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How CBO Uses the ReEDS Model to Analyze Policies in the Electric Power Sector

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Abstract

In this working paper, the Congressional Budget Office provides an overview of CBO-ReEDS, an adapted version of the National Renewable Energy Laboratory's Regional Energy Deployment System (NREL's ReEDS) model for analyzing policies in the electric power sector. The paper discusses the strengths and limitations of the model and how CBO modifies it to align with the agency's assessment of electricity demand, fuel prices, and technology costs. Finally, the paper provides projections of the effects of the 2022 reconciliation act (Public Law 117-169) on emissions of carbon dioxide.

CBO projects that over the 2022–2050 period, key provisions of the reconciliation act that affect the electric power sector will cause carbon dioxide emissions in the sector to be about half what they would be otherwise. That projection incorporates adaptations of the ReEDS model to reflect real-world constraints on both the growth in transmission capacity and the siting of renewable generators. Nonetheless, uncertainty about those factors and about the effects of the 2022 reconciliation act on the mix of fuels and technologies used to generate electricity means that the amount of carbon dioxide emitted could be more or less than CBO estimates, especially over the long term.

Keywords: clean energy policy, electricity, emissions, energy forecasting

JEL Classification: Q47, Q48, Q54, Q58

Notes

Numbers in the text, figures, and tables may not sum to totals because of rounding.

All years referred to in this working paper are calendar years, and all dollar amounts are expressed in 2022 dollars.

Contents

Introduction

To assess the effects of federal policies on the electric power sector—specifically, their effects on carbon dioxide (CO_2) emissions, electricity prices, and the mix of generation—the Congressional Budget Office adopted and modified the Regional Energy Deployment System (ReEDS) model. That model, which is publicly available, is an open-source model of the electric power sector in the continental United States that was developed by the Department of Energy's National Renewable Energy Laboratory (NREL).

This working paper provides a brief overview of ReEDS and describes its strengths and limitations. It also discusses the ways that CBO modifies ReEDS to ensure that the model's estimates are consistent with the agency's own projections of economic activity and its views of future fuel prices and energy technology costs. To distinguish CBO's modified version of the model from the one made available by NREL, CBO refers to its version as CBO-ReEDS.

For this paper, CBO used CBO-ReEDS to analyze the effects of changes in investment and production incentives for certain types of electricity-generating technologies. Those incentives were modified by the 2022 reconciliation act (Public Law 117-169), which was signed into law on August 16, 2022. Specifically, the agency projected how the modifications to those incentives would affect the mix of fuels and technologies used to generate and store electricity, the quantity of CO_2 emitted from the electric power sector, and the policy's abatement cost of avoided CO_2 emissions. (The abatement cost of avoided CO_2 emissions is the difference in public- and private-sector costs divided by the cumulative abatement of CO_2 emissions.)

The effects of those incentives are subject to several sources of uncertainty. One source of uncertainty arises from real-world constraints—such as those on building transmission lines or siting generators—that could limit the adoption of renewable generation. CBO modified ReEDS to reflect those constraints. Even so, limits on transmission and siting could have effects that the agency cannot measure with its modeling approach. Another source of uncertainty arises from the model's inputs: In particular, uncertainty surrounds estimates of the costs of renewable energy, storage, and nuclear power technologies; fuel prices; the uptake of bonus credit provisions in the act; and growth in electricity demand. The agency provides estimates of the uncertainty surrounding those parameters using CBO-ReEDS.

CBO's use of NREL's ReEDS, the description of how the agency has modified that model to create CBO-ReEDS, and the exploration of CBO-ReEDS's sensitivity to key uncertainties—such as projections of costs for various renewable energy technologies—are consistent with the agency's mission to provide transparency about the models that it uses and the estimates that those models produce.

Before the enactment of the 2022 reconciliation act, CBO and the staff of the Joint Committee on Taxation (JCT) prepared an estimate of its budgetary effects. As required by the Congressional

Budget Act of 1974, CBO estimated the effects of the spending provisions, and JCT estimated the effects of the tax provisions.[1] By statute, the cost estimate of the 2022 reconciliation act published by CBO directly incorporated JCT's estimates of the budgetary effects of the energy-related tax provisions of that bill, including those related to electric power, electric vehicles, carbon capture and sequestration (CCS), and clean energy manufacturing. Neither CBO nor JCT used the model described in this working paper when preparing that cost estimate. Moreover, CBO's budgetary baseline incorporates smaller spending provisions of the reconciliation act that are not explicitly incorporated into CBO-ReEDS.

Overview of the ReEDS Model

NREL's ReEDS model is a publicly available model of the electric power sector in the continental United States.[2] It is a capacity-expansion model, which is a type of model that determines the lowest-cost supply of electric power generators needed to meet electricity demand over a specified time frame. ReEDS minimizes systemwide costs in the electric power sector and provides a simulation of generation, storage, and transmission investment that takes a projection of future conditions into account.[3] Systemwide costs include the capital costs of building new power generators, operation and maintenance costs for existing generators, fuel expenditures, and the costs of building new transmission lines, among other costs. The model does not represent individual utilities and their operating decisions, such as whether to produce power from a power plant in each hour; instead, it aggregates total supply by generator type (wind, natural gas, and so on) and on the basis of transmission capacity within subregions across the country.[4] ReEDS takes projected electric power demand as an input and solves for the optimal supply given the constraints in each model year; those constraints include fuel prices, the projected costs of new power generators, and available transmission capacity between subregions

[1] Congressional Budget Office, cost estimate for H.R. 5376, the Inflation Reduction Act of 2022 (August 3, 2022), www.cbo.gov/publication/58366.

[2] National Renewable Energy Laboratory, "Regional Energy Deployment System Model," https://nrel.gov/analysis/reeds. The open-source model can be found at https://github.com/NREL/ReEDS-2.0.

[3] ReEDS solves at the annual level and is set to run biennially by default. For this working paper, CBO ran the model biennially.

[4] ReEDS solves for 17 time periods each year. There are four representative time blocks in each of the four seasons to reflect the power demand profile of a typical day—low demand in the early morning hours, medium demand in the late morning, peak demand in the afternoon, and medium demand in the evening hours—in addition to a 40-hour period that is intended to represent the hours of the year during which demand is highest. In between each solve year, there is an hourly dispatch that occurs to update parameters for the 17 time-period portions of the model. The hourly dispatch informs curtailment and the ability of new transmission to reduce curtailment. There is also an hourly chronological dispatch of storage across seven years of weather data to calculate the ability of storage to serve as a resource during peak hours.

in the model, among others.[5] Additional details about the ReEDS model can be found on NREL's ReEDS website and in the model's documentation.[6] ReEDS is designed to analyze policies in the electric power sector and has been used in recent academic literature, industry analyses, and government reports.[7]

Strengths and Limitations of ReEDS

For the purposes of analyzing policies in the electric power sector, the ReEDS model has strengths and limitations. The model's strengths include its flexibility for policy analysis in the mid- to long term, the fact that it allows for variation in spatial characteristics across the continental United States, and its detailed representation of renewable generators. Limitations of the ReEDS model include a lack of a detailed representation of transmission (including an inability to capture power flows) and its use of exogenous technology costs.

Strengths of the Model. Compared with other options for modeling the electric power sector, ReEDS has several advantages. First, ReEDS is preconfigured to allow for modeling of a wide range of policies, including a carbon tax, a clean electricity standard, a cap-and-trade program, and tax incentives. Those policies can be modeled at both the federal and state levels. Annual emissions caps or eligibility for incentive programs by technology, for example, can be adjusted in the input files. ReEDS also offers representations of existing policy or regulatory incentives, such as state clean energy mandates or voluntary regional carbon markets. Consequently, potential policies or regulation can be layered on top of the existing policy landscape. More

[5] ReEDS has both a supply module and a demand module that can be run iteratively to solve for an equilibrium price and quantity of electricity. However, the convention from the literature using ReEDS is to take demand exogenously and run the supply module to find the optimal supply mix to meet the given levels of demand. CBO follows that convention and takes demand exogenously in this working paper. The model also allows for three possibilities regarding the extent of foresight or expectations about factors that influence the supply of electricity generators in the future, such as fuel prices and power demand. Those three possibilities are myopic expectations for the future, perfect foresight, and a middle ground with an *n*-year window of foresight, where *n* is specified by the user. For this working paper, CBO followed previous literature that utilized the ReEDS model. On the basis of that research, CBO used the myopic expectations that anticipate operating conditions in each model year will remain static for the next 20 years. Stock and Stuart (2021) found minimal changes to their results when varying the choice of foresight in the model. See James H. Stock and Daniel N. Stuart, *Robust Decarbonization of the U.S. Power Sector: Policy Options*, Working Paper 28677 (National Bureau of Economic Research, April 2021), www.nber.org/papers/w28677.

[6] National Renewable Energy Laboratory, "Regional Energy Deployment System Model," www.nrel.gov/analysis/reeds; Jonathan Ho and others, *Regional Energy Deployment System (ReEDS) Model Documentation: Version 2020* (June 2021), www.nrel.gov/docs/fy21osti/78195.pdf.

[7] See, for example, James H. Stock and Daniel N. Stuart, *Robust Decarbonization of the U.S. Power Sector: Policy Options*, Working Paper 28677 (National Bureau of Economic Research, April 2021), www.nber.org/papers/w28677; and Amol Phadke and others, *The 2035 Report: Plummeting Solar, Wind, and Battery Costs Can Accelerate Our Clean Electricity Future* (Goldman School of Public Policy, June 2020), www.2035report.com/electricity/downloads. A further list of publications can be found at www.nrel.gov/analysis/publications.html.

information about those types of incentives for renewable or "clean" energy generators as defined in the 2022 reconciliation act is provided later in this analysis.

Second, ReEDS allows for considerable spatial heterogeneity. The model has 134 modeled balancing areas across the United States; each modeled area can contain one or multiple counties and respects state boundaries (see Figure 1). Those modeled regions are connected by the existing transmission linkages between them. The transmission capacity and connections between regions affect both the export of power from generators and imports of power to meet projected demand within each region. That level of granularity also allows ReEDS to map existing state and regional policies into the modeled regions.

Finally, the model offers a detailed representation of solar and wind generators because the quality of solar and wind resources differs across the United States. That level of detail is achieved in part by directly utilizing inputs from other NREL work that is incorporated into ReEDS. Another NREL model provides detailed information about the options for locating onshore wind and solar photovoltaics (PV) at a very disaggregated level.[8] For example, the generation potential of utility-scale solar is evaluated on the basis of the hourly solar irradiance profile—that is, the hourly intensity of sunlight that determines the generating potential of a solar panel—for each 10-square-kilometer region across the country.[9] That analysis accounts for land-use restrictions on property that is not available for development because of factors such as the terrain or legal protections, as well as whether a given location is more or less sunny or windy. The detailed level of information about where to locate new solar and wind generators allows for the incorporation of spur-line costs in ReEDS, or the additional cost of building transmission lines to connect those resources to the existing transmission network within a given model region.[10] Additionally, for wind and solar generation, ReEDS has 10 classes and 7 classes, respectively, that are based on the quality of wind and solar resources in each location and the varying technical specifications of the technology.[11] Combined with the disaggregated location information, the data provide a detailed depiction of the maximum potential to generate power from new and existing wind and solar generators.

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[8] Jonathan Ho and others, *Regional Energy Deployment System (ReEDS) Model Documentation: Version 2020* (June 2021), www.nrel.gov/docs/fy21osti/78195.pdf.

[9] This is based in part on information provided by NREL's reV model. National Renewable Energy Laboratory, "reV: The Renewable Energy Potential Model" (accessed June 22, 2023), https://tinyurl.com/2t5jc7tz.

[10] Jonathan Ho and others, *Regional Energy Deployment System (ReEDS) Model Documentation: Version 2020* (June 2021), https://tinyurl.com/yc4kbtpd. See also National Renewable Energy Laboratory, "reV: The Renewable Energy Potential Model" (accessed June 22, 2023), https://tinyurl.com/2t5jc7tz.

[11] There are multiple types of wind and solar generation that each have their own classes. Those types include onshore wind, offshore wind, utility-scale solar PV, distributed utility-scale solar PV, and concentrated solar power.

Limitations of the Model. Although the ReEDS model has multiple strengths, it also has limitations. First, because ReEDS is a capacity-expansion model, it does not offer a detailed representation of the flows of energy between nodes in the electric grid. That limitation is not found in other models, such as power-flow models, that incorporate unit-level operations and the flow of power on individual transmission lines. The ReEDS model represents transmission on the basis of the existing transmission network, connecting points among the modeled balancing areas. Although ReEDS allows new intraregional spur lines to connect new wind and solar generators within a region, no new connections are built between model regions in future model years. Instead, only expansions of the carrying capacity of the existing interregional lines are allowed. Because there is no hourly dispatch of generators, potential congestion on local lines or the reliability of the grid on an hourly basis cannot be fully represented or tested.[12] Thus, despite the model's considerable spatial dimensionality, it offers only a simplified representation of transmission lines, which limits the ability to analyze issues related to grid reliability or transmission constraints. For example, although ReEDS allows for changes in the total amount of generating and transmission capacity, it is not well-suited to analyze issues related to individual siting and permitting decisions or issues involving congestion on individual transmission lines.

Second, the costs of technologies are exogenous in the model—that is, the user must specify annual costs for new power generators in each model year. As a result, ReEDS does not allow for feedback effects on the costs of technologies because of fluctuations in supply and demand or learning by doing. For example, incentives for solar power generation might boost the demand for solar panels; however, the model would not account for that increase in demand on the price of the panels.[13] Similarly, there is no representation of the supply chain, allowing near-term buildouts of generators to potentially be more rapid than could occur because the model expects the necessary capacity to be available.

How CBO Uses the ReEDS Model

CBO-ReEDS is a modified version of NREL's ReEDS that reflects CBO's assessment of electricity demand, fuel prices, and technology costs. For the purposes of this working paper, CBO modified NREL's projections of electric power market factors through variables such as

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[12] See footnote 3.

[13] Although the model does not allow the cost of installing solar and wind generators to fluctuate on the basis of demand, the cost per megawatt-hour (MWh) of generation can vary. In the initial years of the projection, the model selects the "best" sites on which to build first—those sites with the lowest cost and the highest potential to generate electricity for each megawatt of installed capacity. As more facilities come online, the siting of new wind and solar generators in the model allows for future sites to have lower expected annual generation, because of factors such as less optimal wind speeds or lower solar intensity. Additionally, there may be potentially increasing spur-line costs for connecting renewable generators farther away from the grid in a model region. Those factors would both tend to increase the cost per MWh of generation for new zero-carbon generators, even as the capital cost of those generators remained fixed.

electric power demand, renewable energy and storage technology costs, and fuel prices. The agency also imposed a growth constraint on new transmission and restricted the siting of new wind and solar generators (see Table 1).[14]

Although supply-chain delays cannot be modeled or quantified in CBO-ReEDS, CBO expects their effect on CO_2 emissions in the electric power sector to be relatively small. Regional and state market structures also cannot be incorporated in CBO-ReEDS; however, in CBO's assessment, the uncertainty surrounding the effects of those structures on the model's projections is roughly symmetric.

Electric Power Market Factors. For this paper, CBO used the projection of electric power demand from the scenario in the Energy Information Administration's (EIA's) latest *Annual Energy Outlook* (AEO) whose macroeconomic forecast most closely aligned with CBO's macroeconomic forecast.[15] CBO's 2023 long-term outlook projected the growth of real gross domestic product (that is, GDP adjusted to remove the effects of inflation) at an average of 1.7 percent from 2022 through 2050.[16] In the 2023 edition of the AEO (hereafter, AEO2023), macroeconomic projections under the "Reference" case show real GDP growing at an average of 1.9 percent from 2022 through 2050.[17] Thus, in the version of CBO-ReEDS described in this working paper, the base case incorporates projections of electric power demand from the Reference case in EIA's AEO2023, and the "No Reconciliation" case incorporates projections of electric power demand from the "No IRA" case in EIA's AEO2023.[18] (Both the base case and the No Reconciliation case are described more fully below.)

CBO also adjusted the projections for renewable energy and storage costs. Default cost projections in ReEDS came from NREL's 2022 Annual Technology Baseline (ATB2022).[19]

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[14] Other changes include increasing the cost of new transmission in the model to better reflect the difficulties of building and siting new lines, as well as updating the data in the Energy Information Administration's latest *Annual Energy Outlook*. See Energy Information Administration, *Annual Energy Outlook 2023* (March 16, 2023), www.eia.gov/outlooks/aeo. The version of ReEDS that was modified for this working paper was used in NREL's *2022 Standard Scenarios Report*. See Pieter Gagnon and others, *2022 Standard Scenarios Report: A U.S. Electricity Sector Outlook* (March 2023), www.nrel.gov/docs/fy23osti/84327.pdf.

[15] Energy Information Administration, *Annual Energy Outlook 2023* (March 16, 2023), www.eia.gov/outlooks/aeo.

[16] Congressional Budget Office, *The 2023 Long-Term Budget Outlook* (June 2023), www.cbo.gov/publication/59014.

[17] Energy Information Administration, *Assumptions to the Annual Energy Outlook 2023: Macroeconomic Activity Module* (March 2023), https://tinyurl.com/2etb6jt8. The "Low Economic Growth" scenario shows real GDP growing at 1.4 percent from 2022 to 2050, while the "High Economic Growth" scenario shows real GDP growing at 2.3 percent over the same period.

[18] "IRA" in EIA's No IRA case is short for Inflation Reduction Act, a name sometimes used to refer to the 2022 reconciliation act.

[19] National Renewable Energy Laboratory, "Annual Technology Baseline" (accessed April 19, 2023), https://atb.nrel.gov.

Those estimates in NREL's ATB2022 project a more optimistic cost reduction in renewable technologies than EIA's AEO2023 does, and the difference grows over time. For example, average projected levelized costs of electricity for onshore wind and solar PV in the "Moderate" scenario in the ATB2022 are about $4 per megawatt-hour ($4/MWh), or 10 percent, lower and $2/MWh, or 6 percent, lower, respectively, than in EIA's AEO2023 Reference case in 2028. CBO adjusted the costs of renewable energy, storage, and other generating technologies in this version of CBO-ReEDS to the values shown in EIA's AEO2023. CBO also updated the fuel prices in the model to the values shown in EIA's AEO2023 from the prior values based on EIA's AEO2022.

Transmission Growth Constraint. Future growth in electric generating capacity is reliant on the ability to connect to the grid to deliver electricity to consumers. The transmission network connects generation from disparate power plants to deliver to load centers. Transmission constraints generally occur when there is insufficient available capacity on the lines to deliver power from one location to another. Insufficient transmission capacity can increase electricity prices by reducing or eliminating the ability for lower-priced generation located farther from the load center to provide power. Transmission constraints can further restrict the interconnection of new generators. Most newly proposed generators currently are zero-carbon generators, or generators that do not emit carbon directly in power generation; thus, transmission constraints would tend to increase both emissions and electricity prices.

Recent research suggests that significant growth in transmission capacity may be necessary to interconnect larger shares of renewable and other clean energy sources in the future.[20] For example, one study projects a 41 percent increase in transmission capacity by 2035; another study finds that recent estimates from the literature that were generated by modeling economywide decarbonization scenarios imply 150 percent to 400 percent more transmission capacity than current levels.[21] However, those studies also indicate that growth in new transmission capacity has been declining in recent years, with transmission capacity growing at about 1 percent per year over the past five years.

Constraints were imposed in CBO-ReEDS to reflect the difficulties of building new transmission lines. ReEDS allows for a cap on transmission capacity growth in the model that can be applied across some or all modeled years. Transmission lines can vary by voltage; for instance, a high-voltage line has more capacity to transmit power per mile than a lower-voltage line. That cap on new transmission in ReEDS is measured in terawatt-miles per year (TW-mi/yr), which allows for

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[20] Jesse D. Jenkins and others, *Electricity Transmission Is Key to Unlock the Full Potential of the Inflation Reduction Act* (REPEAT Project, September 2022), http://dx.doi.org/10.5281/zenodo.7106176; Lucas W. Davis and others, "Transmission Impossible? Prospects for Decarbonizing the U.S. Grid," *Journal of Economic Perspectives* vol. 37, no. 4 (Fall 2023), pp. 155–180, http://dx.doi.org/10.1257/jep.37.4.155.

[21] Ibid.

comparison between a high-voltage line over a short distance and a lower-voltage line over a longer distance. The default constraint on new transmission capacity in ReEDS is 1.4 TW-mi/yr that applies from 2023 to 2027, with no transmission growth constraint thereafter. On the basis of recent average annual construction of new transmission lines over the past five years, CBO used a 1 TW-mi/yr constraint that applies throughout the 2022–2050 projection period. (For additional details on recent historical transmission-line additions and projected transmission in CBO-ReEDS, see the appendix.) A limitation of this constraint is that it applies nationally—specifically, it caps the total annual installations of transmission capacity, but it does not restrict where in the country those new transmission lines are built.

Constraints on Siting Wind and Solar Generators. One approach to alleviating transmission constraints is to build new transmission lines to connect new generators or expand connections between regions. However, siting and permitting can delay or prevent new transmission lines from being built. "Siting and permitting" refers to the regulatory review and approval processes for the location of new electric infrastructure. Siting and permitting concerns can also apply to generators, ranging from concerns about a new fossil fuel–fired plant or wind turbine being located near a populated area to concerns about solar panels being located on previously undisturbed federal lands. Overall, those concerns about both new generators and transmission are most likely to increase reliance on the existing generation fleet by slowing down generation from newer zero-carbon generators, thereby limiting the projected decreases in CO_2 emissions.

Constraints were imposed in CBO-ReEDS to reflect the potential limits on siting renewable generators. ReEDS allows for three siting scenarios for utility-scale wind and solar generators based on other work by NREL. Those scenarios are referred to as "Open Access," "Reference Access," and "Limited Access." For example, a report published in 2021 outlines the different siting scenario options for onshore wind.[22] The default siting scenario in ReEDS is the Reference Access scenario, which includes various land-use restrictions to account for factors such as state and county ordinances and setback requirements for building a wind turbine (that is, the minimum distance it must be from existing infrastructure). CBO adjusted the default siting scenarios for utility-scale solar, onshore wind, and offshore wind from the Reference Access to the Limited Access scenario, the most restrictive siting scenario available. In the Limited Access scenario, wind turbines are prohibited from being located within the line of sight of any radar equipment or on any federal land. In addition, an increased setback requirement from existing infrastructure is applied nationally that is comparable to the most restrictive requirements in 21 counties.[23] (Further details on the siting scenarios and the sensitivity of the projections from

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[22] Anthony Lopez and others, "Land Use and Turbine Technology Influences on Wind Potential in the United States," *Energy*, vol. 223 (May 2021), https://doi.org/10.1016/j.energy.2021.120044.

[23] Ibid.

CBO-ReEDS to the siting and transmission constraints described here can be found in the appendix.)

Other Factors That Are Difficult to Model or Quantify

When analyzing policies that affect the electric power sector, certain factors are difficult to model or quantify. Those factors represent real-world frictions that are likely to cause differences between the modeled results of a policy and the policy's real-world results, and they include supply-chain delays and market structure, among others. Those factors can affect the cost and effectiveness of a policy that reduces CO_2 emissions from the sector by slowing down the deployment of new generating capital, increasing the cost of new installations, or altering the incentives of the market participants. For this working paper, CBO did not model or quantify supply-chain delays or market structure.

Supply-Chain Delays. Supply-chain delays are likely to increase emissions by slowing the rate of turnover for the existing power-generation fleet, similar to siting and permitting concerns. However, the overall effect depends on the extent of the delay. For example, a short-term delay of several months in receiving components for a solar panel could cause new generators to come online one year later, thereby pushing back the decline in emissions by the same time frame. In contrast, a long-term delay could lead component costs to rise to levels sufficient to alter the viability of a particular type of power generation, especially for relatively nascent zero-carbon generating technologies.

Market Structure. There are three major power grids across the continental United States: the Eastern Interconnection, the Western Interconnection, and the Texas Interconnection. The electric power grid is represented in ReEDS as a national grid with those major interconnections, and the model minimizes costs on the basis of investments across the continental United States. However, electric power markets differ from that simplified representation. Specifically, within those major interconnections, regional organizations manage multistate markets and oversee new generation and transmission upgrades across states. At the state level, some states have incumbent electric utilities that are regulated by a state utility commission that approves capital investments at a guaranteed rate of return and sets rates for the utility's consumers.[24] Other states have deregulated markets that borrow some elements from the regulated states but disallow vertical integration of the incumbent utility (owning generation, transmission, and distribution) and allow for competitive bidding for generation services.

Those differing market structures provide incentives that could alter the estimated effects of the 2022 reconciliation act. On the one hand, utilities in regulated markets may want to preserve

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[24] Some states also have "right of first refusal" laws that allow the incumbent utility to construct new transmission lines without participating in a competitive bidding process. See Jeffrey Tomich, "Utilities' Push to Extend Monopolies May Shape Grid's Future," *EnergyWire* (March 15, 2023), https://tinyurl.com/pthu4zke.

their existing generators to continue receiving their guaranteed rate of return on capital that is in use, which would tend to increase emissions. On the other hand, compared with utilities in deregulated markets, those utilities may also be willing to invest in more capital-intensive zero-carbon generators—such as by building a nuclear power plant or retrofitting a fossil fuel–fired plant with CCS—with that guaranteed rate of return.

Effects of the 2022 Reconciliation Act on the Electric Power Sector

Before passage of the 2022 reconciliation act, CO_2 emissions from the electric power sector had been trending downward.[25] Those trends were driven at least in part by previous greenhouse gas mitigation policies at the state and federal level in that sector. Several provisions in the act, such as the extension and expansion of tax credits for zero-carbon generators, are expected to further decrease CO_2 emissions from the electric power sector.[26] For the base case—also referred to in this paper as the "Reconciliation" case—CBO included the 2022 reconciliation act provisions that are current law.[27] CBO also compared that base case with a scenario that does not incorporate the act's provisions, called the No Reconciliation case (see Table 2).

Carbon Dioxide Emissions From the Electric Power Sector

Before passage of the 2022 reconciliation act, annual CO_2 emissions from the electric power sector had declined by about 35 percent between 2005 and 2021. That decline in emissions was largely attributable to a shift away from coal-fired generation to natural gas–fired generation and an increase in generation from renewable sources.[28] Lower natural gas prices and reductions in the cost of renewable generators have been largely responsible for those changes in the share of generation by energy source.[29] Although onshore wind has been responsible for much of the growth in renewable generation in the past several decades, projections before the passage of the

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[25] Congressional Budget Office, *Emissions of Carbon Dioxide in the Electric Power Sector* (December 2022), www.cbo.gov/publication/58419.

[26] John Bistline and others, "Emissions and Energy Impacts of the Inflation Reduction Act," *Science*, vol. 380, no. 6652 (June 2023), pp. 1324–1327, https://doi.org/10.1126/science.adg3781.

[27] Note that not all provisions in the act that may be relevant to the electric power sector are included in the model. Details about which provisions were modeled are discussed below in "Key Provisions in the Act."

[28] Congressional Budget Office, *Emissions of Carbon Dioxide in the Electric Power Sector* (December 2022), www.cbo.gov/publication/58419.

[29] Ibid.

2022 reconciliation act indicated that a larger share of future growth in renewable generation would come from solar PV.[30]

Policies at the state, regional, and federal levels have been put in place to reduce greenhouse gas emissions from the electric power sector. At the state level, renewable portfolio standards (RPSs) or clean electricity standards in some states require a set percentage of electricity generation in a specified year or set of years to come from renewable or clean generators. In some cases, those standards have further carve-outs for specific technologies. For example, Maryland's RPS requires that 14.5 percent of electricity sales in 2030 must come from solar resources.[31] At the regional level, the Regional Greenhouse Gas Initiative is a voluntary cap-and-trade program for CO_2 emissions in the Northeast. That program allows market forces to put a price on CO_2 emissions given an annual cap on total emission allowances—permits to emit one ton of CO_2—subject to a price ceiling and floor.[32]

In addition, federal policies provide incentives that reduce the costs of renewable power. Federal tax preferences for renewable energy generators include the production tax credit (PTC), which has historically supported onshore wind, and the investment tax credit (ITC), which has historically supported solar and offshore wind, among others. The PTC offers a credit per kilowatt-hour of electricity produced over the first 10 years of operations, whereas the ITC offers a credit for a fixed portion of the capital cost of new generation. Before passage of the 2022 reconciliation act, the PTC had expired for new generators that were not under construction by the end of 2021, and the ITC had decreased because of a scheduled phaseout.

The 2022 Reconciliation Act

The 2022 reconciliation act contains provisions that apply to multiple sectors of the economy, but several key provisions apply specifically to the electric power sector. The 2022 reconciliation act restored and extended the PTC and ITC to their previous values —about $27.5/MWh and 30 percent, respectively—for new construction through 2024, with expanded eligibility for additional generating sources starting in 2025. The act also provided a PTC for existing nuclear power plants and increased the value of the tax credits for CCS (45Q tax credits).[33]

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[30] Energy Information Administration, "Annual Energy Outlook 2022 (AEO2022)" (press release, March 3, 2022), www.eia.gov/outlooks/archive/aeo22; Wesley Cole and others, *2021 Standard Scenarios Report: A U.S. Electricity Sector Outlook* (National Renewable Energy Laboratory, November 2021), www.nrel.gov/docs/fy22osti/80641.pdf.

[31] DSIRE, "Renewable Energy Portfolio Standard" (updated November 8, 2023), https://tinyurl.com/4umsy2f8.

[32] Regional Greenhouse Gas Initiative, "Elements of RGGI" (2024), https://tinyurl.com/mue876nt.

[33] There are other incentives in the act that may be relevant to the electric power sector, such as tax preferences for domestic manufacturing of solar cells, wind turbines, batteries, and other technologies. Those and other incentives in the act were not modeled for this working paper.

Key Provisions in the Act. For new construction through 2024, the PTC and ITC are set at an inflation-adjusted base rate of $5.5/MWh and 6 percent, respectively, with higher rates available if certain conditions are met. Specifically, the tax credits increase to about $27.5/MWh and 30 percent, respectively (their previous full values) if the claiming entity meets certain wage and employment requirements. Starting in 2025, any new generators defined as clean in the act—such as wind and solar generators, as well as nuclear power, energy storage, and bioenergy with CCS, among others—is eligible for either tax credit. Those credits are extended through whichever is later: 2032 or when emissions are 75 percent below those from the power sector in 2022. At that point, the credits will begin to phase down before fully phasing out four years later.

In addition, the act provides zero-carbon generators with the opportunity to increase the value of those tax preferences (beyond the $27.5/MWh for the PTC or 30 percent for the ITC) if they meet certain additional requirements, referred to as bonus provisions. For example, siting a zero-carbon generator in an "energy community"—such as building a wind farm near the location of a previously retired coal plant—leads to a 10 percent bonus on the PTC and a 10 percentage-point increase for the ITC. A similar 10 percent or 10 percentage-point bonus can be claimed if the zero-carbon generator meets or exceeds domestic content requirements that are based on specified thresholds of manufacturing or processing materials used to construct the generator domestically.[34]

There are two other key provisions for the electric power sector. First, the act put in place a PTC for *existing* nuclear plants to discourage premature economic retirements of those plants before the end of their operational or licensing lifetime. The value of this PTC differs from those of the tax credits for new construction described above; it can reach up to $15/MWh if prevailing wage and apprenticeship requirements are met minus a reduction based on the average annual price of electricity.[35] That nuclear PTC is available from 2024 through 2032 for existing nuclear power plants. Second, the value of the 45Q tax credits was increased for projects meeting prevailing wage and apprenticeship requirements. For captured carbon that is sequestered permanently, the 45Q tax credit increased from $50 per metric ton ($50/MT) of CO_2 to $85/MT. CCS used in enhanced oil recovery receives a credit of $60/MT of CO_2, up from the previous $35/MT.[36]

How CBO Modeled Provisions of the Act. Recall that CBO and JCT's estimates of the spending effects and tax-related provisions of the reconciliation act, respectively, are not an input into the ReEDS model. When modeling the ITC and PTC in CBO-ReEDS, CBO expects that all

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[34] Guidance on the energy community and domestic content bonuses has been provided by the IRS; see Internal Revenue Service, Notice 2024-30 (April 15, 2024), www.irs.gov/irb/2024-16_IRB, and Notice 2023-38 (May 30, 2023), www.irs.gov/irb/2023-22_IRB.

[35] For additional details on this tax credit, see Congressional Research Service, *Tax Provisions in the Inflation Reduction Act of 2022*, version 10 (August 2022), https://crsreports.congress.gov/product/details?prodcode=R47202.

[36] Ibid.

claiming entities will meet the prevailing wage and apprenticeship requirements that provide a 5x multiplier from their base values, restoring their prior full values of 30 percent and $27.5/MWh, respectively. New onshore wind, offshore wind, and nuclear power plants are estimated to receive the 10 percent bonus credit for domestic content.[37] A recent analysis from Raimi and Pesek (2022) found that roughly half of U.S. land area would qualify as an energy community.[38] Following that, the values of the PTC were increased by 5 percent and those of the ITC by 5 percentage points, or half of the 10 percent bonus credit available for locating a zero-carbon generator in an energy community.

The act allows zero-carbon generators to choose to take either the PTC or the ITC. CBO expects utility-scale solar to claim the PTC instead of the ITC because of lower projected capital costs compared with historical trends. CBO expects onshore wind generators to continue taking the PTC, while offshore wind generators are expected to claim the ITC because of its higher capital costs. Generating units of other technologies that are projected to have higher capital costs, such as advanced nuclear reactors, geothermal plants, and battery storage, are also expected to take the ITC.[39]

Other relevant provisions in the act are the tax preferences for existing nuclear plants and the 45Q credits for CCS. The PTC for existing nuclear plants is modeled by preventing existing nuclear plants that are not already scheduled for retirement in the next few years from retiring before 2032.[40] Nuclear plants are estimated to receive licensing extensions up to a maximum 80-year lifetime but may be retired endogenously because of economic conditions before then. The 45Q credits are modeled on the basis of the $85/MT incentive for CO_2 that is permanently sequestered to reflect the potential incentives for CCS.

Base-Case Projection of the Effects of the 2022 Reconciliation Act

In the base-case projection of the effects of the 2022 reconciliation act using CBO-ReEDS, annual CO_2 emissions decline by 76 percent in 2050 from 2022 levels; that is 66 percent lower than the projection for the No Reconciliation case in 2050 (see Figure 2). On a cumulative basis,

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[37] Based on implementation of the domestic content provisions in EIA's AEO2023. Alternative scenarios for the uptake of bonus credit provisions in the 2022 reconciliation act are discussed on page 19.

[38] Daniel Raimi and Sophie Pesek, "What Is an 'Energy Community'?" *Resources* (blog entry, September 7, 2022), https://tinyurl.com/23bx3x4x.

[39] As noted above, the tax credits phase down after whichever is later: 2032 or when electric power sector emissions fall 75 percent below 2022 levels. The model triggers the phasedown endogenously when or if the 75 percent reduction is reached during a model run.

[40] Diablo Canyon's generating units have been updated for scheduled retirement in 2029 and 2030 based on the recent five-year extension. See Anne C. Mulkern, "California Passes Slew of Climate Bills, but a Big One Fails," *GreenWire* (September 2, 2022), https://tinyurl.com/2xwk6hu8, and Robert Walton, "PG&E Formally Asks NRC to Extend Diablo Canyon Power Plant License to 2030 to Boost Grid Reliability," *UtilityDive* (November 1, 2022), https://tinyurl.com/4xccuxj8.

total emissions from 2022 to 2050 are projected to decline by 46 percent because of the 2022 reconciliation act. The projected decrease in CO_2 emissions in the CBO-ReEDS base case adds to a growing number of projections of the effects of the 2022 reconciliation act on the electric power sector (see Figure 3).

The projected reduction in CO_2 emissions is attributable to a further shift away from fossil fuel–fired generation to zero-carbon or "clean" generation as defined in the 2022 reconciliation act. In the base case, the act is projected to increase the share of clean generation in 2030 to 65 percent and by up to 83 percent in 2050.[41] The tax preferences for clean generators are not projected to expire until the end of the 2022–2050 projection period in the base case. By comparison, lower costs for zero-carbon generators and state-level policies are projected to increase the share of clean generation in the No Reconciliation case to 52 percent in 2030 and to 55 percent in 2050—up from 41 percent in 2020.

The difference in clean generation is largely attributable to increased generation from solar and wind. For the base-case projection of the 2022 reconciliation act, the share of generation from wind and solar is projected to increase by 13 percentage points in 2030, while that of coal- and natural gas–fired generation is projected to decrease by 18 percentage points relative to the No Reconciliation case (see Figure 4). By 2050, the share of wind and solar generation is projected to increase by 28 percentage points, offset by an 18 percentage-point decrease in the share of natural gas–fired generation and an 8 percentage-point decrease in the share of coal-fired generation.

In the base case, the tax preferences in the act are anticipated to reduce wholesale electricity prices over the next decade, on average, by $2.30/MWh, or 3 percent, by providing federal subsidies that decrease the cost of power produced by zero-carbon generators. In the long term, average wholesale prices in the base case are projected to decease by $2.85/MWh, or 5 percent, over the projection period, with the increase in capital costs for new generators and for expansions of the electric power grid to interconnect new generators being offset by a reduction in expenditures on fuel and the tax preferences for zero-carbon generators.

CBO estimates the overall abatement cost of a policy to reduce CO_2 emissions in CBO-ReEDS as the sum of both the private and public costs divided by the net abatement in cumulative emissions; additional details about the calculation of the cost per metric ton of CO_2 avoided can be found in the appendix. In the base case, the modeled provisions of the 2022 reconciliation act

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[41] Total generation in the base case and in the No Reconciliation case differs because of provisions in the act that incentivize increased electrification. The projected demand in each case comes from the AEO2023 Reference and No IRA cases.

in CBO-ReEDS are projected to have an abatement cost of about $40/MT of avoided CO_2 emissions; that value is consistent with other estimates in the literature.[42]

Sensitivity of Electric Power Sector Outcomes to Uncertainty

In addition to the non-policy-related factors discussed previously, several uncertain factors could affect the projected electric power sector outcomes stemming from the 2022 reconciliation act:

- The extent to which various bonus credit provisions in the act will be claimed;
- Future natural gas prices;
- Future costs of renewable energy, storage, and nuclear power technologies; and
- The growth of electricity demand.

Uptake of Bonus Credit Provisions in the 2022 Reconciliation Act

The value of the tax preferences provided by the 2022 reconciliation act is uncertain because of the multiple bonus credit provisions. In particular, the extent of the uptake of those bonus credit provisions for locating new zero-carbon generators in energy communities and for achieving minimum domestic content requirements by eligible entities is uncertain. To examine the sensitivity of the base-case results to the uptake of the bonus credit provisions, CBO estimated scenarios with the base inflation-adjusted rate of $27.5/MWh and 30 percent PTC and ITC, respectively, but with differing uptake of bonus credit previsions. Specifically, one scenario ("Low Bonus Credit Uptake") applies no bonus credit provisions, whereas another scenario ("High Bonus Credit Uptake") allows full uptake of both the energy community and domestic content bonus credits—a 20 percent or 20 percentage-point increase to the base PTC and ITC values, respectively.

In the High Bonus Credit Uptake scenario, higher take-up of the bonus credit provisions provides a larger subsidy to zero-carbon generators, leading the share of clean generation to increase by 3 percentage points in 2030 and average wholesale prices to decrease by $0.60 (1 percent) over the next decade. That leads projected annual CO_2 emissions to be 12 percent lower in 2040 and projected cumulative emissions to be 0.2 billion metric tons lower than in the base-case projection under the 2022 reconciliation act (see Figure 5). However, annual CO_2 emissions in 2050 are 67 percent higher in the High Bonus Credit Uptake scenario than in the base case because the 75 percent threshold for the phasedown of the tax credits is reached in the early 2040s in that scenario. Emissions rise toward the end of the projection period with the expiration

[42] John Bistline and others, "Emissions and Energy Impacts of the Inflation Reduction Act," *Science*, vol. 380, no. 6652 (June 2023), pp. 1324–1327, https://doi.org/10.1126/science.adg3781.

of tax preferences for clean energy generators, which is projected to lead to a decrease in wind capacity and an increase in capacity from natural gas–fired plants.

With lower uptake of the bonus credit provisions in the Low Bonus Credit Uptake scenario, fewer zero-carbon generators come online through 2040 with less subsidization of clean generation (see Table 3). With lower uptake of the bonus credit provisions, annual CO_2 emissions are projected to be about 15 percent higher in 2050, and cumulative emissions are projected to be 600 million metric tons more than in the base-case projection of the act (see Table 4).

Future Natural Gas Prices

Since the mid-2000s, lower natural gas prices have shifted generation away from coal-fired to natural gas–fired generation. The future trajectory of fuel prices is uncertain. Using CBO-ReEDS, CBO estimated the sensitivity of the projected electric power sector outcomes to natural gas prices by modeling alternative scenarios using EIA's projections of high and low natural gas prices.[43]

In the "Low Natural Gas Price" scenario, low natural gas prices lead to a larger share of generation from natural gas–fired generators, offset by a relative decrease in both coal and solar generation. Altogether, that shift in the generation mix tends to lower annual emissions through the 2030s by accelerating the decline in more-carbon-intensive coal-fired generation. However, in the 2040s, an increase occurs that results in more generation from natural gas–fired generation versus zero-carbon generation (see Figure 6). Low natural gas prices would also lead to lower average wholesale prices, as natural gas–fired generation is frequently on the margin and thus sets the market-clearing price in electric power markets.

Higher natural gas prices in the "High Natural Gas Price" scenario are projected to lead to a larger share of clean generation over the 2022–2050 period as natural gas–fired generation becomes more expensive. Although high natural gas prices also increase coal-fired generation, overall emissions are projected to decline relative to the base case starting in the mid- to late 2030s as the growth in the share of clean generation offsets the increased emissions from coal-fired generation. In the High Natural Gas Price scenario, total CO_2 emissions fall below the amounts in both the Low Natural Gas Price scenario and the base case by 2040. Wholesale prices are projected to increase because of the higher price of natural gas, while the policy's abatement

[43] Those natural gas price paths correspond to the "Low Oil and Gas Supply" and "High Oil and Gas Supply" scenarios from EIA's AEO2023, respectively.

cost of avoided CO_2 emissions is comparable to that in the base case because the higher public and private costs are offset by a smaller reduction in emissions (see Table 4).[44]

Future Clean Generator Costs

In addition to the marginal costs of fossil fuel–fired generation, uncertainty exists regarding the fixed costs of new zero-carbon generators. For example, the higher costs of building new solar and wind generators and battery storage could increase generation from existing or new natural gas–fired generators. However, the lower costs of those zero-carbon generators and others, such as nuclear power generators, could accelerate the retirement of fossil fuel–fired generators.

Lower renewable energy, nuclear, and storage costs in the "Low Clean Generator Cost" scenario are projected in CBO-ReEDS to decrease annual CO_2 emissions in 2040 by a quarter and to increase annual CO_2 emissions in 2050 by about the same amount following the expiration of the tax preferences for clean generators in the 2040s. Cumulative emissions over the 2022–2050 period are projected to be about a billion metric tons lower than in the base case (see Figure 7). The share of clean generation is projected to increase to 68 percent by 2030 and to 82 percent by 2040; that share then decreases to 80 percent by 2050 (see Table 3). Solar and wind generation combine to provide over 60 percent of generation by 2050 under the 2022 reconciliation act with low renewable energy and storage costs, compared with 46 percent of generation in the No Reconciliation case with low renewable costs. Average wholesale prices are projected to decrease because of the lower private cost of new wind and solar generators in addition to the subsidies provided from the act's tax preferences. By comparison, in the "High Clean Generator Cost" scenario, higher costs for zero-carbon generators are projected to lower the share of solar and wind generation to 38 percent in 2040 and to increase average wholesale prices because of the higher cost of building new wind and solar generators.

Growth of Electricity Demand

Growth in the demand for electricity is uncertain, as it will be driven both by the expected growth of the economy and by the pace of electrification. On the one hand, incentives in the 2022 reconciliation act will spur increased electrification of other sectors—such as transportation (electric vehicles), residential heating (heat pumps), and manufacturing—which will increase electricity demand.[45] On the other hand, other incentives in the act will reduce electricity demand by providing rebates for improving home insulation, other energy-efficiency upgrades, and tax preferences for rooftop solar. Faster-than-anticipated growth in electricity demand would spur

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[44] The policy's abatement cost is calculated relative to the corresponding No Reconciliation case with high or low natural gas prices.

[45] Heat pumps are expected to increase electricity demand in the cooler winter months by substituting primarily for fossil fuel–fired home boiler heaters. However, heat pumps also provide residential cooling services that are more energy efficient than traditional air conditioners, thereby lowering electricity demand in the warmer summer months.

more investment in generating capacity, while more moderate growth than anticipated could slow down the rate of turnover from the existing generation fleet to the new zero-carbon generators incentivized by the 2022 reconciliation act.

CBO uses projected electricity demand from EIA's AEO2023 "High Economic Growth" and "Low Economic Growth" scenarios to estimate the sensitivity to electricity demand. The growth of demand could be higher or lower than those projections suggest. For example, those scenarios include EIA's projections of growth in demand for electric vehicles; recent estimates suggest that the rate of electric vehicle adoption could be substantially higher than EIA's projections.[46]

In general, the projected effects of the 2022 reconciliation act under higher and lower electricity demand suggest a lower sensitivity to power demand as compared with the previous sensitivities to the costs of generating power in CBO-ReEDS (see Table 4). The shares of clean generation under high and low electricity demand are roughly unchanged from those in the base case, leading to slightly higher emissions with high electricity demand and slightly lower emissions with low demand (see Figure 8). The abatement cost of the act is lower under conditions of low electricity demand than it is in the base case with reductions in the levels of spending to build new generators and expand transmission capacity on the grid.

[46] David Austin, *Modeling the Demand for Electric Vehicles and the Supply of Charging Stations in the United States*, Working Paper 2023-06 (Congressional Budget Office, September 2023), www.cbo.gov/publication/58964.

Appendix

This appendix provides information about transmission, siting, and the interconnection queue as modeled in CBO-ReEDS. In addition, it provides calculations of policy abatement costs produced by that model. CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory's Regional Energy Deployment System (NREL's ReEDS) model for analyzing policies in the electric power sector.

Transmission, Siting, and the Interconnection Queue

CBO assessed various options for projecting transmission capacity, future siting decisions, and the interconnection queue.

Historical and Projected Transmission Capacity

From 2009 to 2022, newly installed transmission lines averaged about 1,900 line miles on an annual basis (see Figure A-1). Installation of new transmission peaked in 2013 with the completion of multiple transmission lines in West Texas as part of Texas' Competitive Renewable Energy Zone initiative.[1] However, additions of new transmission lines have declined in recent years, averaging about 1,000 line miles annually from 2017 to 2022.

Because transmission lines vary in their voltage and thus their ability to transmit power, transmission can also be measured in terawatt-miles per year (TW-mi/yr), which allows for comparison between a high-voltage line over a short distance and a lower-voltage line over a longer distance. From 2017 to 2022, new transmission lines totaled fewer than 1.1 TW-mi/yr.[2] On the basis of that recent rate of transmission additions, CBO imposes a 1 TW-mi/yr cap on new transmission in CBO-ReEDS throughout the 2022–2050 projection period. In the base case (the "Reconciliation" case), CBO-ReEDS projects that transmission capacity will increase by 8 percent by 2035 and by 15 percent by 2050 (see Figure A-2).

The projected growth in transmission capacity in the base case in CBO-ReEDS falls below that projected in other studies that report on transmission capacity in future years. For example, one study estimating the effects of the 2022 reconciliation act on the power sector projects a 41 percent increase in transmission capacity by 2035.[3] However, that study also projects much larger growth in electricity demand—about 5,600 terawatt-hours (TWh)—in 2035, compared

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[1] Department of Energy, *Land-Based Wind Market Report: 2023 Edition* (August 2023), https://tinyurl.com/45pxk7m6.

[2] Transmission capacity calculated using conversion rates of capacity by line voltage noted within ReEDS.

[3] Jesse D. Jenkins and others, *Electricity Transmission Is Key to Unlock the Full Potential of the Inflation Reduction Act* (REPEAT Project, September 2022), http://dx.doi.org/10.5281/zenodo.7106176.

with 4,700 TWh in CBO's base case and less than 5,400 TWh by 2050. That larger projected demand in turn leads to projected rates of additional generating capacity that exceed the rates of new capacity added in recent history, as well as both short-term projections of new capacity and those additions projected in CBO-ReEDS. Further, the restrictions imposed in CBO-ReEDS on siting utility-scale wind and solar generators (discussed below) have been found in other studies to reduce projected new transmission capacity.[4]

Although the transmission constraint imposed in CBO-ReEDS is consistent with recent history, transmission capacity in the future could be higher or lower than CBO's base-case projections. On the one hand, increasing the interconnection of resources farther away from load centers or higher-than-projected energy demand would tend to increase total transmission capacity. On the other hand, recent technological innovations such as dynamic line rating can increase transmission capacity on existing lines.[5] Strategically locating energy storage near areas of high demand or software-based innovations such as topology optimization could reduce congestion along existing transmission lines and potentially reduce new construction of transmission capacity. Reconductoring—replacing existing transmission lines with higher-voltage, higher-capacity lines using newer technologies—could increase transmission capacity beyond CBO's base-case projections. However, by using existing right-of-way, it would largely avoid siting and permitting concerns.[6]

Siting Renewable Generating Capacity

NREL developed three scenarios for siting new utility-scale solar, onshore wind, and offshore wind: "Open Access," "Reference Access," and "Limited Access." Although the default siting scenario in ReEDS is the Reference Access scenario, the base case in CBO-ReEDS (described above) uses the most restrictive scenario available, Limited Access. That scenario includes restrictions such as prohibiting new construction on federal lands and setback requirements for onshore wind comparable with the most restrictive requirements in 21 counties (see Table A-1). CBO did not use the Open Access scenario because, in the agency's assessment, that scenario does not reflect impediments that would limit the siting of wind and solar production facilities.

Using the most restrictive siting scenario for utility-scale wind and solar and the limit on new transmission capacity in the base case increases both average annual and cumulative emissions

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[4] Paul Denholm and others, *Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035*, NREL/TP6A40-81644 (National Renewable Energy Laboratory, 2022), www.nrel.gov/docs/fy22osti/81644.pdf.

[5] The total amount of power that can flow safely through a transmission line is based on prespecified temperature, wind, and other thresholds. Dynamic line rating can increase that line limit with the use of sensors that measure real-time weather conditions to adjust the maximum safe flow of power along the line.

[6] Emilia Chojkiewicz and others, *Accelerating Transmission Expansion by Using Advanced Conductors in Existing Right-of-Way*, Working Paper 343 (Energy Institute at Haas, November 2023), https://haas.berkeley.edu/wp-content/uploads/WP343.pdf.

from 2022 to 2050 compared with a version of the Reconciliation case that uses NREL's Reference Access siting scenario and the default 1.4 TW-mi/year constraint on new transmission capacity from 2023 to 2027 (see Figure A-3). Average annual emissions are 7 percent higher and cumulative emissions from 2022 to 2050 are 6 percent higher in the base case in CBO-ReEDS than in a Reconciliation case using the default siting and transmission constraints in NREL's ReEDS. Annual emissions in 2050 are about a third *lower* in 2050 in the base case because the 75 percent threshold for the phasedown of the tax credits is reached in the early 2040s in the Reconciliation case without the transmission and siting constraints.

Interconnection Queue

Projects in the interconnection queue are those that have been proposed and whose developers have requested a series of feasibility or other studies to interconnect to the grid. The interconnection queue has been growing in recent years: At the end of 2022, there were over 2,000 gigawatts (GWs) in the queue, including 947 GW of solar, 300 GW of wind, and 680 GW of stand-alone storage.[7] By comparison, the total installed capacity of the U.S. electric power sector is about 1,200 GW. Further, those proposed capacity additions all exceed the projected new solar, wind, and storage capacity in CBO-ReEDS through 2050. Because of the speculative nature of some projects in the queue, not all of them are completed; only about 21 percent of projects that were in the queue from 2000 to 2017 were producing power by 2022.[8]

Calculating a Policy's Abatement Cost in CBO-ReEDS

CBO estimates the abatement cost of an emission reduction policy in CBO-ReEDS by dividing the difference in total public-sector and private-sector costs by the cumulative abatement of emissions, relative to a reference case. The public cost component is the tax credits, whereas the private cost is calculated on the basis of wholesale electricity prices in ReEDS (described below). The method and definitions described here follow those used in Stock and Stuart (2021).[9]

Wholesale Electricity Prices

Wholesale prices are an output created by ReEDS after a model run. CBO uses national average electricity prices, which are defined in the ReEDS model documentation as follows:

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[7] Joseph Rand and others, *Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection As of the End of 2022* (Lawrence Berkeley National Laboratory, April 2023), https://tinyurl.com/9xmmsfwr.

[8] Ibid.

[9] James H. Stock and Daniel N. Stuart, *Robust Decarbonization of the U.S. Power Sector: Policy Options*, Working Paper 28677 (National Bureau of Economic Research, April 2021), www.nber.org/papers/w28677.

Average electricity prices are calculated as the annualized total costs of building and operating the system in a certain geographic area, divided by the electricity load in that area. At [the] national level, the prices are calculated as:

$$p(\text{costtype}, \text{year}) = \frac{\text{systemcost}_{\text{costtype,year}}}{\text{load}_{\text{year}}}$$

where system costs consist of both annualized capital and operational costs. Annualized costs for existing (i.e., pre-2010) power plants are also considered given plants' initial investment costs and the built year.[10]

Abatement Cost of Avoided Emissions

To get a measure of total system cost, the average wholesale electricity price described above (in dollars per megawatt-hour, or $/MWh) is multiplied by total generation (MWh) to get an annual cost measure. The wholesale prices reported in ReEDS include the effects of federal expenditures or transfers; for example, wholesale prices would decrease with federal subsidies and increase with federal taxes. This also means that the effects on federal revenues from a carbon policy—such as a carbon tax or clean energy tax credits—would not be captured by this price-based cost measure. Therefore, system costs are adjusted to reflect the investment tax credit or production tax credit (ITC/PTC) represented in CBO-ReEDS as follows:

$$System\ Cost = National\ Average\ Wholesale\ Price \left(\frac{\$}{MWh}\right) * Generation\ (MWh) + Tax\ Credits\ (\$)$$

The abatement cost of a carbon policy is then calculated by dividing the change in total system cost through 2050 by the change in carbon dioxide (CO_2) emissions, where the change is defined as the difference between the policy scenario and the corresponding reference case. The corresponding reference case is the case with input assumptions similar to those of the policy scenario; for example, CBO compares its "Reconciliation" case with the "No Reconciliation" case, and the "Low Natural Gas Price" scenario is compared with a version of the No Reconciliation case with low natural gas prices. A policy's abatement cost is calculated as:

$$Abatement\ Cost = \frac{\Delta\ Cumulative\ System\ Cost\ through\ 2050\ (\$)}{\Delta\ Cumulative\ Emissions\ Abatement\ through\ 2050\ (ton\ CO_2)},$$

where

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[10] Jonathan Ho and others, *Regional Energy Deployment System (ReEDS) Model Documentation: Version 2020* (June 2021), p. 135, www.nrel.gov/docs/fy21osti/78195.pdf.

$$\Delta\ System\ Cost\ (\$) = \sum_{2022}^{2050} System\ Cost(Reference\ Scenario) - \sum_{2022}^{2050} System\ Cost(Policy)$$

and the CO_2 emissions abatement denominator is calculated as

$$\Delta\ CO_2\ Abatement\ (ton) = \sum_{2022}^{2050} Emissions(Policy) - \sum_{2022}^{2050} Emissions(Reference\ Scenario).$$ [11]

[11] Because the system cost generally increases and emissions generally decrease under a policy scenario, the differences in the numerator and denominator are ordered so that the overall abatement cost measure of avoided emissions will be positive.

Figures

Figure 1. [Return to Text]

Model Regions in ReEDS

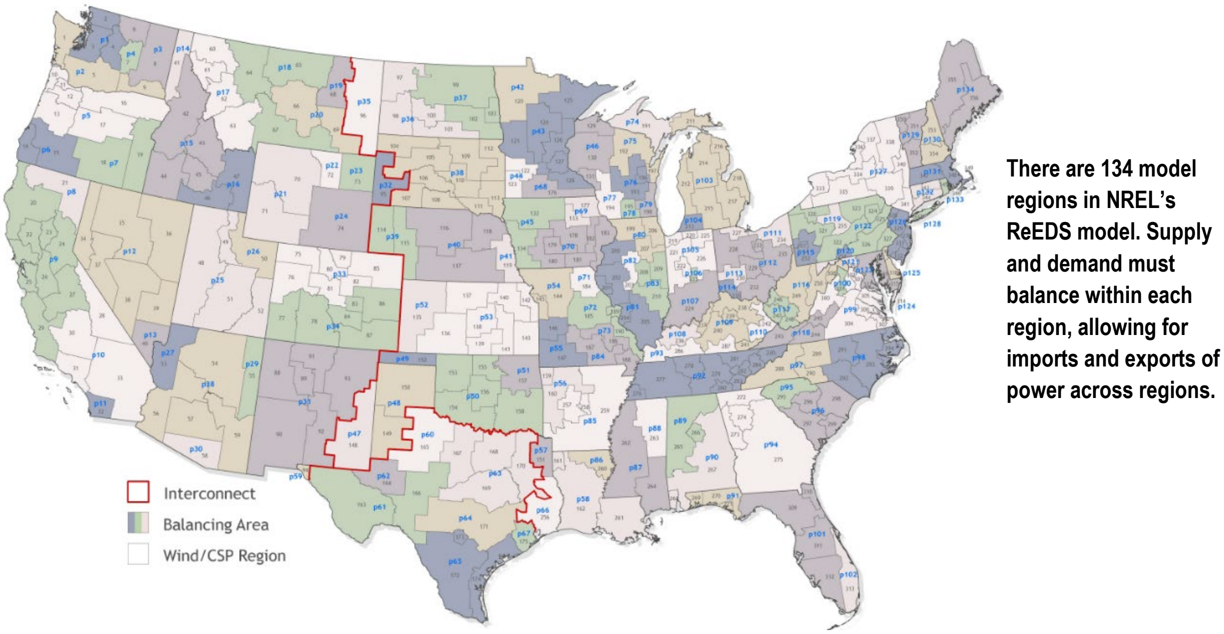


Image reprinted from National Renewable Energy Laboratory (NREL), www.nrel.gov/analysis/assets/pdfs/reeds-model-regions-map.pdf.

The model regions—denoted in the map by the blue labels—are the balancing areas in ReEDS, or the regions where demand must be met by total electricity supply (including imports, which are limited by transmission capacity to a given model region). Within those model regions are 356 wind/CSP resource supply regions that allow for varying characteristics of the generation potential of wind and CSP generating resources. The red lines denote the three major interconnects, or power grids, across the continental United States (the Eastern Interconnection, the Western Interconnection, and the Texas Interconnection).

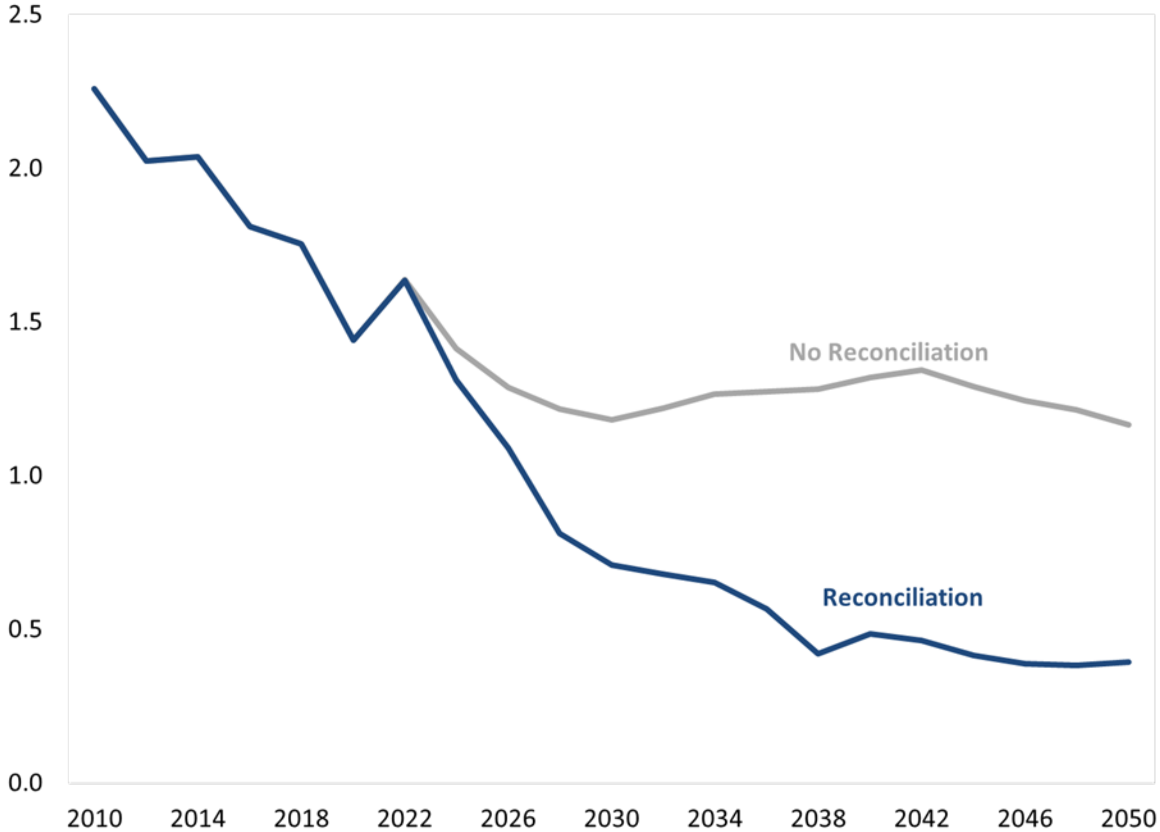
The ReEDS model is NREL's Regional Energy Deployment System model for analyzing policies in the electric power sector.

CSP = concentrating solar power.

Figure 2. [Return to Text]

Projected Carbon Dioxide Emissions: The "Reconciliation" Case Versus the "No Reconciliation" Case

Billions of metric tons



Data source: Congressional Budget Office, using CBO-ReEDS.

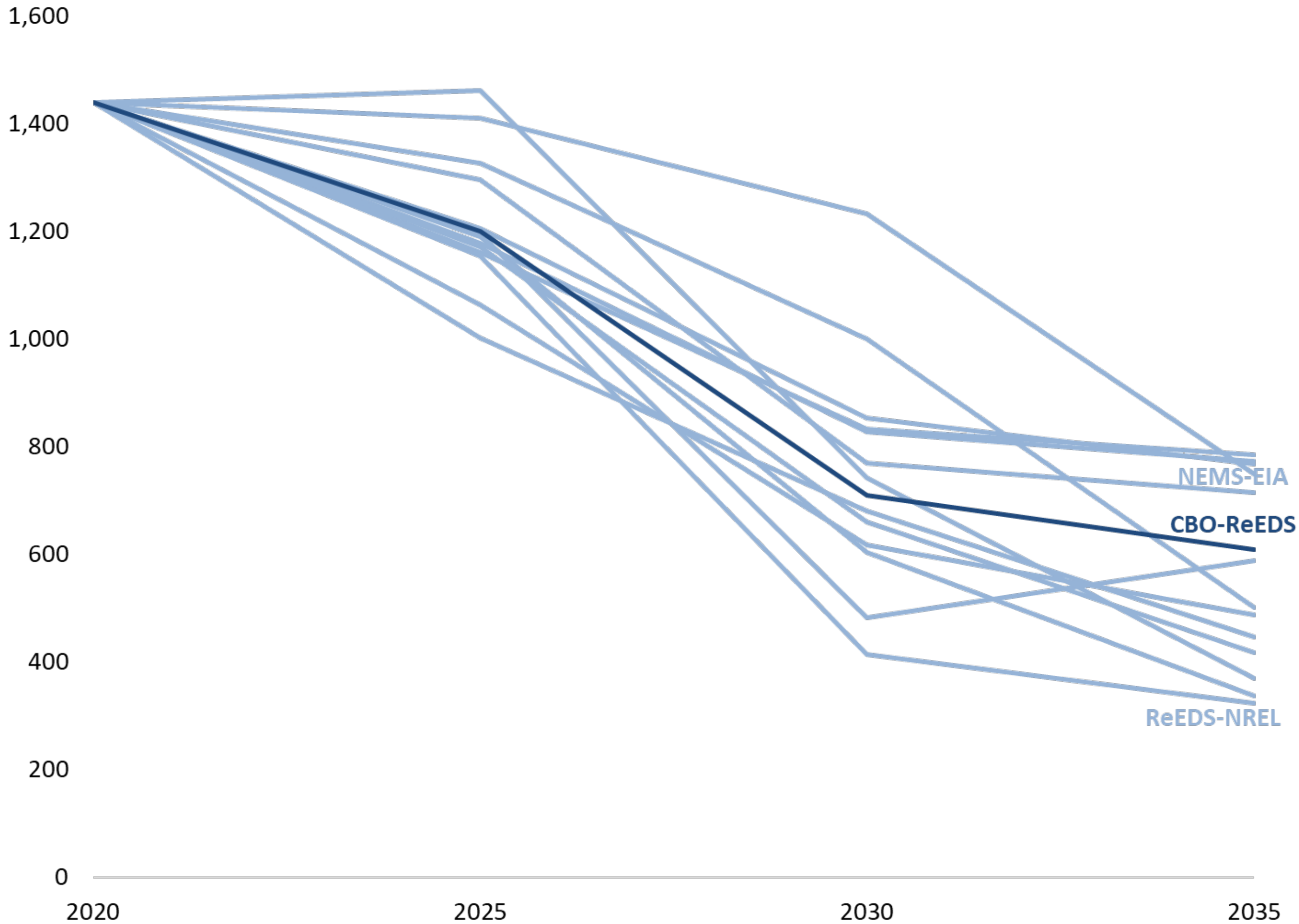
The "Reconciliation" case reflects the base-case estimate of the effects of the 2022 reconciliation act. The "No Reconciliation" case is similar to the Reconciliation case but excludes the effects of the 2022 reconciliation act.

The CBO-ReEDS model is an adapted version of the National Renewable Energy Laboratory's Regional Energy Deployment System (NREL's ReEDS) model.

Figure 3. [Return to Text]

Comparison of CBO's Projections With Other Projections of Carbon Dioxide Emissions

Millions of metric tons



Data sources: Congressional Budget Office, using CBO-ReEDS and estimates from Environmental Protection Agency, Electricity Sector Emissions Impacts of the Inflation Reduction Act: Assessment of Projected CO_2 Emission Reductions From Changes in Electricity Generation and Use, EPA 430-R-23-004 (September 2023), www.epa.gov/inflation-reduction-act/electric-sector-emissions-impacts-inflation-reduction-act.

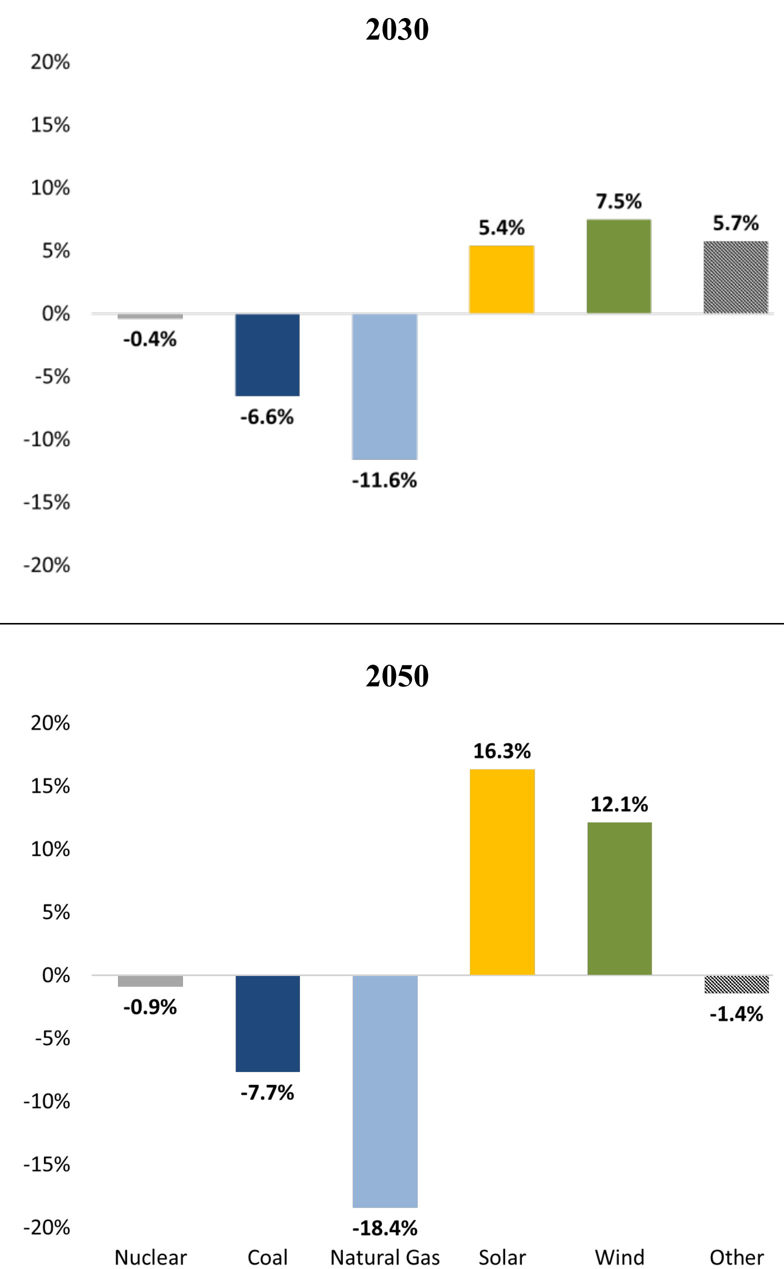
CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory's Regional Energy Deployment System (NREL's ReEDS) model.

NEMS-EIA is EIA's National Energy Modeling System model.

Figure 4. [Return to Text]

Difference in Generation Mix: The “Reconciliation” Case Versus the “No Reconciliation” Case

Percent



Data source: Congressional Budget Office, using CBO-ReEDS.

The “Reconciliation” case reflects the effects of the 2022 reconciliation act on shares of generation, by energy source, relative to the “No Reconciliation" case estimate. The “No Reconciliation” case is similar to the Reconciliation case but excludes the effects of the 2022 reconciliation act.

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory’s Regional Energy Deployment System (NREL’s ReEDS) model.

Figure 5. [Return to Text]

Projected Carbon Dioxide Emissions With High and Low Uptake of Bonus Credit Provisions

Billions of metric tons

Data source: Congressional Budget Office, using CBO-ReEDS.

The “Low Bonus Credit Uptake” scenario is estimated with no domestic content or energy community bonus added to the value of the energy tax credits with the prevailing wage and apprenticeship requirements met. The “High Bonus Credit Uptake” scenario includes the full 10 percent value for each of those bonuses for all eligible technologies, resulting in a total bonus of 20 percent for the production tax credit or 20 percentage points for the investment tax credit.

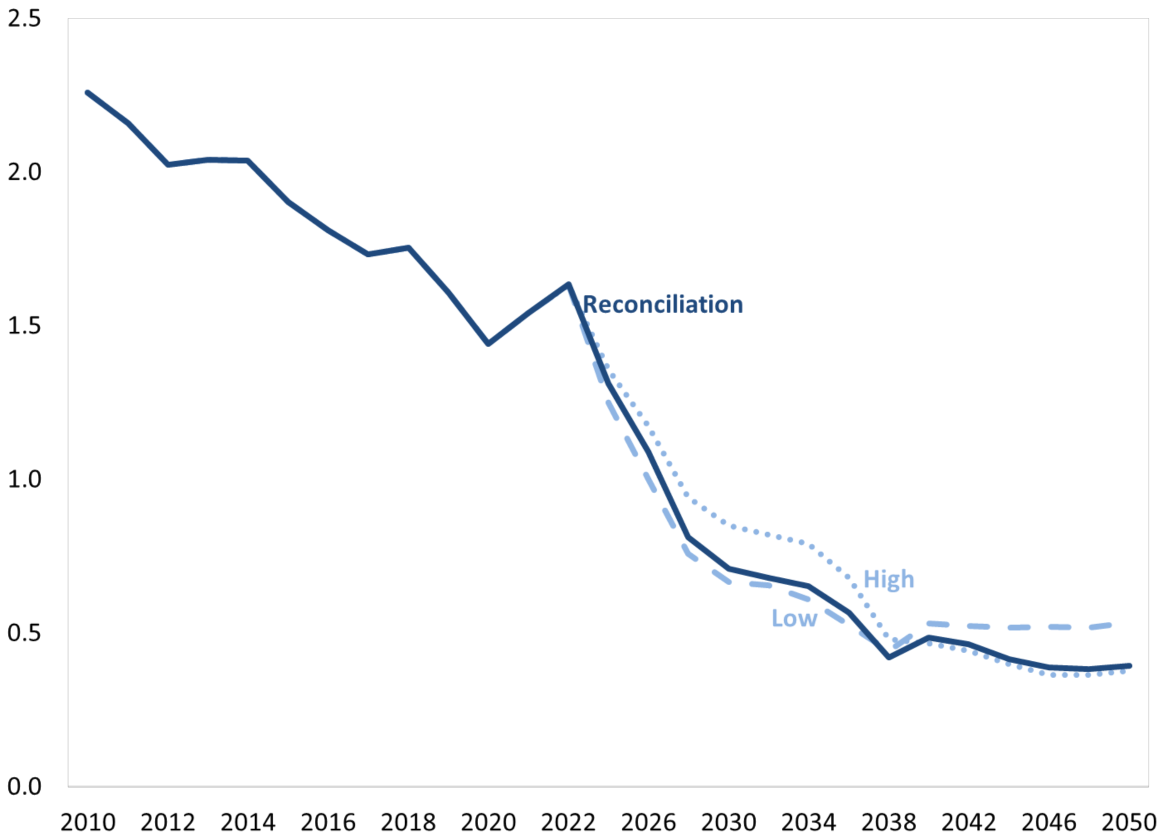
The “Reconciliation” case reflects the base-case estimate of the effects of the 2022 reconciliation act.

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory’s Regional Energy Deployment System (NREL’s ReEDS) model.

Figure 6. [Return to Text]

Projected Carbon Dioxide Emissions With High and Low Natural Gas Prices

Billions of metric tons



Data source: Congressional Budget Office, using CBO-ReEDS.

High and low natural gas prices underlying the "High" and "Low" scenarios come from the "Low Oil and Gas Supply" and "High Oil and Gas Supply" scenarios in the Energy Information Administration's *Annual Energy Outlook 2023*, respectively.

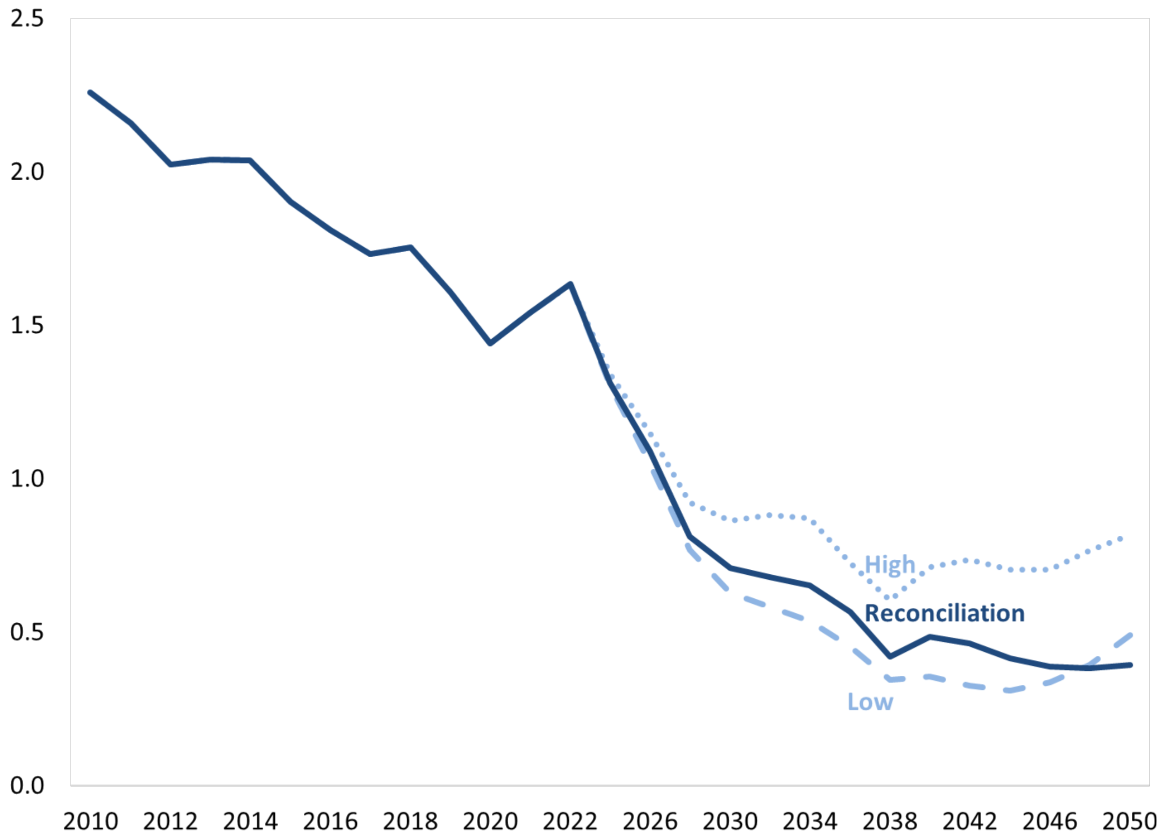
The "Reconciliation" case reflects the base-case estimate of the effects of the 2022 reconciliation act.

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory's Regional Energy Deployment System (NREL's ReEDS) model.

Figure 7. [Return to Text]

Projected Carbon Dioxide Emissions With High and Low Clean Generator Costs

Billions of metric tons



Data source: Congressional Budget Office, using CBO-ReEDS.

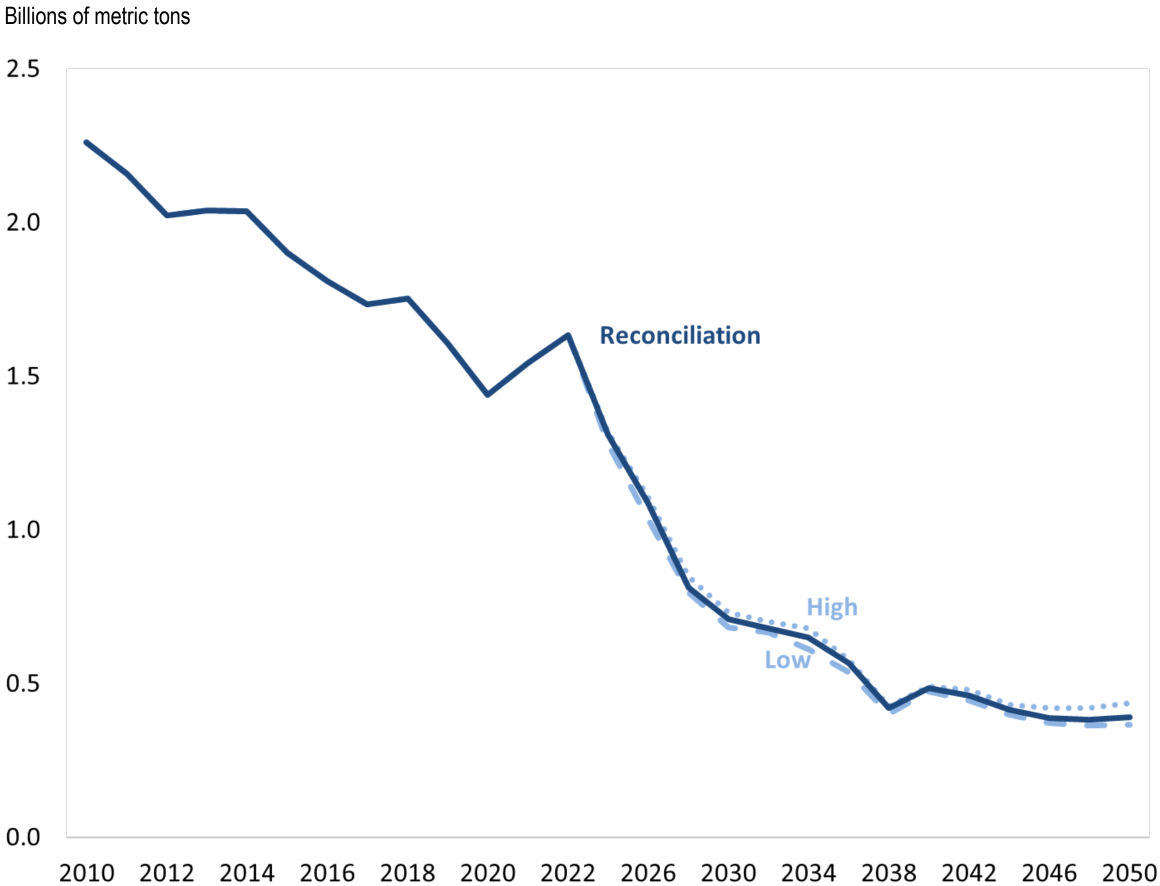
High and low generator costs underlying the “High” and “Low” scenarios come from the “High Zero-Carbon Technology Cost” and “Low Zero-Carbon Technology Cost” scenarios in the Energy Information Administration’s *Annual Energy Outlook 2023*, respectively.

The “Reconciliation” case reflects the base-case estimate of the effects of the 2022 reconciliation act.

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory’s Regional Energy Deployment System (NREL’s ReEDS) model.

Figure 8. [Return to Text]

Projected Carbon Dioxide Emissions With High and Low Electricity Demand



Data source: Congressional Budget Office, using CBO-ReEDS.

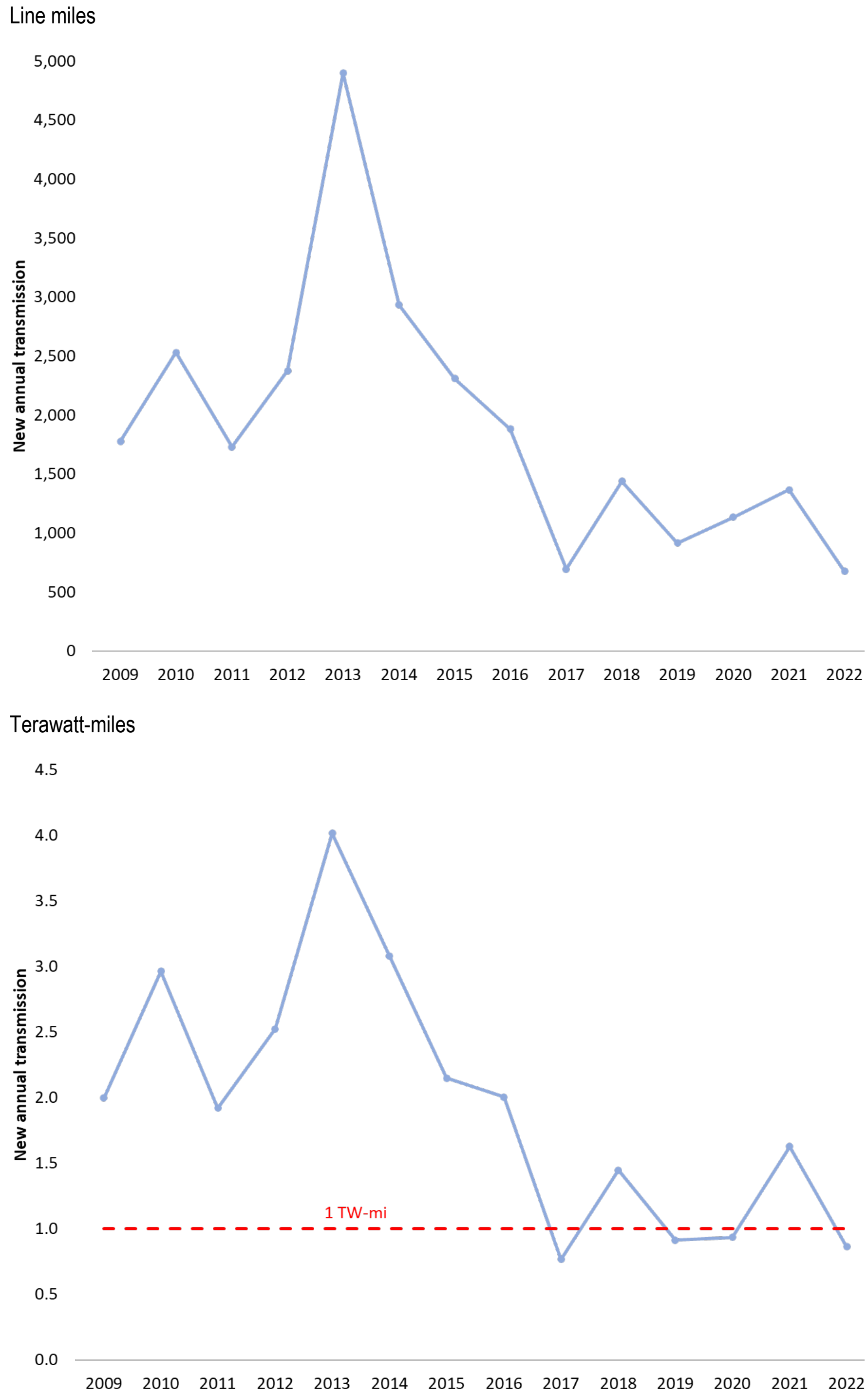
Demand underlying the “High” and “Low” scenarios comes from the “High Economic Growth” and “Low Economic Growth” scenarios in the Energy Information Administration’s *Annual Energy Outlook 2023*.

The “Reconciliation” case reflects the base-case estimate of the effects of the 2022 reconciliation act.

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory’s Regional Energy Deployment System (NREL’s ReEDS) model.

Figure A-1. [Return to Text]

Annual Additions of Transmission Lines and Capacity



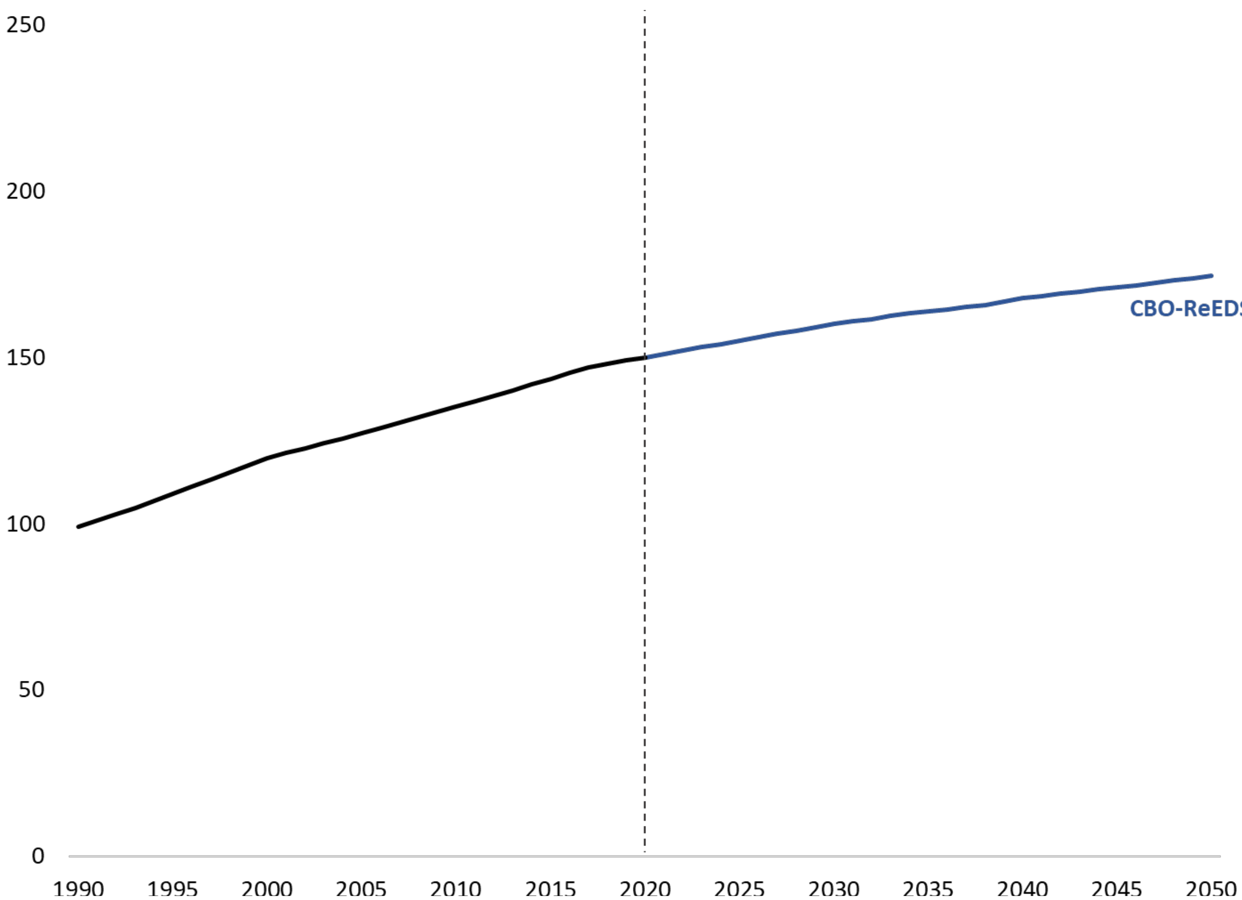
Data source: Congressional Budget Office, using the Federal Energy Regulatory Commission's monthly Energy Infrastructure Updates.

The red dashed line indicates the annual limit on new construction of transmission lines imposed in CBO-ReEDS.

Figure A-2. [Return to Text]

Historical and Projected Transmission Capacity

Terawatt-miles



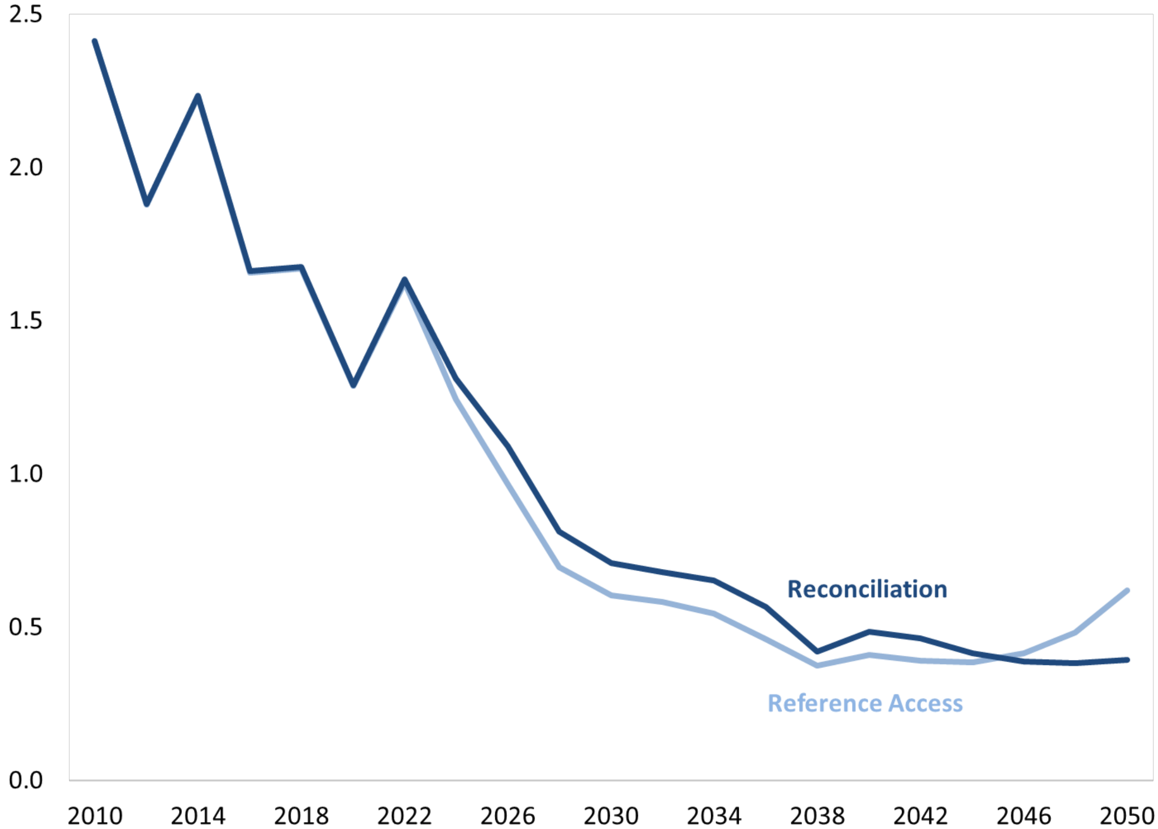
Data sources: Congressional Budget Office, using CBO-ReEDS and estimates of historical rates of new transmission capacity additions over time from Jesse D. Jenkins and others, *Climate Progress and the 117th Congress: The Impacts of the Inflation Reduction Act and the Infrastructure Investment and Jobs Act* (REPEAT Project, July 2023), https://repeatproject.org/docs/REPEAT_Climate_Progress_and_the_117th_Congress.pdf.

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory's Regional Energy Deployment System (NREL's ReEDS) model.

Figure A-3. [Return to Text]

Projected Carbon Dioxide Emissions: The “Reconciliation” Case Versus the “Reference Access” Case

Billions of metric tons



Data source: Congressional Budget Office, using CBO-ReEDS.

The “Reconciliation” case reflects the base-case estimate of the effects of the 2022 reconciliation act.

The “Reference Access” scenario includes NREL’s Reference Access siting scenario for onshore wind, offshore wind, and utility-scale solar, as well as NREL’s ReEDS default growth constraint on new transmission of 1.4 terawatt-miles per year applied from 2023 to 2027.

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory’s Regional Energy Deployment System (NREL’s ReEDS) model.

Tables

Table 1. [Return to Text]

Description of Changes Made in CBO-ReEDS

Main Changes in CBO-ReEDS	Description of the Change
Fuel Prices	Updated fuel prices to correspond to those from EIA's latest AEO.
Technology Costs	Adjusted default cost projections from NREL's ATB to correspond to those in EIA's latest AEO.
Power Demand Growth	Updated projections of growth in demand for electric power to match the scenario from EIA's latest AEO that most closely corresponds to CBO's long-term outlook on real GDP growth. For this version of CBO-ReEDS, real GDP growth in EIA's AEO2023 "Reference" case most closely matches CBO's 2023 long-term projections (averaging 1.9 percent in AEO2023 versus 1.7 percent in CBO's projections for 2022 to 2050).
Annual Transmission Growth	Imposed a 1 terawatt-mile per year constraint on new transmission lines in CBO-ReEDS through 2050, roughly based on annual rates of construction of new transmission lines from 2017 to 2022.
Siting of Wind and Solar Generators	Used the "Limited Access" siting scenarios from NREL's ReEDS for onshore wind, offshore wind, and utility-scale solar generators.

Data sources: Congressional Budget Office, the National Renewable Energy Laboratory's Annual Technology Baseline (https://atb.nrel.gov), and the Energy Information Administration's Annual Energy Outlook (www.eia.gov/outlooks/aeo).

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory's Regional Energy Deployment System (NREL's ReEDS) model.

AEO = *Annual Energy Outlook*; ATB = Annual Technology Baseline; GDP = gross domestic product.

Table 2. [Return to Text]

Description of Scenarios in CBO-ReEDS

Case Name	Description
Reconciliation Case (Base Case)	CBO's base-case projection of the 2022 reconciliation act on the electric power sector. PTC and ITC include the 5x multiplier for meeting wage and apprenticeship requirements. Onshore wind, offshore wind, and advanced nuclear are eligible for the 10 percent domestic content bonus starting in 2023. 5 percent bonus for energy communities for all clean generators.
No Reconciliation Case	Similar to the base case but excludes the 2022 reconciliation act. Inputs are based on EIA's AEO2023 "No IRA" case.
Sensitivities:	Same as the base case, except for the following:
Low Bonus Credit Uptake	No domestic content or energy community bonuses applied to the ITC and PTC for any technology.
High Bonus Credit Uptake	Domestic content and energy community bonuses are set at full value for all technologies for the ITC and PTC.
Low Natural Gas Prices	Natural gas prices are based on EIA's AEO2023 "High Oil and Gas Supply" scenario.
High Natural Gas Prices	Natural gas prices are based on EIA's AEO2023 "Low Oil and Gas Supply" scenario.
Low Clean Generator Costs	Costs of new renewable energy, nuclear, and storage technologies are based on EIA's AEO2023 "Low Zero-Carbon Technology Cost" scenario.
High Clean Generator Costs	Costs of new renewable energy, nuclear, and storage technologies are based on EIA's AEO2023 "High Zero-Carbon Technology Cost" scenario.
Low Demand	Electricity demand is based on EIA's AEO2023 "Low Growth" scenario.
High Demand	Electricity demand is based on EIA's AEO2023 "High Growth" scenario.

Data source: Congressional Budget Office.

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory's Regional Energy Deployment System (NREL's ReEDS) model.

AEO2023 = *Annual Energy Outlook 2023*; EIA = Energy Information Administration; IRA = Inflation Reduction Act (another name for the 2022 reconciliation act); ITC = investment tax credit; PTC = production tax credit.

Table 3. [Return to Text]

Share of Clean Generation, by Scenario

Percent

	2020	2030	2040	2050
No Reconciliation Act	41	52	53	55
Reconciliation Act	-	65	74	83
Low Bonus Credit Uptake	-	63	71	80
High Bonus Credit Uptake	-	68	78	73
Low Natural Gas Prices	-	63	70	75
High Natural Gas Prices	-	72	82	90
Low Clean Generator Costs	-	68	82	80
High Clean Generator Costs	-	58	61	64
Low Demand	-	65	74	83
High Demand	-	65	74	83

Data source: Congressional Budget Office, using CBO-ReEDS.

Clean generation includes battery storage, pumped storage hydropower, Canadian hydropower imports, and distributed generation such as rooftop solar in addition to utility-scale renewable and nuclear power generation.

Table 4. [Return to Text]

Summary of Results

	Annual Emissions in 2050 (BMT CO_2)	Cumulative Emissions (BMT CO_2)	Cumulative Abatement (BMT CO_2)	Average Wholesale Price in 2050 ($/MWh)	Abatement Cost ($/MT CO_2)
No Reconciliation	1.16	19.34	-	$56.77	-
Reconciliation	0.39	10.39	8.95	$50.34	$43.50
Reconciliation, Low Bonus Credit Uptake	0.45	11.00	8.34	$51.63	$45.07
Reconciliation, High Bonus Credit Uptake	0.65	10.24	9.10	$51.92	$42.40
Reconciliation, Low Natural Gas Price	0.53	10.68	7.67	$45.79	$47.44
Reconciliation, High Natural Gas Price	0.38	11.12	8.04	$54.24	$42.64
Reconciliation, Low Clean Generator Costs	0.49	9.49	8.31	$49.04	$29.88
Reconciliation, High Clean Generator Costs	0.82	13.42	6.70	$57.90	$61.68
Reconciliation, Low Demand	0.37	10.06	8.59	$49.60	$40.42
Reconciliation, High Demand	0.43	10.69	9.36	$50.63	$41.39

Data source: Congressional Budget Office, using CBO-ReEDS.

Emissions are reported in billions of metric tons of carbon dioxide (BMT CO_2). Cumulative emissions and abatement costs were calculated biennially over the 2022–2050 period, relative to the corresponding “No Reconciliation” scenario. A policy’s abatement cost is calculated as the sum of private and public costs reported in CBO-ReEDS divided by the cumulative abatement over the period. Additional details on this calculation are provided in the appendix.

MT = metric ton; MWh = megawatt-hour.

Table A-1. [Return to Text]

Constraints on Siting Available in ReEDS

Siting Exclusion Category	Open Access Scenario	Reference Access Scenario	Limited Access Scenario
Infrastructure			
Setbacks to transmission rights-of-way, railroads, roads, building structures[a]	Structure only, no setback	Setback = 1.1x wind turbine tip height	Setback = 3x wind turbine tip height
Urban areas and airports	Excluded	Excluded	Excluded
Radar	—	4-km NEXRAD, 9-km SRR/LRR	NEXRAD and SRR/LRR line-of-sight
Regulatory			
Documented state and county setback and height ordinances[a]	—	Applied	Applied
Protected public lands and conservation easements	Excluded	Excluded	Excluded
Other federal lands	—	—	Excluded
Physical			
Slope >25%	—	Excluded	Excluded
Mountainous landforms and high (>9,000 ft) elevation	Excluded	Excluded	Excluded
Water and wetlands (with 305-m buffer)	Excluded	Excluded	Excluded

Reprinted from Anthony Lopez and others, "Land Use and Turbine Technology Influences on Wind Potential in the United States," *Energy*, vol. 223 (May 2021), https://doi.org/10.1016/j.energy.2021.120044.

CBO-ReEDS is an adapted version of the National Renewable Energy Laboratory's Regional Energy Deployment System (NREL's ReEDS) model. For this paper, CBO-ReEDS used the "Limited Access" siting scenario, with the exclusions for onshore wind presented in the rightmost column of the table.