Energy Modeling for Decarbonization Planning:

Advice and Resources for States

April 10, 2023

Energy Modeling for Decarbonization Planning

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www.cesa.org

State of California Energy Commission

Connecticut Green Bank

Department of Energy & Environment

Energy Trust of Oregon

IPA Illinois Power Agency

Maine Governor's Energy Office

State of New Hampshire Department of Energy

Massachusetts Clean Energy Center

Maryland Energy Administration

EGLE Michigan Department of Environment, Great Lakes, and Energy

BPU New Jersey Board of Public Utilities

New Jersey's cleanenergy program njcleanenergy.com

New Mexico emnrd Energy, Minerals and Natural Resources Department

New York State NYSERDA

mn Commerce Department

SMUD Powering forward. Together.

State of Rhode Island Office of Energy Resources

Vermont Department of Public Service Clean Energy Development Fund

Virginia Energy

Rhode Island Commerce Corporation

Commissioner Stephanie Garcia Richard New Mexico State Land Office

Illinois Commerce Commission ICC

OEI Wisconsin Office of Energy Innovation

Prairie Island Indian Community in the State of Minnesota

Washington State Department of Commerce

Connecticut Energy & Environment

DOER Massachusetts Department of Energy Resources

Oregon Department of Energy

Inclusive Prosperity Capital

MassDEP

OPC-DC Office of the People's Counsel

ADVOCACY | EDUCATION | PROTECTION

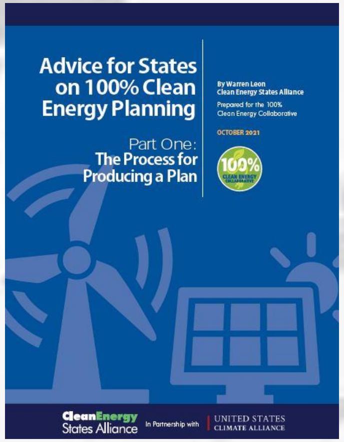
Clean Energy States Alliance | UNITED STATES CLIMATE ALLIANCE

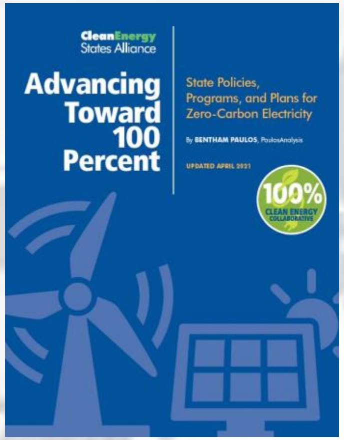
100% Clean Energy Collaborative Resources

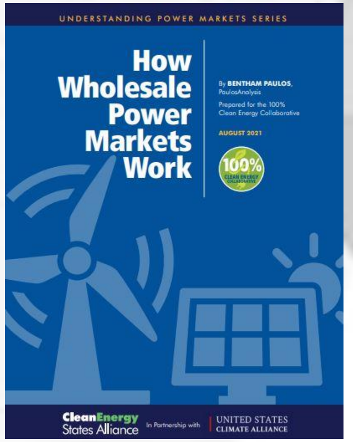
The 100% Collaborative produces frequent webinars, a monthly newsletter, and periodic reports. We also host working group meetings for state representatives.

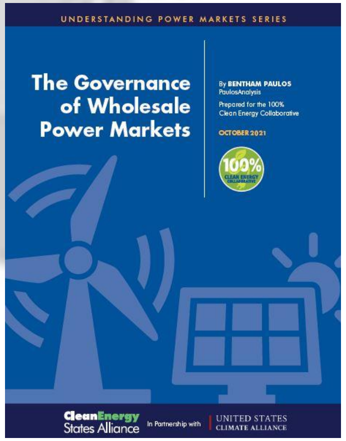
CESA's *Guide to 100% Clean Energy States* includes:

- Table of 100% Clean Energy States
- Map and Timelines of 100% Clean Energy States
- Summaries of State 100% Clean Energy Plans
- Visual Comparison of State 100% Clean Energy Plans
- State Legislation, Plans, Reports, and Other Documents
- State Monitoring, Reporting, and Verification (MRV) Procedures









CleanEnergy States Alliance

How Energy Modeling Works

The Uses and Limitations of Energy Modeling for Decarbonization Planning

CHARLES HUA
Research Fellow
Clean Energy States Alliance

BENTHAM PAULOS
PaulosAnalysis

Prepared for the 100% Clean Energy Collaborative

MARCH 2023

Read this report at CESA.org/100

Webinar Speakers

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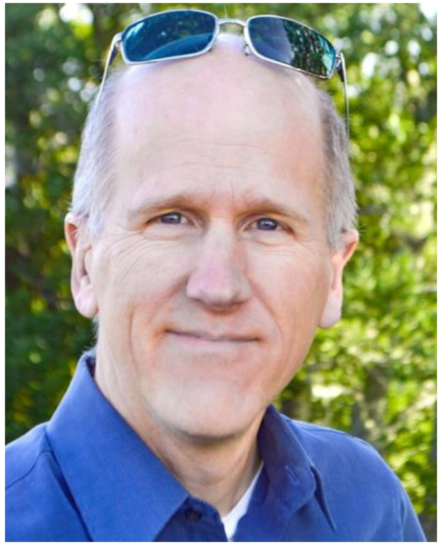
Senior Research Engineer, Grid Planning and Analysis Center, NREL

Nikit Abhyankar
Scientist, Electricity Markets and Policy Department, LBL

Charles Hua
Research Fellow, Clean Energy States Alliance



Bentham Paulos,
Senior Research Associate, Clean Energy States Alliance (moderator)

NREL Transforming ENERGY

BERKELEY LAB

Clean Energy States Alliance

Thank you for attending our webinar

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Learn more about the **100% Clean Energy Collaborative** at www.cesa.org/100

Upcoming Webinars

Implementing Community Programs Alongside Resilience Hub Development
Tuesday, April 25, 1-2pm ET

Progress Towards 100% Clean Energy: A State Leaders Roundtable
Wednesday, April 26, 3-4pm ET

Building a Resilient Workforce: The Detroit Clean Energy Contractor Accelerator Program
Wednesday, May 3, 1-2:30pm ET

Read more and register at www.cesa.org/webinars

How Energy Modeling Works

The Uses and Limitations of Energy Modeling for Decarbonization Planning

Charles Hua | 4.10.2023

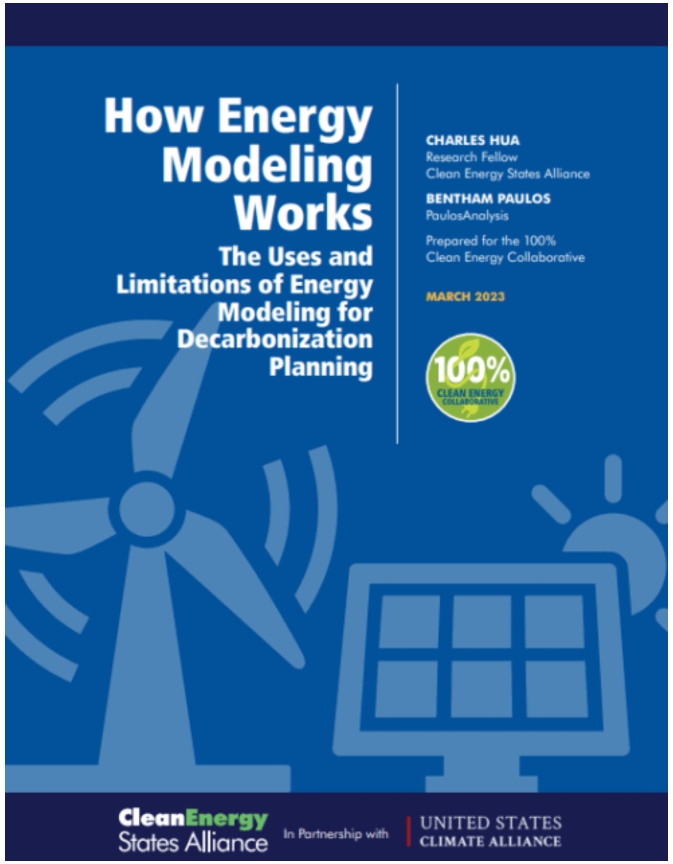
Roadmap

- What is energy modeling?
- Why is energy modeling important?
- How does energy modeling work?
- What are common pitfalls of energy modeling?
- What are some pieces of advice for energy modeling?

What is the aim of this report?

- To bridge the gap between technical and non-technical stakeholders who need to know how to interpret and act upon model results

- To discuss the capabilities, benefits, and limitations of energy modeling and decarbonization planning

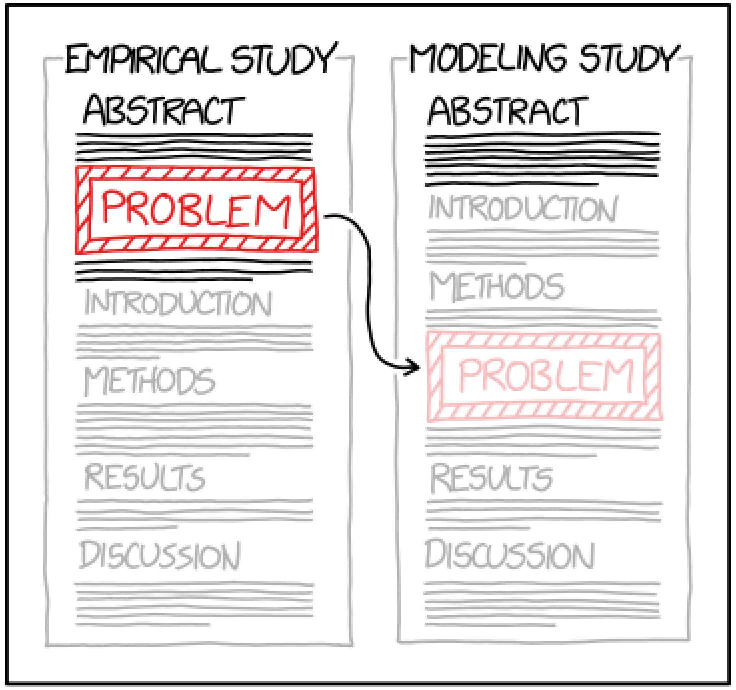


What is modeling?

What *really* is modeling?

- An effort to simulate the real world and its complex systems and conditions
  - Often using mathematical equations, algorithms, and software

- Three main components:
  1. Inputs
  2. Model
  3. Outputs



A MATHEMATICAL MODEL IS A POWERFUL TOOL FOR TAKING HARD PROBLEMS AND MOVING THEM TO THE METHODS SECTION.

Why do we need modeling?

- Because systems are complex!
- Models help break things down and make it easier to understand how specific inputs impact specific outputs.

"Prediction is difficult, especially about the future."

What are the limitations of modeling?

- Models are simplifications of reality
- Models may not work for all systems
  - Datasets may differ in quality
  - Models for specific scenarios may not generalize to broader conditions or settings
- Modeling is hard
  - Systems are fundamentally interconnected
    - e.g. economic, political, social systems
- …this often leads to many misconceptions!

"All models are wrong, but some are useful."

100% Clean Energy Collaborative

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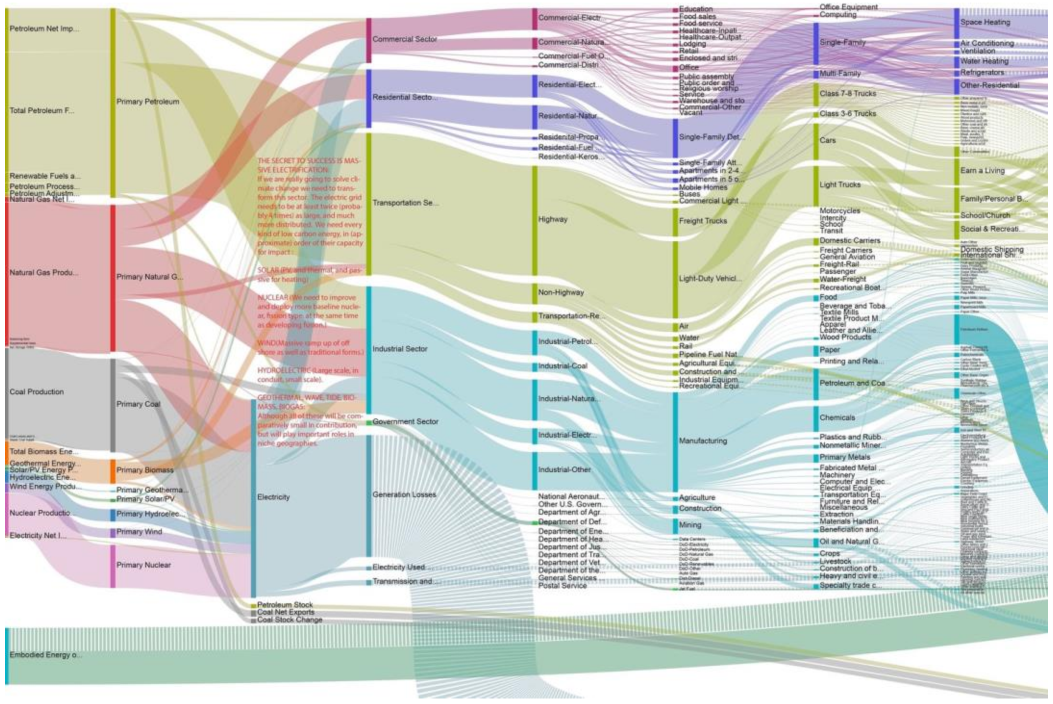
What are the misconceptions of modeling?

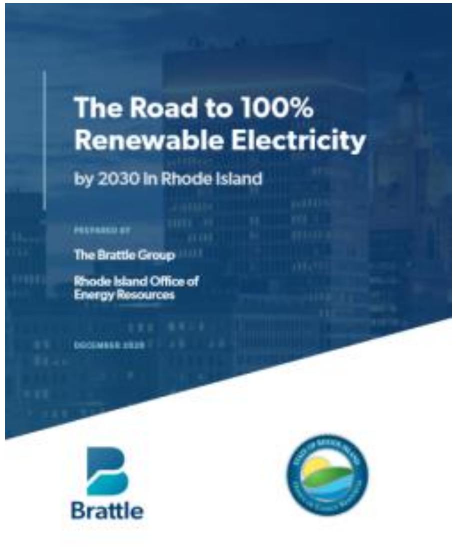
- ~~*Myth 1: Modeling is an entirely objective process.*~~
  - Many components of the modeling process are subjective:
    - e.g., type of model used, assumptions, parameters, interpretation, communications
  - But this isn't inherently bad and doesn't invalidate the utility of models. Rather, it shows how principled modeling is important.
- ~~*Myth 2: Models are perfectly accurate.*~~
  - Even the best models are imperfect representations of reality.
- ~~*Myth 3: Modeling is a prediction of the future.*~~
  - Models show how certain assumptions and choices lead to certain outcomes.

What is energy modeling?

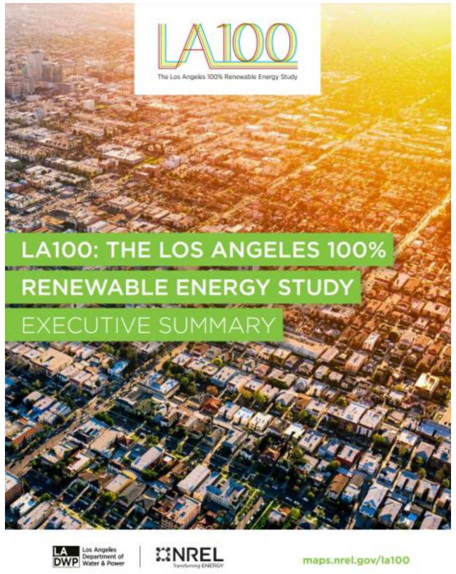
- Using computer software, mathematical equations, and complex optimization techniques to simulate the growth and function of energy systems
- Advanced energy models have improved and can now address a wider range of problems, capture more complex interactions, reflect newer decarbonization approaches



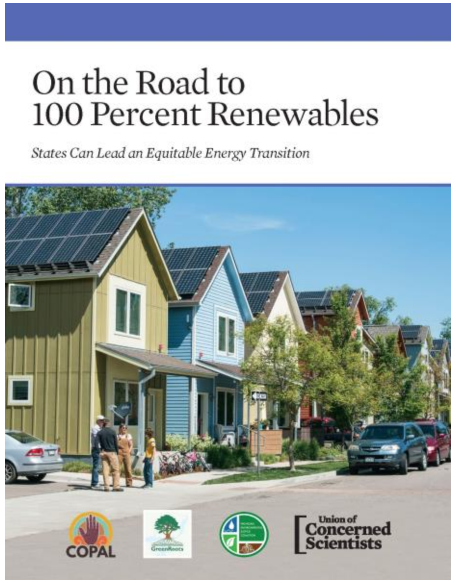
What are examples of energy modeling?



States

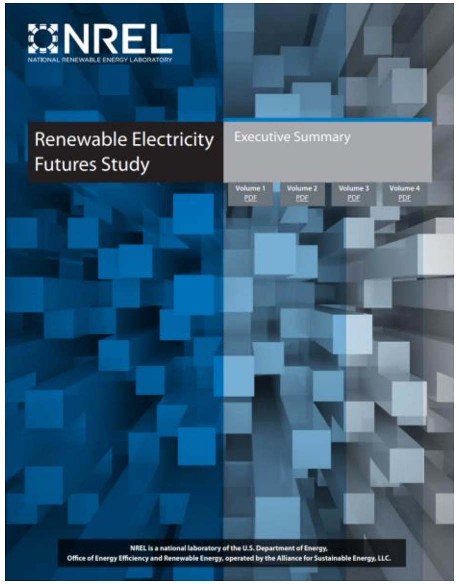


Cities



NGOs

Academia

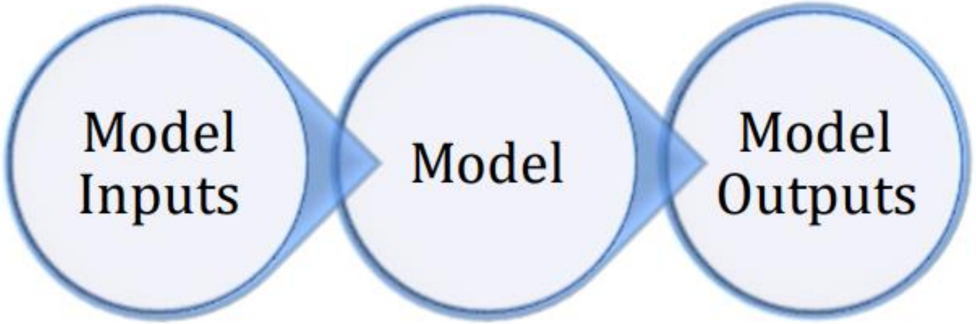


Labs

How does energy modeling work?

- Model Inputs and Outputs
  1. Current Energy Systems Data
  2. Future Energy Systems Data
  3. Constraints

- Model Types
  1. Capacity Expansion Model
  2. Production Cost Model
  3. Power Flow Model*



*lies outside of the scope of this report

What types of data are collected?

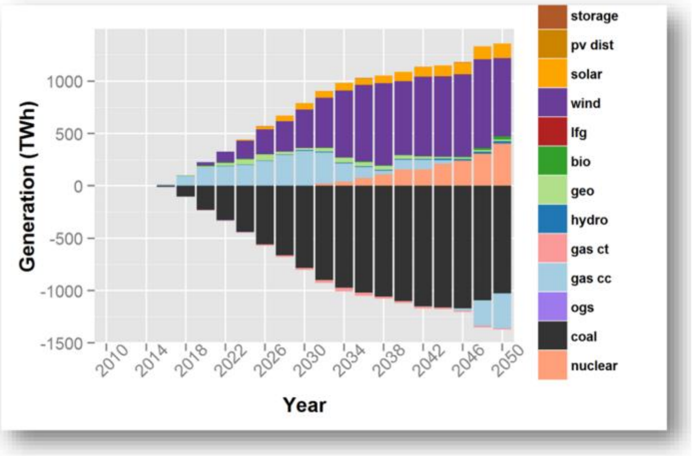
- Energy Systems Data
  1. Current Data
     - e.g., fuel availability and prices, electric capacity and generation, energy demand, geospatial renewable energy resource data
  2. Future Data
     - e.g., projections of future costs, policies, fuel prices, demand
  3. Constraints
     - e.g., economic, technological, political, social, equity

Where do data come from?

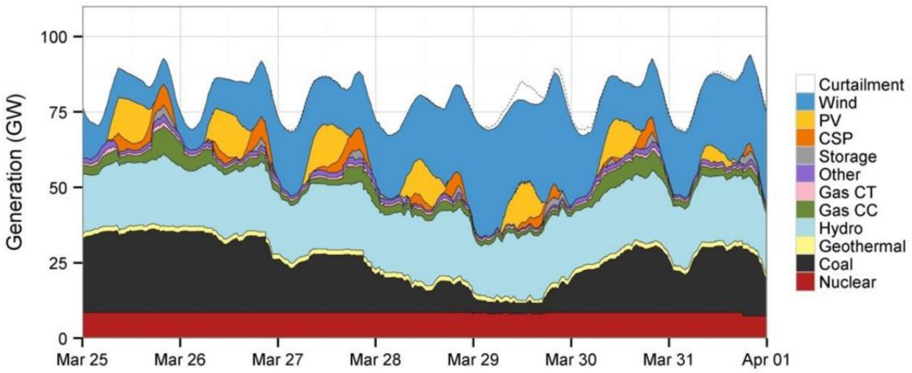
Public

Private

What types of models are used?

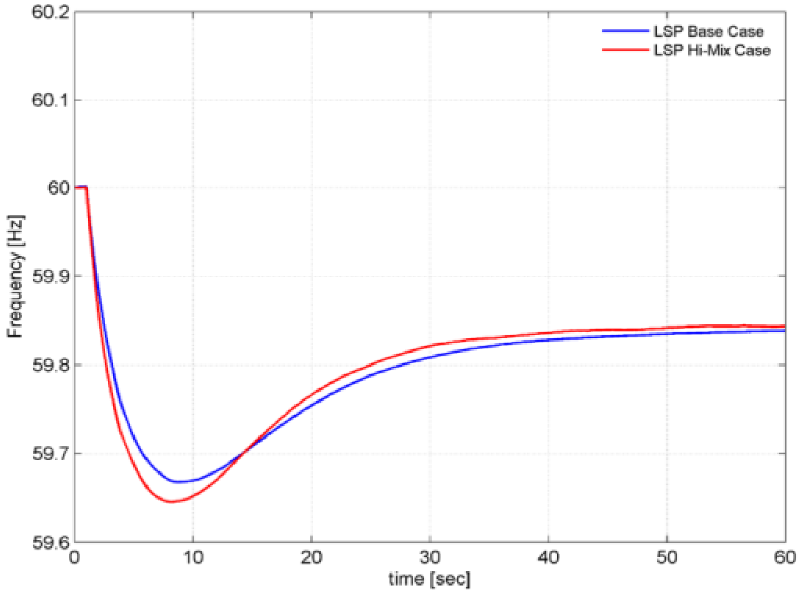


Capacity Expansion Model



Production Cost Model

What types of models are used?



Power Flow Model*

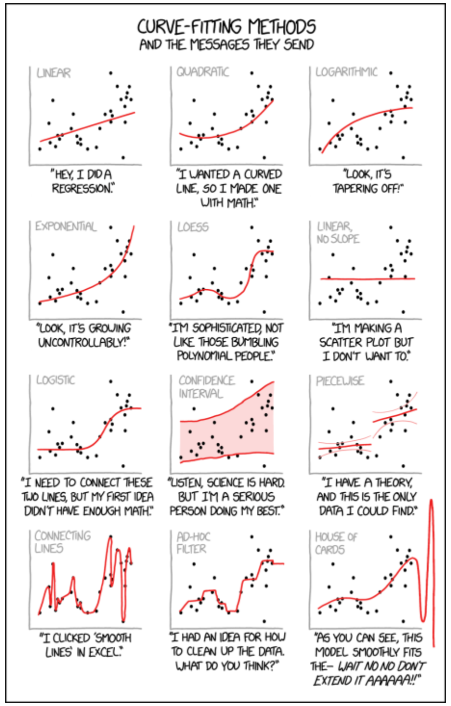
*lies outside of the scope of this report

What is the difference between these models?

	Capacity Expansion Model	Production Cost Model
Purpose	Describe how an energy system changes over time.	Describe how a system operates.
Time Horizon	Typically 5-20 years	Typically <1 year
Use Cases	Evaluate economic, environmental, equity impacts of policies on generation and capacity	Simulate granular operations and performance of energy systems, assess resource adequacy and reliability impacts, analyze how changes to energy systems affect operations

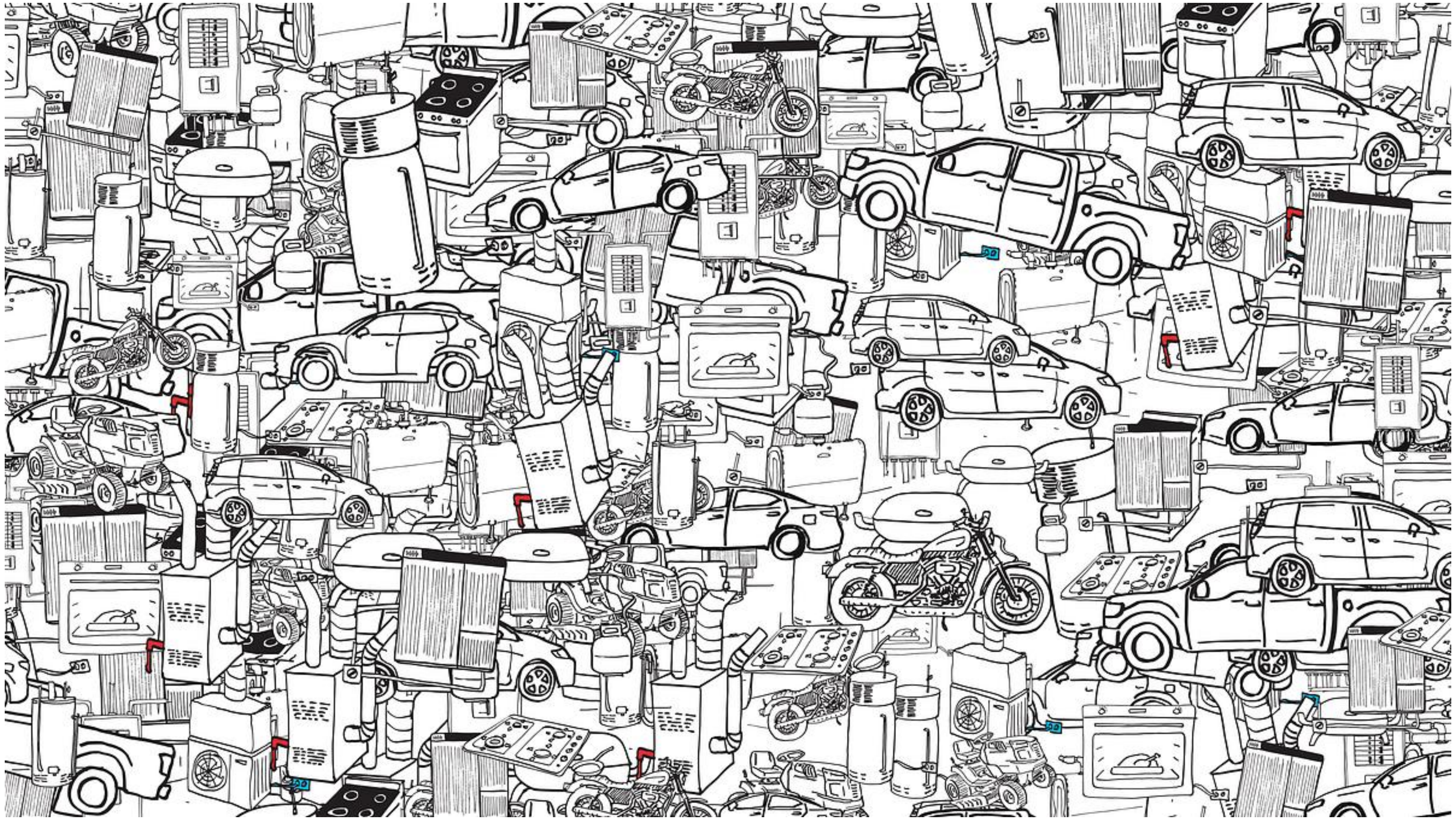
How do you know which model to use?

- It depends on what your goal is.
- Follow a three-step process:
  1. *Identify the question you are trying to answer.*
  2. *Understand how various modeling techniques and approaches fit into the specific question.*
  3. *Identify and apply specific modeling tools.*



"If your only tool is a hammer, everything looks like nails."

Why is energy modeling important?



Source: Saul Griffith

Why is robust energy modeling important?

- Bad modeling locks in long-term investments in undesirable strategies while overlooking opportunities to pursue desirable ones

- Good modeling can help stakeholders make better decisions by understanding the consequences of actions in a structured and disciplined manner

- Good modeling sheds light on opportunities and barriers posed by certain energy goals and decarbonization pathways and helps suggest the right questions to ask

Why is understanding energy modeling critical?

- Modeling can provide valuable information to develop and implement energy policies
- Non-technical stakeholders increasingly need to understand how modeling works
- There are many possible pitfalls to be aware of
  - e.g., poor design, flawed assumptions, low-quality data, misinterpretation, miscommunication, and other risks/uncertainties

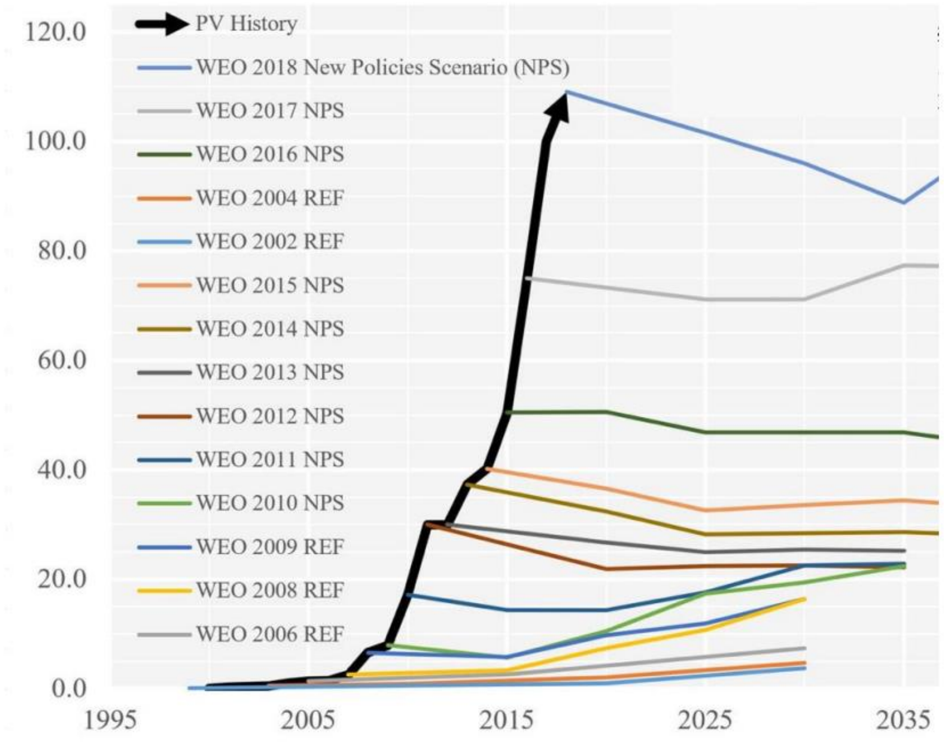
How can models be abused?

- They can support pre-conceived policy positions and business models and affirm incumbent and status quo interests
- They can yield confirmation bias by aligning with pre-existing preferences or future expectations
- Robust commercial energy modeling can be expensive and/or require a lot of modeling experience or computing power
- Non-technical stakeholders in particular can feel shut out
- There can be errors in modeling and interpretation
- Bad actors can take advantage of barriers to deliver misleading modeling results or interpretations misaligned with the public interest

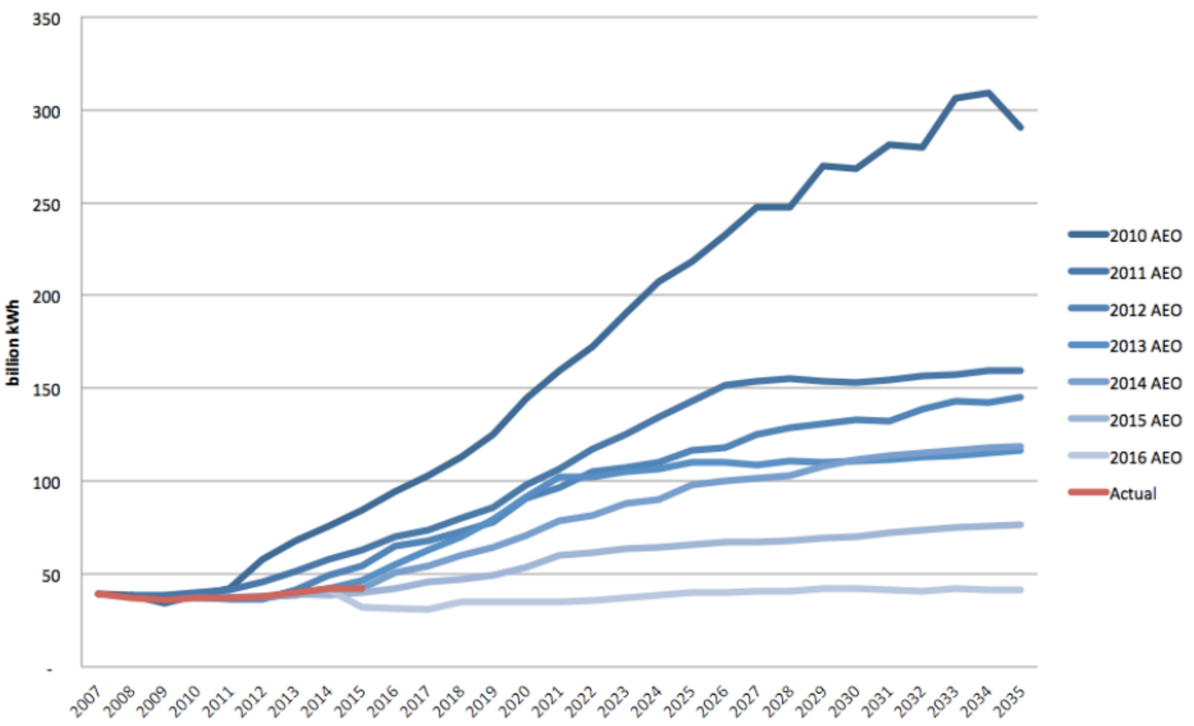
What are common errors in modeling?

- Poor model design
- Low quality data
- Skewed parameters based on pre-existing beliefs or status quo
- Misaligned incentives
- Unrealistic assumptions (e.g., perfect markets, perfect information, rationality)
- Self-interested intent
- Incorrect design choices & scope
- Wildcard "black swan" events
- Fundamental limits to modeling capabilities

What are common errors in modeling?



Source: Auke Hoekstra

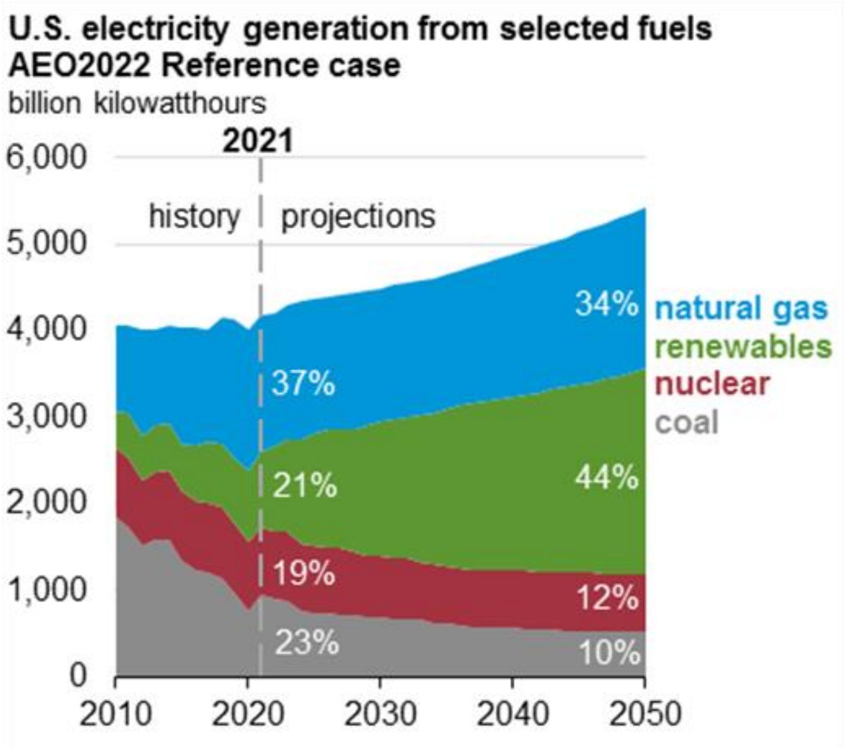


Source: PaulosAnalysis, using EIA data

How can models be misinterpreted?

US EIA Annual Energy Outlook (AEO)

- The public and media treat it as a definitive, correct vision of the future
- The AEO is “not a prediction of what will happen, but rather a modeled projection of what might happen given certain assumptions and methodologies.” –US EIA
- The AEO is based on the unlikely assumption of no new policy adoption



How can these risks be mitigated?

- Know what models can and can't do and what they are and aren't for
- Practice transparency, honesty, humility!
- Best practices for modeling:
  - Have transparent, open, and inclusive stakeholder engagement
  - Identify objectives of modeling and key considerations
  - Select appropriate models for a given task based on specific needs
  - Lay out a range of scenarios based on differing assumptions
  - Indicate uncertainty and relative likelihoods of outcomes
  - Identify key drivers of the uncertainty and conduct sensitivity analysis
  - Maintain transparency through clear description of methodologies
  - Communicate results in clear and accessible way

What are some pieces of advice?

1. *Don't expect models to predict the future.*
2. *Match the model to the problem.*
3. *Make assumptions, frameworks, and methods transparent.*
4. *Understand the limitations of models.*
5. *Utilize a diverse range of tools and methods to address uncertainty in models.*
6. *Consider how renewable energy systems, in particular, are modeled.*
7. *Communicate well.*
8. *Expect and identify bias.*
9. *Consider all energy scenarios.*
10. *Conduct retroactive analyses to identify best practices and common mistakes.*

Source: NREL

DIY Modeling


Questions?

NREL
Transforming ENERGY

NREL Planning Resources for States

Elaine Hale

April 10, 2023

CESA Webinar on Energy Modeling for Decarbonization Planning: Advice and Resources for States

Photo from iStock-627281636

NREL at-a-Glance

2,926

Workforce, including

219 postdoctoral researchers

60 graduate students

81 undergraduate students

World-class

facilities, renowned technology experts

More than **900**

Partnerships

with industry, academia, and government

Campus

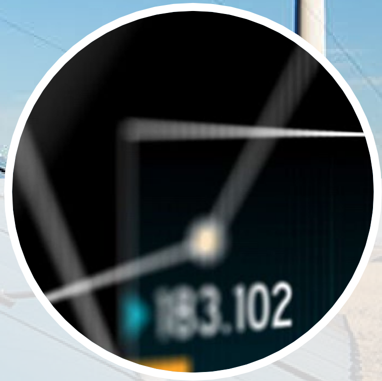
operates as a living laboratory

NREL examines the interactions between electricity users and infrastructure to enable a cost-effective and reliable grid at all scales

People +

Advanced technology +

Grid operations +



Markets and policy +

Economy-wide decarbonization

Publicly available, free resources

Annual Technology Baseline (ATB)

Standard Scenarios

Electrification Futures Study (EFS)

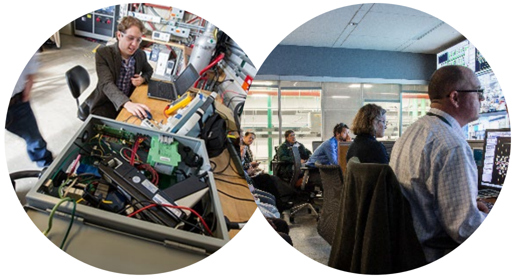
Annual Technology Baseline (ATB)

Credible, consistent, transparent, timely, relevant, and public data

Highly reviewed and vetted assumptions

Covers wide array of electricity and transportation technologies

Addresses key cost and performance metrics



1. Define resource bins for each technology

2. Develop cost and performance data

3. Calculate LCOE

IMPACT

Enables understanding of technology cost and performance across energy sectors and thus informs electric sector analysis nationwide.

For more: https://atb.nrel.gov/

ATB Technologies and Cost Projections Example

Electricity

Renewable Energy Technologies

- Wind
- Solar photovoltaics (PV)
- Concentrating solar power (CSP)
- Hydropower
- Geothermal
- Storage

Fossil Energy Technologies

- Natural gas
- Coal

Other Technologies (EIA AEO Data)

- Nuclear
- Biopower

Transportation

Light-Duty Electric Vehicles

- Gasoline
- Diesel
- Natural Gas
- Gasoline Hybrid
- Plug-In Hybrid
- Battery Electric
- Fuel Cell

Fuels

- On-Road Fuels
- Jet Fuel
- Marine Fuel

Parameter
Multiple values

Scenario
All

Financials
○ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

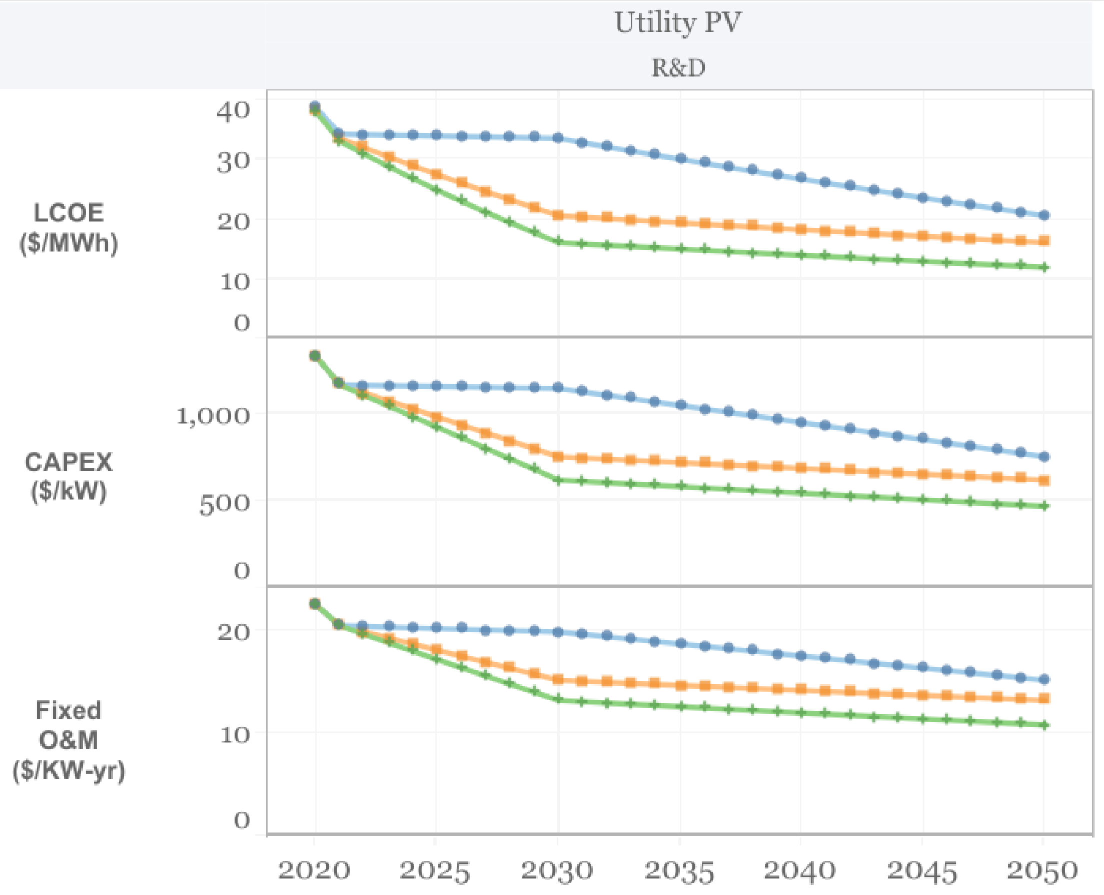
Utility PV - Class 5

Technology Detail Filter
Default

data updated: 05/23/2022

NREL

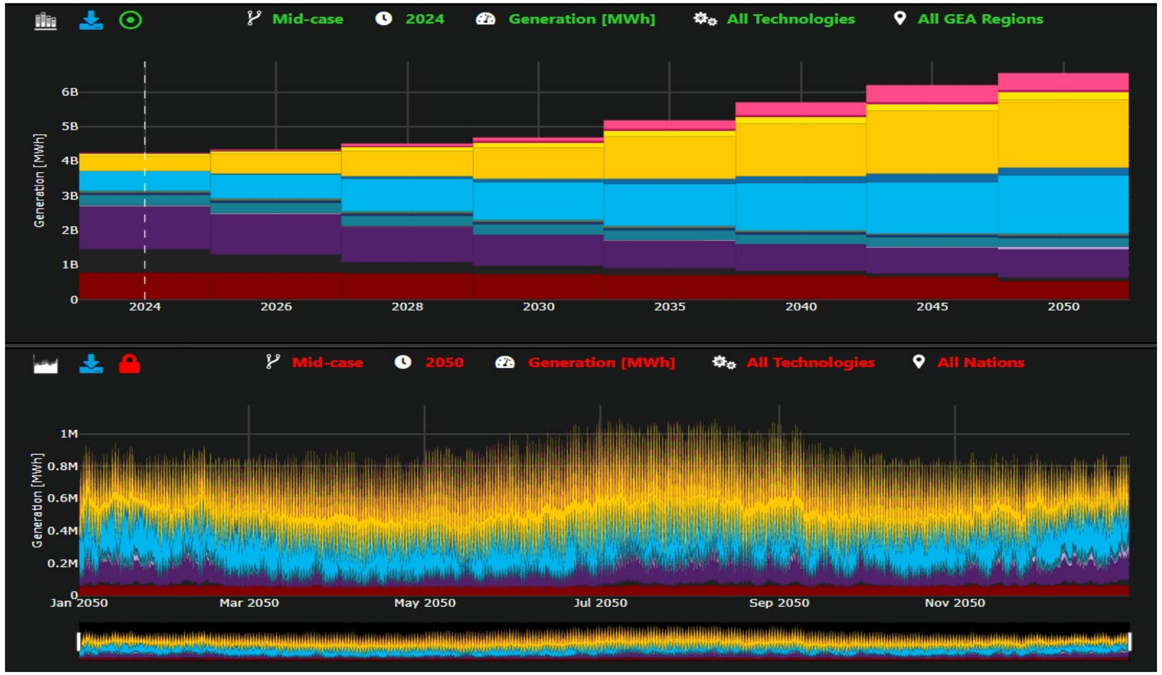
ATB data for technologies on..



Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

Cambium and Standard Scenarios



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Cambium Standard Scenarios ReEDS

Pieter Gagnon

Wesley Cole

IMPACT

Hundreds of building engineers, architects, regulators, utilities, and other stakeholders use Cambium in their decision-making workflows—and Cambium data are part of a Carbon Index, LEED pilot credit, and published guidance for clean energy procurement decisions.

For more:
https://nrel.gov/analysis/standard-scenarios.html

EFS: The Electrification Futures Study

Technologies: What electric technologies are available now, and how might they advance?

Consumption: How might electrification impact electricity demand and use patterns?

System change: How would the electricity system need to evolve to meet changes in demand?

Flexibility: What role might demand-side flexibility play to support reliable operations?

Impacts: What are the potential costs, benefits, and impacts of widespread electrification?

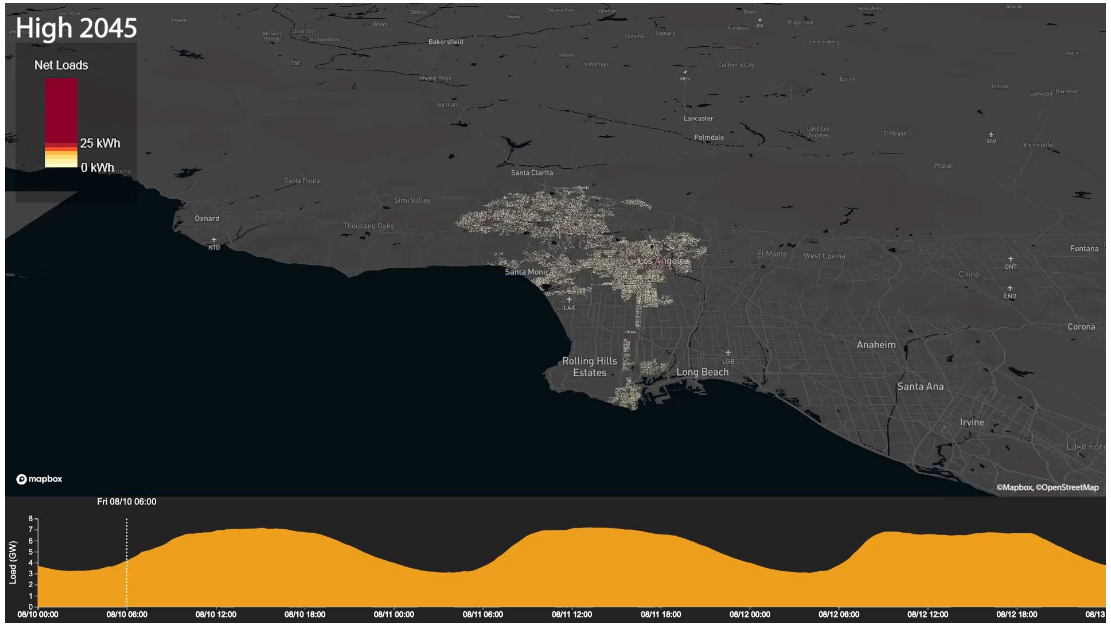
IMPACT

Answers crucial questions about technologies, consumption, system change, flexibility, and cost/benefit.

For more: https://nrel.gov/EFS

Local and regional integration studies

LA100: Los Angeles 100% Renewable Energy Study



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dsgrid reV dGen

+ dozens of other NREL models, including RPM

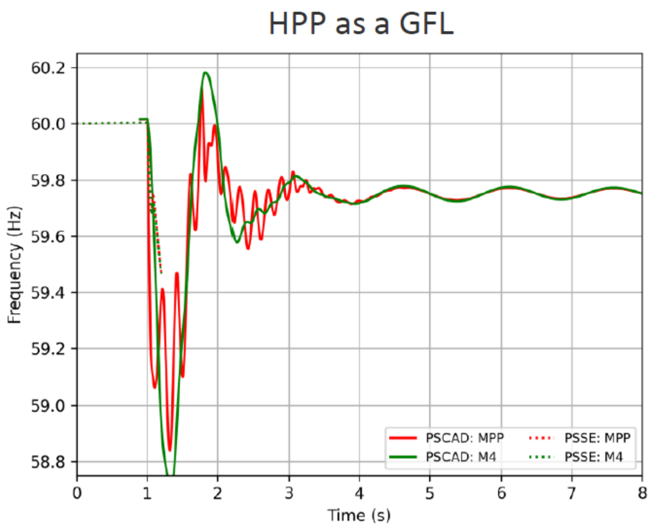
Jaquelin Cochran

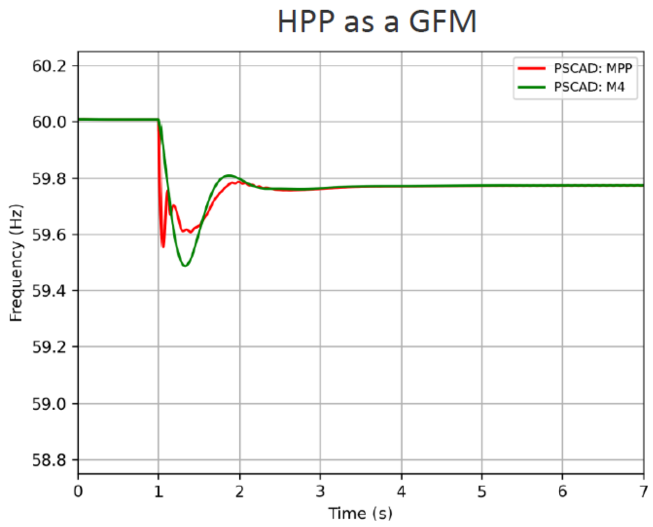
IMPACT

The Mayor and City Council of Los Angeles cited LA100 as the basis for their 100% clean energy by 2035 target. The study also provided the foundation for DOE's Clean Energy to Communities program and is informing other major 100% studies, including Lithuania 100 and Puerto Rico 100.

For more: https://maps.nrel.gov/la100

Inverter-Based Operation of Maui





IMPACT

Hawaiian Electric has advanced to the next step in a complex due-diligence process working toward operating Maui with 100% inverter-based resources—and is on track to achieve Hawaii's goal of reducing carbon emissions in 2030 by as much as 70% below 2005 levels.

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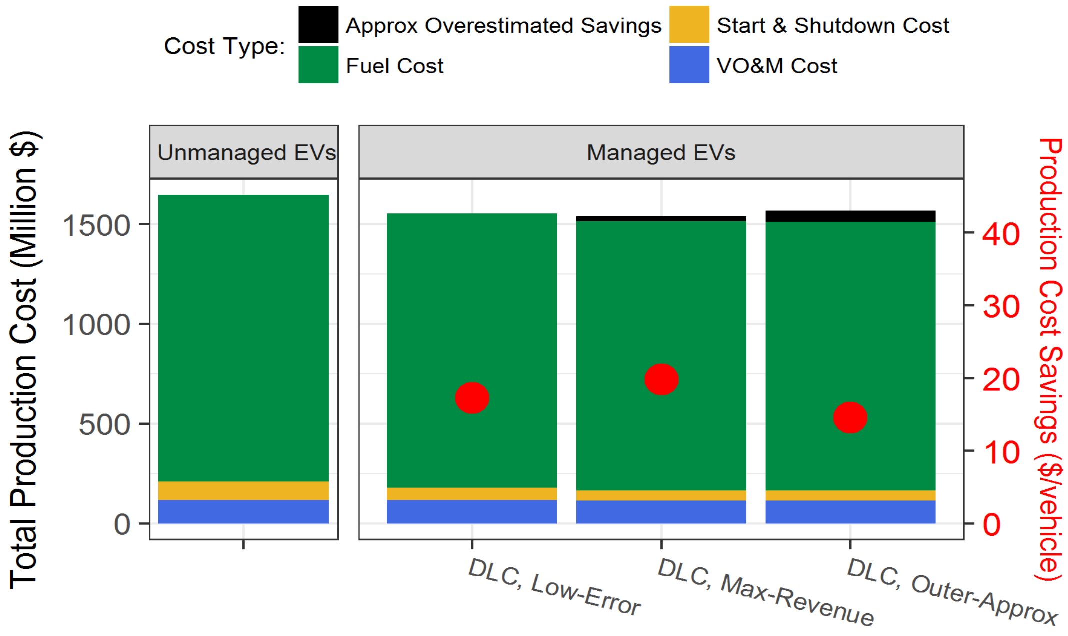
PSCAD

Bri-Mathias Hodge

For more:

https://www.osti.gov/biblio/1760667, https://www.osti.gov/biblio/1922192, https://www.osti.gov/biblio/1898009

Valuing Electric Vehicle (EV) Managed Charging for Bulk Power Systems



Results for 100% participation of all light-duty EVs (45% of the passenger light-duty vehicle fleet) in an envisioned 2038 ISO-NE system.

IMPACT

The new modeling approach unlocks more detailed insights for aggregators, utilities, and independent system operators (ISOs) who are planning power systems with widespread EV adoption and lots of wind and solar.

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dsgrid

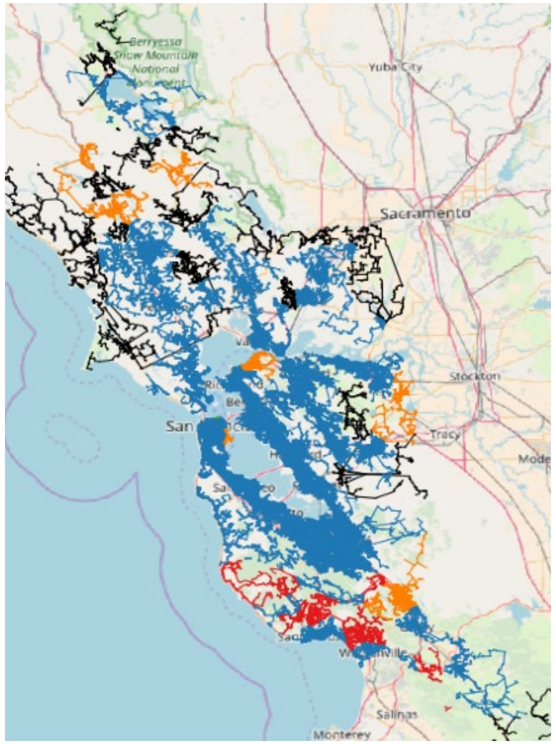
TEMPO

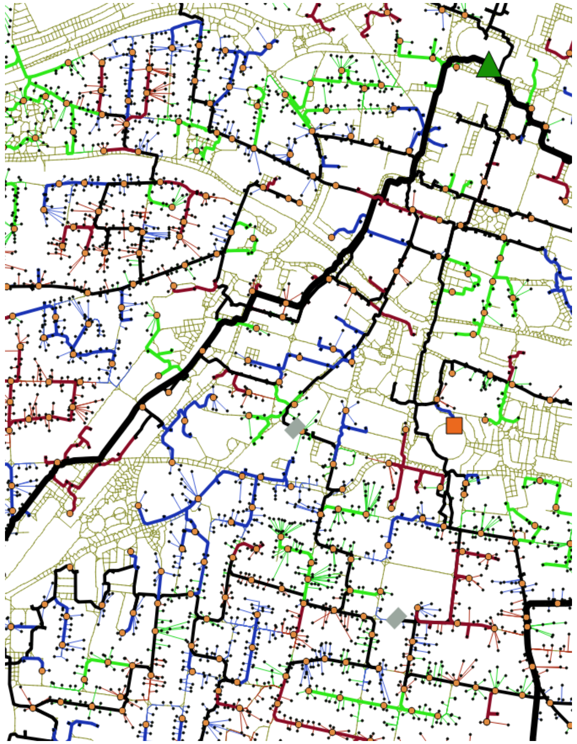
Elaine Hale

Luke Lavin

For more:
https://www.nrel.gov/docs/fy22osti/83404.pdf

Impact of Widespread EV Fast Charging on the Distribution Network





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PyDSS

Bryan Palmintier

IMPACT

Identifying the most effective control strategies to mitigate the impact of widespread fast charging of light-duty and commercial passenger EVs.

For more:
https://www.osti.gov/biblio/1855174,
https://www.osti.gov/biblio/1958890

Forward vision

Standard scenarios for every state

We are working toward specific, robust data sources for all key grid planning inputs

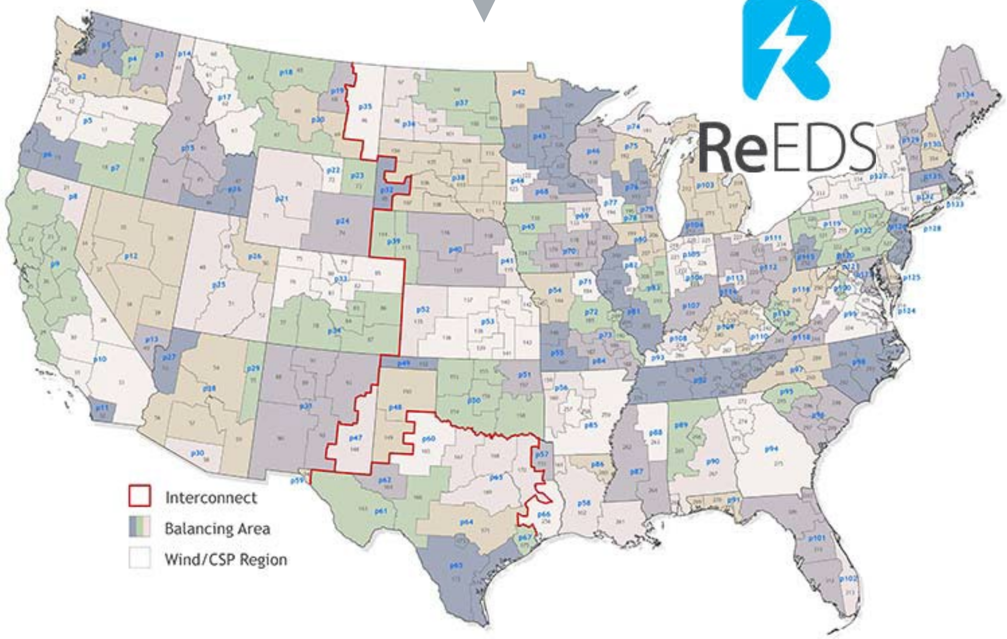
Existing System	Load Projections	Renewable Resource
GridDB	dsgrid Demand-Side Grid Toolkit	rev
Aggregate generators, storages, transmission	Aggregate over sectors, end-uses, counties	Supply curves for wind, solar, etc.

Strong link

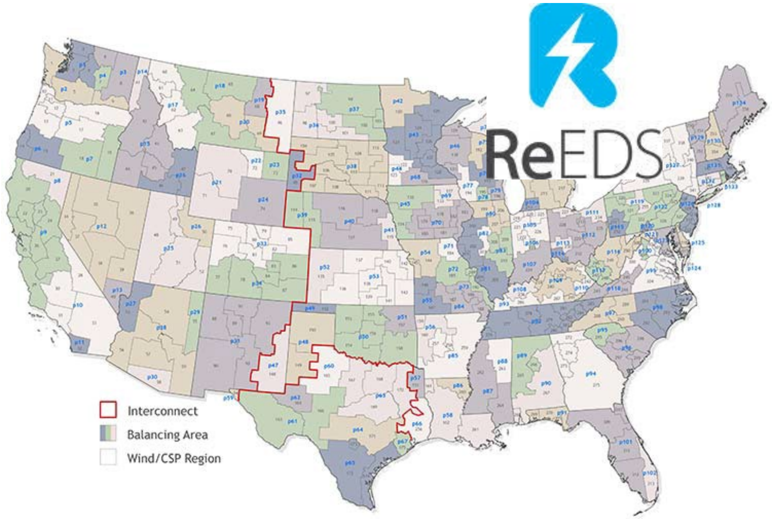
Initial link

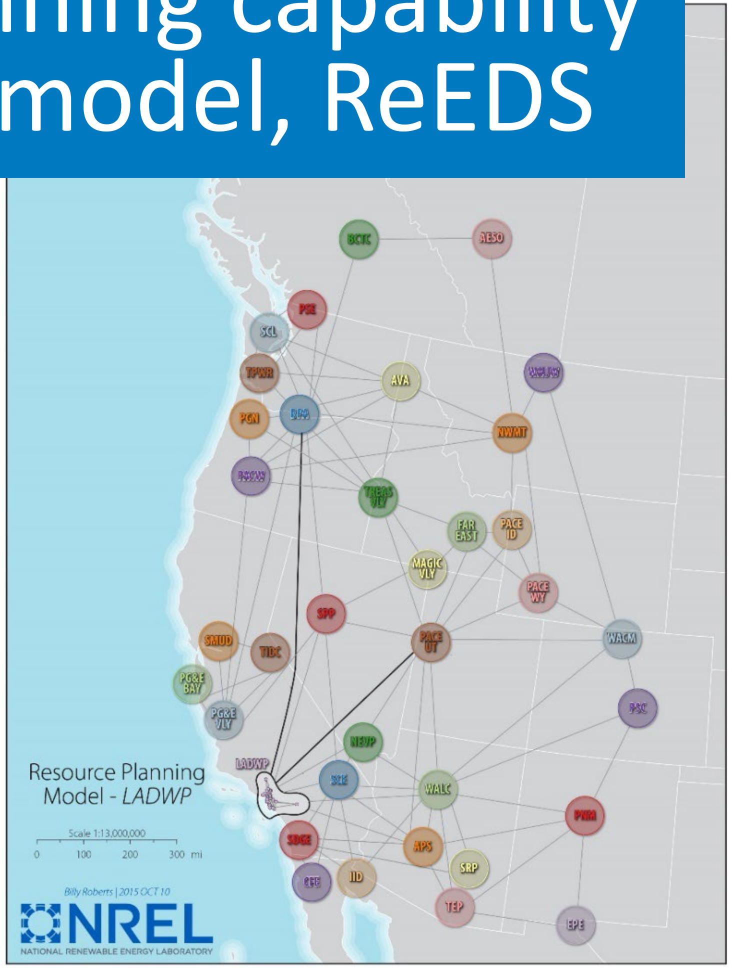
Planned link

ReEDS



We are merging our nodal-zonal planning capability with our flagship national planning model, ReEDS





National-scale

- Balancing authorities
- Aggregated generators
- Pipe-flow transmission

Regional-scale

- Nodal-zonal structure
- Linear power flow within the focus region
- Limited validation

Community-scale

- Highly validated
- Additional reliability constraints (e.g., deliverability of reserves)

Combined with sufficient computing and staff resource, those developments could enable Standard Scenarios for each state

Existing System — GridDB

Load Projections — dsgrid Demand-Side Grid Toolkit

Renewable Resource — rev

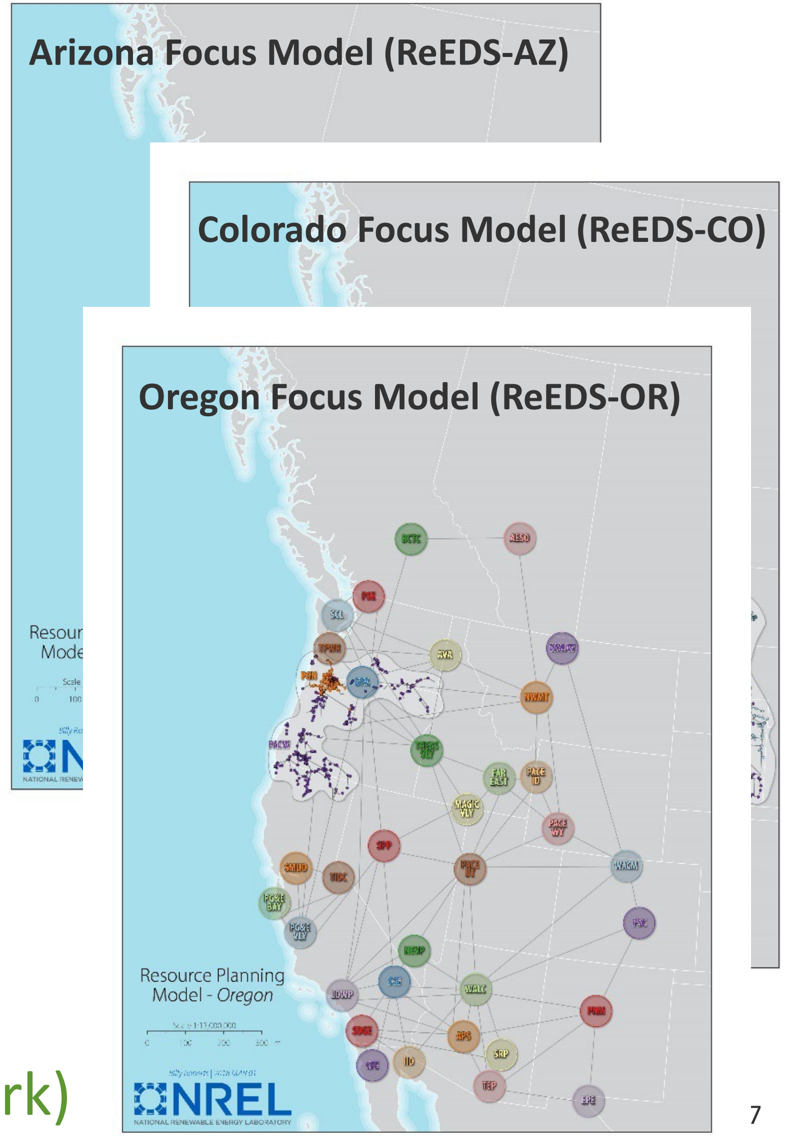
Filter by Geography

Aggregate Neighboring Systems' Data

Unit-level and Nodal Data for Focus State

Annually update ....

?
(Desired Future Work)



Conclusion

Helpful resources

- **Free, publicly available resources:**
  - ATB, Standard Scenarios, EFS
  - Open Energy Data Initiative, NREL Data Catalog
  - State and local data portal: SLOPE
- **NREL-led integration studies**: LA100, Grid Forming Inverters on Maui, EV Managed Charging in New England, DCFC in San Francisco, and many more
- **Supporting capabilities:**
  - Renewable resource and generation profiles: reV
  - Customer-owned PV adoption: dGen
  - High resolution load data for grid models: dsgrid

Forward vision:

Standard Scenarios for each State

- Independent, transparent scenarios that can be used to, e.g., benchmark utility integrated resource plans
- Independent, transparent load, renewable resource, and system data that can be used by others
- Nodal-zonal models to capture state specifics (units, lines, ownership) and connections with neighbors

Please reach out if you are interested or would like to provide feedback!

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Thank You

www.nrel.gov

NREL Transforming ENERGY

Power Sector Planning Resources for States:

Study Examples

Dr. Nikit Abhyankar

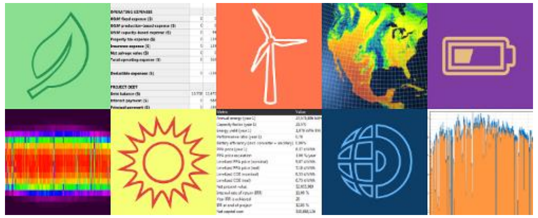
Lawrence Berkeley National Laboratory

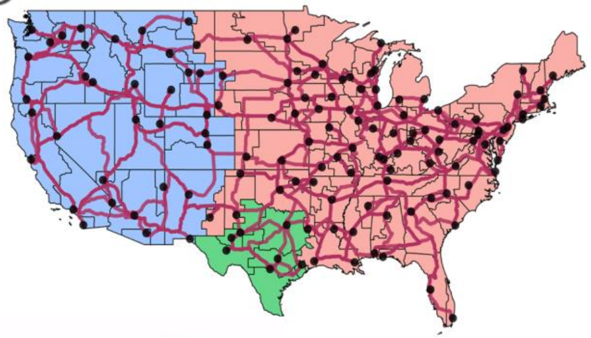
University of California, Berkeley

CESA Webinar on Energy Modeling for Decarbonization Planning

April 10, 2023

How can the US achieve 80% Clean Grid by 2030 ?





Renewable Energy Resource Assessment

- NASA MERRA-2 satellite data for resource assessment, multiple weather years
- NREL SAM model for RE generation profiles

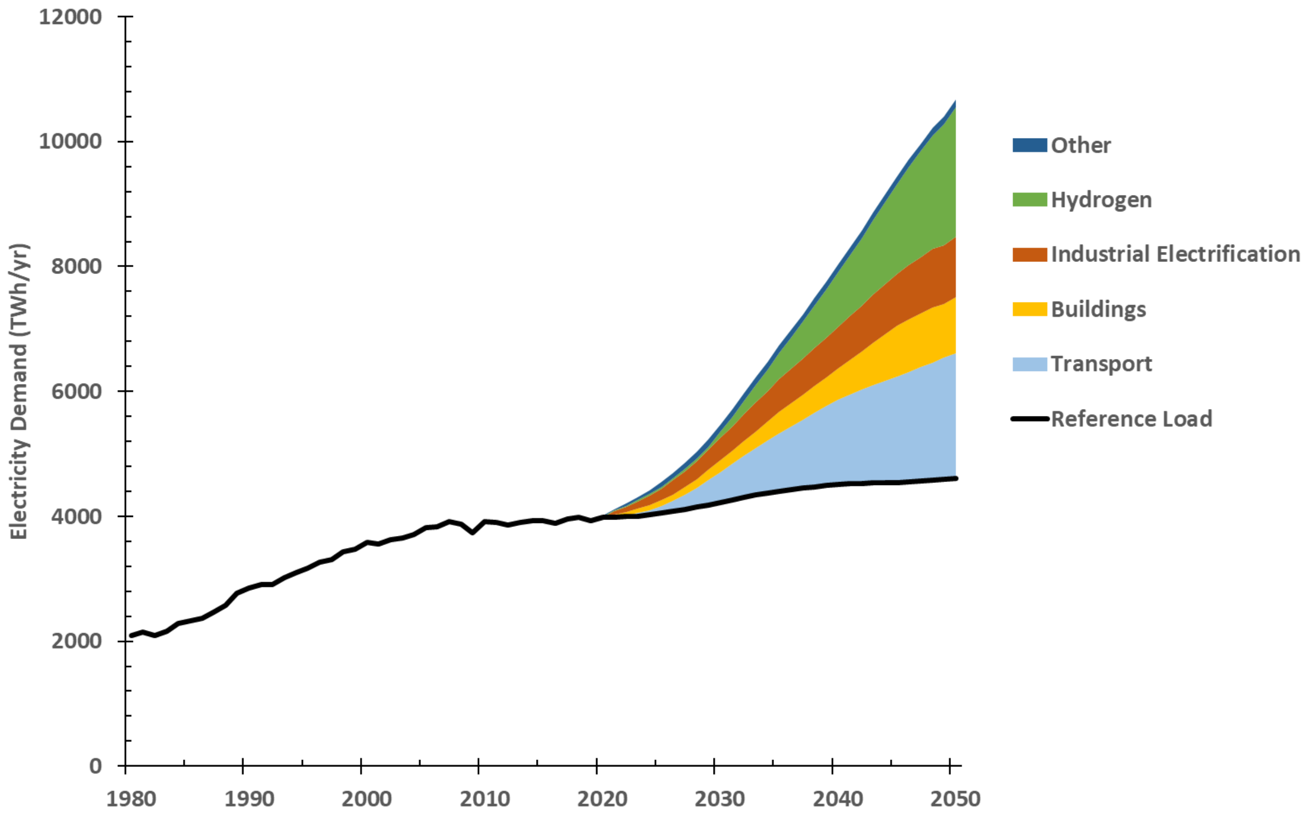
Capacity Expansion

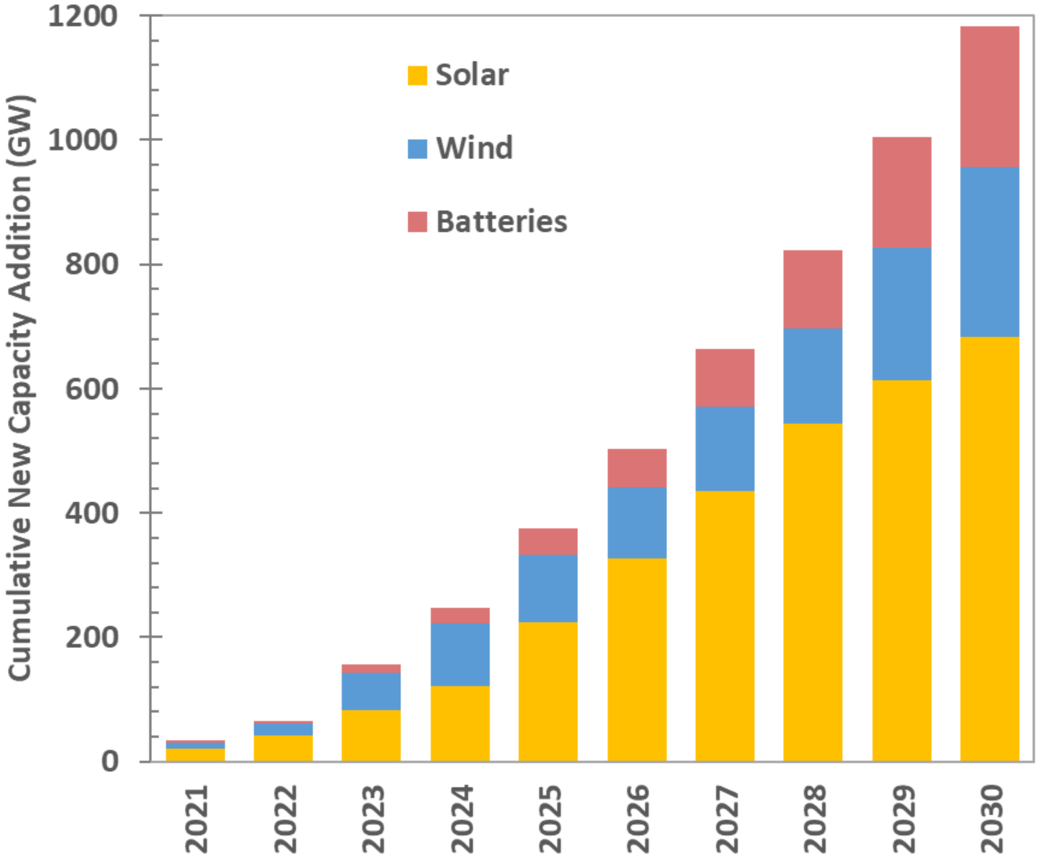
- NREL ReEDS (134 U.S. Regions; 320 transmission corridors)
- Multiple policy scenarios and sensitivities

Production Cost

- PLEXOS (>20,000 individual power plant level hourly dispatch)

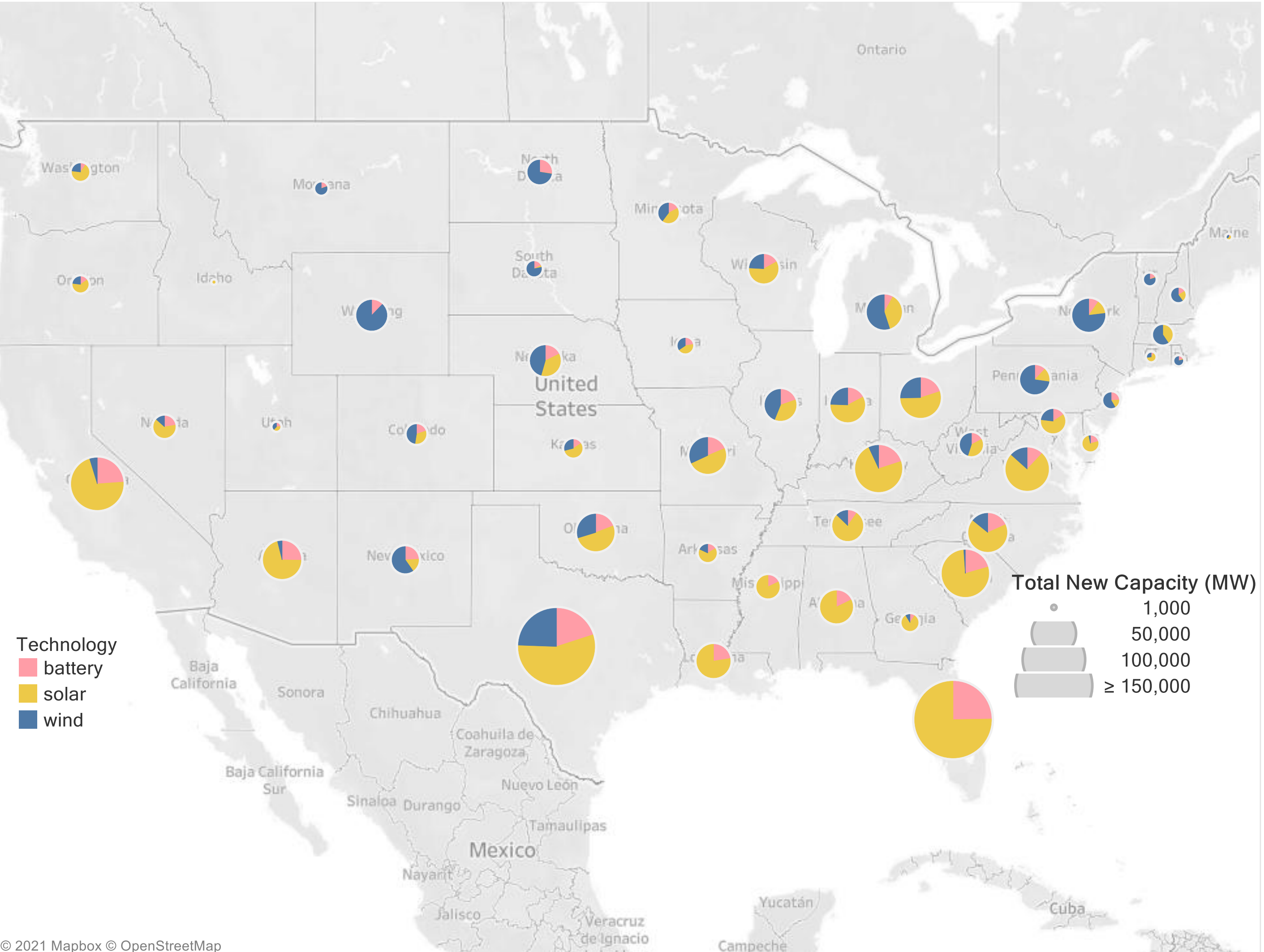
With a net-zero emissions grid, US electricity demand will likely triple by 2050





80% CLEAN GRID DRIVES NEW INVESTMENTS IN ALL STATES

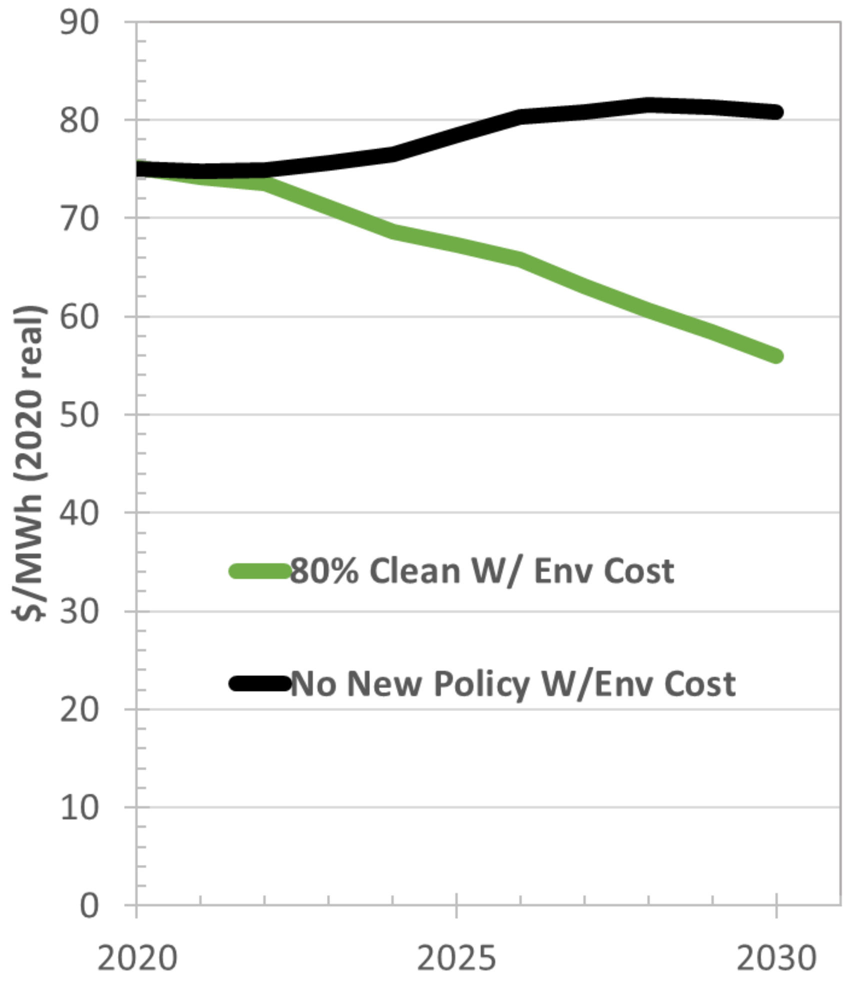
Cumulative New Investments by State (2021-2030)

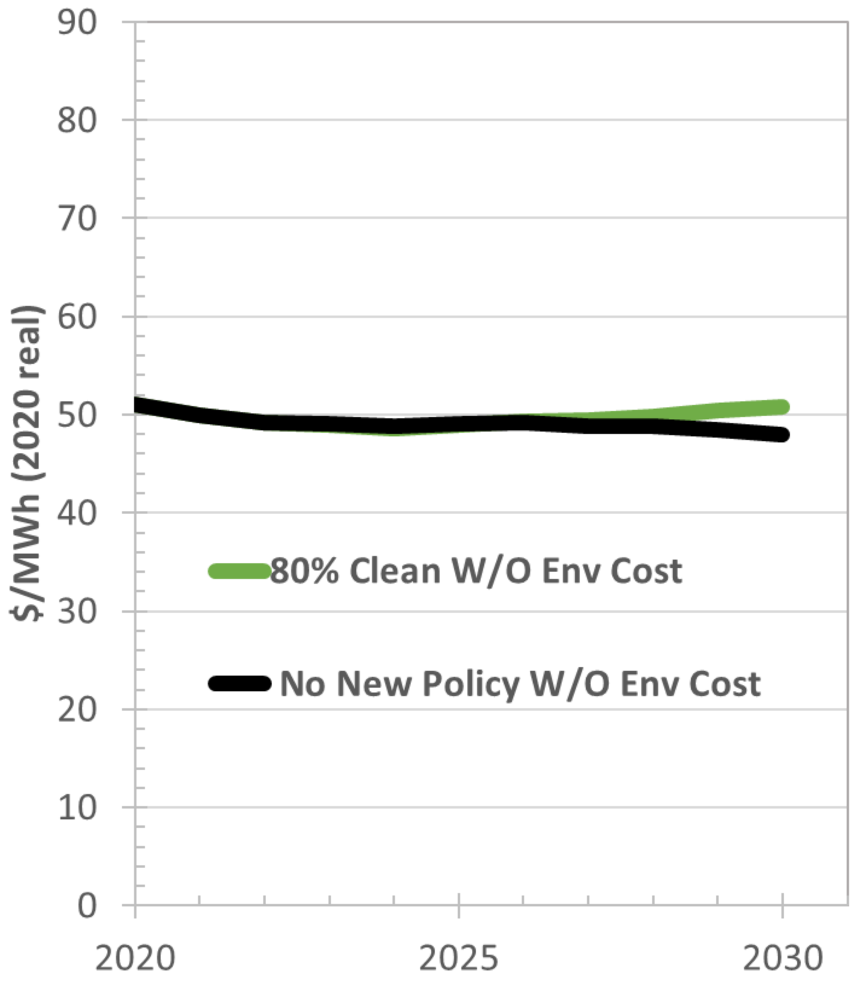


Top-15 States by New Clean Energy Investments in the 80% Clean Case (2021-2030 total)

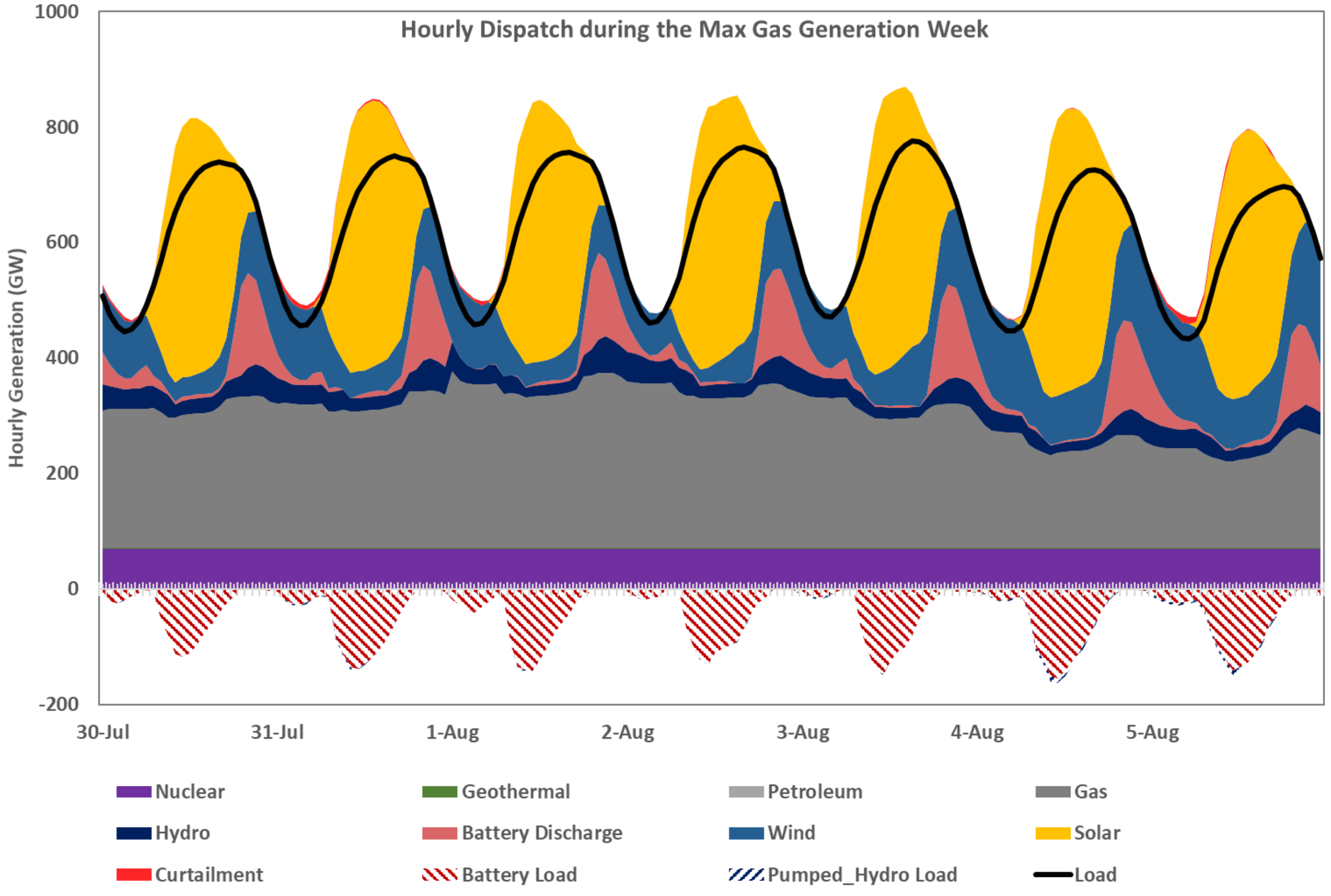
State	GW	$Billion (2020 real)
Texas	153	190
Florida	153	171
California	70	92
Kentucky	56	65
South Carolina	56	59
Virginia	47	59
Ohio	46	55
New York	27	53
Arizona	37	46
Missouri	34	45
Michigan	34	44
Oklahoma	35	44
North Carolina	38	42
Indiana	32	40
Wyoming	24	38

ELECTRICITY COSTS LOWER THAN TODAY





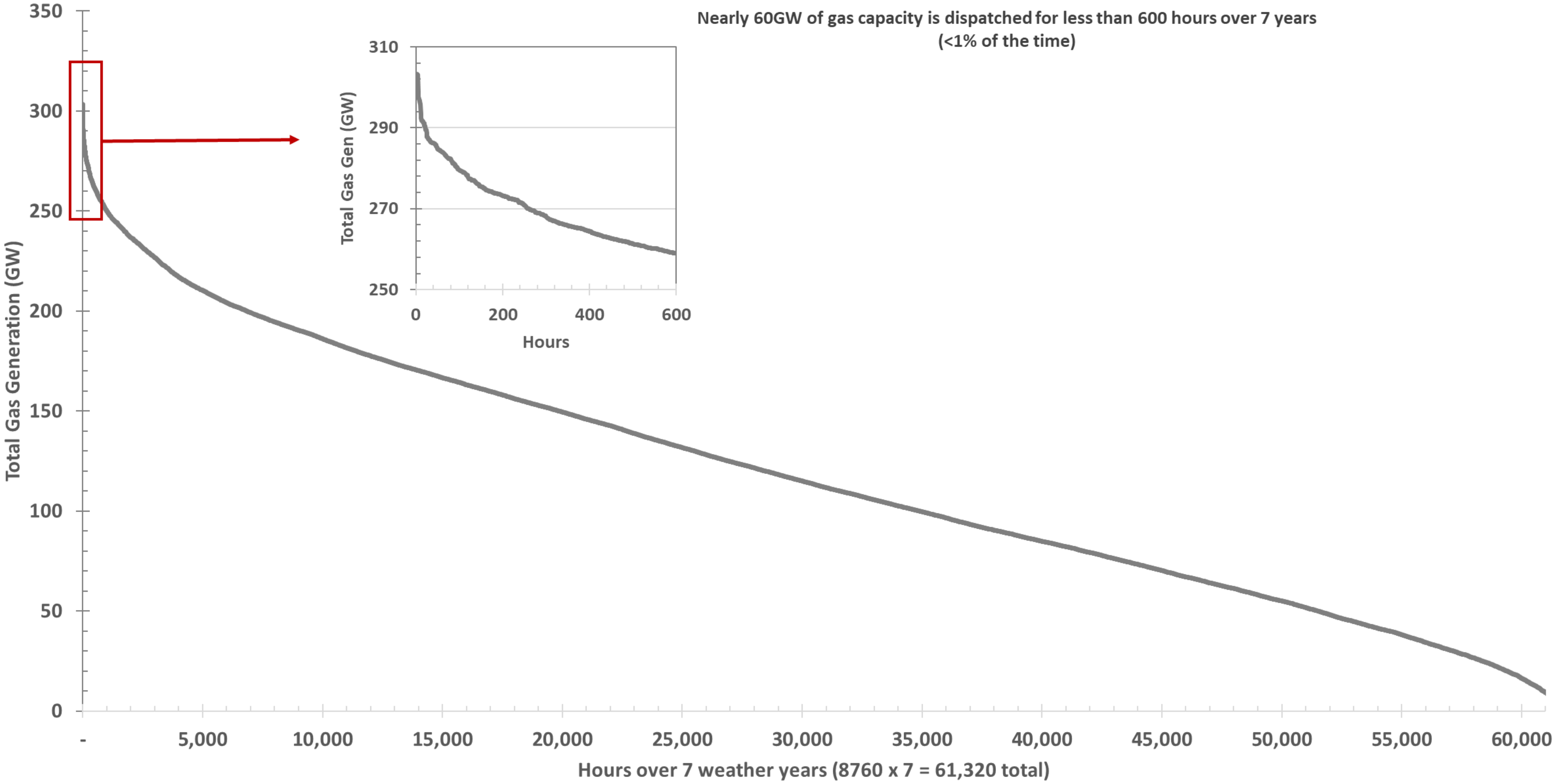
GRID IS DEPENDABLE WITHOUT COAL OR NEW GAS



The chart shows national hourly dispatch in 2030 during the maximum gas generation week.

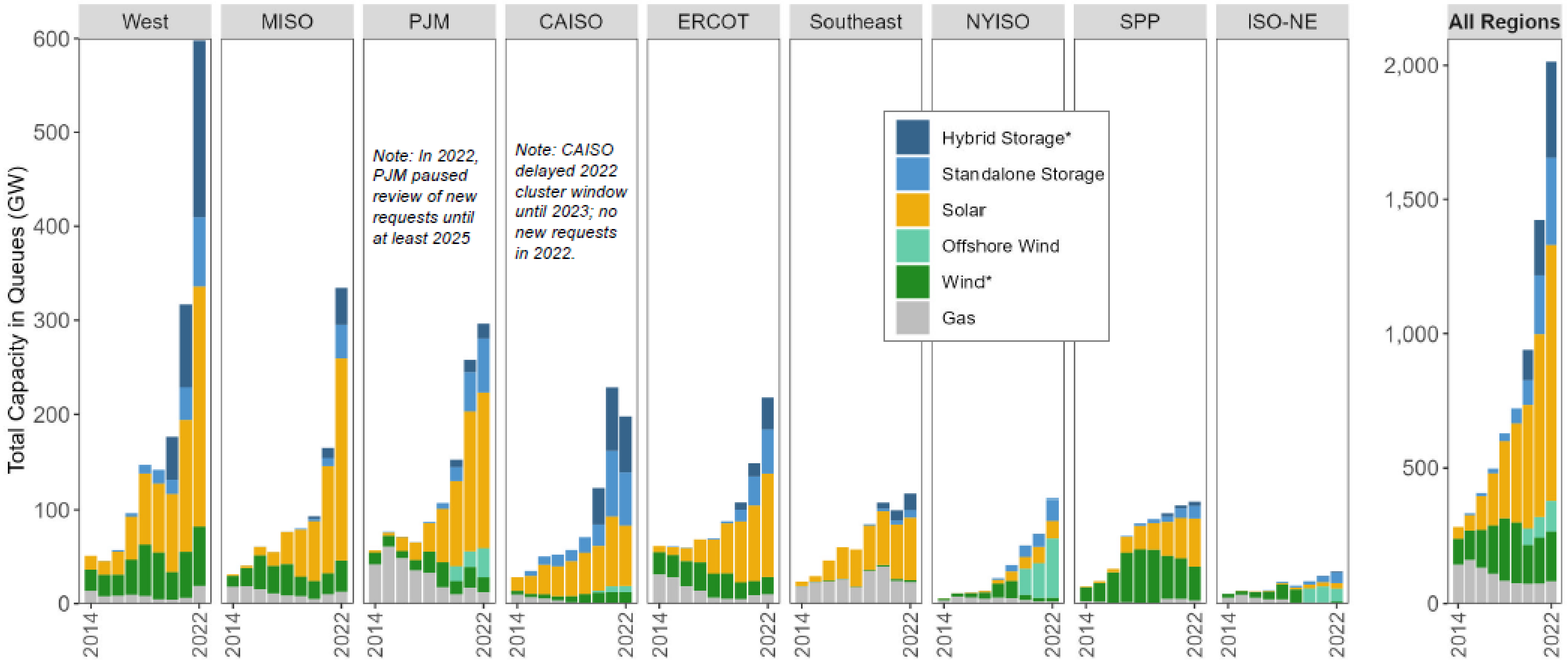
Maximum gas dispatch (303GW) occurs on August 1 at 8 pm EST in the weather year 2007.

OVER 60 GW OF GAS IS DISPATCHED FOR <1% OF TIME



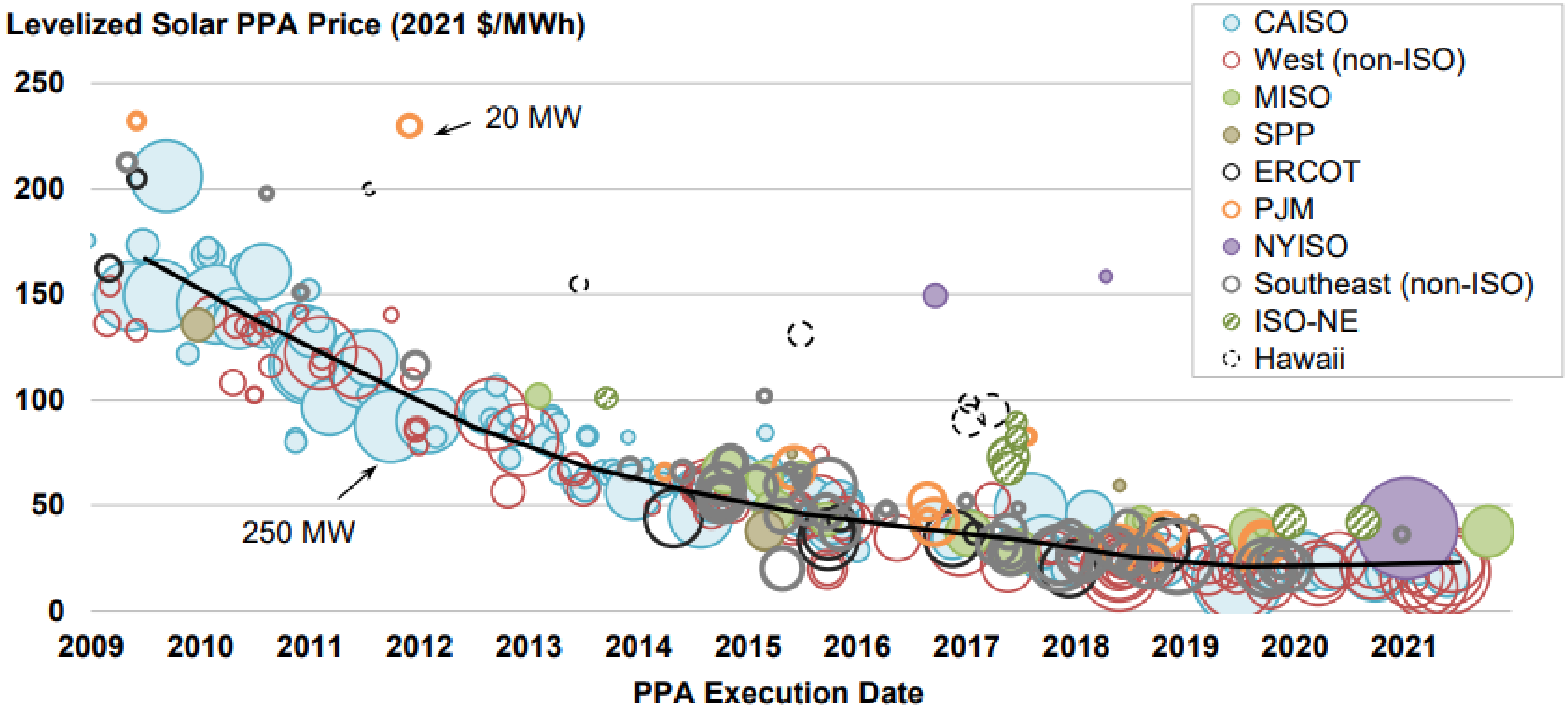
Detailed data on the interconnection queues

~2,000 GW of interconnection queues mapped to individual project



Source: Rand et al (2023)

Detailed data on utility-scale RE installations and PPA prices



Source: Bolinger et al (2022)

Thank you !

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