NREL
Transforming ENERGY

Implementing the Inflation Reduction Act: What we expect and how we might get there

Presenter: Caitlin Murphy

MIT CEEPR Spring Technical Workshop, Session 6

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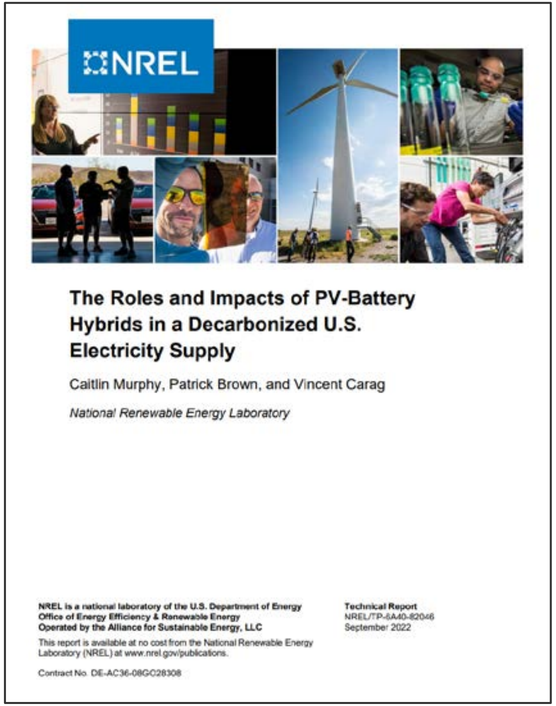
  - Strategic Analysis (PV-Battery Hybrids)
  - Wind Energy Technologies Office and Water Power Technologies Office (FlexPower, or Wind-PV Hybrids)

This presentation includes work by many colleagues:

- **IRA Analysis:** Daniel C. Steinberg, Maxwell Brown, Ryan Wiser, Paul Donohoo-Vallett, Pieter Gagnon, Anne Hamilton, Matthew Mowers, and Ashreeta Prasanna
- **PV-Battery Hybrids:** Patrick Brown and Vincent Carag
- **Wind-PV Hybrids:** Patrick Brown, Travis Williams, Matthew Irish, Maxwell Brown

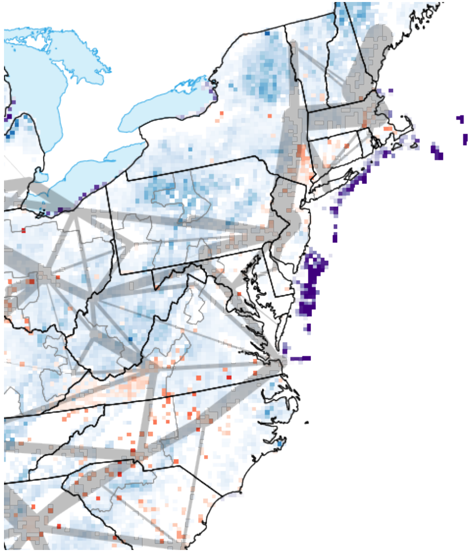
Outline

https://www.nrel.gov/docs/fy23osti/85242.pdf



https://www.nrel.gov/docs/fy22osti/82046.pdf

Optimal design and deployment of wind-solar hybrids in low-carbon U.S. power system



In preparation for submission to *Applied Energy*

Nationwide Capacity Expansion Modeling: ReEDS

Objective: Minimize total **capital + operational** cost of electric power system

subject to…

Price-forming constraints: Energy balance; planning/operating reserves; RPS/carbon policies

Additional constraints: Resource availability (spatial & temporal); energy/reserve trading; generation/storage operations; fuel supply; planned builds and retirements; etc.

Inputs

- **Existing & planned** capacity
- **VRE** temporal (hourly) & spatial (11.5km×11.5km) availability
- State & federal **policies** (current and hypothetical)
- **Load** (hourly) projections for 134 zones across contiguous U.S.
- Capital, O&M, and fuel **cost** projections
- **Technology** availability & performance projections

Regional **E**nergy **D**eployment **S**ystem

ReEDS

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

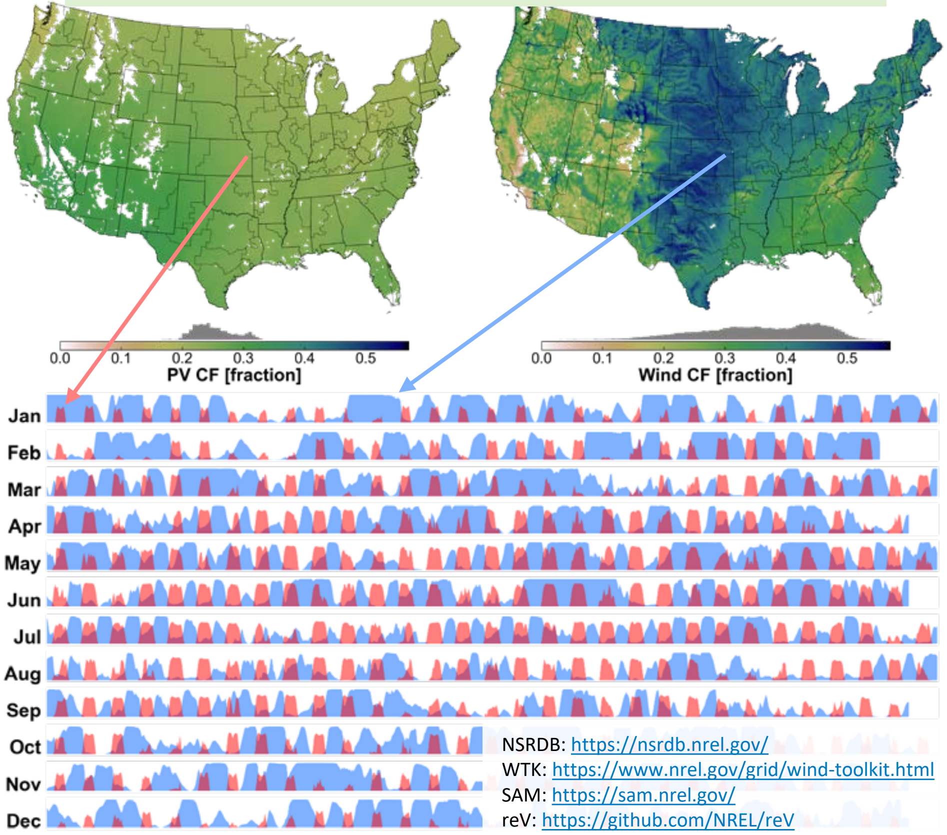
Outputs

- Generation and storage **capacity** additions & retirements in each solve year
- **Transmission** capacity additions
- **Operations**: Energy generation, firm capacity, & operating reserves by tech
- CO_2, NO_x, SO_2, CH_4 **emissions**
- System **cost** [$billion], electricity **price** [$/MWh], retail **rates** [¢/kWh]

ReEDS: Key Inputs

RE temporal availability

National Solar Radiation Database + WIND Toolkit → SAM → reV model → Hourly CF profiles for >50k sites across U.S.

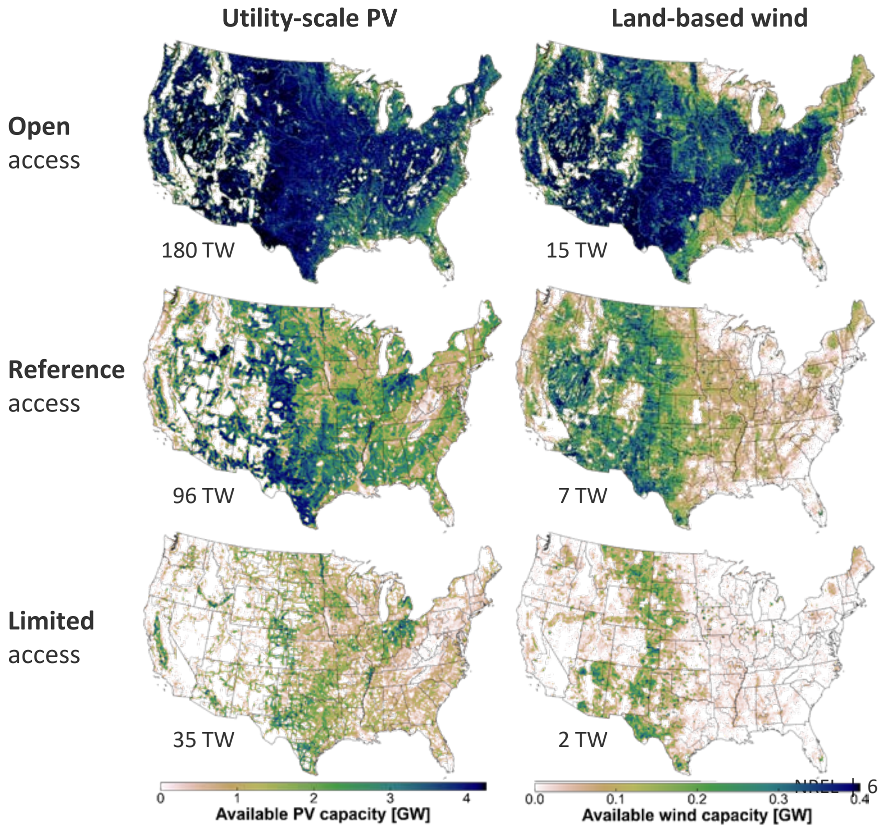


NSRDB: https://nsrdb.nrel.gov/
WTK: https://www.nrel.gov/grid/wind-toolkit.html
SAM: https://sam.nrel.gov/
reV: https://github.com/NREL/reV

RE spatial availability

High-resolution supply curves for renewable energy resources (e.g., Lopez et al. 2021)

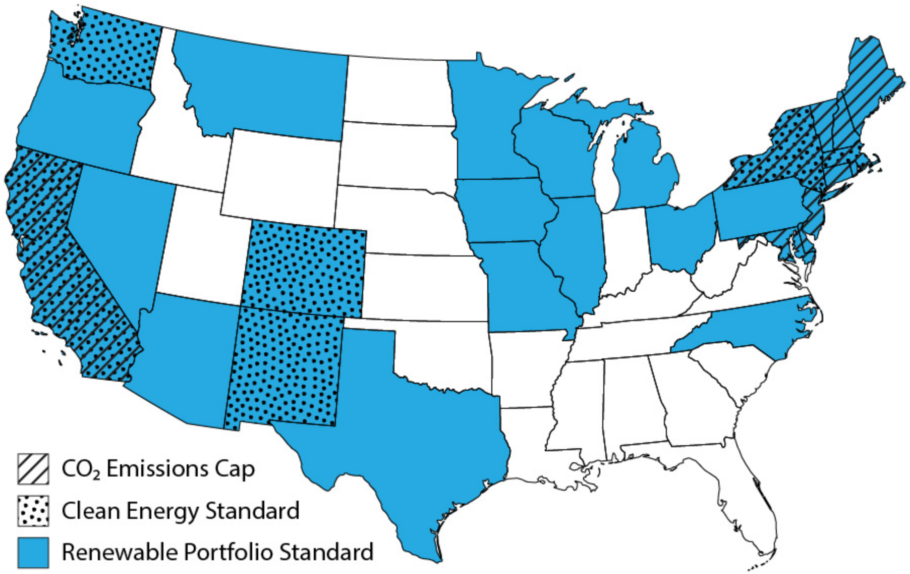
Multiple land-type exclusions → reV model → Developable wind/PV potential for same >50k sites



ReEDS: Key Inputs

Regional and state policies

(Updated annually)

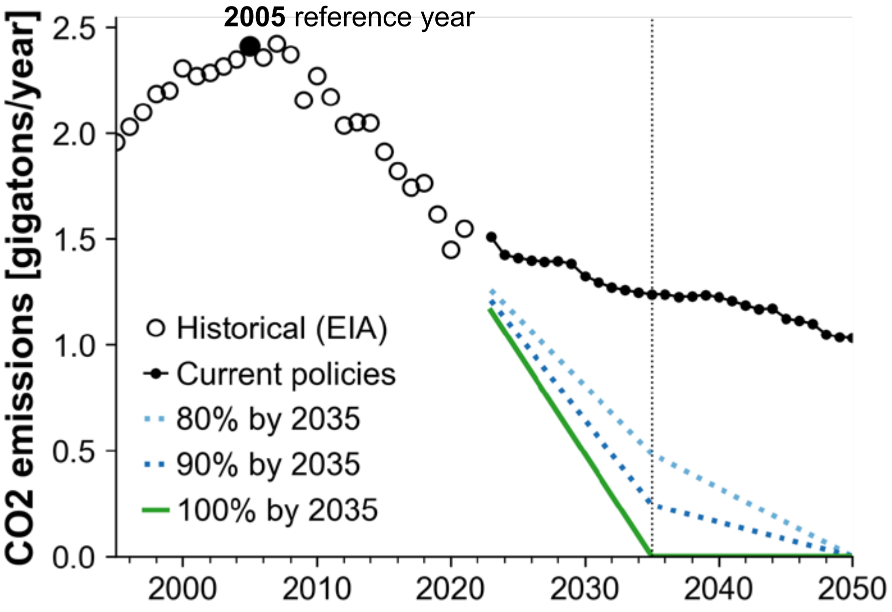


The Prospective Impacts of 2019 State Energy Policies on the U.S. Electricity System (Mai et al., 2020)

Including state-specific:

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

National policies



Additional options:

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

Evaluating Impacts of the Inflation Reduction Act and Bipartisan Infrastructure Law on the U.S. Power System

https://www.nrel.gov/docs/fy23osti/85242.pdf

Scenario Framework

Scenario	Description
No New Policy	• Federal and state policies frozen as of September 2022; excludes IRA and BIL • Electricity demand growth from EIA's AEO 2022: 0.7%/year average
IRA-BIL	• Includes major IRA and BIL power sector policies and programs • Increased demand modified from Electrification Futures Study: 1.1%/year average
IRA-BIL Constrained	• Captures possible impacts of non-economic institutional barriers • Restricted renewable resource available for deployment: wind, solar, geo, biomass • Annual transmission expansion capped at recent historical average (1.4 TW-mi/yr) • Does not allow new inter-regional (across 11 regions) transmission expansion • Doubled CO_2 transport, injection, and storage costs

Sensitivities

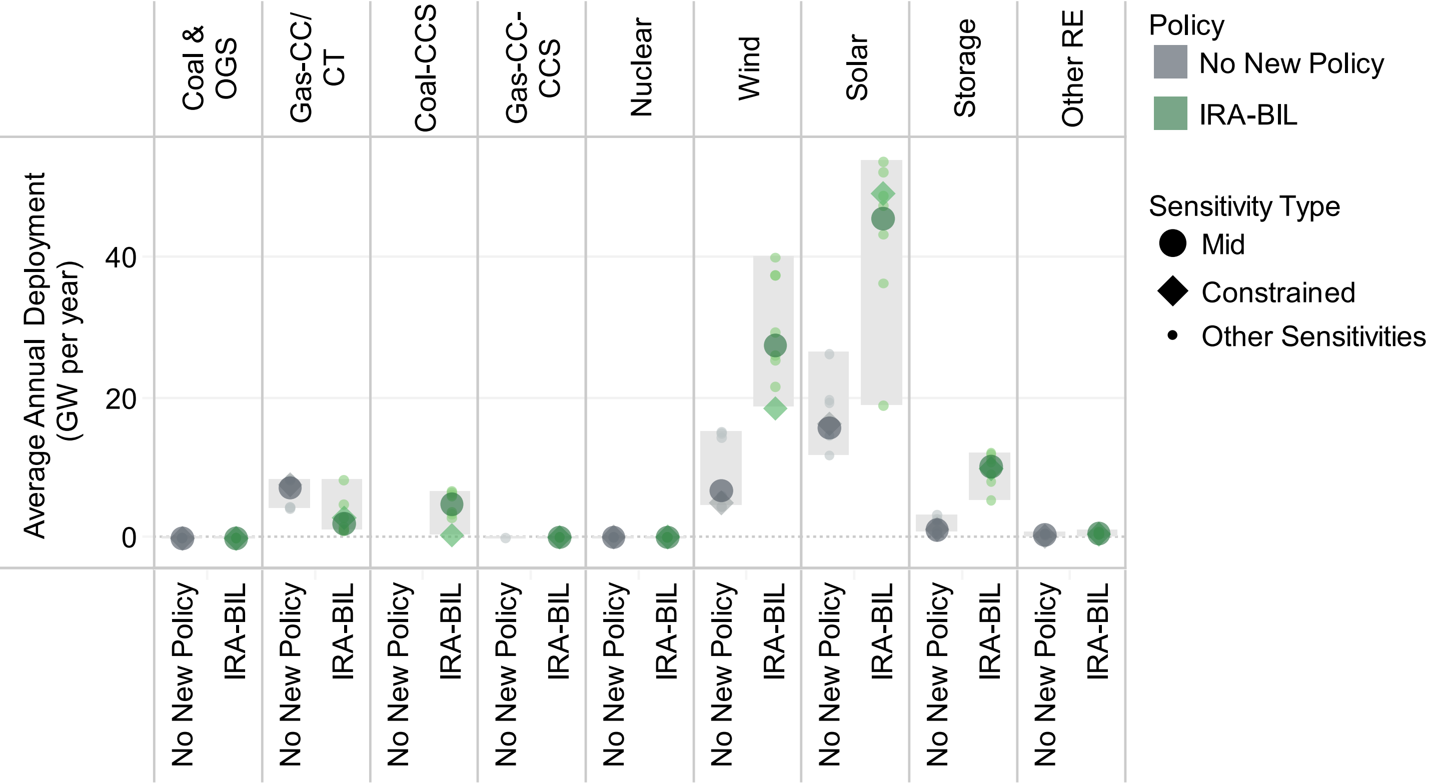
- *Natural gas prices*: High and low from AEO 2022 High- and Low- Oil and Gas Resource cases
- *Technology cost and performance*: NREL ATB Advanced and Conservative trajectories
- *IRA impact*: Vary bonus and credit monetization assumptions

Summary of IRA and BIL Policy Implementation

IRA-BIL Policy	Implementation Assumptions
ITC and PTC (48, 48E, 45, 45Y)	• All projects meet prevailing wage and apprenticeship requirements, so receive full ITC/PTC • ITC or PTC selection based on exogenous analysis, does not vary with time or geography • Endogenous phase out (with safe harbor) when emissions reach 25% of 2022 levels
ITC and PTC Bonuses	• All qualifying projects receive ½ bonus (5%) ramping to one bonus (10%) by 2028 • Additional 0.9 GW-dc/year of distributed solar exogenously added to dGen results due to 48(e) environmental justice bonus credit (and other non-tax IRA programs, including EPA GHG Fund)
Nuclear PTC (45U)	• No endogenous retirements allowed through 2032 due to PTC and Civil Nuclear Credit • Tax credit value and expenditures not endogenously tracked
Carbon Capture (45Q)	• Geologic storage assumed • New build and retrofits allowed
Credit Monetization	• Transferability + partial direct pay assumed to reduce tax credit value by 10% • Additional direct pay allowance for CCS assumed to reduce value by only 7.5%
Accel. Depreciation	• Technologies that qualify for technology-neutral PTC or ITC also qualify for 5-year depreciation
Other Provisions	• Most grant, loan, demo programs assumed to support and/or direct modeled outcome • Some additionality assumed for subset of programs, evaluated outside ReEDS and dGen

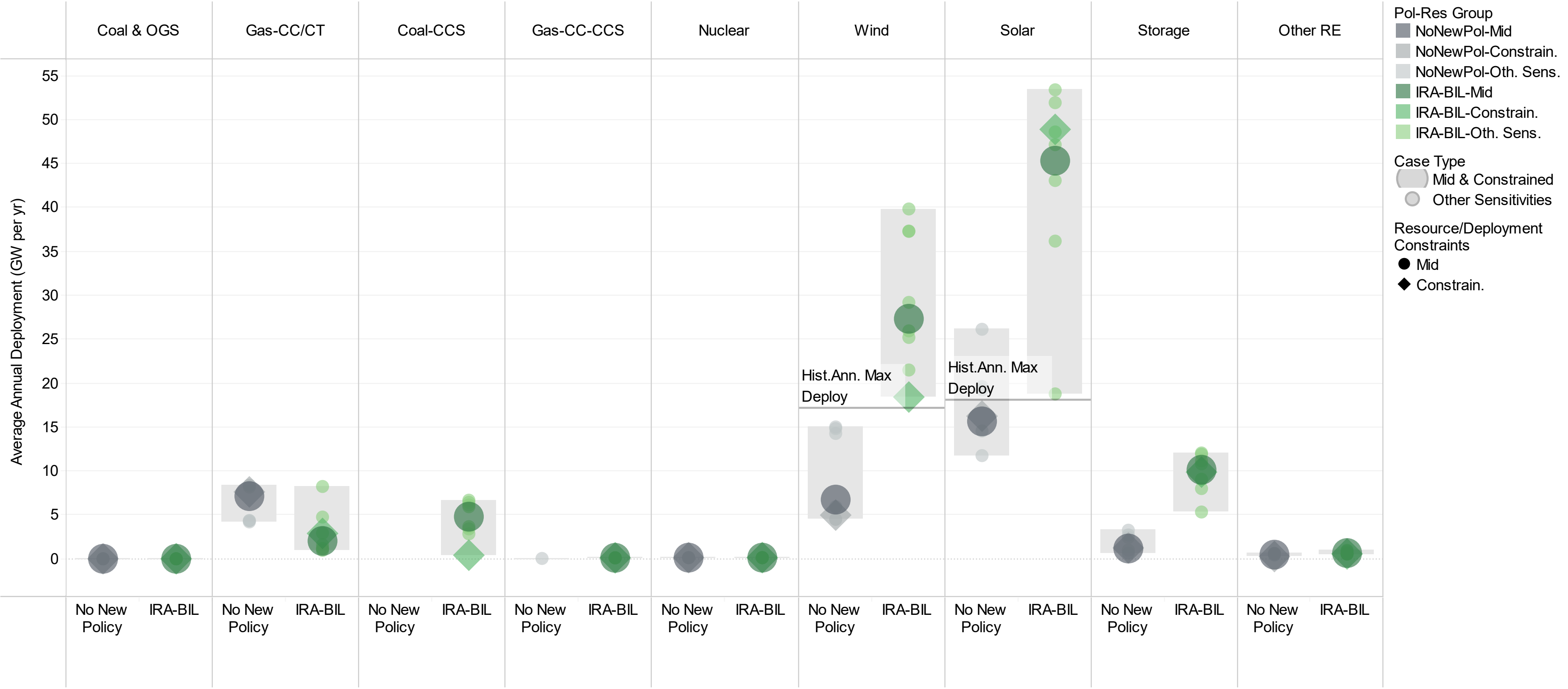
Additional caveats: *H_2 45V PTC and DAC 45Q not represented; simple load growth assumptions*

Clean Electricity Generation Across IRA Analysis Scenarios



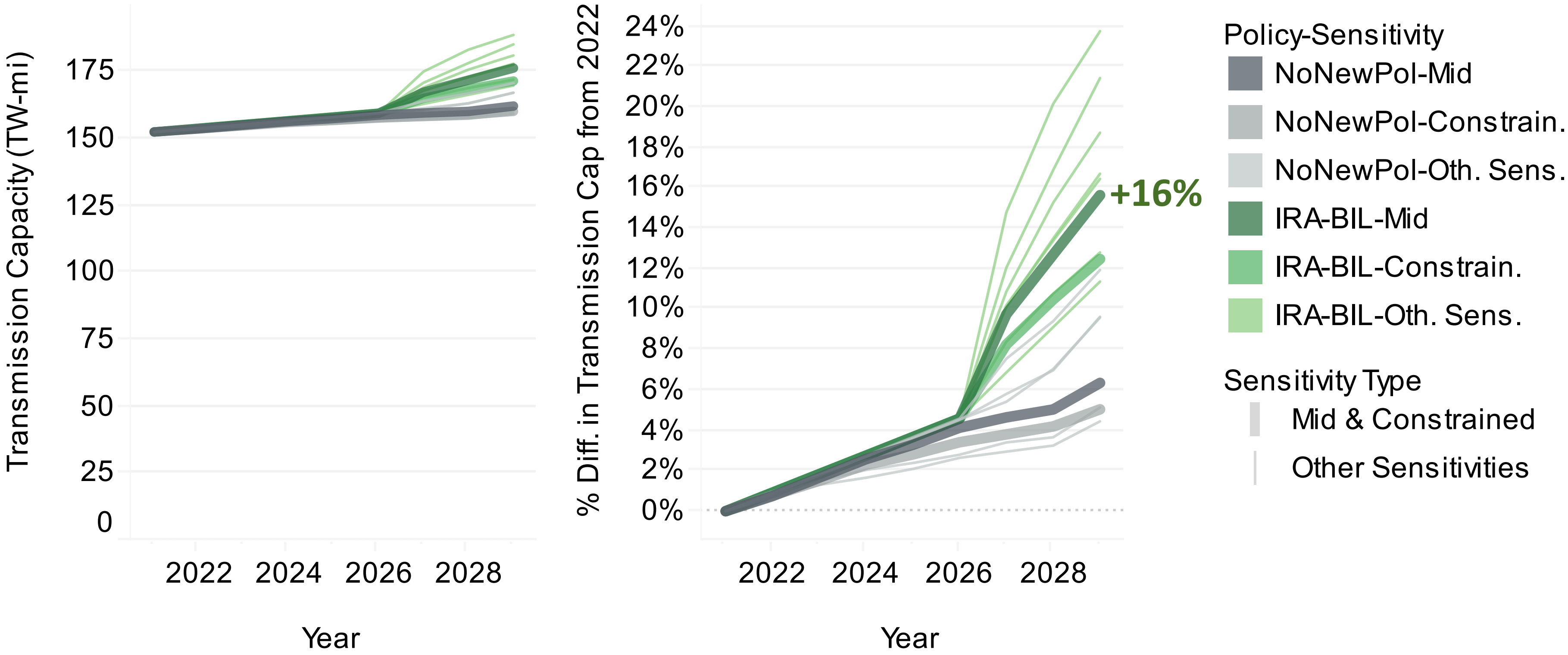
The inclusion of IRA drives clean electricity to capture 71%-90% of total generation by 2030, where the range reflects the different sensitivities explored

Generation and Storage Expansion Across IRA Analysis Scenarios



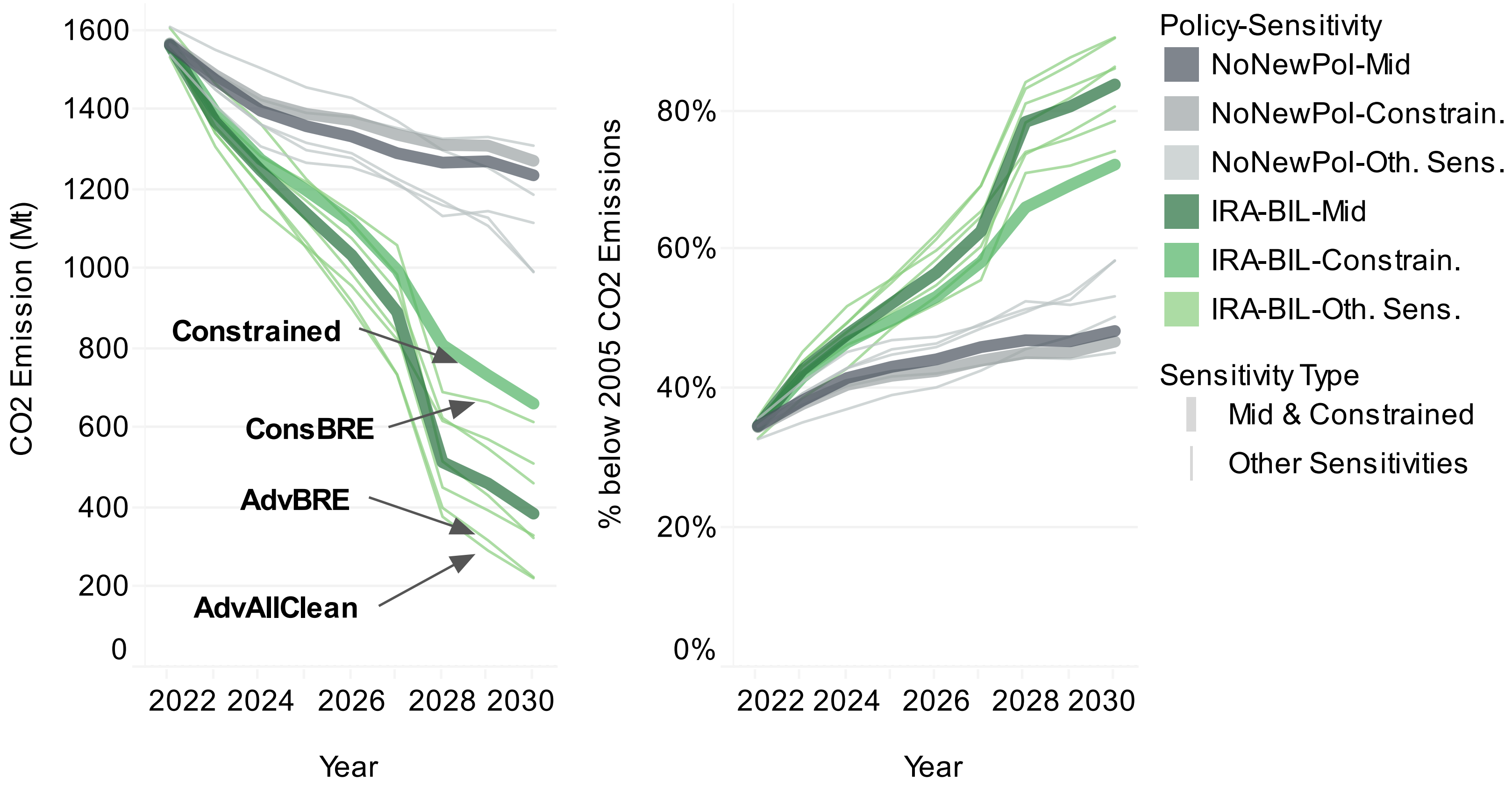
The inclusion of IRA drives wind, solar, and storage deployment rates to more-than-double relative to historical annual maximum levels

Transmission Expansion Across IRA Analysis Scenarios



The inclusion of IRA results in 11-24% growth in long-distance transmission capacity by 2030 (relative to 2022 levels), where the range reflects the different sensitivities explored

Power Sector CO_2 Emissions Across IRA Analysis Scenarios



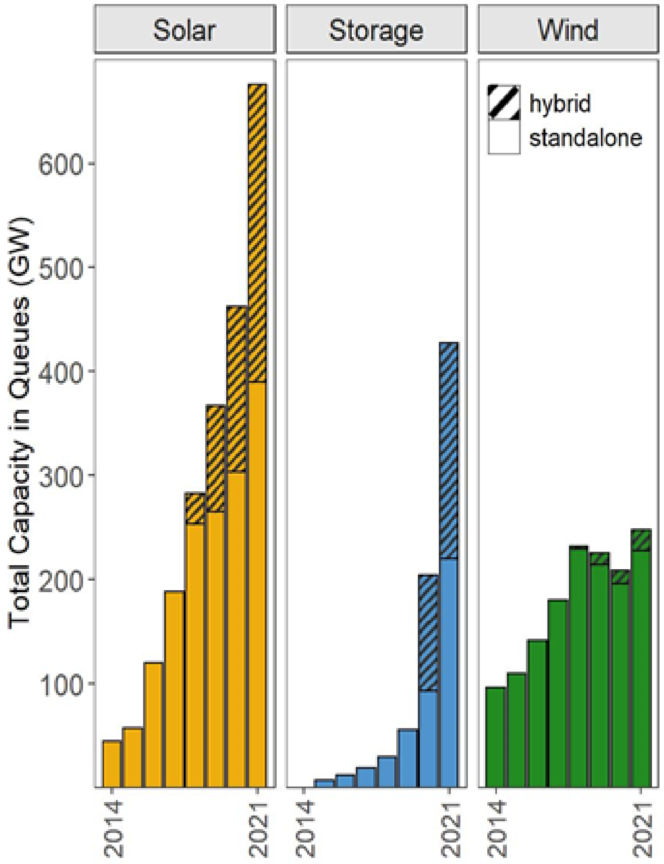
Emissions decline to 72% to 91% below 2005 emissions levels in 2030

The Roles and Impacts of Hybrid Systems in a Decarbonized Power System

https://www.nrel.gov/docs/fy22osti/82046.pdf

Hybrids now comprise a large (and increasing) share of proposed projects

- Drivers of industry interest include:
  - **Shared balance of system costs** including shared interconnection costs and potentially faster permitting/siting
  - **Increased capacity factor** for hybrids that combine complementary resources
  - **Reduced variability**, which helps to facilitate VRE integration, increases dispatchability/reliability services with reduced storage requirements, and maximizes transmission utilization

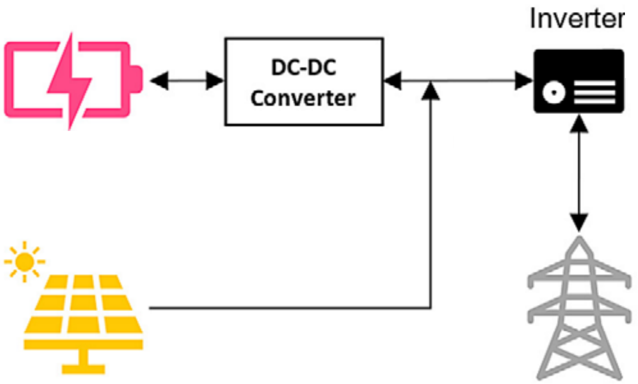


Rand et al. (2022), https://emp.lbl.gov/sites/default/files/queued_up_2021_04-13-2022.pdf

Analysis Framework: PV-Battery Deployment Potential

PV-Battery Representation:

- Use explicit **time series profiles for the ILR-dependent amount of clipped energy** that can be recovered and used by the coupled battery;
- Represent the **shared costs associated with hybridization,** so cost savings are design-dependent
- Assume the battery component in a PVB hybrid receives **100% of the ITC value**
- Capture **curtailment-reduction benefit** associated with charging batteries directly from renewable energy

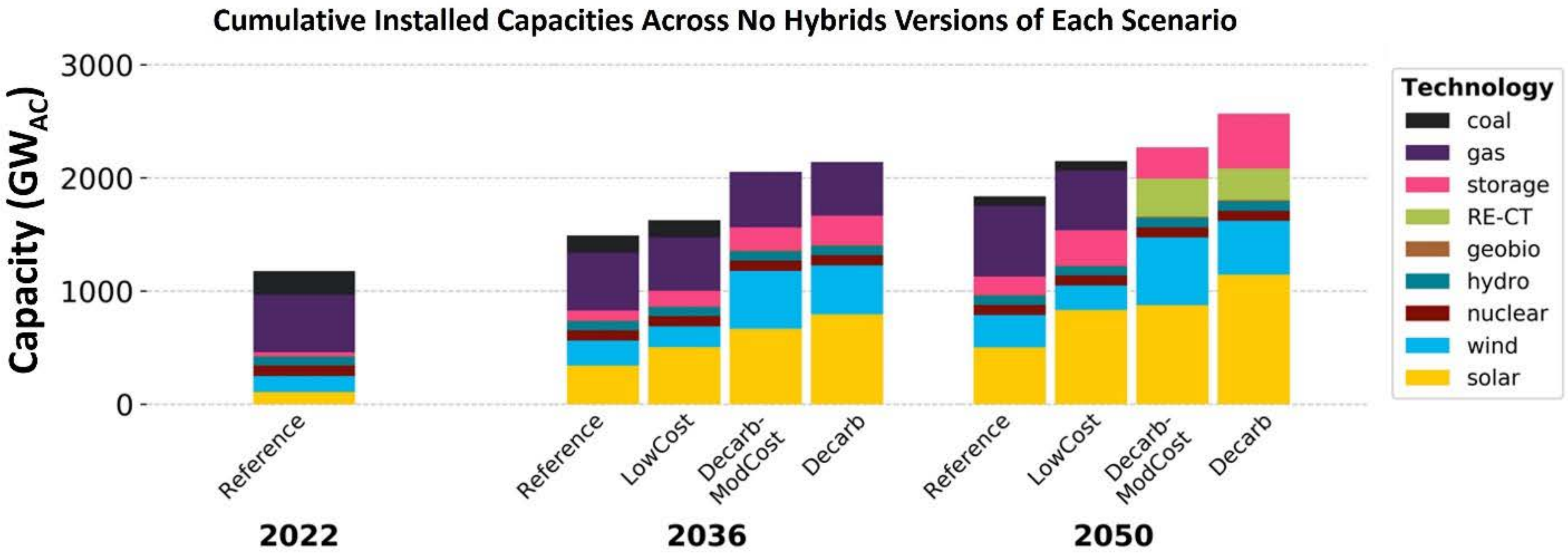


Dimension	Option #1	Option #2
PV and Battery Costs	Moderate reductions	Advanced reductions
Power Sector Decarbonization Policies	Existing policies as of June 2021	95% reduction by 2035, 100% by 2050
PV-Battery Availability	Not Available	Two technology options available

The scenario matrix includes all perturbations of combining option #1 and option #2 for each dimension explored

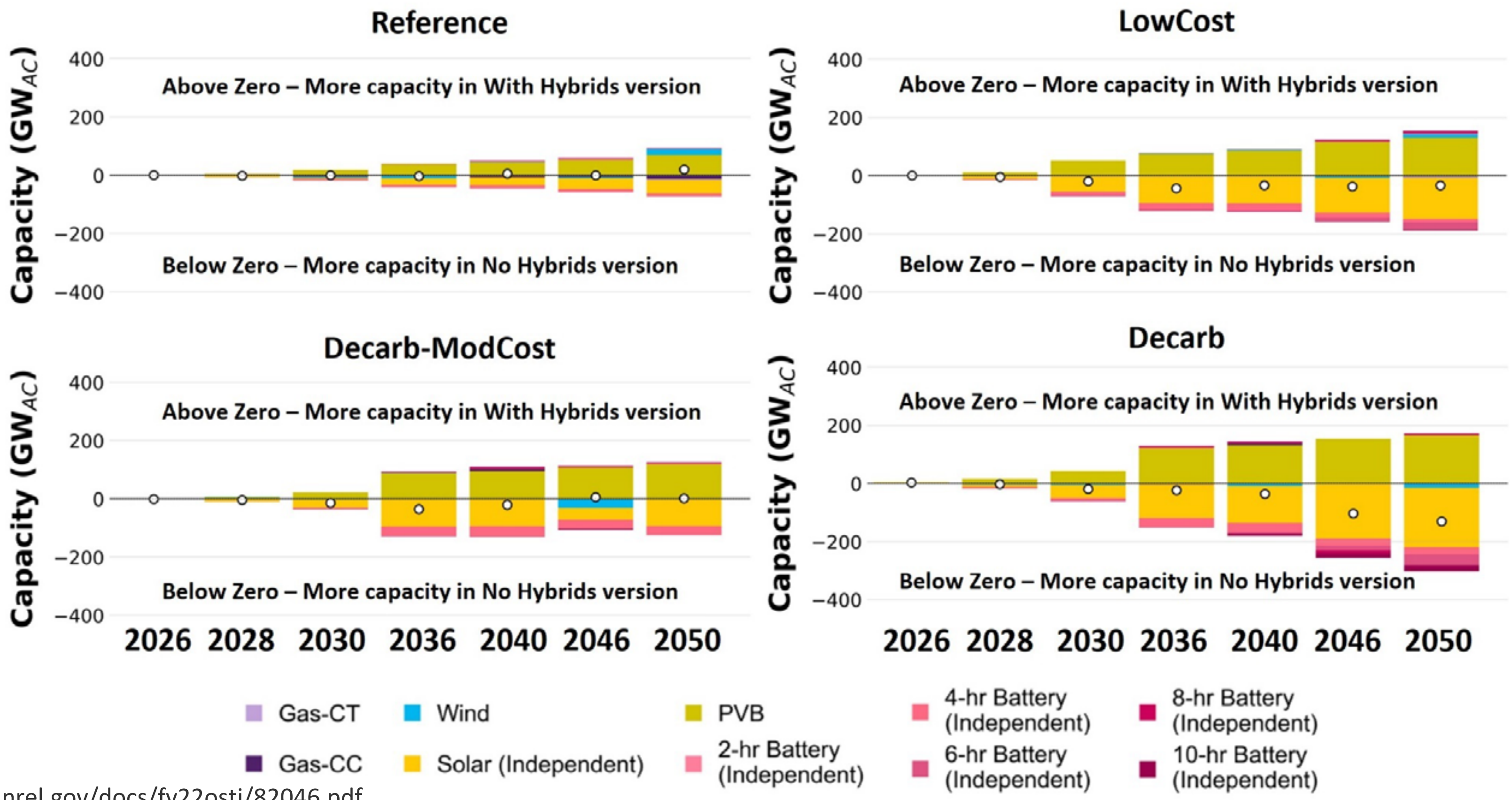
https://www.nrel.gov/docs/fy22osti/82046.pdf

All scenarios involve the widespread deployment of solar, wind, and storage technologies



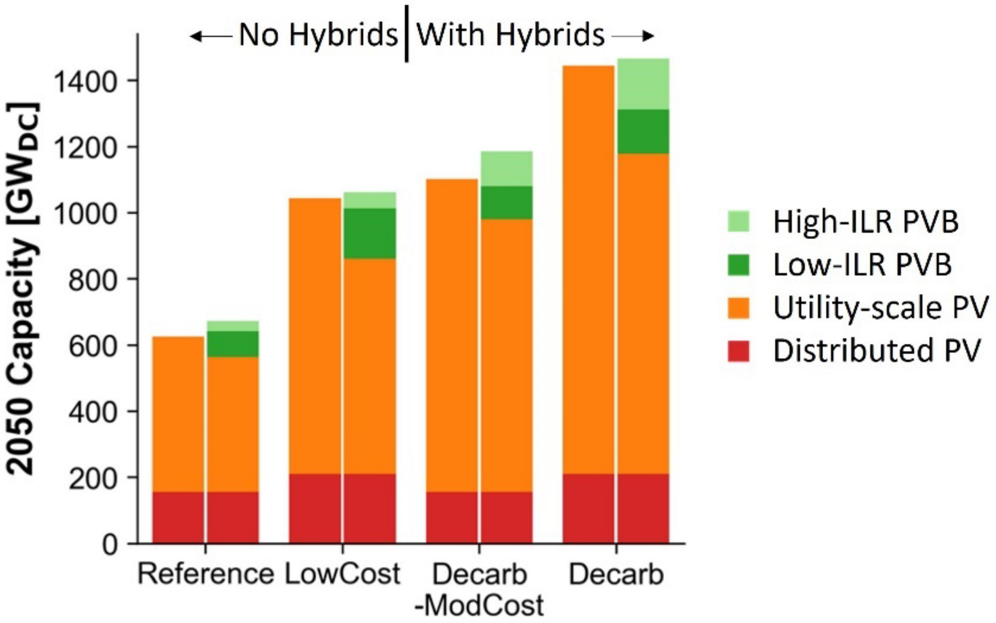
https://www.nrel.gov/docs/fy22osti/82046.pdf

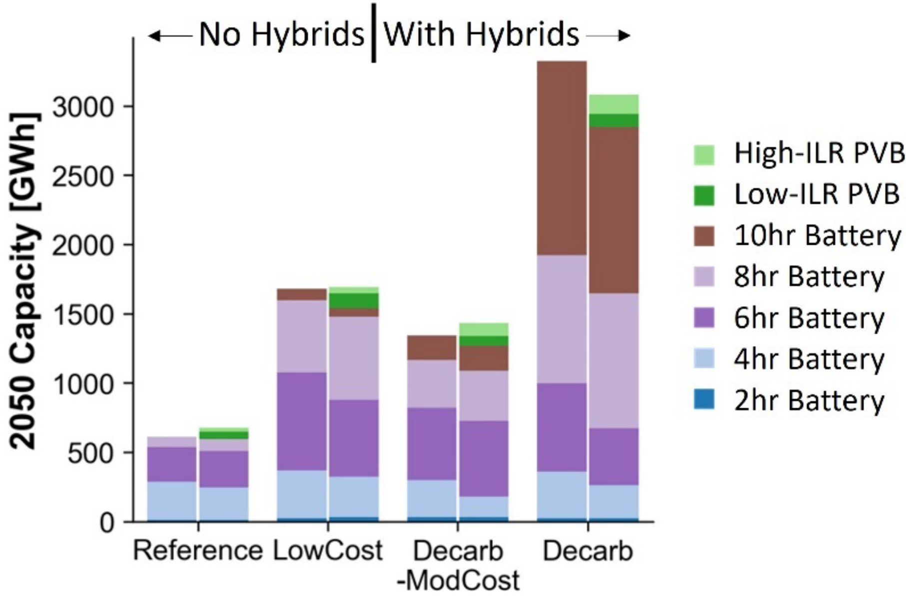
PV-Battery hybrids primarily displace standalone PV and battery capacity



https://www.nrel.gov/docs/fy22osti/82046.pdf

Hybrids represent a relatively small share of total PV and battery capacity



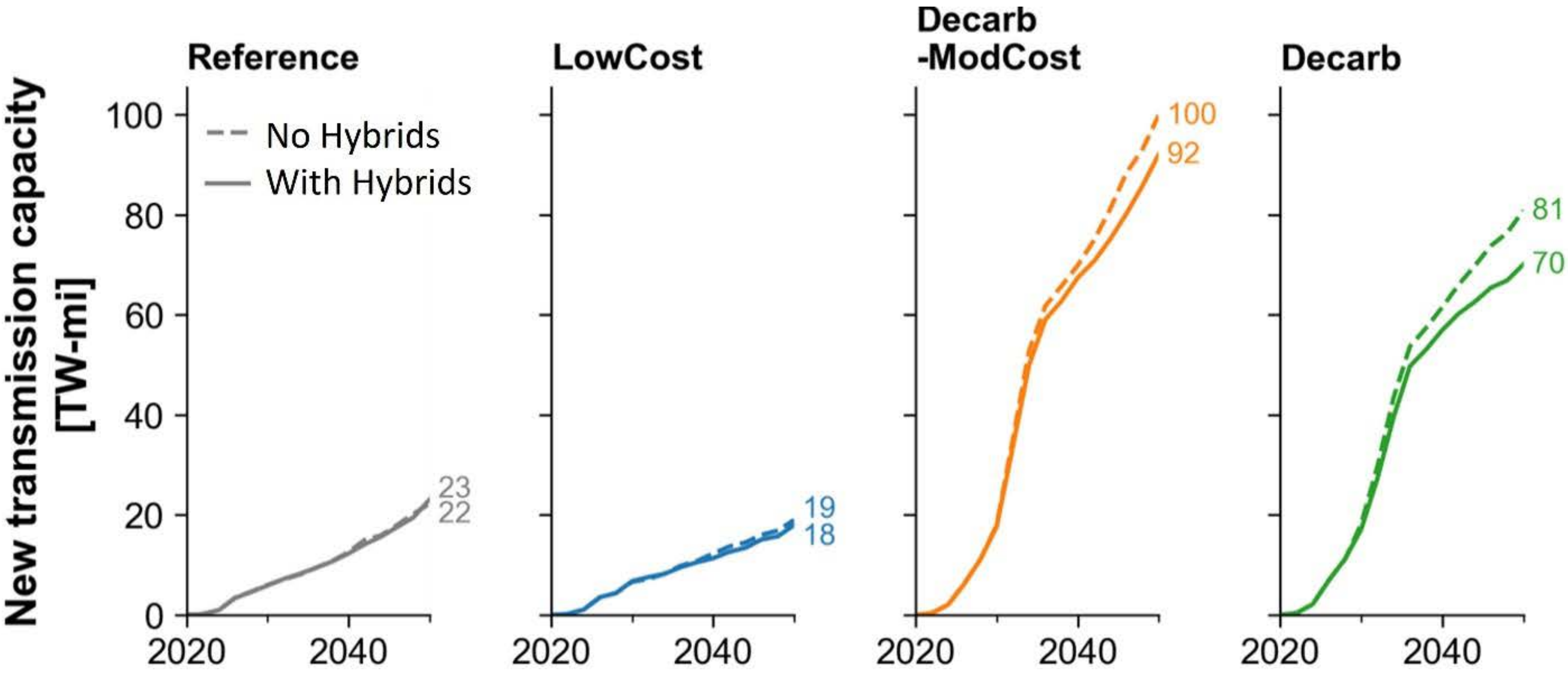


PVB hybrids account for 16-20% of DC-rated PV capacity

Coupled (4hr) batteries largely displace standalone diurnal (4-6hr) storage

https://www.nrel.gov/docs/fy22osti/82046.pdf

PV-Battery hybrids enable similar levels of solar generation with less transmission expansion and lower system costs



0.1% reduction in system costs

0.2% reduction in system costs

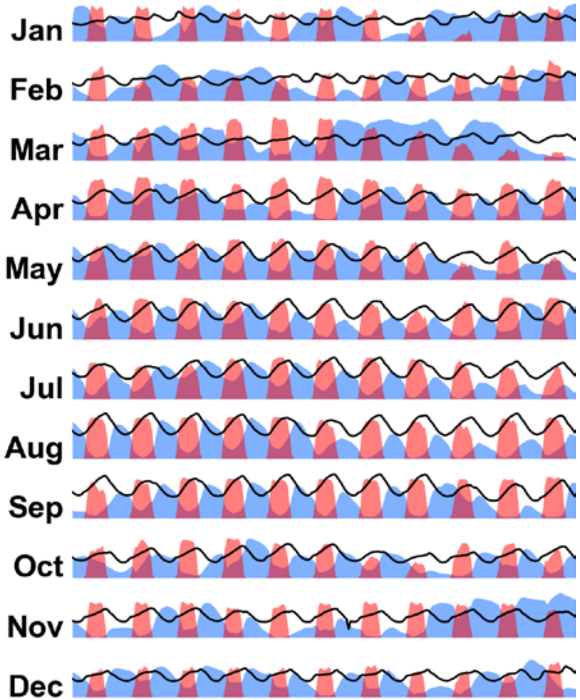
0.2% reduction in system costs

0.7% reduction in system costs

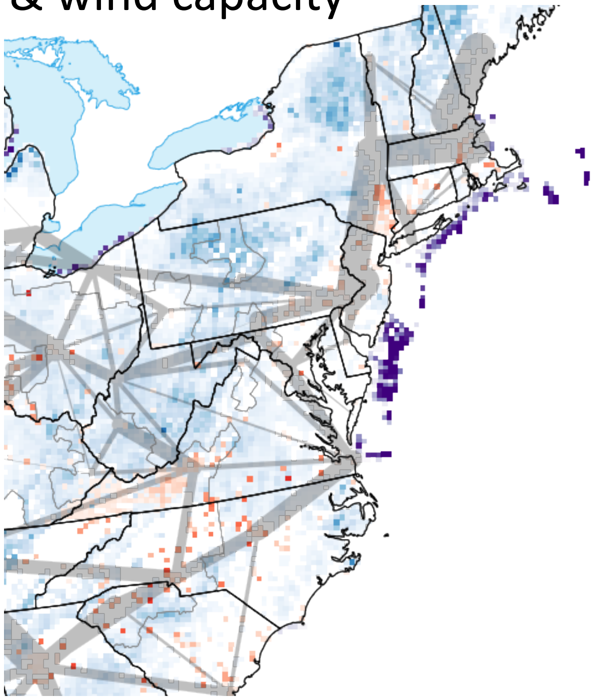
https://www.nrel.gov/docs/fy22osti/82046.pdf

Exploring Wind-PV Hybrid Deployment

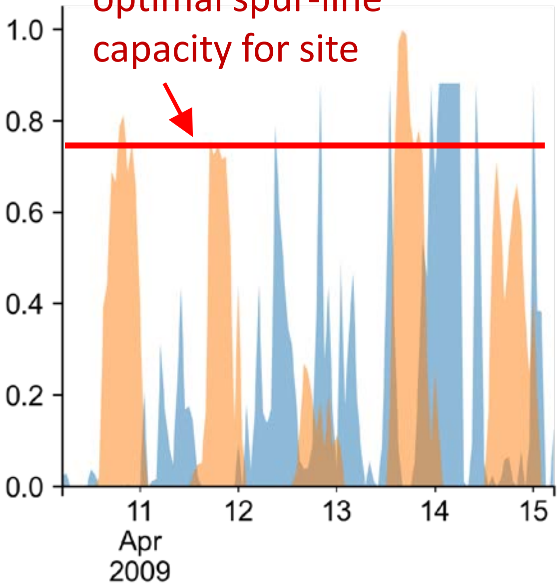
1. Hourly resolution for PV:wind complementarity



2. Individual-site-resolution for spur-line costs and PV & wind capacity



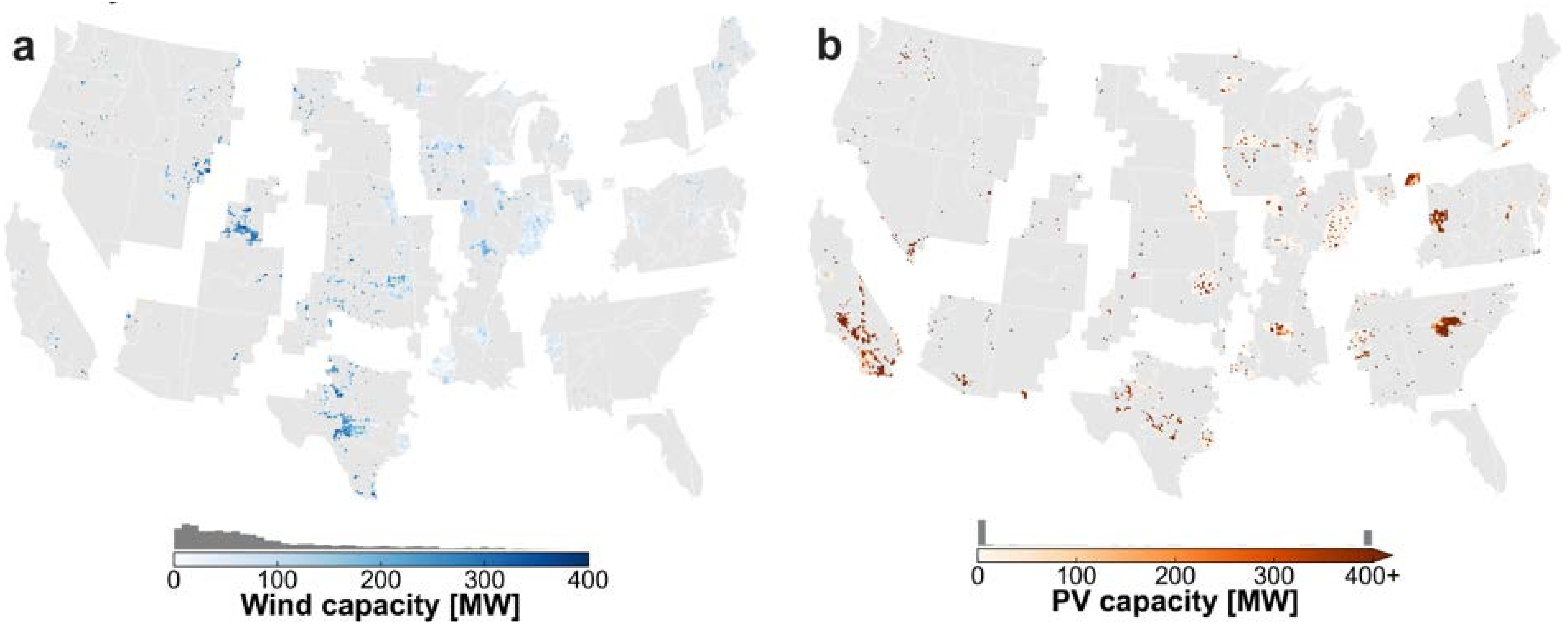
3. Site spur-line capacities optimized in ReEDS



Brown et al. "Optimal design and deployment of wind-solar hybrids in low-carbon U.S. power system." In prep.

Wind and PV Deployment: No Hybrids

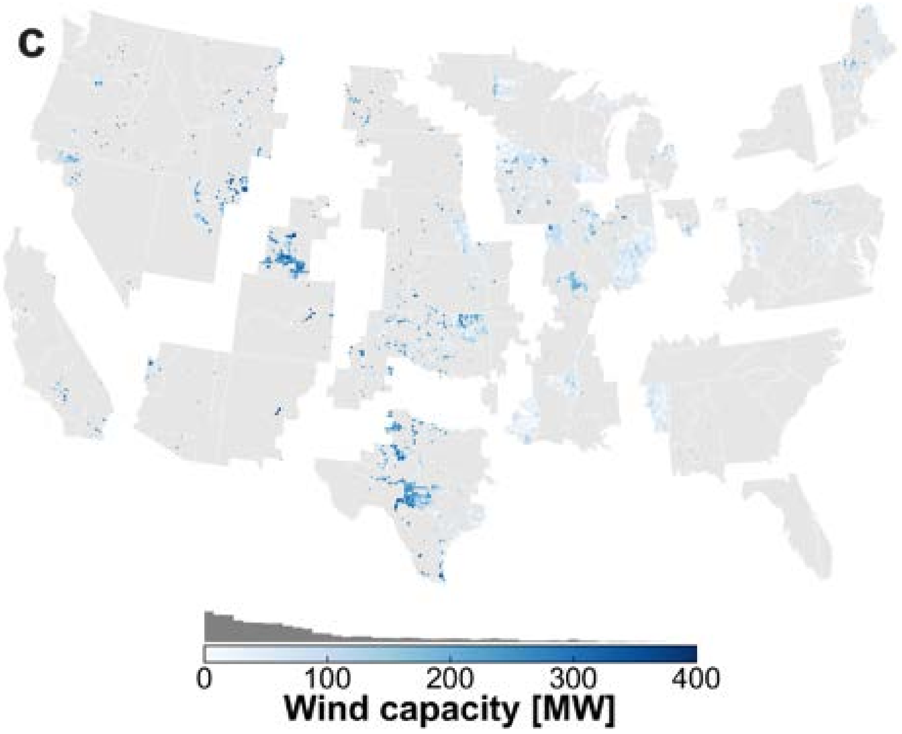
2040 zero-carbon systems

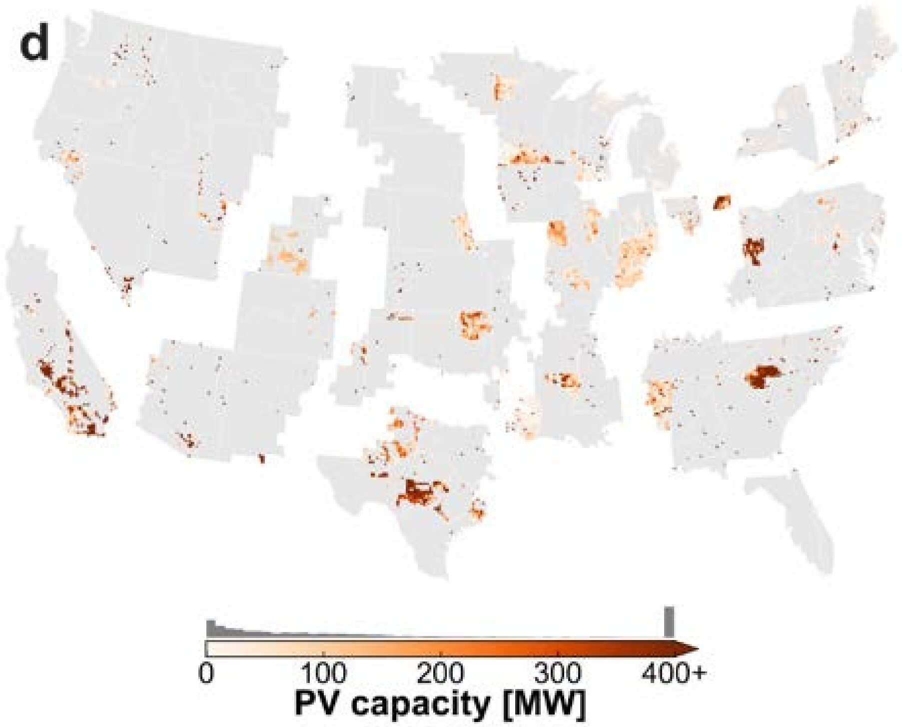


Brown et al. “Optimal design and deployment of wind-solar hybrids in low-carbon U.S. power system.” In prep.

Wind and PV Deployment: With Hybrids

2040 zero-carbon systems

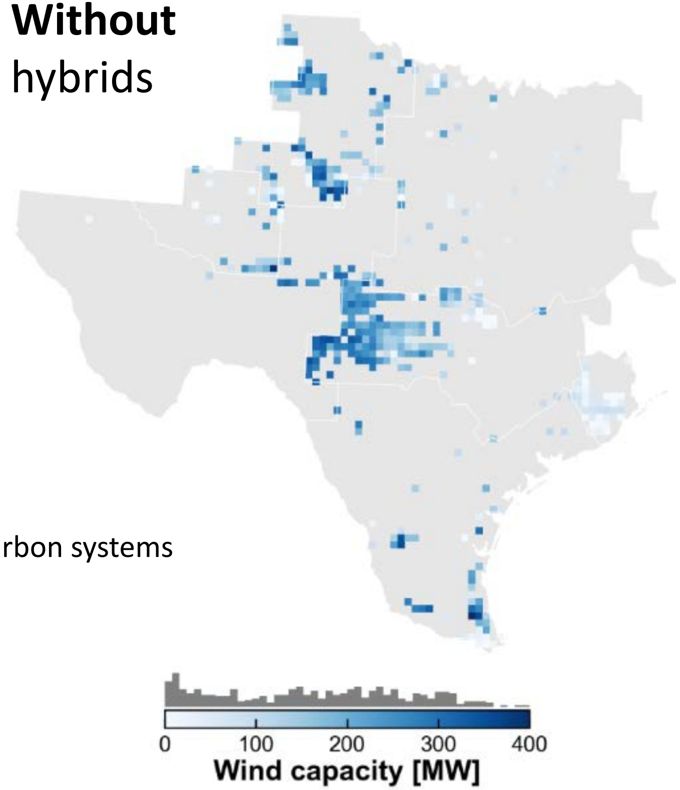




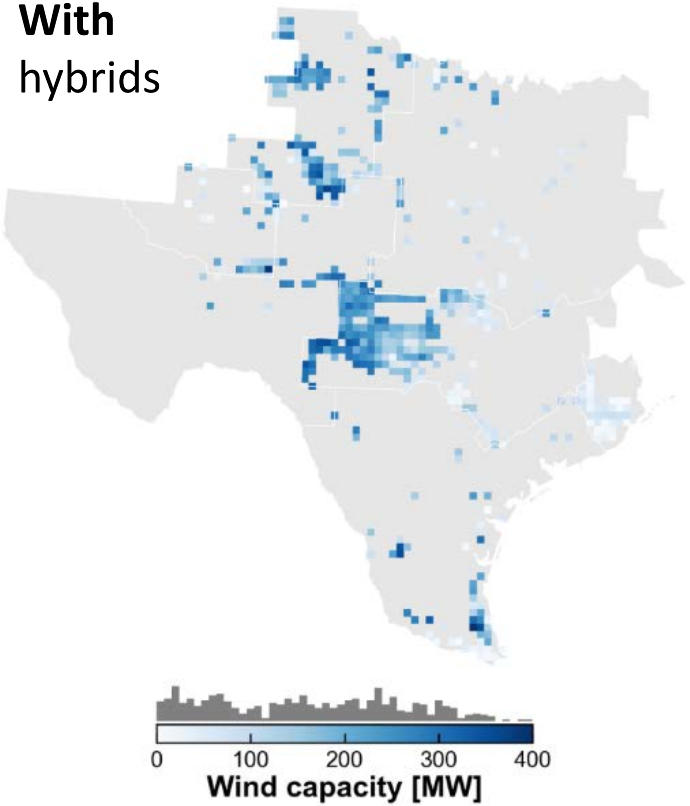
Brown et al. "Optimal design and deployment of wind-solar hybrids in low-carbon U.S. power system." In prep.

Wind Deployment in ERCOT: Minimal Shift with Hybridization

Without hybrids



With hybrids

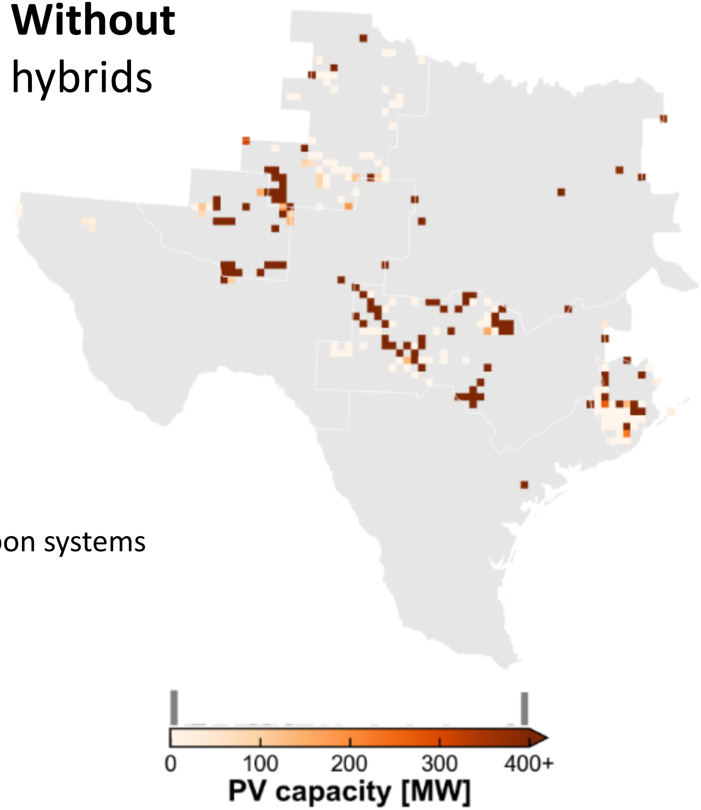


2040 zero-carbon systems

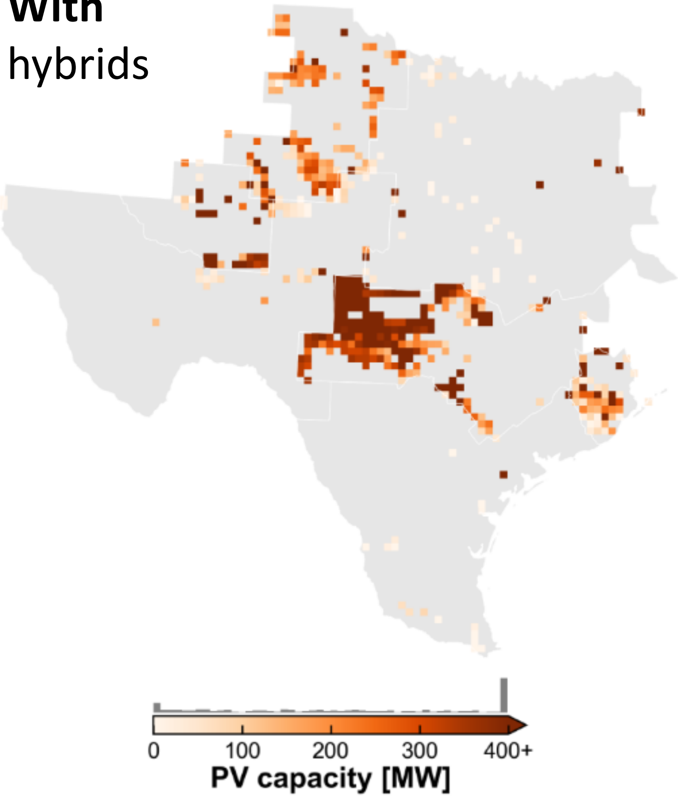
Brown et al. “Optimal design and deployment of wind-solar hybrids in low-carbon U.S. power system.” In prep.

PV Deployment in ERCOT: Relocation to Wind Sites With Hybridization

Without hybrids



With hybrids

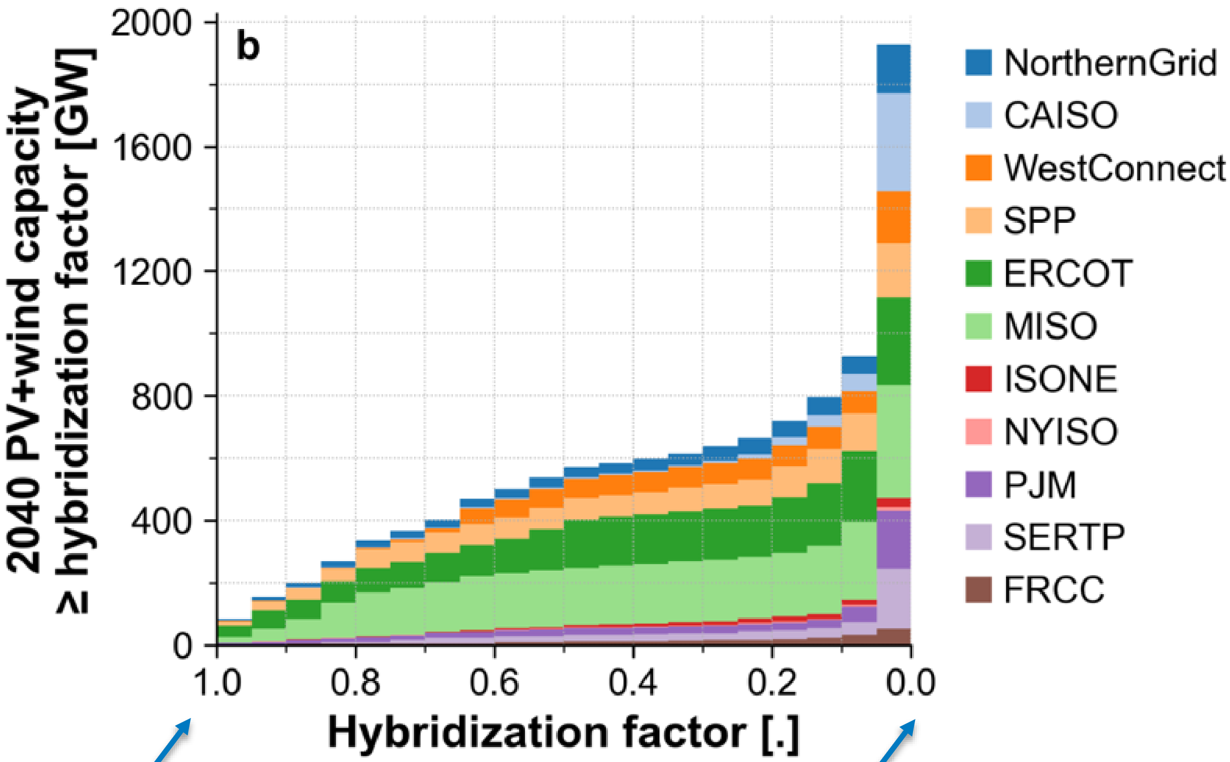


2040 zero-carbon systems

Brown et al. “Optimal design and deployment of wind-solar hybrids in low-carbon U.S. power system.” In prep.

How Much Hybrid Capacity is Deployed?

2040 zero-carbon system



Wind-PV Hybrid with 1:1 Capacity Ratio

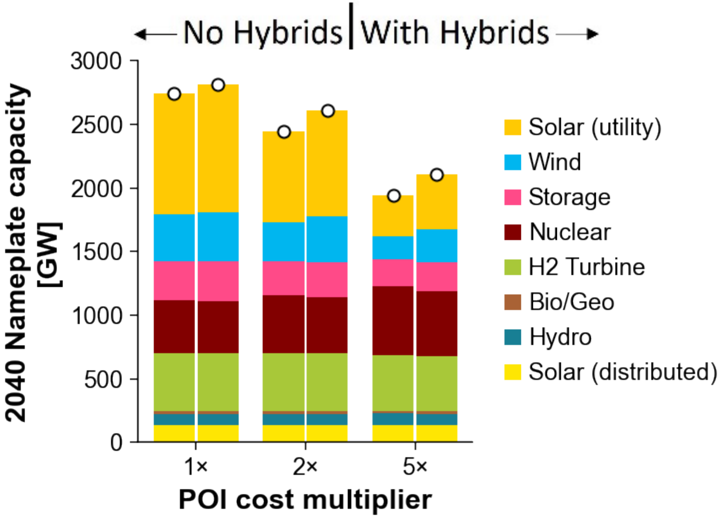
Wind-only or PV-only

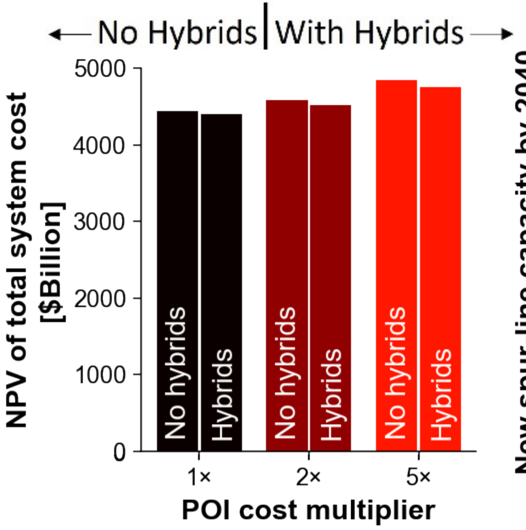
Brown et al. "Optimal design and deployment of wind-solar hybrids in low-carbon U.S. power system." In prep.

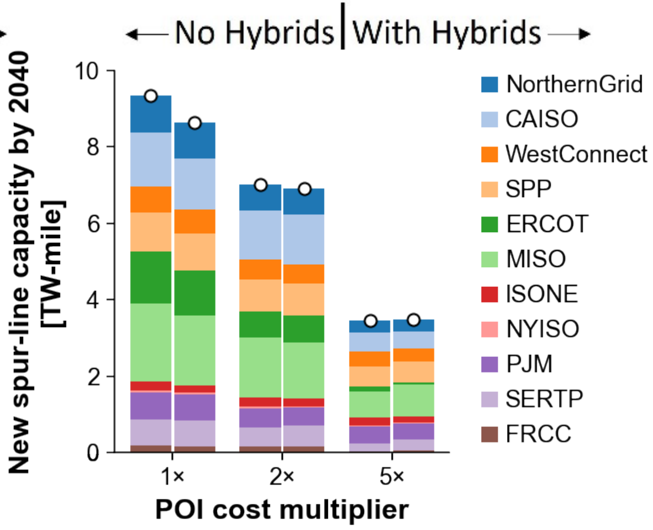
- Most PV/wind capacity is **not** hybridized
- Still a significant amount of hybrids: 195 GW of POI capacity = **348 GW of nameplate PV + wind** (versus 218 GW nameplate PV + wind at end of 2020)

What Value Does Hybridization Provide?

2040 zero-carbon ERCOT system







PV/wind deployment increases (but transmission costs matter more)

$2.5–12 billion in NPV of savings (0.6–2.8%) depending on spur-line cost assumptions

20–30% decrease in spur-line capacity [TW-miles]

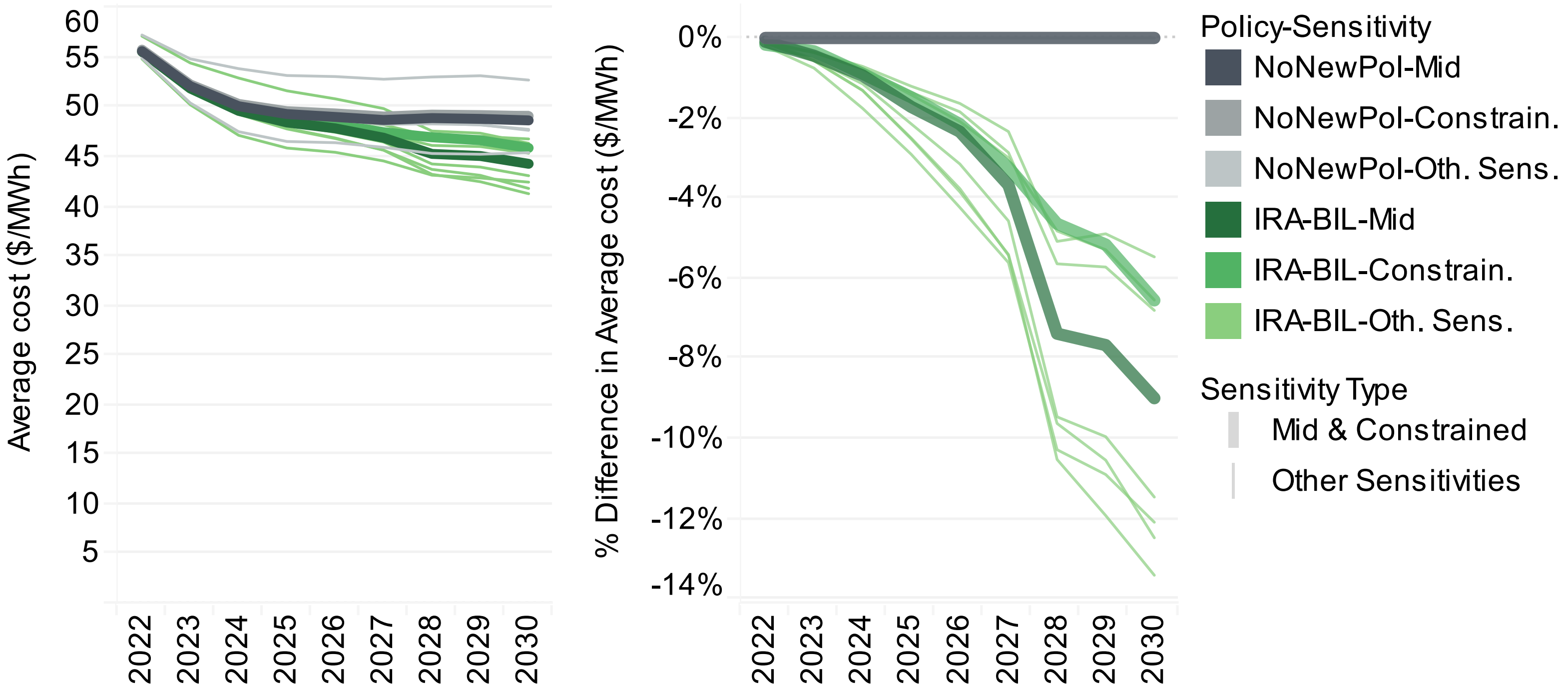
Brown et al. “Optimal design and deployment of wind-solar hybrids in low-carbon U.S. power system.” In prep.

Conclusions

- **Clean generation**: Clean electricity shares could increase substantially with IRA, ranging from 71% to 90% of total generation by 2030 (up from 50%-63% under no new policy)
- **Renewable and storage deployment**: the year-over-year deployment rate for wind, solar, and storage deployment rates could substantially exceed their historical annual maximum levels
- **Fossil-CCS:** IRA could drive 10s of GWs of retrofits of fossil generation capacity with carbon capture reaching 1%-8% of generation
- **Emissions:** decrease to 72% to 91% below 2005 emissions levels
- **Transmission**: barriers to new transmission could partially mitigate clean energy deployment and emissions benefits
- **Hybrid Systems:** hybrids can help accelerate wind and solar deployment in the face of transmission barriers, but they remain a relatively small share of total wind, PV, and storage capacity in all scenarios explored.
  - Storage-based hybrid systems can facilitate similar shares of variable renewable energy generation with smaller amounts of long-distance transmission capacity
  - Wind-PV hybrid systems can facilitate similar shares of variable renewable energy generation with smaller amounts of new interconnection capacity

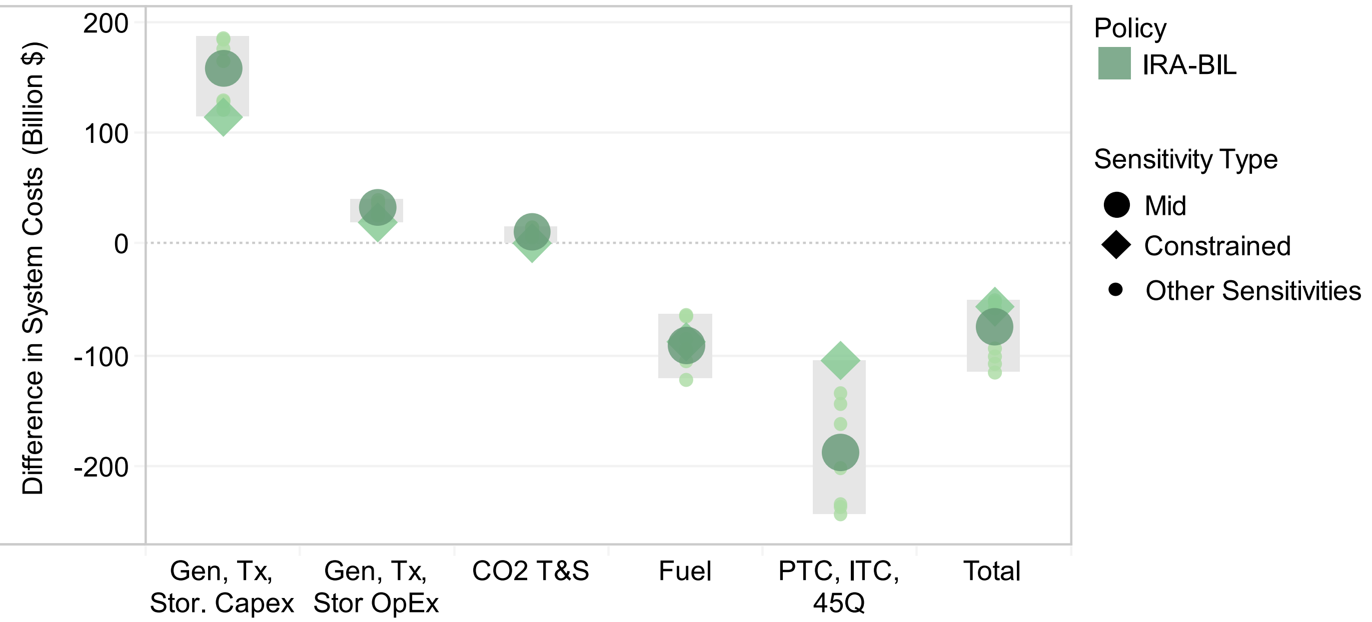
Photo from iStock-627281636

Bulk-system costs decline (net of tax credits) by $3 per MWh to $6 per MWh (5%-13%)

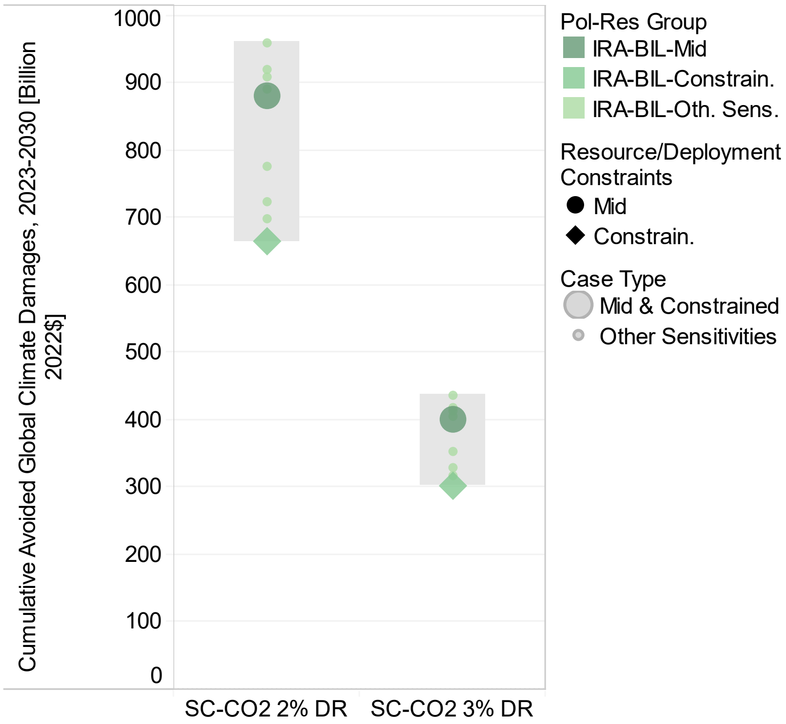


Provisional results – do not distribute or cite

IRA and BIL drive gross increases in investment, but net change in costs is negative driven by value of fuel savings and tax credits



Emissions reductions are associated with substantial avoided climate and health damages

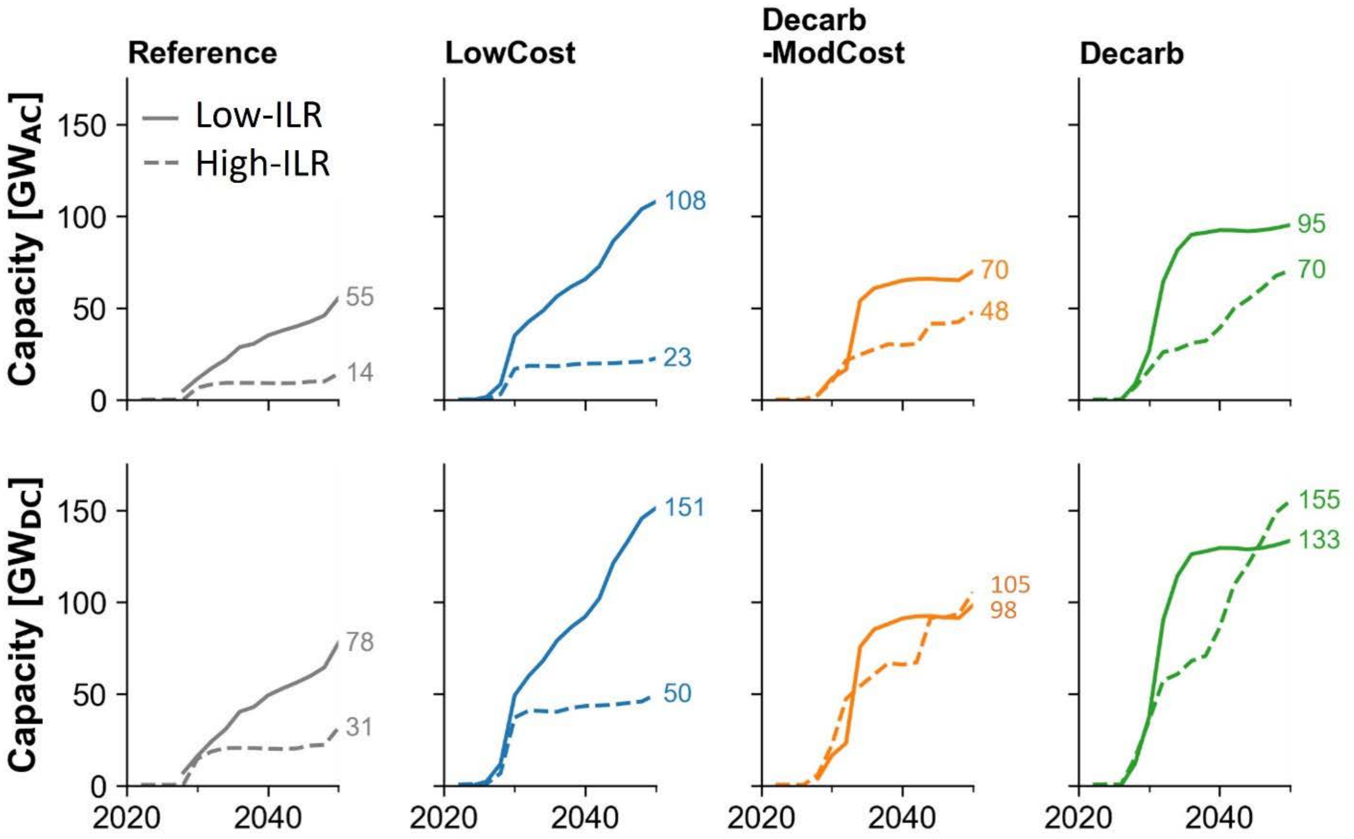


- Avoided climate damages are estimated using SC-CO_2 values from Rennert et al. (2022):
  - "Preferred mean," 2% near-term discount rate: $185 per t CO_2
  - 3% near-term discount rate: $80 per t CO_2
- Avoided health damages associated with reduced mortality:
  - ACS study: $45 billion-$76 billion, cumulatively 2023-2030
  - H6C study: $120 billion-$190 billion, cumulatively 2023-2030

Scenario Design

Scenario Name	PV and Battery Costs	Power Sector Decarbonization Policies	PVB Hybrid
Reference[a]	Moderate reductions	Existing policies as of June 2021	Unavailable
LowCost	Advanced reductions		
Decarb-ModCost	Moderate reductions	95% reduction by 2035, 100% by 2050	
Decarb[a]	Advanced reductions		
Reference With Hybrids	Moderate reductions	Existing policies as of June 2021	Low-ILR PVB: Slightly oversized PV arrays (ILR = 1.4) and relatively small battery (BIR = 0.25) High-ILR PVB: Significantly oversized PV arrays (ILR = 2.2) and slightly larger battery (BIR = 0.5)
LowCost With Hybrids	Advanced reductions		
Decarb-ModCost With Hybrids	Moderate reductions	95% reduction by 2035, 100% by 2050	
Decarb With Hybrids	Advanced reductions		

PVB Hybrid Deployment

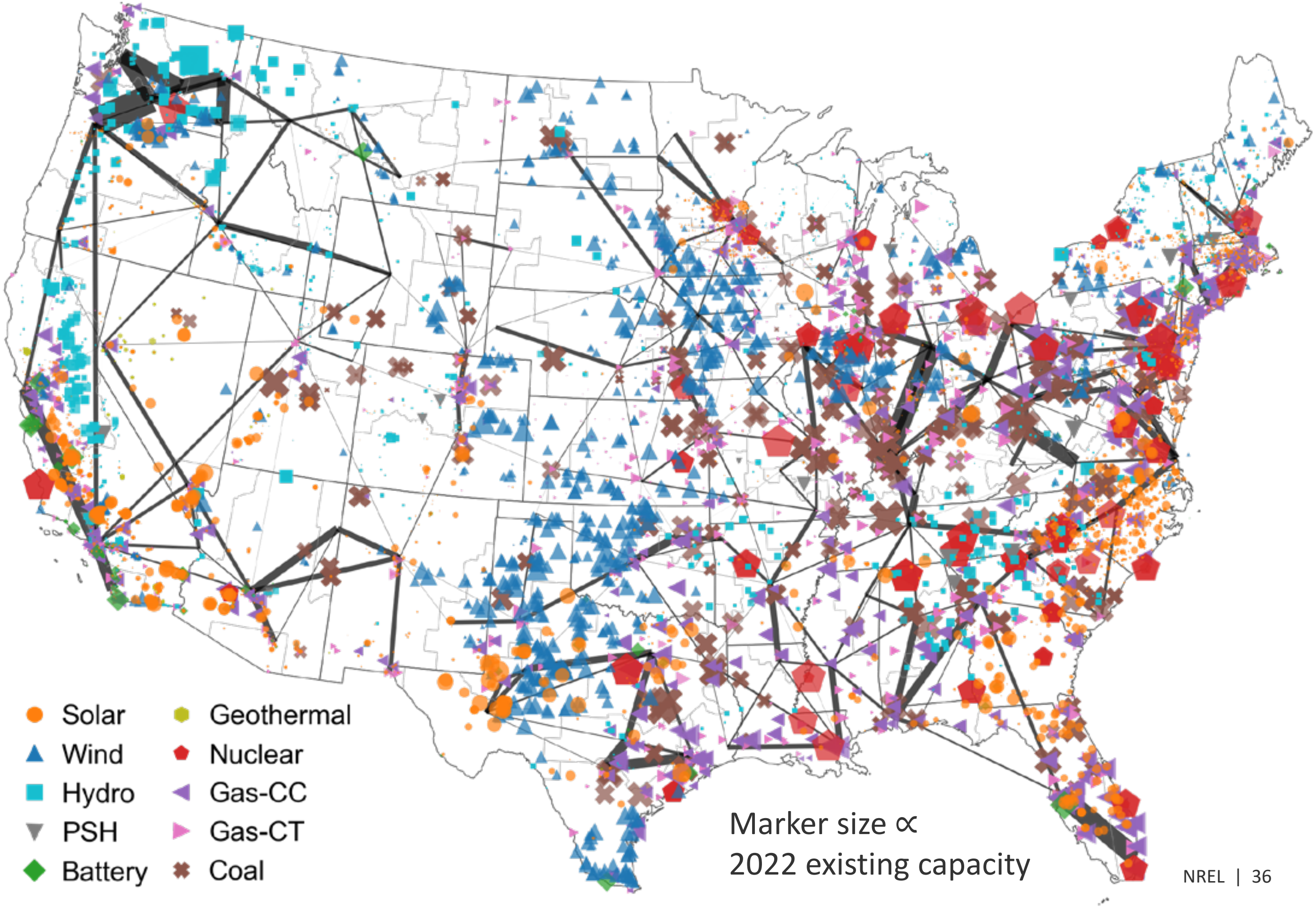


ReEDS: Key Inputs

Existing & planned capacity

- **Generation capacity:** EIA National Energy Modeling System (NEMS)
    - Updated annually
- **Transmission capacity:**
    - Initial inter-zone transfer capacities from nodal GridView analysis (currently being updated)
    - New inter-zone lines tracked individually

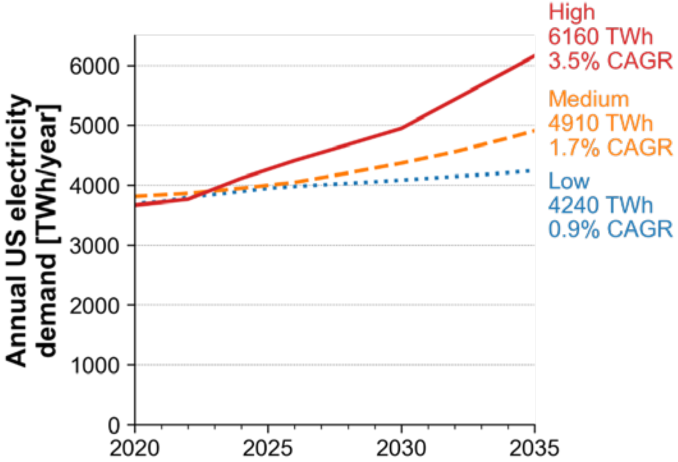
→ Maintained or retired in order to minimize total system cost

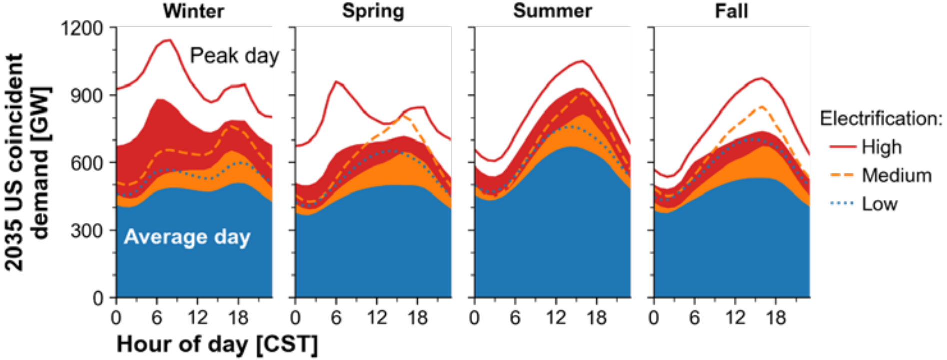


ReEDS: Key Inputs

Demand

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

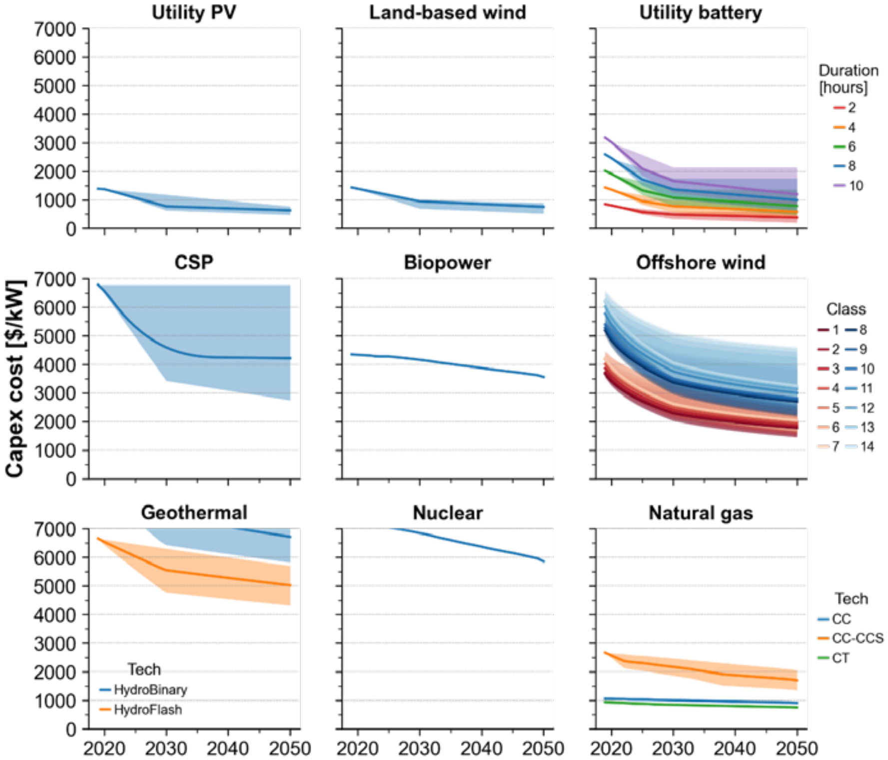




Technology cost & performance

Annual Technology Baseline (ATB)

https://atb.nrel.gov/

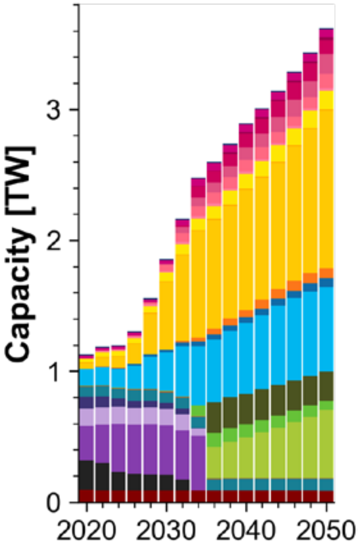


+ Fuel costs from EIA Annual Energy Outlook (AEO)
+ Interconnection spur line costs, discussed later

ReEDS: Key Outputs

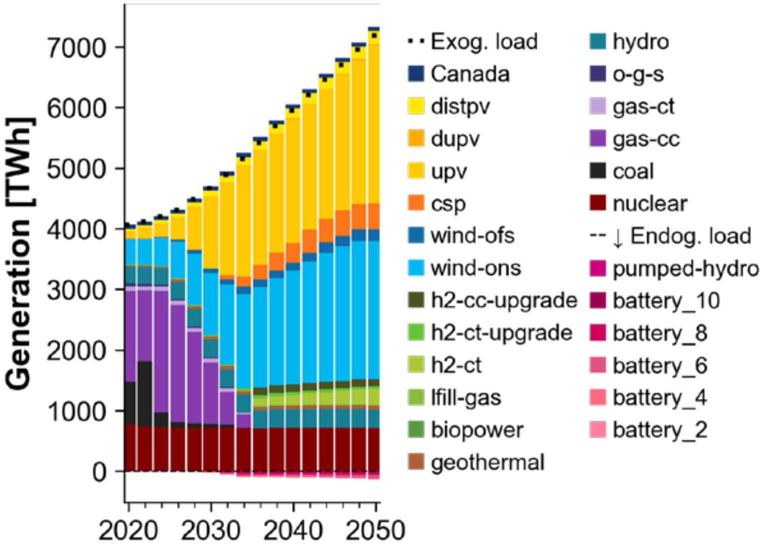
System design

Capacity

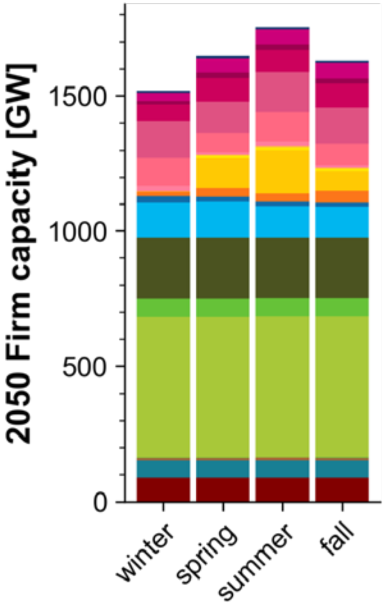


System operation & service provision

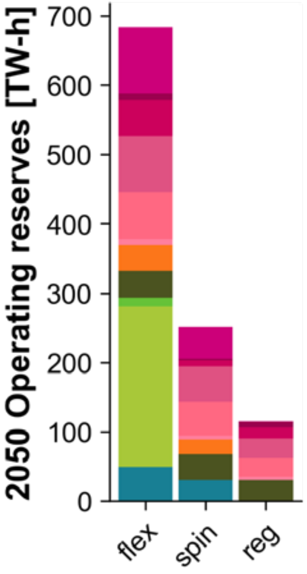
Generation



Firm capacity



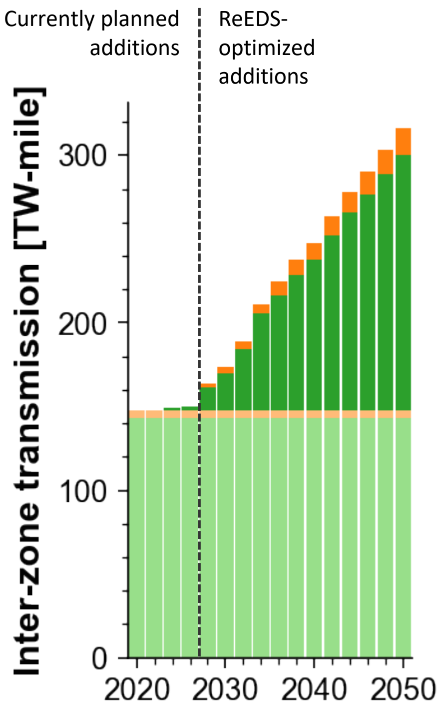
Operating reserves

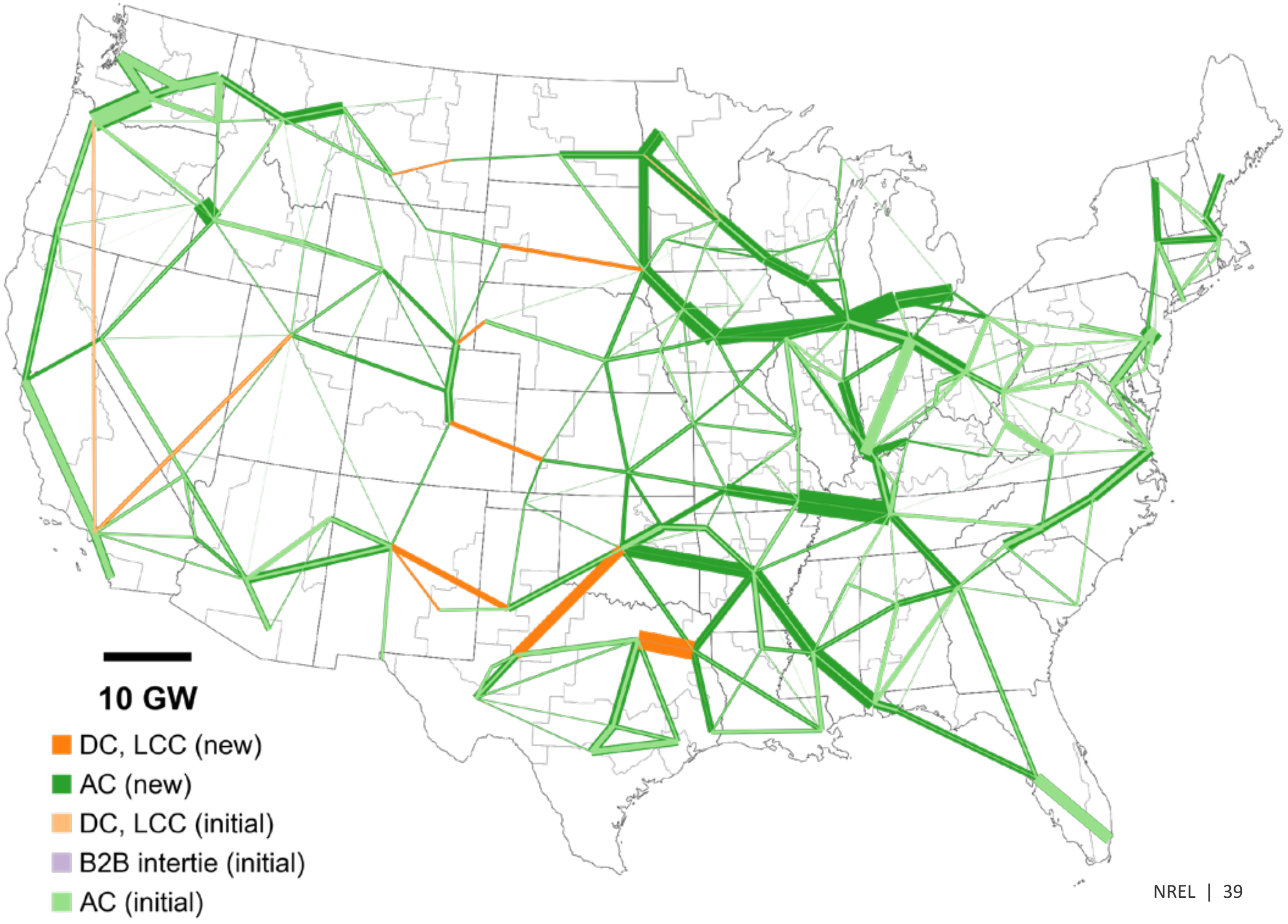


ILLUSTRATIVE modeling results only

ReEDS: Key Outputs

Transmission additions





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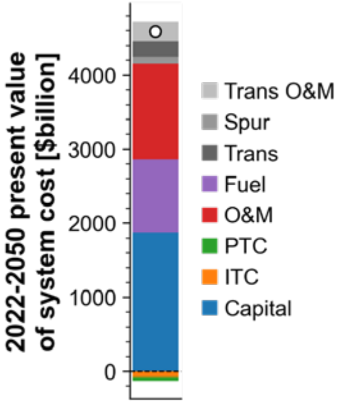
ReEDS: Key Outputs

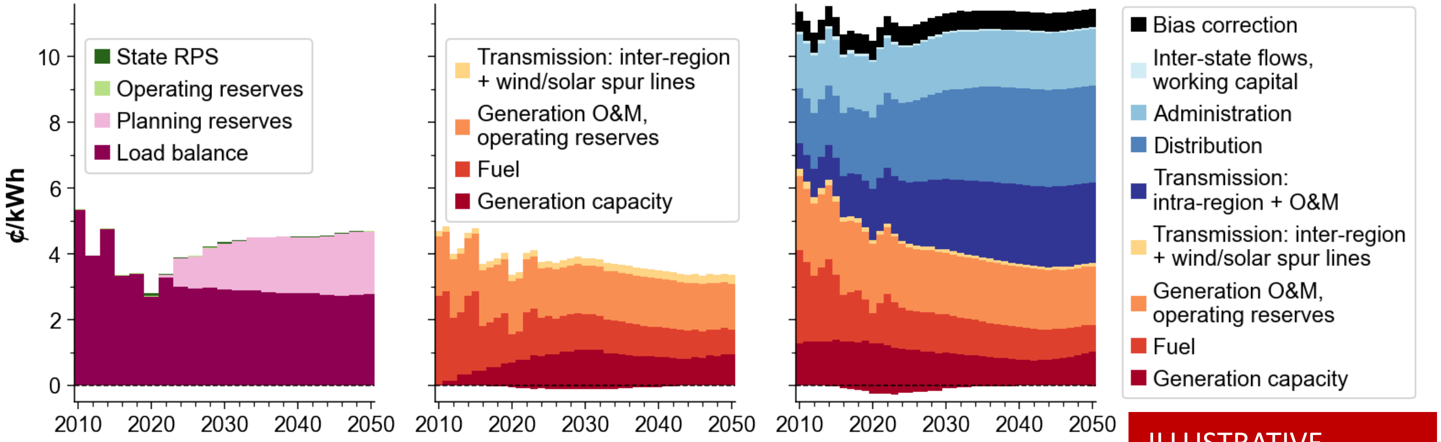
NPV of costs over full model horizon



Marginal price

System cost

Retail rate



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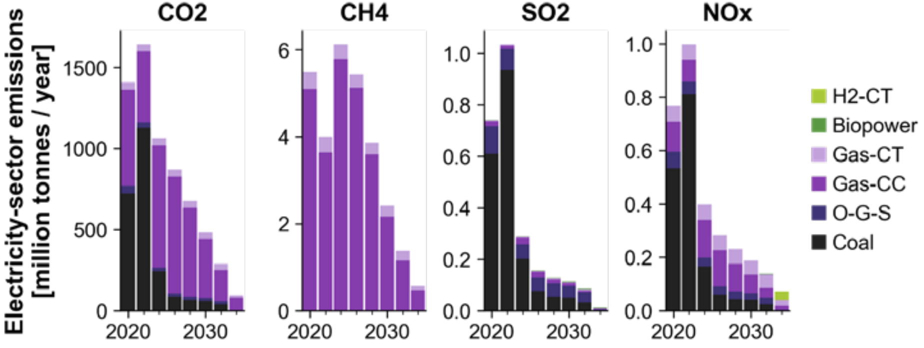
Emissions (CO_2, CH_4, SO_2, NO_x)



Health impacts