

Cross-Sectoral Economic Impact Analysis of Climate Change in New York State

Chapter 5: Energy Sector

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Cross-Sectoral Economic Impact Analysis of Climate Change in New York State

Chapter 5: Energy Sector

Final Report

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Abstract

The energy sector is affected by climate and weather patterns, such as temperature, precipitation, and extreme storms. Climate conditions can impact both the physical energy system infrastructure as well as energy supply and demand. For this sector, we modeled and quantified the economic impacts associated with the impacts of extreme heat, precipitation, and extreme events on transmission and distribution infrastructure, and changing energy demand and supply in response to shifting climate conditions. Other potential impacts are discussed qualitatively but were not able to be modeled for this study, including the impacts of climate change on communications infrastructure. Proactive, forward-looking adaptation that incorporates future climate conditions was only able to be modeled for the transmission and distribution analysis and showed that adaptation measures could significantly reduce the economic impacts in that subsector. As with all modeling, this work could not capture every aspect of the energy sector, and there are data and modeling limitations that are inherent in any analysis like this.

Keywords

climate change, impacts, economics, projections, scenarios, adaptation, socioeconomic, energy infrastructure, electricity demand, transmission and distribution, system resilience, economic impacts

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Acronyms and Abbreviations

CDD	cooling degree days
Climate Act	Climate Leadership and Community Protection Act
GCM	global climate model
GDP	gross domestic product
GHG	greenhouse gas
HDD	heating degree days
NPV	net present value
NYISO	New York Independent System Operator
PRM	Planning Reserve Margin
SSP	Shared Socioeconomic Pathway
TWh	Terawatt-hour
UCAP	unforced capacity
UKESM	UK Earth System Model
USD	U.S. dollars
VSL	value of statistical life

Report Summary

This chapter is part of a report that projects the economic impacts of climate change in New York State across eight sectors through 2100 under multiple climate, socioeconomic, and adaptation scenarios. The research team identified and applied existing literature and models to quantify or qualitatively assess climate-related impact categories, using standardized climate and socioeconomic inputs. The analysis used downscaled Coupled Model Intercomparison Project Phase 6 (CMIP6) climate data and gross domestic product (GDP)/population projections to estimate sector-specific impacts under Shared Socioeconomic Pathway (SSP)2-4.5 and SSP5-8.5 emissions scenarios. While the estimates reflect current best practices and modeling capabilities, limitations such as data availability, missing feedback loops, and gaps in demographic sensitivity likely lead to underestimation of total impacts.

Energy Sector Chapter Insights

The following is a summary of findings for climate economic impacts in the energy sector that are detailed in this chapter:

- Quantified economic impacts for the energy sector indicate damages to transmission and distribution infrastructure of about \$200 million to more than \$300 million annually by late century.
- Electric system supply costs are projected to decline overall through the end of the century for the modeled effects of a decarbonization scenario, which is most consistent with full implementation of New York State’s Climate Leadership and Community Protection Act (Climate Act). The decline in overall costs under future climate change reflects a higher climate resilience of electric supply options, such as renewables, implemented in this scenario, relative to their performance under the current climate.
- Proactive adaptation has the potential to substantially reduce transmission and distribution infrastructure damages by about 45% statewide in the near-century period, by more than 60% in the midcentury period, and by about 70% in the late century period under both greenhouse gas (GHG) emissions scenarios.

1 Introduction

Impact studies in the energy sector focus on energy demand and supply costs, system resiliency to climate conditions, and the potentially related impacts on communication infrastructure. The first two subsectors are estimated quantitatively; the third is a partially quantified summary.

The quantitative results for electric energy supply and demand incorporate the impacts of temperature and precipitation on the optimal composition and cost of energy resources needed to fulfill the full range of electric energy demand in New York State. This chapter describes the energy demand and supply modeling in much greater detail than other components of this assessment, primarily because of the additional complexity associated with this system and the uncertainty associated with the future electric energy production and user infrastructure anticipated to result from efforts to decarbonize the electric generating system consistent with New York State’s Climate Leadership and Community Protection Act of 2019 (Climate Act).

The direct effects of temperature, precipitation, and extreme events on the integrity and useful life of electricity transmission and distribution infrastructure are quantified separately. Finally, this chapter partially quantifies the effect of extreme weather, more concentrated precipitation, and increased temperatures on communications systems, focused on the potential for climate change to damage infrastructure and increase the frequency of service disruptions. Table 5-1 summarizes the sector impacts assessed in this chapter.

This analysis includes quantification of how proactive adaptation affects impacts in the electricity transmission and distribution infrastructure subsection (Table 5-2). Proactive adaptation was not quantified for energy supply and demand; for that subsector, the analysis assumes a reactive response scenario, including market adjustments toward the most cost-effective electricity supply and new demand-side energy efficiency investments. For this study, the reactive response scenario assumes that response and associated costs increase as impacts and damages increase, but that adaptation practices stay the same and continue to assume historical climate and existing technology trends, including regulatory requirements, rather than incorporating future climate change. Proactive adaptation includes measures that incorporate future climate change. See Chapter 1, Methodology, for more information on the adaptation and response scenarios considered in this study.

Table 5-1. Annual Statewide Economic Impacts to Energy Categories

Values represent total statewide impacts relative to the baseline by Shared Socioeconomic Pathway (SSP). Reported in millions of 2021 USD.

Category	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Electricity Transmission and Distribution Infrastructure, Reactive Response	\$175	\$192	\$235	\$307	\$191	\$340
Electricity Transmission and Distribution Infrastructure, Proactive Adaptation	\$94	\$108	\$89	\$125	\$57	\$120
Energy Supply and Demand, Reference ^a	\$375	\$573	\$684	\$1330	\$723	\$2560
Energy Supply and Demand, Decarbonization ^a	-\$42	-\$139	-\$239	-\$412	-\$569	\$278
Communication Infrastructure	Extreme weather, more concentrated precipitation, and increased temperatures are expected to affect communications, damaging infrastructure and increasing the frequency of service disruptions, with a potential annual magnitude of more than \$10 million in economic impacts.					

^a Impacts listed under SSP2-4.5 refer to total costs under the moderate climate scenario relative to the baseline; impacts listed under SSP5-8.5 refer to total costs under the severe climate scenario relative to the baseline. See details of these custom climate scenarios in the remainder of this chapter and in Appendix B. Impacts shown for the Energy Supply and Demand entries include the sum of changes in both electricity system and fuel costs associated with the climate and infrastructure scenario in each future era.

Table 5-2. Summary of Response Assumptions for the Energy Sector

Reactive response for these impacts does not reflect modeling of the effectiveness and costs of specific strategies but is implicitly reflected in data on historical climate response sensitivity and the resulting physical and economic impacts. The adaptation strategies listed as examples in this table were identified based on other information available on adaptation strategies employed in the sector.

Category	Reactive Response Assumptions	Proactive Adaptation
Electricity Transmission and Distribution	Current actions to protect transmission and distribution infrastructure based on the current climate, including transformer replacement, line ampacity upgrades, steel reinforcement of poles, and limited protection of substations vulnerable to coastal flooding.	All measures included in the reactive response, with periodic infrastructure replacements upgraded to be resilient to future climate, and protection of substations vulnerable to coastal flooding with hard structures.
Energy Supply and Demand	- Market adjustments toward the most cost-effective electricity supply (e.g., solar, wind, fossil fuel-fired). - New demand-side energy efficiency investments (e.g., upgrades to building shells).	Not quantitatively estimated

1.1 Related Impacts: Connections across Sectors

This section highlights related impacts and connections across other sectors.

- **Society and economy:** Power outages related to distribution and transmission grid failures have substantial impacts on businesses.
- **Human health and safety:** Power outages have been linked to specific human health impacts, such as food contamination, carbon monoxide poisonings, and impacts on populations dependent on electric supply for medical equipment.

2 Quantitative Damages

This section discusses the quantitative analyses performed for this sector.

2.1 Electricity Transmission and Distribution Infrastructure

The scope of economic impacts considered includes costs to repair electric transmission and distribution infrastructure failure, and incremental damage associated with heat stress, precipitation, and extreme events.

Changes in climate contribute to alterations in the regular maintenance costs and period of performance of electric distribution and transmission infrastructure. This analysis is based on a previous study (Fant et al. 2020) that considers the effect of a range of climate drivers (e.g., extreme temperature, extreme storms, lightning, vegetation growth, wildfire activity, coastal flooding) on three electrical grid components:

1. Transmission and distribution lines
2. Poles and towers
3. Transformers

The costs are based on changes to repair activities at the time a climate stressor causes damage to the infrastructure. Figure 5-1 shows the framework of this approach.

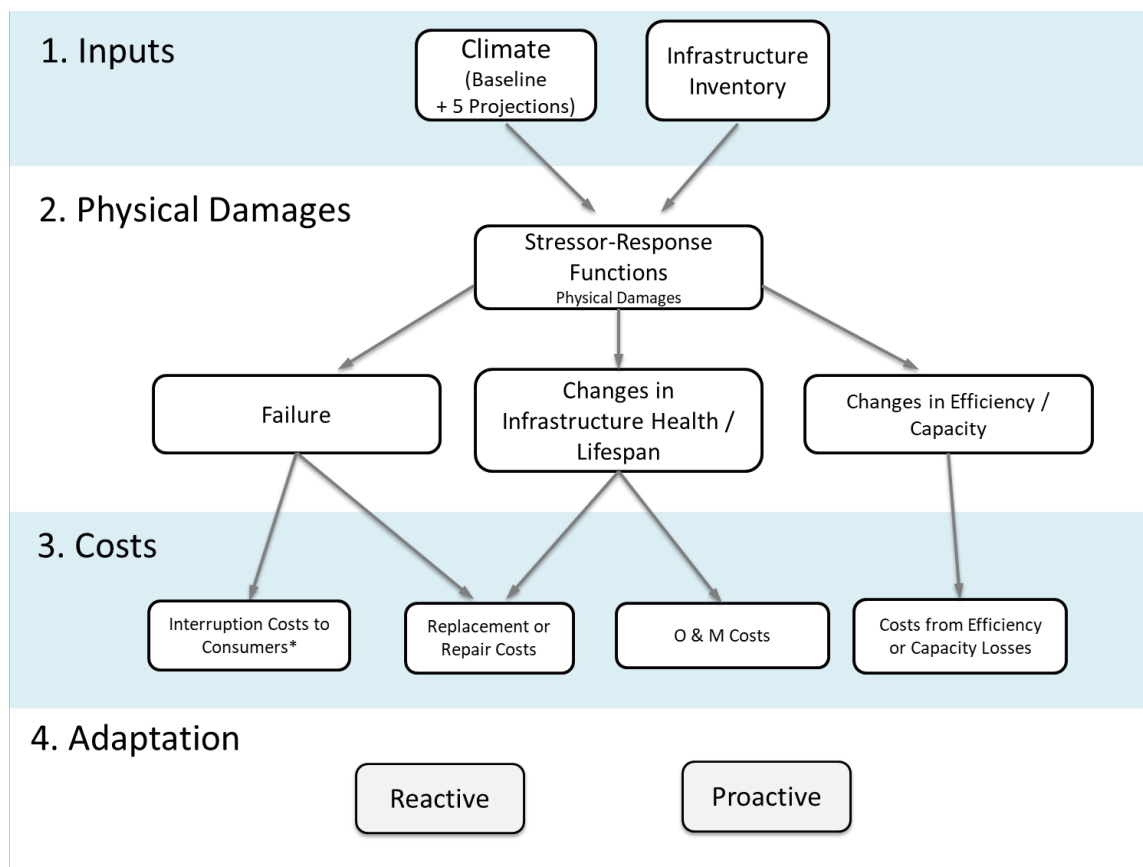
Climate stressors also cause power outages, which have potentially high direct and indirect costs, resulting from grid infrastructure failure. Power outages currently happen, and the risk of those outages could increase in the future as a result of either grid infrastructure failure or electric generating capacity shortfalls associated with future climate change. The approach used in this section, and in the Energy Supply and Demand section of this chapter (Section 2.2) estimates the additional investments needed to limit increases in the risk of power outages attributable to climate change. This approach reflects the

expectation that the electric sector has traditionally applied a forward-looking planning approach to these investments. An alternative approach might estimate an incremental cost to society of “inaction” with respect to timely infrastructure investments, but that is not the framework used here.

Figure 5-1. Conceptual Framework for the Impacts of Climate Change on Electric Distribution and Transmission Infrastructure

Interruption costs to consumers in Fant et al. (2020) and this analysis are only considered qualitatively. The other three categories of costs are quantified.

Source: Author's analysis based on Fant et al. (2020).



2.1.1 Methodology

This analysis focuses on the subset of infrastructure–climate stressor combinations from Fant et al. (2020) that meet two criteria: (1) they can be characterized with reasonable certainty, and (2) they are likely to have significant costs. Meeting the first criterion requires usable projections of the climate stressor within the existing framework and a stressor-response function that relates how the stressor affects the infrastructure. Note that Fant et al. find that high winds and ice storms are climate stressors

that are too uncertain to estimate given the current state of global climate models (GCMs)—this analysis also excludes these stressors. Also following this work, the impacts of inland flooding are excluded because aside from rare cases, it is not usually a cause of major damage to transmission and distribution infrastructure. Wildfires are also excluded because the underlying study that drove wildfire impacts in Fant et al. focused solely on the Western U.S., and even there the impacts caused by burned areas were minor compared to other climate stressors. Appendix B includes additional details on the methods and data used.

Table 5-3 summarizes the impacts included in this analysis as well as the approach used to simulate adaptation for each of the stressors under the two adaptation scenarios that represent the focus of this analysis: reactive response and proactive adaptation. These two scenarios represent a range of potential climate response efforts, but are not the only possible adaptation responses to climate hazards. Other adaptation options are also possible, and new strategies may evolve over time.

Under both reactive response and proactive adaptation strategies, utilities respond by designing infrastructure to either recent climate (reactive) or an expected future climate based on projections (proactive). This is done by upgrading infrastructure until it meets the baseline performance or service level. For example, for wood pole lifespan reductions, upgrades are made until the historical aggregate baseline lifespan is achieved. Reactive response and proactive adaptation are distinguished by designing to different climates, either reactive to the past climate or proactive to a projected future climate. Proactive adaptation designs to the future lifespan using an expected climate. Perfect foresight is not used, as it would be unrealistic. Instead, it is designed using the mean over all the climate projections to provide a projected change from current climate. In this way, proactive adaptation is forward-looking but does not design perfectly.

Table 5-3. Summary of Climate Change Damages and Adaptation Assumptions for the Electric Grid Infrastructure Analysis

Source: Author's summary based on Fant et al. (2020).

Climate Hazard	Impact	Description	Reactive Response	Proactive Adaptation
Increased temperature	Reduced transformer lifespan and capacity (both substation and distribution)	Changes in air temperature cause changes in the lifespan and capacity of large power transformers	Build replacement transformers adapted to recent climate	Build replacement transformers adapted to projected climate
Increased temperature	Reduced transmission line capacity	High temperatures reduce transmission line ampacity	Ampacity upgrade of existing lines using recent climate	Ampacity upgrade of existing lines using projected climate
Precipitation and temperature changes	Wood pole decay	Precipitation and temperature changes alter decay rates at wood pole bases	Steel reinforcement as needed based on the recent climate	Steel reinforcement as needed based on the projected climate
Precipitation and temperature changes (indexed to temperature changes)	Change in vegetation management needs	Climate changes alter vegetation growth, requiring management adjustments	No adaptation options considered	No adaptation options considered
Sea-level rise and storm surge	Substation damage from sea-level rise and storm surge	Sea-level rise inundation or increasing storm surge heights require the repair or relocation of substations	Ancillary beach nourishment to protect the beach and property	Ancillary beach nourishment and engineered structures to protect property

Appendix B provides additional details on the model approach used for each of the impacts in Table 5-3.

2.1.2 Results

Figure 5-2 shows annual costs relative to a 1981–2010 baseline for both response scenarios, indicating how the different response strategies compare with each other, under both SSP2-4.5 and SSP5-8.5.¹

Under SSP2-4.5 (Figure 5-2, top), impacts under reactive response increase by about \$60 million from the 2030s to 2050s, then decline by about \$45 million from the 2050s to 2080s, due to the timing of substation and other infrastructure replacement.

¹ A no-adaptation scenario was modeled but is not included in this analysis due to its low likelihood. In this scenario, utilities make no adjustments to infrastructure design to address climate change. That is, infrastructure is replaced with the same design/model at the end of its life cycle. The results for this scenario are very similar to the reactive response scenario, except in the 2080s. In this timeframe, the no-adaptation scenario results in significantly higher costs than the reactive response scenario.

Substantial reductions in costs occur only after the end of the useful life of this infrastructure, when a substation is replaced with a unit designed for the recent historical climate (reactive) or for future climate (proactive). In the proactive strategy, consideration of future climate change over the anticipated useful life of the infrastructure, which begins to diverge from current and recent historical climate as soon as the 2030s, means that impacts are well below costs for the reactive response in the 2030s and decline thereafter for SSP2-4.5. Under SSP5-8.5, a similar pattern is evident for the two scenarios but is more pronounced—and impacts under the proactive scenario are relatively constant over time, increasing slightly from \$108 million in the 2030s to \$125 million in the 2050s but then decrease to \$120 million in the 2080s. Proactive costs decrease from the 2050s to 2080s because earlier capital costs spent on adaptation in the 2030s and 2050s are effective and reduce impacts in the 2080s. The trajectory of costs reflects the concept that cost-effective investments in more climate resilient infrastructure pays off with lower impacts in subsequent periods. That phenomenon is evident in both the reactive and proactive scenarios but is much more prominent in the forward-looking proactive scenario.

Figure 5-2. Annual Economic Impacts on Electric Transmission and Distribution Infrastructure Due to Climate Change by Response Scenario for SSP2-4.5 (top) and SSP5-8.5 (bottom)

Reported in millions of 2021 USD.

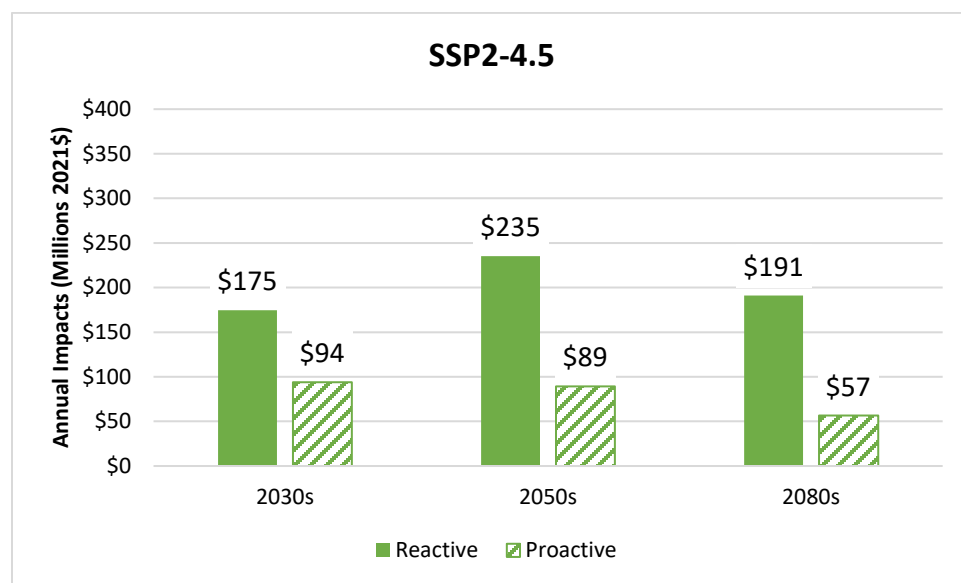


Figure 5-2 (continued)

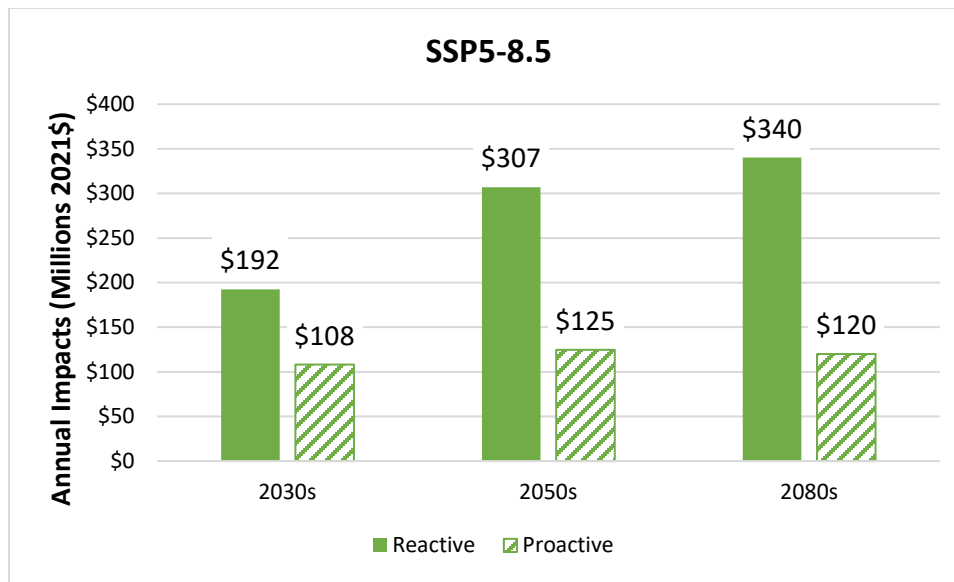


Table 5-4 shows these impacts by region for all three eras and both SSP2-4.5 and SSP5-8.5 under the reactive response scenario (Appendix B includes results for other scenarios), and Figure 5-3 shows the per capita impacts by county for SSP2-4.5. The Great Lakes region has the largest total impacts followed by the Mohawk River Valley. The regions with the lowest impacts are the St. Lawrence Valley, Champlain Valley, and the Catskills. For the most part, these patterns can be explained by the amount of infrastructure exposed to climate. New York City, for example, has undergrounded most of its power lines. This analysis does not consider impacts to underground infrastructure, which may be exposed to flooding but are not directly exposed to ambient air temperature changes. Impacts per capita are highest in Fulton County at about \$170 million per year and lowest in Kings County at only \$2 million per year.

Table 5-4. Annual Economic Impacts on Electric Transmission and Distribution Infrastructure Due to Climate Change by Region, Reactive Response Scenario

Change from baseline. Economic impacts represent the estimated additional cost due to climate change to maintain the same level of service of the electric grid, assuming a reactive scenario. Results are reported in millions of 2021 USD per year and averaged across GCMs. Values may not sum due to rounding.

Region	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5	SSP2-4.5	SSP5-8.5
Adirondacks	\$8.6	\$9.8	\$11.5	\$14.9	\$8.9	\$16.0
Catskills	\$4.7	\$5.2	\$6.2	\$8.1	\$5.3	\$8.7
Central/Finger Lakes	\$26.0	\$28.7	\$33.7	\$43.8	\$28.3	\$48.1
Champlain Valley	\$3.9	\$4.4	\$5.5	\$7.2	\$3.7	\$7.3
Great Lakes	\$36.1	\$40.1	\$46.8	\$60.6	\$38.7	\$68.0
Long Island	\$11.5	\$12.6	\$16.0	\$21.3	\$13.9	\$25.0
Mohawk River Valley	\$24.5	\$26.7	\$35.5	\$45.9	\$26.7	\$47.6
New York City	\$8.8	\$9.4	\$12.4	\$16.5	\$10.9	\$20.9
North Hudson	\$20.5	\$22.4	\$28.4	\$37.2	\$22.9	\$41.4
South Hudson	\$9.0	\$9.9	\$12.2	\$16.3	\$10.6	\$18.3
Southern Tier	\$17.6	\$19.2	\$22.3	\$29.0	\$17.6	\$32.6
St. Lawrence Valley	\$3.6	\$4.1	\$4.9	\$6.3	\$3.5	\$6.5
Statewide	\$174.7	\$192.4	\$235.4	\$307.0	\$191.2	\$340.3

Figure 5-3. Annual Impacts of Climate Change on Electric Transmission and Distribution Infrastructure per Capita for SSP2-4.5 by County, Reactive Scenario, 2050

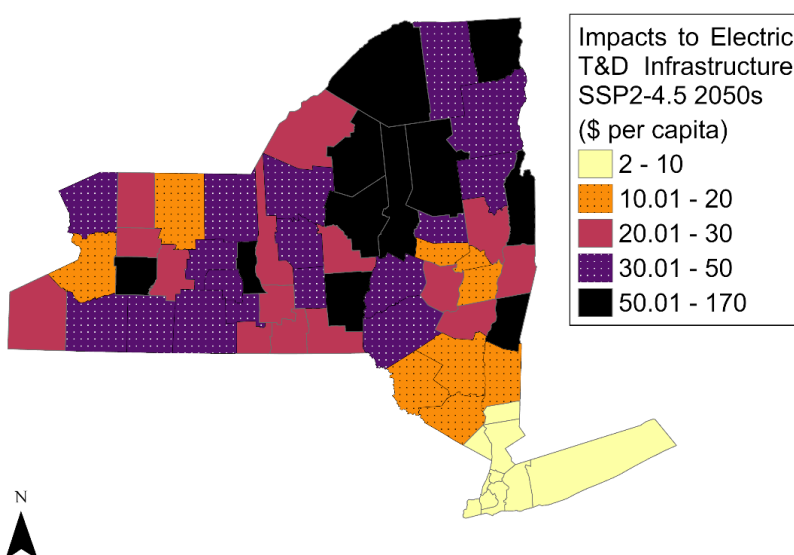


Figure 5-4 shows the annual impacts by type. The largest impacts for New York State come from heat impacts on transformers, including both smaller distribution transformers near households and large power transformers, or substations. This makes up about three quarters of the total costs. Wood pole decay, driven by changes in soil moisture and ground temperature, is the second highest at about 21%–22% of the total costs. Vegetation management, which was shown to be substantial in other parts of the country in Fant et al. (2020), is not a major concern in the Northeast according to this analysis. Coastal flooding, shown here as the annual expected costs, is also relatively minor compared to other impact types. The finding of minor coastal flood impacts on substations may be surprising in light of the well-publicized damage to electric substations from the 2012 Superstorm Sandy flooding, but many substations potentially vulnerable to coastal flooding were relocated or elevated as a result of those events. This analysis makes use of an updated database of substation inventory current through June 2020.

Figure 5-4. Annual Impacts of Climate Change on the Five Types of Impacts to Transmission and Distribution Infrastructure, Reactive Response, 2050

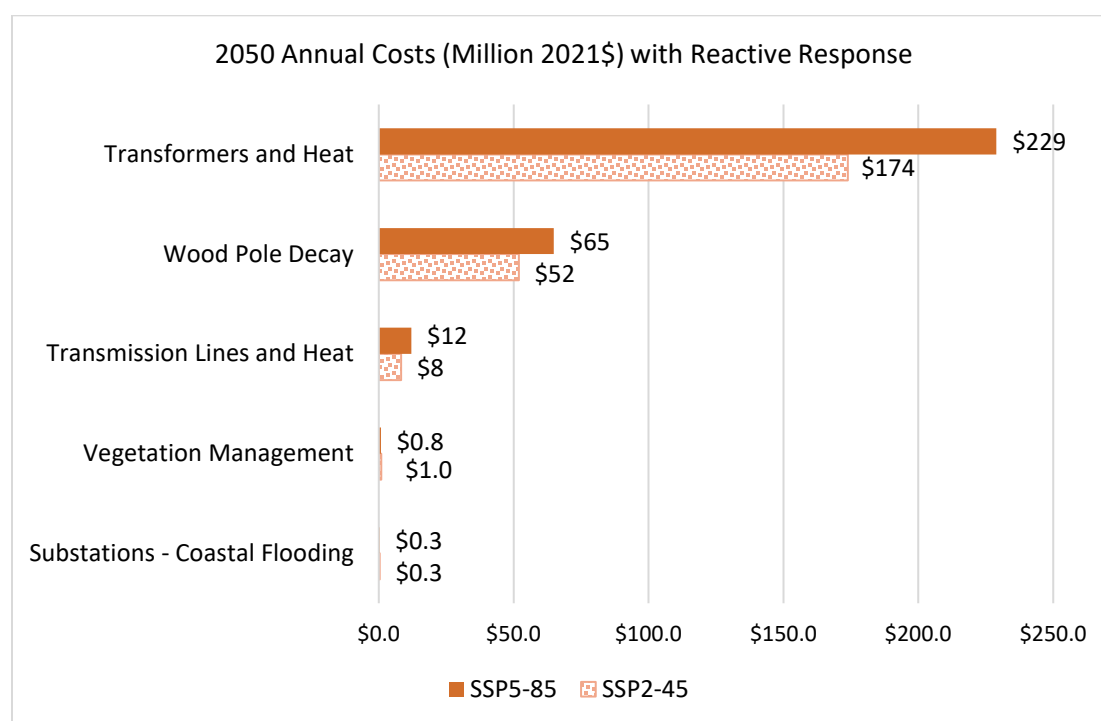
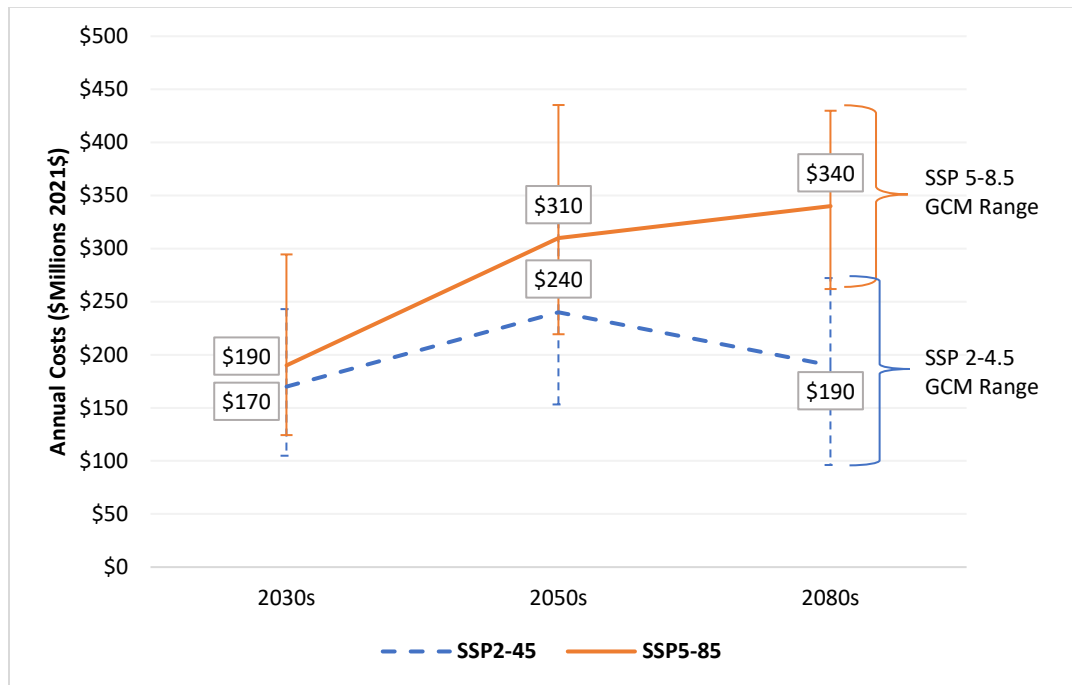


Figure 5-5 shows the annual impacts by era for the reactive scenario for both SSPs, for the average across GCMs as indicated by the horizontal line, as well as the range across GCMs as indicated by the vertical lines and whiskers. The range across the GCMs is substantial for all adaptation scenarios, SSPs, and eras, and ranges between \$140 million for the 2030s to roughly \$180 million in the 2050s and 2080s for SSP2-

4.5, at about 80%–90% of the mean. SSP5-8.5 ranges are similar, ranging between \$170 million and \$216 million annually. For the proactive scenario, the range varies in magnitude but is similar relative to the mean across GCMs.

Figure 5-5. Annual Impacts to Transmission and Distribution Infrastructure above the Baseline (1981–2010 Average) Due to Climate Change by Era, Reactive Response

Whiskers show the range across GCMs.



2.1.3 Limitations

This analysis includes several limitations related to data, modeling assumptions, and scope, which may affect the interpretation and generalizability of the results.

- This work focuses on a subset of stressor-response infrastructure interactions, which ideally capture the majority of the readily quantifiable impacts but does only capture a proportion of the range of climate change impacts to the electric grid.
- While the stressor-response functions are primarily based on physical processes and relationships rooted in engineering principles, they are designed require a limited set of inputs. Fant et al. (2020) list the specific caveats to each of these.

- The current state of the infrastructure (e.g., age and deterioration) is not considered due to lack of information. If the infrastructure is already in need of replacement and repair, costs may be higher in the near term. On the other hand, infrastructure components are assumed to be designed to historical climate where vulnerabilities that result in impacts occur as the climate changes outside the range of observed climate. If design of these components has already incorporated long-term trends in climate, costs may decrease. Also, advances in technology may help to reduce adaptation costs and future impacts.

2.2 Energy Supply and Demand

The scope of economic impacts considered includes changes in the demand for and costs to supply electricity to all classes of electricity consumers in the State for space heating and cooling, industrial applications, and electrified transportation, in the context of planned and anticipated changes in electric supply infrastructure and how changes in climate could affect the demand for and performance of that infrastructure.

The primary focus of this section is on the impacts of climate change on the New York State energy system. These include impacts of warming temperatures on both electricity demand and supply and the impact of warming on fuel demand for nonelectric end uses (primarily space heating). 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. Supporting details for this impact category can be found in a separate report (NYSERDA 2023).

2.2.1 Methodology

The analytical framework for this assessment 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 economywide representation of the New York State 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

Independent System Operator's (NYISO) reliability standard² and meeting the policy goals of each scenario. The New York State Energy Research and Development Authority (NYSERDA) developed this framework to support the Final Scoping Plan approved by the New York State Climate Action Council. A brief overview of the framework is provided below and additional technical details of this framework, including an overview of the development of all inputs and assumptions, can be found in Appendix G of the Final Scoping Plan.³ 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, which are described in greater detail in Appendix B and in NYSERDA (2023).⁴

The impacts of warming temperatures on many aspects of the electricity system are well-documented (e.g., heating and cooling demand, transmission ampacity, thermal generator output, and solar output), while for other components of the electricity system, the impacts are less well-known or the relationship has not been thoroughly studied. Figure 5-6 summarizes the modeled and non-modeled impacts of climate change.

² 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.

³ The Scoping Plan was published in December 2022, and the full document, including Appendix G and supporting Annexes (in Excel), is available at: <https://climate.ny.gov/Resources/Scoping-Plan>.

⁴ See <https://www.nyserda.ny.gov/About/Publications/Energy-Analysis-Reports-and-Studies/Greenhouse-Gas-Emissions> for a list of studies supporting the Integration Analysis. The NYSERDA (2023) report here is available at: <https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Energy-Analysis/23-30-Impacts-of-Climate-Change-on-the-New-York-Energy-System-acc.pdf>.

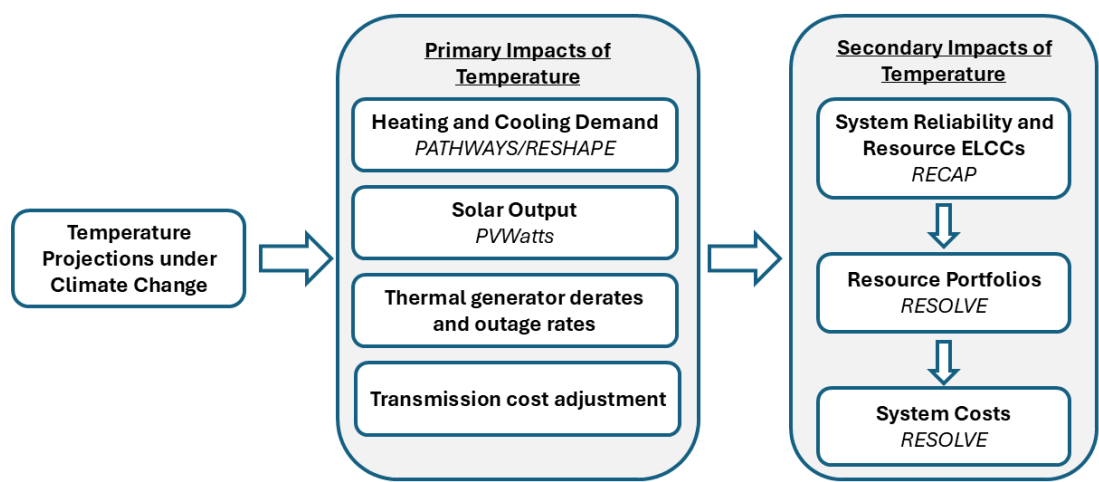
Figure 5-6. Matrix of Modeled and Non-Modeled Climate Change Impacts on New York State’s Electricity System

Source: NYSERDA (2023).

	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 impacts, the temperature outputs from each climate scenario served as inputs into the Integration Analysis framework, described in the following sections and shown in Figure 5-7.

Figure 5-7. Incorporation of Temperature into Integration Analysis Framework



2.2.1.1 Overview of Infrastructure Scenarios

The assessment 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, and a statewide Clean Energy Standard including technology carveouts.

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. Both cases include the tax credits available to generators under the Inflation Reduction Act. The reference case includes only the 70% by 2030 clean energy goal, while the decarbonization scenario also includes the 100% by 2040 zero-carbon electricity goal enroute to the net-zero economywide goal by 2050. Appendix B summarizes assumed infrastructure impacts.

2.2.1.2 Overview of Climate Scenarios

This analysis relies on hourly temperature projections derived from GCMs to examine the impacts of climate change on the electricity system in New York State.

Prior work as part of New York State’s Climate Action Council’s Scoping Plan process used a set of proxy assumptions for the impact of climate change on future demand, assuming that cooling demand would grow by 1% per year and that future heating demand would remain unaffected. Based on a review of the range of GCMs available for this economic analysis, this assumption set aligns most closely with the INM-CM4-8 GCM in SSP2-4.5.

This analysis defines a mild scenario that continues the 1% per year Scoping Plan assumption through 2050 and then uses levels of warming projected by INM-CM4-8 in the 2050-2100 period. This mild scenario serves as the energy planning baseline for this analysis, and the study measures economic impacts as the difference between other climate scenarios and the mild scenario.

A maximum of two additional climate scenarios could be adopted in this work, owing to computational and resource requirements of the modeling platform. One moderate scenario 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. The second is a “severe” scenario that reflects some of the highest warming impacts 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.

The analysis uses the ACCESS GCM under the SSP2-4.5 pathway as the moderate climate scenario and the UK Earth System Model (UKESM) GCM under the SSP5-8.5 pathway as the severe climate scenario. Appendix B includes more details on the development of climate scenarios for this analysis and the justification for selecting these specific scenarios.

2.2.2 Results

This section presents the modeled impacts of climate change–driven changes in temperature on the New York State energy system, leveraging projected hourly temperatures under different climate scenarios as inputs into the economy-wide Integration Analysis framework. The overview of results in this chapter focuses on the impacts of climate-driven temperature changes on electricity demand and briefly touches on 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 nonelectric heating fuel costs under each climate scenario. Additional detailed results are included in Appendix B and the standalone NYSERDA report (2023) on this component of the modeling.

2.2.2.1 Impacts of Climate Change on Electricity Demand

This section separates the impacts of climate change–driven changes in temperature on electricity demand into:

1. The impacts on annual electricity demand as a result of changes in average cooling degree days (CDDs) and heating degree days (HDDs)
2. The impacts on peak electricity demand as a result of changes in seasonal minimum and maximum temperatures.

2.2.2.2 Impacts on Annual Electricity Demand

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 HDDs and associated electric load.

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 CDDs as a result of climate change. However, the moderate reference and severe reference cases experience much sharper increases in CDDs, with cooling demand in the severe case reaching twice that of the mild case in 2050 and 3.6 times by 2100.

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 terawatt-hours (TWh) in 2020 to 31 TWh in 2050 in the mild scenario. Energy efficiency measures, such as upgrades to building shells, also play a critical role in 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 close to today's level of 20 TWh through midcentury and decreases further in the future. 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 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. 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.⁵

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 a decrease in electrified heating demand, leading total demand to remain relatively unchanged. By 2100, total demand in the reference case ranges from 211 to 244 TWh, and in the decarbonization scenario, it ranges from 357 to 361 TWh.

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 at least 5 TWh higher than in the decarbonization scenario in the severe scenario. 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 again highlights the value of energy-efficient heat pumps and building shell improvements in the decarbonization scenario, which limits the increase in cooling demand relative to the reference case in which those measures are not adopted.

⁵ Note that the reference case includes growth in traditional air conditioning penetration, consistent with increases in CDDs due to climate change, as well as some growth in heat pump installation, though at a much slower rate than in the decarbonization scenario. Table B-15 in Appendix B includes the details.

Figure 5-8. Modeled Impacts of Climate Change on Heating Demand

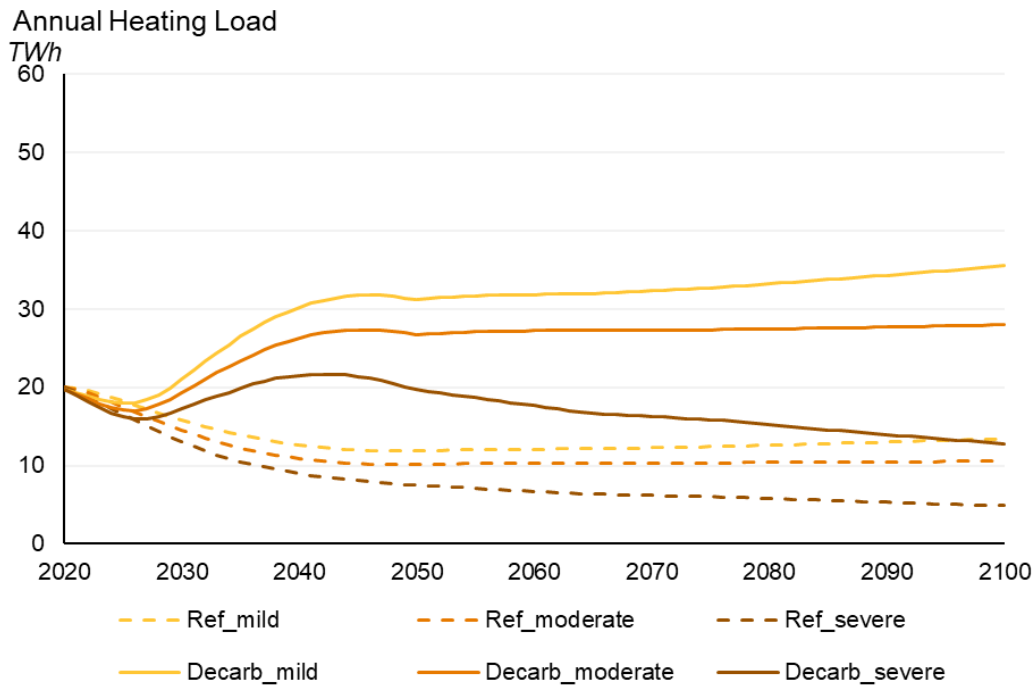


Figure 5-9. Modeled Impacts of Climate Change on Cooling Demand

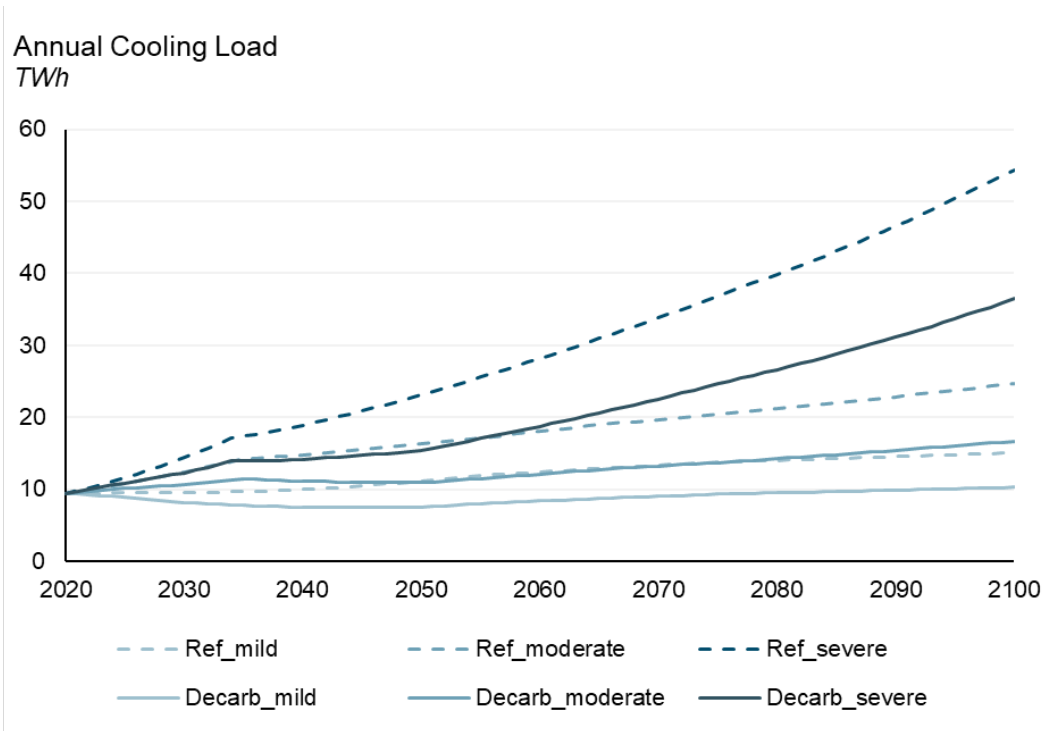
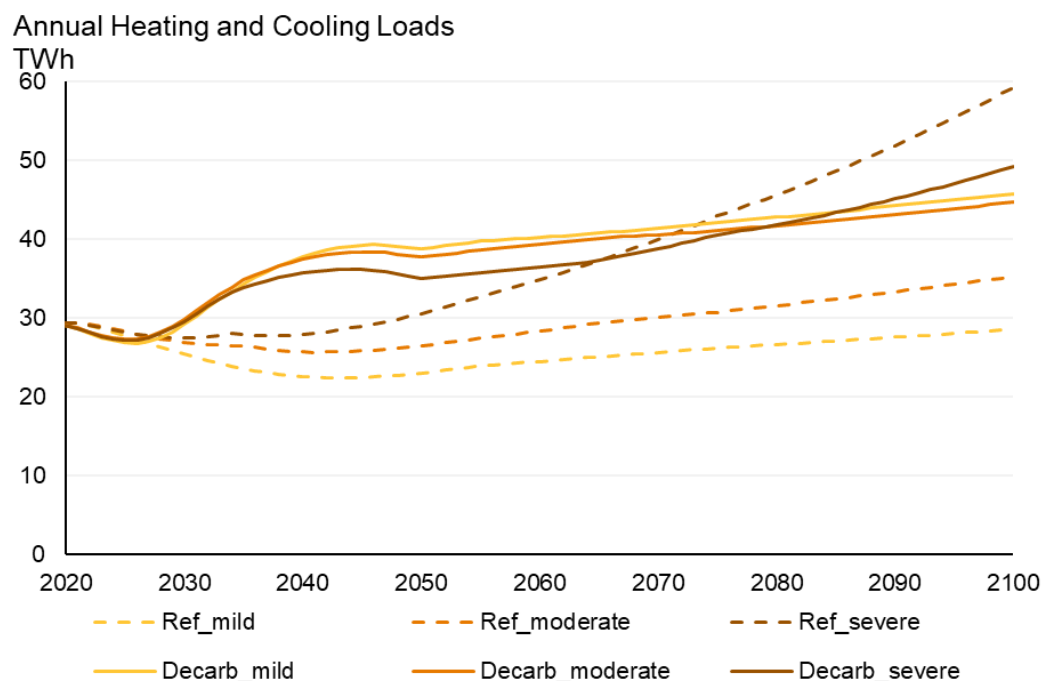


Figure 5-10. Modeled Impacts of Climate Change on Heating and Cooling Demand



2.2.2.3 Impacts on Peak Demand and System Reliability Needs

To maintain bulk electric system reliability, the New York State Reliability Council determines a Planning Reserve Margin (PRM) that specifies the amount of capacity that the system should hold above expected peak demand; this reserve margin accounts for both required operating reserves and interannual 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 PRM has, in recent years, been set at around 10% on an unforced capacity (UCAP) basis.⁶

The analysis performed in this assessment 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 cases accordingly. However, when examining the decarbonization scenario, the assessment in RECAP indicates that interannual variability between winter peak temperatures is considerably greater. As a result, when determining the resources that would be required above median peak winter conditions, a higher reserve margin is needed in the mild

⁶ A UCAP basis indicates that the PRM represents the amount of capacity needed after accounting for generator availability during peak times.

decarbonization scenario of about 18%. The reserve margin requirements as a percentage of peak load decline in the moderate and severe decarbonization scenarios as the system shifts toward a dual-peaking system, in which interannual load variability is not as significant. Table 5-5 presents the target reserve margin by policy and climate scenario.

Table 5-5. Reserve Margin Requirements under Each Policy and Climate Scenario

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

2.2.2.4 Impacts of Climate Change on System Costs

The cost assessment represents the culmination of the preceding sections by aggregating the increases in both the cost of additional 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.

2.2.2.5 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 a net present value (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 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 and moderate decarbonization scenarios relative to the mild decarbonization scenario. As a result, declines in the build-out of zero-carbon firm capacity and battery storage lead to reductions in the costs of the overall portfolio. The cost impacts of climate change in the decarbonization scenario vary in direction between time periods and are primarily driven by whether the system is summer- or winter-peaking in a given period. 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 (with respect to the mild scenario) 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 and more pronounced reductions in winter heating demand. 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 used 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 5-6 presents the impacts on electricity system costs for the single years 2030, 2050, 2080, and 2100, as well as the NPV over the twenty-first century. Estimates in this table are consistent with Table 5-7 of NYSERDA (2023) and are annual values for individual years rather than annual averages over the 30-year eras used in other chapters of this report.

Table 5-6. Annual Impacts of Climate Change on Electricity System Costs by Year and Climate Scenario, Reference Infrastructure Scenario

Electric system costs for the reference infrastructure scenarios, reported in millions of 2021 USD. This table is consistent with Table 5-7 of NYSERDA (2023) but for consistency with other parts of the current report is updated from 2020\$ to 2021\$2020 USD to 2021 USD using the Consumer Price Index–Urban (CPI-U). Results shown for years 2030, 2050, 2080, and 2100 are for single years of the modeling simulation, rather than 30-year eras. The NPV calculation uses a discount rate of 3.6% applied to annual values from 2020 through 2100.

Climate Scenario	2030	2050	2080	2100	NPV
Mild	5,421	8,119	9,465	10,481	180,474
Moderate	5,642	8,857	10,245	11,314	193,865
Moderate/Mild (%)	4%	9%	8%	8%	7%
Severe	5,786	9,309	11,952	13,954	207,343
Severe/Mild (%)	7%	15%	26%	33%	15%

Table 5-7. Annual Impacts of Climate Change on Electricity System Costs by Year and Climate Scenario, Decarbonization Infrastructure Scenario

Electric system costs for the decarbonization infrastructure scenarios, reported in millions of 2021 USD. This table is consistent with Table 5-7 of NYSERDA (2023) but for consistency with other parts of the current report is updated from 2020 USD to 2021 USD using the Consumer Price Index–Urban (CPI-U). Results shown for years 2030, 2050, 2080, and 2100 are for single years of the modeling simulation, rather than 30-year eras. The NPV calculation uses a discount rate of 3.6% applied to annual values from 2020 through 2100.

Climate and Policy Scenario	2030	2050	2080	2100	NPV
Mild	6,613	17,877	22,187	24,810	334,316
Moderate	6,699	17,580	21,720	23,899	330,730
Moderate/Mild (%)	1%	-2%	-2%	-4%	-1%
Severe	6,717	17,422	22,399	25,718	331,778
Severe/Mild (%)	2%	-3%	1%	4%	-1%

2.2.2.6 Impacts on Nonelectric Costs

The policy scenarios also vary in their reliance on fuels to meet energy demand. Nonelectric fuel costs were estimated for the residential, commercial, transportation, and industrial sectors and reflect the electrification assumptions for these sectors shown in Table B-15 in Appendix B. The annual estimates of these nonelectric fuel costs, however, are small compared to the electric system costs summarized above (Tables 5-6 and 5-7). 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 increases in summer temperatures increase electric system costs in the reference case, increases in winter temperatures and declines in heating demands lead to a reduction in the overall costs to meet building heating demands.

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. Consequently, electricity costs and nonelectric energy costs both decline in the moderate and severe scenarios relative to the mild. Nonelectric fuel costs decline due to reduced heating needs between the mild and severe climate scenarios. In aggregate, total energy costs, including electric system and nonelectric fuel costs, decrease with respect to the mild climate scenario.

Tables 5-8 and 5-9 present the electric system, nonelectric fuel costs, and the total costs for each of the three 30-year eras and two SSPs examined in this report, for the reference case and decarbonization scenarios. Note that estimates in these tables represent 30-year annual averages for the indicated eras, consistent with estimates in the remainder of this report. The estimates in Tables 5-8 and 5-9 differ from estimates that might be calculated from Tables 5-6 and 5-7 for the following reasons:

1. The estimates in these tables are differences between the moderate and mild (baseline) scenarios for the respective SSP, and between the severe and mild (baseline) scenarios. In other words, they represent the incremental impact of the two climate scenarios relative to baseline.
2. These estimates include the nonelectric fuel costs not presented in Tables 5-6 and 5-7.
3. These estimates are 30-year averages calculated from the full annual trajectory of results, rather than single-year values.

Table 5-8. Average Annual Impacts on Electricity System Costs, Fuel Costs, and Total Cost Due to Climate Change by Era and Climate Scenario for the Reference Infrastructure Scenario

Values are relative to the mild scenario. Results are reported in millions of 2021 USD per year. Estimates are for the reference infrastructure scenario. Era level estimates for electric system costs are based on an undiscounted average of estimated costs within the relevant 30-year eras (i.e., 2020–2049, 2040–2069, and 2070–2099, respectively). These 30-year averages differ from those presented in Table 5-6 above, which are for single years. The third row of this table (Total) is also reported as the summary results in Table 5-1 of this chapter. Impacts listed under SSP2-4.5 refer to total costs under the moderate climate scenario relative to the baseline (mild scenario); impacts listed under SSP5-8.5 refer to total costs under the severe climate scenario relative to the baseline (mild scenario). See details of these custom climate scenarios in the text and in Appendix B.

Category	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5 (moderate)	SSP5-8.5 (severe)	SSP2-4.5 (moderate)	SSP5-8.5 (severe)	SSP2-4.5 (moderate)	SSP5-8.5 (severe)
Electricity system costs	\$375.90	\$574.80	\$684.60	\$1332.50	\$723.80	\$2557.30
Nonelectric fuel costs	-\$0.50	-\$1.00	-\$0.60	-\$1.40	-\$0.60	-\$1.50
Total of electric and nonelectric fuel costs	\$375.40	\$573.90	\$684.00	\$1,331.00	\$723.20	\$2,555.90

Table 5-9. Average Annual Impacts on Electricity System Costs, Fuel Costs, and Total Cost Due to Climate Change by Era and Climate Scenario for the Decarbonization Infrastructure Scenario

Values are relative to the mild scenario. Results are reported in millions of 2021 USD per year. Estimates are for the decarbonization scenario only. Era level estimates for electric system costs are based on an undiscounted average of estimated costs within the relevant 30-year eras (i.e., 2020–2049, 2040–2069, and 2070–2099, respectively). These 30-year averages differ from those presented in Table 5-6 above, which are for single years. The third row of this table (Total) is also reported as the summary results in Table 5-1 of this chapter. Impacts listed under SSP2-4.5 refer to total costs under the moderate climate scenario relative to the baseline (mild scenario); impacts listed under SSP5-8.5 refer to total costs under the severe climate scenario relative to the baseline (mild scenario). See details of these custom climate scenarios in the text and in Appendix B.

Category	Near Century (2030s)		Midcentury (2050s)		Late Century (2080s)	
	SSP2-4.5 (moderate)	SSP5-8.5 (severe)	SSP2-4.5 (moderate)	SSP5-8.5 (severe)	SSP2-4.5 (moderate)	SSP5-8.5 (severe)
Electricity system costs	-\$41.20	-\$137.90	-\$239.00	-\$411.50	-\$569.10	\$278.30
Nonelectric fuel costs	-\$0.30	-\$0.60	-\$0.10	-\$0.30	-\$0.10	-\$0.20
Total of electric and nonelectric fuel costs	-\$41.50	-\$138.50	-\$239.100	-\$411.9	-\$569.20	\$278.10

2.2.3 Limitations

This analysis includes several limitations related to data, modeling assumptions, and scope, which may affect the interpretation and generalizability of the results.

- This analysis provides a comprehensive assessment 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.
- The analysis did not consider the impacts of rising temperatures on the distribution system; however, the previous section addresses these impacts to the extent possible using existing data and methodologies. The possibility of interactive effects of climate change on the power generation system (considered in this section) and impacts on the transmission and distribution systems (considered in the previous section) were not analyzed. The omission of interactive effects likely results in an underestimate of impacts of climate on the overall electric generation, transmission, and distribution system.
- 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.

2.2.4 Potential for Adaptation to Reduce Impacts

Electricity systems are characterized by a high degree of adaptability, with strong market incentives to minimize fuel supply, transmission and distribution, and other costs. Additional adaptation measures, beyond the fuel and other supply optimization and energy efficiency measures incorporated in this analysis, including grid updates that might facilitate even greater temporal and flexibility of supply, especially for renewables. Additional battery or other forms of storage could also increase flexibility, ameliorate peak demand price increases, and reduce overall costs. Additional efficiency measures beyond those modeled in this analysis could further reduce overall costs of electric system supply. Finally, some investments could be made to increase electric reliability during extreme events, which in turn could reduce overall system costs. Those measures could include undergrounding of power lines (targeted in the most vulnerable areas, such as coastal areas subject to frequent high winds, where they are likely to be most cost-effective) and the development of microgrids in certain areas.

3 Partially Quantified and Qualitative Damages

This section includes a partially quantified characterization of climate change impacts on communication infrastructure. This category has at least some components of impacts that have been quantified and monetized in relevant literature, but the impacts could not be modified or adjusted for the specific climate scenarios used in this study. Most of the current literature on impacts to communication infrastructure examines impacts on the coupled electricity delivery and communications sectors, so estimating the impacts related only to communication infrastructure is challenging.

3.1 Communication Infrastructure

Telecommunications and broadcasting directly contributed \$70.4 billion in annual gross domestic product (GDP) in New York State in 2019 (Bureau of Economic Analysis 2021), and communication infrastructure is essential to the effective functioning of other key industries, particularly during emergencies. These interdependencies multiply the consequences of communications disruptions, and the reliance of communications on the electric power network may further increase vulnerability (Zamuda et al. 2018).

Communication infrastructure is primarily sensitive to increased frequency and severity of extreme weather under climate change. Costs may include direct damage to infrastructure and equipment from extreme weather events and lost productivity due to service interruptions. Climate-driven changes to precipitation, temperature, and sea-level rise may also impact communications either directly or via effects on energy production or delivery (Jacob et al. 2011, Leichenko et al. 2011, Blake et al. 2019).

Most of the current literature examines impacts on the coupled electricity delivery and communications sectors, so estimating the impacts related only to communication infrastructure is challenging. Case studies give some additional insight into historical damages.

Table 5-10. Climate Change Impacts on Communication Infrastructure

Element	Description
Description of Impacts	Extreme weather, more concentrated precipitation, and increased temperatures are expected to affect communications, damaging infrastructure and increasing the frequency of service disruptions.
Primary Climate Stressors	• Extreme weather (increased damages) ◦ More frequent and severe storms: Direct damage to infrastructure, service disruptions • Precipitation (increased damages) ◦ More concentrated precipitation: Increased risk of flooding, icing • Temperature (increased damages) ◦ Rising temperatures: Increased demands on the grid, potential for blackouts
Economic Values	• Cost of productivity losses • Cost of infrastructure adaptation and repair
Primary Affected Regions	Statewide
Potential Magnitude of Impact in New York State	Greater than \$10 million

3.2 Relevant Literature

Jacob et al. (2011) identified several climate-related threats to communication infrastructure that are expected to worsen by the end of the century. These threats include icing, flooding, and other direct damage to infrastructure from heavy precipitation, severe storms, and sea-level rise, as well as increases in service interruptions due to power outages resulting from high demand during heat waves. The researchers designed a hypothetical composite winter storm with three weather bands (rain, freezing rain/ice, and snow), each representing a winter precipitation extreme expected to occur on average once every 100 years under the current climate. While the simultaneous occurrence of all three precipitation bands would not necessarily be expected, the scenario is designed to be a combined assessment of the impacts of all three. The researchers then modeled the economic impacts of this composite storm, with a primary focus on communication infrastructure and a secondary focus on the power grid. The researchers found that productivity losses due to communication disruptions alone could amount to \$900 million and total losses (including impacts like spoiled food and damage to crops) could approach \$2 billion. New York State already has the highest average occurrence of ice storms in the contiguous U.S., and storms like the one modeled are expected to increase in frequency and severity under climate change (Jacobs et al.).

Leichenko et al. (2011) drew on the hypothetical storm described in Jacob et al. (2011) and estimated that the annual incremental costs of climate change impacts on communications without adaptation

could reach \$30 million–\$60 million by the 2080s, assuming a 10%–20% increase in storm damage due to climate change.⁷ The researchers also calculated that annual costs of adaptation in the form of backup networks, specifically a wireless backup network in New York City and a fiber optic network in the upstate region, would approach \$24 million by the 2080s but could yield benefits up to \$95 million annually.

In addition to impacts from storms, high temperatures can also affect communication infrastructure. Anderson and Bell (2012) examined outcomes from the largest blackout in U.S. history, which occurred in August 2003 when high temperatures caused a power line to sag and trip due to contact with vegetation, leading to cascading outages as redirected power overloaded other lines (U.S.–Canada Power System Outage Task Force 2004). Anderson and Bell estimated that 90 excess deaths in New York City were attributable to the blackout and cited failure of cellular service and difficulty contacting emergency services as contributing factors.

Another consideration is the particular vulnerability of rural communities. Less redundancy in infrastructure, including communication infrastructure, means rural communities tend to be at higher risk from climate threats. Such communities may have difficulty reporting service disruptions and accessing assistance during outages and emergencies and often wait longer for service to be restored (Jacobs et al. 2011).

3.3 Conclusion

While the estimates presented in Jacob et al. (2011) and Leichenko et al. (2011) rely on simplified assumptions and a hypothetical scenario, they offer insight into the magnitude of the potential impacts and adaptation costs of climate change for communication infrastructure. Suggested adaptation strategies focus on increasing both resiliency and redundancy via burying wires, decoupling communications from electricity provision, installing emergency generators, standardizing power systems for communication devices, and diversifying communication media.

Adaptation may be facilitated by the relatively short cycle of replacement for communication infrastructure. Rapid technological advancement already necessitates frequent updating of

⁷ Leichenko et al. (2011) refer to the composite storm as a 1-in-50-year winter storm, while it appears that Jacob et al. describe the storm as a 1-in-100 year winter storm. The presence of the three combined weather bands, while plausible based on historical storms, may complicate the reliable assignment of a return period for the composite storm, which nonetheless would be expected to have a changing return period in the future, with climate change.

communication infrastructure, so incorporation of more resilient technology and system improvements is considerably easier and cheaper than in other sectors with longer cycles for replacement (Jacob et al. 2011, Leichenko et al. 2011). A recent report by the U.S. Chamber of Commerce (2024) shows that \$1 spent on proactive adaptation results in \$13 of averted economic costs, damages, and cleanup. The authors note that an interdependent system is only as resilient as its least resilient link. As such, adaptation of communication infrastructure must be paired with protections to bring resilience levels to the same storm return period standard as that for the power grid to achieve the desired level of climate resilience (Blake et al. 2019).

4 References

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