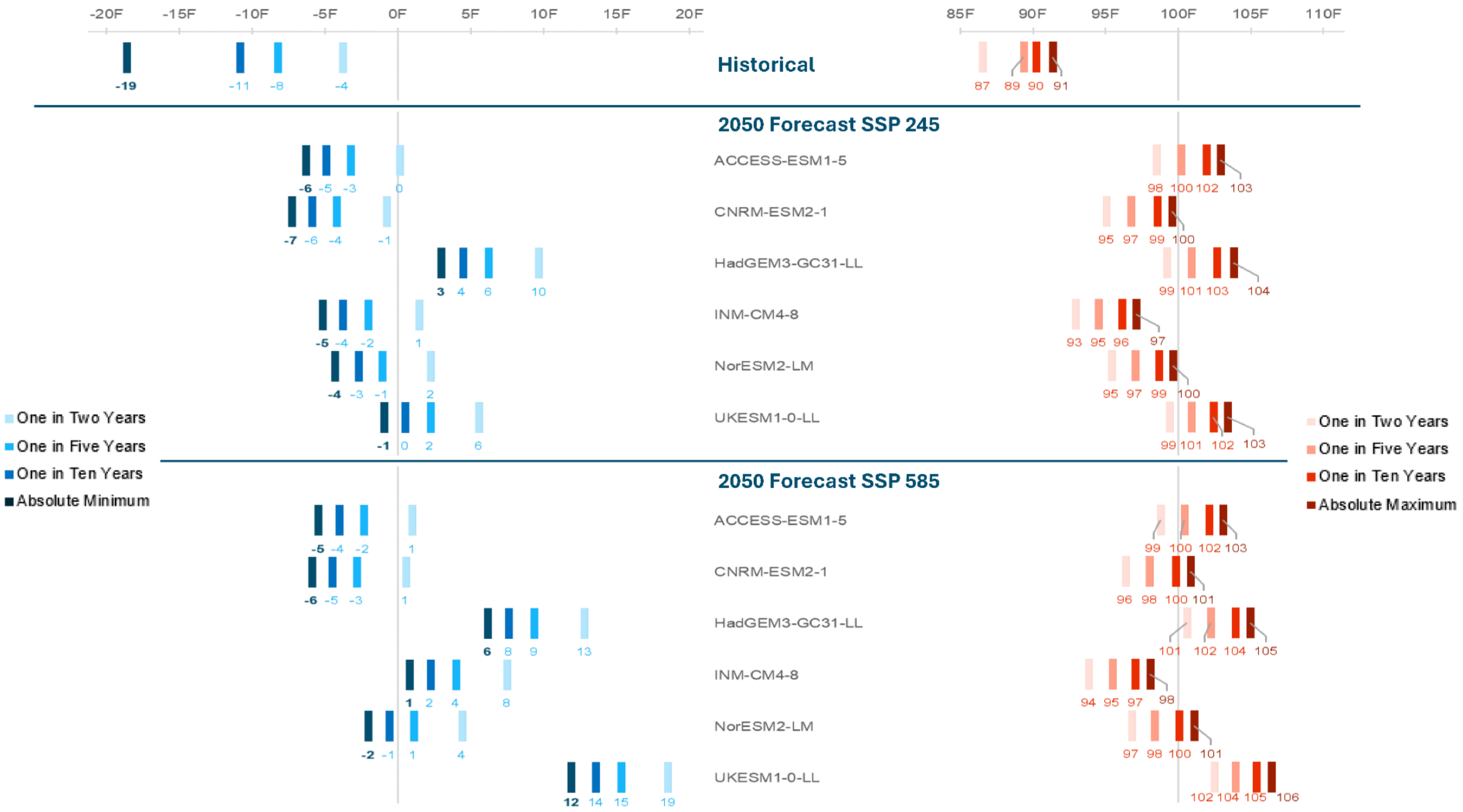
1.1.1 Overview of Climate Scenarios

This analysis relies on hourly temperature projections from General Circulation Models (GCMs) in order to examine the impacts of climate change on the electricity system in New York State. There are a number of GCMs that vary in their sensitivity to different climate drivers which in turn impact the degree of change that each GCM projects in New York State. In addition, GCMs can be run for multiple different shared socioeconomic pathways (SSPs), which contain different assumptions about future emissions and other inputs. The GCM projections are based on climate model analysis performed by Columbia University for the New York State Climate Impacts Assessment. The Columbia University results prepared for the impacts assessment were further downscaled spatially (to county level) and temporally (to hourly level) by IEc and consultant Dr. Craig to ensure the projections met the input requirements for this energy system analysis.

By combining six different GCMs with two different SSPs, 12 different climate projections were available for examination. However, to allow for a focused examination of energy system impacts, E3 sought to select three distinct GCMs. These three climate scenarios may not reflect equally likely outcomes. The intention was to broadly capture a wide range of potential climate futures, and the corresponding range of potential impacts that climate change would have on the bulk electricity system.

Temperature projections from GCMs were used to bias-correct the historical temperature data from 1979-2018 used in the Scoping Plan. This yielded multiple realizations of future weather years that contained inter-annual variability while capturing the expected climate-driven trend. To determine the range of scenarios to use in its assessment of low and high range of electric infrastructure impacts, E3 focused primarily – but not exclusively – on the seasonal extremes. E3 first calculated statewide hourly temperatures averaged across all counties, and then assessed the hottest and coldest temperatures in each year of projected climate realizations and compared climate scenarios using their median ("One in Two") temperatures as well as outer quantiles (shown below). The median temperature is a particularly important metric because many system planners, including the NYISO, develop their planning requirements around the median system peak.[5]

Figure 1. Historical and Projected Minimum and Maximum Temperatures in New York State



E3's prior work as part of the CAC Scoping Plan process used a set of proxy assumptions for the impact of climate change on temperatures and thus demand through 2050. It was assumed that CDDs would grow by 1%/year, and HDDs would remain unchanged. Based on its review of the range of GCMs provided, this assumption set falls most closely to the INM-CM4-8 GCM in SSP 2, RCP 4.5. In this work, E3 has defined a "Mild" scenario that continues the 1%/year CDD growth and 0% HDD growth assumptions from the Scoping Plan through 2050 and then uses levels of warming projected by INM-CM4-8 in the 2050-2100 period.

E3 then sought to use two more scenarios: one "Moderate" scenario that is intended to capture relatively higher levels of overall warming in the summer, with extreme summer temperatures on the hottest days, and more muted impacts of warming on cold winter temperatures, relative to other GCM projections. E3 also selected a "Severe" scenario which reflects some of the highest warming impacts both in the summer, leading to increased cooling demand across the entire summer and extreme hot days, as well as in the winter, with climate impacts leading to a substantial increase in winter minimum temperatures and corresponding reductions in heating demand. Based on its assessment of the climate realizations in Figure 1, E3 selected the ACCESS GCM under the SSP 2, RCP 4.5 pathway as its "Moderate" climate scenario, and the UKESM GCM under the SSP 5, RCP 8.5 pathway as its "Severe" climate scenario. A more detailed comparison of the projected distribution of winter and summer extreme temperatures under each scenario are shown below in Figure 2 and Figure 3, respectively. These figures show the extremes identified after calculating an hourly average temperature across all counties in the state.

Figure 2. Projected Winter Minimum Temperatures under Selected Scenarios (Statewide)

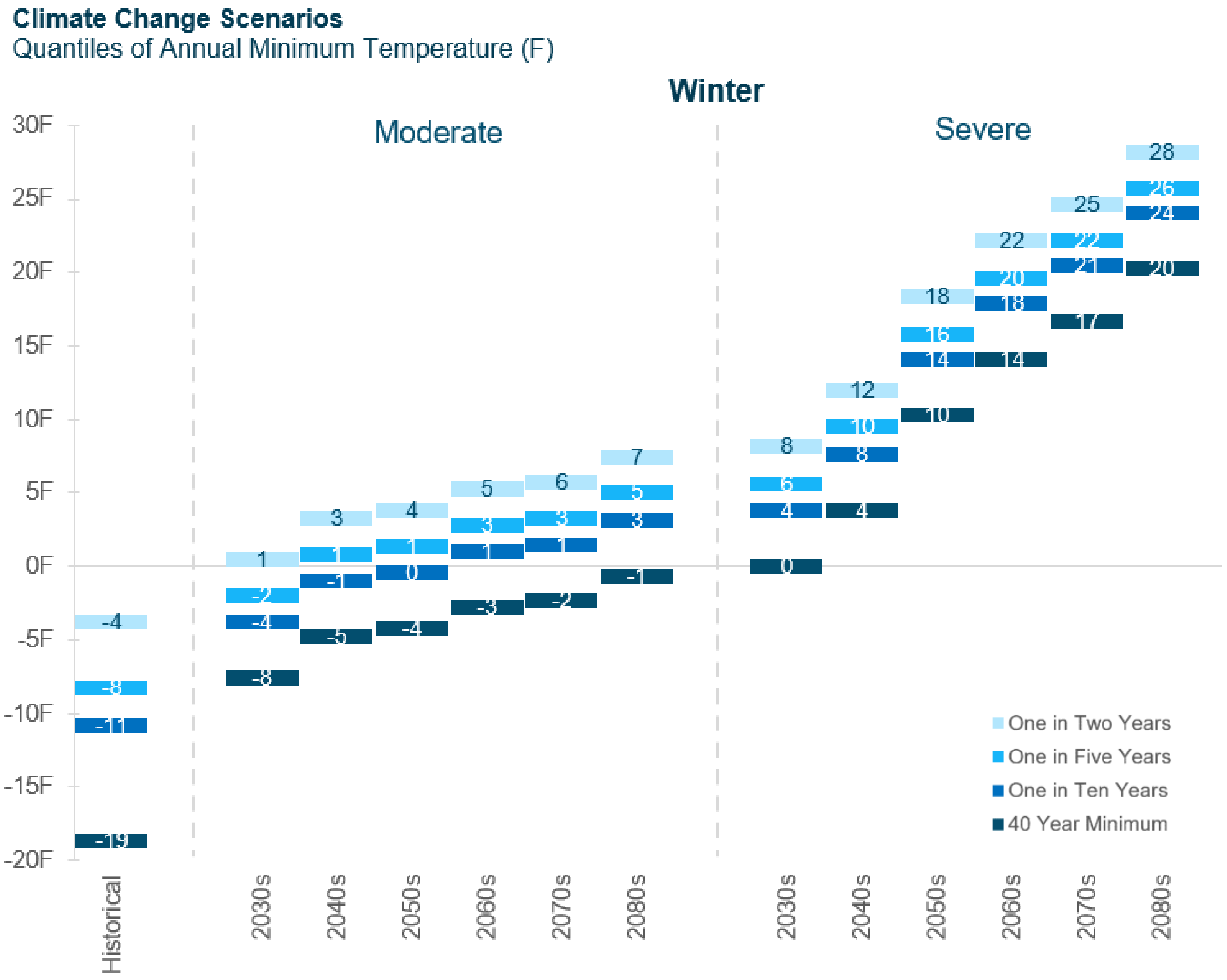
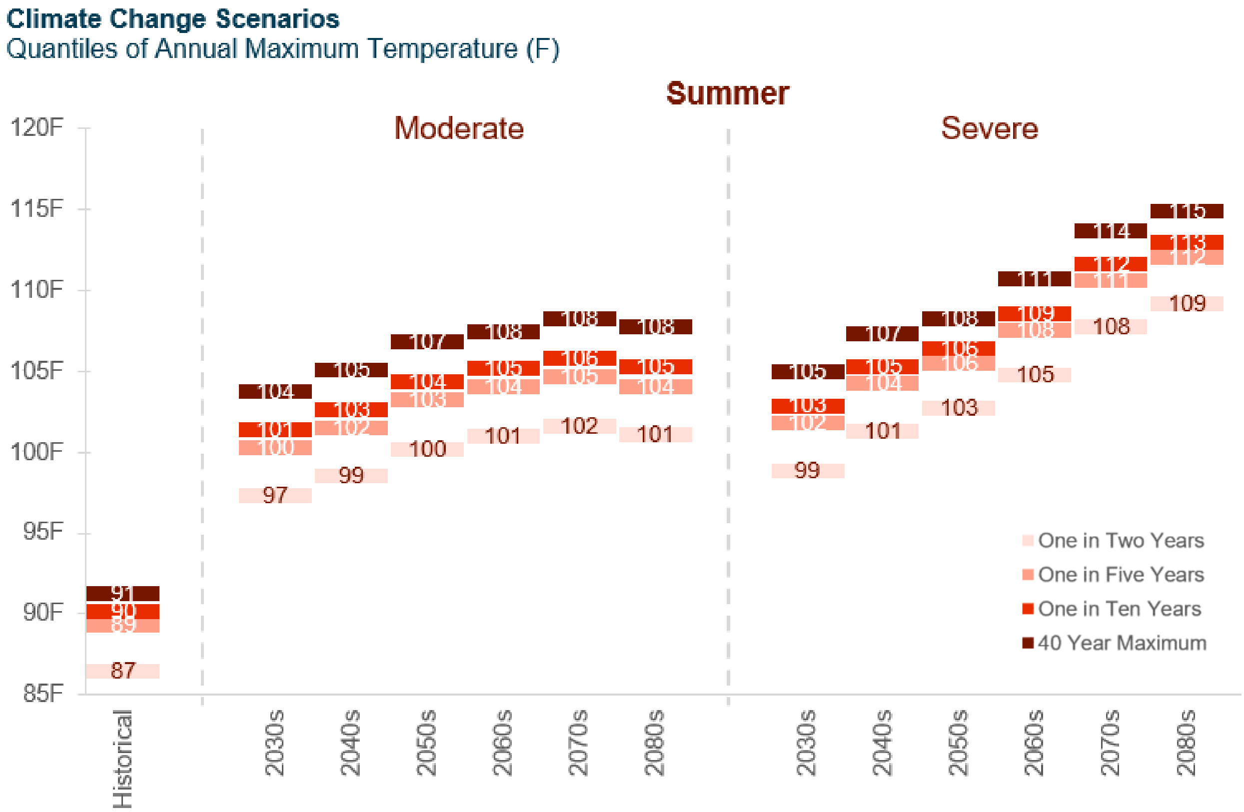
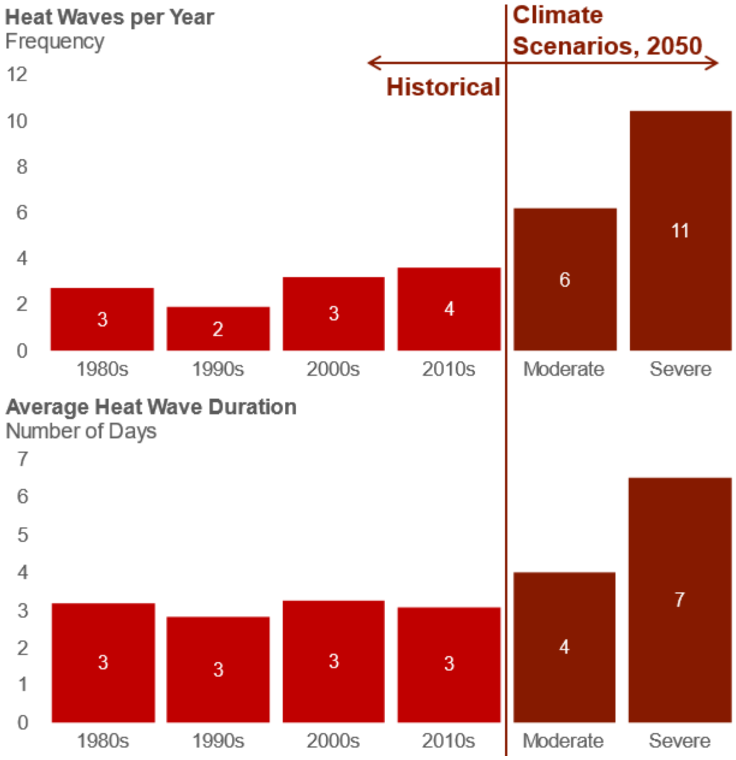


Figure 3. Projected Summer Maximum Temperatures under Selected Scenarios (Statewide)



Extreme temperatures shown influence peak demand for electricity. In addition to the intensity of heat waves, the duration and frequency also matter, the impacts of which are captured in the modeling. The frequency and duration of heat waves is also forecasted to increase in the Moderate and Severe scenarios as shown in Figure 4 for a few past decades and forecasts for 2050. These indicators are calculated in line with EPA's definitions.[6]

Figure 4. Projected Heat Wave Frequency and Duration in 2050 under Selected Scenarios



Annual demand for electricity is influenced by the overall temperature distribution comprising of temperature forecasts in each hour of the year. Table 1 shows the annual change in CDD and HDD forecasted in each climate scenario. The "Severe" scenario shows the highest level of aggregate warming too, with the "Moderate" scenario chosen showing warming roughly in-between the "Severe" and the "Mild."

Table 1. Impact of Warming on Cooling and Heating Degree Days

CDD and HDD Change by Period, by Climate Scenario			
Period	CDD growth		
	Mild	Moderate	Severe
2020 - 2050	1%	2.52%	4.15%
2020 - 2100	0.52%	1.29%	2.52%
Period	HDD growth		
	Mild	Moderate	Severe
2020 - 2050	0%	-0.64%	-1.49%
2020 - 2100	-0.04%	-0.39%	-1.25%

It should be noted that all GCMs evaluated in this analysis provide a clear signal of warming winter temperatures, including extreme temperatures. However, severe winter storms and polar vortex events are likely to continue to be a significant risk to the reliability of the electricity system for years, if not decades, to come. The “Mild” scenario represents a case in which winter temperatures resemble historical climate conditions through 2050, and there is no discernible impact on winter heating demand on either an annual or peak basis. In the Moderate and Severe scenarios, the modeling is performed using the temperature projections of the GCMs directly; as a result, annual and peak winter heating demand are considerably lower than in the Mild scenario, and thus the system requires less generator capacity to maintain system reliability during winter cold snaps. However, in the context of reliability planning, even as winters are projected to get warmer on average, there may be value in planning for a system peak based on historical extremes, especially under decarbonization pathways in which most customers convert to a reliance on electricity for heating needs via heat pump adoption.

1.1.2 Overview of Infrastructure Scenarios

The analysis examined the impacts of climate change on two future infrastructure scenarios: a Reference Case and a Decarbonization Scenario.

The Reference Case is defined as a business-as-usual case that contains all implemented policies in New York State as of 2021 (the start of the Scoping Plan analytical work), including but not limited to energy efficiency achieved by funded programs, funded building electrification, a statewide zero-emission vehicle mandate, a statewide 70% Clean Electricity Standard by 2030 alongside some electric technology-specific goals. A 100% zero-emission electricity goal by 2040 is not modeled in the Reference Case. There have been several State policy developments that have occurred since the development of the Draft Scoping Plan that are not embedded in the Reference Case; for example, in the electricity sector, the Reference Case does not include recent announcements such as the development of the 10 GW Distributed Solar goal, the establishment of the 6 GW Storage target, or the announcement of a second Tier 4 project. At the federal level, the Reference Case also includes federal appliance standards and national Corporate Average Fuel Economy standards.

The Decarbonization Scenario represents a scenario that is fully compliant with the Climate Act, using “Scenario 2: Strategic Use of Low Carbon Fuels” from the Final Scoping Plan Integration Analysis as the starting point. A summary of infrastructure impacts assumed is presented below.

The electric sector modeling leverages the “High IRA Benefits” sensitivity from the Scoping Plan that included the passage of the Inflation Reduction Act (IRA), given the impact that the tax credits have on economic decision-making and the cost-effectiveness of each technology. Both the Reference Case and the Decarbonization Scenario include the impacts of the IRA electric sector tax credits. ITC and PTC for eligible electric generators are assumed to be available through 2042 with a safe harbor period.

Modeling improvements were made to the Scoping Plan framework, including better representation of building heating contributions to peak demands, reflecting heat pump performance improvements over time, and better representation of the flexibility of electric vehicle demand.[7] As a result of these improvements, the results presented in the Mild climate scenario vary from the results published in the Final Scoping Plan but are similar in magnitude, and key takeaways between infrastructure scenarios remain unchanged.

Figure 5. Overview of Select Decarbonization Pathway (“Scenario 2” of Scoping Plan)

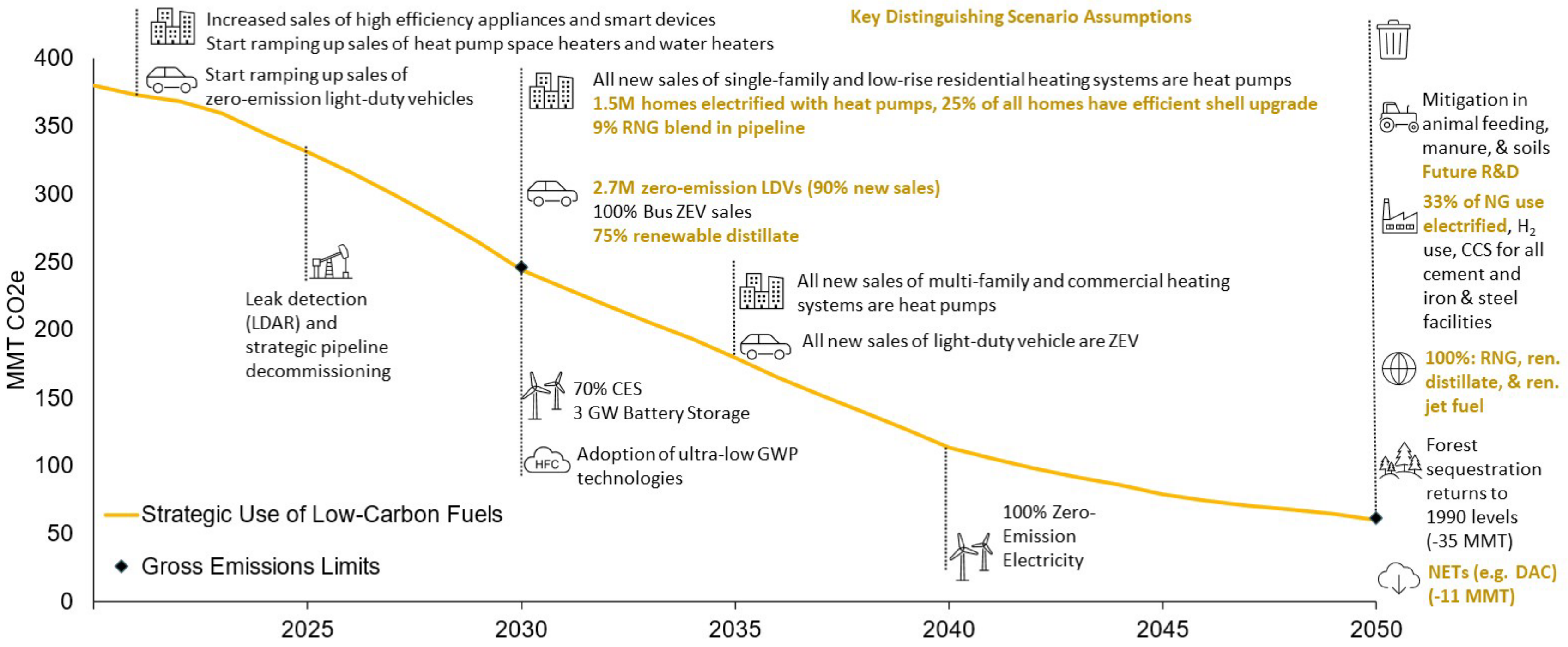


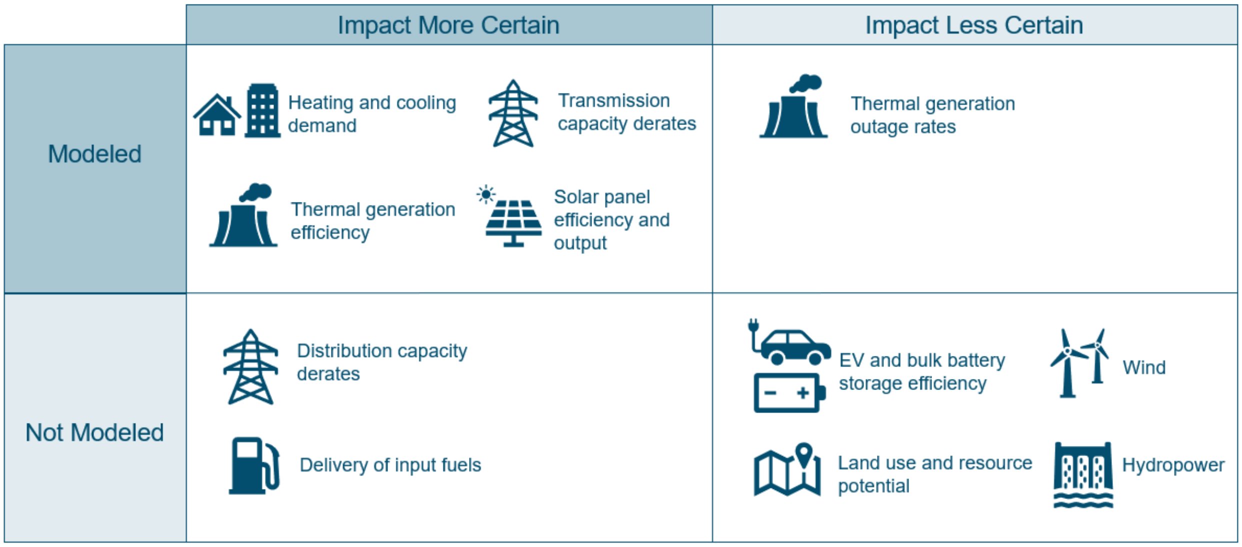
Table 2. Summary of Assumptions and Infrastructure Impacts between the Reference and Decarbonization Scenarios

	Reference	Decarbonization
New Sales of HPs	4% by 2025	77% by 2029, 100% by 2030/2035 (SF/MF+Com)
Share of Electrified Buildings	7% by 2030 & 2050 0.6 Mil. Households by 2030 & 2050 0.6 Bil. Com sqft by 2030 & 2050	18% by 2030, 92% by 2050 1.5 Mil. Households by 2030, 7.8 Mil. by 2050 1.1 Bil. Com sqft by 2030, 5.3 Bil. By 2050
Residential Efficient Shell Penetration	3% Deep Shell, 4% Basic Shell by 2030 5% Deep Shell, 10% Basic Shell by 2050	7% Deep Shell, 18% Basic Shell by 2030 26% Deep Shell, 66% Basic Shell by 2050
Zero-Emission Vehicles Sales	LDV: 30% by 2030, 50% by 2040, 63% by 2050 [50% vehicles charge flexibly] HDV: 7% by 2030, 17% by 2040, 27% by 2050 Bus: 7% by 2030, 20% by 2040, 30% by 2050	LDV: 90% by 2030, 100% by 2035 [50% vehicles charge flexibly] HDV: 40% by 2030, 100% by 2045 Bus: 100% by 2030
Low Carbon Fuels	No advanced renewable fuels; existing federal ethanol blend (~7% by energy) and New York State (B20 heating oil blend by 2030)	9% RNG, 75% renewable distillate by 2030 100% RNG and renewable distillate by 2050
Non-Energy (Waste, Agriculture, Forestry and Land Sinks, Negative Emissions Technologies)	Moderate increase in forest sequestration, no additional afforestation on marginal lands, no direct air capture or other NETs	Waste diversion and reduced methane leakage from existing and future landfills, anaerobic digesters in solid waste; abatement in manure, animal feeding, and soil management; forest sequestration returns to 1990 levels, additional afforestation on marginal agricultural lands; 11 MMT abatement from direct air capture or other NETs
Annual Electricity Demand in Mild (GWh)	172 TWh in 2050, 206 TWh in 2100	304 TWh in 2050, 351 TWh in 2100
Median Peak Electricity Demand in Mild (not including PRM)	34 GW in 2050, 42 GW in 2100	47 GW in 2050, 56 GW in 2100 (winter peaking in mid 2030s and beyond)
Electric Sector Goals	70x30 CES, Technology specific targets (3 GW storage by 20308, 9 GW OSW by 2035)	70x30 CES, Technology specific targets (10 GW distributed solar by 2030, 3 GW storage by 2030[8], 9 GW OSW by 2035), 100% GHG-free electricity by 2040

1.1.3 Incorporation of Climate Impacts into the Integration Analysis Framework

In this analysis, E3 adapted and extended the Integration Analysis framework to directly examine the impacts of warming temperatures from climate change on the electricity system and fuel demand. The impacts of warming temperatures on many aspects of the energy system are well-documented (e.g. heating and cooling demand, transmission ampacity, thermal generator output, and solar output), while for other components, the impacts are less well-known, or the relationship has not been thoroughly studied. The modeled and non-modeled impacts of climate change are summarized in Figure 6.

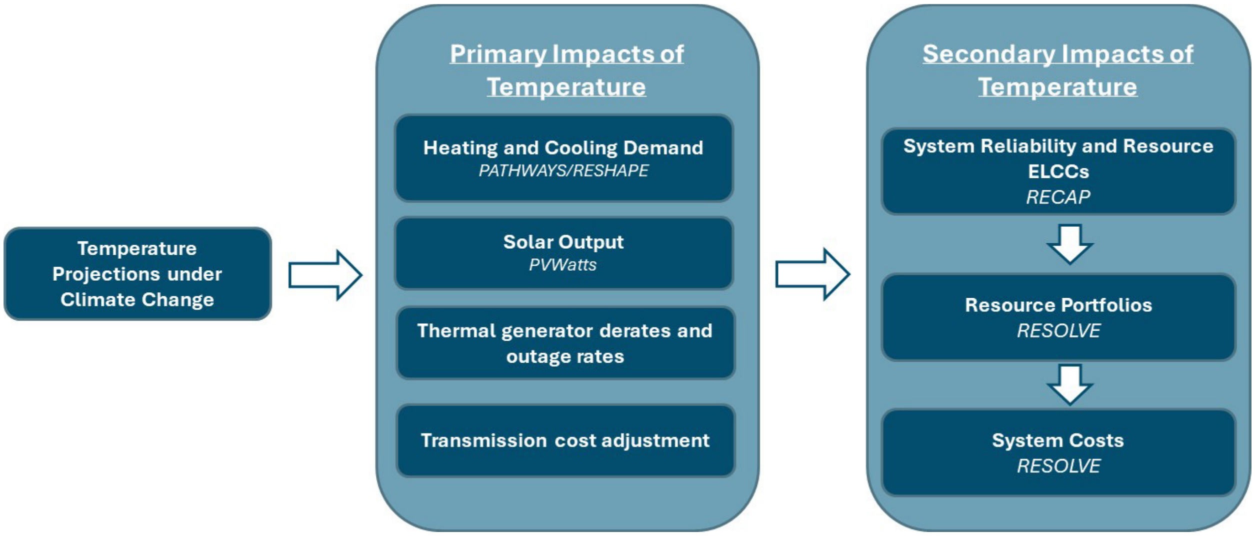
Figure 6. Matrix of Modeled and Non-Modeled Climate Impacts on New York Energy System



	Impact More Certain	Impact Less Certain
Modeled	Heating and cooling demand Transmission capacity derates Thermal generation efficiency Solar panel efficiency and output	Thermal generation outage rates
Not Modeled	Distribution capacity derates Delivery of input fuels	EV and bulk battery storage efficiency Wind Land use and resource potential Hydropower

For each of the modeled climate impacts, the temperature outputs from each climate scenario served as inputs into the Integration Analysis framework, described in the following sections.

Figure 7. Incorporation of Temperature into Integration Analysis Framework



1.1.3.1 Impacts of Temperature on HVAC Demand

HVAC demands were simulated using two tools: PATHWAYS and RESHAPE. PATHWAYS is E3's in-house energy accounting model, and is used to examine changes to energy demands across New York State at the end use level, e.g. by tracking the number of air source heat pumps (ASHPs) with electric resistance (ER) backup installed in residential buildings across the State over time. Demand from different types of heating and cooling equipment, including ASHPs with ER, ASHPs with fuel backup, ground source heat pumps, and air conditioners (ACs), are accounted for. PATHWAYS is used to estimate the impacts on annual heating and cooling demand as a result of climate change, using calculated changes in HDD and CDD under each climate scenario. RESHAPE is E3's in-house HVAC energy demand simulation tool, used to model hourly demand of electrified end uses, including new heating and cooling equipment. The hourly temperatures of each GCM serve as inputs into RESHAPE, which is then used to develop a normalized hourly shape that captures changes in the distribution of heating and cooling demand over the course of the year.

The temperature outcomes of each GCM were used to develop projections of changes in heating and cooling demand relative to historical levels in New York State. Bias-corrected and spatially downscaled dry bulb temperature forecasts from GCMs were used as inputs, and the impacts of climate change on humidity were not directly accounted for. However, historical heating and cooling demand data used in this study is inherently a function of both temperature and humidity historically observed. Demand forecasts are thus developed based on changes to dry bulb temperature expected due to climate change. Specific humidity, i.e. the mass of water vapor per unit mass of air, will likely increase as a result of climate change, while impacts of warming on relative humidity, or the mass of water vapor in the air relative to the mass needed for air to be saturated at that temperature, are uncertain and there is not agreement across GCMs on these impacts.

Leveraging the projected annual changes in heating and cooling demand from PATHWAYS, coupled with hourly simulations of HVAC demands from RESHAPE under each set of temperature projections, provides a detailed picture of changes in both the magnitude and timing of HVAC demands as a result of climate change.

The temperature projections under each GCM were used to calculate CDD and HDD growth rates by decade and by geographic region, using a standard reference temperature of 65 degrees Fahrenheit. The projected changes in CDD and HDD are shown in Table 1.

Warming winters will also reduce fuel-based heating demand. The magnitude of impact on fuel requirement is contingent on how much of the heating demand stays non-electrified. The HDD growth rates were also used to adjust the fuel demand that remains after electrification of heating is accounted for in each respective infrastructure scenario.

1.1.3.2 Impacts of Temperature on Solar PV Output

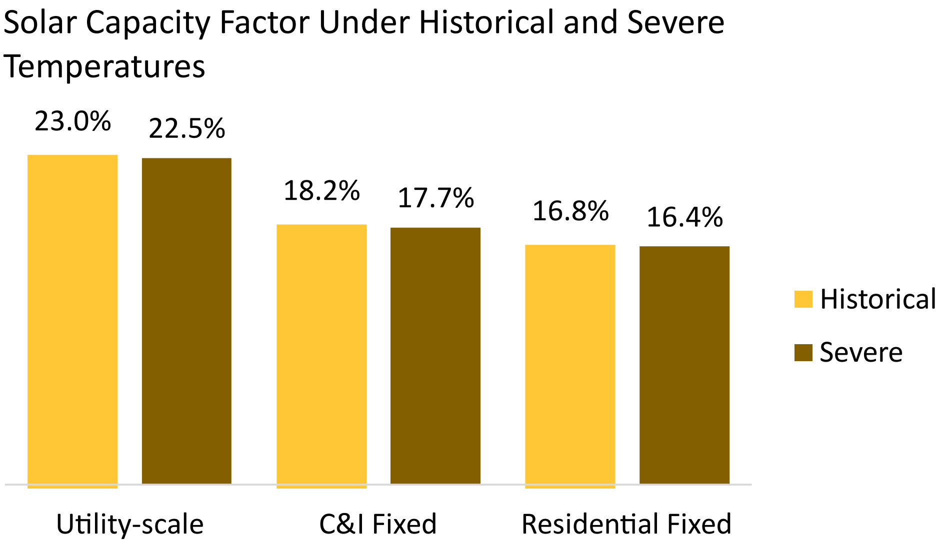
The output of solar photovoltaic (PV) panels has a direct relationship with the temperature of the panel. Specifically, the available output is determined by the module's short-circuit current (ISC) and open-circuit voltage (VOC), and as the temperature of the module increases, ISC increases slightly but VOC decreases substantially, leading to reduced power output.

The National Renewable Energy Lab's PVWatts model was used to simulate solar output profiles. By feeding in historical temperatures and then temperature forecasts from the climate models in sequential model runs, it was found that solar output reduces by 0.22% per °F increase in temperature. This is consistent with the findings from other studies.[9,10,11] So, for example, if the temperature in an extreme hour during a heat wave increases by 10 °F, the solar output in that hour may reduce by 2.2%.

Solar profiles previously used in the Scoping Plan were kept unchanged for the Mild Scenario. Hourly temperature differences between the Mild and Moderate and then the Mild and Severe scenarios in 2050 were then used to adjust the solar profiles for use in the Moderate and Severe scenarios respectively. As shown below, the capacity factor of solar reduced by 0.5% (absolute) in the Severe Scenario relative to the Mild.

This analysis focused solely on the impacts of temperature on solar PV output using projected air temperatures as a proxy for changes on the temperature of the solar module itself. However, climate change may impact other weather variables such as cloud-cover, and thus insolation reaching the module surface, or wind speeds that could impact cooling of the panels and module temperatures. These impacts were not accounted for.

Figure 8. Modeled Impacts of Increased Temperatures on Solar PV Output



The changes in solar PV output profiles as a function of temperature served as inputs into the electricity sector modeling framework. E3's reliability model, RECAP, was used to assess the impacts that adjustments to solar output profiles have on the contributions of solar resources to overall system reliability. The solar profiles were also updated in RESOLVE, E3's capacity expansion model, such that the economic decision-making and resource selection under each climate scenario take into account the impacts of warming temperatures on solar output.

1.1.3.3 Impacts of Temperature on Thermal Power Plants

Thermal generators are weather-dependent in two ways: (1) their output is a function of ambient temperature and (2) thermal units have historically performed worse during both extreme cold and extreme heat conditions.

Combustion turbines are impacted by ambient temperature because they rely on air recirculation for cooling. As a result, the larger the delta between the temperature of combustion and the temperature of ambient air, the higher the efficiency and rated output of the turbine. As temperatures increase, the rated output of the turbine declines nearly linearly.

Because fossil units are more likely to experience outages during extreme temperature conditions, this means that their performance has a correlation with projected loads. Using historical data, a relationship between extreme temperatures and fossil outages can be determined using a probability function. Fossil outages were simulated using the hourly temperatures under each GCM, and then RECAP was used to examine the relationship between fossil outages and hours of potential loss of load. In combination with ambient temperature derates, the reliability contributions of each generation technology can be developed.

The relationship between the probability of thermal outages and temperature was derived from a recent paper that examined historical data from PJM.[12] This empirical relationship is an area of emerging study and is one of increasing importance as recent winter storms have severely threatened grid reliability in Texas, PJM, and elsewhere. During winter storm Elliot, PJM estimated that over 10 GW of thermal capacity was unavailable due to fuel supply issues.[13] Although it did not lead to severe loss of power like Uri did in Texas, Elliot provides another extreme case of correlated outages during extreme cold–out of 186 GW of UCAP capacity in PJM, 46 GW was unavailable during the storm, with plant equipment issues and fuel supply issues identified as the leading contributors of outages.

To date, a similar study has not been conducted within New York State directly; instead, the results of the study conducted by Murphy et al. were extended to New York State generators. However, differences between the two regions may complicate the applicability of the relationship, especially during extreme cold events. Many generating units in New York City are required to maintain fuel oil storage on-site in order to remain available in case of gas pipeline outages, potentially mitigating one of the key contributors to thermal outages during extreme cold. Although there are not any direct requirements for on-site fuel storage in PJM, PJM's capacity market structure includes performance incentives and penalties that provide additional financial motivation for generators to be available during challenging periods, known as a "pay-for-performance" model[14], which the New York ISO does not have. Due to these differences between the two regions in requirements and incentives for maintaining reliability during extreme cold, caution should be used when interpreting the ELCC findings for thermal generators in New York.[15]

1.1.3.4 Impacts of Temperature on Transmission Ampacity

The ampacity of transmission lines also declines as a function of increasing temperature, and as a result climate change is likely to lead to reductions in transfer capacity across transmission systems during the summer as temperatures continue to rise. Capturing the impacts of increasing temperature on transfer capacity in New York State is difficult within this modeling exercise due to the high-level topology used to represent the New York transmission system, as well as factors that may require further study (for example, Central East, one of the most limiting interfaces in New York, is a voltage-limited interface that would not be impacted by temperature-driven changes in thermal transfer capacity).

As a proxy for the impacts of temperature on transmission, a multiplier was applied to the transmission deliverability costs for renewable builds. This approach captures the increased costs of renewables-driven transmission expansions that have already been identified in the Mild case; however, the analysis does not consider additional upgrades that may be required in areas of the existing system that are not needed in the Mild case but become necessary as a result of the more significant temperature rise in the Moderate or Severe cases. A much more granular representation of the transmission system and an assessment of areas that are already nearly constrained would be required for such an exercise.

Transmission derates in each hour were calculated corresponding to the hourly temperature in each of the three climate scenarios.[16] The average of the derates in each climate scenario was then calculated over the hours from noon to 7PM in the summer months of June-August. The choice was informed by the finding that temperature, demand, and thus loss of load probability can be high in these hours. These hours are also aligned with the summer peak load window defined by the NYISO and have been previously used for the accreditation of duration-limited resources (e.g. energy storage) in the capacity market. The average derates in the Moderate and Severe scenarios were then compared to the Mild, to yield the transmission cost increases applicable in those scenarios, which are applied as a cost multiplier relative to the cost assumptions used in the Scoping Plan and the Mild scenarios in this analysis. Exceptions were made for transmission upgrades expected to be underground (Zone J) and transmission lines expected to be underwater (offshore wind interconnected to Zones J and K); for these lines, costs were not increased to account for warming. For the remainder of the system, this analysis assumes that costs are incurred for the upgrades to existing overhead lines; however, future hardening efforts may include an increased focus on building new lines underground.

Table 3. Calculated Impacts of Temperature on Transmission Upgrade Costs

NYISO Zones	Transmission Cost Increase in Moderate	Transmission Cost Increase in Severe
A-E	3.7%	7.9%
F	3.6%	8.5%
G-I	4.5%	8.6%
J	6.8%	9.3%
K	5.7%	7.4%

1.1.3.5 Extension of Integration Analysis Framework to Late-Century

For this study, the Integration Analysis framework has been extended to cover a longer time horizon, through the end of the century, in order to capture the impacts of climate change on the electricity system throughout the period for which climate projections are available.

Most energy modeling efforts use 2050 as an end point, including the Integration Analysis performed for the Scoping Plan, as well as notable, publicly available national sources such as the Energy Information Administration and DOE's National Renewable Energy Laboratory, which serve as foundational datasets for the Integration Analysis. As with any modeling effort, projections become more uncertain as a function of time relative to the year in which the modeling is being conducted; this effort is made more uncertain due to the lack of projections for future fuel prices, technology costs, and other underlying drivers, past 2050. As a simplifying assumption, these variables are held constant after 2050.[17]

There are only two input variables that change between 2050-2100: (1) hourly temperatures, which are outputs of each GCM and (2) population growth. Population growth assumptions came from the Cornell Program on Applied Demographics, which was focused on 2020-2040, but the rates of population growth (Table 4) were assumed to be constant through 2100. These two variables have downstream effects because they lead to changes in electricity demand, which in turn lead to changes in required infrastructure, fuel consumption, and associated costs.

Table 4. Assumed Population Growth Rate by Region

Region (NYISO Zones)	Annual Population Growth Rate
Upstate (A-E)	-0.13%
Upstate (F)	0.07%
Downstate Hudson (G-I)	0.24%
Downstate NYC (J)	0.34%
Downstate Long Island (K)	0.04%

1.1.4 Non-Modeled Impacts

This analysis focused on the impacts of temperature change on key components of the energy system where their relationship with temperature is well-understood and well-documented. However, there are many components of energy system planning that will be impacted by climate change that are currently not well-understood. The remainder of this section provides a brief overview of non-modeled impacts, which may be areas for future research.

1.1.4.1 Electric Vehicle Charging

In addition to the electrification of building heating demands, the Decarbonization scenario also relies on significant electrification of vehicles as a key strategy to meet the Climate Act goals. The Integration Analysis framework does not currently capture seasonal or temperature-driven changes in electric vehicle charging patterns; while it is well-documented that colder temperatures lead to reduced range for EVs, the detailed relationship between temperatures and resulting electricity demand has not been studied. Additionally, data of seasonal driving patterns suggest that vehicle miles travelled (VMT) are lowest in the winter and peak during the summer months, which may partially offset the impacts of cold temperatures and reduced range on overall annual electricity demand.[18]

Lastly, as the market share of electric vehicles continues to grow, another source of uncertainty is whether vehicle or battery manufacturers develop innovative ways to compensate for this limitation, which may in turn lead to less significant impacts on overall electricity demand.

1.1.4.2 Wind and Hydropower

In addition to solar PV output (described above), New York State is projected to rely on other weather-dependent resources including onshore wind, offshore wind, and hydropower. However, unlike solar PV output, the quality of evidence and/or agreement among studies on the impact of climate change on wind and hydropower in New York State is not high.[19]

While climate change is projected to have significant impacts on hydropower in the Western United States due to increases in drought conditions, the impacts of climate change on rainfall and hydropower outputs in the Northeast are projected to be less significant and are highly uncertain. A large percentage of hydropower generation in New York State comes from the Niagara and St. Lawrence Power Projects, which use an ample supply of water from the Great Lakes system. While seasonal runoff and streamflow may shift in timing and amount, these are not likely to have a large effect on these hydroelectric facilities. Extreme events such as intense rainfall or short-term droughts may impact smaller run-of-river hydro projects.

There is uncertainty about the degree to which wind speeds will change in New York State and the effects on wind generation. The IPCC's Sixth Assessment Report indicates, on a global basis, that "observed mean wind speed is decreasing over most land areas where observational coverage is high." However, the same report indicates elsewhere that "mean wind speed and wind power potential are projected to decrease in Western North America (high confidence) with differences between global and regional models lending low confidence elsewhere."[20] Another study suggests little change in hub height wind speeds (± 0.2 m/s) or power production (±5% in gross capacity factor) across New York State and adjacent offshore waters.[21]

As a result of the uncertainty characterized above, the impacts of climate change on hydro and wind generation in New York State were not modeled in this study.

1.1.4.3 Electricity Distribution and Fuel Delivery Systems

The distribution and fuel delivery systems are not represented in the Integration Analysis framework at the level of granularity that would be needed to perform an examination of the impacts of climate change on these systems. As a result, these systems are not included within the scope of this analysis. These non-quantified impacts include distribution system derates due to the impacts of temperature on line ampacity, increasing cooling requirements for substations, impacts on fuel pipelines and storage, needs for storm hardening, and other factors. Con Edison recently completed a comprehensive climate change vulnerability study for its system, and the New York Public Service Commission has directed all New York utilities to conduct a similar study over the coming years.[22, 23]

1.1.4.4 Land Use and Resource Potential

The Integration Analysis leveraged the Clean Energy Standard Cost Study to develop estimates of the available land-based wind and solar PV potential in New York State. The CES Cost Study performed a geospatial analysis of suitable land for renewable development.[24] Climate change may have significant impacts on land use in New York State. For example, climate change may affect land use for agriculture and livestock grazing, climate-induced migration (both inter and intra-state) and its impact on land use, and other factors. The impacts of climate change on the total available land for wind and solar development in New York State are highly uncertain and were not considered in this analysis.

2 Results

This section details the modeled impacts of climate change-driven changes in temperature on the New York energy system, leveraging projected hourly temperatures under different climate scenarios as inputs into the economy-wide Integration Analysis framework. This section first details the impacts of climate-driven temperature changes on electricity demand, and subsequently examines the impacts of changes in electricity demand as well as the output and availability of different generator types on overall system reliability needs. Lastly, the section assesses the aggregate impact of climate change on least-cost resource portfolios that meet New York State’s goals while maintaining reliability, and the associated infrastructure and operating costs of electricity sector portfolios and non-electric heating fuel costs under each climate scenario.

2.1 Impacts of Climate Change on Electricity Demand

Within this section, the impacts of climate change-driven changes in temperature on electricity demand are separated into: (1) the impacts on annual electricity demand as a result of changes in average CDD and HDD, and (2) the impacts on peak electricity demand as a result of changes in seasonal minimum and maximum temperatures.

2.1.1 Annual Electricity Demand

The PATHWAYS tool is used to examine the impacts of temperature changes under each GCM for both the Reference Case and the Decarbonization Scenario.

As shown in Figure 9, in the Reference Case, the amount of heating service demand supplied by electricity remains relatively low throughout the forecast horizon, due to minimal adoption of heat pumps, with efficiency gains and stock turnover of aging electric resistance equipment leading to declines in total demand for electric heating relative to today’s levels. The relatively low amount of electric heating demand in the Reference Case is further lowered when comparing the Moderate Reference and Severe Reference Cases to the Mild Reference Case, as increases in winter temperatures lead to declines in HDD and associated electric load.

As shown in Figure 10, the amount of cooling service demand gradually increases in the Mild Reference Case, in part because it is assumed that New York State reaches full saturation of air conditioning equipment, and because the Mild case includes increases in cooling degree days as a result of climate change. However, the Moderate Reference and Severe Reference Cases experience much sharper increases in CDD, with cooling demand in the Severe case reaching 2x that of the Mild in 2050 and 3.6x in 2100.

As shown in Figure 9, in the Decarbonization Scenario, heating service demand grows sharply over the next few decades, as electrifying heating needs in residential and commercial buildings is a key pillar to achieve the State's climate targets. Space heating demand increases from 20 TWh in 2020 to 31 TWh in 2050 in the Mild Scenario. Energy efficiency measures, such as upgrades to building shells, are critical to managing the impacts of electrification on system demand, and the Decarbonization Scenario reflects deep investments in building shells in residential and commercial buildings; in the absence of these investments the increase in space heating demand would be much larger. However, in the Severe climate scenario, heating demand stays approximately within today's level of 20 TWh through mid-century and reduces further beyond it. This is a result of warming of winter temperatures outweighing the significant increase in the number of homes and businesses meeting their heating needs with electricity.

The heat pumps installed also provide more efficient forms of cooling than conventional air conditioning units. As a result of heat pump installations coupled with investments in building shells and other energy efficiency measures, cooling demand grows more slowly in the Decarbonization Scenario than in the Reference Case, as shown in Figure 10. In the Decarbonization Scenario in 2100, space cooling demand ranges from 10 to 36 TWh across the climate scenarios whereas in the Reference Scenario, it ranges from 15 to 54 TWh.

Figure 9. Modeled Impacts of Climate Change on Heating Demand

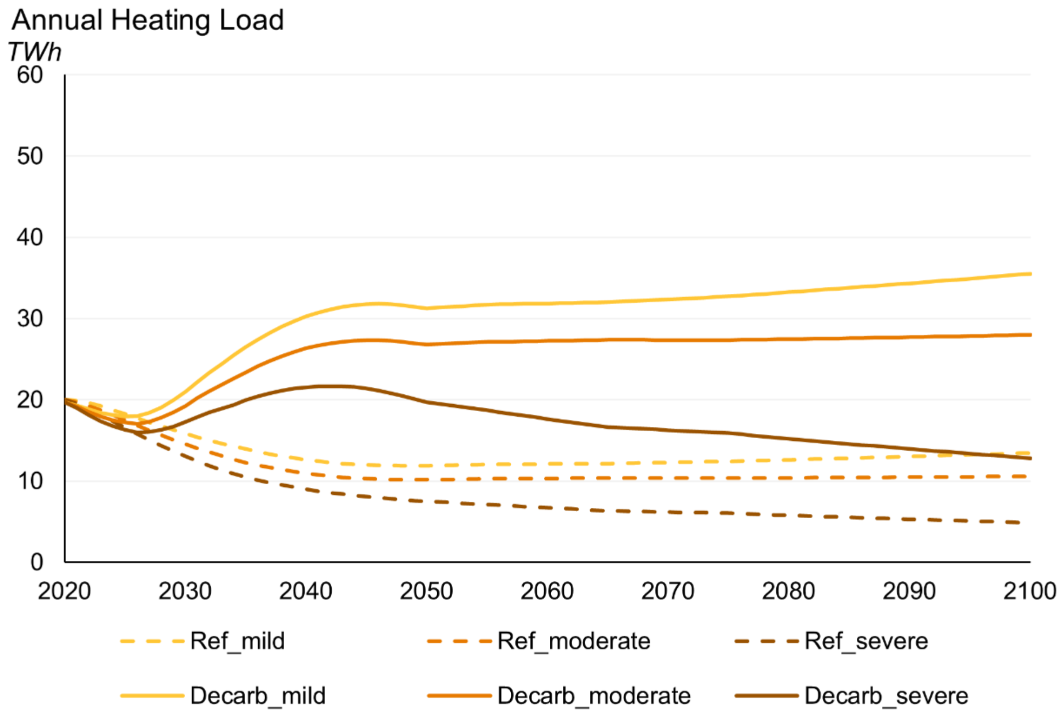


Figure 10. Modeled Impacts of Climate Change on Cooling Demand

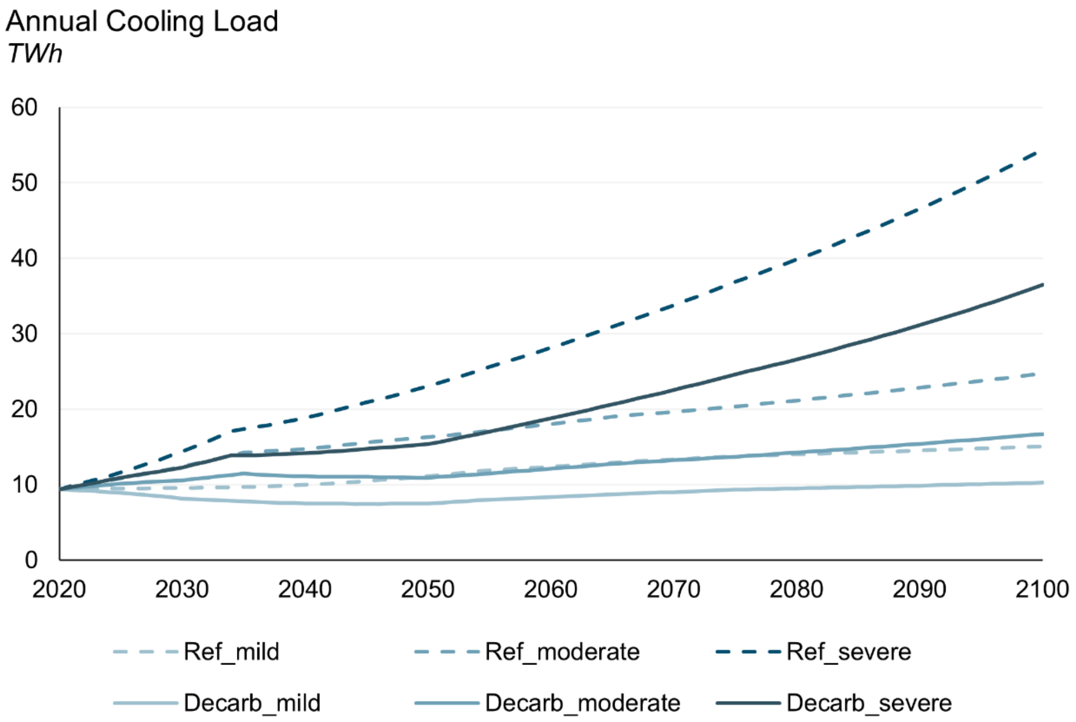
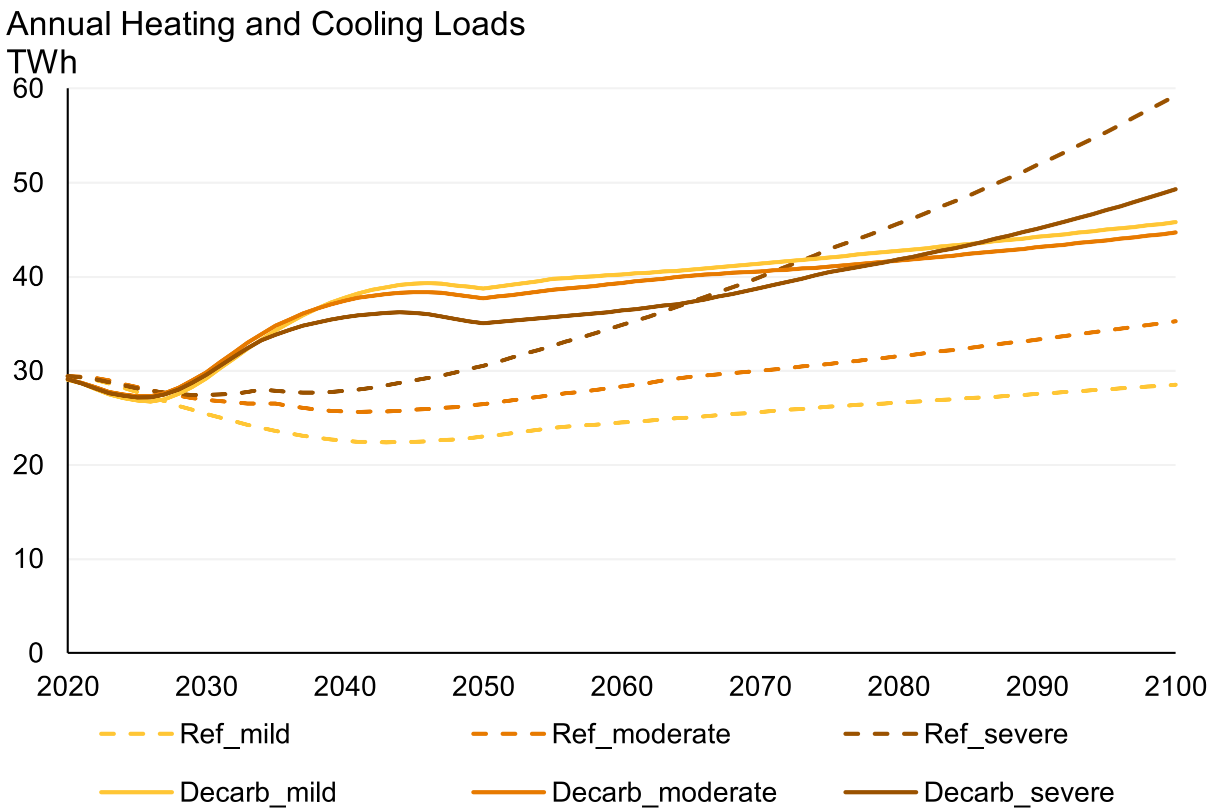


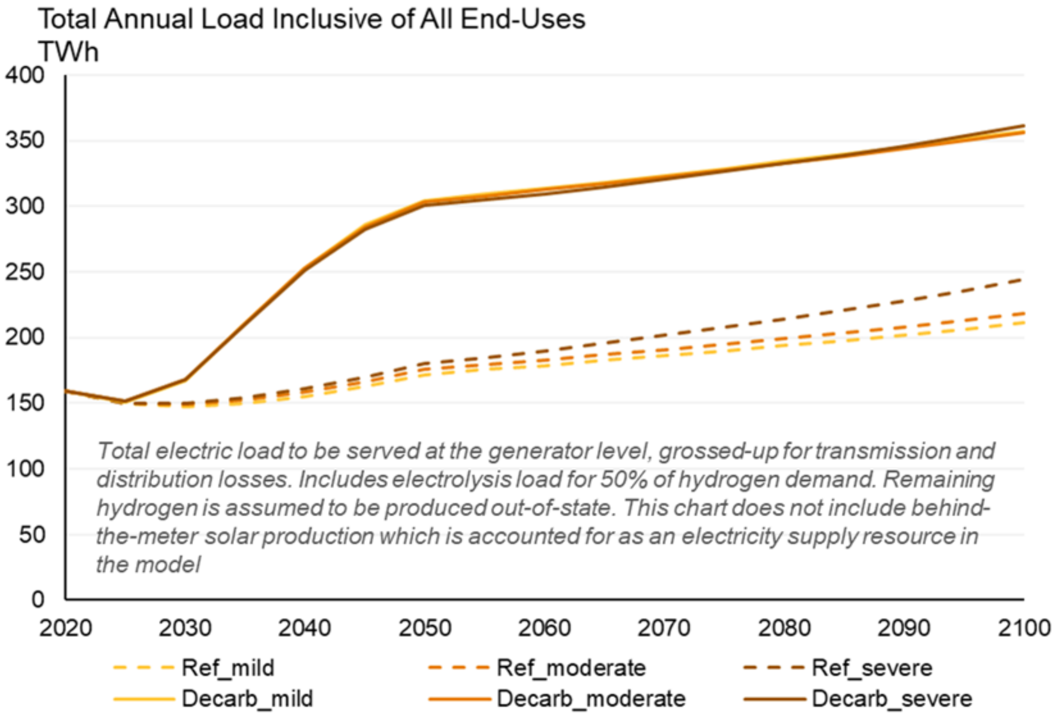
Figure 11. Modeled Impacts of Climate Change on Heating + Cooling Demand



Despite the additional electric heating demand introduced in the Decarbonization Scenario by 2100, the total space cooling and heating demand in the Reference Case is 10 TWh higher than that in the Decarbonization Scenario in the Severe scenario as shown in Figure 11. In other words, in the later period and in the presence of Severe climate change, less electricity is needed to meet the heating and cooling load of the nearly 92% of buildings that install a heat pump than the energy expended to heat and cool the less efficient building stock in the Reference Case with only 3% of buildings with heat pumps. This highlights the value of energy efficient heat pumps and building shell improvements in the Decarbonization scenario, which limit the increase in cooling demand relative to the Reference Case in which those measures are not adopted.

As shown in Figure 12, the total demand is higher in the Decarbonization scenario relative to Reference Case given the higher amount of electrification of different end-uses, including transportation and industry, assumed in the former. Total demand in the Reference scenario increases with increasing cooling demand driven by warming. In the Decarbonization scenario, the increase in cooling demand is offset by the decrease in electrified heating demand leading to the total demand not changing significantly and leading to a system that is more stable across climate outcomes. By 2100 the total demand in the Reference Case ranges from 211-244 TWh and that in the Decarbonization Scenario ranges from 357 to 361 TWh. The upper end in both scenarios is driven by higher space cooling demand, partially offset by reduced space heating demand. In 2100 in the Reference Mild Case, space cooling demand is 8% of the total demand. In the Severe scenario, it increases to 24% of the total, driven by lack of energy efficiency measures.

Figure 12. Modeled Impacts of Climate Change on Total Demand



2.1.2 Peak Electricity Demands

In addition to a warming trend across both the winter and summer months, the underlying temperature data shows a more pronounced impact on temperature extremes, consistent with the broader climate literature. This analysis framework allows us to capture both the impacts on annual demand as well as the impacts on daily and hourly demand, providing a detailed examination of the impacts of climate change on summer and winter peak demands and associated reliability challenges. Systems are typically designed for the higher of the two peaks and sufficient "headroom" exists to meet the lower one. However, in some cases, both peaks may be similar in magnitude and thus of equal importance.

In the Reference Case, and in the absence of a major policy shift towards electrification of the buildings and transportation sectors, the New York electricity system remains summer-peaking, and the impacts of climate change will place additional stress on summer peak demands over the forecast horizon. As shown in Figure 13, by the 2080s, severe climate change could drive up to a 10 GW difference in summer peaks relative to the mild climate change scenario. Summer peaks in the Reference Case are comparable to those in the Decarbonization Scenario, despite the higher levels of overall electrification in the latter. This is driven by the sharp increase in cooling load shown in Figure 10 without heat pumps and other energy efficiency measures. In the Severe Scenario, the Reference Case summer peak in fact exceeds that in the Decarbonization Scenario by 2 GW in 2080.

In the Decarbonization Scenario, under the Mild scenario, New York State's electricity system becomes winter-peaking by the mid-2030s as a result of the electrification of heating demand. By 2050, if winter extreme temperatures are relatively unaffected by climate change, as modeled in the Mild scenario, winter peaks are projected to reach about 47 GW.

However, in the Severe Climate scenario, winter extreme temperatures become significantly warmer due to climate change, leading to declines in winter peak demand even as the number of buildings being heated by electricity remains the same. At the same time, summer extreme temperatures increase, leading to the Severe / Decarbonization scenario becoming a dual-peaking system by 2050, and returning to a summer-peaking system in the 2080s.

In the Reference case, the annual peak is 46 GW and 55 GW in 2100 in the Moderate and Severe Climate scenarios respectively. It is very comparable to the annual peaks of 48 GW and 53 GW in the Decarbonization scenario in each corresponding climate scenario. In the Severe scenario, the peak in Reference starts exceeding that in Decarbonization starting 2060. Given the low heating, industry, and transportation electrification and low winter peak in the Reference Case, additional capacity is needed to simply meet the high cooling demand driven by less efficient ACs and lack of other energy efficiency measures described above. The Decarbonization scenario involves aggressive electrification of both heating and cooling, among other end-uses and investments in energy efficiency, which leads the system to a similar peak demand outcome as the Reference in the long run. However, the Decarbonization Scenario results in more "efficient" utilization of generation and transmission infrastructure because this infrastructure is leveraged to support both summer and winter peak demand. Additionally, while both cases require incremental investment to meet a similarly sized annual peak in the later period under moderate and severe climate change, there are significant incremental carbon and health benefits as documented in the Final Scoping Plan associated with the adoption of energy efficiency, higher electrification, and reliance on carbon-free resources in the Decarbonization Scenario.

Figure 13. Projected Summer and Winter Total Peak Demand by Infrastructure and Climate Scenario

2.2 Impacts of Climate Change on System Reliability Needs

As described in Section 2.1.2, the seasonality and magnitude of the peak load varies based on the level of warming and the level of electrification (including that of space heating and cooling) assumed. This in turn influences the periods when challenges to system reliability are the highest and the reliability value of different resources to meet these needs. Assessing the timing of reliability needs and the contributions of each individual resource and the contributions of the portfolio in aggregate are a critical component of ensuring that selected resource portfolios not only meet New York's policy requirements, but also maintain system reliability.

2.2.1 Impacts on System Reliability Needs

In order to ensure system reliability, the New York State Reliability Council conducts a reliability study each year to determine the amount of required resources needed to ensure system reliability, defined by criteria that specifies New York State should not experience a loss-of-load event more frequently than 1 day every 10 years (referred to as a 1-in-10 LOLE).[25] To meet this reliability threshold, the NYSRC sets a “reserve margin” which specifies the amount of capacity that the system should hold above expected peak demand; this reserve margin accounts for both required operating reserves and inter-annual load variability, i.e. the risk that actual demand could be considerably higher than the projected peak due to higher than expected summer temperatures. The planning reserve margin, or PRM, has in recent years been set at around 10% on a UCAP basis.[26]

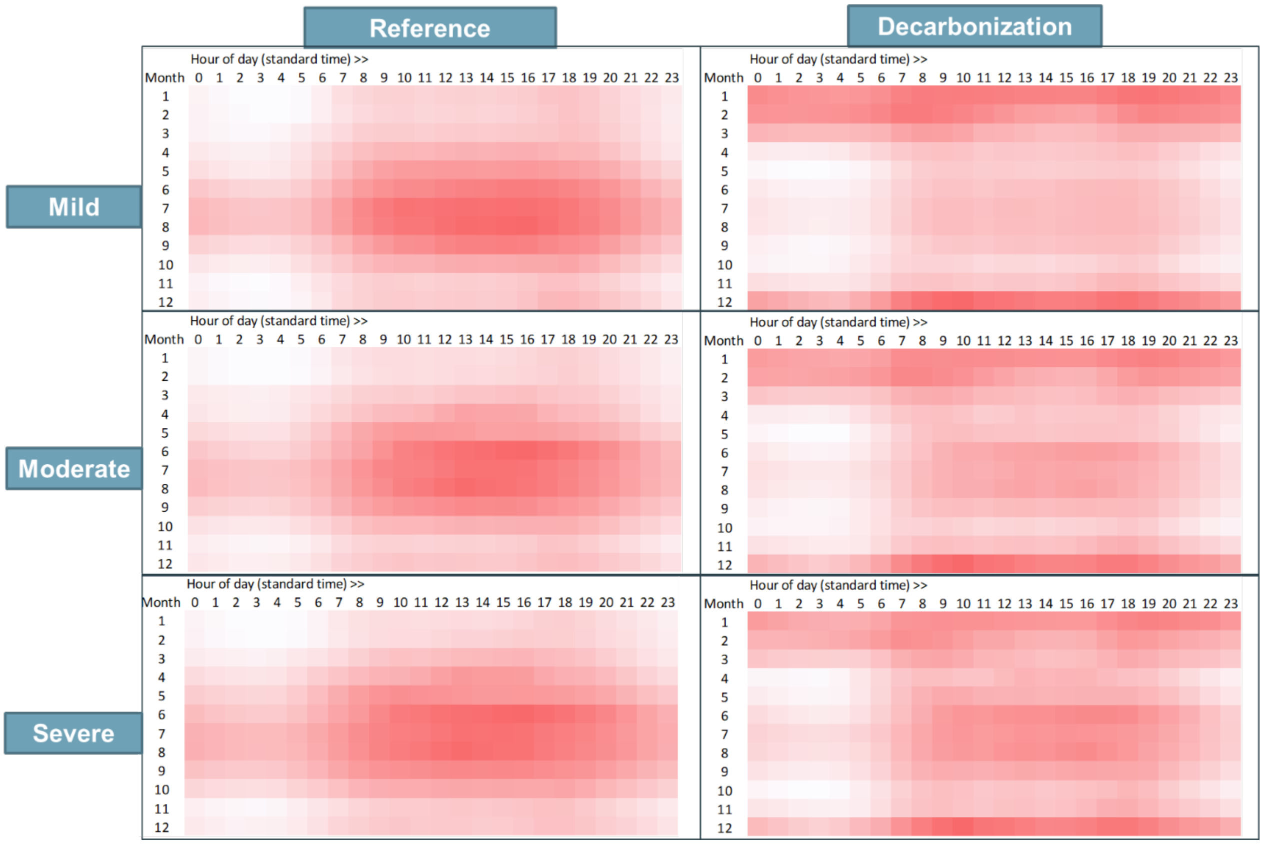
The analysis performed in this study finds a similar target PRM in the Mild / Reference Case, but as temperatures increase and the variability between summer peak temperatures increase, the reserve margin increases in the Moderate and Severe / Reference Case accordingly, from 10% to 12%. However, when examining the Decarbonization Scenario, the analysis in RECAP indicates that interannual variability between winter peaks is considerably greater. Higher variability in winter minimum temperatures and sensitivity of heat pump performance to extreme cold (which may also require switching to inefficient backup electric resistance heaters beyond a certain threshold) may both contribute to this. As a result, when determining the amount of resources that would be required above “median” peak winter conditions, a higher reserve margin is needed in the Mild / Decarbonization Scenario of about 18% in 2050. The reserve margin requirements as a percentage of peak load decline in the Moderate nd Severe / Decarbonization scenarios as winter gets milder and the system shifts towards a dual-peaking system, in which interannual load variability is not as significant, resulting in a drop from 18% to 11%. Additional energy efficiency and conservation measures assumed in the Decarbonization scenario also help limit demand on the hottest days. The target reserve margin by Infrastructure and Climate Scenario is presented in Table 5.

Table 5. Reserve Margin Requirements under Each Infrastructure and Climate Scenario

Infrastructure Scenario	Climate Scenario	Target PRM in 2050
Reference	Mild	10% (Current NYISO PRM)
	Moderate	11%
	Severe	12%
Decarbonization	Mild	18%
	Moderate	15%
	Severe	11%

The timing of peak system demand can be observed in Figure 14. In the Reference scenario, the demand is highest in the summer hours, and the summer peak grows from the Mild / Reference Case to the Severe / Reference Case as shown in Figure 13. In the Mild / Decarbonization Scenario, electrification of space heating combined with winter extreme temperatures shifts the peak demand and reliability need to the winter. With warming winters and summers, the peak demand hours and reliability risk gradually spread back into the summer with the Moderate / Decarbonization Scenario still staying winter peaking while the Severe / Decarbonization Scenario is dual peaking. The highest demand is generally observed from hours 7 to 21 in both summer and winter peaking systems. Extreme temperatures lead to high cooling/heating demand, which - when coincident with other types of demand during people's waking hours - leads to the system peak. In some instances, extreme temperatures and relatively high demand have been observed through the night speaking to the long duration of some extreme weather events captured that are important to plan for.

Figure 14. Month-Hour Heatmap of Peak Demand in Each Infrastructure and Climate Scenario in 2050



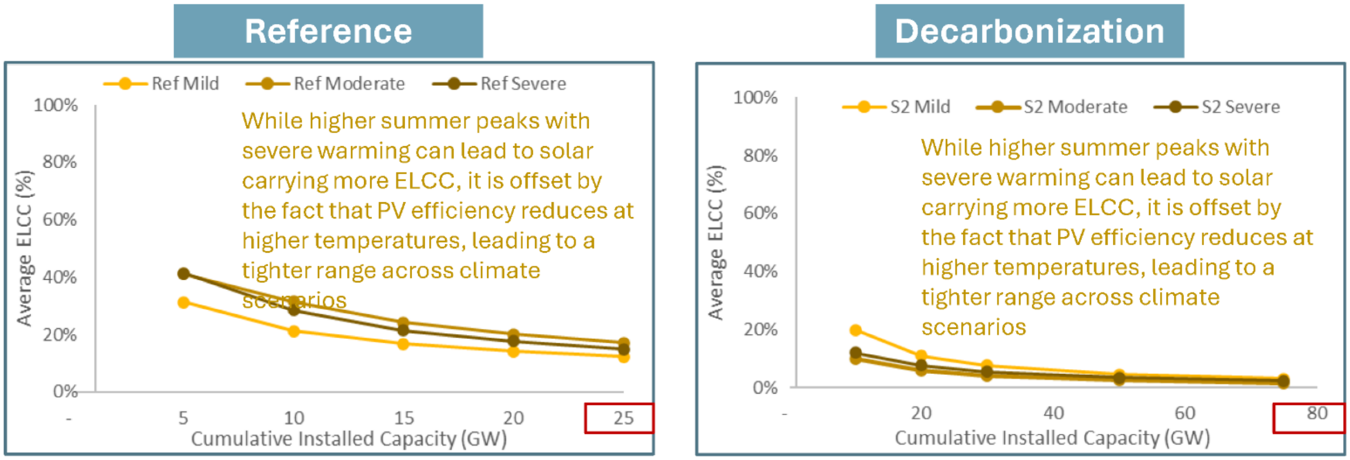
2.2.2 Impacts on Renewable and Storage ELCCs

The impacts of increased temperatures on electricity demand also leads to changes in the contributions of each resource towards the system's capability to reliably meet demand, because changes in the timing of system demand – both seasonally and within the day – lead to shifts in how well the outputs of each resource align with peak demand. In addition, the impact of temperature on the output profile of solar PV impacts the contributions of that resource towards system reliability. Through simulations of the system over hundreds of years of plausible weather conditions, RECAP captures the reliability contributions of each resource under each climate scenario using an ELCC methodology, which represents the equivalent "perfect" capacity each resource can substitute for. The weather conditions modeled include cloudy days and periods with wind lulls to ensure that the solar and wind ELCCs reflect the effective capacity they can provide in such periods so the overall resource portfolio can be built to maintain reliability. However, these events were informed by those historically observed. Variables besides temperature were not adjusted for future climate impacts given reasons in section 1.1.4

2.2.2.1 Impact on Solar ELCCs

In the Reference scenario, the demand is highest in the summer hours, when solar production is high. The summer peak grows from mild to severe. While higher summer peaks with severe warming can lead to solar carrying more ELCC, it is offset by the fact that PV efficiency reduces at higher temperatures, leading to a tighter range across climate scenarios as shown in Figure 15. In the Decarbonization scenario, electrification of space heating leads to higher demand in the winter, when solar production is typically lower. This leads to lower solar ELCCs in this scenario relative to Reference in each climate scenario. Variation between climate scenarios is minimal. The first tranche of solar gets higher ELCC in the Mild scenario driven by high solar production on some cold winter mornings, but later tranches get very similar ELCCs across climate scenarios. Across all scenarios adding more solar leads to the net peak shifting outside of daylight hours leading to reducing marginal ELCC for solar.

Figure 15. Solar ELCCs across All Scenarios in 2050



While higher summer peaks with severe warming can lead to solar carrying more ELCC, it is offset by the fact that PV efficiency reduces at higher temperatures, leading to a tighter range across climate scenarios

While higher summer peaks with severe warming can lead to solar carrying more ELCC, it is offset by the fact that PV efficiency reduces at higher temperatures, leading to a tighter range across climate scenarios

Existing hydro and pumped storage, 10 GW each of LBW and OSW in starting portfolio

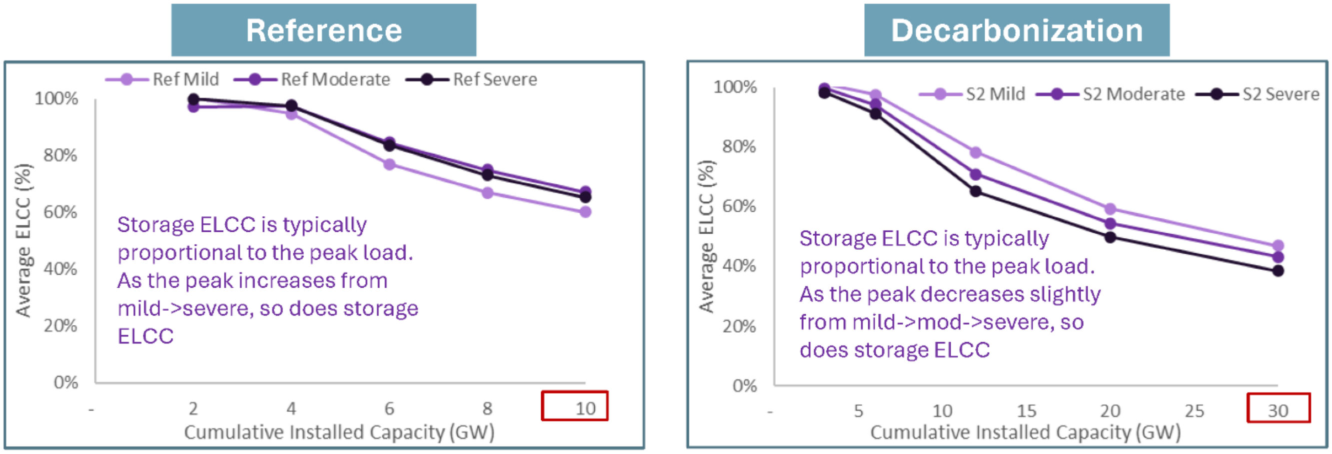
Existing hydro and pumped storage, 20 GW each of LBW and OSW in starting portfolio

Note the difference in X axis

2.2.2.2 Impact on storage ELCCs

Storage ELCCs typically increase as the peak of the system increases. As a result, in the Reference scenario, storage ELCC is highest in the Severe scenario, and in the Decarbonization scenario, it is highest in the mild scenario, as shown in Figure 16. Solar and storage can interact to provide more value in combination than they can by themselves. To capture this interactive value, a solar-storage ELCC "surface" was constructed using different combinations of solar and storage.

Figure 16. 4-Hr Storage ELCCs across All Scenarios in 2050



Existing hydro and pumped storage, 10 GW each of LBW and OSW in starting portfolio

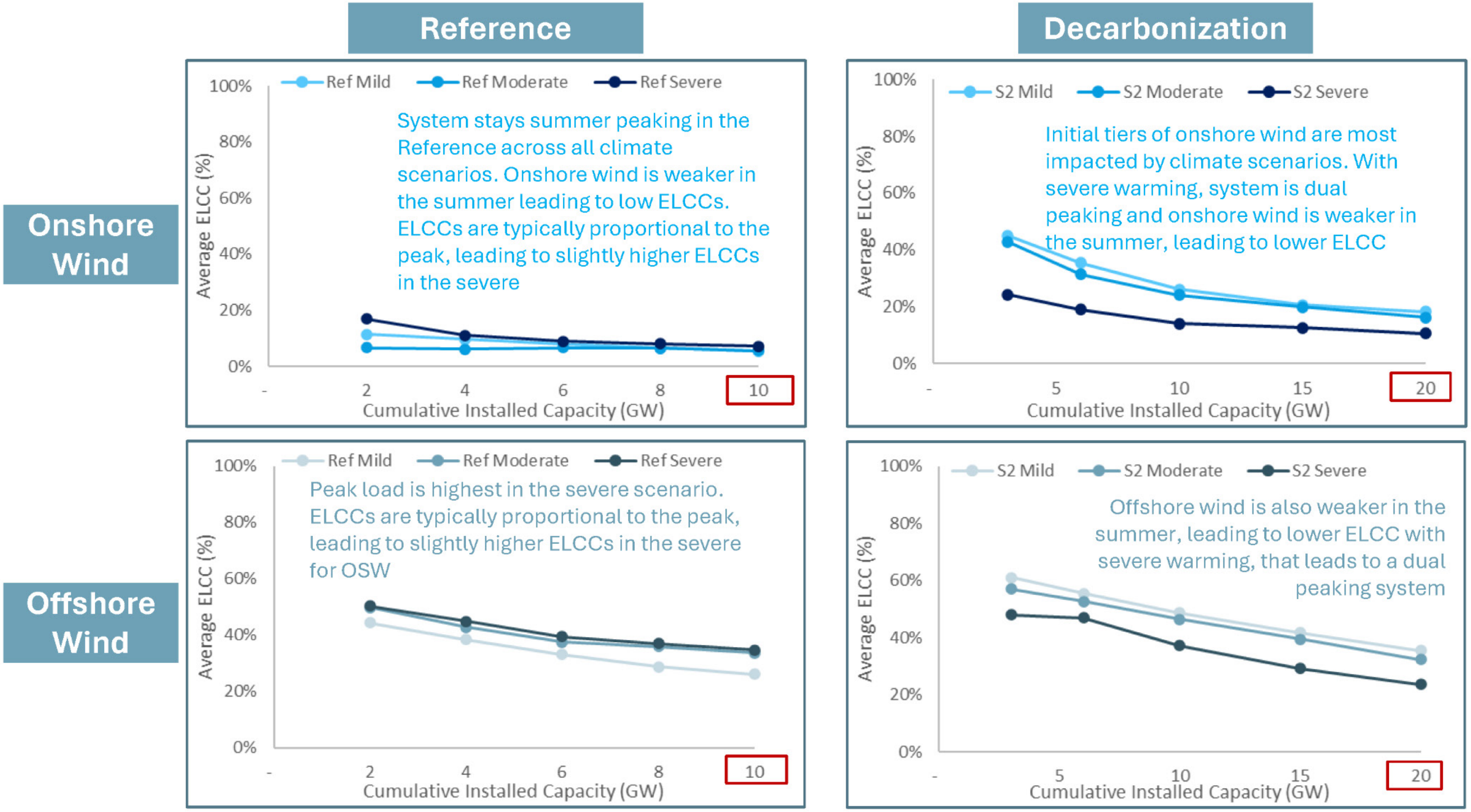
Existing hydro and pumped storage, 20 GW each of LBW and OSW in starting portfolio

Note the difference in X axis

2.2.2.3 Impact on Wind ELCCs

The system stays summer peaking in the Reference across all climate scenarios. Onshore wind is weaker in the summer leading to lower ELCCs relative to solar, as shown in Figure 17. ELCCs are typically proportional to the peak coincidence, leading to slightly higher ELCCs in the Severe scenario. Since onshore wind is better aligned with winter peak load hours, it gets a higher ELCC in the winter peaking mild and moderate scenarios in the Decarbonization scenario. With severe warming, the system is dual peaking leading to lower ELCC. Offshore wind is also better aligned with winter peak hours and thus shows the same ELCC dynamics as onshore wind. However, the absolute magnitude of Offshore wind ELCC is higher than that of Onshore wind due to the higher and more consistent generation offshore. As with solar and storage, a surface was also built to capture the interactive value between the two sources of wind. However, this interaction is not as significant as that between solar and storage.

Figure 17. Wind ELCCs across All Scenarios in 2050



System stays summer peaking in the Reference across all climate scenarios. Onshore wind is weaker in the summer leading to low ELCCs. ELCCs are typically proportional to the peak, leading to slightly higher ELCCs in the severe

Initial tiers of onshore wind are most impacted by climate scenarios. With severe warming, system is dual peaking and onshore wind is weaker in the summer, leading to lower ELCC

Peak load is highest in the severe scenario. ELCCs are typically proportional to the peak, leading to slightly higher ELCCs in the severe for OSW

Offshore wind is also weaker in the summer, leading to lower ELCC with severe warming, that leads to a dual peaking system

Existing hydro and pumped storage in starting portfolio

Existing hydro and pumped storage in starting portfolio

Note the difference in X axis

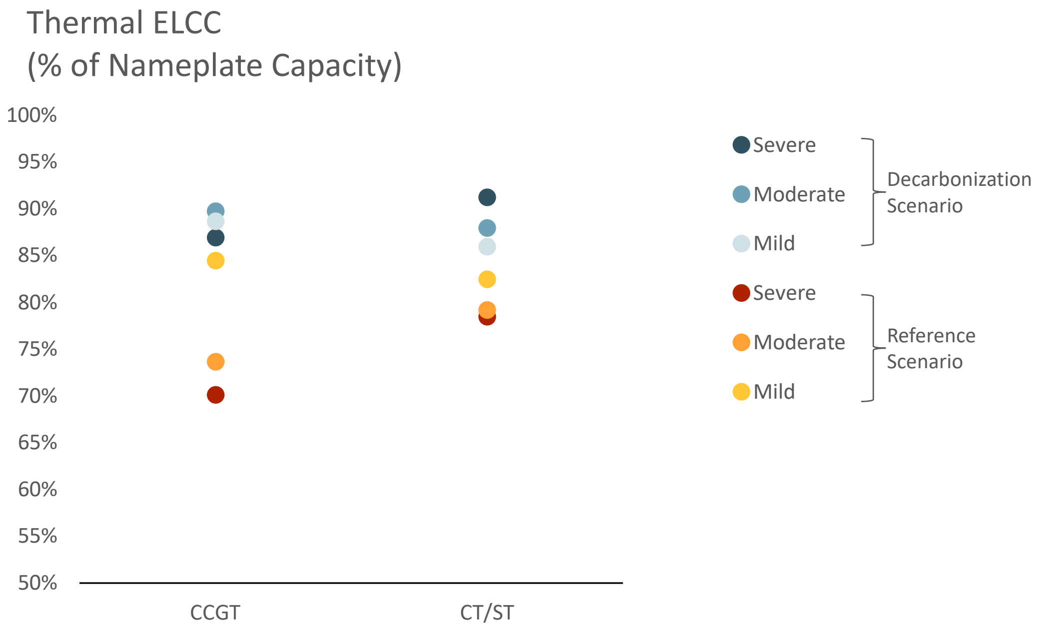
2.2.3 Impacts on Thermal ELCCs

As discussed in Section 1.1.3.3, there are two impacts of temperature on the performance of thermal units: (1) an ambient temperature derate due to lower cooling efficiency at higher temperatures and (2) an increase in forced outages during extreme cold and extreme heat. This study leverages hourly temperature forecasts by climate scenario to develop unique hourly derates and forced outage rates for each climate scenario. This informs hourly thermal availability in RECAP. RECAP is also fed with hourly electricity demands under each of the two infrastructure scenarios. This setup is used to assess the ELCC of thermal resources under each infrastructure and climate scenario.

The Reference case is summer peaking and thus thermal availability during hot summer days impacts its ELCC. In the Reference Case, as temperatures increase from the Mild to Severe climate scenarios, the availability of thermal units declines under extreme heat conditions. Both increased forced outage risk and higher ambient temperature derates may contribute to this decline. As a result, the ELCC of thermal resources reduces from Mild to Severe.

In the Decarbonization Scenario, the system is winter peaking in the Mild and Moderate scenario with colder temperatures in the Mild. This results in higher thermal forced outage risk during cold days with high heating demand and thus lower thermal ELCCs in the Mild relative to Moderate. The Severe scenario is dual peaking. Forced outage risk reduces meaningfully in warmer winters. The reduced risk may or may not be fully offset by higher forced outage risk and ambient temperature derates during warmer summer hours. Therefore, the thermal ELCCs in the Severe scenario vary based on characteristics of each individual thermal resource type across the two seasons. Combined Cycle Gas Units get slightly lower ELCCs and Combustion Turbines get slightly higher ELCCs in the Severe relative to the Mild.

Figure 18. Projected Thermal ELCCs by Infrastructure and Climate Scenario in 2050



In the Scoping Plan, which the Mild scenario is based on, UCAP%s established by the NYISO were used. This study continues to use these UCAP% for the Mild scenario and adjusts them for the Moderate and Severe scenarios. The ratio of Moderate to Mild ELCCs and Severe to Mild ELCCs calculated in this study were used for this adjustment. A 100% multiplier implies UCAP% from NYISO is used as is.

Table 6. Thermal UCAP% Multipliers Calculated by Resource Type, Infrastructure, and Climate Scenario

Resource Type	Infrastructure Scenario	Climate Scenario	NYISO UCAP% Multiplier
CCGT	Reference	Mild	100%
		Moderate	87%
		Severe	83%
	Decarbonization	Mild	100%
		Moderate	101%
		Severe	98%
CT/ST	Reference	Mild	100%
		Moderate	96%
		Severe	95%
	Decarbonization	Mild	100%
		Moderate	102%
		Severe	106%

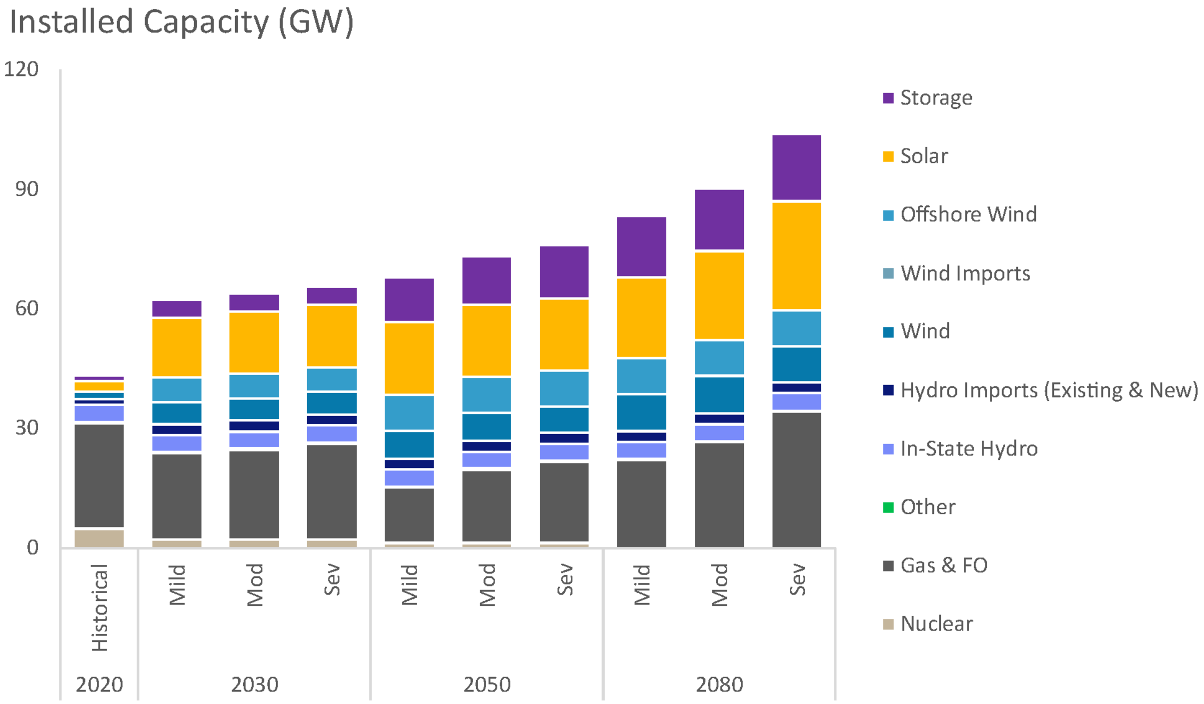
2.3 Impacts of Climate Change on Future Resource Portfolios

The results of the preceding sections, using temperature projections from the GCMs to simulate the impacts of climate change on hourly electricity system demands; transfer capacity of new local transmission; and the reliability contributions of wind, solar, storage, and thermal generators, serve as inputs into the capacity expansion modeling exercise. In this way, the resulting portfolios are optimized to meet electricity demand while maintaining reliability by taking directly into account the impacts of climate change on loads, resources, and transmission.

2.3.1 Reference Case Portfolios

In the Reference Case, electrification of space heating is minimal, and the system remains summer peaking. As a result of increased warming in the Moderate and Severe scenarios, the increase in demand driven by rising summer temperatures results in a need for additional capacity to meet reliability needs, as well as additional renewable energy generation required by the 70% Clean Energy Standard. To meet increasing reserve margin requirements, driven both by increases in system peaks as well as increases in load variability that lead to an increased PRM requirement, the system builds over 3 GW of additional gas-fired capacity, which are allowable due to the exclusion of the Climate Act 100x40 requirement in this case and 1 GW of additional battery storage capacity by 2100 in the Moderate / Reference Case relative to the Mild / Reference, and nearly 12 GW of gas-fired capacity and nearly 6 GW of battery storage capacity in the Severe / Reference relative to the Mild. Additionally, to maintain the 70% clean energy requirements under increases in annual load, solar capacity is the primary resource selected as an increasing proportion of load occurs in the summer and is most coincident with solar output. As a result, an additional 0.4 GW of solar capacity is built by 2100 in the Moderate / Reference Case, and nearly 8 GW of additional solar capacity is built by 2100 in the Severe / Reference Case, compared to the Mild / Reference Case.

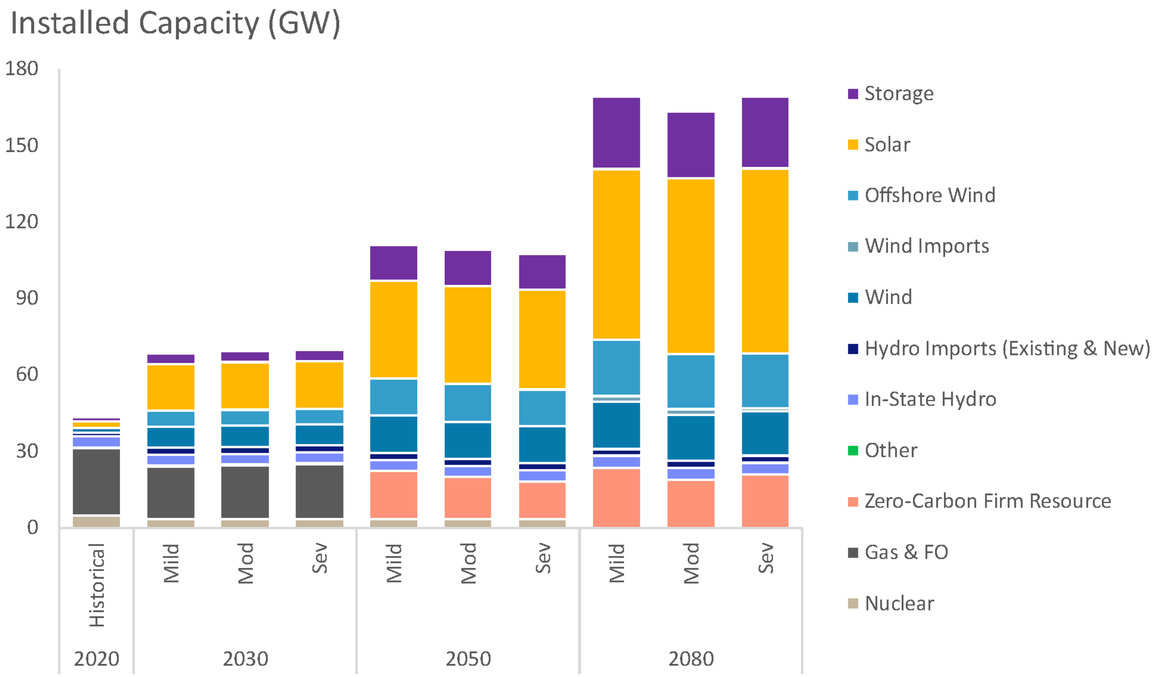
Figure 19. Comparison of Climate Change Scenarios under the Reference Case



2.3.2 Decarbonization Scenario Portfolios

In the Decarbonization Scenario, winter demand increases substantially due to electrification of building space heating, and as a result New York State transitions to a winter-peaking system in the mid-2030s in the Mild / Decarbonization scenario. However, under each climate scenario, increased warming leads to both a decrease in winter heating demand and a significant increase in summer cooling demand, which are largely offsetting on an annual demand basis, but lead to significant declines in overall peak load compared to the Mild / Decarbonization scenario. As a result, the primary drivers of changes in the resource portfolio driven by climate change are: (1) declines in system reserve margin requirements which lead to a lower build-out of zero-carbon firm capacity and battery storage, and (2) changes in the timing of demand that leads to higher coincidence of demand with solar output and lower coincidence of demand with wind output. In the Moderate / Decarbonization Scenario, the primary shift occurs in the build-out of firm capacity and battery storage, with nearly 7 GW less zero-carbon firm capacity and 2 GW less battery storage by 2100 and impacts on the renewable resource mix are negligible relative to the Mild / Decarbonization Scenario. In the Severe / Decarbonization Scenario, there is a smaller decline in effective capacity requirement by 2100 relative to the Mild because of significant increases in summer peak demand, and as a result there is a decline of 4 GW of zero-carbon firm capacity by 2100 relative to the Mild / Decarbonization portfolio. In addition, the shift towards summer demand from an annual energy perspective is more pronounced in the Severe / Decarbonization Scenario, which leads to a significant shift in the renewable resource mix, with nearly 9 GW of additional solar capacity and 2 GW of lower land-based and offshore wind capacity relative to the portfolio in the Mild Decarbonization Scenario.

Figure 20. Comparison of Climate Change Scenarios under the Decarbonization Scenario



2.4 Impacts of Climate Change on System Operations

This section highlights the challenges the system faces on the extreme temperature days in both seasons, under all infrastructure and climate scenarios modeled, using a 90th percentile temperature in the summer and a 10th percentile temperature in the winter in 2050. Figure 21 shows the 1-in-10 winter peak day in the Decarbonization scenario that assumes high levels of electrification. Cold days lead to high demand driven by space heating and may also experience more thermal outages. In the Mild scenario, winter extremes like those observed historically are simulated. The statewide average 10th percentile temperature is -11F, which increases demand to 59 GW. 16% of the thermal fleet, simulated as hydrogen burning gas turbines may be unavailable due to forced outages. As the 1-in-10 day gets warmer from mild to severe, the peak load and thermal outage risk also reduces.

Figure 21. 10th Temperature Percentile Winter Day in the Decarbonization Scenario in 2050

Mild

10th Temperature Percentile (F)	-11
Peak Demand on this Day (GW)	59
Thermal Nameplate (GW)	23
Thermal Unavailability in this Hour (% of Nameplate)	16%

Moderate

10th Temperature Percentile (F)	0
Peak Demand on this Day (GW)	57
Thermal Nameplate (GW)	20
Thermal Unavailability in this Hour (% of Nameplate)	14%

Severe

10th Temperature Percentile (F)	14
Peak Demand on this Day (GW)	52
Thermal Nameplate (GW)	19
Thermal Unavailability in this Hour (% of Nameplate)	9%

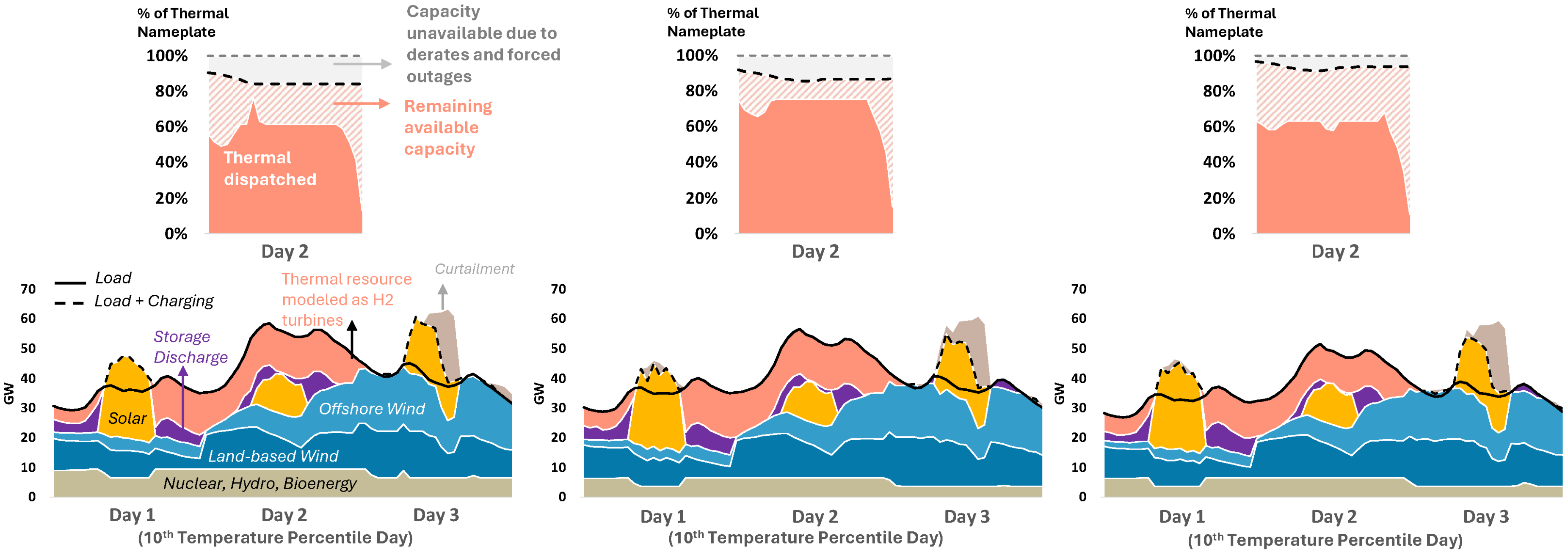


Figure 22. 90th Temperature Percentile Summer Day in the Decarbonization Scenario in 2050

Mild

90th Temperature Percentile (F)	90
Peak Demand on this Day (GW)	40
Thermal Nameplate (GW)	23
Thermal Unavailability in this Hour (% of Nameplate)	16%

Moderate

90th Temperature Percentile (F)	104
Peak Demand on this Day (GW)	41
Thermal Nameplate (GW)	20
Thermal Unavailability in this Hour (% of Nameplate)	27%

Severe

90th Temperature Percentile (F)	106
Peak Demand on this Day (GW)	42
Thermal Nameplate (GW)	19
Thermal Unavailability in this Hour (% of Nameplate)	28%

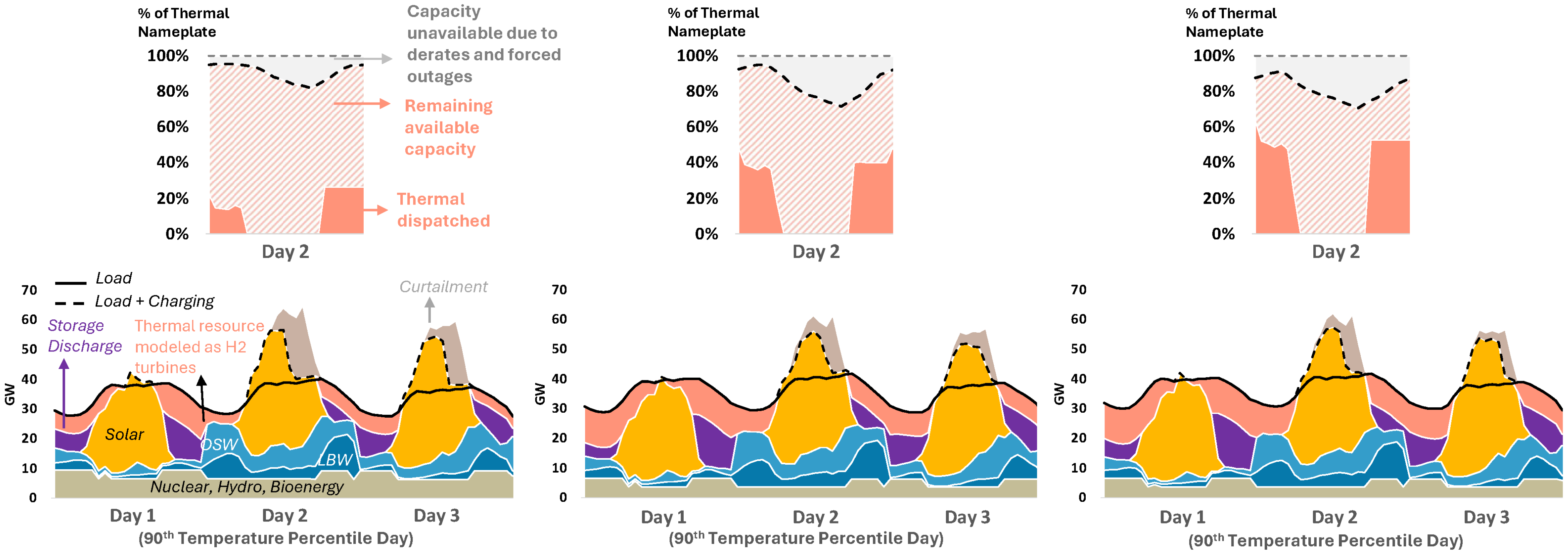


Figure 22 shows the 90th percentile summer day in the Decarbonization Scenario. The first observation is that the temperature and demand consistently stay high in this stretch, speaking to the possibility of multi-day heat waves that have already been observed and may get worse with warming. While the hottest temperature attained increases meaningfully from mild to severe, the peak demand does not increase as drastically. The switch from less efficient ACs to highly efficiency heat pumps alongside other efficiency and conservation measures assumed also helps limit the peak increase. The thermal fleet is impacted by both higher forced outage risk and higher ambient temperature derates which both increase because of warming from 16% to 28% from the mild to the severe scenario. Solar PV efficiency drops by 4% in the Severe scenario relative to the Mild. In addition, transmission lines also need to be oversized to compensate for the derates expected, as described earlier.

Figure 23 shows the 90th temperature percentile summer day in the Reference Scenario, which assumes lower levels of electrification, energy efficiency, conservation and higher reliance on fossil-based power given absence of a net-zero goal. This system is impacted similarly by warming, with higher cooling demand and increased thermal forced outages and derates. Relying on less efficient ACs and absence of other efficiency measures drives a peak increase of 11% from mild to severe. Given the heavier reliance on fossil fueled generation that can be severely impacted at high temperatures, when demand is also high, the system may be very stressed as reflected in the low amount of remaining available (thermal) capacity in the early evening hours.

Figure 23. 90th Temperature Percentile Summer Day in the Reference Scenario in 2050

Mild

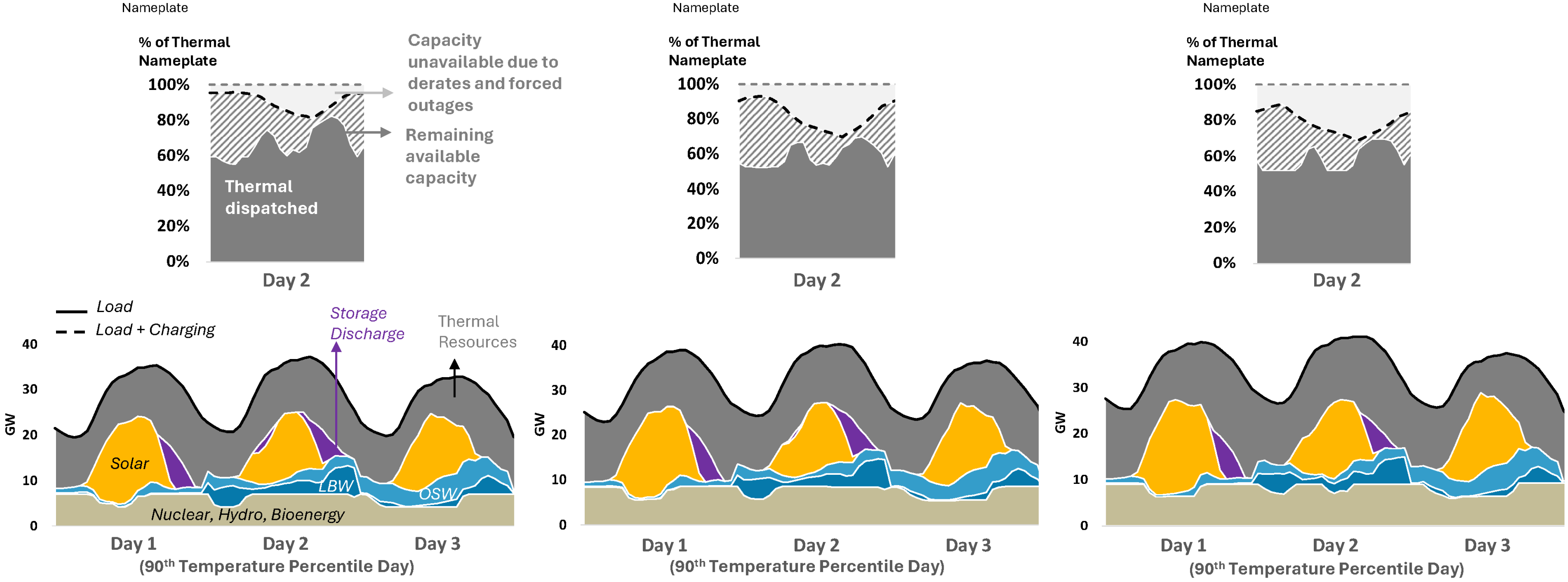
90th Temperature Percentile (F)	90
Peak Demand on this Day (GW)	37
Thermal Nameplate (GW)	18
Thermal Unavailability in this Hour (% of Nameplate)	19%

Moderate

90th Temperature Percentile (F)	104
Peak Demand on this Day (GW)	40
Thermal Nameplate (GW)	23
Thermal Unavailability in this Hour (% of Nameplate)	30%

Severe

90th Temperature Percentile (F)	106
Peak Demand on this Day (GW)	41
Thermal Nameplate (GW)	26
Thermal Unavailability in this Hour (% of Nameplate)	31%



There is a lot of uncertainty associated with how climate change may impact extreme cold weather events. While warming may make winters milder overall, extremes akin to those experienced in the past may still occur infrequently and may thus be important to continue planning for. In addition to supply-side measures, demand side measures like investing in energy efficiency and conservation, in the form of deploying more efficient heat pumps, building shell improvements etc. are also key to maintaining reliability.

2.5 Impacts of Climate Change on System Costs

The cost analysis represents the culmination of the preceding sections by aggregating the increases in both infrastructure investments and operating costs necessary to reliably operate the electricity system under each climate scenario, while meeting the relevant policy requirements in the Reference Case and Decarbonization Scenario, respectively. The analysis also considered changes to operating costs outside of the electricity sector as a result of the impacts of warming on heating demand.[27]

2.5.1 Impacts on Electricity System Costs

Electricity system costs increase significantly in the Moderate / Reference Case and Severe / Reference Case, increasing by 7% and 15% respectively on an NPV basis, relative to the Mild / Reference Case. These cost impacts are driven by the increased resource builds described in the above section, as well as additional transmission investments required to provide the same level of deliverability on the system under increasing temperatures. Notably, the impacts of increasing temperatures on electricity system costs rise substantially over the forecast period, particularly in the Severe climate scenario, where annual cost impacts more than double between 2050 and 2100, increasing from 15% in 2050 to a 33% cost increase in 2100, relative to the Mild / Reference scenario.

In the Decarbonization Scenario, the impacts of climate change on total electricity system costs are nearly negligible because both cooling needs and heating needs are being met with electricity. Warming winter temperatures and the declines in winter heating demand offset the increases in summer temperatures and associated increases in summer cooling demand. Reserve margin requirements to maintain system reliability are lower in the Severe / Decarbonization Scenario and Moderate / Decarbonization Scenario relative to the Mild / Decarbonization Scenario. As a result, declines in the build-out of zero-carbon firm capacity and battery storage lead to minor reductions in the costs of the overall portfolio. The cost impacts of climate change in the Decarbonization Scenario vary in direction between periods and are primarily driven by whether the system is summer or winter-peaking in a given period. In the near-term through 2030, annual costs increase as a result of rising summer temperatures in both the Moderate and Severe / Decarbonization Scenarios. In the medium-term through 2050, annual costs decrease because the system is winter-peaking and the reduction in winter peak demand leads to net declines in cost. In the Moderate / Decarbonization Scenario, the system remains winter-peaking past 2050 and becomes dual-peaking by 2100, and as a result, continued increases in winter temperatures and corresponding reductions in aggregate system needs lead to continued declines in cost. In the Severe / Decarbonization Scenario, the system becomes summer-peaking past 2050 due to both increases in summer temperatures as well as more pronounced reductions in winter heating demand, and as a result system costs start to increase again as the increases in summer temperatures drive system peaks back up.

The electric grid is larger and more heavily utilized in the Decarbonization Scenario given higher levels of electrification across the economy, including buildings, transportation, and industry. This also results in a higher cost relative to the Reference Case. However, the total cost is more stable across climate scenarios. Given the offsetting impacts of reduced heating demand and increased cooling demand, and the energy efficiency investments that keep the cooling demand increase in check, the Decarbonization Scenario sees a 1% decrease in costs over the entire modeling period in the Moderate and Severe scenarios relative to the Mild. In contrast, the Reference Case costs increase 7% to 15% relative to the Mild on an NPV basis between now and 2100, with even more pronounced cost impacts in the second half of the century.

Table 7. Electricity System Costs

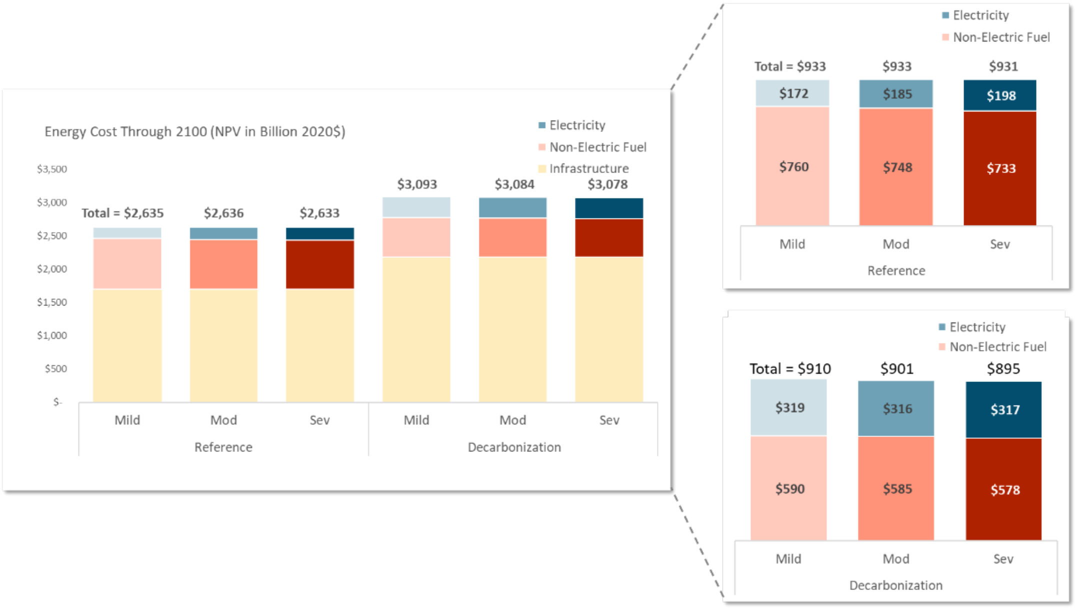
Electric System Costs ($M 2020)					
	2030	**2050**	**2080**	**2100**	**NPV**
Reference Case					
Mild, Reference	5,178	7,755	9,040	10,011	172,376
Moderate, Reference	5,389	8,460	9,785	10,806	185,166
Mod / Mild (%)	*4%*	*9%*	*8%*	*8%*	*7%*
Severe, Reference	5,526	8,891	11,416	13,328	198,039
Sev / Mild (%)	*7%*	*15%*	*26%*	*33%*	*15%*
Decarbonization Scenario					
Mild, Decarbonization	6,316	17,075	21,191	23,697	319,315
Moderate, Decarbonization	6,398	16,791	20,745	22,827	315,890
Mod / Mild (%)	*1%*	*-2%*	*-2%*	*-4%*	*-1%*
Severe, Decarbonization	6,416	16,640	21,394	24,564	316,891
Sev / Mild (%)	*2%*	*-3%*	*1%*	*4%*	*-1%*

2.5.2 Impacts of Climate Change on Non-Electric Costs

The policy scenarios also vary in their reliance on fuels to meet energy demand. Non-electric fuel costs were estimated for the residential, commercial, transportation and industrial sectors. In the Reference Case, there is little electrification of building heating demand, and heating needs continue to be met with fuels such as natural gas and fuel oil. As a result, while higher summer temperatures increase electric system costs by up to $26B, from $172B to $198B in the Reference Case under Severe warming, higher winter temperatures and declines in heating demands lead to declines in the fuel costs to meet building heating demands of as much as $27B, from $760B to $733B.

In contrast, in the Decarbonization scenario, in which almost all building heating needs are met with electricity, winter demand is a primary driver of electricity system costs, and consequently electricity costs and non-electric energy costs both decline in the Moderate and Severe scenarios relative to the Mild. Electricity cost declines from $319B to $316B from the Mild to Moderate climate scenarios, and costs declines are slightly lower to $317B in the Severe climate scenario, given the late century cost increases due to the impacts of the summer peak under severe warming, as noted earlier. Non-electric fuel cost reduces from $590B to $578B due to reduced heating need between the Mild and Severe Climate scenarios; in aggregate, the energy costs–including both electric system plus non-electric fuel cost–experience a reduction from $910B to $895B.

Figure 24. Energy Costs, NPV



The infrastructure cost shown in Figure 24 includes the cost of heating and cooling equipment, vehicles, energy efficiency measures, etc. and is higher in the Decarbonization Scenario relative to the Reference Case. These investments contribute to the achievement of New York State's climate goals and are partially offset by the reductions in energy costs (combined electric plus fuel costs), as the energy costs in the Decarbonization Scenario are $32B to $36B lower than energy costs in the Reference Case across the 3 climate scenarios. This reduction in energy costs is achieved with substantially higher reliance on carbon-free electricity and fuels that also help reduce emissions and drive associated health benefits. The impact of warming temperatures on energy costs, while meaningful in absolute terms, is a small fraction of the total.

3 Conclusions and Limitations

3.1 Conclusions

This report builds on ongoing energy system planning efforts in New York State by performing a detailed analysis of the impacts of climate change on the State's energy system. The study coupled (1) temperature projections under three climate change scenarios, and (2) the impacts of changes in temperature on key components of energy supply and demand, leveraging the Integration Analysis modeling toolkit to examine a Reference case and a Climate Act-compliant Decarbonization scenario.

The study finds that in addition to driving significant increases in annual average temperatures, climate change is projected to impact seasonal extremes, leading to temperature increases during hot summer days while reducing the severity of extreme cold during the winter. The impacts of warming temperatures on heating and cooling demand, transmission ampacity, thermal generator output, and solar output are well-documented and thus accounted for in this study.

Climate-driven warming will have divergent impacts on seasonal electricity demands, increasing cooling demand and decreasing heating demand. The resulting impacts on the energy system will be highly dependent on the extent of New York State's investments in building decarbonization. In addition to being a key pillar of New York State's decarbonization strategies, energy efficiency and the adoption of efficient heat pumps may also have the additional benefit of mitigating the impacts of extreme summer warming. Without these investments, the summer peak in the Reference scenario increases substantially under increased warming. In the late century, it in fact exceeds the annual peak of the Decarbonization scenario, despite the latter having higher levels of electrification of end uses in buildings, transportation, and industry to enable decarbonization. In the Decarbonization scenario, both the summer and winter peaks stay similar in magnitude under increased warming, leading to a more efficient use of the resource capacity.

The challenge associated with maintaining system reliability during summer peak demand periods is compounded by the impacts of rising temperatures on electric infrastructure. Warming also increases derates and forced outage risk for combustion-based power plants during the summer (though this is in some cases offset by reduced forced outage risk during milder winters), lowers transfer capacity across the transmission system, and reduces output from solar panels due to reduced efficiency. These impacts on generation and transmission infrastructure, in conjunction with increased cooling demand, result in increased resource capacity needed to both maintain reliability as well as an increase in renewable resources to maintain achievement of the 70% Clean Energy Standard in the Reference Scenario.

In the Decarbonization scenario, while the electric system must grow to meet newly electrified end-uses, warming temperatures are projected to reduce the “peak heat” challenge of meeting winter peak demand. The severity of extreme cold snaps declines as winters get warmer, and with increasing summer temperatures, additional generation capacity is required to meet summer peak demand as well. However, there is still uncertainty associated with how climate change may impact extreme cold weather events and the ability to plan the electric system around expected warmer winters. The system will need to remain reliable during extreme winter events even as they become less frequent or possibly less severe because of climate change.

Without broader adoption of building decarbonization measures, the cost impacts of warming are largely offsetting, but are unevenly distributed across sectors. The electricity sector will face sharp increases in costs as a result of more extreme summers, which are largely offset by winter fuel savings, though these savings are experienced on the gas distribution system rather than the electric system. With broader adoption of heat pumps and energy efficiency measures, increased warming has the potential to reduce costs in the electric sector as well by partially mitigating the electric infrastructure investments required as a result of electrification-driven load growth.

As the impacts of climate change intensify, it will become increasingly important for energy system planners to directly account for the effects that warming will have across every segment of the industry, including generator and transmission impacts in addition to impacts on system demand.

3.2 Limitations

This study provides a comprehensive analysis of known temperature impacts on the bulk electricity system; however, there are many climate-driven events that are not captured, such as sea level rise and increased frequency and magnitude of storms, that will have an impact on electric infrastructure in New York State. This will result in a combination of increased hardening costs to improve the resilience of the energy system and/or increased costs associated with damage from these climate-driven events. Additionally, the impact of rising temperatures on the distribution system was not considered in this analysis. There are also several climate impacts that are currently highly uncertain and as a result are not modeled but may be the subject of future exploration.

Additionally, the analysis provides a projection of the impacts of climate change through 2100; however, this includes a projection of least-cost resource portfolios when the costs of many technologies and fuels are highly uncertain and for simplicity are held static after 2050.

Appendix A. Annual Minimum and Maximum Temperatures

Table A-1. Quantiles of Annual Min and Max Temperatures (Statewide)

Quantiles of Annual Min Temperature	Winter						
		2050s			2080s		
	Historical	Mild*	Mod	Severe	Mild*	Mod	Severe
1-in-2	-4	-4	4	18	-2	7	28
1-in-5	-8	-8	1	16	-6	5	26
1-in-10	-11	-11	0	14	-8	3	24
Min	-19	-19	-4	10	-16	-1	20
Quantiles of Annual Max Temperature	**Summer**						
		2050s			**2080s**		
	Historical	**Mild***	**Mod**	**Severe**	**Mild***	**Mod**	**Severe**
1-in-2	87	96	100	103	99	101	109
1-in-5	89	100	103	106	103	104	112
1-in-10	90	101	104	106	104	105	113
Max	91	103	107	108	106	108	115

* Unlike Moderate and Severe temperature projections, which directly come from GCMs, Mild temperature projections are calculated starting from the Historical temperatures and applying a 1%/year CDD annual growth and 0%/year HDD annual growth through 2050, consistent with the Integration Analysis. After 2050, CDD and HDD growth rates projected by the GCM, INM-CM4-8 in SSP 2, RCP 4.5 are applied. Temperature extremes will not necessarily grow at the same rate as the annual CDD/HDD will. This is a simplifying assumption.

Endnotes

[1] No more than 1 day of lost (unmet) load in 10 years. Independent of the infrastructure or climate scenario modeled, the resource portfolio is always selected to meet this standard. Thus, loss of load does not become more frequent with climate change in the system modeled. More resources will be added, if needed, to maintain reliability.

[2] The Scoping Plan was published in December 2022, and the Technical Appendix G can be found here: https://climate.ny.gov/Resources/Scoping-Plan. Since then, some modeling improvements have been made and the updated inputs and outputs can be found in IA Annexes 1 and 2 here - https://www.nyserda.ny.gov/About/Publications/Energy-Analysis-Reports-and-Studies/Greenhouse-Gas-Emissions

[3] Cooling Degree Days and Heating Degree Days are a standard measurement used to normalize the heating and cooling demand for a given jurisdiction, defined as the sum-product of the number of days and the difference in a day between the temperature in a location relative to 65 degrees Fahrenheit. For example, a single day in which the temperature was constant at 80 degrees would be equivalent to 15 cooling degree days. A full week in which the temperature was constant at 80 degrees would be equivalent to (7 * 15) = 105-degree days. For more information, see: https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php .

[4] Effective load carrying capability is defined as the quantity of "perfect capacity" that can be replaced with a resource while providing equivalent system reliability, where perfect capacity represents capacity that is fully available every hour of every year.

[5] Itron on behalf of NYISO, "New York ISO Climate Change Impact Study, Phase 1: Long-Term Load Impact," December 2019, https://www.nyiso.com/documents/20142/10773574/NYISO-Climate-Impact-Study-Phase1-Report.pdf

[6] The EPA defines heat waves as "a period of two or more consecutive days when the daily minimum apparent temperature (the actual temperature adjusted for humidity) in a particular city exceeds the 85th percentile of historical July and August temperatures (1981–2010) for that city." For this analysis, only temperatures were used to identify heat waves. For more information, see: https://www.epa.gov/climate-indicators/climate-change-indicators-heat-waves

[7] See IA Annexes I and II at https://www.nyserda.ny.gov/About/Publications/Energy-Analysis-Reports-and-Studies/Greenhouse-Gas-Emissions

[8] In the Scoping Plan and this study, a 3 GW storage target by 2030 was modeled, which has since been doubled to 6 GW by 2030 by NY State.

[9] Dubey, Swapnil et al, Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review, Energy Procedia, Volume 33, 2013, Pages 311-321

[10] Segbefia, O.K. et al, Investigation of the Temperature Sensitivity of 20-Years Old Field-Aged Photovoltaic Panels Affected by Potential Induced Degradation. Energies 2022, 15, 3865

[11] Tobnaghi, D.M et al, The Effect of Temperature on Electrical Parameters of Solar Cells, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Volume 2, 2013, Issue 12

[12] Murphy, S. et al. "A time-dependent model of generator failures and recoveries captures correlated events and quantifies temperature dependence", Applied Energy, November 2019, available at: https://www.sciencedirect.com/science/article/pii/S0306261919311870

[13] PJM, "Winter Storm Elliot", January 11, 2023, available at: https://www.pjm.com/-/media/committees-groups/committees/mic/2023/20230111/item-0x---winter-storm-elliott-overview.ashx

[14] PJM Manual 18: PJM Capacity Market, published February 9, 2023, available at: https://www.pjm.com/~/media/documents/manuals/m18.ashx

[15] An additional area of uncertainty is presented in the Decarbonization Scenario, in which one or more emerging technologies may provide the estimated capacity in the "zero-carbon firm resource" category. This analysis adopts the Integration Analysis approach of modeling the zero-carbon firm resource as a hydrogen-fueled, combustion-based resource, which would be expected to be impacted by temperatures similarly to existing combustion-based resources. However, part of the impacts of extreme cold temperatures in particular on the availability of thermal units is intertwined with the reliance of those units on natural gas infrastructure that may also be constrained by fuel demands driven by building space heating needs; this may not be a factor for hydrogen infrastructure, which is not expected to play a meaningful role in building heating in the pathways modeled as part of the Scoping Plan. Alternatively, if other technologies such as long-duration battery storage provide zero-carbon firm capacity, the temperature-based relationship would not be applicable.

[16] Matthew Bartos et al (2016). Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States. Environ. Res. Lett. 11 114008, https://iopscience.iop.org/article/10.1088/1748-9326/11/11/114008/meta

[17] In the Decarbonization Scenario, there would be little impact of modeling continued stock turnover; building heating and light-duty vehicle are nearly entirely electrified by 2050.

[18] U.S. Department of Transportation, "Seasonally Adjusting Vehicle Miles Traveled," https://www.bts.gov/sites/bts.dot.gov/files/docs/explore-topics-and-geography/topics/202101/seasonally-adjusted-vmtv7.pdf

[19] Michael T. Craig et al, A review of the potential impacts of climate change on bulk power system planning and operations in the United States, Renewable and Sustainable Energy Reviews, Volume 98, 2018, Pages 255-267

[20] Arias, P. et al (2021). Technical summary. In V. Masson-Delmotte, G. M. Flato, & N. Yassa (Eds.), Climate change 22 2021: The physical science basis (pp. 33–144). Intergovernmental Panel on Climate Change. 23 https://doi.org/10.1017/9781009157896.002

[21] Freedman, J et al (2019, December). High-resolution dynamic downscaling of CMIP5 model data to assess the effects of climate change on renewable energy distribution in New York State. American Geophysical Union Fall Meeting, San Francisco, CA. https://agu.confex.com/agu/fm19/meetingapp.cgi/Paper/515612

[22] ConEdison, Climate Change Vulnerability Study, December 2019, available at: https://cdnc-dcxprod2-sitecore.azureedge.net/-/media/files/coned/documents/our-energy-future/our-energy-projects/climate-change-resiliency-plan/climate-change-vulnerability-study.pdf?rev=5b8c1152e5424477a480b1a6d91fa7d2&hash=24C8291EDE99AD0A61592A36249E45B7

[23] New York Public Service Commission, "PSC Directs Utilities to Conduct Climate Vulnerability Studies." June 2022, https://dps.ny.gov/system/files/documents/2022/10/psc-directs-utilities-to-conduct-climate-vulnerability-studies.pdf

[24] Sustainable Energy Advantage on behalf of NYSERDA and DPS, Clean Energy Standard Cost Study: Appendix A, published in June 2020, available under Department of Public Service case number 15-E-0302: https://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?Mattercaseno=15-E-0302

[25] New York State Reliability Council, "New York Control Area Installed Capacity Requirement for the Period May 2023 to April 2024," December 2022, available at: https://www.nysrc.org/PDF/Reports/ICS%20Annual%20Reports/2023%20IRM%20Study%20Technical%20Report%2012-14-2022%20Final%20-%20rev%203.pdf

[26] A UCAP, or unforced capacity, basis indicates that the PRM represents the amount of capacity needed after taking into account generator availability during peak times.

[27] Total costs are shown in Figure 24 which includes the electricity system cost, non-electric fuel cost and cost of heating, cooling, energy efficiency and transportation infrastructure through 2100, maintaining the approach followed in the Scoping Plan. This cost includes both components that will be impacted by climate-change induced warming and those that will not. Disaggregating these cost components was not feasible and so we present total costs.

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and support to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

To learn more about NYSERDA's programs and funding opportunities, visit nyserda.ny.gov or follow us on Twitter, Facebook, YouTube, or Instagram.

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

State of New York
Kathy Hochul, Governor

New York State Energy Research and Development Authority
Richard L. Kauffman, Chair | Doreen M. Harris, President and CEO