Stuart Cohen
National Renewable Energy Laboratory
May 14th, 2024

Many slides and figures are credited to other ReEDS team members and NREL staff.

Outline

A brief history of ReEDS

Brief, not total

ReEDS was born on a basic premise

"The large scope and focus on today's dominant conventional energy forms [in existing models] do not allow a detailed treatment of the more important issues for wind energy technologies."

From: Short, W., N. Blair, D. Heimiller, and V. Singh (2003). Modeling the long-term market penetration of wind in the United States

The Evolution of ReEDS

Photo by Josh Bauer and Bryan Bechtold, NREL

- **1999** Spreadsheet model uses geospatial data for regional grid planning
- **2001** DOE funds WinDS optimization model; documentation and first analysis is presented at AWEA in 2003
- **2008** WinDS becomes Regional Energy Deployment System (ReEDS)
- **2012** Powered by ReEDS, the *Renewable Electricity Futures Study* is released—the catalyst for a decade of visionary studies
- **2017** ReEDS is re-coded for improved efficiency and capabilities
- **2019** NREL releases ReEDS as an open-access tool
- **2023** ReEDS gains new spatial and temporal flexibility

Continual advancement is possible by the broader ReEDS team

ReEDS

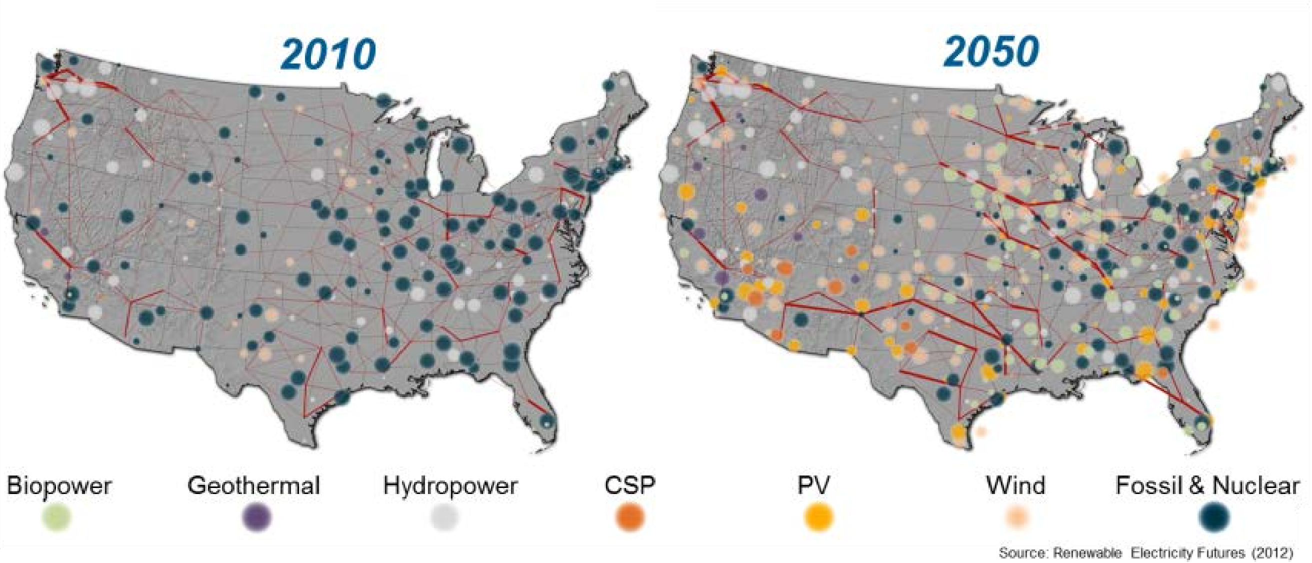
+ Many others who provide critical data, input, and guidance for the model

What does ReEDS do?

Overview

ReEDS

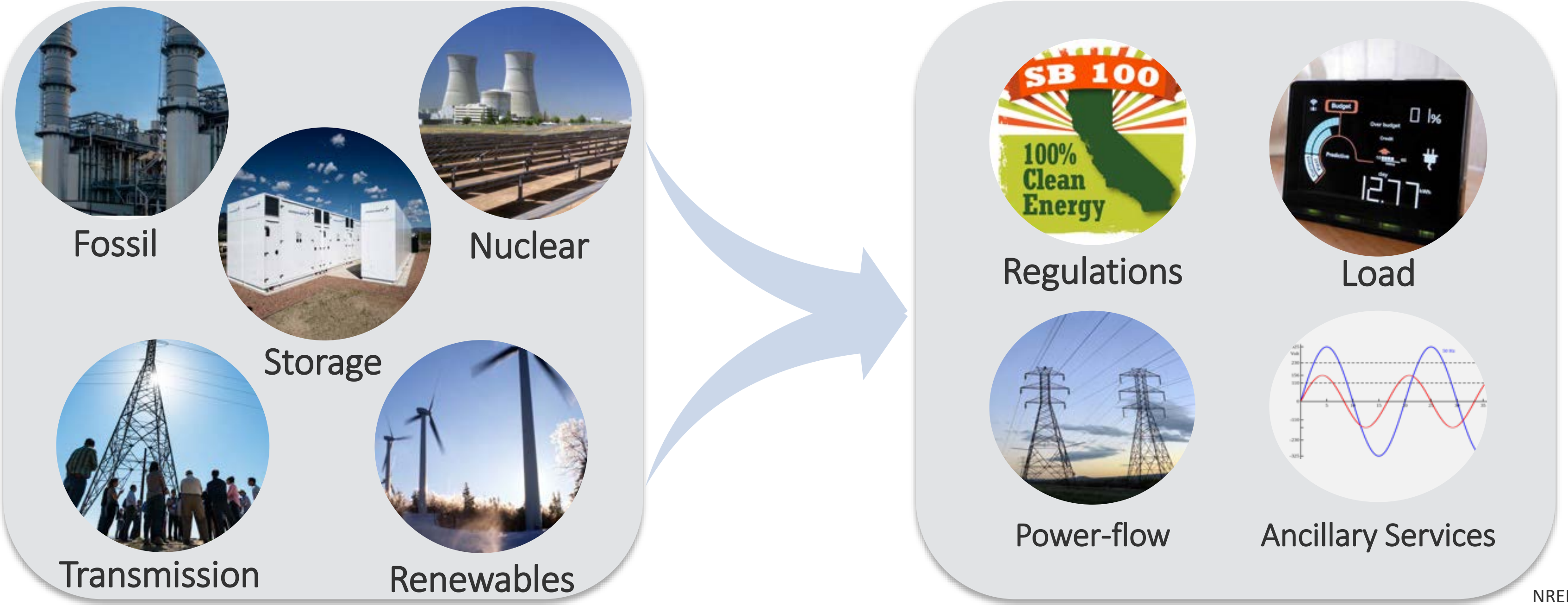
What does ReEDS do?



Given a set of input assumptions, ReEDS simulates the evolution and operation of US generation, storage, transmission, and some carbon mitigation technologies

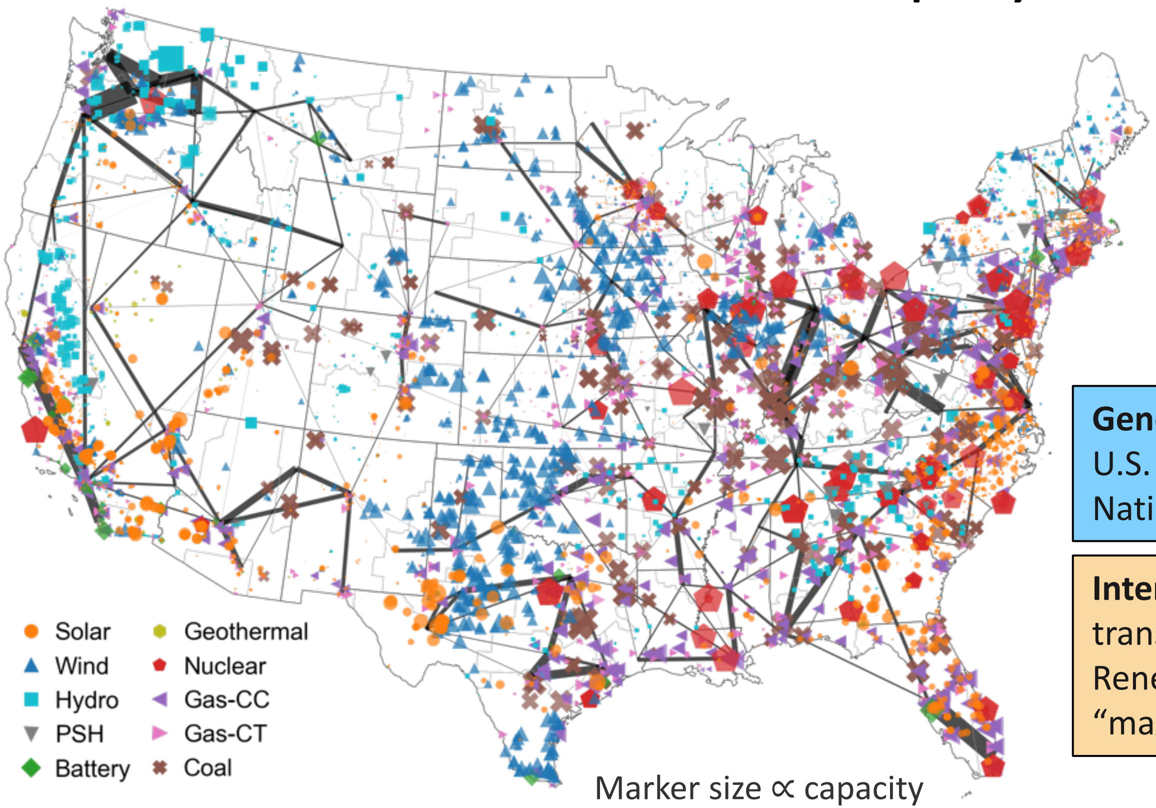
How does ReEDS work?

ReEDS uses **optimization** to identify the **least cost investment and operation** of grid assets that simultaneously meets load, all other electricity service requirements, and other physical, environmental, or policy constraints.



Key inputs: Existing and Planned Capacity

2022 Generation and Transmission Capacity

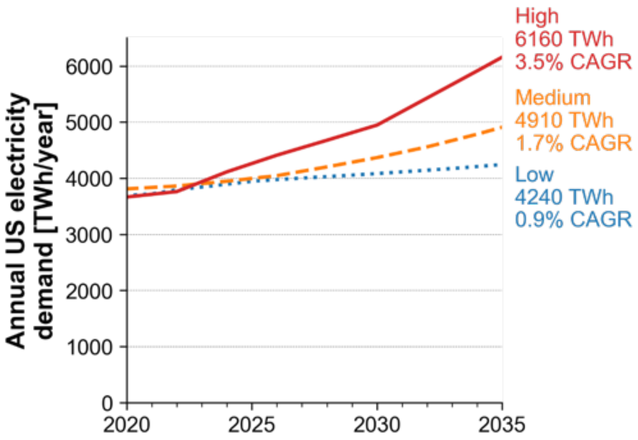


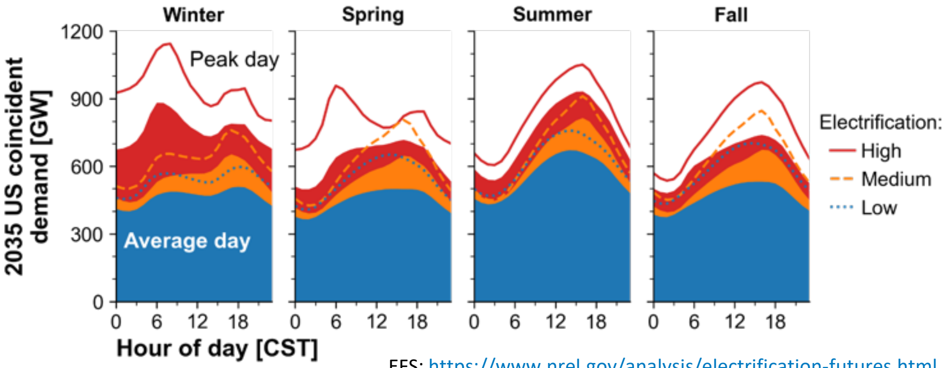
Generation capacity based on data from the U.S. Energy Information Administration (EIA) National Energy Modeling System (NEMS)

Interface transmission limits derived from transmission data from The North American Renewable Integration Study (NARIS) using a “maximum potential flow” optimization

Key inputs: Demand and Technology Parameters

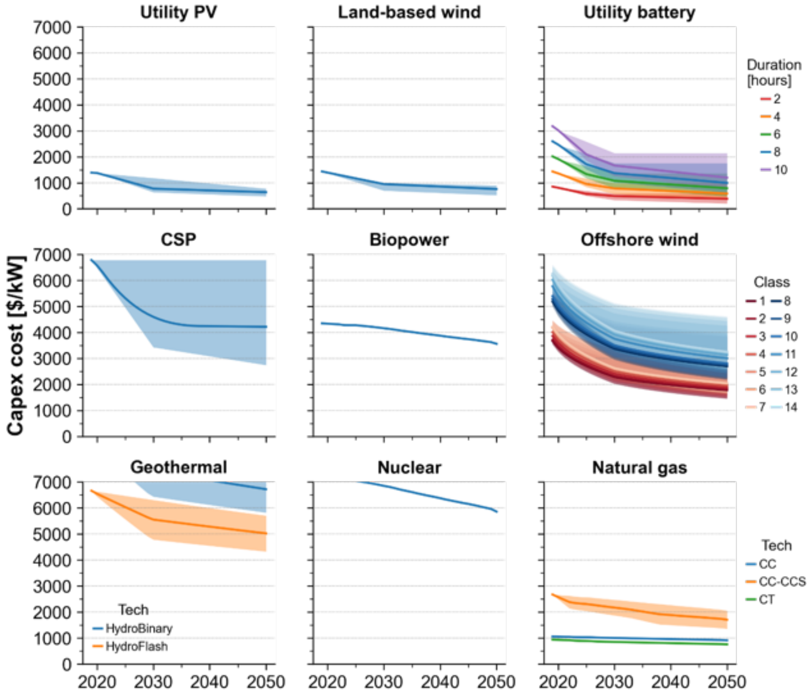
Demand





EFS: https://www.nrel.gov/analysis/electrification-futures.html
AEO: https://www.eia.gov/outlooks/aeo/

Technology cost & performance



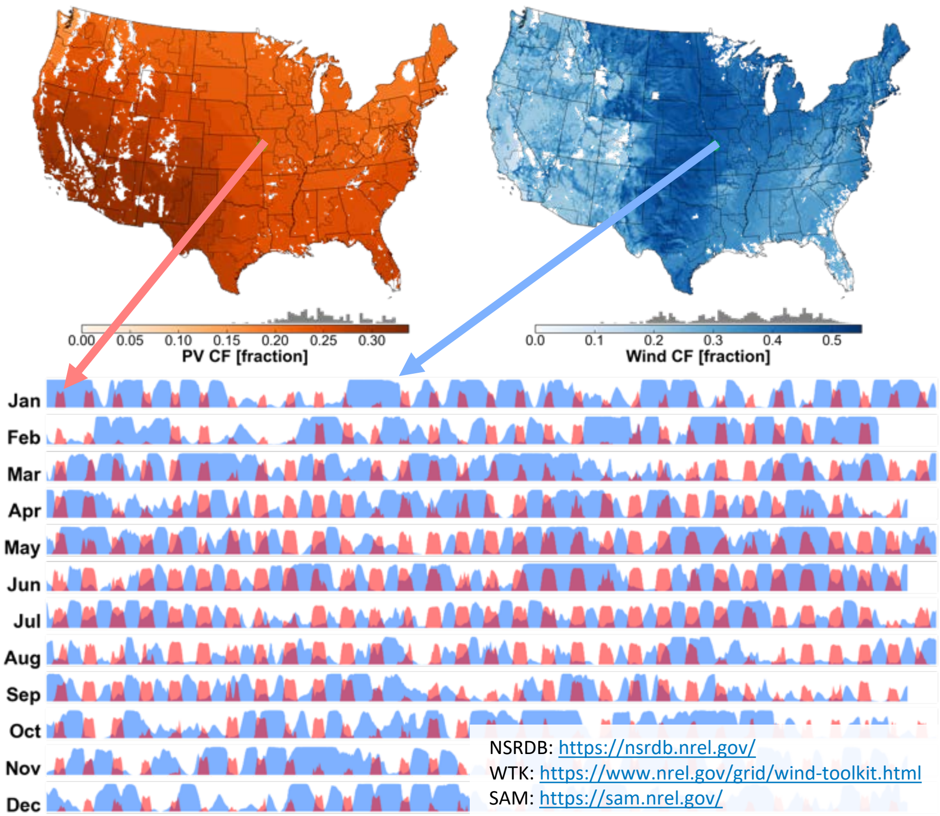
Annual Technology Baseline (ATB): https://atb.nrel.gov/

+ Fuel costs from EIA Annual Energy Outlook (AEO)
+ Interconnection spur line costs

Key inputs: Renewable Resource Availability

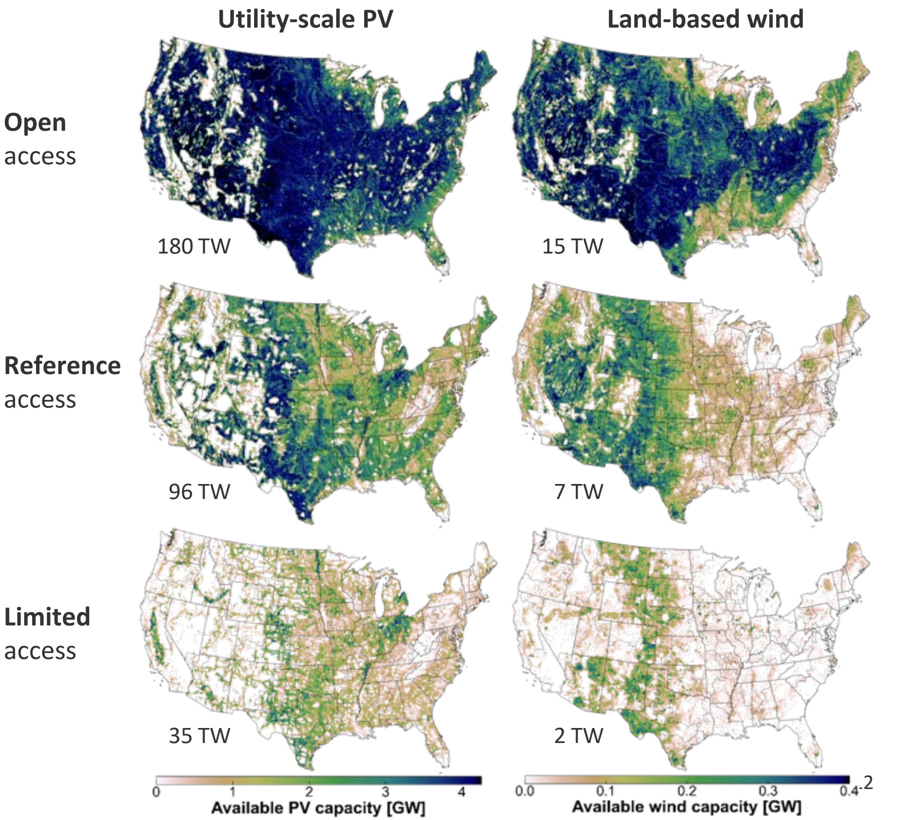
https://github.com/NREL/reV

Temporal availability



NSRDB: https://nsrdb.nrel.gov/
WTK: https://www.nrel.gov/grid/wind-toolkit.html
SAM: https://sam.nrel.gov/

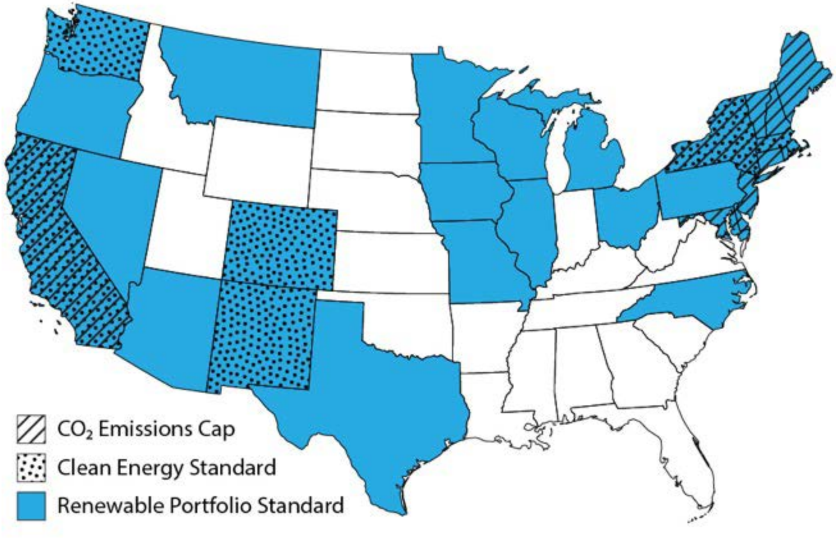
Spatial availability



Key inputs: State and National Policies

Regional and state policies

(Updated annually)

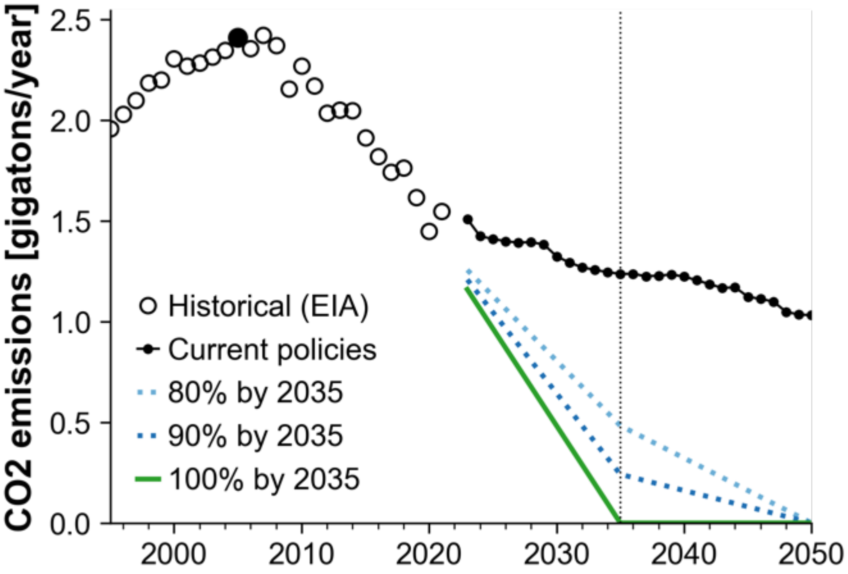


The Prospective Impacts of 2019 State Energy Policies on the U.S. Electricity System (Mai et al., 2020)

Including state-specific:

- Mandates and RPS carve-outs (e.g., offshore wind, solar)
- Technology deployment constraints (e.g., nuclear)

National policies

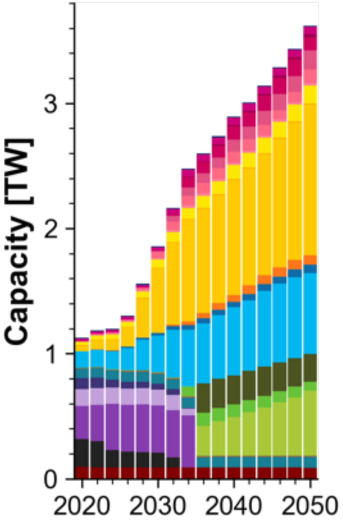


Existing and possible policies related to:

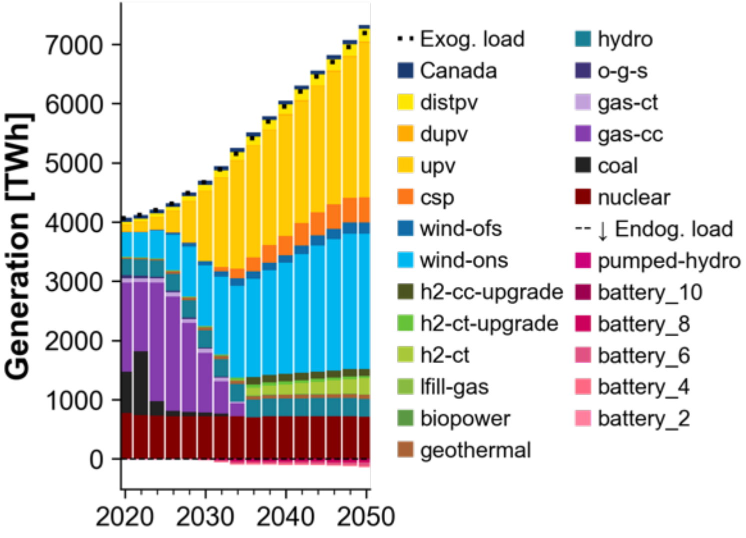
- Renewable Portfolio Standard / Clean Energy Standard [%]
- Emissions rate constraint [gCO_2/kWh]
- Technology-specific incentives (ITC, PTC, 45Q, etc.)

Key Outputs: Capacity and Generation

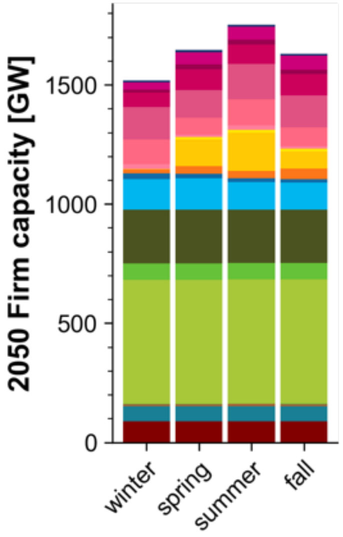
Capacity



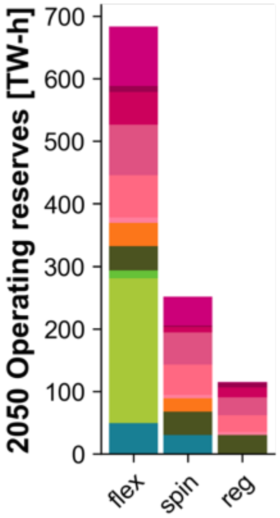
Generation



Firm capacity



Operating reserves

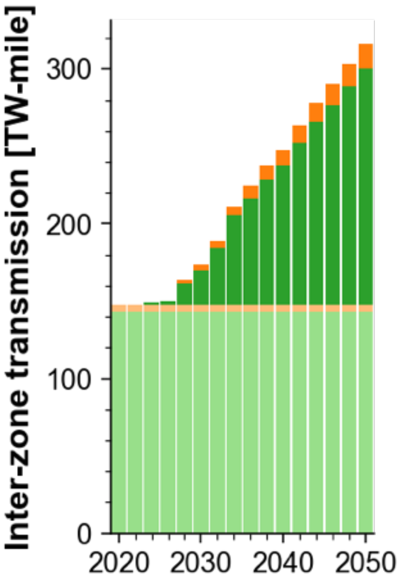


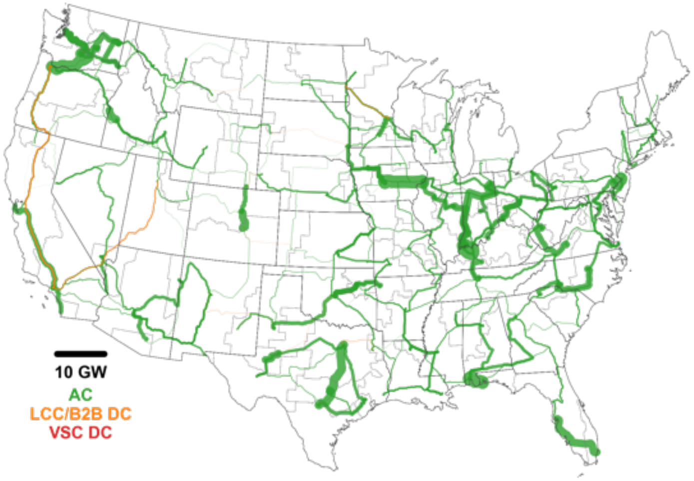
ILLUSTRATIVE modeling results

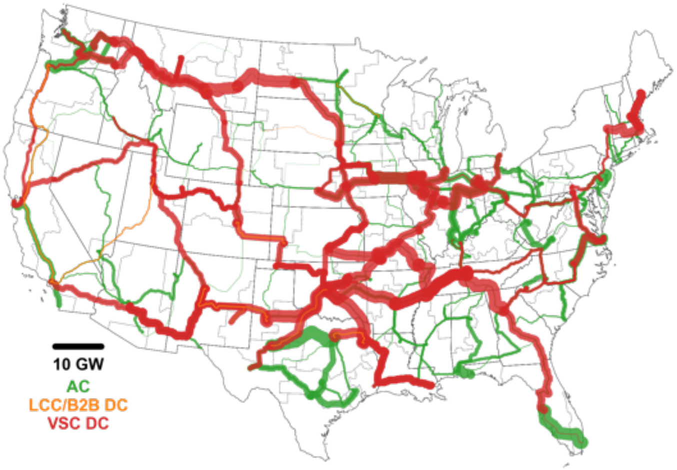
Key Outputs: Transmission

Transmission capacity expansion between model zones (134 zones shown)

Including AC, DC, and interties



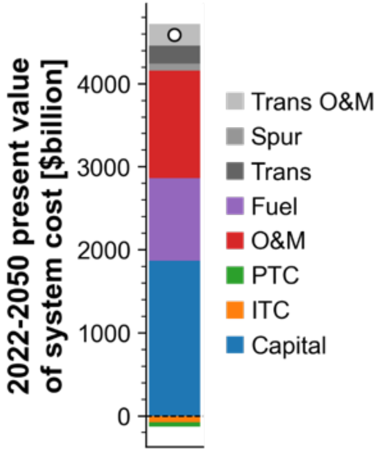




ILLUSTRATIVE modeling results

Key Outputs: System Costs and Average Prices

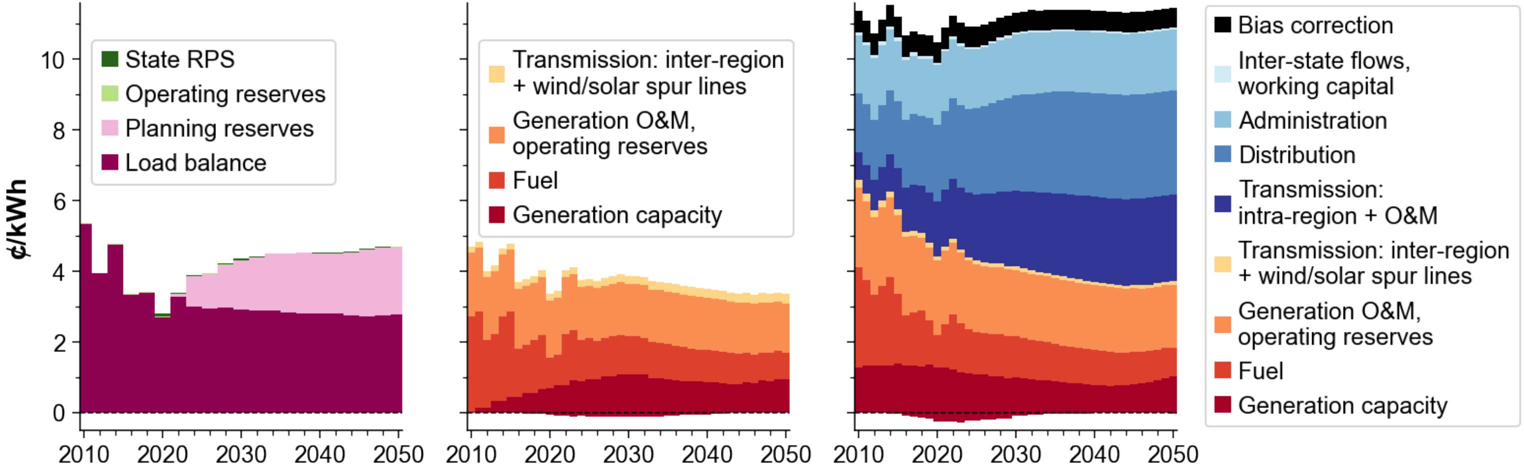
NPV of costs over full model horizon



Marginal price

System cost

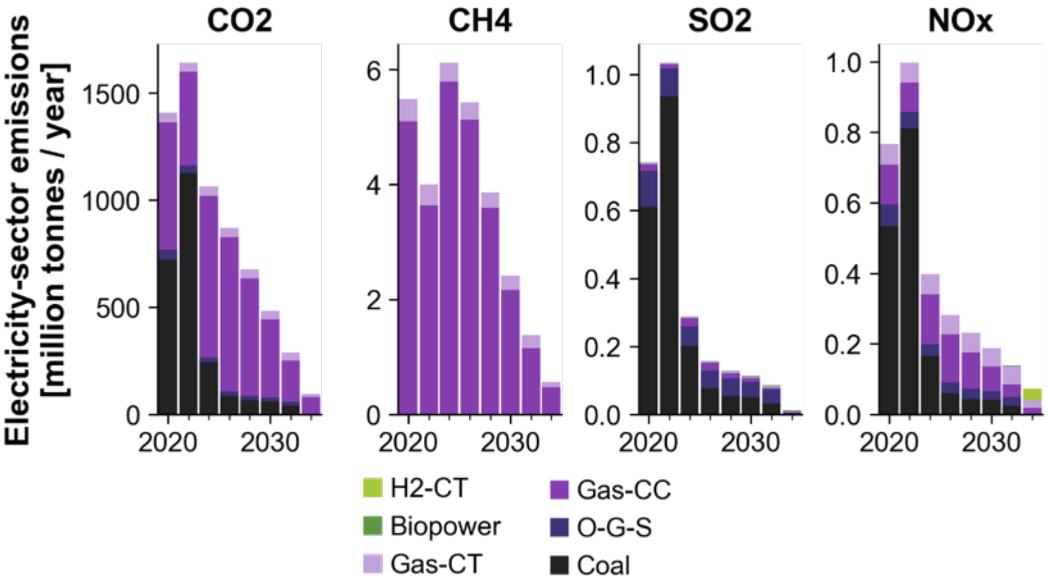
Retail rate



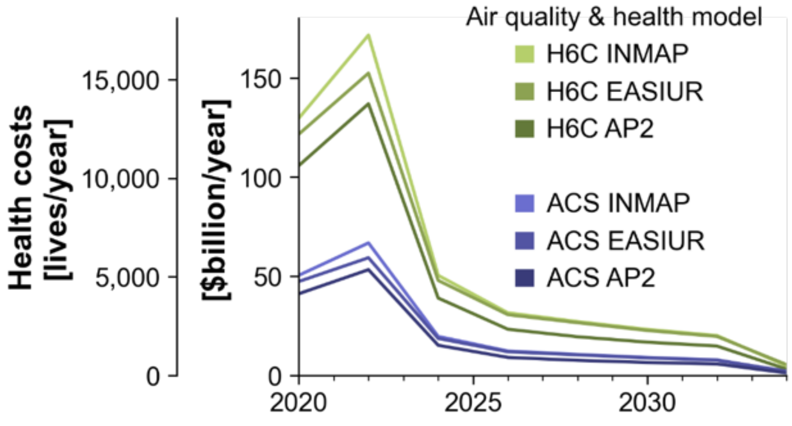
ILLUSTRATIVE modeling results

Key Outputs: Emissions and Health Impacts

Emissions (CO_2, CH_4, SO_2, NO_x)



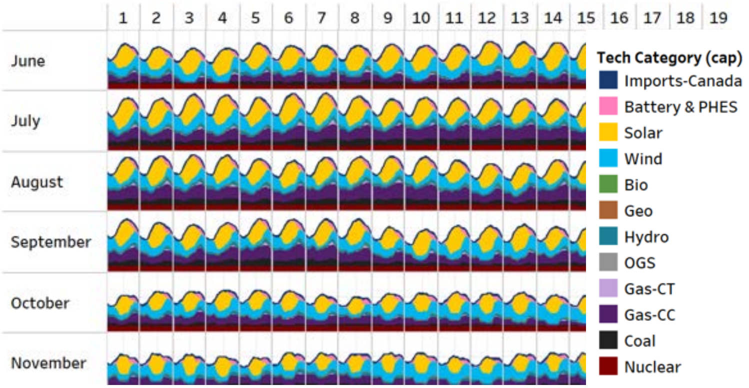
Health impacts

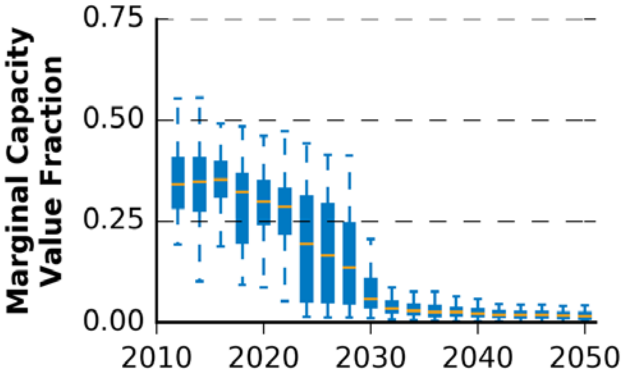


ILLUSTRATIVE modeling results

ReEDS has numerous features and options tailored to study emerging grid trends

- 7-years of hourly data helps characterize firm capacity credit and curtailment
- Technologies are differentiated by sub-types, vintages, performance, and resource classes
- Spatial and temporal flexibility enables high-resolution regional case studies
- Endogenous CO_2 and H_2 production, transport, and storage facilitates new scenarios





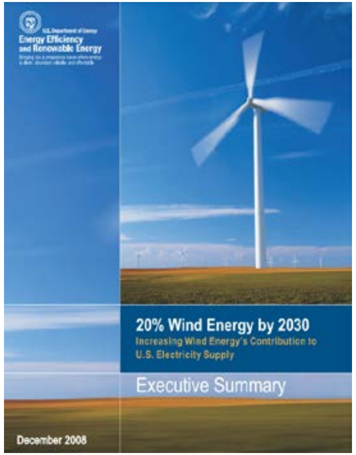
ILLUSTRATIVE modeling results

How is ReEDS used?

A few examples

Identifying decarbonization pathways for the electric sector

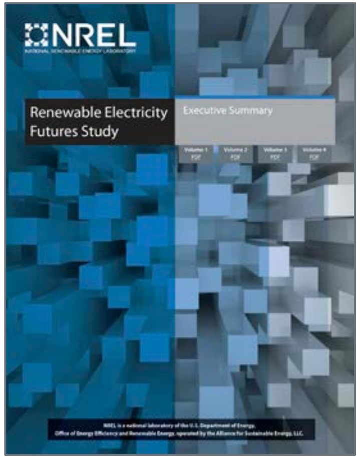
20% wind by 2030



20% Wind Study (2008)

https://www.nrel.gov/docs/fy08osti/41869.pdf

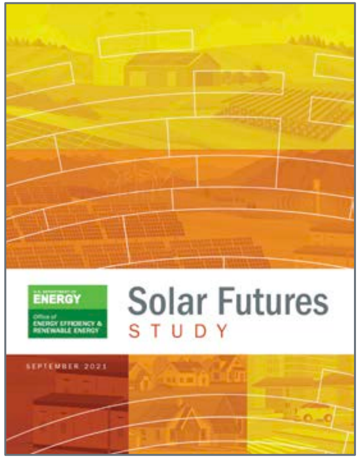
80% renewable by 2050



Renewable Electricity Futures Study (2012)

https://www.osti.gov/servlets/purl/1338443/

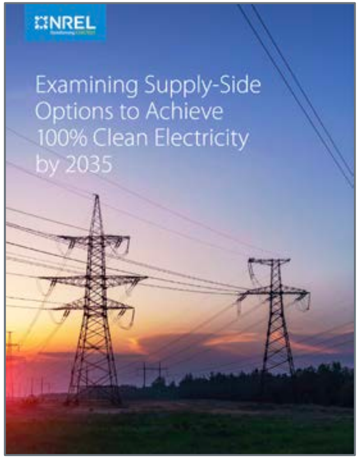
Zero-carbon by 2050



Solar Futures Study (2021)

https://www.energy.gov/sites/default/files/2021-09/Solar%20Futures%20Study.pdf

Zero-carbon by 2035

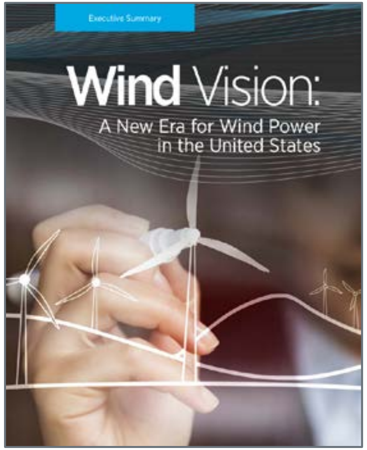


100% Clean Energy by 2035 Study (2022)

https://www.nrel.gov/docs/fy22osti/81644.pdf

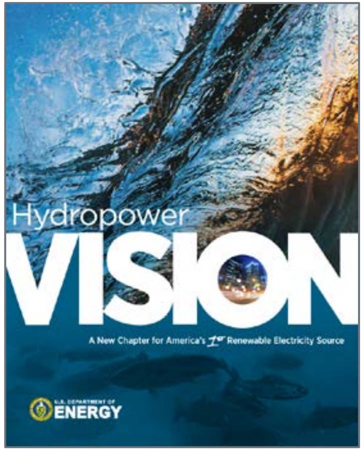
Exploring impacts of technology innovation

Wind Vision (2015)



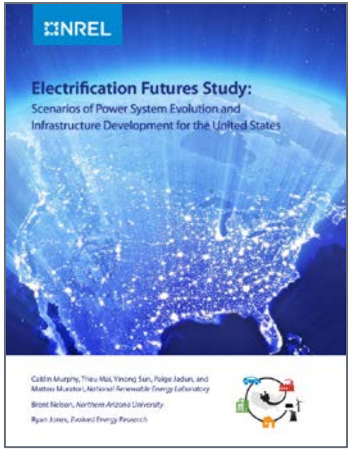
https://www.energy.gov/sites/prod/files/wv_executive_summary_overview_and_key_chapter_findings_final.pdf

Hydropower Vision (2016)



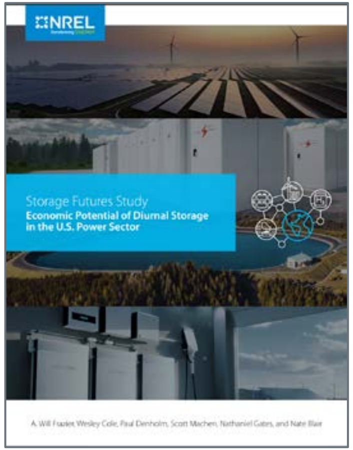
https://www.energy.gov/sites/default/files/2018/02/f49/Hydropower-Vision-021518.pdf

Electrification Futures (2021)



https://www.nrel.gov/docs/fy21osti/72330.pdf

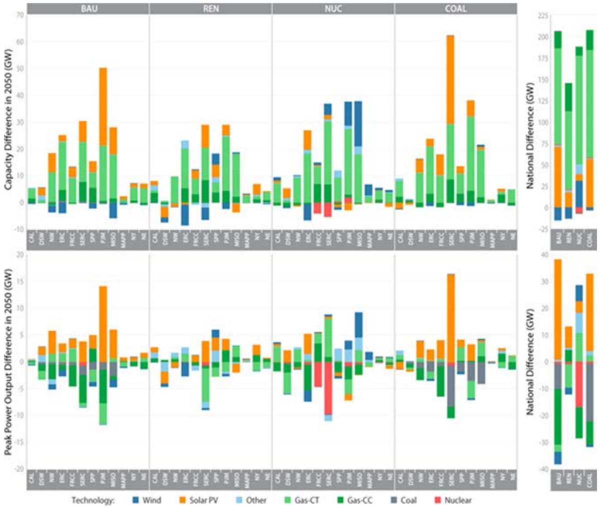
Storage Futures (2021)



https://www.nrel.gov/docs/fy21osti/77449.pdf

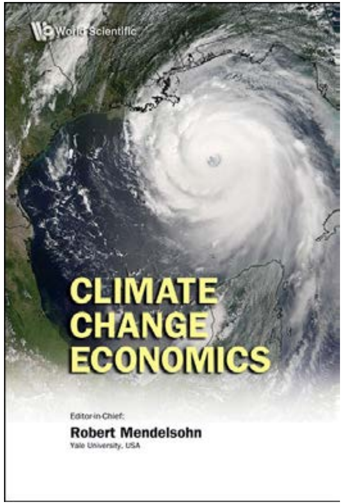
Mulisectoral interactions with the electric sector

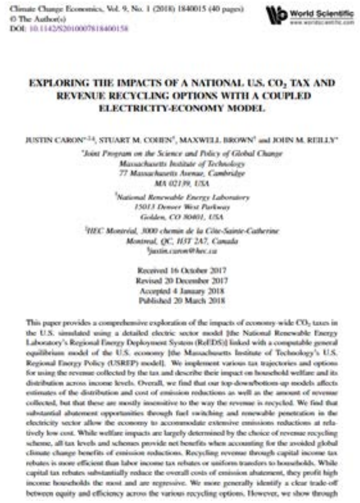
Energy-Water-Climate Interactions



https://www.osti.gov/pages/servlets/purl/1576487

Grid-Economy Interactions





Climate Change Economics, Vol. 9, No. 1 (2018) 1840015 (40 pages)
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DOI: 10.1142/S2010007818400158

EXPLORING THE IMPACTS OF A NATIONAL U.S. CO_2 TAX AND REVENUE RECYCLING OPTIONS WITH A COUPLED ELECTRICITY-ECONOMY MODEL

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Revised 20 December 2017
Accepted 4 January 2018
Published 20 March 2018

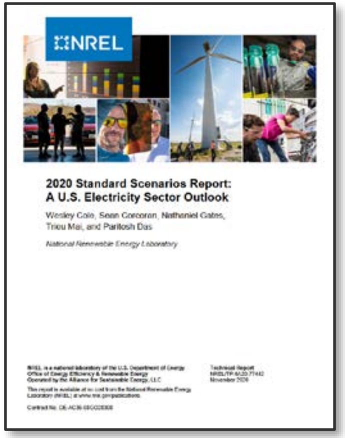
This paper provides a comprehensive exploration of the impacts of economy-wide CO_2 taxes in the U.S. simulated using a detailed electric sector model [the National Renewable Energy Laboratory's Regional Energy Deployment System (ReEDS)] linked with a computable general equilibrium model of the U.S. economy [the Massachusetts Institute of Technology's U.S. Regional Energy Policy (USREP) model]. We implement various tax trajectories and options for using the revenue collected by the tax and describe their impact on household welfare and its distribution across income levels. Overall, we find that our top-down/bottom-up models affects estimates of the distribution and cost of emission reductions as well as the amount of revenue collected, but that these are mostly insensitive to the way the revenue is recycled. We find that substantial abatement opportunities through fuel switching and renewable penetration in the electricity sector allow the economy to accommodate extensive emissions reductions at relatively low cost. While welfare impacts are largely determined by the choice of revenue recycling scheme, all tax levels and schemes provide net benefits when accounting for the avoided global climate change benefits of emission reductions. Recycling revenue through capital income tax rebates is more efficient than labor income tax rebates or uniform transfers to households. While capital tax rebates substantially reduce the overall costs of emission abatement, they profit high income households the most and are regressive. We more generally identify a clear trade-off between equity and efficiency across the various recycling options. However, we show through

https://www.worldscientific.com/doi/abs/10.1142/S2010007818400158

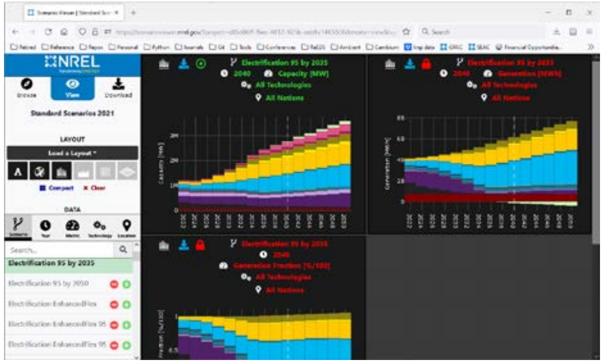
NREL’s Standard Scenarios

2023 marks the 9th edition of a report on a wide range of possible futures for the U.S. electric sector

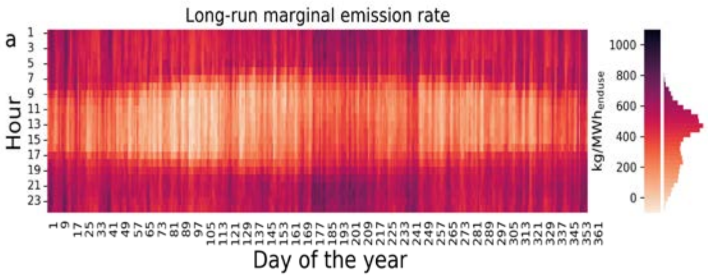
Report



Scenario Viewer and Downloader



Cambium Database
(hourly metrics for a subset of scenarios)

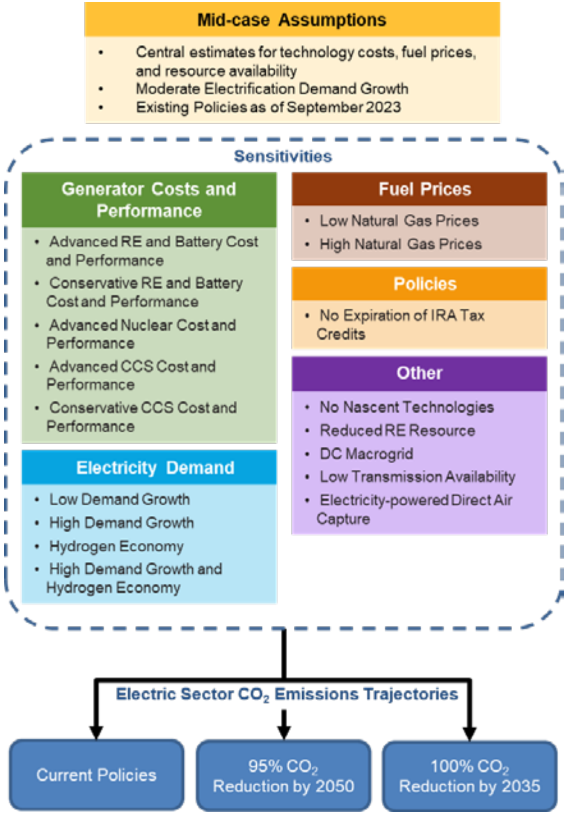


https://www.nrel.gov/docs/fy24osti/87724.pdf

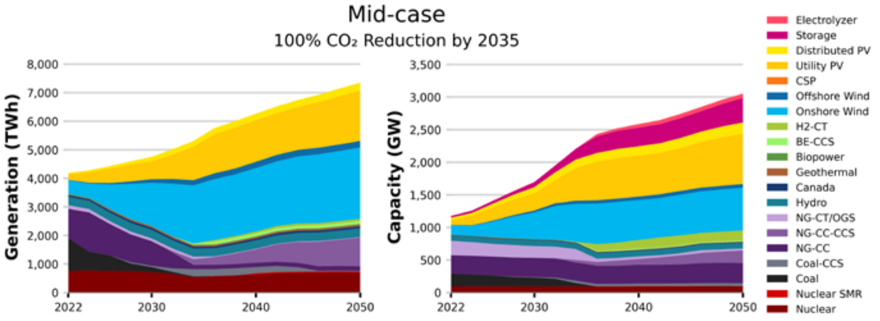
https://www.nrel.gov/analysis/standard-scenarios.html

Dozens of scenarios reflect the latest thinking about possible U.S. electric sector futures

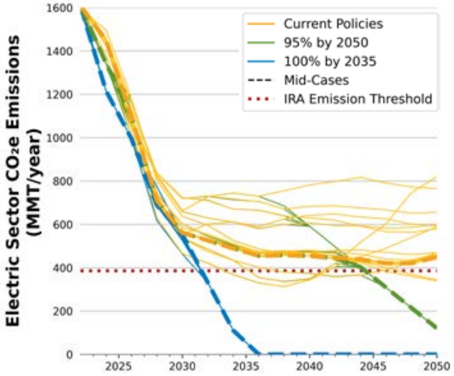
Scenarios



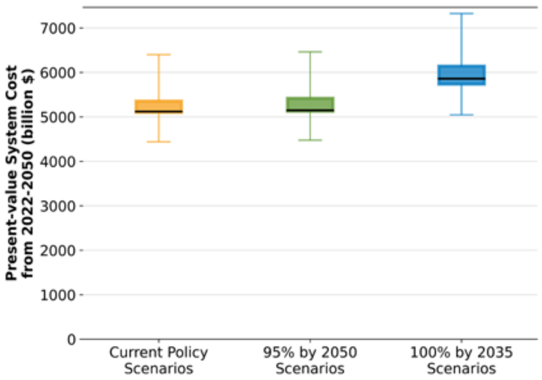
Grid Mixes



Emissions



Cost



Expanded analysis with external users

ELSEVIER

Energy
Volume 294, 1 May 2024, 130727

The impacts of local wind power objection on the power system of the Midcontinent Independent System Operator area

Nhu "Claire" Nguyen [a], David R. Johnson [b c]

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[b] School of Industrial Engineering, Purdue University, West Lafayette, USA
[c] Department of Political Science, Purdue University, West Lafayette, USA

https://www.sciencedirect.com/science/article/pii/S0360544224004997

ELSEVIER

The Electricity Journal
Volume 36, Issue 8, October 2023, 107334

A new era for rural electric cooperatives: New clean energy investments, supported by federal incentives, will reduce rates, emissions, and reliance on outside power

Nikit Abhyankar [a], Umed Paliwal [a], Michael O'Boyle [b], Michelle Solomon [b], Jeremy Fisher [c], Amol Phadke [a]

[a] University of California, Berkeley, United States
[b] Energy Innovation, LLC, United States
[c] The Sierra Club, United States

https://www.sciencedirect.com/science/article/pii/S104061902300101X

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Article | Open access | Published: 05 December 2022

Air pollution disparities and equality assessments of US national decarbonization strategies

Teagan Goforth & Destenie Nock

Nature Communications 13, Article number: 7488 (2022) | Cite this article

8649 Accesses | 21 Citations | 34 Altmetric | Metrics

https://www.nature.com/articles/s41467-022-35098-4

NBER NATIONAL BUREAU of ECONOMIC RESEARCH

Home > Research > Working Papers > Robust Decarbonization of the US Power...

Robust Decarbonization of the US Power Sector: Policy Options

James H. Stock & Daniel N. Stuart

https://www.nber.org/papers/w28677

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Perceptions of risk in increasingly capital-intensive electricity grids : measuring the impacts of accurate cost of capital representation on investment planning for future energy systems

Access full-text files
CORCORAN-THESIS-2022.pdf (3.77 MB)

Date
2022-05-11

Authors
Corcoran, James Sean

Abstract
The U.S. electric grid is experiencing unprecedented change as the system continues a path toward a more diversified and decarbonized generation mix, with increased investment in wind, solar, storage and other energy transition technologies. Concurrently, market structures continue their evolution away from highly regulated monopolies and towards competitive markets, expanding the share of deployable capital that engages with the power sector and introducing a broader range of investor classes and preferences. These two factors create complex financing dynamics that ultimately determine which set of technologies are deployed onto the grid. However, many of the leading tools used by stakeholders to guide long-term system planning do not sufficiently account for these dynamics with oversimplified financing cost representations. Through the modeling of the ERCOT electric grid using the Regional Energy Deployment System (ReEDS), this study assesses the significance of improved representation of financing costs for the various stakeholders who interact with large-scale capacity expansion models. This is achieved through the exploration of two distinct but connected research objectives, the first being relevant to energy modelers and the second to policymakers. First, the impacts of repre-

https://repositories.lib.utexas.edu/items/0512ad20-dfb0-4baf-a688-4e20e4908ed5

Analyzing the Financial Implications of Increasing Renewable Energy Penetration in Indonesia's Power System

1st Umi Rusilowati, Department of Management, Pamulang University, Tangerang Selatan, Indonesia
2nd Nuke Puji Lestari Santoso, Department of Information System, University of Raharja, Tangerang, Indonesia
3rd Aulia Azmi, Department of Science and Technology, University of Raharja, Tangerang, Indonesia
4th Sabda Maulana, Department of Information System, University of Raharja, Tangerang, Indonesia
5th Adam Faturahman, Department of Information System, University of Raharja, Tangerang, Indonesia

https://ieeexplore.ieee.org/abstract/document/10455284

How to access and use ReEDS

Become a user

Download and use ReEDS yourself

Regional Energy Deployment System

The Regional Energy Deployment System (ReEDS) is NREL's flagship capacity planning model for the power sector.

The model simulates the evolution of the bulk power system—generation and transmission—from present day through 2050 or later.

Learn more about the ReEDS model on GitHub, check out the user guide for suggestions on improving usage of the model, or watch a video training series. Each tutorial focuses on a different aspect of the model and includes a demonstration by a ReEDS developer. For additional questions about the model, please contact the ReEDS staff.

ReEDS Model Is Now Available

The ReEDS model is now open source.

Access on **ReEDS GitHub**.

README | GPL-3.0 license

ReEDS 2.0

Welcome to the Regional Energy Deployment System (ReEDS) Model!

This GitHub repository contains the source code for NREL's ReEDS model. The ReEDS model source code is available at no cost from the National Renewable Energy Laboratory. The ReEDS model can be downloaded or cloned from https://github.com/NREL/ReEDS-2.0.

A ReEDS training video (based on the 2020 version of ReEDS) is available on the NREL YouTube channel at https://youtu.be/aGj3Jnspk9M?si=iqCRNn5MbGZc8ZIO.

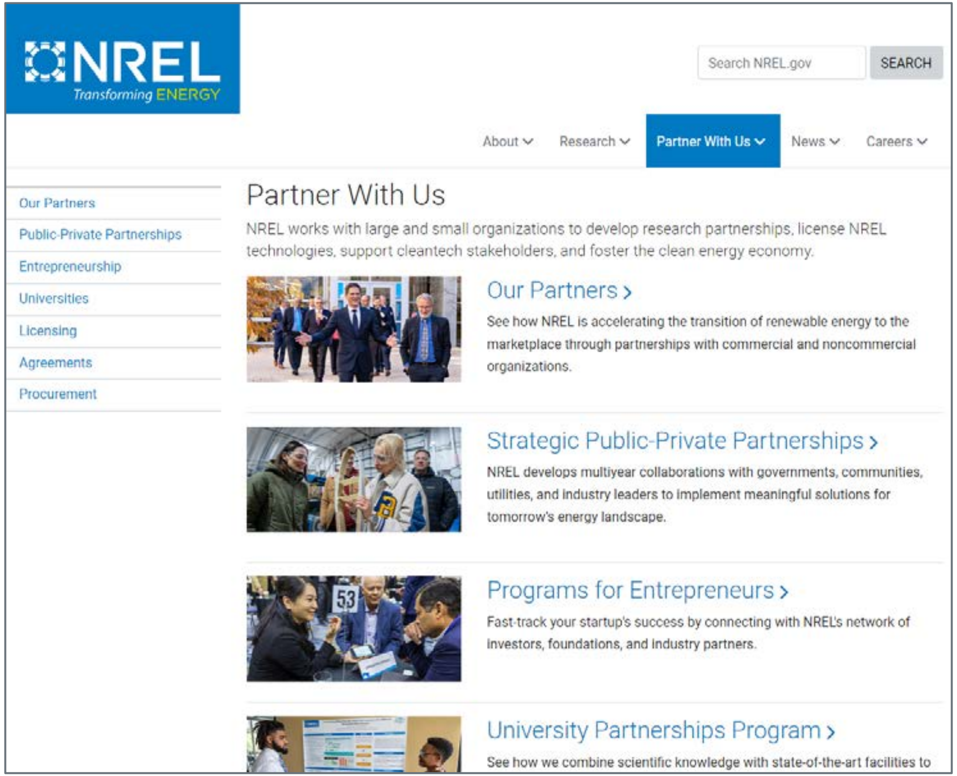
Contents

https://www.nrel.gov/analysis/reeds/

https://github.com/NREL/ReEDS-2.0

Collaborate with the NREL ReEDS team

- ReEDS staff listing: https://www.nrel.gov/analysis/reeds/staff.html
- Information on NREL partnerships: https://www.nrel.gov/workingwithus/
- Information on NREL internships: https://www.nrel.gov/careers/internships.html
- U.S. Department of Energy funding opportunities: https://www.energy.gov/funding-financing
- NREL is eligible and interested in a wide variety of non-DOE funding opportunities



So, in Conclusion:

1. ReEDS is a continually evolving, versatile tool to explore power sector futures using a variety of performance, economic, and environmental metrics.

2. The model has advanced features tailored to study renewable energy and other technologies, policies, and institutions directed towards decarbonization.

3. You can become a ReEDS user by downloading the source code and/or working with the ReEDS team.

Thank You. Questions?

www.nrel.gov/analysis/reeds

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