Data Center Power Play

How Clean Energy Can Meet Rising Electricity Demand While Delivering Climate and Health Benefits

Technical Appendix

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CONTENTS

For this analysis, the Union of Concerned Scientists (UCS) used the National Renewable Energy Laboratory's (NREL) Regional Energy Deployment System (ReEDS) model to analyze the impacts of different policies and assumptions about electricity demand growth from data centers. Model results focus on the composition of US electricity generation, emissions, and electricity system costs (Cole et al. 2024). This document contains the technical appendix for the Data Center Load Growth project. We used a modified version of the ReEDS model that NREL used in its 2024 Standard Scenarios report (Cole et al. 2024; Gagnon et al. 2024).

ReEDS Overview

ReEDS is NREL's flagship energy system optimization model designed primarily for capacity expansion problems. ReEDS is formulated as a linear program that minimizes the total system cost for each year in the model time horizon according to physical and policy-related constraints in the GAMS language. The objective function minimizes the total capital and variable costs and may be represented by:

$$minimize\ \sum_i capcost_i \cdot C_i + vomcost_i \cdot G_i,$$

Where

$capcost_i$ = capital costs for the i[th] technology (\$/MW)
C_i = the capacity of the i[th] technology (MW)
$vomcost_i$ = the variable operating costs, including fuel costs for the i[th] technology (\$/MWh)
G_i = the total annual generation for the i[th] technology (MWh),

subject to various constraints, including energy balance at all time steps, exogenous capacity inputs, federal and state policy constraints, and more. The full details of ReEDS' mathematical implementation are published in the model documentation and are also available online (ReEDS Modeling and Analysis Team et al. 2021).[1]

Spatial and Temporal Resolution

ReEDS represents the contiguous United States with 134 balancing areas. This spatial resolution may be further aggregated into states, FERC regions (e.g., MISO, PJM), or interconnections (e.g., Eastern Interconnection). Our analysis used the default balancing area representation because it balances spatial resolution with computational tractability.

ReEDS aggregates time series data (e.g., renewable energy capacity factors, electricity demand, temperature) into representative periods; intra-period timesteps are aggregated into "chunks." Each period is assigned weights that, when multiplied by the representative period, minimize the error compared with the fully time-resolved counterpart (Brown, Cole, and Mai 2025). For this analysis, we used the default 33 representative days/periods with chunk lengths of three hours. For the model time horizon, we used 2050 as the final year and

[1] *Online documentation is available at https://nrel.github.io/ReEDS-2.0/*

modeled every third year between 2023 and 2050. Table 1 summarizes the temporal and spatial resolution parameters used in this analysis.

Table 1. Summary of Spatial and Temporal Resolution Options Used in This Analysis

Parameter	Value
Spatial Resolution	134 Balancing Areas
Representative Periods	33
Chunk Length	3 hours
Model year delta	3 years
Set of modeled years	2026, 2029, 2032, 2035, 2050

Modifications to ReEDS

UCS made several changes to the base version of the ReEDS model to create "UCS ReEDS." From this point, "ReEDS" or "ReEDS model" refers to the UCS version.

ELECTRICITY DEMAND

We used electricity demand projections developed by Evolved Energy Research (EER) from its Annual Decarbonization Perspective 2024 report (Jones et al. 2024). The projections and hourly demand profiles for each state, economic sector, and subsector were based on the EER's "current policies" case, "central" economy-wide net zero emissions by 2050 case, and "central high data center demand" case. These cases included a range of low and high data center demand growth.

1. **Current policies:** This case makes demand projections based on current policies and incentives in the United States as of March 2025. Major policies include the Inflation Reduction Act (IRA) and state renewable and clean electricity standards. Given limited US climate policy, this scenario includes some electrification in transportation as well as for building heating and cooling, but it does not include economy-wide electrification. Note: we received these data in April 2025, before the passage of the One Big Beautiful Bill Act (OBBBA).

2. **Central:** This is EER's core decarbonization case; it includes economy-wide electrification and EER's reference data center demand.

3. **Central, high data center case:** This scenario is identical to the central case except that it includes higher data center demand growth.

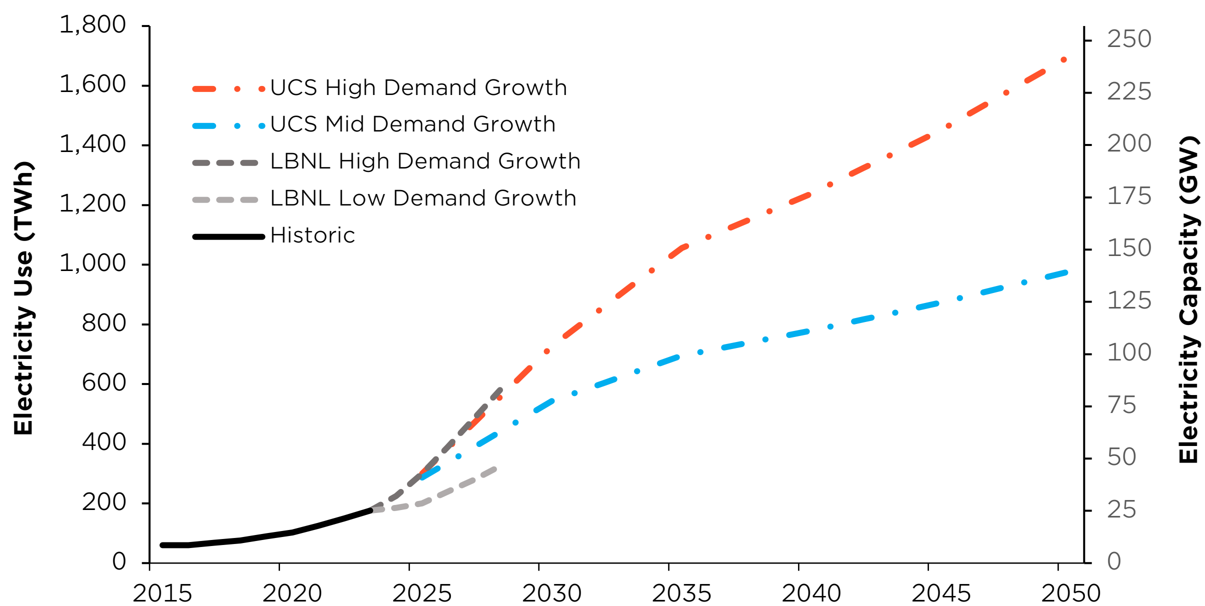
The central and current policies cases have identical data center demand growth. Based on these three cases, we developed two additional cases:

4. **Current policies with high data center demand growth:** This case replaces the demand projections for data centers in the current policies case with the data center growth projections from the central case with high data center case.

5. **Current policies with no data center demand growth:** This counterfactual case is identical to the current policies case but has zero demand growth from data centers.

Using a database of existing data centers from Baxtel, the EER developed its data center projections to identify current data center deployment and electricity demand by state (Baxtel 2025). The EER assumed that near-term deployment (through 2030) would be concentrated in states with existing data centers using a range of low and high growth rates based on a literature review of existing studies. Through 2050, the EER assumed that half of data center deployment would occur in states where data centers are currently concentrated using low and high growth rates from the literature and the other half would occur in places with low electricity prices based on projections from their model. Figure 1 shows the EER's low and high data center demand projections for the United States, along with near-term projections through 2030 from a literature review from Lawrence Livermore National Laboratory (LBNL).

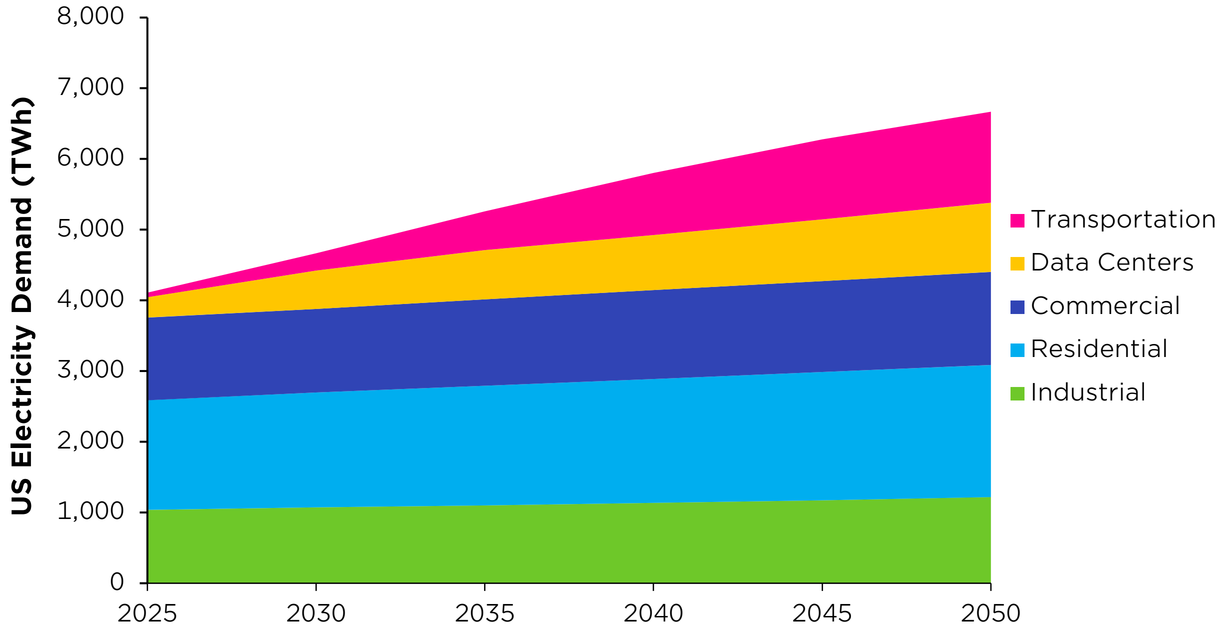
Figure 1. UCS Projections for US Data Center Electricity Use and Capacity



Our projections for data center demand are in the range of recent bottom-up projections from the LBNL that represents other recent academic and industry studies (BCG 2024; EPRI 2024; Shehabi et al. 2024).

Data centers are the biggest driver of near-term growth, while increased electrification of other sectors (especially transportation) is a bigger long-term driver (Figure 2).

Figure 2. US Electricity Use by Sector, Mid Data Center Demand Growth



Under our reference demand growth case, the share of total demand from data centers increases from 4.4 percent in 2023 to 11.6 percent in 2030 and 15 percent in 2050. Data centers represent 46 percent of the near-term increase in demand between 2025 and 2030. This share declines to 27 percent by 2050 as the share of electrification from other sectors (especially transportation) increases.

The EER's electricity demand projections for data centers assumed improvements in power usage efficiency (PUE) that resulted in lower energy use of nearly 11 percent from 2024 to 2028 and 18 percent by 2035, based on projections from the LBNL (Shehabi et al. 2024). These reductions were driven by a shift to more energy-efficient hyperscale and co-located facilities, combined with an increase in liquid-cooled servers. The EER's projections also included limited energy efficiency improvements and modest increases in electrification in the buildings, transportation, and industrial sectors.

UCS rescaled the EER's demand forecasts for Arkansas, Illinois, Louisiana, Michigan, Mississippi, and Wisconsin to include data not captured in the EER's projections from 2024, including news reports about announced projects and utility filings. For this rescaling process, we developed a near-term projection of data center growth based on the power demand of announced and anticipated projects. Based on this, we estimated the total annual energy consumption from data centers (E') using EER and MISO data that assume data centers have an 80 percent load factor. To address the known uncertainty in data center proposals, we conservatively assumed (based on assumptions used in MISO and S&P Global forecasts) that only half of the capacity from recently announced projects would get built and that it would take up to five years to reach full capacity (MISO 2024a; S&P Global 2025).

Finally, we updated the subset of demand from data centers by taking the L-1 norm and then multiplying by E'. For each year:

$$e'_{ij} = E' \frac{e_{ij}}{\sum_i^S \sum_j^T |e_{ij}|}$$

Where

$S = \{\text{"data center it", "data center cooling"}\}$

$T = \text{the set of hours in the data (8784)}$

$e_{i,j} = \text{the energy consumption at the } j^{th} \text{ timestep in } T \text{ for the } i-th \text{ subsector in } S$

$e'_{i,j} = \text{the new energy consumption at the j} - \text{th timestep in T for the i} - \text{th subsector in S}$

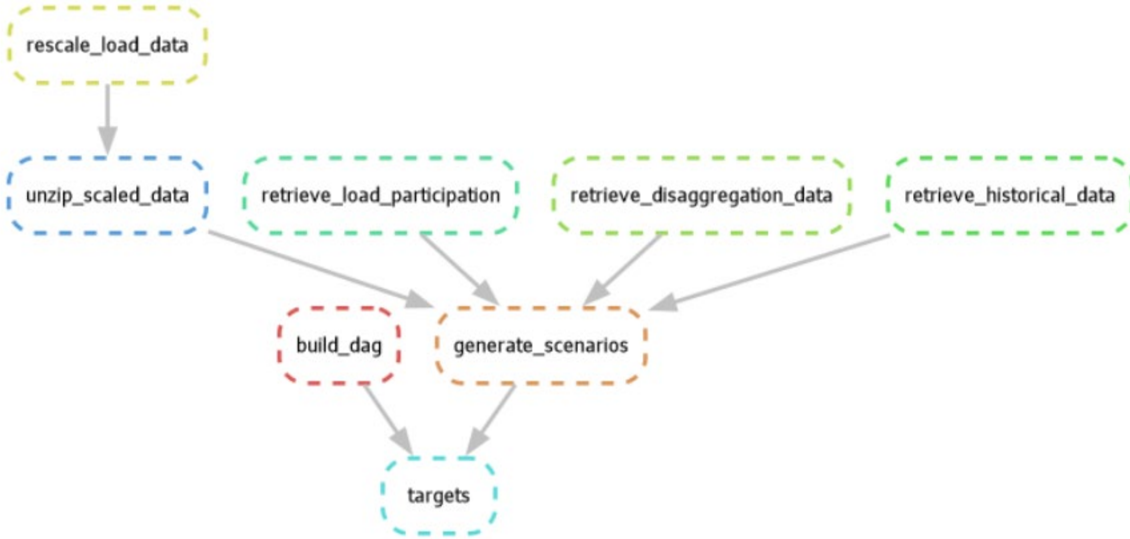
$E' = \text{the new annual energy consumption}$

After rescaling the data center projections, we combined the sectoral data to create a time series for the total electricity demand. Then we spatially disaggregated the data into ReEDS balancing areas by allocating a fraction of the total electricity demand according to the estimated population in each balancing area.

Because the EER's projections are in five-year increments (e.g., 2025, 2030, …, 2050), we calculated electricity demand for each in-between year using a two-step process. First, we linearly interpolated the total electricity demand between known years. Then we forward-filled the demand shapes and rescaled them according to the linearly interpolated total demand from the previous step. For example, the years 2026–2029 have identical temporal characteristics to the year 2025, but each year has a higher total demand based on the linear interpolation.

Finally, we combined these rescaled projections with historical data from EER and NREL to create a serially complete dataset for the years spanning 2010 to 2050. We used the Snakemake workflow management tool to automate the workflow that generated the demand scenarios for this report (Mölder et al. 2021). Figure 3 shows the directed-acyclic graph (DAG) for the Snakemake workflow. The data and scripts to execute the Snakemake workflow are available on GitHub (Dotson 2025).

Figure 3. The Snakemake DAG Illustrating the Workflow to Generate the Demand Scenarios



TRANSMISSION DEPLOYMENT

For our Current Policies cases, we used NREL's "low" transmission availability assumptions to reflect current market conditions that limit deployment of new transmission. For our clean energy and decarbonization policy scenarios, we used the transmission availability from NREL's "reference" transmission scenario in the 2024 Standard Scenarios (Gagnon et al. 2024). These allow for additional transmission deployment. We assumed that any decarbonization policies would facilitate transmission deployment to meet clean energy targets (Table 2).

MISO TRANCHE 2.1

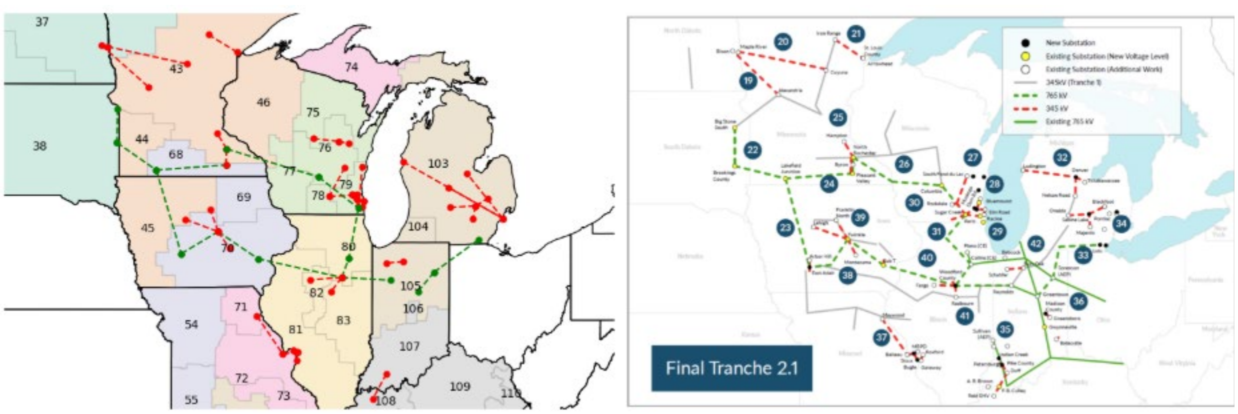
In addition to making assumptions about transmission growth, we modeled the planned transmission lines from MISO's Tranche 2.1. We began by pulling the list of proposed lines from the 2024 MISO Transmission Expansion Plan (MTEP24) (MISO 2024b). Then we extracted location data for the electricity infrastructure of each state affected by Tranche 2.1 using the Python library OSMNx (Boeing 2017). From there, we selected the transmission lines and substations that matched the list in MTEP24. We estimated the locations of new substations based on MISO's map of Tranche 2.1. We used a balancing area spatial resolution which only requires enough precision to accurately assign substations to a balancing area. Finally, we assigned each substation to the corresponding balancing area and added the resulting transmission capacity to the transmission_capacity_future_ba_baseline.csv input file. Figure 4 shows our final map of Tranche 2.1 (left) and MISO's original map of Tranche 2.1 (right).

Table 2. NREL's Transmission Availability Assumptions in ReEDS

Group	Scenario Setting	Notes
Transmission Availability	Reference Transmission Availability	No unannounced intra-regional transmission investment until 2032, then unrestricted investment between ReEDS regions currently connected. Existing Line-commuted converters (LCC) can be expanded but no new interfaces. Voltage source converter (VSC) HCDC transmission lines disabled as investment option
	High Transmission Availability	No unannounced intra-regional transmission investment until 2032, then unrestricted transmission expansion between regions currently connected. Existing LCC can be expanded but no new interfaces. VSC HVDC transmission lines enabled as investment option.
	Low Transmission Availability	No unannounced intra-regional transmission investment until 2032, then 1.07 TW-mile/year limit on new transmission investment, only allowed within 11 transmission lines disabled as investment option. Existing LCC can be expanded but no new interfaces

Reproduced from Gagnon et al. (2024).

Figure 4. Final Modeled Map for ReEDS (left) and Original Map of Tranche 2.1 (right)



We estimated the capacity of each based on the voltage and length using typical ratings for transmission lines within MISO territory (MISO 2023).

Model Scenarios and Policy Assumptions

NREL's Standard Scenarios 2024 modeled state, regional, and federal policies and regulations that were in place as of August 2024 (Gagnon et al. 2024). These policies include renewable portfolio standards (RPS), clean energy standards (CES), energy storage standards (ESS), the Regional Greenhouse Gas Initiative (RGGI), California's cap and trade program, and existing nuclear power plant assistance programs. Federal policies and regulations include the Cross-State Air Pollution Rule, EPA Clean Air Act 111 power plant carbon standards, and tax incentives included in the Inflation Reduction Act (IRA) and the Investment, Infrastructure and Jobs Act (IIJA).

We modified these policies for the scenarios in this report:

- **Current Policies:** We modeled the OBBBA by representing the electricity sector tax credit provisions in the OBBBA in all Current Policies scenarios. The OBBBA tax credit provisions are compared with the NREL's representation of the IRA provisions in the section and table below. We excluded NREL's representation of the EPA's Clean Air Act 111 power plant carbon standards in our Current Policies scenarios; the standards were in the process of being repealed by the Trump Administration when we conducted the modeling.

- **Restored Tax Credits**: An extension of federal clean energy tax credits after the OBBBA tax credits expire, using NREL's representation of the IRA provisions; and

- **Low-Carbon Policy:** A national decarbonization policy scenario that would reduce power sector carbon dioxide (CO_2) emissions 70 percent below 2023 levels by 2035, 80 percent by 2041, and 95 percent by 2050. We assumed greater reductions would occur through 2035 based on economy-wide decarbonization studies that point to more cost-effective solutions to reduce emissions in the power sector than other sectors (Clemmer et al. 2023). The reduction targets also provide a balance, enabling some states and big tech companies to meet their near-term ambitious climate and carbon-free electricity goals, while giving other states the space to achieve these goals over a longer timeframe. This scenario also included complementary policies to help meet the emissions reduction targets that would:

    - Extend federal clean energy tax credits using NREL's representation of the IRA;

    - Adopt federal power plant carbon standards in 2030 using NREL's representation of the EPA's Clean Air Act 111 proposal under the Biden Administration but delayed by five years; and

    - Facilitate the development of new transmission using NREL's mid-case transmission availability assumptions.

- **Stronger state policies:** Several scenarios assumed that several focus states adopt stronger policies. These include Wisconsin's adopting a 100 percent CES by 2050. ReEDS already includes the existing 100 percent CES by 2040 in Michigan and the Climate and Equitable Jobs Act (CEJA) in Illinois. We also modeled a declining CO_2 emissions limit in Wisconsin, Illinois, and Michigan. Figure 5 illustrates the annual emissions limits for these states. These scenarios show how data center demand growth affects state efforts to achieve strong climate and clean energy goals.

    - For Illinois's CO_2 emissions limit, we assumed that the state will reduce emissions by 40 percent in 2030 below 2023 emissions, 70 percent by 2040, and 100 percent by 2050. We based these targets on existing emissions reduction deadlines for in-state coal- and gas-fired power plants and the state's overall goal of reaching a 100 percent carbon-free electricity sector by 2050.

    - For Michigan, we assumed the state sets targets of an 80 percent reduction by 2040 and 100 percent by 2045. These targets follow the pattern of existing regulation in Michigan, where the renewable portfolio standard peaks at 60 percent by 2035 and the clean energy standard reaches 80 percent by 2035 and 100 percent by 2040 (Public Act 235 2023).

- For Wisconsin, we implemented the CES requirement (40 percent by 2030, 70 percent by 2040, 100 percent by 2050) to align with similar goals previously advocated for in the state and wider decarbonization research (GridLab 2022; Shukla et al. 2022). Limits on CO_2 emissions again reflect past advocacy of decarbonization goals (one-third reductions by 2030, 50 percent by 2035, two-thirds by 2040, 100 percent by 2050). CES values are effective values and are in effect generalized versions of RPSs; their model representations are very similar with technology eligibility being the primary difference. We assumed all zero- and low-carbon-emitting sources (on a direct emissions basis) can contribute to the CES requirement. This included all renewable energy technologies (including hydropower and distributed photovoltaics), nuclear power, gas and coal with carbon capture and storage, and imports from Canada.

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Figure 5. State Emissions Caps by Year Relative to 2023 Emissions Levels

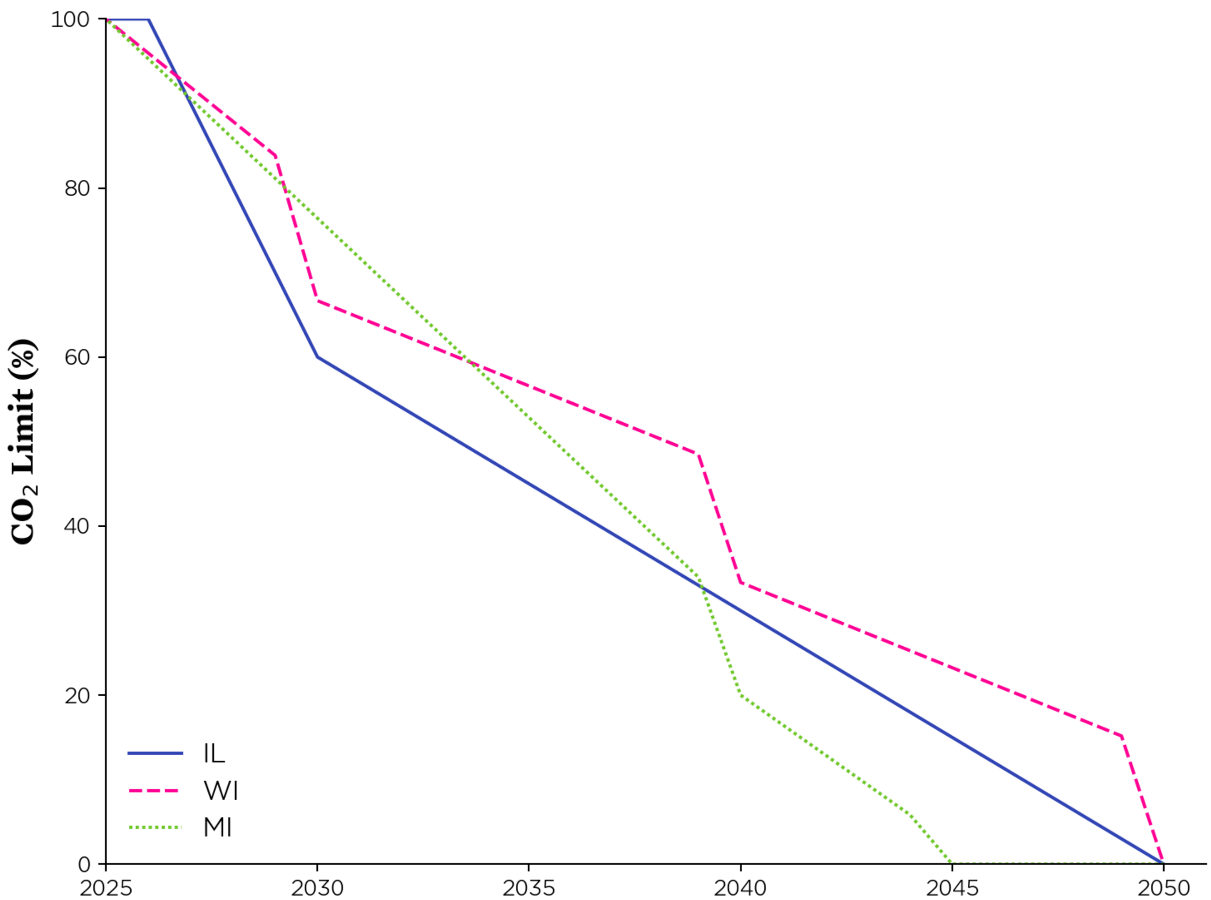

Table 3. Summary of Differences Among Scenarios

Data Center Demand Growth	Federal Tax Credits	EPA Power Plant CO_2 Standards	NREL Transmission Availability	CO_2 Reduction Policy	CES/RPS	Model Version
None	OBBBA	No	Low	No	None	fy25-national
Low	OBBBA	No	Low	No	None	fy25-national
High	OBBBA	No	Low	No	None	fy25-national
Low	IRA	No	Low	No	None	fy25-national
High	IRA	No	Low	No	None	fy25-national
Low	IRA	Yes	Mid	95 by 2050	None	fy25-national
High	IRA	Yes	Mid	95 by 2050	None	fy25-national
Low	OBBBA	No	Mid	State	State	fy25-la-cap
High	OBBBA	No	Mid	State	State	fy25-la-cap
Low	IRA	No	Mid	State	State	fy25-la-cap
High	IRA	No	Mid	State	State	fy25-la-cap

Technology Cost and Performance Assumptions

The technology assumptions in this analysis were based primarily on the 2024 Standard Scenarios version of the NREL's ReEDS model (Gagnon et al. 2024). Electricity generation technology cost and performance assumptions come primarily from the NREL's Annual Technology Baseline (ATB) 2024 mid-case cost assumptions, with a few exceptions noted below (NREL 2024).

Here is a summary of key changes we made to NREL's assumptions:

- For **new nuclear plants and carbon capture and storage (CCS) projects** at new and existing gas and coal plants, we used the cost and performance assumptions from NREL's higher "conservative" cost case.

- For **distributed solar** deployment, we used NREL's high case projections from the 2024 Standard Scenarios ReEDS/dGen model for our current policy scenarios and NREL's decarbonization case for our stronger policy scenarios.

Here are more details on the changes we made to these assumptions and why we made those changes:

- **Illinois's CEJA representation**: This 2021 legislation established emissions limits that apply to different categories of fossil fuel power plants in the state between 2030 and 2045. For modeling purposes, we assumed that these emissions limits would result in plant retirements, and we adjusted ReEDS to retire the generating capacity of individual units based on our projections of when the limits would apply to them. These projections were developed using information provided by the Illinois Environmental Protection Agency and other state entities, industry sources, and UCS' own assessments (IEPA 2024, IETWC 2023).

- **Offshore wind deployment delay:** NREL's representation of offshore wind deployment in the 2024 Standard Scenarios version of ReEDS used project specific data from their 2024 US Offshore Wind Market Report to identify near-term builds by state and assumed further development would occur over the long-term to meet state offshore requirements (McCoy et al. 2024). Due to recent executive actions by the Trump Administration and subsequent announcements by project developers, we assumed five offshore wind projects currently under construction (totaling 5,830 MW) will be completed by the end of 2027, but most additional near-term project development will be delayed by up to five years. Starting in 2032, we assumed project development will be accelerated to allow states to meet their mandated offshore wind targets.

- **Distributed solar deployment:** We used projections from the 2024 Standard Scenarios ReEDS/dGen model for distributed solar deployment; dGen projects distributed PV deployment over time using marginal electricity costs from ReEDS. NREL has several projections; we used the high rooftop PV adoption projection for our current policies scenario to reflect the current adoption rates of distributed PV. We used NREL's 95 percent by 2050 decarbonization scenario in our corresponding current policies and national CES/stronger state policies scenarios.

- **Ultility scale solar:** NREL's representation of utility scale solar in the 2024 Standard Scenarios version of ReEDS used project specific data from the EIA in the summer of 2024. The levels of utility scale solar in Michigan being captured by the model were much lower than the Standard Scenarios expected given recently filed utility renewable energy plans and reporting from the Michigan Public Service Commission (Michigan Public Service Commission 2024; DTE 2024; Consumers Energy 2024). Our analysis reflects the identified planned project builds (totaling 18 GW).

- **New nuclear costs:** For all scenarios, we used the NREL's conservative cost projections for new large light water reactors and new small modular reactors (SMRs) (NREL 2024). The cost and performance of new nuclear reactors are highly uncertain, as only a few have been deployed in the United States over the past 20 years. NREL's conservative cost assumptions have near-term costs that are more consistent with a small number of recent projects built or proposed in the United States—such as the 2,200 MW Vogtle plant in Georgia and NuScale's recently cancelled 462 MW SMR project in Utah[2]—and other sources like Lazard.

- **Carbon capture and storage:** For all scenarios, we used NREL's conservative cost and performance projections for adding CCS to existing coal and gas plants and for new gas plants with CCS (NREL 2024). NREL's assumptions are based primarily on data from the Department of Energy's National Energy Technology Laboratory (NETL) and the Energy Information Administration (EIA). Similar to new nuclear plants, CCS costs have a high level of uncertainty, as very few power plants with CCS are operating in the United States or other countries. However, at least 38 power plant CCS projects in 15 states have been proposed to take advantage of the generous incentives available in the Inflation Reduction Act, according to a Clean Air Task Force (CATF) database.[3] Some of these proposed projects are experiencing significant cost increases and delays.[4]

  While NREL's ATB 2024 includes several plant configurations with different capture rates, we assumed a 95 percent capture rate for this analysis. Engineering studies by NETL show that it is technically feasible to achieve these and even higher capture rates. However, actual projects have achieved much lower capture rates to date (Schlissel, and Juhn 2023).

Federal Tax Credit Assumptions

We used NREL's representation of the IRA tax credits for our Restored Tax Credits and Low-Carbon Policy scenarios (Steinberg et al. 2023). We modified these assumptions to represent the electricity sector provisions recently adopted under the OBBBA for our Current Policies cases. Below we describe how specific provisions in the IRA and OBBBA were represented in ReEDS. Table 4 also compares the tax credit expiration dates for different technologies under the IRA and OBBBA that are represented in the model. For more detail on the value and representation of the IRA tax credits in ReEDS, see NREL's documentation.

Technology eligibility: Under both the IRA and OBBBA policies, eligible technologies can select whether to take the 45Y technology neutral production tax credit (PTC) or the 48E investment tax credit (ITC). Based on an analysis of which tax credit was likely to be more valuable to specific technologies under the IRA, NREL assumed land-based wind, utility-scale solar PV (UPV), and biopower will choose the PTC and offshore wind, concentrating solar power (CSP), geothermal, hydropower, new nuclear, pumped storage hydro (PSH), distributed solar PV (DPV), and battery storage will choose the investment tax credit (ITC). NREL further assumed that PV-battery hybrid projects will receive both the PTC (for the PV portion) and ITC (for the battery portion). Existing nuclear and hydrogen are only

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[2] *The cost of NuScale's project increased 53 percent from $58/MWh in 2021 to $89/MWh in 2023, including federal incentives, and is estimated to cost $119/MWh with federal incentives (Schlissel and Juhn 2023).*
[3] *Examples include the Petra Nova retrofit of an existing coal plant in Texas, the cancelled Kemper new integrated combined cycle coal plant in Mississippi, and the Boundary Dam retrofit of an existing coal plant in Canada. For more information on these projects, see Robertson and Mousavian (2022).*
[4] *The CATF CCS database includes proposals at 11 existing coal plants, 22 new and existing gas plants, and 5 biomass and waste to energy plants (Clean Air Task Force n.d.).*

eligible for a PTC, and NREL assumed fossil fuel and biopower with CCS projects will opt to take the more valuable 45Q captured CO_2 incentives instead of the 45Y/48E technology neutral tax credits.

In addition, NREL assumed the value of the tax credits is reduced by 10 percent for non-CCS technologies and 7.5 percent for CCS technologies to approximate the costs of monetizing the tax credits such as through tax equity financing. NREL also assumed that all projects will receive 10 percent energy community bonus credits and hydro, geothermal, and storage will get 5 percent domestic bonus credits, phased in over a five-year period. The OBBBA added "advanced nuclear energy community" to the definition of energy communities that can receive the 10 percent bonus credit.

Unless noted otherwise, we assumed that all of NREL's assumptions for the IRA would persist under the OBBBA.

Emissions reduction targets: Under the IRA, the PTC and ITC start phasing out when electricity sector greenhouse gas emissions fall below 25 percent of 2022 levels or 2032, whichever is later. This provision was removed in the OBBBA. We retain NREL's representation of these targets in modeling the IRA provisions but exclude it when modeling the impacts of the OBBBA.

Impact of Foreign Entities of Concern (FEOC) provisions on battery storage projects: The OBBBA includes new and complex provisions that require certain clean energy projects that begin construction after January 1, 2026, to meet increasingly stringent restrictions on the source of manufactured products used in those facilities. It also prohibits credit payment to specified foreign entities (like China) and foreign-influenced entities (Sweeney, Hanlon, and Kaercher 2025). Because lithium-ion battery storage projects currently import a large percentage of their products from China, we assumed they will not be able to meet these restrictions after 2026. However, we assumed projects that begin construction before the end of 2026 will be able to meet these restrictions and have up to four years to be placed into service. We assumed all other technologies will be able to comply with the FEOC provisions under the OBBBA.

Existing nuclear PTC (45U): The tax credit for existing nuclear power plants is worth \$15/MWh (2022\$), but it is reduced if the market value of the electricity produced by the generator exceeds \$25/MWh. This provision is not explicitly modeled in ReEDS. As a simplification, NREL assumed that existing nuclear plants are not subject to economic retirement in ReEDS through 2032. We retained this assumption in modeling the impacts of both the IRA and the OBBBA.

Table 4. Federal Tax Credit Termination Dates Under the IRA and the OBBBA

Technology	Tax Credit Code	IRA Termination Date	OBBBA Termination Date
Onshore and Offshore Wind, UPV, and CSP	45Y/48E	Projects that begin construction by **end of 2032** or until emissions reduction targets are reached (whichever is later), must be placed into service within four years.	Projects that begin construction by **July 4, 2026** and meet IRS safe harbor requirements must be placed into service within four years (by **July 4, 2030**). Projects that don't meet IRS safe harbor requirements must be placed into service by **end of 2027**.
Biopower, geothermal, hydropower, new nuclear, battery storage, and PSH	45Y/48E	Projects that begin construction by **end of 2032** or until emissions reduction targets are reached (whichever is later), must be placed into service within six years for new nuclear and four years for other technologies.	Projects that begin construction by **end of 2033** and meet IRS safe harbor requirements must be placed into service within six years for new nuclear and four years for other technologies, then credits ramp down to 75% in 2034, 50% in 2035, and 0% in 2036.
Hydrogen PTC	45V	Projects that begin construction by **end of 2032** must be placed into service within four years.	Projects that begin construction by **end of 2027** must be placed into service within four years.
Carbon Capture (coal, gas, and bioenergy)	45Q	Projects that begin construction by **end of 2032** have up to six years to be placed in service.	No change

Post Processing Steps

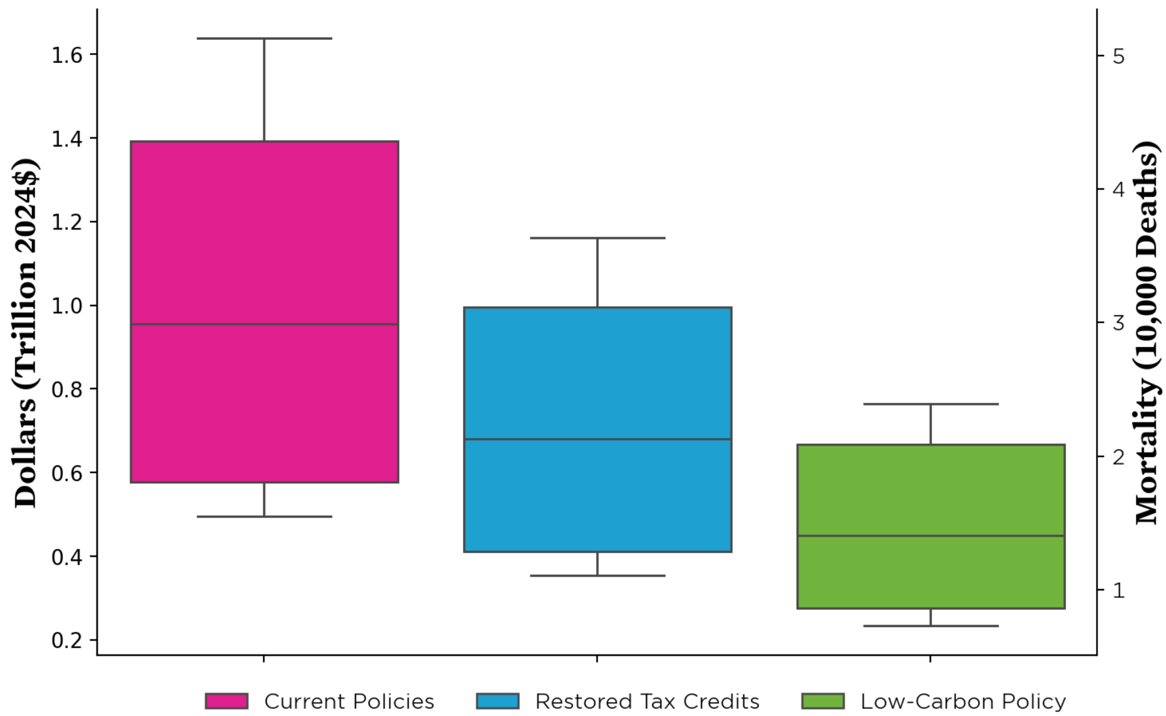
In addition to the results directly generated by ReEDS, UCS calculated the monetary and mortality costs associated with air pollution from the electric power sector and estimated the monetary benefits from avoided greenhouse gas emissions.

CALCULATING HEALTH DAMAGES

ReEDS has a built-in post-processing module to calculate health impacts that takes annual nitrogen oxides (NOx) and sulfur dioxide (SO_2) emissions as an input. However, in our case ReEDS does not automatically calculate these criteria pollutants. To calculate the criteria pollutants, we multiplied the technology-specific emission rates by their annual generation.

Finally, we used the ReEDS health damages post-processor to calculate the monetary and mortality costs for each scenario (Figure 6). This post-processor reported six values for each scenario based on three reduced-complexity air quality models, which estimated particulate matter ($PM_{2.5}$) formation based on the NOx and SO_2 precursors, and concentration response functions from two studies (Cole et al. 2024).

Figure 6. Monetary Damages and Mortalities from Criteria Pollutants



CALCULATING AVOIDED EMISSIONS BENEFITS

We calculated the cost of greenhouse gas emissions, which include carbon dioxide, methane, and nitrogen oxides, using the Environmental Protection Agency's 2023 estimate for the social cost of carbon (SCC) (NCEE 2022). Each pollutant has a unique SCC value in 2020 dollars, as well as different estimates based on an assumed discount rate. We adopted the 2 percent discount rate for this study. The annual costs from air pollution were calculated by:

$$C_{climate} = \sum_{t}^{T} \sum_{p}^{P} SCC_p \cdot \Gamma_{p,t}$$

Where

$C_{climate}$ = the total monetary damages from greenhouse gas emissions (2020$)
P = the set of pollutants (CO_2, CH_4, N_2O)
SCC_p = the social cost of the pth pollutant (2020$/metric ton)
$\Gamma_{p,t}$ = the total annual production for the pth emission in year t (metric ton)
T = the set of modeled years (2026,...,2050)

After calculating the total cost of greenhouse gas emissions, we harmonized the value with ReEDS' other cost metrics by deflating the cost from 2020 dollars to 2004 dollars. We used the deflator values provided within ReEDS. Finally, we used the method described in the 2023

EPA report on the social cost of carbon to monetize the damages by discounting future year values to the year of analysis, 2024 (EPA 2023). The present value for each year is given by:

$$\mathrm{pv}_0 = x_\tau \cdot scghg_\tau \cdot \overline{\delta_\tau}$$

Where

x_τ = the future year emissions (metric tons)

τ = future year - analysis year (year)

$scghg_\tau$ = the social cost of a greenhouse gas ($/metric ton)

$$\overline{\delta_\tau} = \frac{1}{(1+r)^\tau}$$

Where

r = the near-term Ramsey discount rate

Reproducing This Work

Reproducibility and transparency are hallmarks of quality science. This section outlines the steps for reproducing this work. The instructions assume that the reader has a current GAMS license with CPLEX, access to a computer with sufficient resources to run at least one ReEDS scenario (e.g., 32GB of RAM) and is moderately comfortable with either Command Prompt for Windows or Terminal for a Unix-based machine (e.g., Linux or MacOS).

1) Set up the ReEDS model
   i) Clone the UCS version of ReEDS from our GitHub repository.
   ii) Install ReEDS according to NREL's instructions.

2) Download the electricity demand data from the "eer_load_shapes" repository on the UCS GitHub (Dotson 2025). The raw data necessary to run the Snakemake workflow are not published on GitHub.
   i) These data may be downloaded by cloning the GitHub repository.
   ii) The final load shapes are saved in the "results" folder with a ".h5" file extension. Users must copy the files from the "eer_load_shapes\results" folder to the "ReEDS-2.0\inputs\load" directory inside ReEDS.

3) Consult Table 3 to determine which version of the ReEDS model corresponds to the desired scenario. Each "version" is stored as a Git branch.

4) Switch to the appropriate version using the following commands (with *fy25-national* as a representative example):
   i) "git checkout -b fy25-national": Creates a new local branch called "fy25-national" and points the HEAD to that branch.

    ii) "git pull origin fy25-national": Fetches and merges the upstream changes associated with the "fy25-national" version.

5) For Windows users: There is an option for each scenario in the "cases_ucs.csv" file that specifies whether to run on "AWS." This does not require AWS, but it does run ReEDS as a background process with the Unix command "nohup." This command will not work on Windows, and it is recommended that Windows users update this option for each scenario by switching it from a "1" to a "0" in the "cases_ucs.csv" file.

6) Execute ReEDS from the top-level directory with the following commands:
    i) "python runbatch.py"
    ii) When prompted about the prefix, hit ENTER or your preferred prefix.
    iii) When prompted about the scenarios suffix, type "ucs" (all lowercase, do not include quotes) and hit ENTER.
    iv) When prompted about the number of simultaneous runs type "1" and hit ENTER (higher integers may be used but is not recommended unless users are sure of their computer's resources). NOTE: From this point, ReEDS will begin solving. If "AWS" is enabled, the output will be suppressed.

7) Some of the post-processing steps are kept in the "ucsusa/reeds-visualizer" repository. To calculate the social cost of carbon, the following scripts must be executed in order.
    i) First, install and activate the "reeds-viz" conda environment.
    ii) fetch_results.py: grabs the results from a ReEDS-2.0/runs folder and puts them in the *reeds-visualizer/results/fy25* directory. Note: users will need to edit the path to ReEDS in the script.
    iii) extract_scc.py: extracts and processes tabular data from the cited EPA report.
    iv) multiply_emit_by_scc.py: calculates and monetizes the climate impacts from greenhouse gas emissions.

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