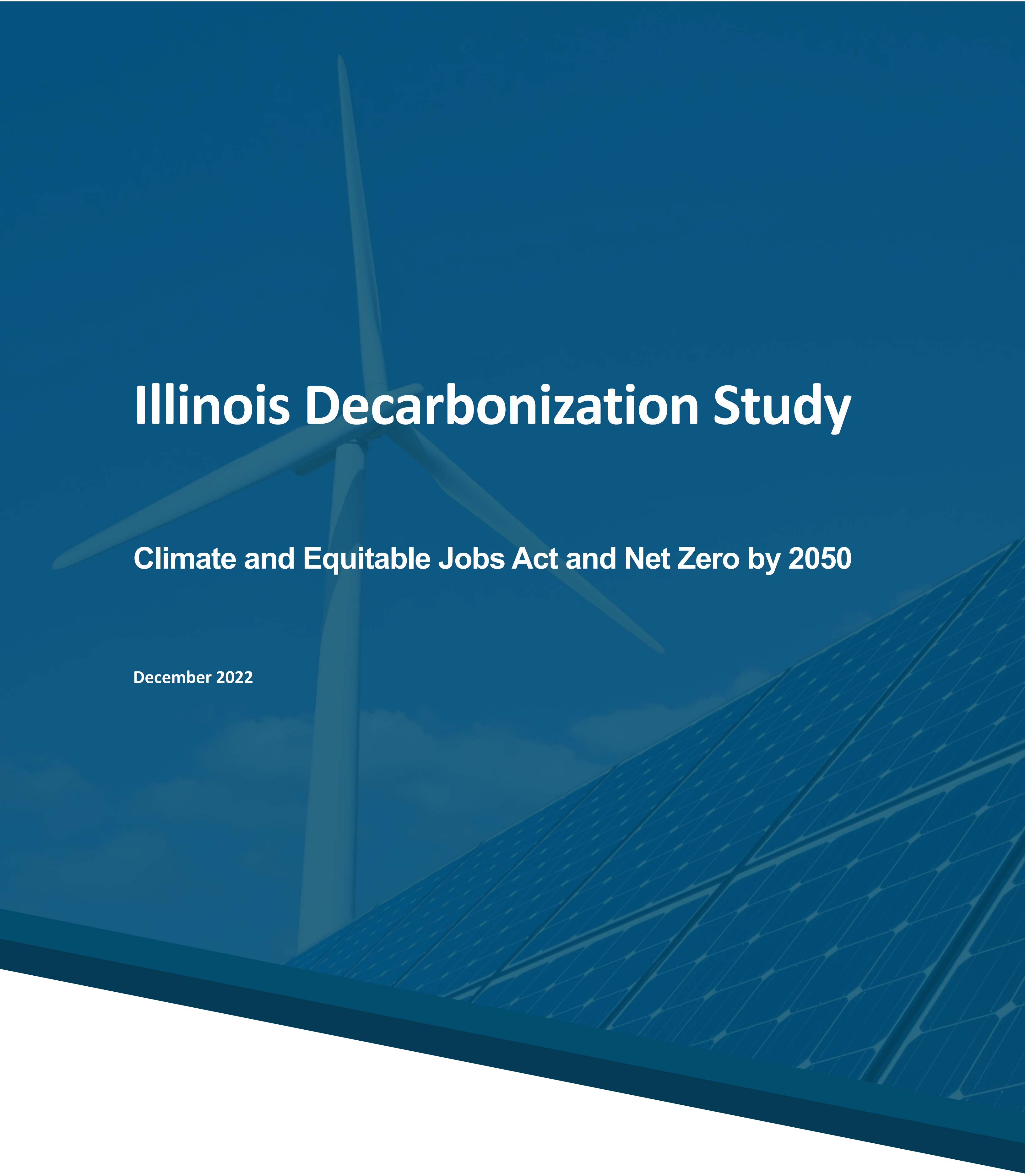

Illinois Decarbonization Study

Climate and Equitable Jobs Act and Net Zero by 2050

December 2022

Energy+Environmental Economics

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Acronym Definitions

Acronym	Definition
ACS	American Community Survey
AEO	Annual Energy Outlook
ANL	Argonne National Laboratory
ASHP	Air Source Heat Pump
ATB	NREL Annual Technology Baseline
BEV/EV	Battery Electric Vehicle/Electric Vehicle
BTU	British Thermal Unit
CAP	Climate Action Plan
CCS	Carbon Capture and Sequestration
CEJA	Climate and Equitable Jobs Act
CETLs	Capacity Emergency Transfer Limits
CO2e	Carbon Dioxide Equivalent
CUB	Citizens Utility Board
DAC	Direct Air Capture
DOE	Department of Energy
EDF	Environmental Defense Fund
EIA	Energy Information Administration
ELCC	Effective Load Carrying Capability
ELPC	Environmental Law and Policy Center
EMAAC	Eastern Mid-Atlantic Area Council
EPA	Environmental Protection Agency
FEJA	Future Energy Jobs Act
GHG	Greenhouse Gas
GSP	Gross State Product
HFCs	Hydrofluorocarbons
ICE	Internal Combustion Engine
IECC	International Energy Conservation Code
IPA	Illinois Procurement Authority
IPPU	Industrial Processes and Product Use
IRA	Inflation Reduction Act
LDV/MDV/HDV	Light/Medium/Heavy-duty vehicle
Li-ion	Lithium-ion
LOLP	Loss-of-load Probability
LSE	Load Serving Entity
LULUCF	Land-Use, Land-Use Change and Forestry
MISO	Midcontinent Independent System Operator
MMT	Million Metric Ton
MSW	Municipal Solid Waste
NEMS	National Energy Modeling System
NETs	Negative Emissions Technologies
NPV	Net present value
NQC	Net Qualifying Capacity
NRDC	Natural Resources Defense Council

NYISO	New York Independent System Operator
PRM	Performance Reserve Margin
PV	Solar Photovoltaics
RECs	Renewable Energy Credits
RECS	Residential Energy Consumption Survey
ReEDS	NREL Regional Energy Deployment System
RNG	Renewable Natural Gas
RPS	Renewable Portfolio Standard
RTO	Regional Transmission Organization
TAC	Technical Advisory Committee
TVA	Tennessee Valley Authority
USCA	US Climate Alliance
USDOT	US Department of Transportation
ZEV	Zero-emission Vehicle

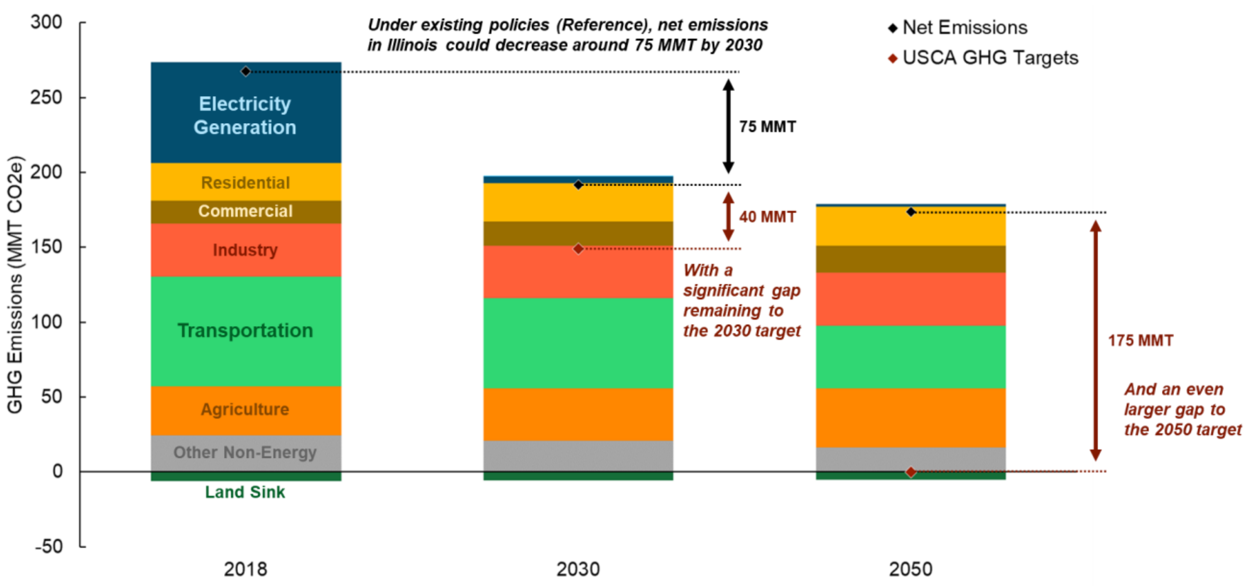
Executive Summary

About This Study

Illinois has started the transition to a deeply decarbonized economy and Commonwealth Edison (ComEd) will play a critical role in supporting that transition. In 2019, Governor Pritzker joined the US Climate Alliance which targets net-zero greenhouse gas (GHG) emissions by 2050. In 2021, the Illinois Legislature passed the Climate and Equitable Jobs Act (CEJA) which sets the state's electric power sector on a path towards decarbonization. A decarbonized electric sector is the lynchpin of deep decarbonization that enables GHG reductions in other sectors via electrification. The challenge before the State of Illinois now is to decarbonize sectors of the economy that were not targeted under CEJA.

Figure 1 shows the emissions in 2030 and 2050 under a business-as-usual trajectory, which includes CEJA and the Inflation Reduction Act (IRA). The gaps in emissions reductions needed to meet the UC Climate Alliance 2030 and 2050 Targets are shown as red lines with arrows. Figure 1 illustrates that achieving decarbonization in Illinois will be challenging given the State's emissions portfolio, which has a proportionately large share of emissions from the industrial and agricultural sectors relative to other states. Given the technological and economic challenges of reductions to those sectors, achieving deep emissions reductions from the electric, transportation, and buildings sectors is critical.

Figure 1: Illinois GHG Emissions in 2018, 2030, and 2050 Relative to USCA Targets

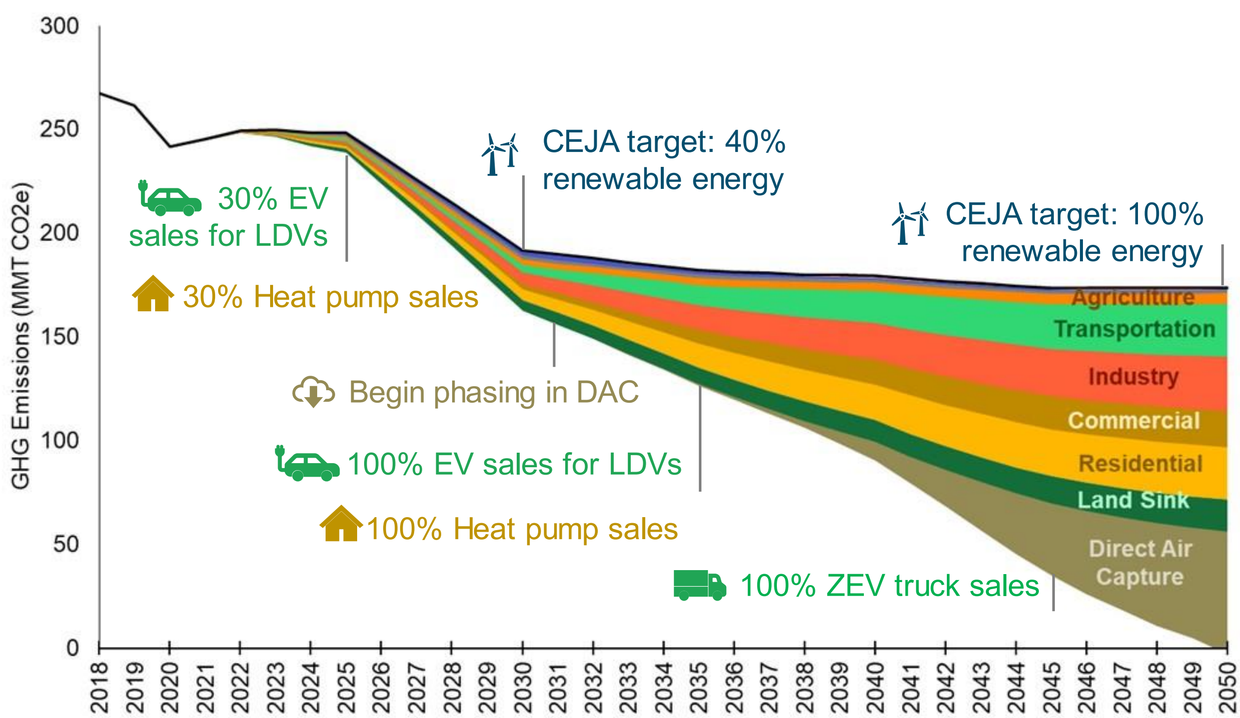


The goals of this study are to 1) determine the impact that CEJA and the IRA will have on GHG emissions in Illinois and 2) identify what additional measures are needed to achieve net-zero. To do so, E3 worked with ComEd and a technical advisory committee (TAC) to develop three scenarios. Those scenarios include:

- **Reference:** A business-as-usual scenario that includes all existing State and federal policies as of September 2022 but does not assume any additional policies impacting energy or emissions.
- **Moderate Electrification:** A scenario that achieves net-zero GHG emissions economy-wide by 2050 at the state level through transformations in all sectors. This scenario includes high levels of electrification, a larger role for hydrogen in transportation and industry, and the use of air source heat pumps with fuel back-up in most (70%) buildings.
- **High Electrification:** A scenario that achieves net-zero GHG emissions economy-wide by 2050 at the state level through transformations in all sectors. This scenario includes very high levels of electrification with a lesser role for hydrogen in transportation and industry, and all-electric heat pumps in 70% of buildings, with the remainder having fuel back-up.

These scenarios were developed for the state as well as for ComEd's service territory from 2022 to 2050. The two mitigation scenarios make deep cuts to emissions across the economy, expand sequestration in Illinois' lands, and leverage direct air capture to achieve carbon neutrality by 2050. The transportation, industrial, and buildings sectors see the most dramatic emissions reductions. Those reductions are primarily driven by electrification and, consistent with CEJA, are powered by a rapidly decarbonized electric grid. Renewable fuels play a limited, though critical, role in both carbon neutral scenarios by addressing sectors of the economy that are difficult to electrify and in supporting electric reliability.

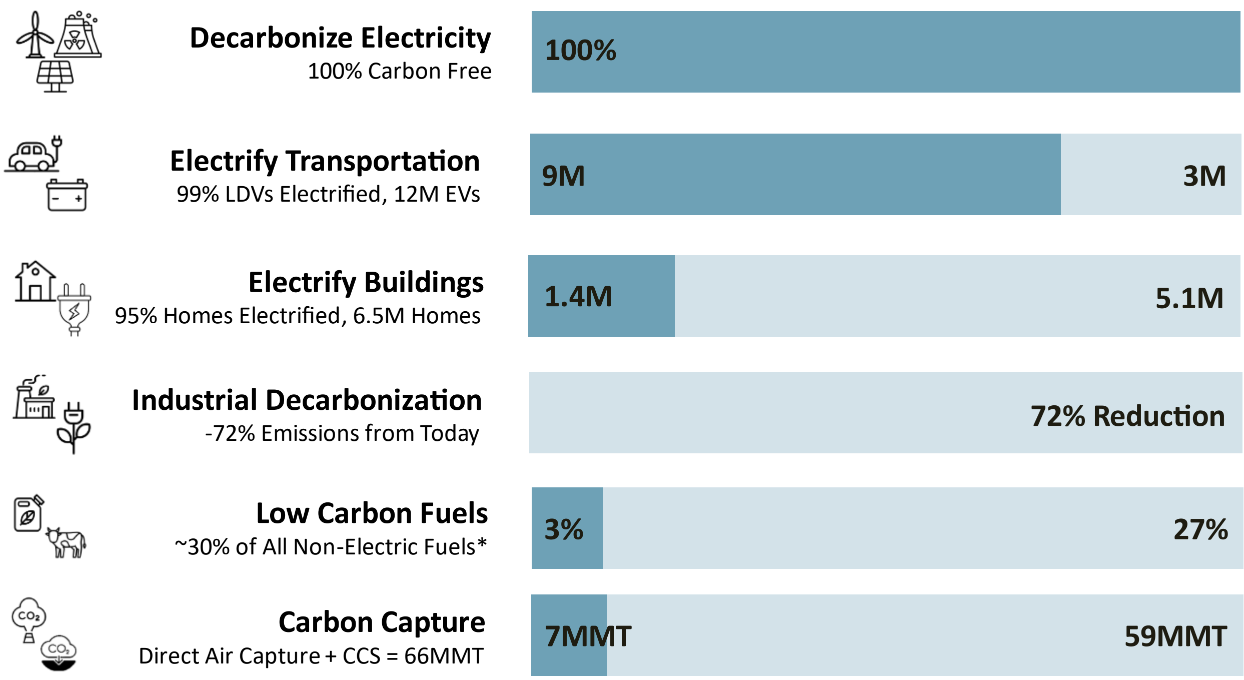
Figure 2: Incremental GHG Reductions by Sector to Achieve Net-Zero by 2050



Key Findings

CEJA and the IRA support high levels of electric and transportation sector decarbonization, but **new policies are needed to address buildings, heavy-duty transportation, industry, and agriculture**. By 2050, Illinois will need to electrify around 6.5 million residential homes and will need to add 12 million light-duty electric vehicles to the road. Existing policies will support electrification to an extent but given the long lifetime of many of these technologies, **near-term actions are needed spur adoption of electrification technologies and to accelerate the transition towards decarbonization**.

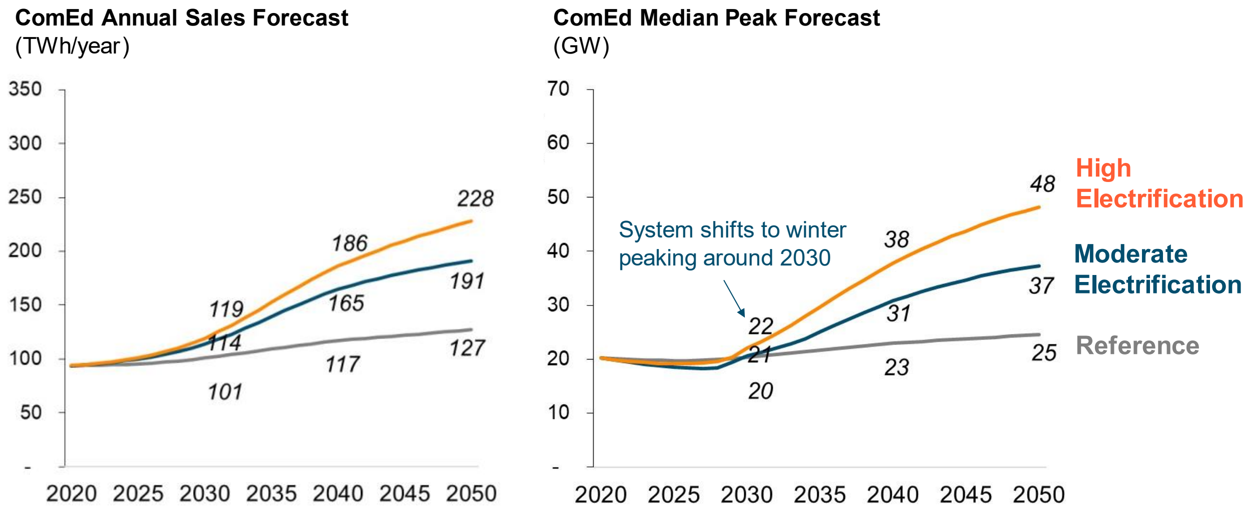
Figure 3: CEJA + IRA Contributions to Net Zero & Remaining Policy Gaps to Net Zero



** 30% represents a range from 190 – 386 TBtu depending on scenario assumptions*

While CEJA ensures that the electric grid is decarbonized**, additional electric grid investment is critical to ensure success of decarbonization measures** in all scenarios explored. In both mitigation scenarios, ComEd's annual and peak load growth approximately double by mid-century relative to today. Additional investments in electric infrastructure would also be required to support hydrogen production and direct air capture technology. Additional analysis is required to assess how much of the hydrogen production and direct air capture technology would need to be directly supported by the ComEd grid, as there is opportunity to import these fuels or buy carbon credits from facilities elsewhere, however, both of these solutions are required to meet carbon neutrality by 2050 given the hard to abate sectors in Illinois like industry and agriculture.

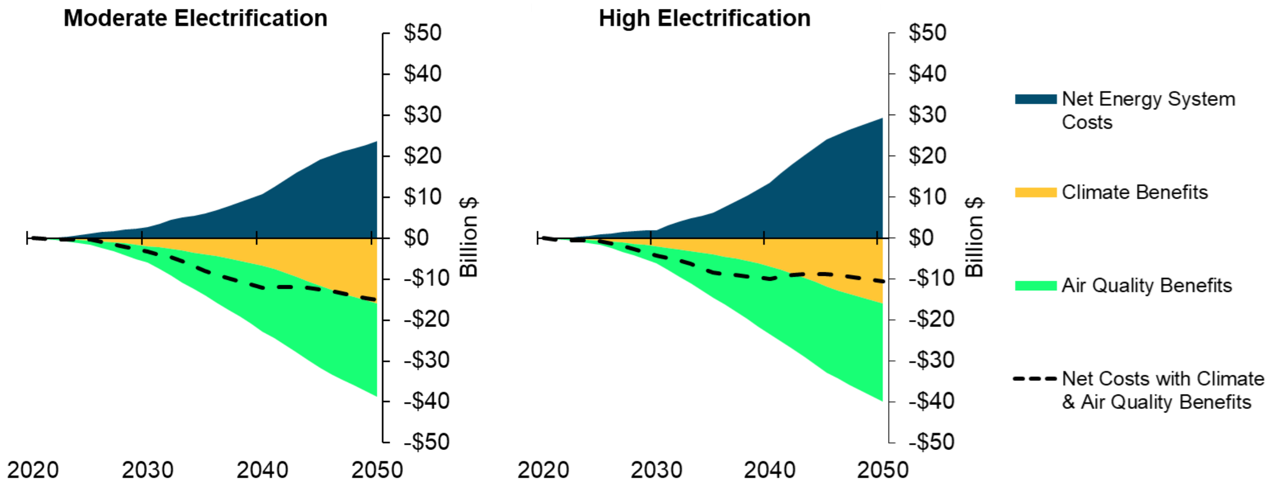
Figure 4: Magnitude of Annual Sales and Peak Load Growth



As heating load in Illinois transitions from natural gas to electricity, the nature of the electric grid and the operations will change. Today electric systems in Illinois are planned around a summer peak representing load from air conditioning on hot days, **in the future (as early as 2030), the state's electric system will transition to a winter peak due to increased electric heating**. This transition will impact system operations, require expansion of electric supply and delivery infrastructure, and implicate the ability of different resources to support resource adequacy. As peak demands shift from summer afternoons to sustained, multi-day cold snaps, **long duration storage resources like hydrogen** or other clean firm resources will be needed to deliver sufficient heating energy during cold snaps.

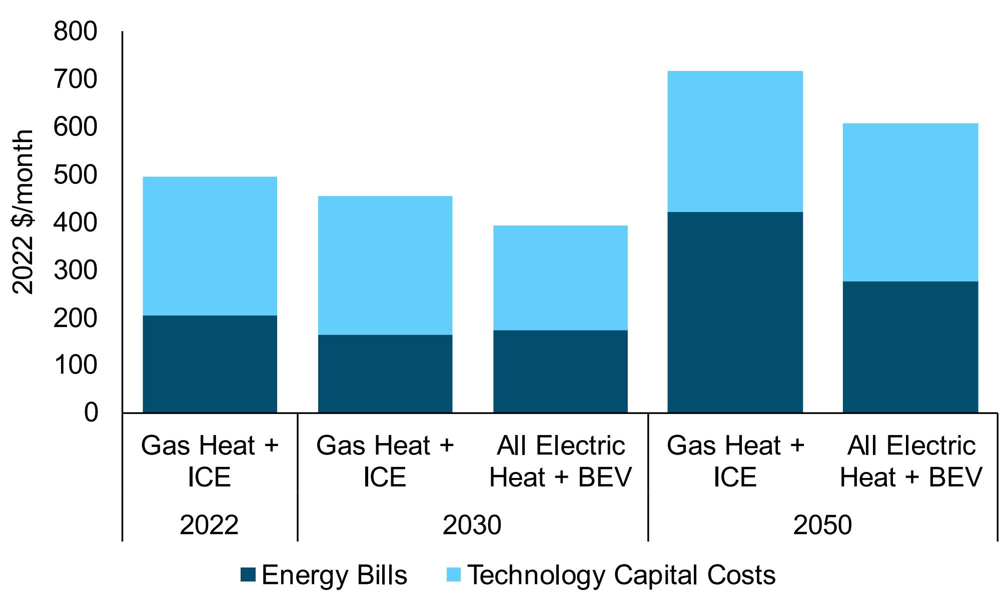
Investments will need to be made across all sectors of the economy to achieve carbon neutrality. These include the electric grid investments mentioned above, as well as investments to deliver and store hydrogen. On the consumer side, achieving net-zero requires a wholesale transformation of the way households and businesses use energy. That transition will require rapid shifts in customers' investment decisions from fossil fuel-based technologies towards electric alternatives like battery electric vehicles and heat pumps. On a per-capita basis, the net costs of decarbonization in 2050 range from $125-$160 per person. However, those incremental costs are lower than the benefits resulting from avoided climate damages and avoided air quality impacts on mortality. When these benefits are factored in, **decarbonization results in net societal annual benefits equaling $145-$840 per capita by 2050.**

Figure 5: Total Annual Net Costs of Decarbonization, Inclusive of Incremental Energy System Costs, Avoided Climate Damages and Air Quality Benefits



Decarbonization could result in reduced energy costs for customers who are able to leverage the most generous incentives available under the Inflation Reduction Act (IRA). Beyond 2030, decarbonization puts upward pressure on customer costs due to increasing electric and gas rates, as well as the incremental cost of unsubsidized equipment like heat pumps as IRA incentives expire. Costs from both customer and economy-wide perspectives are generally lower in the Moderate Electrification case because that scenario reduces the electric sector cost impacts of achieving net-zero. Both cases make it clear that policy support is needed to ensure an equitable electrification transition. Customers with natural gas heating in buildings and internal combustion engine (ICE) vehicles (Gas Heat + ICE), see their costs increase as more customers transition to electric only (e.g., all electric homes and battery electric vehicles (BEVs)) in line with the decarbonization measures.

Figure 6: Customer Affordability Under the High Electrification Scenario



Introduction

Motivation

ComEd is the largest electric utility in Illinois, serving more than 3.8 million customers across Northern Illinois, including Chicago. For more than 100 years, ComEd has been the primary electric delivery services company for Northern Illinois. Given ComEd's central role in the Illinois energy economy, the motivation for this study is to explore how ComEd can support the State in the achievement of its climate and policy goals as established through the adoption of the US Climate Alliance pledge and the Climate and Equitable Jobs Act (CEJA).

The key questions in this study include:

+ What are the impacts of CEJA and 2050 carbon neutrality on ComEd's customers?
+ Beyond CEJA, where are emissions reductions required to achieve carbon neutrality by 2050?
+ What is ComEd's role in Illinois toward achieving carbon neutrality by 2050?

US Climate Alliance Targets

In 2019, Illinois joined the U.S. Climate Alliance (USCA), a collection of states committed to achieving the Paris Agreement's goal of keeping global temperature increases below 1.5 degrees Celsius.[1] Governor Pritzker issued an Executive Order marking this commitment, but it has not yet been affirmed by legislation. At the time of Illinois' joining, the USCA had a collective target of achieving a 26-28% reduction in net GHG emissions below 2005 levels by 2025. Since then, the USCA has also adopted collective target of achieving a 50-52% reduction in net GHG emissions below 2005 levels by 2030 and achieving economy-wide net-zero GHG emissions by no later than 2050.[2] The USCA targets are aligned with the national GHG targets announced by the Biden Administration in 2021.[3] While the USCA targets are collective goals, the contribution of each individual state to achieving these targets is uncertain and beyond the scope of this analysis. As a result, E3 chose to model Illinois independently achieving net zero GHG emissions by 2050 in the mitigation scenarios for this study. The interim year targets were not treated as binding but are shown to illustrate the gap between those targets and the state's business-as-usual emissions trajectory.

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[1] Executive Order Number 19-6, https://www.illinois.gov/government/executive-orders/executive-order.executive-order-number-6.2019.html

[2] United States Climate Alliance, http://www.usclimatealliance.org/

[3] White House Fact Sheet, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/

Climate and Equitable Jobs Act (CEJA)

In 2021, Illinois passed groundbreaking legislation to support achievement of the State's climate goals. CEJA established several jobs, equity, and decarbonization measures including:

- Phasing out fossil fuels in the power sector by 2045
- Requiring 40% of Illinois' energy come from renewables by 2030 and 50% by 2040
- Requiring the State move toward 100% clean energy by 2050
- Establishing a goal of adopting 1,000,000 electric vehicles in Illinois by 2030
- Creating planning processes for beneficial electrification, and providing rebates for electric vehicles and electric vehicle charging infrastructure

Scope of this Study

Study Scope

This study explores the questions outlined above from today to mid-century (2050) for three geographies: the State of Illinois, ComEd's service territory, and a simple downscaling for Chicago to assess alignment with the Climate Action Plan (CAP).[4] Three scenarios were analyzed, one Reference scenario that is a business-as-usual trajectory that incorporates Federal and State policies as of Fall 2022, and two scenarios that achieve carbon neutrality by 2050. Those two scenarios represent different pathways towards decarbonization and explore the role of electrification in buildings, transportation, and industry, and conversely the role of hydrogen and other low carbon fuels, in supporting the State's decarbonization goals.

Results include greenhouse gas (GHG) emissions, energy demands, technology stocks, and economy-wide costs presented annually. Economy-wide costs are reported for the two decarbonization scenarios, measured relative to the Reference scenario. A more granular affordability assessment was also conducted which shows cost impacts for a subset of customers for each scenario. In addition, E3 worked with ANL to incorporate impacts from climate change, specifically temperature impacts, on the heating and cooling required in buildings and the impacts those climate-induced temperature changes would have on peak loads.

All sectors of the economy area represented in this analysis, though some sectors were not the focus of the study and are therefore treated with broader inputs and assumptions. Additional analysis should be conducted to better understand the contributions and mitigations available from the agriculture sector, land-use, land-use change and forestry (LULUCF), the industrial sector, and waste. Building and transportation electrification were represented with detailed modeling, but additional policy implementation research should be conducted to explore a wider range of technology options and adoption mechanisms.

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[4] Chicago Climate Action Plan. 2022. https://www.chicago.gov/content/dam/city/sites/climate-action-plan/documents/CHICAGO_CAP_20220429.pdf

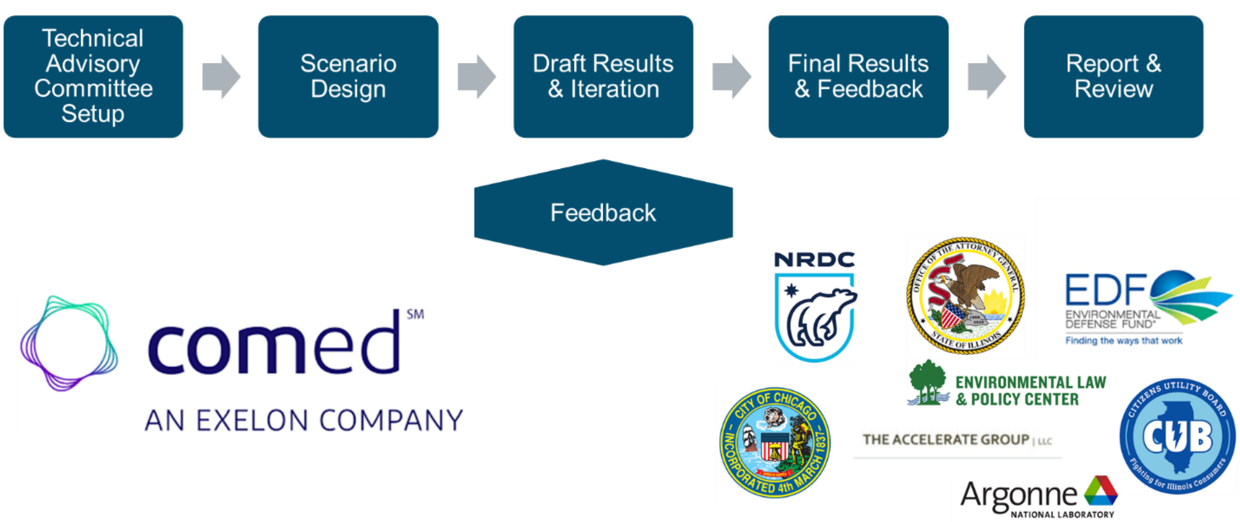
This study incorporates the impacts of climate change, but more research is needed to fully understand those impacts and their implications for resource adequacy in the future. Key climate impacts assessed include changes in annual heating and cooling degree days, as well as changes in annual minimum and maximum temperatures. We did not include an exhaustive or detailed look at all the ways climate change could impact the grid going forward, including impacts on renewable resource potentials and production or impacts from extreme events induced and exacerbated by climate change. E3 modeled electric sector capacity expansion consistent with CEJA and net-zero but did not conduct a detailed reliability assessment. Additional research is needed to characterize the relationships more fully between CEJA eligible resource generation availability and the high winter-time heating loads identified in this study.

Study Process

As a first step to the process, E3 worked with ComEd to establish a Technical Advisory Committee (TAC) made up of Argonne National Laboratory (ANL), the Natural Resources Defense Council (NRDC), the Environmental Defense Fund (EDF), the City of Chicago, the Citizens Utility Board (CUB), the Office of the Attorney General for the State of Illinois, Environmental Law and Policy Center (ELPC), and the Accelerate Group. The TAC provided feedback on critical milestones throughout the project. While the TAC's feedback was incorporated into the study, their participation does not imply endorsement of the results.

The TAC engagement began with a collaborative process to establish and design the scenarios explored in the analysis. Following this, E3 modeled those scenarios, presented draft results, gathered feedback from the TAC and ComEd, and incorporated that feedback into the analysis. The final analysis was then conducted, which culminated in the results presented in this report.

Figure 7: Study Process



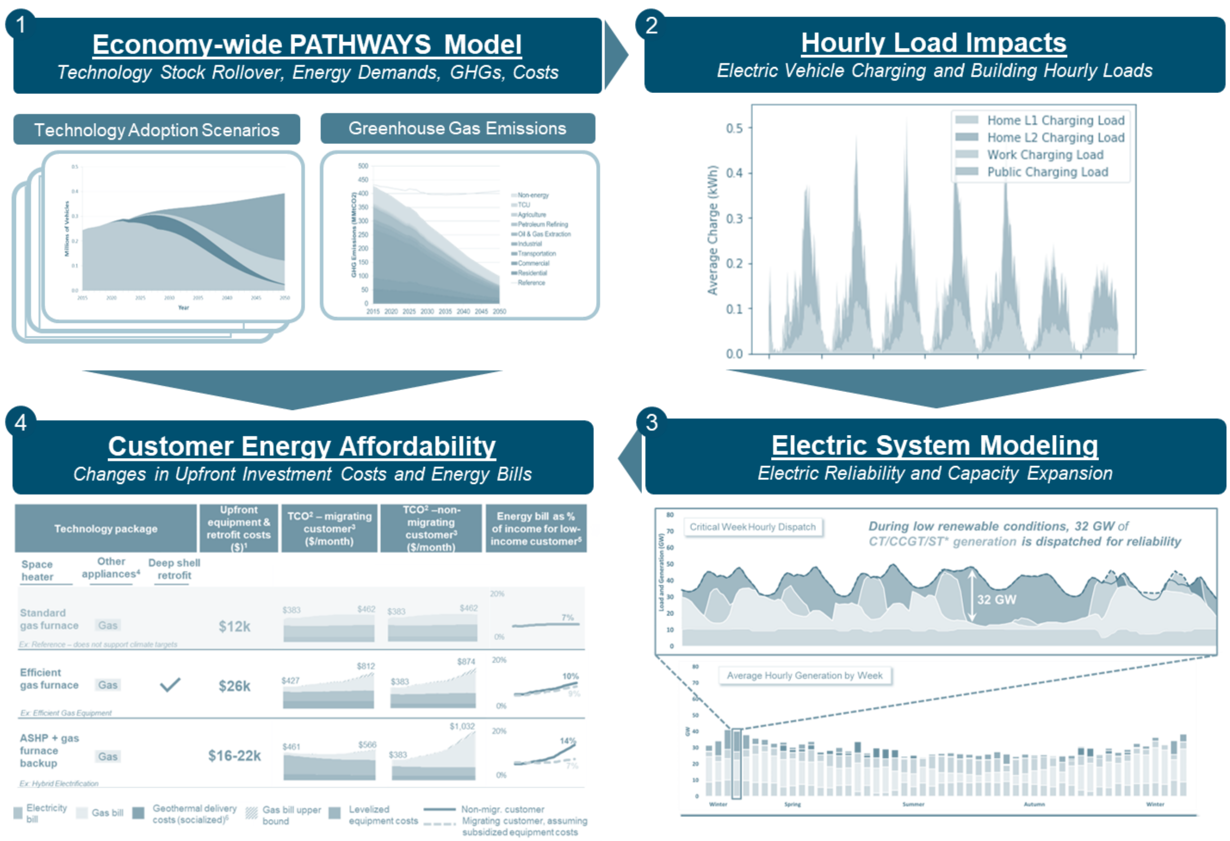
Approach

Modeling Framework

Modeling Methodology

E3 used several of our in-house models to conduct this analysis. The flow of the information and analysis between the models is shown in Figure 8 and described below.

Figure 8: Integrated Energy Systems Decarbonization Analysis Flow



1. E3's **Economy-wide PATHWAYS Model** is used to identify greenhouse gas (GHG) reduction measures from transportation, buildings, industry, electricity, and other sectors, and capture interactions among measures to create a detailed picture of emissions, energy demands, technology stocks, and costs through 2050. For this analysis, E3 developed a representation of energy and emissions within ComEd's service territory in the PATHWAYS model as well for the State of Illinois.
2. E3's **Hourly Load Impact** tools translate annual energy demands from the PATHWAYS model into hourly load profiles that take into account electric vehicle driving/charging patterns, heat pump performance, and load flexibility.

3. E3's **Electric System Modeling** approach leverages the least-cost optimization model RESOLVE to model the capacity build within ComEd's service territory within the larger PJM market context. RESOLVE takes the loads developed in the previous two modeling steps and identifies a least-cost system capacity expansion plan to meet those loads and meet reliability criteria. In addition, E3 assessed the impacts to ComEd's transmission and distribution infrastructure from peak demand growth at a system level.
4. E3's **Customer Energy Affordability** tool leverages all the information from prior modeling steps to assess the impacts of the decarbonization scenarios on representative residential customers. The tool calculates electric and gas bills and upfront capital investments in technologies (e.g. electric vehicles) representative of the underlying scenarios and the changes to the system those scenarios imply. Various representative customers are considered to reflect different income classes and technology adoption schedules across the scenarios.

Additionally, E3 performed a **county-level air quality analysis** for five major criteria air pollutants that examines the health benefits of reduced fuel combustion in Illinois. This analysis leverages existing county-level criteria air pollutant emissions data from the EPA National Emissions Inventory, future changes to fuel combustion from the PATHWAYS and RESOLVE models, and peer-reviewed studies estimating the marginal damages associated with emissions of criteria air pollutants.

Illinois Energy Market Context

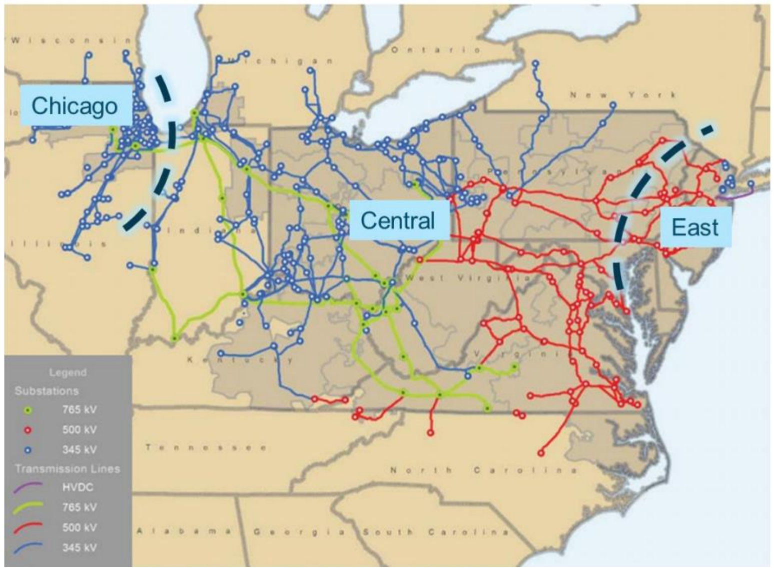
The State of Illinois has two major utilities, ComEd and Ameren, which participate in two separate regional electricity markets – PJM and Midcontinent Independent System Operator (MISO), respectively. Given the difference in market participation, this means the regions served by these two utilities are not well-integrated in terms of electric sector planning and their operations are largely untethered. However, the state does play a part in planning each entity's resource mix into the future via the Illinois Power Authority (IPA). The IPA is responsible for procuring energy resources on behalf of the utilities to meet their loads and ensure Illinois is on track to meet decarbonization goals set by CEJA and other policies.

ComEd is part of PJM, a regional electricity market. This connection with other entities across the Midwest and Mid-Atlantic States means that future changes that happen across PJM will impact ComEd; especially in the context of Illinois's decarbonization goals. The State goals, regulatory structure of procurement, and participation in PJM's market all were considered in the modeling ComEd's system in RESOLVE.

RESOLVE models the PJM system using a zonal transmission topology to simulate power flows among three zones represented in the model based on PJM's annual capacity auctions, Eastern Mid-Atlantic Area

Council (EMAAC), Central (regional transmission organization, or RTO), and ComEd. While zones may vary each year as system conditions change, these still capture the core regions with common dynamics in PJM.

Figure 9: High-Voltage Transmission Map Highlighting Modeled RESOLVE Zones



No external zones were modeled in RESOLVE[5], meaning PJM is unable to import or export to the MISO, the New York Independent System Operator (NYISO), or the Tennessee Valley Authority (TVA). Model zones align with the capacity auction zones of ComEd (Chicago: ComEd in Northeastern Illinois), EMAAC (East: Load serving entities (LSEs) in the regions of New Jersey, Delaware, Southeast Pennsylvania, and Eastern Maryland), and RTO (Central: Remaining LSEs in central PJM)

The Capacity Emergency Transfer Limits (CETLs) for ComEd and EMAAC are used as the transfer limits between these two zones and the RTO. The zonal import and export capabilities implemented in the model is 5,971MW for transfers between ComEd and RTO, and 9,752MW for transfers between EMAAC and RTO.[6]

Figure 10: PJM Transmission Topology Modeled in RESOLVE

[5] One representation of external resources was modeled via the 2 GW SOO Green Transmission line

[6] 2022/2023 RPM Base Residual Auction Planning Period Parameters Report, https://www.pjm.com/-/media/markets-ops/rpm/rpm-auctioninfo/2022-2023/2022-2023-rpm-bra-planning-parameters-report.ashx?la=en

Decarbonization Scenarios

E3 modeled three scenarios of future energy demand and GHG emissions for both Illinois as a whole and for ComEd's service territory:

- **Reference:** A business-as-usual scenario that includes all existing State and Federal policies as of September 2022 but does not assume any additional policies impacting energy or emissions
- **Moderate Electrification:** A scenario that achieves net-zero GHG emissions economy-wide by 2050 at the state level through transformations in all sectors. This scenario includes high levels of electrification, a large role for hydrogen in transportation and industry, and the use of air source heat pumps with fuel back-up in most (70%) buildings.
- **High Electrification:** A scenario that achieves net-zero GHG emissions economy-wide by 2050 at the state level through transformations in all sectors. This scenario includes very high levels of electrification with a lesser role for hydrogen in transportation and industry, and all-electric heat pumps in 70% of buildings, with the remainder having fuel back-up.

It is important to note that PATHWAYS is not an optimization model. Future scenarios of energy demand and GHG emissions are determined by user inputs for factors including technology adoption, energy efficiency levels, and non-energy emissions mitigation. The two net-zero scenarios modeled in this analysis are not forecasts of likely or optimal decarbonization; they are user-defined scenarios that are primarily designed to explore a range of plausible decarbonization net-zero GHG trajectories and the resultant electrification loads that ComEd could see in its service territory. A summary of the measures modeled in all three scenarios is shown in Table 1, with further detail on modeling assumptions provided in the appendix.

Table 1: Key Mitigation Measures by Sector and Scenario

Sector	Reference	Moderate Electrification	High Electrification
Electricity Generation	• CEJA Requirements, including 100% carbon-free in-state generation by 2050	• *Same as Reference*	• *Same as Reference*
Residential & Commercial Buildings	• **Efficiency:** Future Energy Jobs Act (FEJA) efficiency targets met • **Electrification:** small increase in heat pump sales share to replace electric resistance space heaters	• **Efficiency:** 60% of residential buildings either built to IECC 2018 code or have efficiency improvements by 2050 • **Electrification:** 100% sales of electric devices for all end-uses by 2035 • **Heat Pump Backup Heat:** 70% of heat pumps use gas combustion, remainder are all-electric	• **Efficiency:** 60% of residential buildings either built to IECC 2018 code or have efficiency improvements by 2050 • **Electrification**: 100% sales of electric devices for all end-uses by 2035 • **Heat Pump Backup Heat:** 70% of heat pumps are all-electric, remainder use gas combustion for back-up

Sector	Reference	Moderate Electrification	High Electrification
Industrial	• **CCS:** ~7 MMT of CCS capacity added to iron & steel, cement, ethanol, and refining facilities by 2035[7]	• **CCS:** *Same as Reference* • **Efficiency:** 26% reduction in energy demand for manufacturing[8] • **Electrification:** 12% of natural gas use electrified[9], 45% of liquid fuels use electrified • **Hydrogen:** 66% of natural gas use, 55% of liquid fuels use converted to hydrogen	• **CCS:** *Same as Reference* • **Efficiency:** 26% reduction in energy demand for manufacturing[8] • **Electrification:** 69% of natural gas use electrified[9], 95% of liquid fuels use electrified • **Hydrogen:** 29% of natural gas use, 5% of liquid fuels use converted to hydrogen
Transportation	• **LDVs:** 68% EV sales by 2035 based on ComEd projections with federal IRA and State incentives • **MHDVs:** 7% ZEV sales by 2035 based on E3 estimates of federal IRA incentives impact	• **LDVs:** 100% EV sales by 2035 • **MHDVs:** 100% ZEV sales by 2045, with 72/28 split between battery electric/hydrogen fuel cell vehicles[10]	• **LDVs:** 100% EV sales by 2035 • **MHDVs:** 100% ZEV sales by 2045, with 95/5 split between battery electric/hydrogen fuel cell vehicles[10]
Agriculture	• *No mitigation measures included*	• Abatement measures available below \$100/tCO2e for agricultural CH4 and N2O emissions[11,12]	• Abatement measures available below \$100/tCO2e for agricultural CH4 and N2O emissions[11,12]
Industrial Processes and Product Use (IPPU)	• **HFCs**: Phasedown based on EPA HFC Allowance Allocation and Trading Program[13]	• **HFCs**: *Same as Reference*	• **HFCs**: *Same as Reference*
Other Non-Energy	• *No mitigation measures included*	• Abatement measures available below \$100/tCO2e for coal mine methane, fugitive methane from oil & gas systems, and waste[11]	• Abatement measures available below \$100/tCO2e for coal mine methane, fugitive methane from oil & gas systems, and waste[11]

[7] CCS deployment based on Rhodium Group analysis of cost-effective opportunities below $85/ton: https://rhg.com/research/carbon-capture-american-jobs-plan/

[8] Industrial energy efficiency potential based on ACEEE Halfway There (2019) report: https://www.aceee.org/sites/default/files/publications/researchreports/u1907.pdf

[9] Natural gas electrification based on NREL Electrification Futures Study. Moderate Electrification and High Electrification assumptions are based on NREL Medium and High scenarios, respectively, with High Electrification also including full electrification of gas boilers: https://www.nrel.gov/docs/fy18osti/71500.pdf

[10] Battery electric vs. hydrogen fuel cell split based on NREL MHDV cost analysis. Moderate Electrification and High Electrification are based on NREL Central Case and Conservative H2 Case, respectively: https://www.nrel.gov/docs/fy22osti/82081.pdf

[11] EPA non-CO2 emissions mitigation potential: https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases

[12] Nature4Climate United States Natural Climate Solutions Mapper: https://nature4climate.org/nature-in-action/united-states-ncs-mapper/

[13] Final Rule - Phasedown of Hydrofluorocarbons: Establishing the Allowance Allocation and Trading Program under the AIM Act, https://www.epa.gov/climate-hfcs-reduction/final-rule-phasedown-hydrofluorocarbons-establishing-allowance-allocation

Sector	Reference	Moderate Electrification	High Electrification
Land-use, Land-use Change, and Forestry (LULUCF)	• *No mitigation measures included*	• ~15 MMT increase in natural carbon sequestration by 2050 based on abatement measures available below \$100/tCO2e[12]	
Biofuels	• *No advanced biofuels included*	• Advanced biofuels production using Illinois' population-weighted share of national waste and residue feedstocks • 2050 Renewable natural gas use: 60 TBtu • 2050 Renewable diesel use: 58 TBtu • 2050 Renewable jet kerosene use: 23 TBtu	
Negative Emissions Technologies (NETs)	• *No NETs included*	• Direct air capture (DAC) deployed to remaining emissions gap to net zero after all other measures have been implemented, resulting in ~59 MMT of DAC capacity needed in 2050	

Energy Efficiency and Load Flexibility

Both net-zero scenarios assume adoption of more efficient building shells. Efficient building shells reduce space heating demands by reducing heat and air exchange with the outdoor environment. This reduces the amount of heating or cooling needed to bring a building to its desired set point, which in turn reduces peak and annual demands in the electric and gas sectors. The building shell retrofits deployed in the net-zero scenarios are assumed to reduce annual heating demands by 27% and 40% for single-family and multi-family homes, respectively, and to reduce annual cooling demands by 23% for all housing types. These values are based on E3 analysis used to support the New York Climate Action Council Draft Scoping Plan.[14] In addition to building efficiency, E3 assumed both net-zero scenarios see a 26% reduction in manufacturing energy demand based on expanding existing and emerging practices identified in ACEEE's 2019 Halfway There report. Finally, the transportation sector includes direct energy efficiency measures in the form of the latest CAFE standards for passenger vehicles announced by the US Department of Transportation (USDOT) for model years 2024-2026.[15]

Load flexibility was assumed for LDV and HDV charging. For both load categories, E3 simulated managed vehicle charging using its EV Load Shaping Tool. These managed shapes shifted charging away from peak charging hours to be more evenly distributed across the day. This particularly impacted LDV charging, in which peak evening charging was shifted to the subsequent morning and early afternoon.

[14] New York Climate Action Council Draft Scoping Plan. https://climate.ny.gov/Our-Climate-Act/Draft-Scoping-Plan
[15] USDOT Announces New Vehicle Fuel Economy Standards for Model Year 2024-2026. https://www.nhtsa.gov/press-releases/usdot-announces-new-vehicle-fuel-economy-standards-model-year-2024-2026

Biofuels and Hydrogen

E3's Renewable Fuels Module assesses the most cost-effective way to deploy scarce biomass resources to produce liquid and gaseous fuels to economic sectors. Once final demand for liquid and gaseous fuel is determined after electrification, hydrogen fuel-switching, and energy efficiency measures, E3's Renewable Fuels Module is employed to determine the most-effective use of biomass to produce advanced renewable liquid and gaseous fuels. The advanced biofuels produced are treated as chemically identical to fossil fuels, meaning they are not subject to the same blend limits for use in existing equipment as conventional biofuels like ethanol or biodiesel. Furthermore, these fuels are considered to have net-zero lifecycle emissions and are phased into scenarios after 2030. For this analysis, available feedstocks were determined using the Department of Energy *2016 Billion-Ton Report* and NREL estimates of biogas potential in the United States.[16,17] The feedstocks included can categorized into three groups:

1. **Wastes**: Animal-related wastes (manure), municipal solid waste (MSW) destined for landfill or incineration disposal, and byproducts of wastewater treatment facilities. These feedstocks require no additional agronomic inputs (e.g. land or fertilizer) as they are existing byproducts.
2. **Forest and Agriculture Residues**: Forest residue feedstocks include logging residues, wood wastes from mills, and harvest from forest thinning, fuel reduction, and regeneration cuts. Agriculture residue feedstocks include crop residues from corn stover, cereal straws (wheat, oats, and barley), and sugarcane. Both forest and agriculture residues require no additional cultivation of land as they are natural byproducts of existing forestry and agriculture practices.
3. **Dedicated Energy Crops**: These include both cellulosic crops like miscanthus, switchgrass, and sorghum and woody crops like willow, poplar, eucalyptus and other purpose-grown trees. Unlike wastes and residues, these feedstocks require additional cultivation of land, which can be achieved using marginal agricultural lands, converting existing agricultural or forestry land to energy crop production, or re-purposing land used for other uses.

Both net-zero scenarios only include feedstocks from wastes and forest and agriculture residues; no dedicated energy crops are included in this analysis due to sustainability and land-use concerns.[18] E3 assumed that Illinois would have access to the state's population-weighted share of national feedstocks. Based on the available feedstocks, biomass conversion costs, and remaining energy demands for liquid and gaseous fuels, both net-zero scenarios consume 141 TBtu of advanced renewable fuels in 2050 (23 TBtu of renewable natural gas, 58 TBtu of renewable diesel, and 60 TBtu of renewable jet kerosene). Hydrogen in this analysis modeled as being produced via electrolysis powered by renewable energy. That hydrogen production is assumed to occur in dedicated facilities and is delivered to Illinois via pipelines.

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[16] US DOE 2016 Billion-Ton Report. https://www.energy.gov/sites/prod/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf

[17] NREL Biogas Potential in the United States Oct 2013. https://www.nrel.gov/docs/fy14osti/60178.pdf

[18] The Role of Gas Distribution Companies in Achieving the Commonwealth's Climate Goals. https://thefutureofgas.com/content/downloads/2022-03-21/3.18.22%20-%20Independent%20Consultant%20Report%20-%20Decarbonization%20Pathways.pdf

Decarbonization Pathways Key Results

Economy-wide Energy and Emissions

Base Year Emissions

Table 2 shows GHG emissions by sector in Illinois for 2018, the base year of the PATHWAYS model, and the contribution to total gross emissions. The transportation sector is the largest source of emissions, followed closely by electricity generation, and together the two sectors account for more than half of gross emissions in 2018. Residential and commercial buildings collectively are the third largest source of emissions, followed closely by industrial fuel use. Together, energy-related combustion emissions account for 80% of the gross GHG emissions in Illinois. The remaining 20% of emissions come from non-energy, non-combustion emissions. Of these, agriculture is by far the largest source, with most emissions in the sector coming from N2O emissions from agricultural soils. Most of the remaining non-energy emissions in the state come from hydrofluorocarbons (HFCs) (included in the IPPU sector), and fugitive emissions from waste facilities.

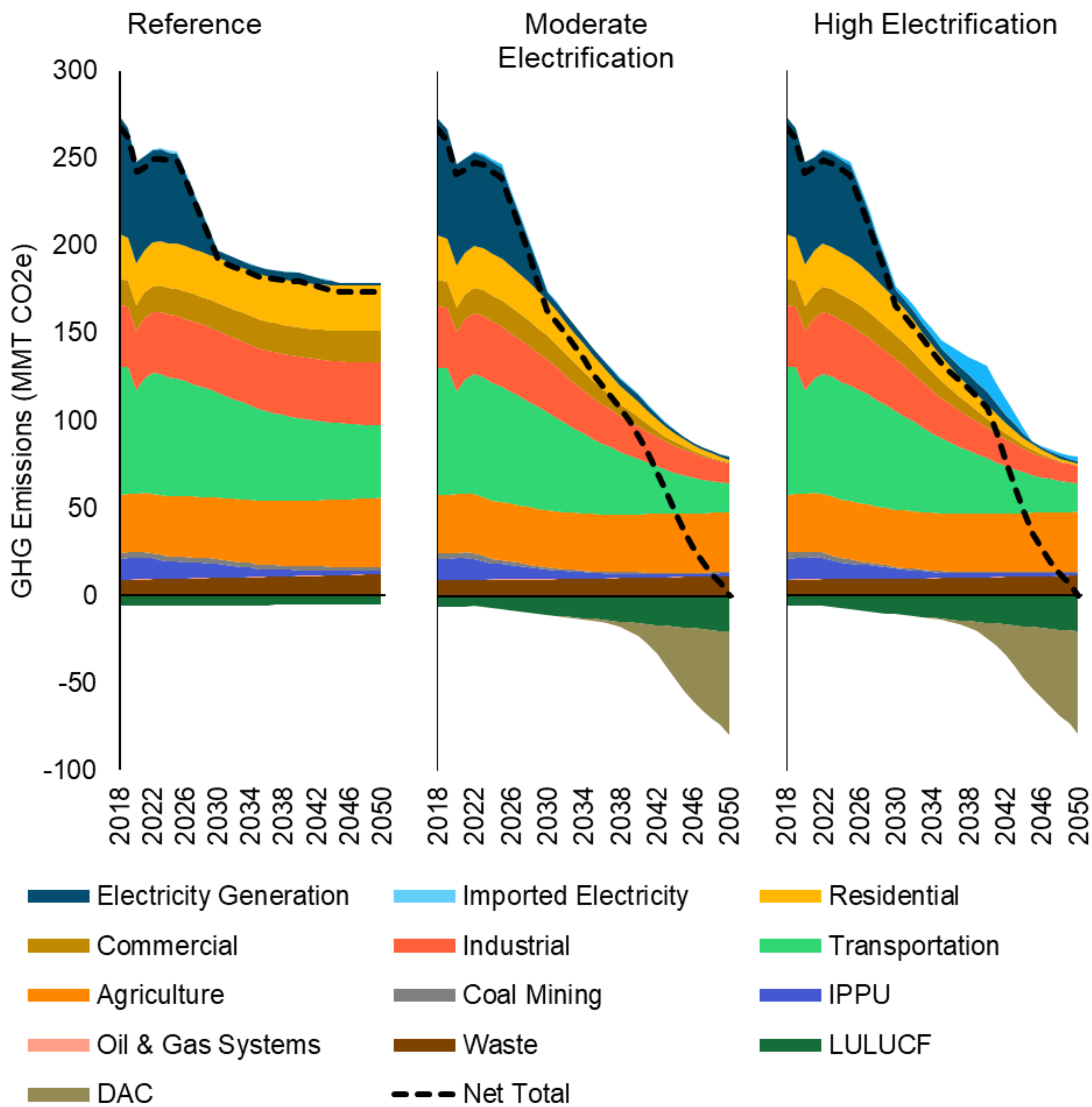
Table 2: GHG Emissions by Sector for Illinois in 2018

Category	Sector	Emissions (MMT CO2e)	Share of Gross Emissions
Energy	Electricity Generation	67	25%
	Residential	25	6%
	Commercial	15	9%
	Industrial	35	13%
	Transportation	73	27%
Non-Energy	Agriculture	33	12%
	Coal Mining	3	1%
	IPPU	12	4%
	Oil & Gas Systems	<1	0%
	Waste	9	3%
	Gross Total	**273**	**100%**
	LULUCF	-6	
	Net Total	**267**	

Annual Emissions

Figure 11 shows the change in annual emissions by sector in each of the three scenarios. The Reference scenario sees a dramatic reduction in electricity sector emissions by 2030 due to CEJA requirements, followed by smaller reductions in the transportation sector due to passenger EV sales and fuel economy improvements and in the IPPU sector due to new EPA HFC regulations. However, despite these reductions, net GHG emissions are still over 170 MMT CO2e in 2050, leaving a large gap to achieving net-zero.

Figure 11: GHG Emissions by Sector in Illinois for All Scenarios



The Moderate Electrification and High Electrification scenarios have a similar trajectory in emissions on the path to net-zero. Similar to the Reference scenario, electricity emissions decline sharply by 2030 and remain low (the High Electrification sees an increase in imported electricity emissions that peak in 2040 before declining again by 2050, further detail on this dynamic is provided in subsequent chapters focusing on electricity sector modeling). However, these scenarios require much deeper reductions in the remaining energy demand sectors, moderate reductions in non-energy sectors, and significant expansion of natural carbon sinks along with deployment of NETs.

In both net-zero scenarios, building sector emissions are almost eliminated by 2050, through electrification of space heating, water heating, and cooking. A small amount of combustion remains from old devices that have not yet been retired and from furnaces that provide supplemental space heating during cold snaps. Renewable natural gas blends range from 33-53% in 2050 in the Moderate and High Electrification scenarios, respectively, and help to reduce emissions from remaining fuel use in buildings.

Industrial sector emissions decrease by around 70% by 2050 in both net-zero scenarios through a mixture of efficiency, electrification, and hydrogen fuel-switching, with a small role for industrial CCS. On-road transportation is almost fully decarbonized by 2050 due to an ambitious ramp up in sales of ZEVs for both LDVs and MHDVs and a high blend of renewable diesel by 2050 (>90%) for remaining diesel trucks. Remaining transportation sector emissions in both net-zero scenarios are mostly from aviation, which sees less aggressive decarbonization, although there is an 11% blend of renewable jet kerosene by 2050.

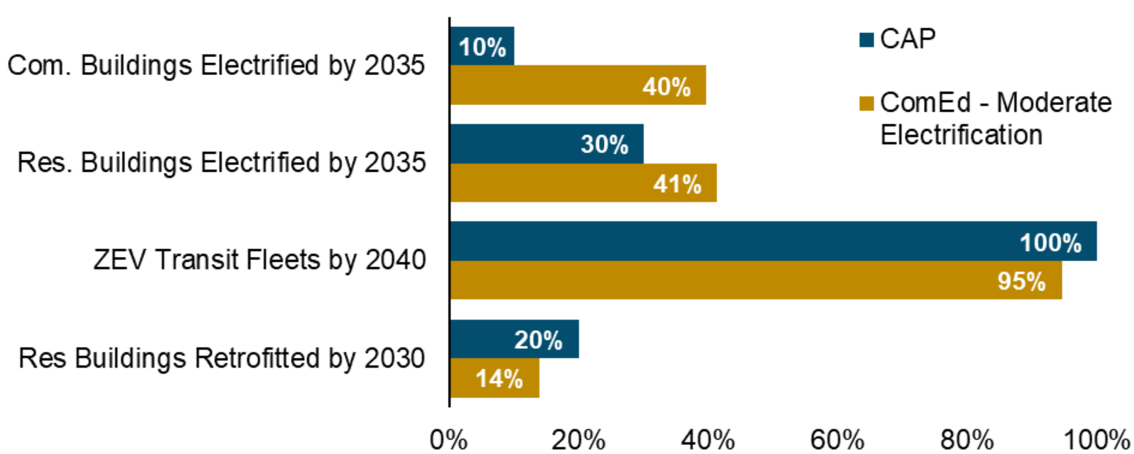
Emissions reductions in the non-energy sectors are notably smaller than those of energy demand sectors. While collective emissions from buildings, industry, and transportation decline around 80% by 2050 in both net-zero scenarios, collective emissions from the non-energy sectors only decline by 17%, due to the challenge of abating N2O and CH4 emissions from agriculture and waste. As a result, both net-zero scenarios have 80 MMT CO2e of gross emissions remaining in 2050 that must be offset. Even with an aggressive assumption that natural carbon sinks in Illinois can more than triple their annual carbon sequestration by 2050, large deployments of NETs are needed to capture 60 MMT CO2e.

These measures indicate that Illinois has a relatively challenging emissions profile to achieve net-zero compared to other leading states. That challenge stems from the large share of emissions for hard to abate sectors like agriculture and industry. As a result, other sectors of the economy, like transportation and buildings, must approach zero emissions for the overall net-zero goal to be achieved.

Chicago

GHG reductions for ComEd's territory in the net zero scenarios are similar to the Chicago Climate Action Plan (CAP) target of 62% reduction by 2040. This indicates that the decarbonization actions modeled in this study would support Chicago achieving its GHG target. Additionally, many of the individual targets for Chicago in the CAP are achieved or nearly achieved in ComEd's service territory in the net zero scenarios.

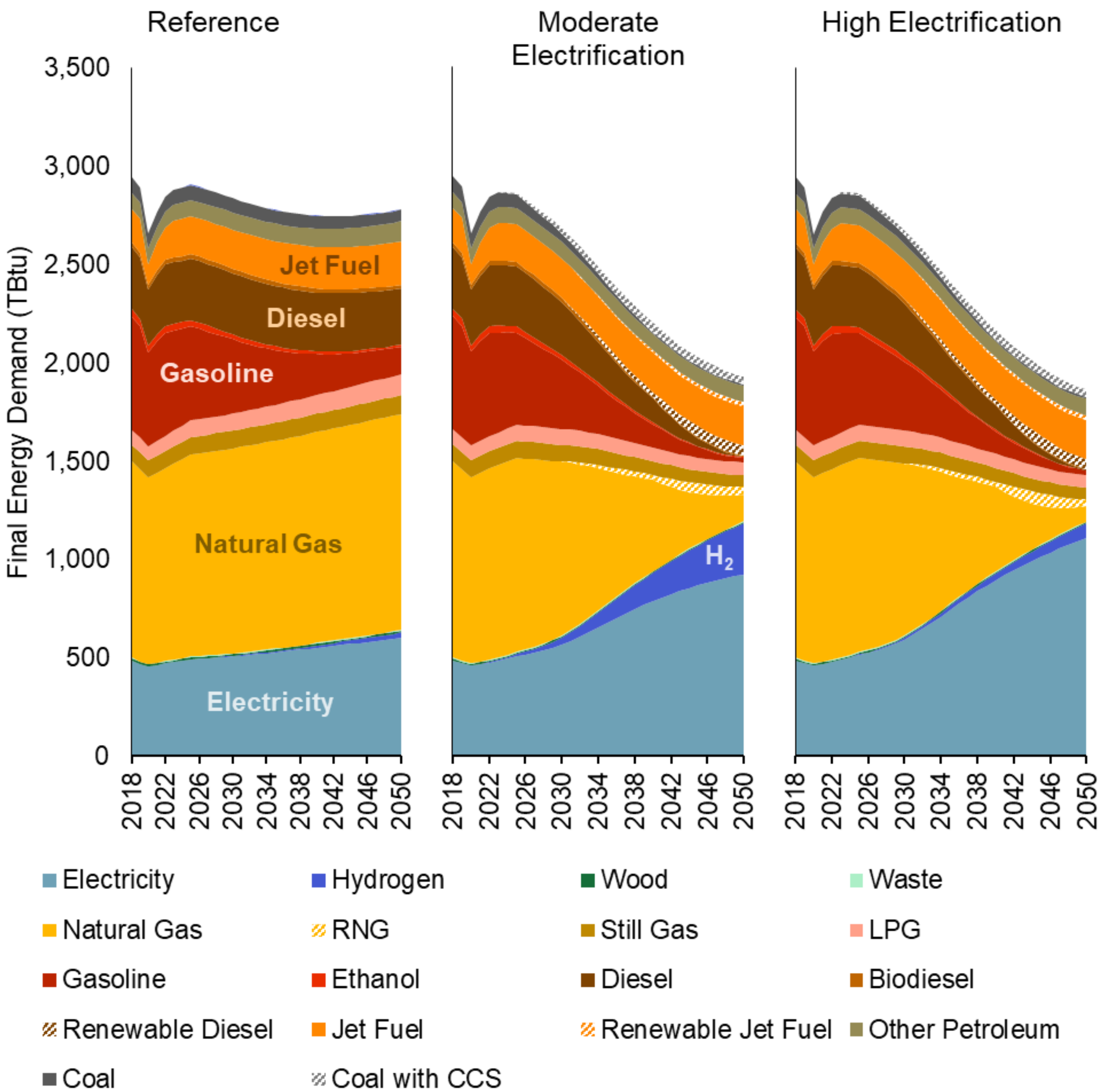
Figure 12: Chicago CAP Targets Compared to the Moderate Electrification Scenario for ComEd



Annual Energy Demand

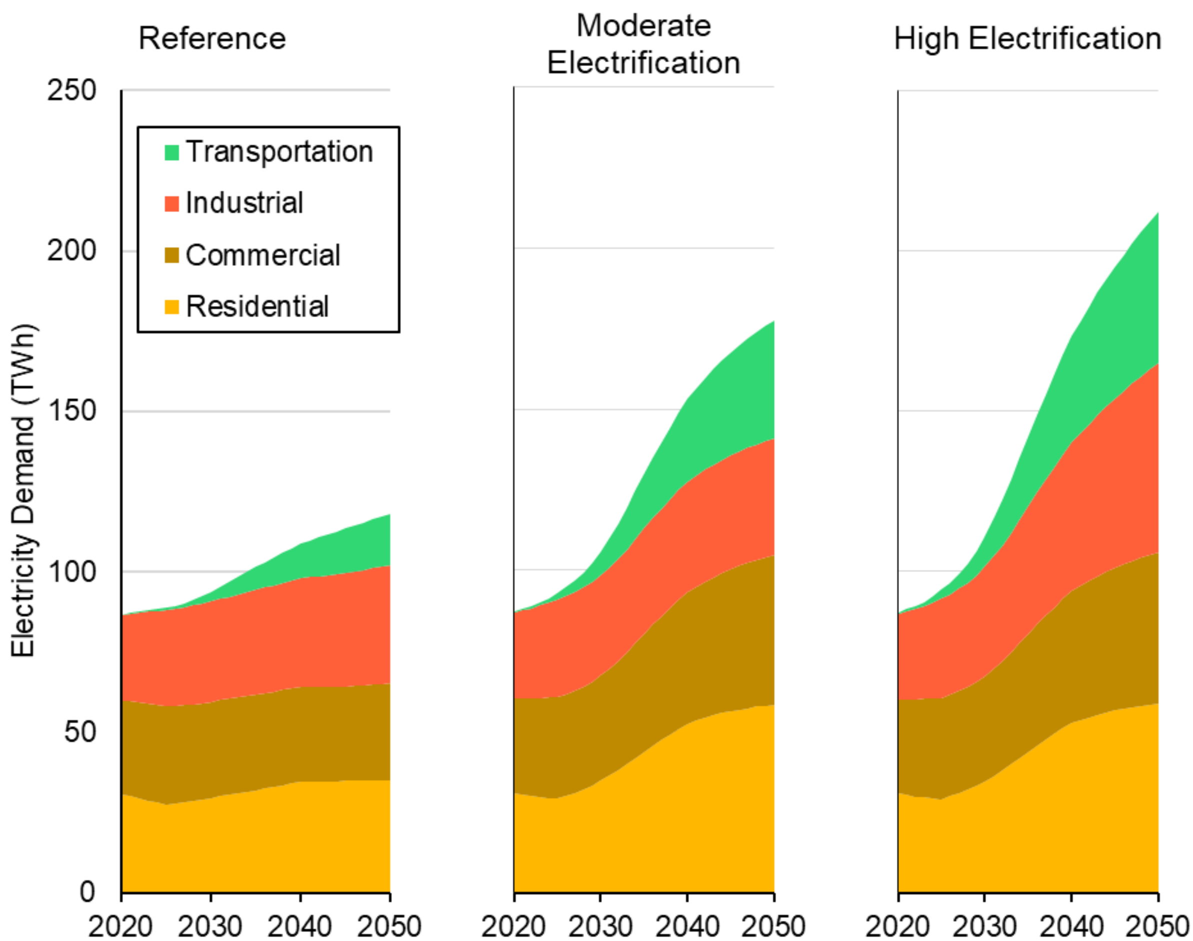
Figure 13 below shows the change in final energy demand over time in each of the modeled scenarios. In the Reference scenario, final energy demand declines between 2018 and 2050 after experiencing a sudden drop and subsequent rebound due to the COVID-19 pandemic. The decline through 2050 is driven by passenger vehicle electrification and improving fuel economy standards for internal combustion vehicles. Demand for other fuels is largely flat or slightly increasing over time due to growth in population and economic activity in Illinois.

Figure 13: Final Energy Demand by Fuel in Illinois for All Scenarios



Total final energy demand declines by over a third by 2050 in both net-zero scenarios. This is partially due to conventional energy efficiency measures like building shell improvements, fuel economy standards, and manufacturing efficiency, but the largest driver of final energy demand reductions is the embedded efficiency of electrification. Electric vehicles and heat pumps are significantly more efficient than conventional internal combustion vehicles and combustion furnaces/boilers, so converting on-road transportation and building heating to electric devices reduces both direct GHG emissions and final energy demand. As a result of electrification for buildings, industry, and transportation, statewide electricity demand grows by 89% and 127% in the Moderate Electrification and High Electrification scenarios, respectively. Load growth within ComEd's service territory is even higher; as shown in Figure 14 below, 2050 electricity demand is double that of 2020 in the Moderate Electrification scenario, and almost 2.5x

Figure 14: Final Electricity Demand in ComEd Service Territory by Sector for All Scenarios



higher than 2020 levels in the High Electrification scenario.

Beyond electrification, both net-zero scenarios include consumption of low carbon fuels like hydrogen and biofuels and conventional fossil fuel use with CCS for final energy demands. Hydrogen use varies significantly, reaching 170 and 44 TBtu by 2050 in the Moderate Electrification and High Electrification scenarios, respectively. The increase in hydrogen demand in the Moderate Electrification scenario is driven by a greater market share for fuel cell MHDVs and more conversions of industrial natural gas demands to hydrogen than in the High Electrification scenario. Finally, biofuels like renewable diesel, renewable natural gas, and renewable jet kerosene and conventional fossil fuels with CCS for certain industrial subsector have a relatively small role in both scenarios, collectively meeting only 8% of final energy demand by 2050.

Electric System Impacts within ComEd's Service Territory

Annual Load and Peak Load Impacts

In the Reference scenario, which represents business-as-usual trajectories, State and Federal policies on the books as of Fall 2022, and internal ComEd forecasts and plans, annual and peak loads experience a slow and steady growth. This is reflective of the modest electrification assumed in the transportation sector and tempered by continued progress on energy efficiency.

Figure 15: ComEd Annual Load Forecast for a Median Weather Year by Scenario

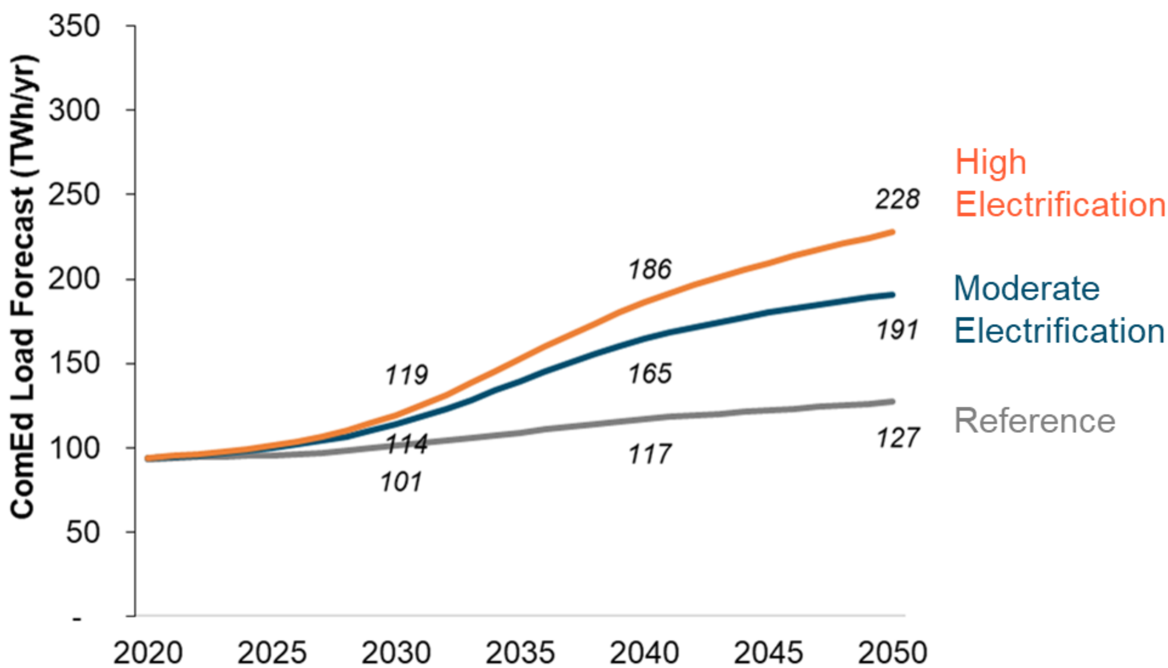
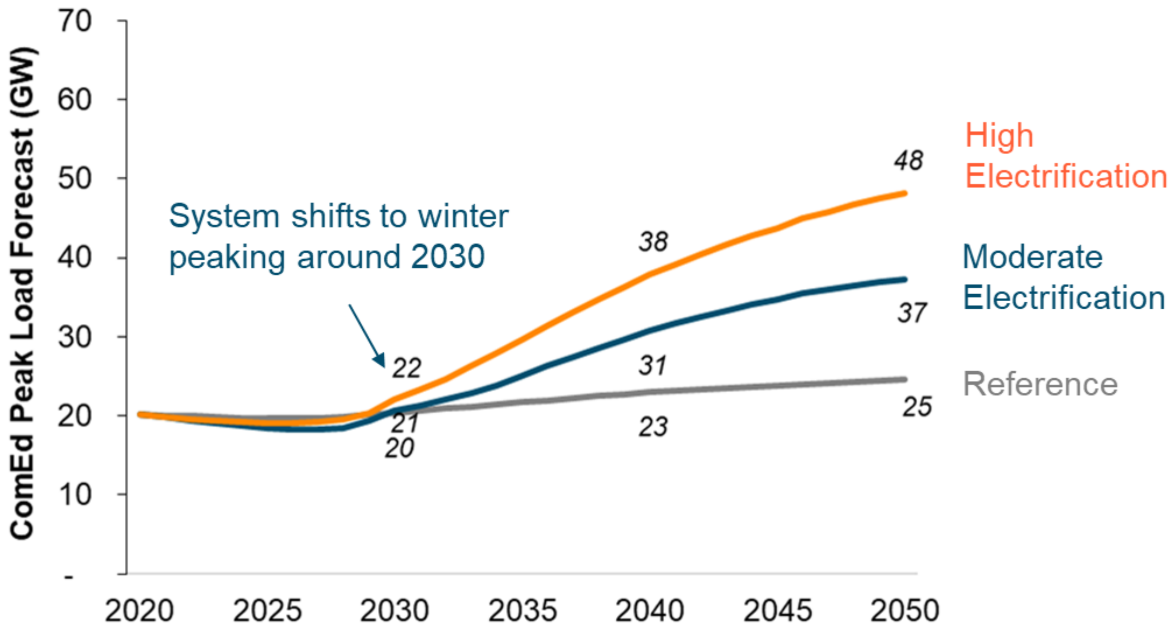


Figure 16: ComEd Peak Load Forecast for a Median Weather Year by Scenario



Both annual sales (Figure 15) and peak demands (Figure 16) increase markedly over Reference in both the Moderate and High Electrification scenarios. Annual sales increases are driven by a combination of transportation, building and, particularly in the High Electrification scenario, industry electrification. Peak demands are primarily driven by building electrification. While both scenarios have a similar overall level of heat pump deployment, the Moderate Electrification scenario has lower peak demands due to higher levels of gas back-up heating (70%) being available for extremely cold days. In contrast, a higher proportion of heat pumps are all-electric (70%) in the High Electrification scenario. In both cases, the ComEd system shifts from summer to winter peaking by approximately 2030.

Figure 17: ComEd Peak Load by Scenario: Median and Cold-Snap

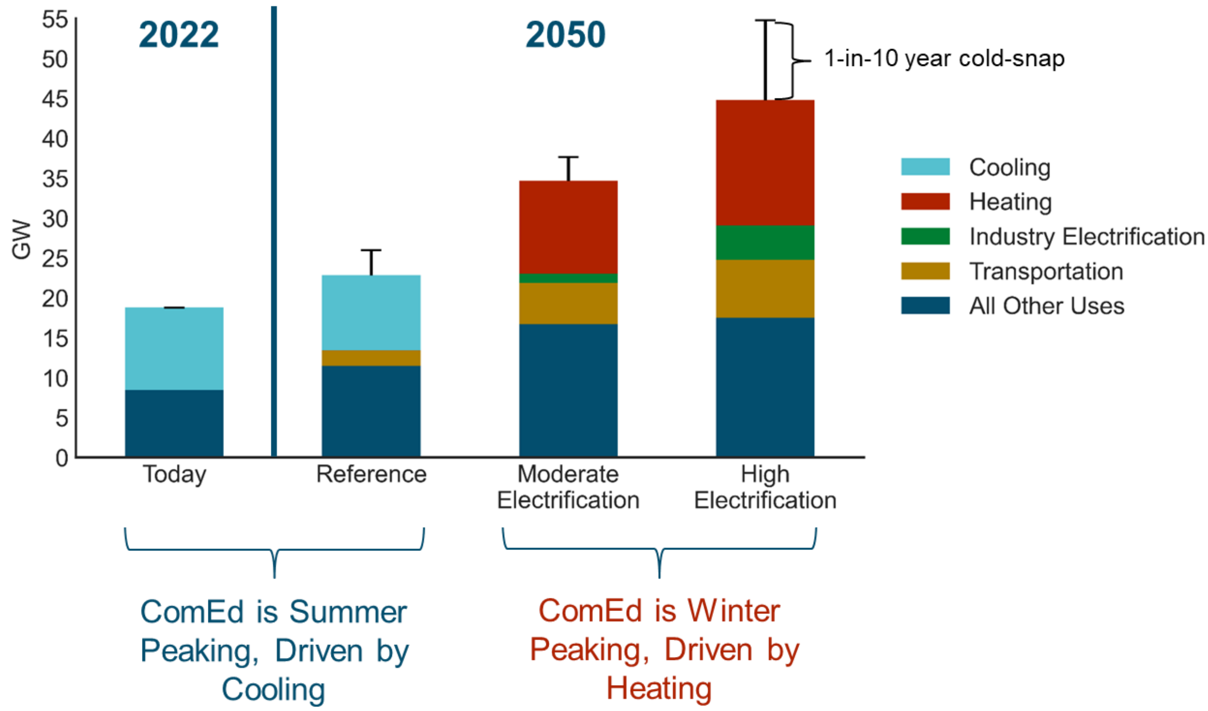
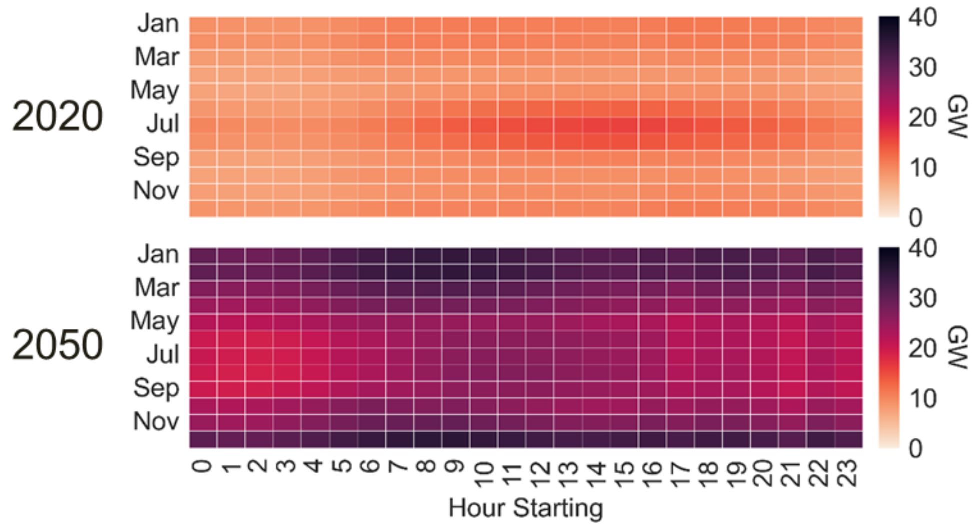


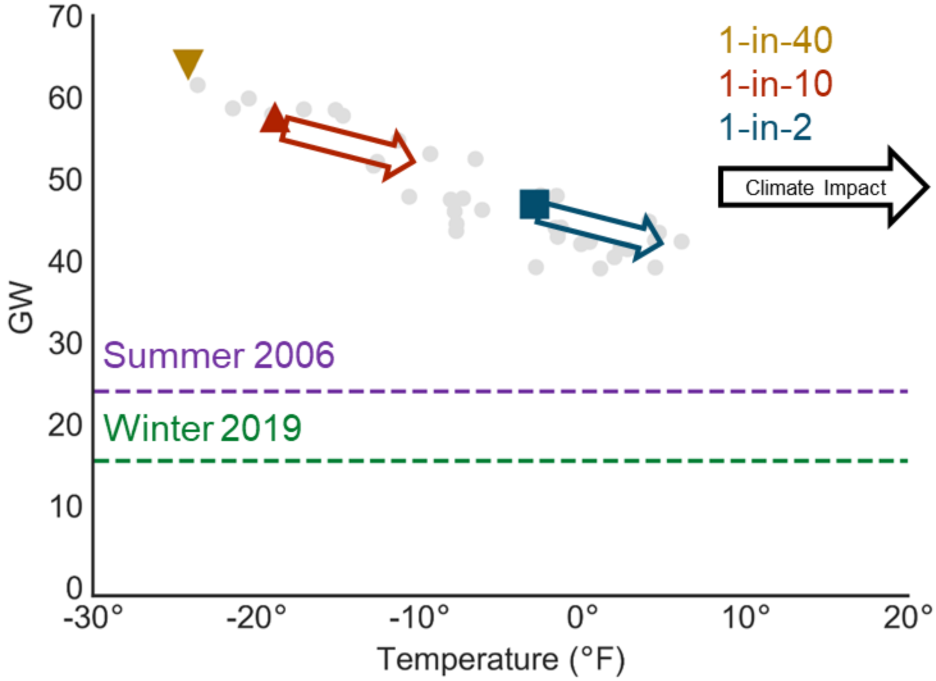
Figure 17 shows the composition of peak demands today vs 2050. Today, ComEd's system peak is driven by cooling loads, which tend to occur in summer afternoons or early evenings. In contrast, in both net-zero scenarios building heating becomes the largest source of incremental peak demand. The High Electrification scenario exhibits more sensitivity to extreme weather because of higher levels of all-electric buildings. The Moderate scenario leverages hybrid heating to reduce those impacts. While not explicitly shown here, managed EV charging avoids about 5-6 GW peak contribution and shifts system peaks to the morning, coincident with space heating peaks.

Figure 18: Month-Hourly Average Loads for the High Electrification Scenario



Not only do ComEd's peaks shift from the summer to the winter, but they also shift from the afternoon to the evenings and early mornings, as shown Figure 18. As noted above, the seasonal shift will be driven by incremental heating loads. The highest heating loads occur during the mornings and late evenings during the coldest hours of the day. As a result, ComEd must plan for its most challenging hours for reliability to shift from solar-rich hours today to times of lower renewable energy production. In addition, under scenarios of deep decarbonization, loads in general will be higher in all hours of the year in comparison to today, as shown in Figure 18. As a result, ComEd will not only face the reliability challenge of securing enough transmission, distribution, and generation capacity, but it will also need to plan to secure high levels of hourly electricity generation to ensure loads are always met.

Figure 19: Impacts of Climate Change and Comparison to Past Peaks on the ComEd System.



Finally, one notable methodological aspect of this study is that the heating demands estimated by E3 incorporate the impacts of climate change. E3 leveraged downscaled climate model outputs from Argonne National Laboratory (ANL) to estimate how the minimum temperature observed would change in a typical year ("1-in-2") versus a year with a cold-snap ("1-in-10"). As shown in Figure 19, winter minimum temperatures are expected to increase under both conditions. Notably, ANL expressed greater certainty from their modelling that minimum temperatures in a typical year will increase, but that more extreme years require further study to quantify such changes with similarly greater certainty. For that reason, E3 did not develop an estimate for how peak demand would change under the most extreme ("1-in-40") weather conditions observed in the past.

After the impacts of climate change are accounted for, the peak demand impacts remain large relative to the most extreme Summer (2006) and Winter (2019) conditions the ComEd system has experienced. This outcome occurs due to the large numbers of electrically heated homes in each scenario, as well as the additional impacts of electrification in other sectors like industry and transportation.

Installed Capacity and Annual Generation

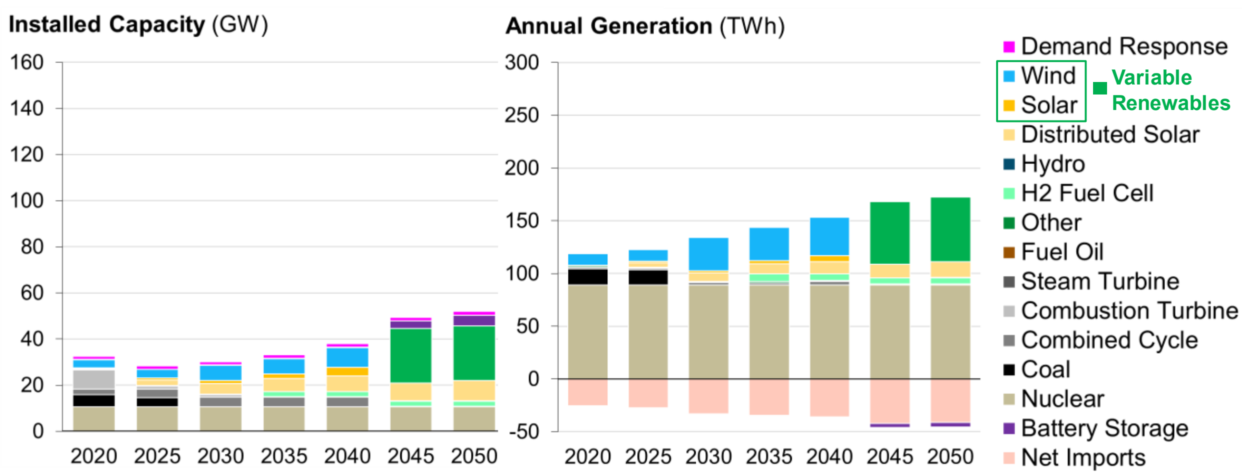
To conduct the electric sector capacity expansion modeling, E3 used the RESOLVE least-cost optimization tool to plan for the loads described in previous sections. A detailed description of the model and inputs and assumptions can be found in the appendices.

Renewable portfolio standards (RPS) under CEJA are subject to a monetary budget cap that scales with load. The RPS is met by renewable energy credits (RECs), which are mostly unbundled for ComEd and supplied by eligible in-state resources and renewable imports (e.g. SOO Green transmission resources).

Per CEJA, 45% of the RECs need to come from wind, and 55% from solar. The solar RECs are further split into utility-scale solar and distributed solar, with distributed solar further split into categories including residential, commercial and industrial, and community solar. ComEd provided a set of forecasts for wind, utility-scale solar, and distributed solar energy and capacity that would satisfy the CEJA RPS cap for each load scenario. E3 modeled distributed solar capacity per ComEd's forecasts (see "Resource Options" section in Appendix B) and incorporated REC costs in the electric system revenue requirement using the utility-scale RECs forecasted by ComEd.

The Reference scenario capacity build results show that the entire 6 GW of local wind are built in early years and all nuclear capacity is relicensed to provide clean firm capacity and energy. Nuclear capacity, along with the SOO Green HVDC Link[19] and hydrogen fuel cells, fill in as clean firm resources to meet system need after gas generation is retired.

Figure 20: Capacity Builds and Annual Generation in ComEd, Reference Scenario

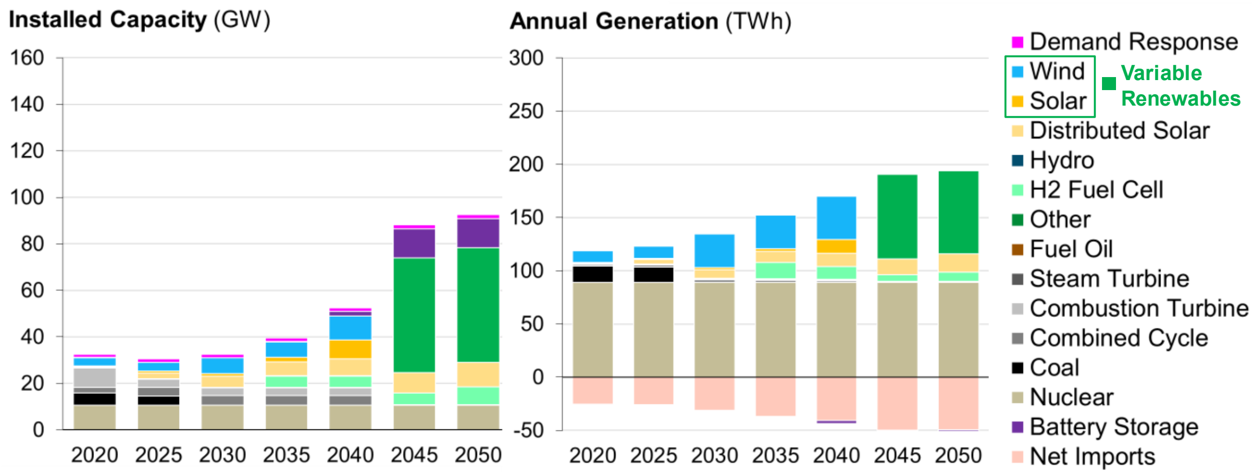


The two electrification scenarios show a similar trend. System builds include large amounts of wind and solar to provide zero-emissions energy to meet growing electrification loads. All nuclear units are selected to be relicensed and by 2050, 8 GW of hydrogen fuel cells are built in the Moderate Electrification scenario and over 11 GW in the High Electrification scenario. Those nuclear and fuel cell resources are particularly valuable for their ability to provide clean firm capacity in an otherwise renewables-based system.

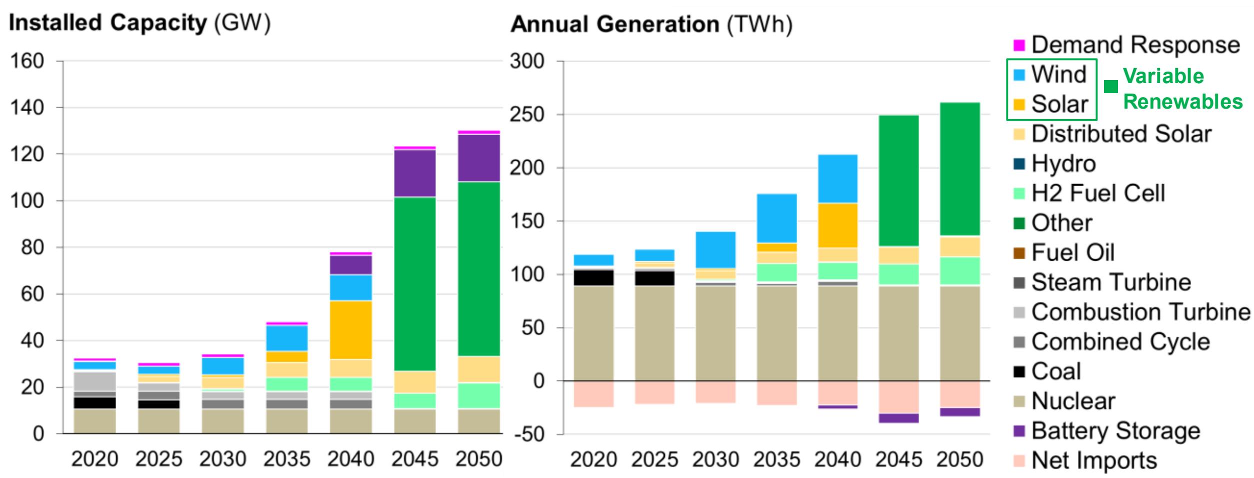
[19] Assumed to be built given changes enabled via CEJA, but not currently under construction

Figure 21: Capacity Builds and Annual Generation in ComEd, Electrification Scenarios

Moderate Electrification



High Electrification



E3 combined wind and solar resources into a single "Variable Renewables" category in 2045 and 2050 to represent the uncertainty inherent in how these resources can and will contribute in the long run. Additional research will need to be conducted to assess the long-term resource potential of wind and solar, and how each of these resources can contribute to resource adequacy in a winter peaking system. Additional uncertainties exist for transmission availability to import clean firm resources. The 2 GW SOO Green transmission line was modeled as a clean firm resource represented as wind in the bar charts above. Hydrogen receives a substantial incentive through the IRA which, when modeled in a least cost framework, would lead to substantial hydrogen build in 2035. Given constructability concerns, for the fuel cells themselves and the infrastructure required to produce and deliver hydrogen to them, E3 applied annual caps to hydrogen capacity builds in the model. That said, should additional hydrogen or other clean firm resources be available at that price, it would likely be cost-effective to procure. The main takeaway is that there is a premium on clean firm resources to meet reliability and energy needs, especially in later years.

System Reliability

This study does not include a detailed treatment of system reliability and resource adequacy. E3 applied existing planning standards for PJM, expressed as a 9% planning reserve margin (PRM) requirement over the system median (1-in-2") peak. However, E3 notes that the reserve margin required to meet industry reliability standards (e.g., no loss of load due to inadequate supply more than once every ten years) may be higher, particularly due to the increased weather sensitivity of loads that follows from high levels of building electrification. Table 3 below outlines the amount of firm capacity build required for load and resource adequacy for each scenario and time horizon. More description of system reliability assumptions can be found in Appendix B.

Table 3: Reliability Targets (1-in-2 peak load plus PRM) for ComEd

Scenario	2020	2030	2050
	GW	*GW*	*GW*
Reference	22	22	27
Moderate Electrification	22	22	41
High Electrification	22	24	52

Another important caveat to this analysis is its treatment of the capacity value of variable renewable resources. For this analysis, the amount of effective capacity eligible to count towards the PRM requirements for a given resource is measured through effective load carrying capabilities (ELCCs) or net qualifying capacity (NQC). Given the lack of new loss-of-load probability (LOLP) analysis in this study, these ELCCs and NQCs were established based on the historical ComEd system, which is summer peaking. However, the mitigation measures implemented in this analysis for the Moderate and High Electrification scenarios transition the system peak from summer to winter by 2030. This transition would change the capacity contributions of CEJA eligible resources, particularly variable renewable resources. Additional research is needed to quantify to what extent the resource adequacy contributions of variable renewables would change in a winter peaking system. E3 estimates that if the capacity contribution of renewables were half that assessed here, the ComEd region may need an additional 10 GW of firm capacity in the High Electrification scenario, which would increase the total investment cost of the modeled portfolios by approximately 10% in 2050.

Electric Sector Emissions

CEJA requires that the State of Illinois achieves 100% clean energy by 2050. This target is largely met with the assumption that fossil generators retire by 2045 and no new fossil capacity is added under CEJA. In addition, electricity generation using green hydrogen[20] and relicensing of existing nuclear power plants

[20] "Green hydrogen" is defined as electrolytic hydrogen produced "in a manner that produces zero carbon and co-pollutant emissions" per CEJA: https://www.ilga.gov/legislation/102/SB/PDF/10200SB2408lv.pdf.

are modeled as representative resource options that provide firm (non-weather-dependent), clean energy to meet the 2050 target.

While hydrogen-to-power conversion through either fuel cells or combustion does not release CO_2, only hydrogen fuel cells are considered in the study to reflect a stricter interpretation of CEJA. This is because hydrogen combustion in existing commercial technologies is known to generate NO_x,[21] which is a co-pollutant and disallowed under this study's interpretation of CEJA. For the same reason, retrofitting existing gas turbines to burn hydrogen is not considered a candidate resource option, even though CEJA provides the option for gas generators to be retrofitted to use hydrogen as an alternative to retirement. This interpretation can be reassessed as new hydrogen combustion technologies become available.

In this study, imports to ComEd are not subject to the electric sector clean energy target. Imports are not attributed to a specific resource but represent unspecified flows of power into ComEd. Since RTO and EMAAC are not subject to CEJA RPS requirements, energy imports from these zones into ComEd are assumed to have an emissions rate equivalent to gas generation (0.53 tons/MWh), based on the observation that gas generation typically provides marginal energy in the model. In addition, a cost premium of $258/tonne is applied the import energy price starting in 2045 and thereafter to reflect the cost of CO_2 removal through direct air capture to achieve the economywide net-zero GHG target.[22]

Air Quality Analysis

E3 conducted a high-level assessment of the air quality benefits associated with reduced fuel combustion in both net-zero scenarios. To do so, E3 examined changes to annual emissions for the following criteria air pollutants:

- Ammonia (NH4)
- Nitrogen Oxides (NOx)
- Primary PM 2.5
- Sulfur Dioxide (SOx)
- Volatile Organic Compounds (VOCs)

Baseline emissions for criteria air pollutants were estimated using county-level 2017 data from the EPA National Emissions Inventory.[23] State-level fuel consumption data from the EIA State Energy Data System was used to scale criteria air pollutant emissions from energy-related sources to 2018, the base year for

[21] Lewis, Alastair C. "Optimizing air quality co-benefits in a hydrogen economy: a case for hydrogen-specific standards for NO_x emissions." *Environmental Science: Atmospheres* 1, no. 5 (2021): 201-207. https://pubs.rsc.org/en/content/articlepdf/2021/ea/d1ea00037c.

[22] DAC cost estimated based on: National Academies of Sciences, Engineering, and Medicine. 2019. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/25259. Assuming capital and operating costs for a medium solid sorbent direct air capture system.

[23] https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data

the PATHWAYS model.[24] Future year criteria air pollutant emissions were then estimated by scaling 2018 emissions based on future changes in fuel combustion. For example, residential natural gas combustion in Cook County led to an estimated 9,033 tons of NOx emissions in 2018. In the Moderate Electrification scenario, residential natural gas combustion declines 92% between 2018 and 2050, so NOx emissions from this source are also assumed to decline 92% to reach 723 tons by 2050. To estimate the air quality benefits of the net-zero scenarios relative to the Reference, the avoided damages of criteria air pollution were compared between scenarios. Damages were calculated by applying marginal damage functions from Krewski, et al. (2009) and Lepeule, et al. (2012) to future year criteria air pollutant emissions.[25,26] The marginal damage functions from Lepeule, et al. (2012) assign a higher dollar value to the damages from criteria air pollutant than those reported in Krewski, et al. (2009), and these higher values are used to calculate the air quality benefits shown in the main body of the report. Results with the lower values from Krewski, et al. (2009) are available in the appendix, along with a more detailed description of the air quality benefits calculations.

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[24] Energy Information Administration U.S. States Profile State Profiles and Energy Estimate. https://www.eia.gov/state/seds/seds-data-complete.phphttps://www.eia.gov/state/seds/seds-data-complete.php

[25] Krewski D, Jerrett M, Burnett RT, Ma R, Hughes E, Shi Y, Turner MC, Pope CA 3rd, Thurston G, Calle EE, Thun MJ, Beckerman B, DeLuca P, Finkelstein N, Ito K, Moore DK, Newbold KB, Ramsay T, Ross Z, Shin H, Tempalski B. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. Res Rep Health Eff Inst. 2009 May. https://pubmed.ncbi.nlm.nih.gov/19627030/

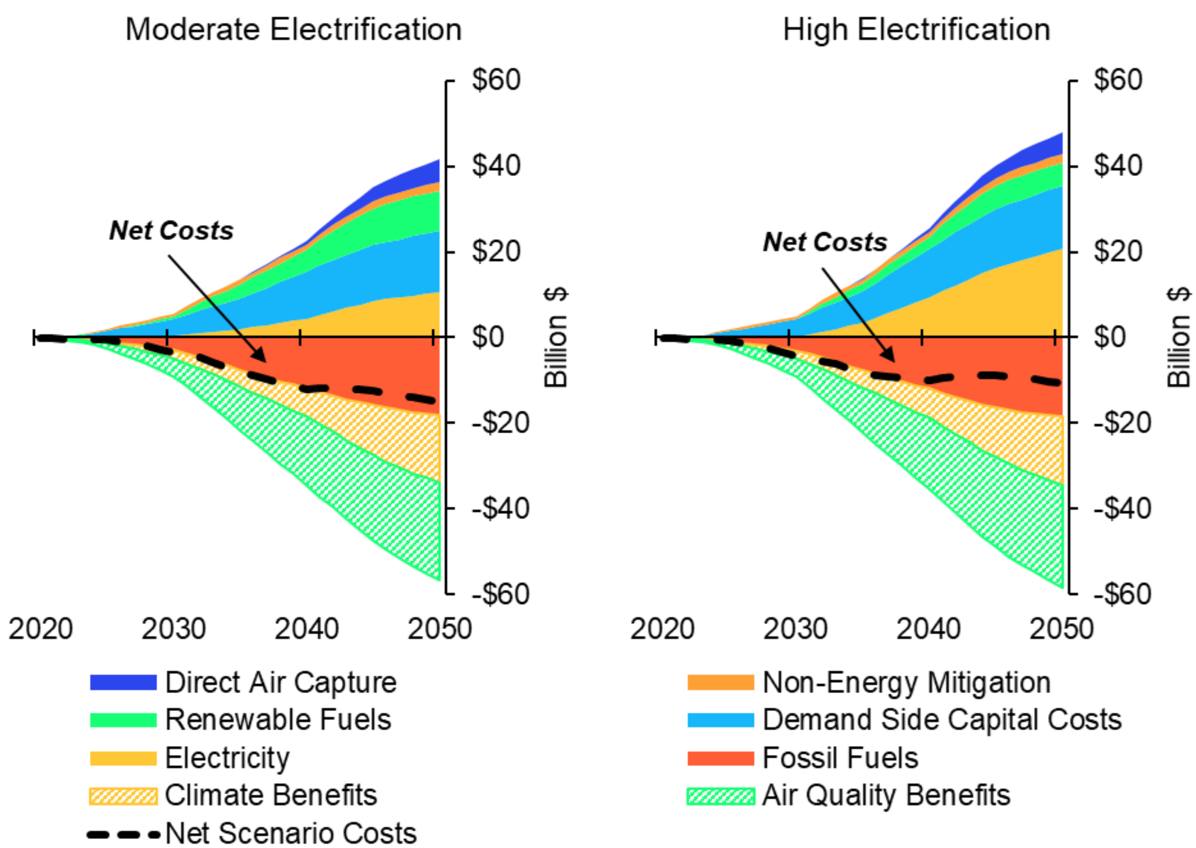
[26] Lepeule J, Laden F, Dockery D, Schwartz J. Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. Environ Health Perspect. 2012. https://pubmed.ncbi.nlm.nih.gov/22456598/

Costs and Customer Affordability

Economy-wide Costs

The PATHWAYS model tracks economy-wide costs for fuels, capital costs for energy-consuming devices like building appliances and vehicles, capital costs for mitigating non-energy emissions, and the capital costs of negative emissions technologies. Calculating the total incremental costs of the net-zero scenarios compared to the Reference scenario provides an indication of how much more (or less) achieving net-zero emissions could cost at the economy-wide level. Figure 22 below shows the incremental costs by category for the two net-zero scenarios relative to the Reference scenario. Both net-zero scenarios see a significant increase in spending for electricity supply infrastructure, capital costs for energy-consuming devices, renewable fuels, mitigation of non-energy emissions, and direct air capture. However, both net-zero scenario also avoid fossil fuel expenses in addition to providing climate and local air quality benefits.

Figure 22: Incremental Statewide Costs for Net-Zero Scenarios Relative to Reference Scenario



Overall, the net energy system costs (all direct costs excluding climate and air quality benefits) of Illinois achieving net-zero emissions reach $24 billion and $29 billion by 2050 in the Moderate Electrification and High Electrification scenarios, respectively. These costs are small relative to the size of Illinois' economy and would range from 1.4% to 1.7% of gross state product (GSP) in 2050 assuming GSP grows at an annual rate of 2.2%.

When including the climate and air quality benefits of the net-zero scenarios, both scenarios demonstrate net benefits. Climate benefits were calculated using the latest values for the social costs of carbon, methane, and nitrous oxide from the Interagency Working Group to the avoided GHG emissions in the net-zero scenarios.[27] Air quality benefits were calculated using the reduced criteria air pollutant emission associated with lower fuel combustion in the net-zero scenarios (described in further detail in the appendix). Table 4 below shows the societal net present value of the net-zero scenarios relative to the Reference. The Moderate Electrification scenario is lower cost in terms of incremental energy system costs and net scenario costs, inclusive of climate and air quality benefits.

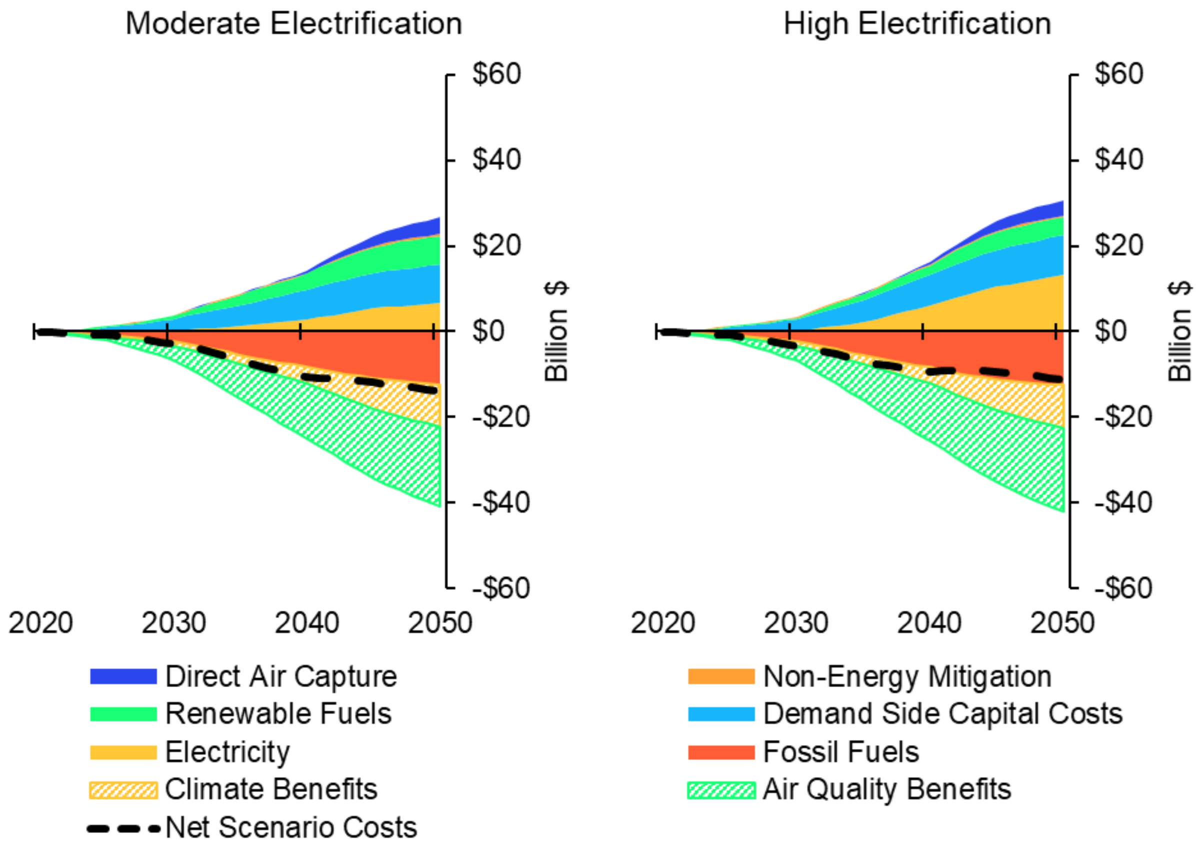
Table 4: Societal Net Present Value (2% Discount Rate) for the Incremental Costs and Benefits of Net-Zero Scenarios Relative to Reference

Cost Category	Moderate Electrification		High Electrification	
	2018-2030	2018-2050	2018-2030	2018-2050
Incremental Energy System Costs	$10B	$163B	$8B	$192B
Climate Benefits	($7B)	($103B)	($7B)	($105B)
Air Quality Benefits	($14B)	($200B)	($14B)	($208B)
Net Scenario Costs **(Incremental Energy System Costs + Climate and Air Quality Benefits)**	($10B)	($140B)	($13B)	($121B)

When assessing the same economy-wide costs for ComEd's service territory, we see the same overall results – both scenarios demonstrate net benefits (Figure 23). The net energy system costs (all direct costs excluding climate and air quality benefits) in ComEd's territory of Illinois achieving net-zero emissions reach $14 billion and $18 billion by 2050 in the Moderate Electrification and High Electrification scenarios, respectively. With the inclusion of climate and air quality benefits, there is a net benefit of $14 billion and $11 billion by 2050 in the Moderate Electrification and High Electrification scenarios, respectively

[27] Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990. https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

Figure 23: Incremental ComEd Costs for Net-Zero Scenarios Relative to Reference



It should be noted that the damages model used to calculate the air quality benefits was developed to be locally specific to Illinois, however, climate benefits developed using the social cost of carbon are global averages in nature and difficult to attribute directly to specific geographies with certainty. That said, the total climate benefits accruing in the ComEd region are represented using the social cost of carbon, but additional research should be conducted to determine the exact climate benefits occurring in specific geographies.

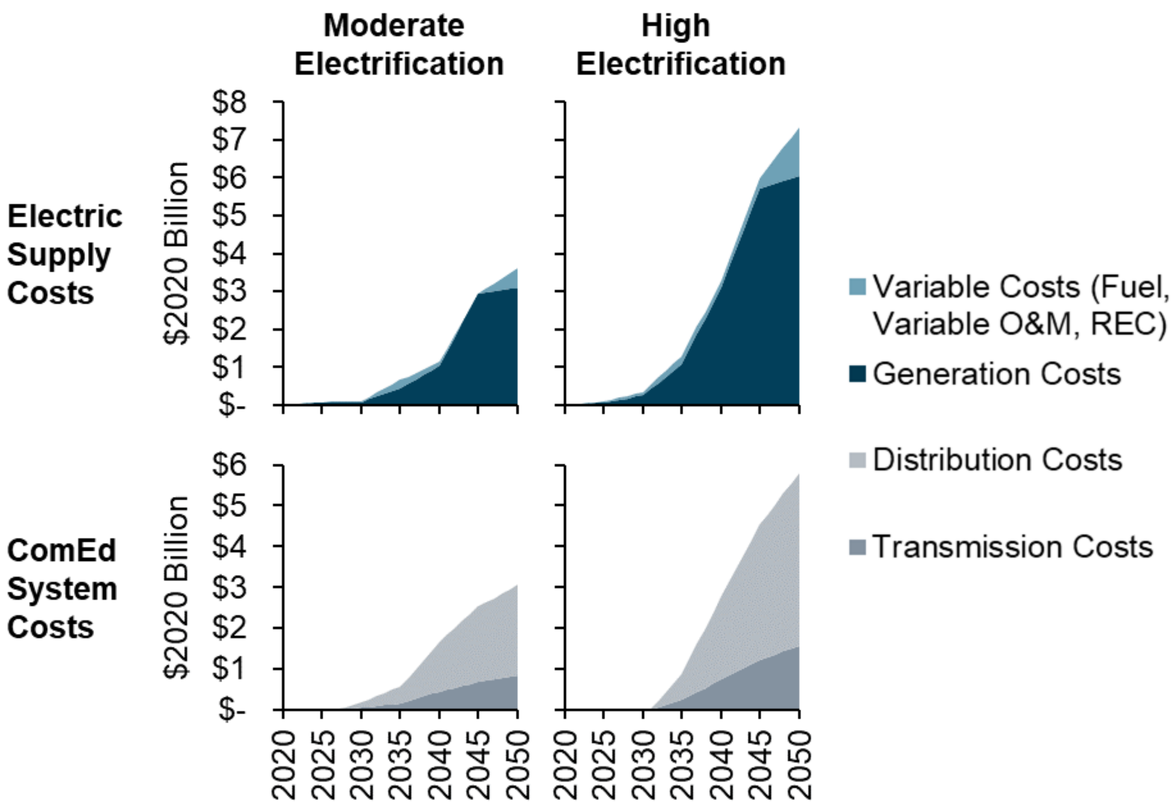
Electric Sector Costs

Both Moderate and High Electrification scenarios see an increase in electric sector costs relative to the Reference case, as shown in Figure 24. The incremental expenditures include investments in new generation, transmission, and distribution infrastructure as well as fuel and operating costs to support the growth in energy and peak demand in both scenarios. As a point of reference, ComEd's retail electric sales revenue in 2020 was on the order of $5 billion.[28] The Moderate and High Electrification scenarios show

[28] Data from S&P Global Market Intelligence; original data from EIA 861 filing.

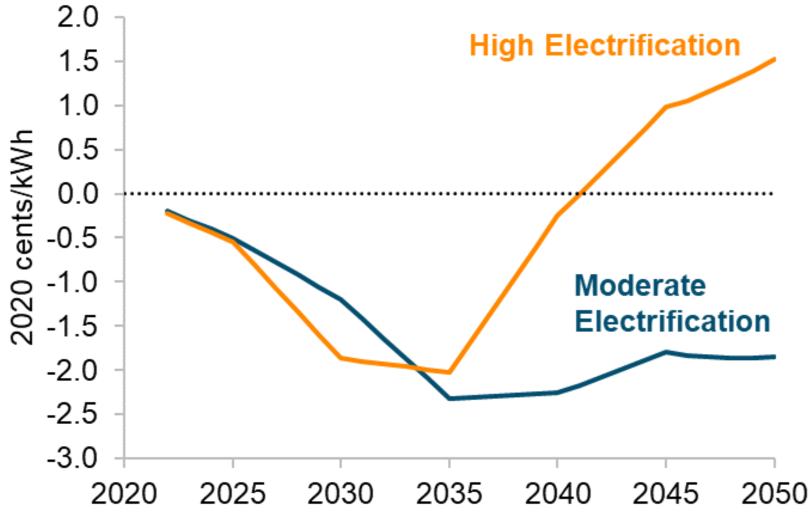
an increase in total cost (sum of electric supply and ComEd system costs) by about $6.7 billion and $13 billion, respectively, by 2050.

Figure 24: ComEd Region Annual Incremental Electric System Costs



E3 calculated simplified average rates as the total costs of the electricity system divided by total electric sales. The average rate impacts on the residential sector relative to the Reference case are shown in Figure 25. Both scenarios demonstrate downward pressure on average electric rates in the near-term as winter electric heating loads improve the load factor of the ComEd system, allowing for more efficient use of existing assets. Longer-term, residential rates are overall lower in the Moderate Electrification scenario than the High Electrification scenario because the former has a higher load factor (i.e., load profile is less peaky) and there is overall more load in the High Electrification scenario given the smaller amount of gas back-up heating.

Figure 25: Average Electric Rates for Residential Sector Relative to the Reference Scenario



It should be noted that E3 did not perform a detailed analysis for ComEd's revenue requirement or rate impacts by customer class. Instead, E3 developed a top-down approach to estimate the electric rates for the residential sector that are used in the customer affordability analysis, as described in Appendix A.

Customer Affordability Assessment

All scenarios rely on a transition in energy use and adoption of new technologies by ComEd customers. To assess the impact of these changes on customers, E3 developed an assessment of the energy costs faced by customers in each decarbonization scenario. This cost assessment focuses on how customer energy bills and upfront costs will change from today to 2050 given shifts from heating delivered via natural gas to the alternative technologies that distinguish the decarbonization scenarios. Key metrics used to assess customer costs include:

- **Energy bill impacts,** accounting for electricity and gas rate changes due to the decarbonization of energy supply, growth or contraction of infrastructure, and changes in the utilization of infrastructure.
- **Upfront capital costs,** or the cost of retrofitting a building shell and purchasing new appliances to transition from traditional gas heating to all-electric or hybrid heating.
- **Levelized cost of ownership,** which evaluates the combined impact of energy bills and upfront costs, assuming the latter is amortized on a monthly basis over the lifetime of each appliance.

To assess the costs faced by customers, E3 modeled customers adopting various technology packages under each scenario to present a full picture of the technologies that customers can adopt and the costs that they will experience with each set of technologies. The technology packages modeled include:

- **Gas Heat + ICE:** Customer with a gas furnace, gas water heater, and gasoline internal combustion engine (ICE) vehicle. This is the technology package of the reference customer.
- **Hybrid Heat + ICE:** Customer with a hybrid ASHP (electric ASHP with gas back-up), electric water heater, and gasoline ICE vehicle.

- **Hybrid Heat + BEV:** Customer with a hybrid ASHP (electric ASHP with gas back-up), electric water heater, and battery electric vehicle.
- **Electric Heat + BEV:** Customer with an electric ASHP, electric water heater, and battery electric vehicle.

Income classes modeled in the Affordability Assessment include:

- **Low-income customer** with an annual income of $20,000 - $49,999 and median income of $30,000. Qualifies as a low-income for federal incentives (<80% of the Area Median Income).
- **Moderate-income customer** with an annual income of $50,000-$99,999 and a median income of $70,000. Qualifies as a moderate-income for federal incentives (80%-150% of Area Median Income).
- **High-income customer** with an annual income of over $100,000 and a median income of $120,000. Qualifies as a high-income for federal incentives (>150% of Area Median Income).

Table 5 details the appliance and building shell costs for a representative residential customer in 2030 with a subset of each technology package. The upfront capital costs for building appliances are sizeable for hybrid heat and electric heat customers, however these costs can be mitigated for a subset of customers through 2030 by IRA incentives for heat pumps and energy efficiency measures, bringing the upfront costs well below those for a gas heat customer. Total energy bills (combined gas and electric bills for household appliances) are also larger for hybrid heat and electric heat customers compared to customers with traditional gas heat in 2030 since gas rates will not yet have escalated significantly due to gas customer departures.

Table 5: 2030 Building Upfront and Bill Costs ($2022) for a Residential Customer

Scenario	Customer Type (Moderate-Income)	Building Capital Costs	Building Capital Costs with Incentives	Monthly Household Energy Bills		
				Gas	Electric	Total
Reference	Gas Heat	$19,100	$19,100	$61	$66	$127
	Hybrid Heat	$36,400	$11,700	$27	$154	$181
	Electric Heat	$37,100	$12,400	$0	$179	$179
Moderate Electrification	Gas Heat	$19,100	$19,100	$63	$60	$122
	Hybrid Heat	$36,400	$11,700	$28	$138	$166
	Electric Heat	$37,100	$12,400	$0	$161	$161
High Electrification	Gas Heat	$19,100	$19,100	$64	$56	$119
	Hybrid Heat	$36,400	$11,700	$29	$129	$158
	Electric Heat	$37,100	$12,400	$0	$151	$151

Table 6 outlines the energy costs that customers face, showing the vehicle upfront costs and fuel costs for each scenario in 2030. In every scenario, customers with a battery electric vehicle spend less on fuel than a customer with a gasoline vehicle. By 2030, costs of electric vehicles are expected to decline below that of a gasoline vehicle, and IRA and Illinois State incentives further reduce the cost.

Table 6: 2030 Vehicle Upfront and Fuel Bill Costs ($2022) for a Residential Customer

Scenario	Customer Type (Moderate-Income)	Vehicle Capital Costs	Vehicle Capital Costs with Incentives	Monthly Household Vehicle Bills	
				Gasoline	Electric
Reference	ICE	$33,000	$33,000	$43	-
	Battery Electric	$29,100	$17,600	-	$27
Moderate Electrification	ICE	$33,000	$33,000	$43	-
	Battery Electric	$29,100	$17,600	-	$24
High Electrification	ICE	$33,000	$33,000	$43	-
	Battery Electric	$29,100	$17,600	-	$22

Figure 26 shows the monthly energy cost for a representative moderate-income customer in ComEd's service territory. Under the IRA, moderate income customers are eligible to receive substantial subsidies for both electric vehicles and, if they are homeowners, heat pumps. As a result of those subsidies, a customer of this type could see lower costs from adopting either an all-electric or hybrid package of electrification technologies compared to a fossil fuel powered baseline. It is important to note that benefits represent an upper bound for the benefits of the IRA. Higher income customers and lower-income renters may not be able to access the IRA's incentives as readily as moderate-income homeowners. In addition, the most generous incentives for heat pumps have limited budgets and as a result are unlikely to be available to all eligible ComEd customers.

Post-2030, E3 assumes that those incentives expire, causing a jump in energy costs for this type of customer. Longer-term, customers could see further increases in cost due to escalating gas and, to a lesser extent, electric rates.

Figure 26: Total ComEd Residential Customer Costs, Inclusive of Energy Bills and Amortized Equipment Costs for a Moderate-Income Customer

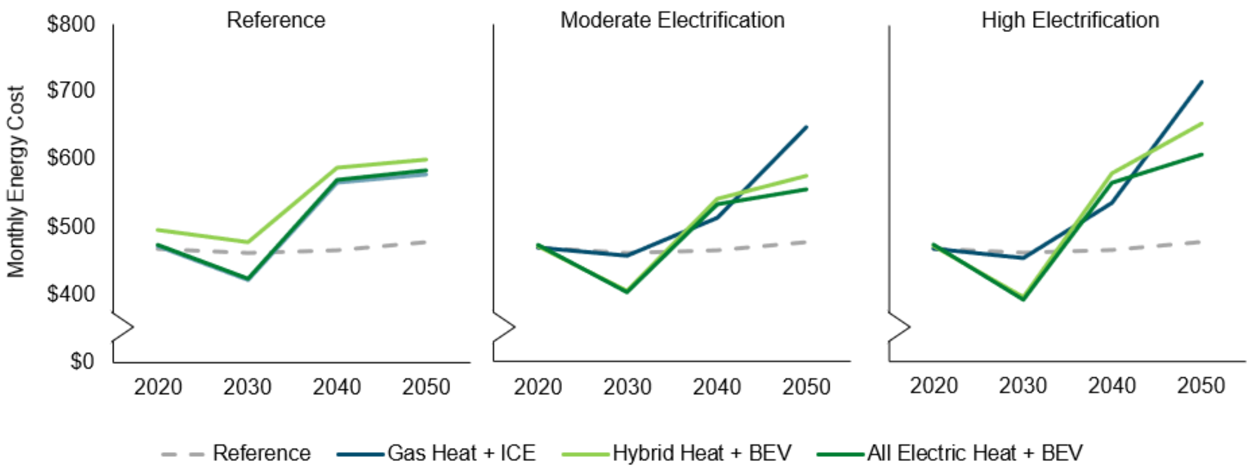
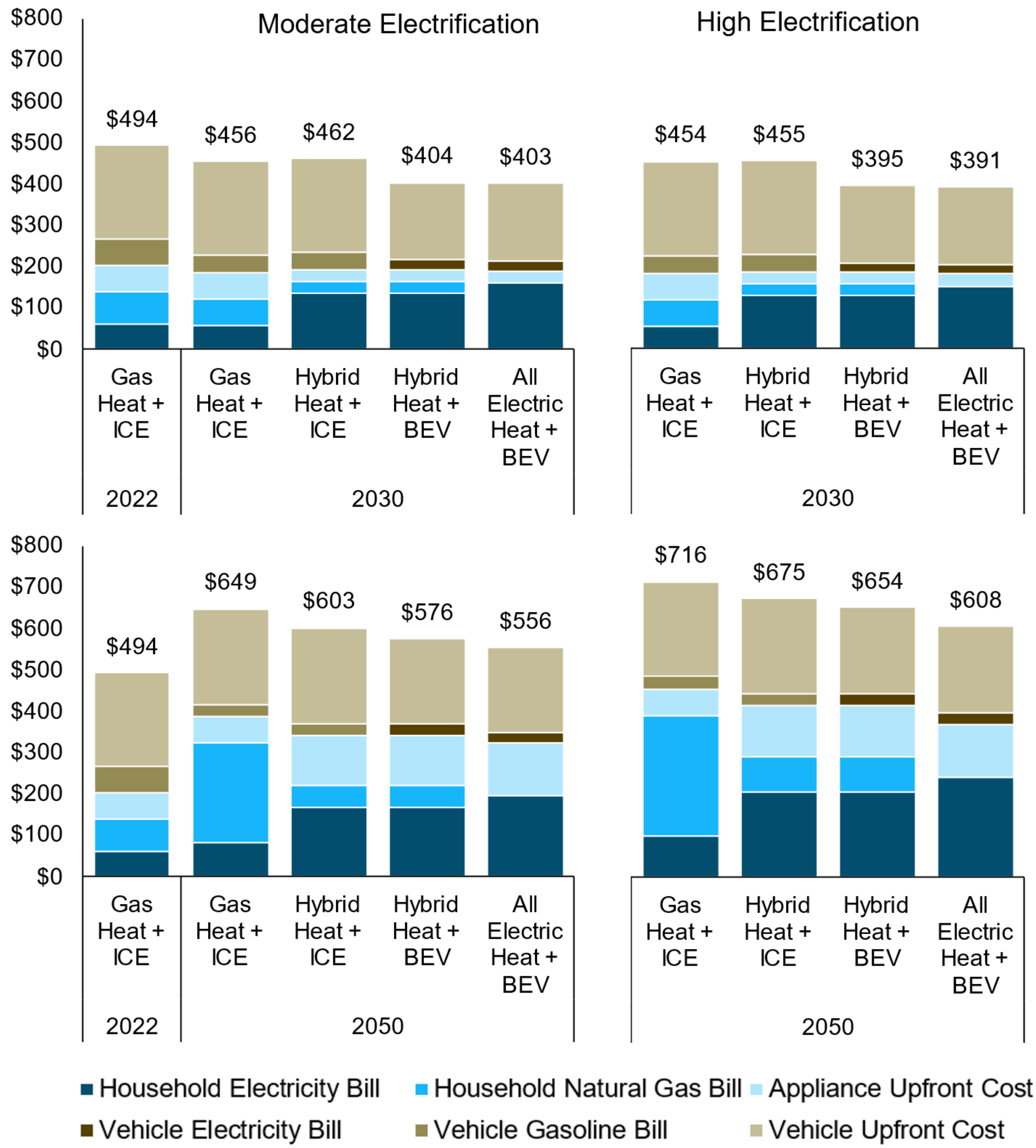


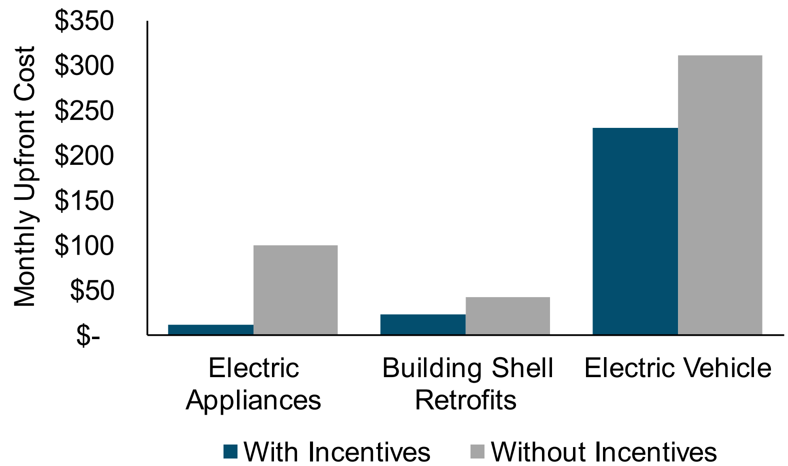
Figure 27 provides a breakdown of the energy costs and amortized equipment costs by technology package. Customers who electrify see a shift in their expenses from natural gas bills and gasoline to electricity. Still, those customers see lower costs than a customer with natural gas and a conventional gasoline car in both 2030 and 2050. The electrification cost advantage in 2030 is discussed above, while the advantage in 2050 is driven by the fact that gas rates escalate more rapidly than electric rates in these scenarios. Gas rates escalate as the fixed costs of the gas system are spread across fewer remaining customers. Another key finding from the customer affordability analysis is that all customers, regardless of technology package, see lower costs in the Moderate Electrification scenario compared to the High Electrification scenario. That outcome occurs because the Moderate Electrification scenario leverages gas back-up to reduce growth in electric peak demands, resulting in a more efficient use of the region's electric system and lower electric rates.

Figure 27: Monthly ComEd Moderate-Income Residential Customer Costs: Gas and Electric Energy Bills and Amortized Equipment Costs



The upfront costs of appliances are a significant contributor to customer's monthly energy bills. The rebates and tax credits made available by the State of Illinois and the Inflation Reduction Act lessens the financial barrier for customers converting to hybrid and all-electric systems in the near-term (Figure 28). After 2030, the rebates and tax credits expire, and customers face higher upfront appliance and vehicle costs that are only reduced as electric appliance and vehicle technologies become cheaper over time.

Figure 28: Electric Technology Monthly Cost Premium in 2022 With and Without Incentives



Without the incentives, customers adopting hybrid heat, all-electric heat, and electric vehicles face higher upfront costs than customers retaining gas appliances and a gasoline vehicle. In 2022, a customer adopting hybrid or all-electric heat appliances will pay an additional $108 each month from appliance and building shell retrofit costs and a customer adopting an electric vehicle will pay $80 per month more in upfront costs. While the IRA offers substantial support to customers adopting electric technologies, many customers will still face upfront cost premiums that are prohibitive given their income levels or lack of access to financing. Moreover, low customer awareness of available incentives may slow the adoption of hybrid and all-electric electric technologies.

Feasibility Considerations

Equity

Absent policy interventions, decarbonization scenarios could have negative impacts on equity. As customers electrify household appliances and leave the gas system, remaining gas customers face substantially higher costs as the fixed costs of the gas system are spread among fewer customers, particularly in the High Electrification scenario. Customers adopting electric appliances will also pay higher energy costs from increased electric rates, though they will not experience the same rapid bill increases as gas customers. All else equal, customers with higher incomes will be better able to absorb these costs, while lower-income customers will not. As a result, it will be essential to support customers in managing the costs of the transition.

Figure 29: Energy Burden for a Residential Customer with an Annual Income of $30,000

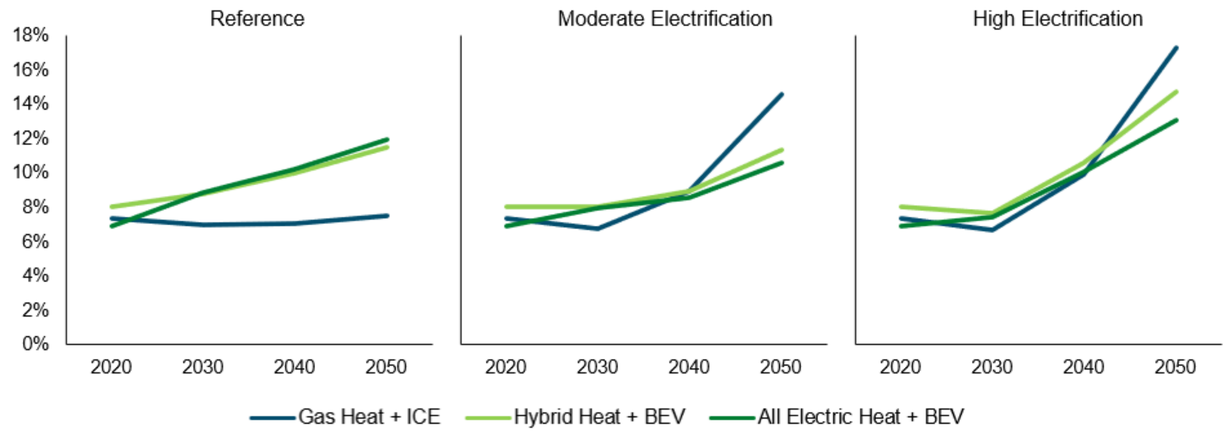
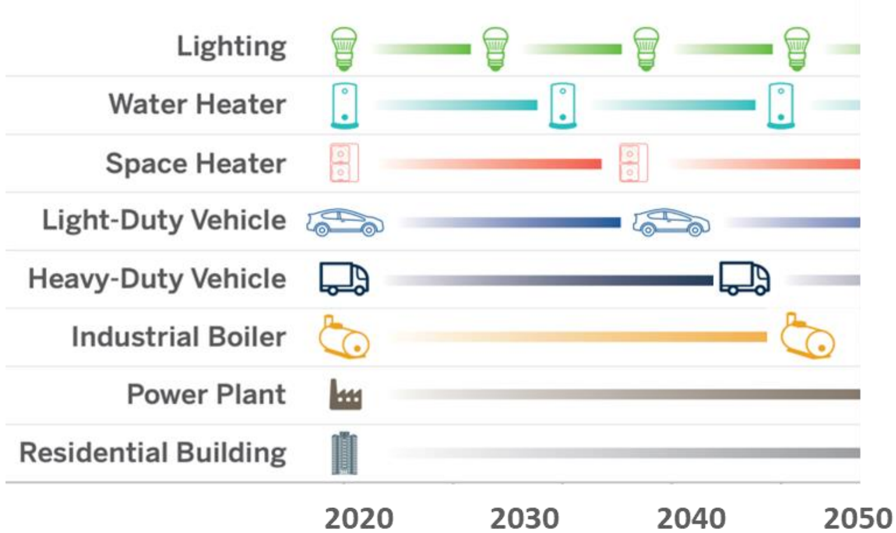


Figure 29 illustrates the energy burden for a low-income residential customer with an annual household income of $30,000. Energy burden reflects the cost of energy bills as a share of household income. It does not include upfront costs for appliances or vehicles. An energy burden greater than 6% is considered to be a high energy burden, though there is sparse literature supporting this threshold. Customers adopting hybrid or all-electric heat and an electric vehicle have a lower energy burden in the long-term than a customer retaining gas heat and a gasoline vehicle in all scenarios. This indicates that financial assistance to low-income customers and renters will be important to ensure that these customers are not left behind on the gas system with disproportionately high energy costs.

Customer Adoption

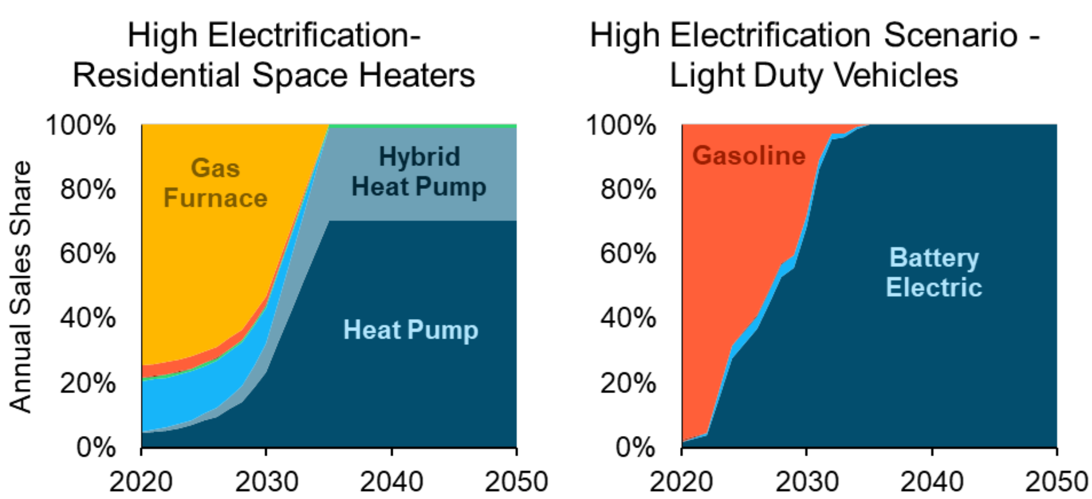
Achieving net-zero in Illinois will require rapid electrification of nearly all building and transportation sector demands. Decisions to electrify will be made by millions of individual households and businesses. The long lifetimes of vehicles, home heating equipment and other customer energy infrastructure mean that devices purchased over the coming decade may still be in service towards mid-century. Figure 30 captures this dynamic, showing illustrative technology lifetimes for energy consuming devices.

Figure 30: Illustrative Lifetimes for Key Technologies[29]



With those long lifetimes of energy consuming equipment in mind, it becomes clear that markets for electrification alternatives to fossil fuel powered vehicles and devices will need to rapidly scale. Figure 31Figure shows the shift in the market for home heating equipment (left) and passenger cars and light trucks (right). In both cases, those markets will need to shift towards a 100% sales share for electric devices by the mid-2030s in order to meet net-zero by 2050.

Figure 31: Market Share for Household Devices and Vehicles



As discussed in the Customer Affordability section above, the IRA provides subsidies to support customer adoption of electric devices. Taken together, IRA incentives for electric vehicles and heat pumps could

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[29] Note this figure was originally published by E3 (Williams et al. 2014) and modified with graphic design improvements by the Building Decarbonization Coalition. Replacement cycles are illustrative and do not precisely reflect values used in modeling.

substantially reduce the upfront costs of electrification for some customers. However, there are several limiting factors that motivate the need for additional support. In terms of the IRA's vehicle subsidies, the income and vehicle price qualification thresholds established in the law may limit the number of customers and models eligible to receive a tax credit, and onshoring requirements for manufacturing may limit the number of models that qualify, particularly in the near term. As noted above, on the buildings side the most generous electrification subsidies are budget limited to the point that E3 estimates fewer than 1 million households nationally will be able to capture the most generous incentives.

The combination of the pace of electrification and limitations in the ability of existing policy to support that pace clearly motivates a need for additional policy support. This is particularly true for buildings, which are likely to be relatively costly to electrify in ComEd's service territory relative to other parts of the country due to the need for high performing cold-climate heat pump technologies and building shell upgrades. Given that, developing strategies to support customer adoption of home heating equipment is a critical need to achieve net-zero in Illinois.

Beyond direct electrification of energy-consuming devices, both net-zero scenarios rely on ambitious energy efficiency measures in buildings, transportation, and industry. For buildings, this includes the adoption of the 2018 International Energy Conservation Code (IECC) building codes for all new construction and widespread shell improvements for existing homes so that 60% of residential buildings have highly efficient shells by 2050. Improvements in manufacturing efficiency leads to a 26% reduction in energy demand below business-as-usual by 2050 in both net-zero scenarios, and finally inclusion of the latest CAFE standards for passenger vehicles means that any internal combustion engine vehicles sold between now and 2035 are more efficient than today's models.

Constructability

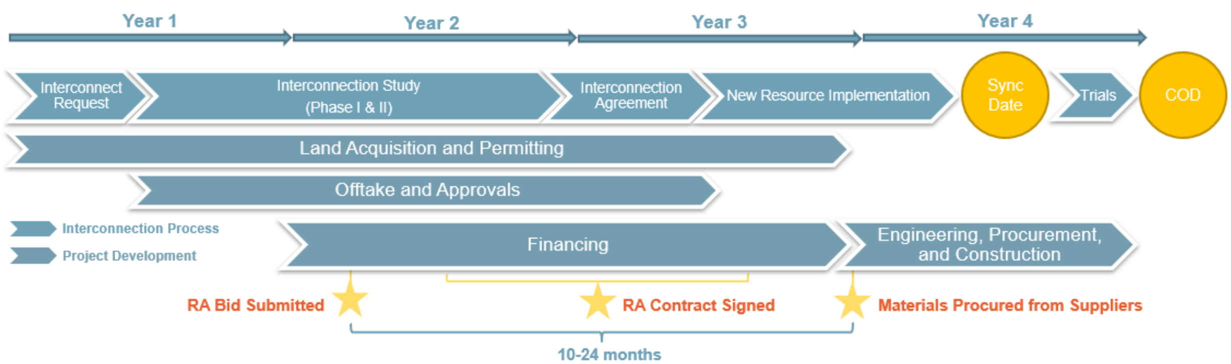
CEJA has put the state's electric sector on a path towards clean, zero-emissions generation. Electrification will necessitate that the system grows, including more than doubling on a peak demand basis within ComEd's service territory and adding 90 GW of installed generation capacity in ComEd's zone of PJM in the Moderate Electrification scenario and 130 GW in the High Electrification scenario. For comparisons sake, there is less than 30 GW of installed capacity in the ComEd zone today. The amount of infrastructure required to achieve Illinois' long-term decarbonization goals is substantial.

Already, the US is facing supply chain constraints that are impacting the deployment of renewables and storage across the country, and processes for getting projects from conception to operational are slow and subject to bottlenecks. Solar, wind, and storage projects tend to take from around four, but sometimes up to eight, years to become operational, and only around 23% of projects that have submitted interconnection requests have reached commercial operation. [30] Figure 32 below illustrates a representative timeline of project start to completion. While PJM recently got approval from FERC to implement reform switching from "first come, first served" in queue to "first ready, first served" – which

[30] Lawrence Berkeley National Lab. "Queued Up v2." February 2020. https://emp.lbl.gov/sites/default/files/interconnection_update_2_18_22.pdf

had an apparent improvement in MISO for speeding up projects through the interconnection process when implemented – there will always be administrative hurdles that delay large-scale deployment.[31]

Figure 32: Project Development Process and Timeline – from Interconnection Request to Commercial Operation



Historically, renewable capacity additions in PJM have not kept pace with other markets, such as CAISO, or projections for additions in the next decade as outlined in this study. The combined solar, wind, and storage additions in PJM over the past decade were 9.5 GW with the largest seen in 2021 of just below 4 GW. ComEd's share of those additions in total were 2.5 GW. By 2030, ComEd *alone* will require around 8 GW of combined new solar, wind, and storage capacity. By 2050, the cumulative new capacity additions (now to 2050) range from 31.5 to 100.9 GW, depending on the scenario, and these numbers do not reflect the additional new hydrogen fuel cell capacity or renewable capacity required to generate electrolytic hydrogen to power the fuel cells.

Producing the quantities of hydrogen assumed in these scenarios (Figure 33) would require an additional 10 GW (High Electrification) to 30 GW (Moderate Electrification) above the portfolio built to directly serve electric loads. The combined electric builds required to directly serve electric loads and produce hydrogen are shown in Figure 34, though not all of this build needs to be in ComEd's territory necessarily. In addition, producing those fuels will require the construction of electrolyzers, as well as hydrogen capable transmission pipelines and storage facilities.

[31] PJM Inside Lines. FERC Approves Interconnection Process Reform Plan. 2022. https://insidelines.pjm.com/ferc-approves-interconnection-process-reform-plan/

Figure 33: ComEd Region Hydrogen Demand

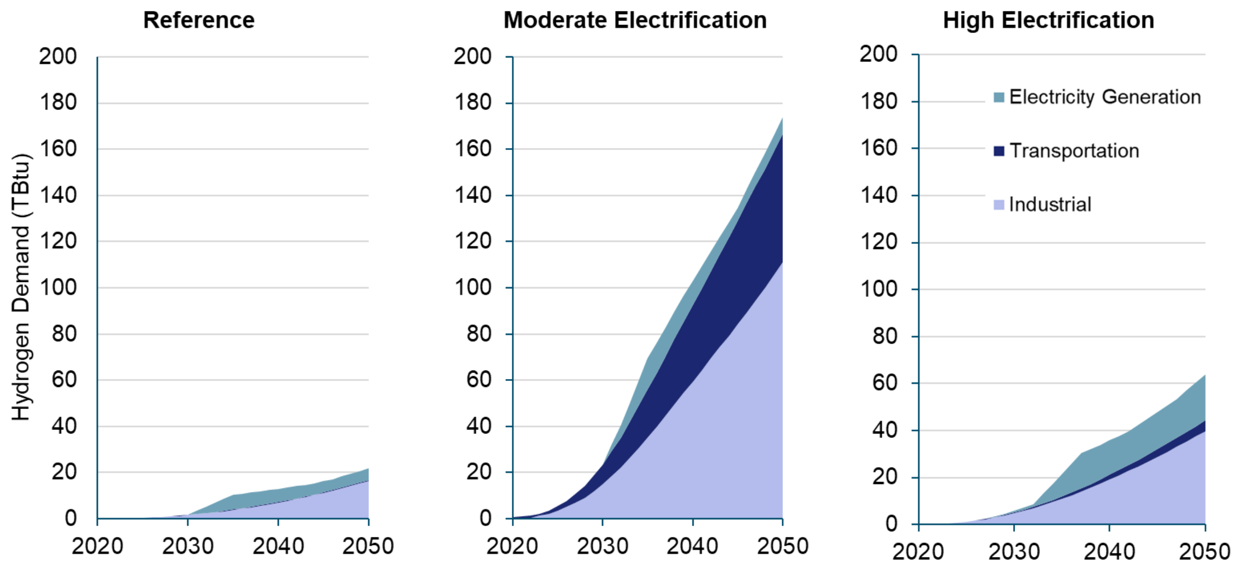
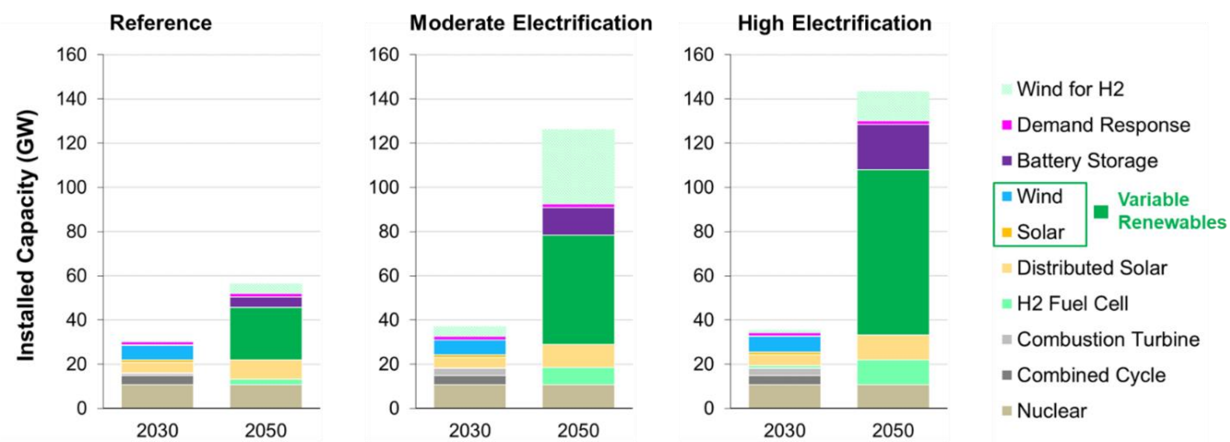


Figure 34: ComEd Total Electric Builds, Inclusive of Hydrogen Production



The magnitude of infrastructure additions required will be challenging from a constructability perspective. Processes related to siting, permitting, interconnection and procurement will need to be streamlined and designed in a manner that allows for deployment of energy infrastructure at a pace that far exceeds recent history.

Technology Readiness

To the extent possible, E3 developed scenarios that primarily rely on technologies that are, or are nearly, commercially mature. On the electric supply side, resources like wind, solar and storage have proven their ability to deliver affordable energy and integrate into the existing bulk electricity system. On the demand side, both all-electric and hybrid heat pump technologies have seen wide deployment elsewhere in the

United States and world, while electric vehicle technologies are rapidly progressing in terms of their performance, cost, the number of models available and customer acceptance.

However, given the magnitude of the challenge in achieving net-zero in Illinois, both the Moderate and High Electrification scenarios rely on less proven technologies. For example, both scenarios include direct air capture (DAC) of CO_2 to balance remaining emissions from hard to abate sectors like agriculture. Over the past decade, direct air capture technologies have rapidly moved from the laboratory setting to initial commercial projects but have not been proven at the scales envisioned here.

Both scenarios also rely on green hydrogen to maintain electric reliability, power heavy duty transportation, and displace the use of natural gas in the industrial sector. Like DAC, achieving the scale of green hydrogen production, delivery and use envisioned in these scenarios would require that industry to scale rapidly. Although the concepts of low-carbon hydrogen and the "hydrogen economy" have been around for decades, the current market for low-carbon hydrogen remains small.

Currently in North America, hydrogen is predominantly consumed as a chemical feedstock, including petroleum refining and ammonia production, with the hydrogen almost exclusively sourced from fossil fuels.[32] In 2020, around 4% of the global hydrogen supply was produced from low-carbon pathways (predominantly electrolysis).[32] Some technologies along the green hydrogen supply chain for hydrogen production (e.g., electrolyzer), storage (e.g., underground salt cavern, aboveground pressure vessel), and transport (e.g., trucking, dedicated hydrogen pipeline) have high levels of technology readiness (i.e., have reached stability or are in commercial operation).[33] However, the cost of low-carbon hydrogen remains higher than its fossil fuel counterpart, and there have not historically been sufficient market and policy incentives to jumpstart a sizable market for low-carbon hydrogen.

The outlook for hydrogen in the US is expected to change with the recent investments in low- and zero-carbon hydrogen. As part of the 2022 Bipartisan Infrastructure Law, the Department of Energy (DOE) will invest up to $7 billion to develop 6-10 regional clean hydrogen hubs across the US.[34] Illinois is a State in the Midwestern Hydrogen Coalition that has applied to this DOE funding. The proposal includes renewables, fossil fuel with carbon capture and storage (CCS), and nuclear energy as targeted feedstocks for hydrogen production, and industry, transportation, and power as targeted end-use sectors.[35] Further, the IRA of 2022 is expected to accelerate the development of low- and zero-carbon hydrogen through various tax incentives for clean hydrogen production (e.g., electrolyzer and other equipment, upstream renewable electricity production) and use (e.g., fuel cell vehicles, sustainable transportation fuels).[36]

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32 "Opportunities for Low-Carbon Hydrogen in Colorado: A Roadmap." October 2021. https://www.ethree.com/wp-content/uploads/2021/12/Colorado-Low-Carbon-Hydrogen-Roadmap.pdf.

33 IEA (2022), *ETP Clean Energy Technology Guide*, IEA, Paris. https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide.

34 Department of Energy. "Regional Clean Hydrogen Hubs." https://www.energy.gov/oced/regional-clean-hydrogen-hubs.

35 Center for Strategic and International Studies. "Hydrogen Hubs Proposals: Guideposts for the Future of the U.S. Hydrogen Economy." July 2022. https://www.csis.org/analysis/hydrogen-hubs-proposals-guideposts-future-us-hydrogen-economy.

36 These tax credits cannot be "stacked" for production at the same "facility", although further clarity is still needed in the case where different parts of the facility are owned by different parties. See: Norton Rose Fulbright. "Hydrogen Tax Credits." October 2022. https://www.projectfinance.law/publications/2022/october/hydrogen-tax-credits/.

These investments are expected to have a far-reaching impact on the role of clean hydrogen in a deeply decarbonized future, expanding its potential into more sectors of the economy.

Key Takeaways

Net-Zero Scenarios Share Several Commonalities

Electrification and Clean Electricity are the Key Drivers of Net-Zero

Both scenarios envision a rapid transformation to net-zero emissions in Illinois and that transition is driven primarily by the combination of electrification and clean electricity. Electrification of transportation, buildings, and industry will increase the size of the Illinois and ComEd electricity systems. In the near-term, load impacts will be moderate because the ComEd system currently has headroom between its summer and winter peak. However, high levels of building electrification shift the ComEd system to winter peaking by approximately 2030 in both net-zero scenarios and could more than double system capacity requirements by 2050. Meeting those growing demands will require intentional planning, investment and shifts in operational practices from ComEd. The use of hybrid electric-gas heat pumps could help to mitigate some of the peak demand impacts of building electrification, while still retaining most of the efficiency and climate benefits of all-electric air source heat pumps.

Electrification will also drive additional electric supply needs as the generation portfolio serving ComEd's service territory must simultaneously expand and decarbonize. Portfolios modeled in this analysis rely on a combination of variable renewables, battery energy storage, nuclear and hydrogen to meet the requirements of CEJA and growing loads.

Renewable Fuels Have a Limited, but Complementary, Role Alongside Electrification

The scenarios are similar in that they envision a limited, though valuable, role for renewable fuels as part of the state's decarbonization transition. Hydrogen is used across several sectors of the economy, particularly as a form of energy storage and source of high temperature heat. RNG is also leveraged in both scenarios to reduce the emissions intensity of remaining methane delivered to industry and a subset of buildings using hybrid heat pumps. However, the supply of RNG is limited, so at most it can serve as a complement, rather than an alternative, to electrification.

Negative Emissions Are Needed Given Hard to Abate Sectors of the Illinois Economy

Finally, given the challenges associated with Illinois' GHG emissions profile, including large agriculture and industrial emissions, all scenarios require substantial levels of NETs and natural sequestration of CO2. For the purposes of this study, E3 assumed DAC as the primary technology used to achieve negative emissions, but in practice a more diverse portfolio of negative emissions options will likely be needed (e.g., bioenergy with carbon capture, biochar, enhanced weathering, etc.).

CEJA and the IRA have kick-started Illinois' transition to Net-Zero, but more policy support will be needed

The results of this study clearly indicate that CEJA and the IRA have put Illinois on a path towards decarbonization. Those policies are expected to be particularly transformative in supporting decarbonization of the electric and transportation sectors, as well as spurring investment in more nascent decarbonization options like hydrogen and negative emissions technologies. However, this study identifies a gap between what those policies can achieve, and the pace of transformation needed to achieve net-zero. E3 notes a particular gap within the building thermal sector, where the IRA can be expected to support some heat pump adoption, but not at the levels envisioned in the Moderate and High Electrification scenarios. Even sectors that are directly addressed by CEJA and the IRA will need careful policy attention going forward. For example, in the electric sector, renewable resource procurement will need to happen at a pace and scale that substantially exceeds present trends. At the same time, Illinois' procurement mechanisms need to support deployment of technologies like battery storage, hydrogen fuel cells and other clean firm options to maintain electric reliability.

Decarbonization Delivers Broad Benefits, but Maintaining Affordability will be a Key Challenge

Net-zero requires adoption of both energy supply and demand technologies that carry costs that are higher than the conventional alternatives used today. While the cost premiums associated with decarbonization can be large, E3's results in this study indicate that customers who fully decarbonize are better off than those left behind (i.e. those with gas vehicles and appliances). In the near-term, adding load without adding new peak demands will serve to moderate rate impacts on ComEd's customers. Over the same timeframe, the IRA could provide substantial support to customers to buy down the upfront costs of electrification. Longer-term the expiration of the IRA will result in higher costs for customers, though those impacts are muted to an extent by expected price declines in the cost of electric vehicles and heat pumps.

From an economy-wide cost perspective, the incremental direct costs of achieving net-zero are a small share of the total Illinois economy, equal to approximately 1% of gross-state product. However, E3 finds that both scenarios deliver societal net benefits when air quality and climate benefits are accounted for . An additional economy-wide conclusion from this work is that, given the cold climate of Northern Illinois, a building electrification strategy that relies primarily on all-electric systems is likely to be more costly than one that allows for a higher share of hybrid heating. However, it is important to caveat that this study represents an initial treatment of a heating sector transformation and further work is needed to investigate how to best balance use of electric and gas infrastructure to meet customers energy needs cost-effectively and reliably.

Areas for Further Research

Resource Adequacy

This study identifies the contours of the electric portfolios that meet the requirements of CEJA and growing electrification loads in ComEd's service territory, however, it does not include a detailed treatment of electric reliability. Additional work is needed to characterize the performance of variable renewable resources more fully, particularly during extreme cold-weather, which in turn would affect the magnitude of "clean firm" resources such as hydrogen fuel cells that are required. Insofar as hydrogen-based resources like fuel cells are used to meet reliability needs, additional work is also needed to characterize the accompanying production, delivery, and storage infrastructure.

Building Electrification

Building electrification is a critical component of achieving net-zero in Illinois, but the transition to electric buildings does not yet have the same level of policy support as the electric generation and transportation sectors. The IRA offers large incentives to a subset of ComEd's customers, but more support will be needed to achieve levels of adoption that are consistent with the net-zero scenarios modeled in this analysis. In addition, the building stock within ComEd's service territory is far more heterogenous than the simplified treatment included here. As a result, E3 recommends a more detailed study focused on options to decarbonize the built environment within Illinois, considering a broader array of technology options and building types. Such a study could also include emerging approaches like the use of networked geothermal systems that hold the potential to reduce the load impacts of heating electrification in Illinois' cold climate.

Gas and Heating Transition

All scenarios see reduced utilization of the state's gas infrastructure, primarily because of electrification. Annual sales of gases fall precipitously in both scenarios. The number of customers connected varies between the Moderate and High Electrification scenarios based on each scenario's level of hybrid versus all-electric heat pump adoption. Given the relatively fixed nature of gas infrastructure costs, declining utilization leads to higher unit costs, particularly on a dollars per therm and, to a lesser extent, a dollars per customer basis. Those higher unit costs in turn translate to higher bills for gas customers over time, particularly in the High Electrification scenario due to its higher levels of gas customer departures. Those bill impacts are likely to be prohibitive for both low- and moderate-income customers, motivating the need for a more thorough investigation of the future of gas utilities in Illinois. Such an investigation should include consideration of hybrid strategies. In this study, hybrid electrification was identified as a path to decarbonized heating with less impact to electric infrastructure. In the context of a gas transition, hybrid heating could offer a pathway that maintains use of some gas infrastructure and potentially reduces the costs associated with retrofitting certain buildings. A gas transition study could also consider new business models for gas utilities such as networked geothermal, as well as explore opportunities to pursue targeted electrification to enable decommissioning of some gas infrastructure.

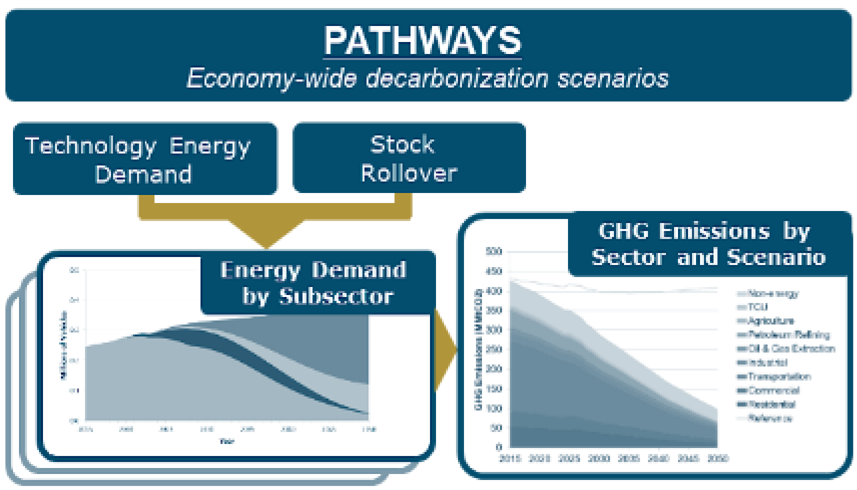
Appendix A. Model Methodology

A.1. PATHWAYS Model

PATHWAYS Model Overview

E3's PATHWAYS model is an economywide representation of infrastructure, energy use, and emissions within a specified geography. E3 developed PATHWAYS in 2008 to help policymakers, businesses, and other stakeholders analyze trajectories to achieve deep decarbonization of the economy; the model has since been improved over time in projects analyzing jurisdictions across North America. Recent examples include working with the Maryland Department of the Environment, New York State Energy Research and Development Authority in New York, with the Calpine Corporation in New England, the California Energy Commission, Xcel Energy in Minnesota, Nova Scotia Power in Nova Scotia, and the Massachusetts Department of Public Utilities 20-80 Future of Gas proceeding.

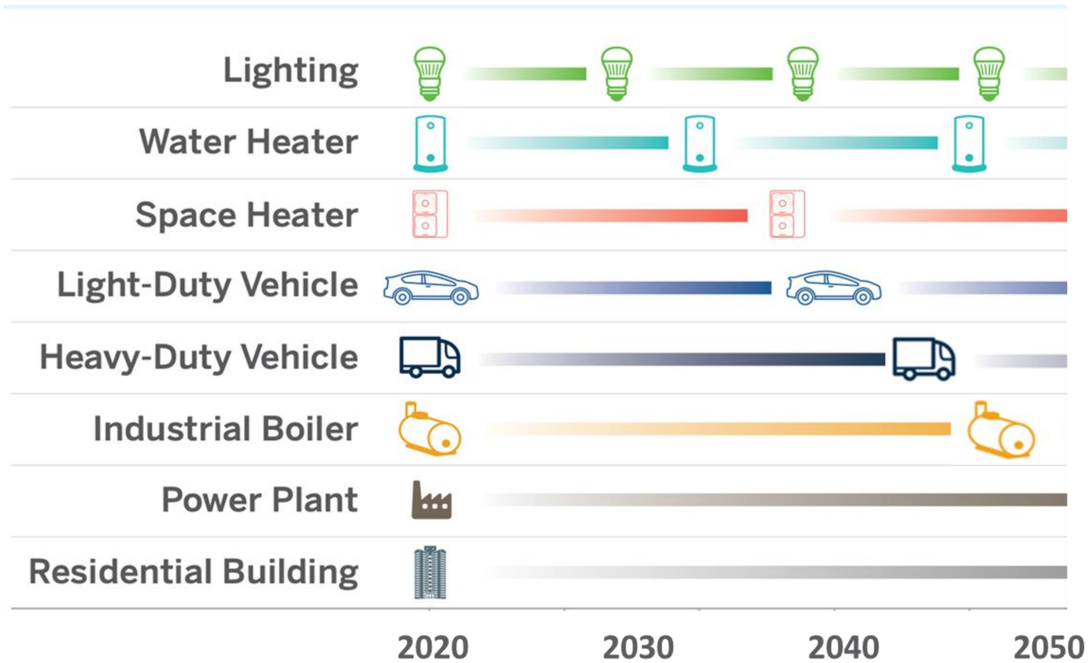
Figure 35: Schematic overview of the PATHWAYS model.



A key feature of PATHWAYS is a characterization of stock rollover of equipment in major sectors of the economy like buildings and transportation. Stock rollover describes a methodology where the total number of devices (stocks) are tracked and retired at the end of a deemed lifetime and replaced with new technologies over time (sales). A stock rollover approach tracks infrastructure turnover of energy-consuming devices while accounting for changes in performance, such as improved efficiency over time. This approach explicitly tracks the time lag between changes in annual sales of new devices and changes in device stocks over time in key building and transportation sectors. Different types of equipment have different lifetimes, which are captured by this approach. For example, some technologies, such as lightbulbs, have life spans of just a few years, while others, such as the built environment, have multi-decade or longer life spans. Tracking technology and infrastructure lifespans informs the pace of transformation necessary in each sector to achieve economywide greenhouse gas (GHG) targets while capturing potential path dependencies. As an example, Figure 36 shows example lifetimes of different end uses and the potential number of replacements that could realistically be achieved between now and

2050. The PATHWAYS model also has the ability to track "early retirements" where devices are assumed to retire before the end of their natural life; this modeling exercise for ComEd assumes natural replacement of devices and does not include early retirements.

Figure 36: Illustrative Timelines for Stock Rollover of Appliance Types and Infrastructure[37]



A.2. RESHAPE

E3's RESHAPE model was designed to simulate heat pump operations given sensible space heating demands in a variety of building typologies across the residential and commercial building subsectors. Using these simulations, RESHAPE produces 40 historical weather years (1979-2018) of space heating load shapes. RESHAPE's sensible heating demands were benchmarked to replicate the seasonality of monthly residential and commercial gas sales as reported by the US Energy Information Administration (EIA) in Illinois from 2016-2018. To further customize RESHAPE to align with space heating demands within ComEd's service territory, 2018 annual gas demands from PATHWAYS and 2018 weather year demand shapes from RESHAPE were combined to estimate daily gas throughput. The throughput on peak day January 1, 2018, was extracted from these data and compared to NICOR's peak day throughput, since NICOR's service territory mostly aligns with that of ComEd (RESHAPE: 4.5 TBTU, NICOR: 4.2 TBTU). In addition, the peak-day to annual throughput ratio was estimated to be 0.90% and 0.88%, for RESHAPE

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[37] This figure was published originally by E3 (Williams et al. 2014) and modified with graphic design improvements by the Building Decarbonization Coalition.

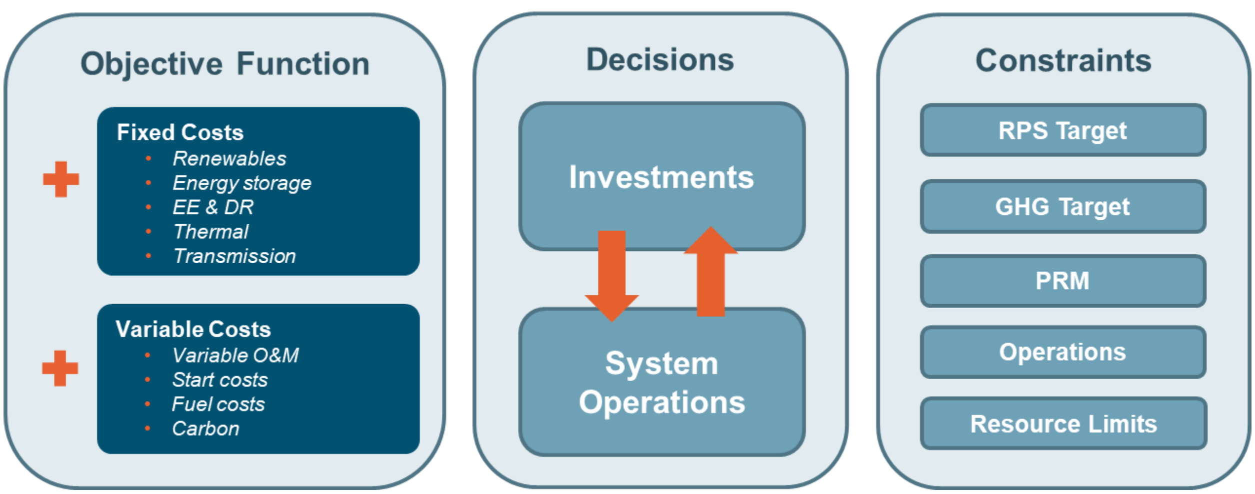
and NICOR, respectively.[38] Given these results, it was assumed that RESHAPE was reasonably benchmarked to ComEd's service territory.

RESHAPE was also used to simulate water heating demands and shapes, drawing on metered data provided by the Northwest Energy Efficiency Alliance for residential systems and from the California Energy Use Survey for commercial systems. Water heating is less weather-dependent on a year-to-year basis. As a result, a single water heating shape was applied for residential and commercial buildings each across all weather years.

A.3. RESOLVE Model

E3's Renewable Energy Solutions Model (RESOLVE) is used in this study to investigate the electric sector resource portfolios and system costs under the different electrification scenarios. RESOLVE is E3's electricity system planning model that identifies optimal long-term generation and transmission investments through linear optimization, subject to reliability, technical, and policy constraints. Designed specifically to simulate power systems operating under high penetrations of renewable energy and energy storage, RESOLVE layers capacity expansion logic on top of a reduced-form production cost model to determine a least-cost investment plan. RESOLVE considers both the fixed and operational costs of different portfolios over the lifetime of the resources. By co-optimizing investment and operations decisions in one stage, the model directly captures dynamic trade-offs between them, such as energy storage investments vs. renewable curtailment/overbuild. The objective function minimizes the net present value (NPV) of electricity system costs, calculated as the sum of fixed investment costs and variable-plus-fixed operating costs, subject to various constraints. Figure 37 provides an overview of the RESOLVE model.

Figure 37: Overview of RESOLVE model



[38] Nicor Gas Company's Comments Addressing Energy Storage. https://www.icc.illinois.gov/downloads/public/Comments%20of%20Nicor.pdf.

RESOLVE uses weather-matched load, renewable and hydro data, and simulates interconnection-wide operations over a representative set of sample days in each year. Weather-dependent load profiles, specifically residential- and commercial-sector space and water heating load profiles, are developed in E3's RESHAPE model. RESHAPE combines a set of characteristic buildings, four decades of historical weather, and a physical model of heat pump operation. Building data comes from EIA's RECS and CBECS surveys. Weather data is derived from NOAA's North American Regional Reanalysis.

A.4. Revenue Requirement and Affordability

Electric Revenue Requirement

E3 determined the total electric revenue requirement needed to serve ComEd's customers in each scenario as the electric system decarbonizes and electrification increases loads. Incremental generation, transmission, and distribution costs associated with decarbonizing PJM electric supply were derived from E3's RESOLVE modeling for this study. Incremental generation costs, including fixed costs (capital costs, fixed O&M, etc.) for new resource additions, ongoing fixed O&M costs to maintain existing resources, fuel costs, and variable O&M costs, were RESOLVE outputs. E3 assessed incremental transmission and distribution capacity costs based on changes in ComEd's system peak, after load flexibility, using a "1-in-10" (one day in ten years) planning standard. The marginal costs used to assess the transmission and distribution capacity costs of each scenario are described in Table 7. These costs were provided by ComEd as an overnight cost and levelized by E3 using expected asset lifetimes and ComEd's weighted average cost of capital.

Table 7: Marginal Transmission and Distribution Capacity Costs

Category	Value
Incremental transmission capacity	\$54/kW-year (2020 \$)
Incremental distribution capacity	\$145/kW-year (2020 \$)

E3 then added incremental electric supply and delivery costs to a forecast of embedded costs to arrive at an annual revenue requirement for the electric sector. E3 developed customer rates by allocating the revenue requirement in each scenario based on the factors described in Table 8 to develop a class revenue requirement. The class revenue requirements were then divided by class electric sales to calculate a volumetric rate for each scenario and model year. These volumetric rates were then leveraged in the customer affordability assessment.

Table 8: Customer Cost Allocation Methodology

Category	Allocation of costs based on (>2020)
Embedded system costs	Historical allocation of costs
Fuel costs and O&M	Customer group's contribution to electric load
Incremental generation costs	Customer group's contribution to electric load
Incremental transmission costs	Customer group's contribution to coincident 1-in-10 peak
Incremental distribution costs	Customer group's contribution to coincident 1-in-10 peak

Gas Revenue Requirement Model

While ComEd does not provide gas services, other gas utilities in the ComEd service area are assumed to play a part in the decarbonization scenarios, and their changing operations would have implications for the total energy costs experienced by ComEd customers. E3's gas revenue requirement and rate model ("gas RR model") is a bottom-up tool that evaluates the implications of the various scenarios on gas revenue requirements and customer rates at a high level. For this analysis, the gas RR model was simplified and used to model future rates paid by customers of the Northern Illinois Gas Company and the Peoples Gas Light and Coke Company, focusing specifically on residential customers. The simplified model draws on publicly available data and Pathways model outputs. First, the current monthly customer charge and per unit distribution charge were used to calculate the average annual revenue received from each residential gas customer in ComEd's service area. As a simplifying assumption, the total revenue requirements for the gas utilities were projected to increase at 1% per year, while the customer counts and volumes of gas sold were projected to change according to the overall trends in the Pathways scenarios. Future average rates were calculated by dividing projected revenue requirements by modeled sales volumes, and average rates were then scaled by the current ratio of distribution revenue to total revenue to estimate future distribution charges. The remaining revenue requirements were divided by the number of customers still on a gas network to find the annual customer charges. Finally, gas commodity rates were retrieved from E3 internal forecasts and combined to represent the modeled mix of natural gas, biogases, and hydrogen.

Customer Affordability Approach

Baseline

While the PATHWAYS model describes the energy demand and cost changes across the entire ComEd service area, the customer affordability model explores how individual residential customers might experience changes in building energy consumption.[39] E3 derived representative customer profiles using data from the American Community Survey (ACS) on building vintages, numbers of units, and resident

[39] While transportation costs do impact customer affordability, this study focuses on the impacts to buildings. As a result, transportation costs were excluded from this analysis.

income. Using that data, E3 selected the three residential profiles described in Table 9. for the primary focus of the report. According to ACS data, 60% of ComEd households are in one-unit buildings, while 40% of households are in multi-unit buildings. The greatest share of housing units (26%) were built between 1960 and 1979, and the next greatest share of units (22%) were built in 1939 or earlier. The ACS data reveals a wide range in income levels within the ComEd service area. 25% of households have an annual income less than $35,000, and 52% of households have an income less than $75,000; meanwhile, 19% of households have an annual income greater than $150,000.

E3 also relied on data from the Residential Energy Consumption Survey (RECS) to describe typical annual energy use. RECS data observations for metro area households that use natural gas for both space heating and cooking were separated and averaged according to income level and housing type. From this, E3 constructed energy profiles for households representative of ComEd customers, broken down by gas and electricity use for heating, cooling, lighting, clothes drying, cooking, water systems, and other miscellaneous end uses. As reflected in Table 9, single-family units consume more energy than multi-family units, and energy use increases with income.

Table 9: Summary of Residential Customer Profiles Used in The Affordability Assessment

Building Category	Structure Type	Income Level Bracket	Approximate Household Income	Vintage	Reference Annual Electricity (KBTU)	Reference Annual Natural Gas (KBTU)
Residential 1	Single Family	$20,000 - $39,999	$30,000	1960 to 1969	24,302	104,297
Residential 2	Single Family	$40,000 - $59,999	$50,000	1960 to 1969	23,093	101,601
Residential 3	Single Family	$80,000 - $99,999	$90,000	1960 to 1969	25,269	115,418
Residential 4	Multi Family	$40,000 - $59,999	$50,000	1980 to 1989	13,936	61,153

Residential Technology Packages

E3 modeled four customers that select a unique package of technologies that are representative of the technologies that would be adopted under the PATHWAYS scenarios. The technology packages include primary household appliances, lighting, building shell measures, and a vehicle. The technology packages corresponding to the four representative customers are summarized in Table 10.

Table 10: A Summary of the Technical Packages Selected for Each Customer

Package Measure/Parameter	Gas Heat + ICE	Hybrid Heat + ICE	Hybrid Heat + BEV	All Electric Heat + BEV
Primary Space Heating	Reference SH	Dual Fuel ASHP	Dual Fuel ASHP	Electric ASHP
Secondary Space Heating	None	None	Reference SH	None
Demand Share of Secondary Space Heating (%)	N/A	N/A	5%	N/A
Water Heating	Refence WH	Electric WH	Electric WH	Electric WH

Clothes Drying	Reference CD	Electric CD	Electric CD	Electric CD
Cooking	Reference CK	Electric CK	Electric CK	Electric CK
Lighting	Reference Lighting	Efficient Lighting	Efficient Lighting	Efficient Lighting
Building Shell	Reference Shell	Light Shell Retrofit	Light Shell Retrofit	Light Shell Retrofit
Vehicle	Gasoline	Gasoline	Electric	Electric

Energy Bills

Monthly energy bills are then calculated by assessing a combination of the customer and volumetric charges for electric and gas against changes in customer usage of those fuels in each technology package. The model begins with the reference "Gas Heat + ICE" residential energy profile as defined with RECS data. For each of the alternative technology packages, the energy consumption for a particular technology end use is scaled according to how the selected technology performs relative to the reference technology. If a given technology is electrified, then the corresponding energy demand is switched from gas to electric. To allow for a comparison of results, it is assumed that household consumer behavior (such as regularity of clothes washing, level of lighting, etc.) remains unchanged, and only the performance of technology at meeting set household needs is adjusted.

The monthly energy bills also include gasoline or electricity costs for the vehicle associated with the customer's technology package. The vehicle energy consumption, and corresponding energy cost, is based on the average energy consumption for a household owning a single vehicle in ComEd's service territory.

First-Costs

Each technology option includes an upfront cost. These estimates include the cost of space heating, space cooling, water heating, cooking, clothes drying equipment, vehicle as well as building shell improvements. Total upfront costs are shown in Table 11. These costs are subsequently used to estimate the total upfront costs of a technology package for a customer type.

Table 11: Upfront Costs Used in the Customer Affordability Model

Subsector	Technology	Single-Family Costs ($/unit)	Multi-Family Costs ($/unit)
Space Heating	Reference SH	$3,900	$3,450
Space Heating	Dual Fuel ASHP	$13,700	$12,100
Space Heating	Electric ASHP	$14,400	$12,700
Water Heating	Reference WH	$1,250	$1,110
Water Heating	Electric WH	$2,350	$2,050
Clothes Drying	Reference CD	$750	$700
Clothes Drying	Electric CD	$450	$400
Cooking	Reference CK	$650	$550
Cooking	Electric CK	$850	$750
Shell Measures	Reference Shell	$12,550	$11,100
Shell Measures	Light Shell Retrofit	$20,150	$17,800
Vehicle	Light-duty Gasoline Car*	$32,350	$32,350
Vehicle	Light-duty Electric Car* (includes charging infrastructure)	$43,450	$43,450
*E3 forecasted technology costs from 2022-2050 and used a 12-year lifetime average for the modeled year. The costs listed above are 2022 costs.			

As an output, upfront costs are calculated for each customer by amortizing the upfront cost monthly spread across the lifetime of the investment. This method provides a high- level indication of the monthly outlays a customer may experience under an arrangement where the costs could be more evenly spread over time.

The modeled upfront costs also consider the impact of residential energy rebates and tax credits made available by the State of Illinois and by the Inflation Reduction Act. The rebates and tax credits are assumed to be available until 2032. The modeled customers have a household income below 80% of the area median income (under $83,350 for a household of four in the Chicago-Naperville-Joliet metro area) and qualify for the highest rebate amounts for approved technologies. Similarly, a 30% tax credit or the tax credit cap is applied to the upfront cost of qualifying technologies. Tax credits and rebates are subtracted from an appliance's upfront cost until 2032.

Key Affordability Model Inputs

Data on average customer energy consumption, equipment costs and efficiency, and scenario-specific rates from the gas and electric sector modeling are used to estimate changes in customer costs under different scenarios. The upfront cost of building electrification and energy efficiency measures were primarily derived from values published in the 2021 Maryland Building Decarbonization Study. Upfront costs, detailed in the modeling assumptions spreadsheet, are derived from a variety of sources, including EIA National Energy Modeling System (NEMS) and the Massachusetts Buildings Technical Report. Data inputs into the model are shown in Table 12.

Table 12: Customer Affordability Model Input Sources

Model Inputs	Data Source
Electric Rates	Electric Revenue Requirement Model
Gas Rates	Gas Revenue Requirement Model
Baseline Energy Consumption	U.S. Department of Energy, 2015 Residential Energy Consumption Survey (RECS) Microdata
Equipment Efficiencies	E3 RESHAPE model simulations, EIA NEMS model documentation, NREL Energy Futures Study
Equipment Costs	Maryland Building Decarbonization Study, The Role of Gas Distribution Companies in Achieving the Commonwealth's Climate Goals
Income	U.S. Census Bureau, 2019 American Community Survey 5-Year Estimates
Housing Characteristics	U.S. Census Bureau, 2019 American Community Survey 5-Year Estimates
Household Energy Use Profiles	U.S. Department of Energy, 2015 Residential Energy Consumption Survey (RECS) Microdata

Appendix B. Inputs and Assumptions

B.1. PATHWAYS Modeling

Representation of Illinois and ComEd Service Territory Energy Demands and Emissions

The PATHWAYS model used for this analysis includes a statewide Illinois region and a ComEd service territory region. Both regions are benchmarked to include all final energy demands and GHG emissions that occur within their boundaries. Base year energy consumption and GHG emissions for 2018 was benchmarked for the Illinois region to statewide energy demand from EIA State Energy Data System (SEDS) and non-energy, non-combustion GHG emissions from the EPA State Inventory Tool (SIT). For the ComEd service territory region, statewide energy demands and GHG emissions were downscaled using the following scaling variables by sector:

- Residential – Share of statewide households (American Community Survey[40])
- Commercial – Share of commercial electricity sales (EIA SEDS and ComEd sales data[41])
- Industry – County-level energy demand estimates (NREL[42])

[40] https://www.census.gov/programs-surveys/acs/data.html
[41] https://www.eia.gov/state/seds/seds-data-complete.php
[42] https://data.nrel.gov/submissions/97

- Transportation – Share of population (American Community Survey)
- Agriculture – Share of planted acreage (USDA[43])
- Industrial Processes and Product Uses (IPPU)/Natural Gas & Oil Systems/Waste – Share of population
- Coal Mining – Assumed no activity in ComEd service territory
- Land-use, Land-use Change, and Forestry (LULUCF) – Share of planted acreage

Sector Representation and Key Drivers

Table 13 below shows the full list of subsectors included in the PATHWAYS model.

Table 13: PATHWAYS Model Subsectors by Type

Subsector Type	Subsector Name	Subsector Type	Subsector Name
Stock Rollover	Residential Building Shell	Energy Only	Residential Other
Stock Rollover	Residential Central Air Conditioning	Energy Only	Commercial Other
Stock Rollover	Residential Room Air Conditioning	Energy Only	Transportation Aviation
Stock Rollover	Residential Clothes Drying	Energy Only	Transportation Other
Stock Rollover	Residential Clothes Washing	Energy Only	Industry Agriculture
Stock Rollover	Residential Cooking	Energy Only	Industry Construction
Stock Rollover	Residential Dishwashing	Energy Only	Industry Mining and Upstream Oil and Gas
Stock Rollover	Residential Freezing	Energy Only	Industry Aluminum
Stock Rollover	Residential General Service Lighting	Energy Only	Industry Cement and Lime
Stock Rollover	Residential Exterior Lighting	Energy Only	Industry Chemicals
Stock Rollover	Residential Linear Fluorescent Lighting	Energy Only	Industry Food
Stock Rollover	Residential Reflector Lighting	Energy Only	Industry Glass
Stock Rollover	Residential Refrigeration	Energy Only	Industry Iron and Steel
Stock Rollover	Residential Single Family Space Heating	Energy Only	Industry Metal Based Durables
Stock Rollover	Residential Multi Family Space Heating	Energy Only	Industry Paper
Stock Rollover	Residential Water Heating	Energy Only	Industry Plastics
Stock Rollover	Commercial Air Conditioning	Energy Only	Industry Refining
Stock Rollover	Commercial Cooking	Energy Only	Industry Wood Products
Stock Rollover	Commercial High Intensity Discharge Lighting	Energy Only	Industry Other
Stock Rollover	Commercial Linear Fluorescent Lighting	Emissions Only	Agriculture
Stock Rollover	Commercial General Service Lighting	Emissions Only	Coal Mining
Stock Rollover	Commercial Refrigeration	Emissions Only	Natural Gas and Oil Systems
Stock Rollover	Commercial Ventilation	Emissions Only	IPPU
Stock Rollover	Commercial Space Heating	Emissions Only	Waste
Stock Rollover	Commercial Water Heating	Emissions Only	LULUCF
Stock Rollover	Transportation Light Duty Cars		

[43] https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index

Subsector Type	Subsector Name	Subsector Type	Subsector Name
Stock Rollover	Transportation Light Duty Trucks		
Stock Rollover	Transportation Light Medium Duty Trucks		
Stock Rollover	Transportation Medium Duty Trucks		
Stock Rollover	Transportation Heavy Duty Trucks		
Stock Rollover	Transportation Buses		

Growth in energy demands and/or emissions for each subsector is driven by a variety of factors, shown in Table 14.

Table 14: PATHWAYS Sectors and Primary Drivers

Sector	Primary Driver	Compound Annual Growth Rate (%)	Sources
Buildings	Residential: Number of households Commercial: Commercial square footage	Households: 0.7% Square footage: 1.0%	Households growth rate: CMAP 2050 Forecast of Population, Households and Employment[44] Commercial square footage growth rate: AEO 2021 Reference Case[45]
Transportation	Per-vehicle vehicle-miles traveled (VMTs); Number of vehicles: population growth	LDV VMT: 0.3% MHDV VMT: -0.37% Population: 0.6%	VMT growth rates: AEO 2021 Reference Case Population growth rate: CMAP 2050 Forecast of Population, Households and Employment
Industry	Varies by fuel and industrial subsector	Overall fuel demand growth: 0.6%	AEO 2021 Reference
Electricity	Buildings, transportation, and industrial electricity demand growth	Bottom-up calculation based on level of electrification by scenario	N/A
Other Non-Energy, Non-Combustion	Various	Various	EPA state-level non-CO2 GHG projections[46]

[44] https://www.cmap.illinois.gov/data/demographics/population-forecast
[45] https://www.eia.gov/outlooks/aeo/tables_ref.php
[46] https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/us-state-level-non-co2-ghg-mitigation-report

B.2. RESOLVE Modeling Assumptions

The RESOLVE model inputs used in this study are derived from a similar model developed for the *Least-Cost Carbon Reduction Policies in PJM* study performed by E3.[47] Key inputs and assumptions, especially ones that reflect updated data sources and CEJA policies are summarized in this section. Additional description of the inputs and assumptions can be found in the *Least-Cost Carbon Reduction Policies in PJM* report.

System Topology

While the ComEd territory is the region of interest in this study, RESOLVE models the PJM system as a whole and uses a zonal transmission topology to simulate power flows among the three zones represented in the model, i.e., Eastern Mid-Atlantic Area Council (EMAAC), Central (regional transmission organization, or RTO), and ComEd. High-level transmission constraints in the PJM grid are also presented in the model. The zonal import and export capabilities are taken as 5,971MW for transfers between ComEd and RTO, and 9,752MW for transfers between EMAAC and RTO. These values are based on the Capacity Emergency Transfer Limits (CETLs) in the PJM 2022/2023 Base Residual Auction.[47] Figure 38 shows the existing topology of PJM system modeled in RESOLVE.

Figure 38: PJM Transmission Topology Modeled in RESOLVE

In addition to the existing transmission capacity, the model includes approximately 2,000 MW of new SOO Green transmission from the Midcontinent Independent System Operator (MISO), scheduled to be added in 2027 and connected to PJM system through ComEd. This new transmission line is assumed to transmit clean, firm energy to serve load in ComEd region, with the imported energy qualified for RPS under CEJA.

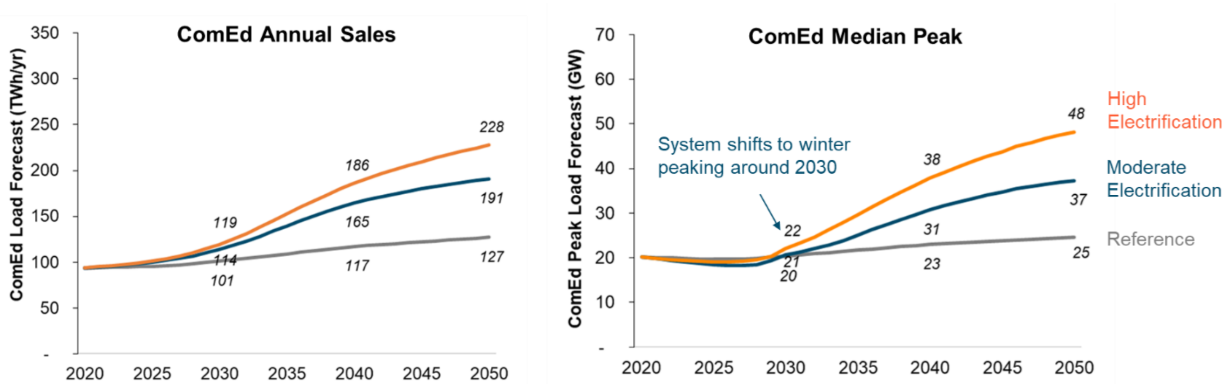
While imports are not carbon constrained (i.e. there is no electric sector specific emissions target), the moderate and high electrification scenarios have economy-wide targets. As such, a hurdle rate for imports equal to the cost of emissions abatement (cost of direct air capture) in the economy was applied to imports 2040 and beyond.

[47] "Least-Cost Carbon Reduction Policies in PJM." October 2020. https://www.ethree.com/wp-content/uploads/2020/10/E3-Least_Cost_Carbon_Reduction_Policies_in_PJM-1.pdf.

Demand Forecasts

Annual energy demands in ComEd region are calculated from E3's PATHWAYS model. Annual system peaks are calculated from annual energy (from PATHWAYS, analysis year from 2020 to 2050) and load profiles (from RESHAPE, 40 historical weather-year data). For each analysis year, the median ("1-in-2") coincident peak out of the 40 historical weather years is chosen as the system peak. Figure 39Figure shows the amount annual loads and median peak modeled in RESOLVE for all three scenarios. The Reference scenario load and peaks experience a slow but steady growth, reflecting modest levels of electrification tempered by continued progress on energy efficiency. The two Electrification scenarios have consistent and similar growth in load due to increasing electrification, with the High Electrification scenario experiencing a larger increase in peak load due to higher penetrations of all-electric space-heating.

Figure 39: ComEd Annual Sales and Median Peak Load Modeled in RESOLVE

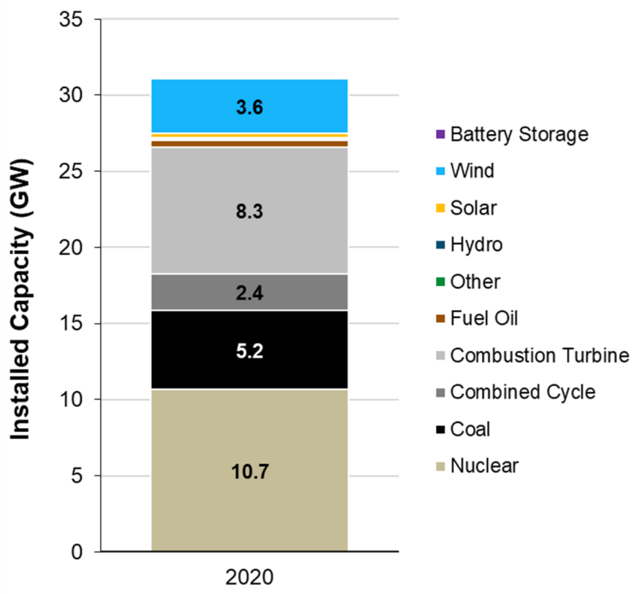


Existing and Planned Resources

The existing resource mix modeled in RESOLVE is based on the generator list developed from Energy Exemplar's 2019 National Database with adjustments and updates made by E3. Today's ComEd system is primarily comprised of thermal resources with minimal amounts of renewable capacity, primarily wind. Throughout the modeling horizon, 10.7 GW of nuclear capacity could be retired at the end of the current contracted period but has the option to be relicensed and continue service. This study does not impose specific limits on the pace of coal and gas generator retirement in the ComEd zone other than retirements that have been announced by utilities and CEJA requirements. Under CEJA, all public coal and gas generators retire by 2045, non-public coal generators retire by 2030, and non-public gas generators retire as early as 2030 subject to criteria such as location relative to environmental justice communities and air pollutant emission rate. By 2025, roughly 1.2 GW of coal capacity in ComEd will be retired, with the remaining 4 GW retiring by 2030 based on utility announcements. Over 5 GW of gas capacity in ComEd will be retired by 2030, and roughly 6 GW more by 2045 per CEJA. The retirement schedule for fossil generation in PJM RTO and EMAAC regions is modeled based on the latest available utility announcements.

Figure 40 shows the existing resources mix in ComEd and the license expiration schedule for nuclear units.

Figure 40: Current Resource Mix Modeled for ComEd[48]



Existing Nuclear License Expiration Schedule

Unit Name	Unit Capacity (MW)	License Expiration
Braidwood 1	1,207	2046
Braidwood 2	1,177	2047
Byron 1	1,187	2044
Byron 2	1,159	2046
Dresden 2	902	2029
Dresden 3	904	2031
LaSalle 1	1,141	2042
LaSalle 2	1,157	2043
Quad Cities 1	908	2032
Quad Cities 2	911	2032

In addition to existing capacity, RESOLVE models planned capacity additions based on recent project announcements and data from the S&P Global Market Intelligence. For ComEd, this includes several new gas generators that are in final stages of construction and are expected to come online in the next few years. These units, however, are also subject to CEJA and will be retired by 2045.

Resource Options

A wide range of technologies and resources are made available for selection in RESOLVE to meet the region’s energy and capacity needs. For the purpose of this study, new coal or gas builds that have not started construction are not considered in the ComEd zone for CEJA compliance. No new nuclear units are licensed per CEJA, but existing nuclear plants can remain active though relicensing as deemed economic by RESOLVE. These nuclear plants are forced to be back online in total and immediately after the license expiration year, as long as it’s selected to be economically relicensed within the study horizon. Nuclear generators are also assumed to be “must-run” in RESOLVE, which makes it a firm baseload resource to meet load needs in ComEd region. Zero-carbon power resources such as solar photovoltaics (PV), onshore

[48] The “Other” resource category includes landfill, gas recovery (repurposed gas that would normally be flared), and small combined heat and power (CHP) generators.

wind,[49] and hydrogen fuel cells are among the primary candidate resources that could be selected by RESOLVE throughout the study period. Renewable resource potential and cost assumptions are primarily informed by the NREL Regional Energy Deployment System (ReEDS) model.

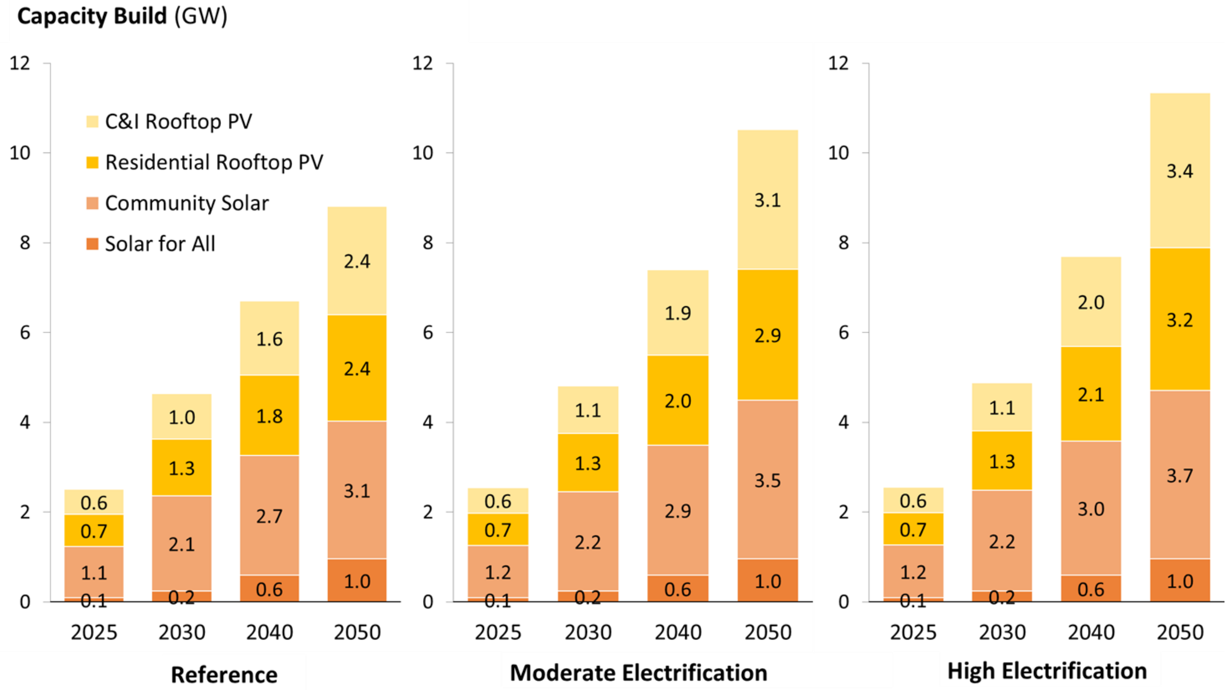
While the model does not specifically constrain the build potential of some emission-free resources such as lithium-ion (Li-ion) batteries, there is a limit to solar and wind additions in each modeling zone, which reflects the technical and practical considerations of the available land area for developing new resources. In this study, land use for renewable development is restricted to 4% of farmland for solar, and 4% of farmland and 2% of forest for onshore wind in each State. These constraints translate to 62 GW of utility-scale solar potential and approximately 6 GW of onshore wind potential in Illinois, which are more stringent than the technical resource potentials in the NREL ReEDS model.[50] The amount of hydrogen fuel cells that can be built from 2030 through 2040 is limited at a level that is scalable based on constructability constraints for hydrogen production. Those constraints are 1 GW in 2030, 5 GW in 2035, 5 GW in 2040 and unconstrained following that.

Distributed solar buildout in ComEd is based on ComEd's estimates, which comply with the RPS budget cap under CEJA, assuming the budget scales with load growth. below shows the assumed capacity build trajectory for distributed solar in the three scenarios modeled.

[49] Offshore wind is not a candidate resource option for the ComEd zone in this version of RESOLVE due to data availability at the time the model was developed. We recognize that offshore wind could play an important role in a deeply decarbonized ComEd grid, especially if the supply of land-based resources become more constrained and the cost for offshore wind continues to decline. Offshore wind is a candidate resource option in other PJM zones in the model and can be part of resource mix of the imports that serve ComEd load.

[50] See more details in: "Least-Cost Carbon Reduction Policies in PJM." October 2020. https://www.ethree.com/wp-content/uploads/2020/10/E3-Least_Cost_Carbon_Reduction_Policies_in_PJM-1.pdf.

Figure 41: Distributed Solar Build Forecasts in ComEd[51]



To model future costs associated with new resources, this study relied on input data from NREL ReEDS as well as cost assumptions from NREL's 2022 Annual Technology Baseline (ATB)[52] and Lazard's Levelized Cost of Storage v7.0.[53] The cost forecasts embed assumptions based on current market conditions and have factored in the influence of the Inflation Reduction Act (IRA) for qualifying resources. The impacts of the IRA on resource costs are primarily reflected as technology-neutral tax credits. E3 assumes that projects will have access to the full credit amounts, with the underlying assumption that the prevailing wage and apprenticeship requirements are satisfied. In addition, the IRA tax credits will phase out the later of 2032 or when the US electric sector achieves 75% GHG emissions reduction relative to 2022 levels.[54] E3 assumes that the electric sector emissions target will be met by 2045, after which the IRA tax credits step down over a three-year period. Figure 42 illustrates the assumed IRA tax credit schedules in this study.

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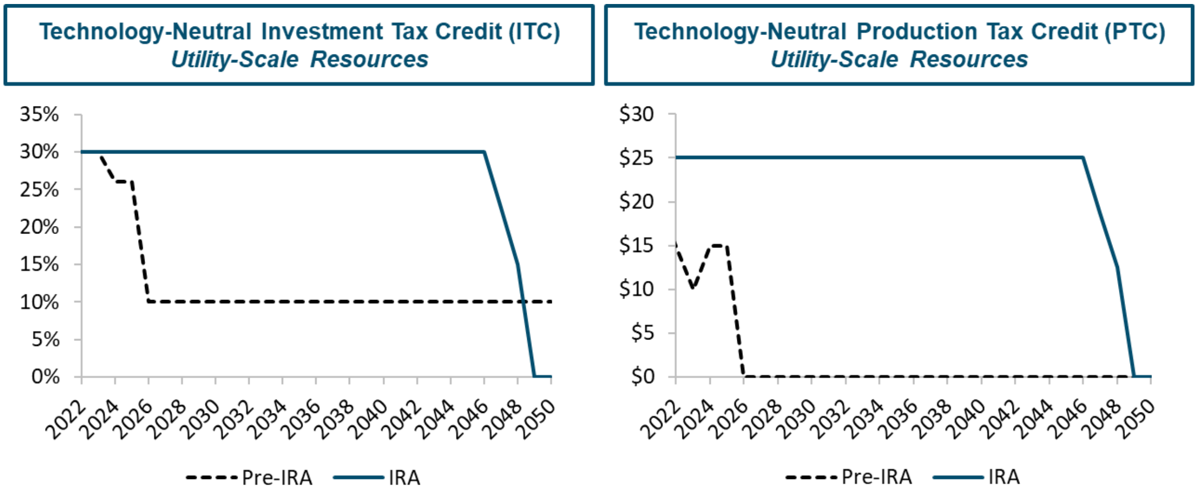
[51] "Solar for All" refers to Illinois' Solar for All program that aims to provide access to solar energy for low-income communities. See: https://www.illinoissfa.com/.

[52] NREL (National Renewable Energy Laboratory). 2022. "2022 Annual Technology Baseline." Golden, CO: National Renewable Energy Laboratory. https://atb.nrel.gov/.

[53] Lazard. 2021. "Lazard's Levelized Cost of Storage Analysis—Version 7.0." https://www.lazard.com/media/451882/lazards-levelized-cost-of-storage-version-70-vf.pdf.

[54] https://www.energy.gov/sites/default/files/2022-10/IRA-Energy-Summary_web.pdf.

Figure 42: Assumed Tax Credit Schedules Under the Inflation Reduction Act (IRA)



Capital costs and annualized all-in fixed costs used in this study are shown in Table 15. Annualized all-in fixed costs, including the capital, fixed O&M, interconnection costs, are used for electric sector investment decisions and are calculated from E3's financial cash flow projection model. Costs of utility-scale solar, onshore wind, and offshore wind vary by factors such as resource quality and distance from the grid, which depend on resource location. These resource costs are represented in RESOLVE using a detailed supply curve obtained from Regional Energy Deployment System (ReEDS) model.

Table 15: Costs of Candidate Resources Assumed in This Study

Candidate Resource	Capital Cost ($2020/kW)		Levelized All-in Fixed Cost ($2020/kW-year)		Data Source and Note
	2030	2050	2030	2050	
Utility-Scale Solar PV	1,036	825	83	107	NREL 2022 ATB with E3 adjustments to reflect current market conditions; Regional adjustments derived from the NREL ReEDS model are reflected in RESOLVE
Distributed Solar PV, Residential	1,169	910	128	101	NREL 2022 ATB
Distributed Solar PV, Commercial & Industrial	1,062	815	101	79	NREL 2022 ATB
Distributed Solar PV, Community	1,142	886	121	96	Capacity-weighted average of distributed residential and commercial & industrial solar costs
Onshore Wind	1,180	990	78	142	NREL 2022 ATB with E3 adjustments to reflect current market conditions; Regional adjustments derived from the NREL ReEDS model are reflected in RESOLVE
Li-ion Battery (4 hour)	1,371	746	143	113	Lazard's Levelized Cost of Storage v7.0 with E3 adjustments to reflect current market conditions
Hydrogen Fuel Cell	1,316	817	136	95	Based on E3's research for New York State Climate Action Council Draft Scoping Plan[55]

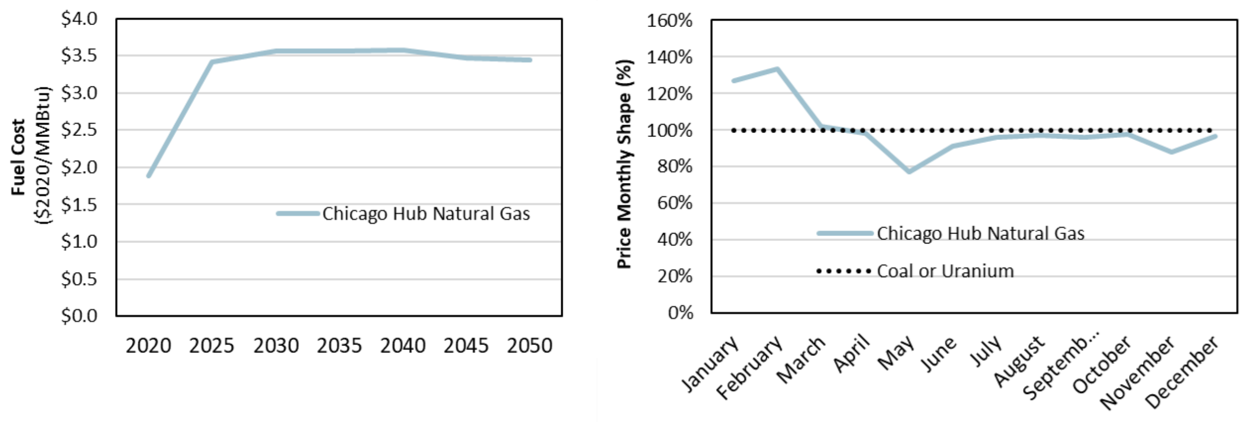
Fuel Price Forecasts

Natural gas price in PJM system is derived using a the latest S&P Global forwards in the near term (2022-2027), trending to the EIA Annual Energy Outlook (AEO) fundamentals-based 2040 forecast for the longer term. Monthly variations in natural gas prices due to pipeline congestion and other constraints are

[55] New York State Climate Action Council Draft Scoping Plan. December 2021. https://climate.ny.gov/Our-Climate-Act/Draft-Scoping-Plan. Appendix G: Annex 1: Inputs and Assumptions.

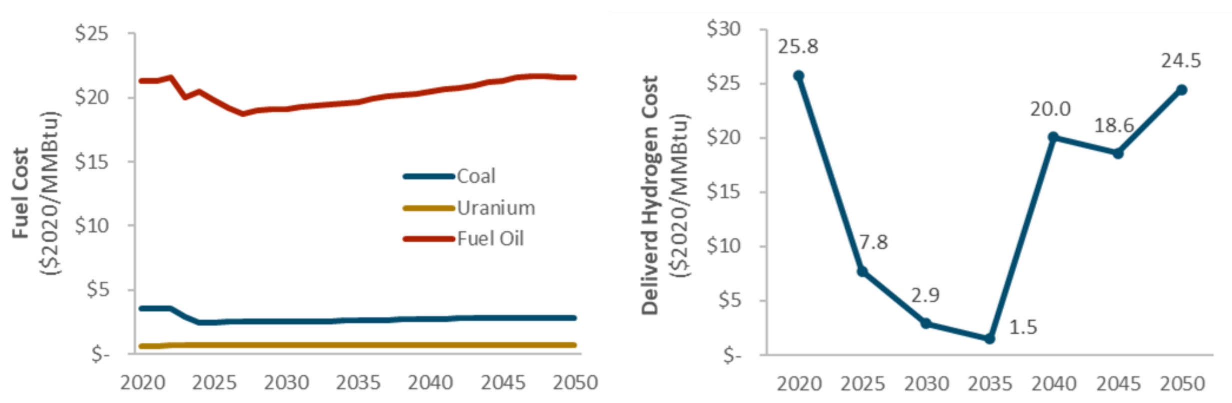
reflected as a monthly shape relative to the annual average. ComEd specific natural gas is priced at Chicago hub, as shown in Figure 43. All natural gas price forecasts implemented in RESOLVE have factored in the recent uptick in natural gas prices across the region.

Figure 43: Natural Gas Price Forecast, Annual (left) and Monthly (right)



The coal price forecast modeled in RESOLVE is from S&P Global, while the uranium and fuel oil price forecasts are derived from EIA's 2021 Uranium Marketing Annual Report[56] and 2022 Annual Energy Outlook (AEO)[57], respectively. The trend of each price stream is showed in Figure 44 (left). The hydrogen costs modeled in RESOLVE reflect a conservative view assuming high costs of production and electrolyzer deployment. In addition, underground salt cavern storage and a 350-mile pipeline was incorporated into the hydrogen cost. The IRA would make hydrogen more cost-effective through a production cost credit, leading to drops in hydrogen price in the mid-2020s through the mid-2040s, as shown in Figure 44 (right).

Figure 44: Coal, Uranium, Fuel Oil, and Hydrogen Price Forecasts



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[56] EIA 2021 Uranium Marketing Annual Report, https://www.eia.gov/uranium/marketing/pdf/2021%20UMAR.pdf

[57] EIA 2022 Annual Energy Outlook distillate fuel oil price forecast, https://www.eia.gov/opendata/v1/qb.php?category=4448812&sdid=AEO.2022.LORENCST.PRCE_NA_ELEP_NA_DSTL_NA_NA_Y13DLRPMMBTU.A

System Reliability

RESOLVE models a planning reserve margin (PRM) constraint to ensure resource adequacy in the system. The target PRM is assumed to be 9% in this model, which is derived from PJM's convention and accounts for forced outages of thermal generation units.[47] The PRM is applied to the median system peak as extra firm capacity that the system needs to build or maintain. The model also captures the dynamic contributions of weather-dependent renewable and energy storage resources to the system, specifically in terms of capacity contributions toward the PRM requirement, with the capacity contribution varying by the penetration of the resource. The firm capacity contributions from renewable and storage resources (in terms of effective load-carrying capability, or ELCC) in this study are calculated using multiyear hourly PJM load and renewable generation profiles. A detailed description of this methodology can be found in the *Least-Cost Carbon Reduction Policies in PJM* study.[47]

B.3. Air Quality Analysis Modeling

Air Quality Analysis Framework

E3 performed a county-level air quality analysis that examines the health benefits of reduced fuel combustion in Illinois for five major criteria air pollutants: ammonia, nitrogen oxides, primary PM 2.5, sulfur dioxide, and volatile organic compounds. Baseline emissions for criteria air pollutants were estimated using county-level 2017 data from the EPA National Emissions Inventory (NEI)[58]. While the NEI contains detailed estimates of air pollutant emissions from a wide range of economic activities, E3 only analyzed changes to criteria air pollutant emissions from energy-related fuel combustion for the following NEI categories:

- Fuel Comb - Comm/Institutional - Biomass
- Fuel Comb - Comm/Institutional - Coal
- Fuel Comb - Comm/Institutional - Natural Gas
- Fuel Comb - Comm/Institutional - Oil
- Fuel Comb - Electric Generation - Coal
- Fuel Comb - Electric Generation - Natural Gas
- Fuel Comb - Electric Generation - Oil
- Fuel Comb - Industrial Boilers, ICEs - Biomass
- Fuel Comb - Industrial Boilers, ICEs - Coal
- Fuel Comb - Industrial Boilers, ICEs - Natural Gas
- Fuel Comb - Industrial Boilers, ICEs - Oil
- Fuel Comb - Industrial Boilers, ICEs - Other
- Fuel Comb - Residential - Natural Gas
- Fuel Comb - Residential - Oil
- Fuel Comb - Residential - Wood
- Mobile - Aircraft

[58] https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data

- Mobile - Locomotives
- Mobile - Non-Road Equipment - Diesel
- Mobile - Non-Road Equipment - Gasoline
- Mobile - Non-Road Equipment - Other
- Mobile - On-Road Diesel Heavy Duty Vehicles
- Mobile - On-Road Diesel Light Duty Vehicles
- Mobile - On-Road non-Diesel Heavy Duty Vehicles
- Mobile - On-Road non-Diesel Light Duty Vehicles

State-level fuel consumption data from the EIA State Energy Data System was used to scale criteria air pollutant emissions from the NEI sources to 2018, the base year for the PATHWAYS model[59]. Future year criteria air pollutant emissions were then estimated by scaling 2018 emissions based on future changes in fuel combustion. For example, residential natural gas combustion in Cook County led to an estimated 9,033 tons of NOx emissions in 2018. In the Moderate Electrification scenario, residential natural gas combustion declines 92% between 2018 and 2050, so NOx emissions from this source are also assumed to decline 92% to reach 723 tons by 2050. To estimate the air quality benefits of the net-zero scenarios relative to the Reference, the avoided damages of criteria air pollution were compared between scenarios. Damages were calculated by applying marginal damage functions from Krewski, et al. (2009) and Lepeule, et al. (2012) to future year criteria air pollutant emissions[60,61]. The marginal damage functions used in this analysis vary based on three emissions height categories: ground level, facility – low, and facility – high. E3 assigned the ground level damage functions to all emissions from residential, commercial, and transportation sources and the facility – low damage functions to all emission from the industrial and electric power sector. The statewide annual air quality benefits (avoided damages) of reduced criteria air pollution in the net-zero scenarios relative to the Reference scenario in 2050 are shown in Table 16. The higher values using the marginal damage functions from Lepeule, et al. (2012) are used in the economy-wide costs and benefits charts shown in the main body of the report.

Table 16: Statewide Annual Air Quality Benefits of Net-Zero Scenarios Relative To Reference In 2050 by Pollutant

Scenario	Damage Function Source	Ammonia	Nitrogen Oxides	Primary PM 2.5	Sulfur Dioxides	Volatile Organic Compounds	Total
Moderate Electrification	Krewski, et al. (2009)	\$1.0 B	\$5.6 B	\$1.9 B	\$0.6 B	\$1.3 B	**\$10.3 B**
High Electrification	Krewski, et al. (2009)	\$1.0 B	\$6.0 B	\$2.0 B	\$0.6 B	\$1.3 B	**\$10.9 B**
Moderate Electrification	Lepeule, et al. (2012)	\$2.0 B	\$11.7 B	\$3.9 B	\$1.3 B	\$2.7 B	**\$21.4 B**
High Electrification	Lepeule, et al. (2012)	\$2.1 B	\$12.4 B	\$4.1 B	\$1.3 B	\$2.7 B	**\$22.6 B**

59 https://www.eia.gov/state/seds/seds-data-complete.phphttps://www.eia.gov/state/seds/seds-data-complete.php
60 https://pubmed.ncbi.nlm.nih.gov/19627030/
61 https://pubmed.ncbi.nlm.nih.gov/22456598/

Appendix C. Technical Advisory Committee Feedback

C.1. First TAC

Agenda: Kickoff and Scenario Design, June 2022

Group	Topic	Time
ComEd – Regulatory	Introductions	10 min
ComEd – Energy Acquisition	Presentation on study purpose and the role of the TAC	20 min
E3 – Dan Aas	Presentation and TAC discussion on study approach, methods and scenario design considerations	60 min
E3 – Dan Aas	Next Steps	10 min
Argonne – Tom Wall	Introduction on Climate Adaptation Study	20 min

Attendees

- Abigail Miner (Attorney General)
- Andrew Barbeau (Accelerate)
- Christie Hicks (EDF)
- David Kolata (CUB)
- Jared Policicchio (City of Chicago)
- JC Kibbey (NRDC)
- Grant Snyder (Attorney General)
- Rob Kelter (ELPC)
- Jim Zolnierek (ICC)
- Thomas Wall (Argonne National Laboratory)
- ComEd
    - Scott Vogt
    - Nisha Begwani

    - Mark Bentley
    - Ryan Burg
    - Isaac Duah
    - Maisha Earl
    - Michael Fountain
    - Stephanie Hardin
    - Bradley Perkins
- E3
    - Amber Mahone
    - Dan Aas
    - Jessie Knapstein

Key Takeaways

Questions

- Why is ComEd conducting this study, and will it be public?
- How to incorporate more community organizations?

Input Assumptions to Consider (Recommender)

- Decarbonization analysis supporting CEJA (Andrew)
- Hydrogen assumptions (Christie)
- Energy efficiency (JC)
- Heat pump costs (JC)

Analysis & Scope

- Consider lifecycle emissions, upstream emissions, and methane leakage not included in inventory
- Consider 20-year global warming potential
- Air quality and local pollutant concerns
- Community level results and study engagement
- Desire to review and provide input on assumptions (gas prices, heat pump prices, etc)

Emissions Reduction Measures

- Skepticism around emissions intensity and co-pollutants of hydrogen and biofuels and role in the scenarios
- Emphasis on demand response and flexible loads
- Consider higher CEJA RPS targets to achieve carbon neutrality in 2050
- Consider nuclear closures/relicensing under least cost optimization
- Consider pushing industrial energy efficiency
- Consider stronger targets for building shells and vehicles
- Reach out to experts on agriculture and NWL assumptions
- Transmission availability/expansion sensitivities

C.2. Second TAC

Agenda: Draft Results Review, August 2022

+ Purpose of the Meeting
    - Technical Update
    - Feedback on Draft Results to incorporate into Final
+ Feedback Areas
    - Building sector
        - How to consider new construction vs retrofit
        - Adoption curve assumptions
    - Electric sector
        - How to treat and account for emissions from imports
        - Candidate resource potential and opportunities for increased transmission
+ Agenda
    - Introduction
    - Economy-wide: Illinois and ComEd
    - Electric Sector: ComEd
    - Key Takeaways & Discussion
    - Next Steps

Attendees

+ Jared Policicchio, City of Chicago
+ JC Kibbey, NRDC
+ Scott Metzger, AG
+ Sarah Moskowitz, CUB
+ Tom Wall, Argonne National Lab
+ David Kolata, CUB
+ Andrew Barbeau, Accelerate Group
+ ComEd
    - Isaac Duah
    - Michael Fountain
    - Kristin Munsch
    - Scott Vogt

    - Nisha Begwani
    - Ryan Burg
    - Mark Bentley

+ E3

    - Dan Aas
    - Jessie Knapstein

Key Takeaways

+ Include impacts from IRA in Scenarios
+ Constrain import emissions
+ Increase demand flexibility consideration

    - Outline and post process options for reducing the peak impacts
    - Mode shifting

+ Mitigate heating challenges

    - Consider geothermal heat pumps and/or networked geothermal
    - Consider technology improvements over time

+ Candidate resources:

    - Increase transmission capability
    - Consider OSW
    - Add in 2027 Tx line
    - Possibly include seasonal storage
    - Opportunity for possible sensitivities

+ Show DAC (direct air capture) and H2 energy needs
+ Include impacts from climate change on heating/cooling
+ Represent NG infrastructure costs

    - Consult Elevate study
    - Highlight participant vs non-participant

C.3. TAC Report Feedback

NRDC

The report adequately addresses the need for additional policy support and limiting factors for building and transportation electrification. However, a deeper discussion on heat pumps could better contextualize *the buildings discussion and indicate areas where further analysis may be useful. To this point, it would be useful to have a section in the 'Technology Readiness' chapter about heat pumps. Some topics that would be relevant include: price trends, performance improvement trends (coefficient of performance and capacity), and advances in cold climate heat pump technology. At minimum, a statement should be made about how the assumptions on these topics impacted the modelling output (for example, that a higher coefficient of performance could lead to lower electrification costs and electricity demand).*

Related to the discussion on heat pumps is the impact of building electrification on the gas system. The 'Areas for Further Research' section includes a discussion on how full electrification leads to price increases for remaining gas customers, but does not address the avoided costs in the gas system that come with electrification. Not addressing the latter topic does not provide a full view of the economics and integrity of the gas system with electrification. Specifically, customer segmentation (new connection versus already connected) to account for the cost of new builds and lower operational costs are both factors that are not mentioned in the draft yet can bias the analysis against electrification. In addition, the already-high fixed costs for gas customers in Illinois should also be mentioned, as Elevate and RMI showed how the high fixed cost price for gas in Illinois make full electrification a more financially attractive option than hybridization. While the gas system was not the focus of the study, the draft should briefly include how these topics impact gas system economics and highlight their importance to any future gas transition studies.

Finally, the draft should address strategies that can decrease peak loads from winter heating, given that peak winter load is a key challenge identified by the study. Specifically, the draft should discuss the roles of demand-side load management and energy efficiency, emphasizing that future studies should consider these peak reduction strategies and how these reductions could have influenced the discussion in this draft. DSM strategies to consider include time-differentiated rates where customers are incentivized to use electricity at off-peak hours, pre-heating spaces before peak times, and staggering thermostat adjustments. Regarding energy efficiency, strategies should be considered for all critical areas, mainly building shell improvements, retrofits, and appliance efficiencies. By pointing out these strategies, readers will have a fuller view of the solution set for the peak loads modelled.