Modeling the Effects of Distributed Generation on Transmission Infrastructure Investment

A Western Case Study

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ESIG
ENERGY SYSTEMS INTEGRATION GROUP

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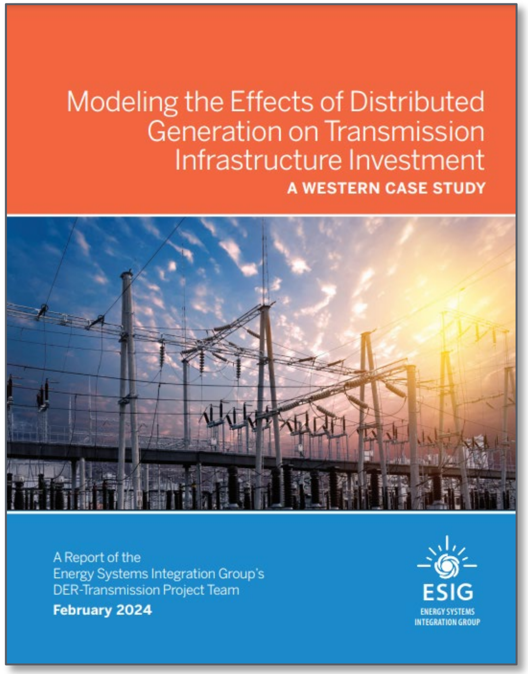
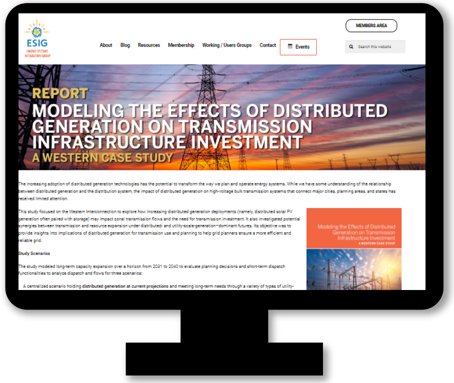
ENERGY STRATEGIES

Study Published on ESIG Website

Full Report



ESIG Project Website



You can find these materials at: https://www.esig.energy/distributed-generation-impact-on-transmission/

Executive Summary

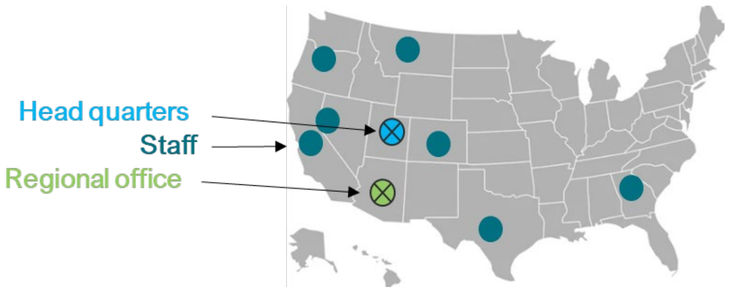
Technical Review Committee

Obadiah Bartholomy, SMUD	Debra Lew, Energy Systems Integration Group	James Okullo, ESIG
Aaron Bloom, NextEra Energy	Robert Margolis, NREL	Ed Smeloff, Consultant
Thomas Carr, Western Interstate Energy Board	Joshua Novacheck, NextEra Energy	
Cullen Howe, Natural Resources Defense Council	Michael O'Boyle, Energy Innovation	
Lorenzo Kristov, Consultant	Ric O'Connell, GridLab	

Energy Strategies Overview

- **Founded in 1986, Energy Strategies is an award-winning independent energy consulting firm providing energy consulting services to power producers, transmission developers, utilities, governments, non-profits, and large energy users across North America**
- **Capabilities and geographic coverage have grown recent years, with the firm excelling at:**
  - Providing market awareness and expertise of large consultancy with trust, access, & insight of small boutique firm or individual consultant
  - Objective and unbiased analysis on complex industry issues – tackle complicated and innovative work with focus on planning, analysis, and deployment of clean energy infrastructure
  - Work tailored to client needs – turn-key projects are not the norm for our company although we do retrain proprietary study methods and databases

Company Footprint



- **Team consists of ~30 expert consultants that generally have between 5-40 years of experience with formal training as:**
  - Engineers & power system experts
  - Economists & regulatory/business analysts
  - Data scientists and programmers

Recent Project Highlights

Study Motivation & Objectives

Study Motivation

- **Distributed generation resources (DGRs) have the potential to transform the way we plan and operate energy systems.**
  - DGRs are defined in this study to include several combinations of distributed solar and storage resources

- **In general, these resources:**
  - Produce power proximate to loads
  - Do not require power transmission
  - Are owned and operated by electricity customers
  - Generate electricity without on-site emissions
  - Can be configured as a source of backup power
  - Are limited in their ability to cost-effectively store generated power
  - Do not alter power production with consideration to the broader power system

Study Motivation

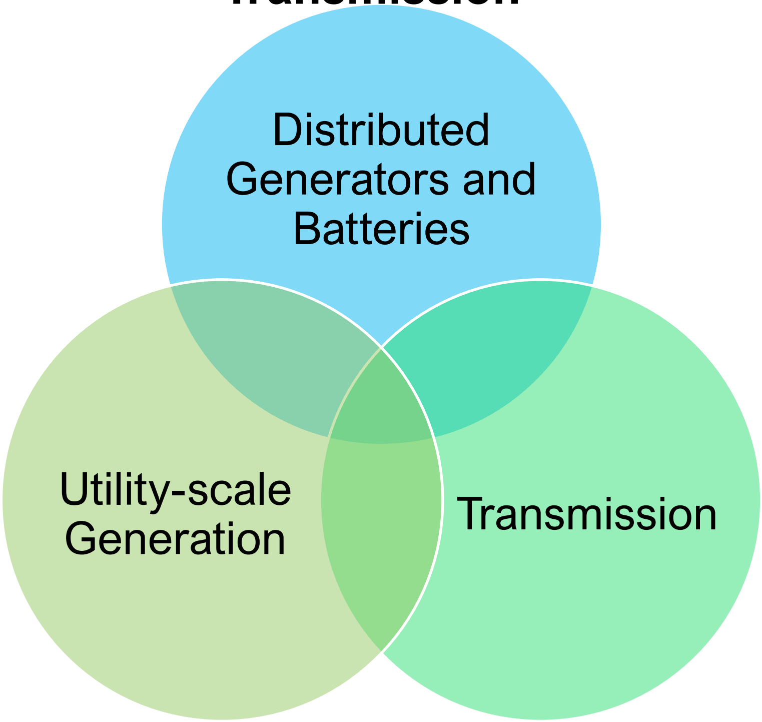
- **Depending on the specifics of design and implementation, distributed solar and storage resources (DGRs) may:**
    - **Drive the need for investment** by causing congestion or overloading in low-voltage distribution infrastructure (wires, transformers) used to get electricity to our homes and businesses
    - **Defer or eliminate the need for new investment** by offsetting loads and reducing loading of distribution infrastructure

- **Unlike the distribution system, little is known about how DGRs may impacts the need for investments high-voltage transmission grid**
    - The motivation of this study is to assess if high adoption rates of DGRs, could reduce the need for some future transmission investments on a macro-scale

Study Objectives

- **Energy Strategies was commissioned by ESIG to investigate the relationship between DGR adoption and the need for transmission investment**
- **Key questions explored in this study included:**
  - Do increasing levels of distributed generation resources impact high-voltage transmission system flows?
  - Can distributed generation resources reduce, defer, or eliminate investment in inter-zonal transmission projects?
  - Is there synergy between transmission investments driven by distributed generation resources vs. utility-scale resources?

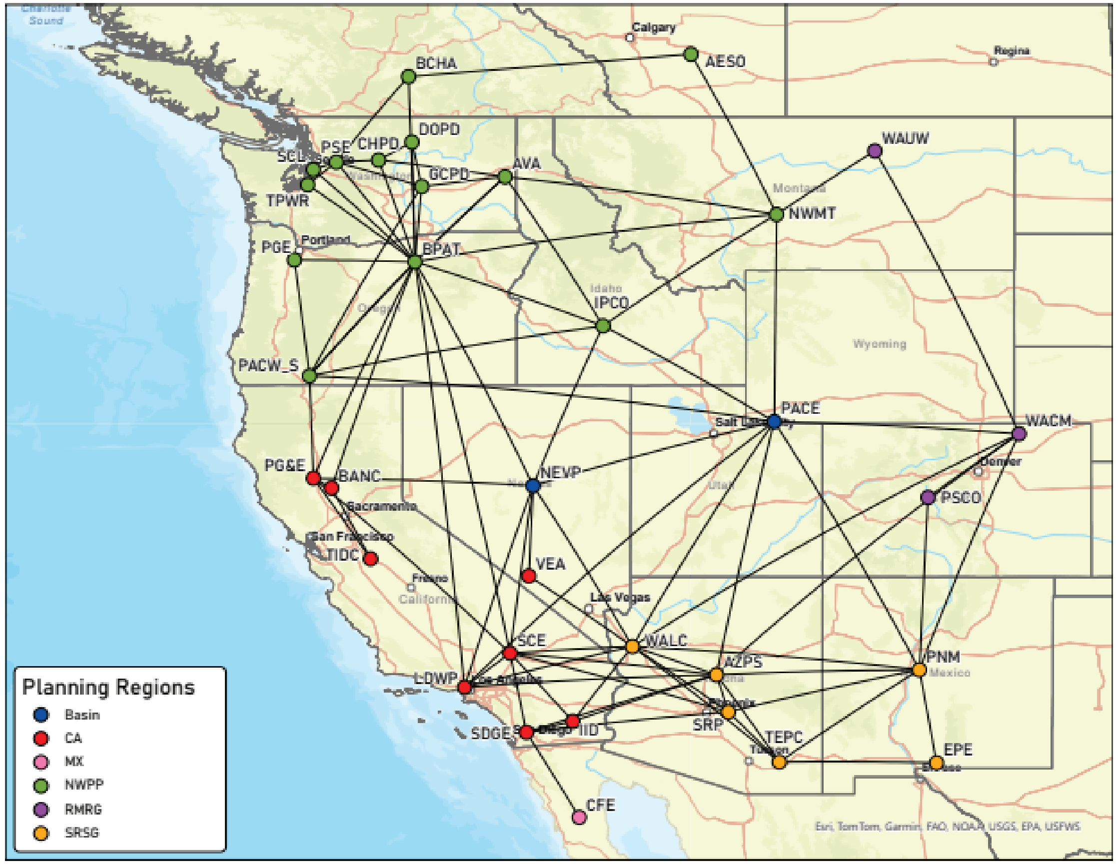
Study Explores Dynamic Between Resource Choices and Transmission



Study Caveats Associated with Study Topology & Approach

- **Model topology is a zonal representation of the western system**
  - This study did not consider the low-voltage distribution system
  - **The study was oriented toward assessing transmission flows on a macro-scale**
- **This study did not seek to provide a comparison of the relative costs or benefits of study portfolios**
  - Study results suggest that there may be an “optimal” adoption level of distributed generators and batteries, but we did not attempt to find that in this study
- **The results of this study are high-level and illustrative, and are not intended to inform investment decisions**
  - This study focuses on distributed solar and storage, other distributed or demand-side technologies/ functionalities (e.g., demand response) were not the focus of our assessment

Geographical Scope & Transmission Topology



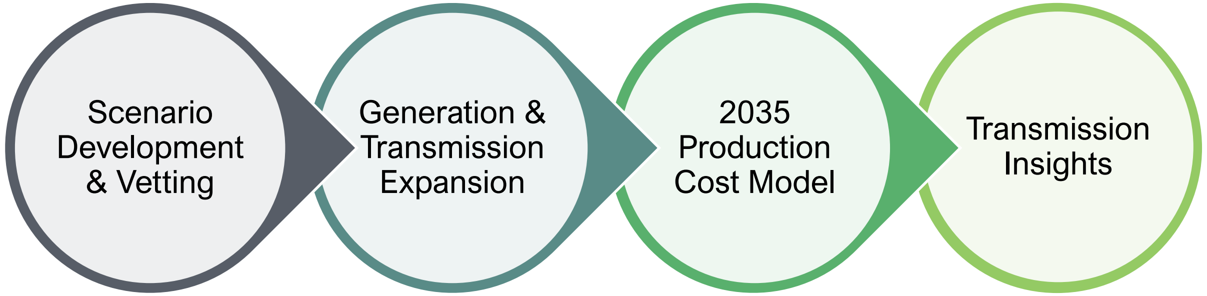
The model's zonal topology shows the model's 34 zones and 102 zonal lines and indicates zones' membership in planning regions.

Methodology & Assumptions

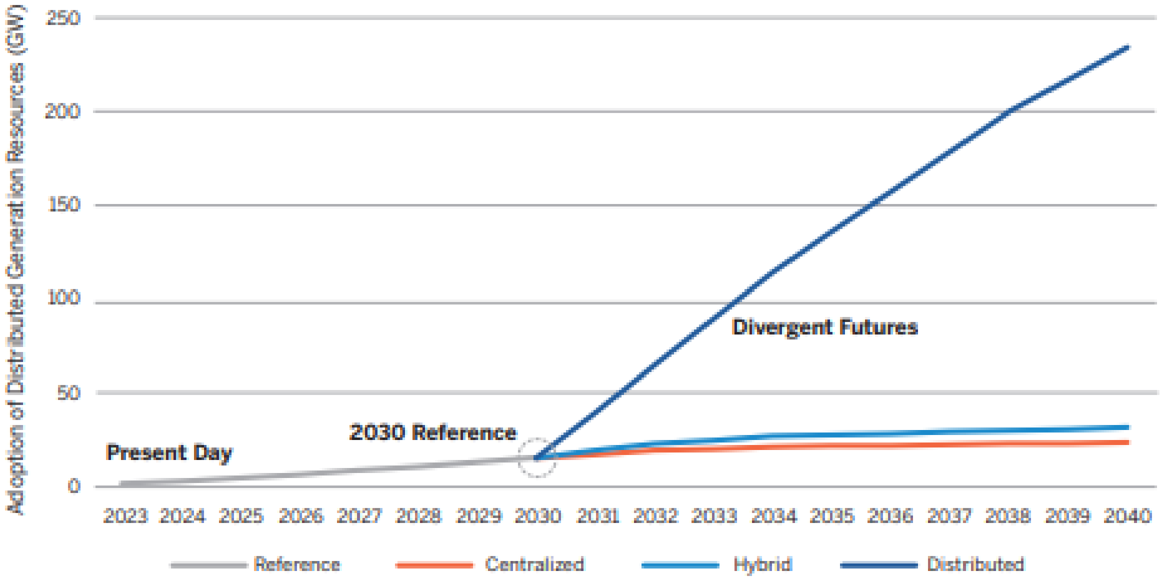
Study Summary

- **The study encompasses 34 balancing authorities in the Western grid, and models a 20-year planning horizon**
  - Started with Energy Exemplar's 2023 WECC Zonal model – a representation of present-day system
  - Region contains generation expansion candidates
  - Zonal transmission expansion options
    - 80 potential transmission candidates included both uprates of existing lines and new lines between zones
    - Allowed one upgrade per path per year; allowed 3 total upgrades per year
- **The study utilizes the PLEXOS capacity expansion and production cost modeling capabilities**
  - Three study scenarios dictate expansion options
  - Each expansion scenario run through 2035 production cost model

Study Process



Study Scenario Divergence After 2030



Study Scenarios

- **Study compared three long-term futures with varying levels of distributed generation**
  - Assumed that the Western system follows a deterministic trajectory for generation and transmission builds and retirements from the present day through 2030 ("Reference Case")
- **Three scenarios for 2030-2040 study horizon include:**
  - **Centralized** – A ***status quo scenario*** with adoption of distributed resources consistent with NREL Standard Scenarios; all additional resources are utility-scale
  - **Hybrid** – ***Accelerated adoption*** rate of distributed resources (2x the Centralized case); all additional resources are utility-scale
  - **Distributed** – ***High bookend future*** *for DG*, with all additional resources source from combinations of distributed PV and distributed batteries

Summary of Study Scenarios

Scenario	Started at 2030 Reference	Could Build Transmission	Could Build Utility-Scale Thermal Generators	Could Build Utility-Scale Renewable Generators	Could Build Distributed Generators	Could Build Long-Duration Storage
Centralized	✓	✓	✓	✓	No; fixed at 1x NREL Standard Scenario rate	
Hybrid	✓	✓	No; fixed to centralized builds	✓	No; fixed at 2x NREL Standard Scenario rate	
Distributed	✓	✓	No; fixed to centralized builds		✓	✓

Types of Distributed Generation Resources Considered in the Study

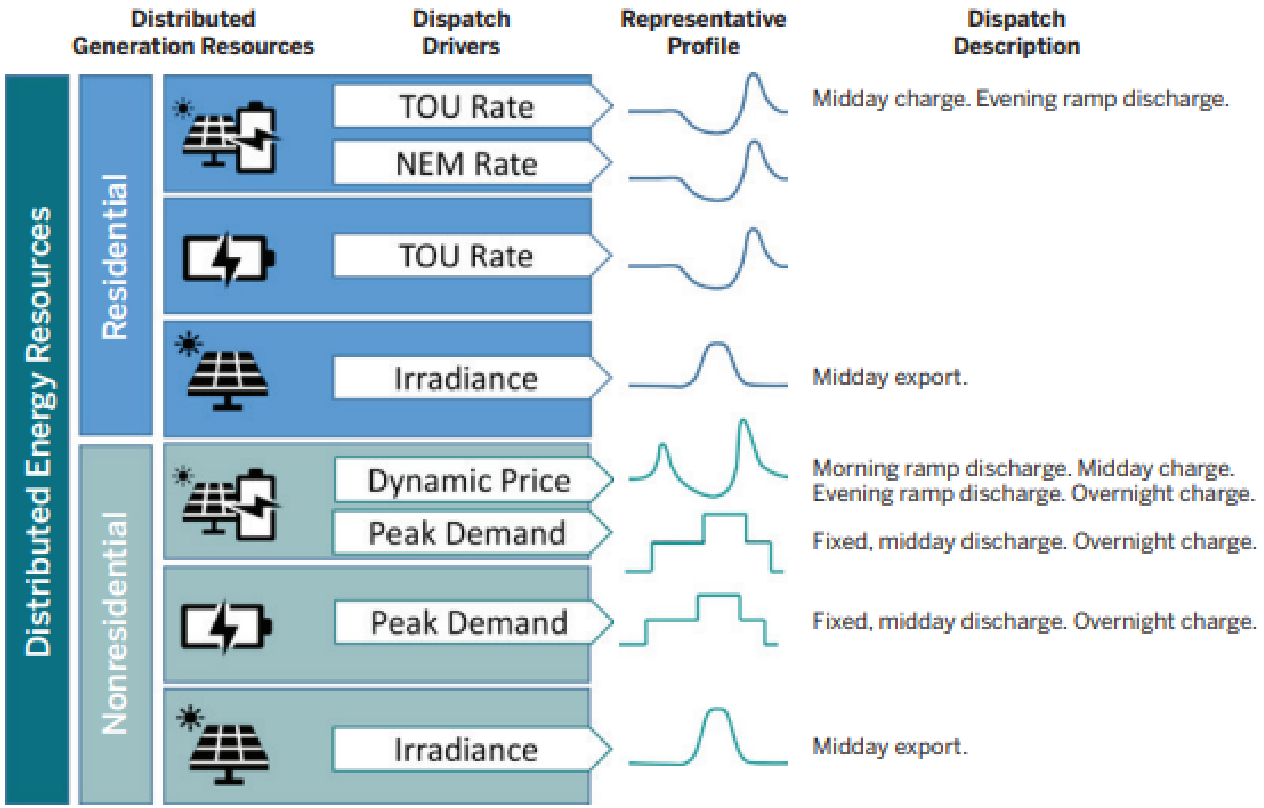
Distributed Generation Studied

- Non-residential Stand-Alone Battery
- Residential Stand-Alone Battery
- Non-residential Stand-Alone PV
- Residential Stand-Alone PV
- Non-residential PV+Battery
- Residential PV+Battery

Modeling Distributed Generators and Batteries

- **Literature review performed to define eight unique DER expansion candidate resource types**
  - Shown in graphic
- **Baseline capacity determined from NREL standard scenarios**
  - Modeled in PLEXOS as generators
  - Included time-of-day price modifiers to model non-optimal dispatch of DER hybrids & batteries (generation-only DGs simply dispatched)
  - DGs could be curtailed if necessary

DG Operational Models



Other Capacity Expansion Considerations

- **Both generation and transmission were candidates for future build decisions**
  - Included set of "planned" transmission projects in all study scenarios
- **Study utilizes a zonal planning reserve margin of 15%. Capacity accreditations to account for:**
  - Resource type
  - Seasonal de-rates
  - Forced & planned outage rates
  - Seasonal load peaks
  - ELCC saturation for VERs and batteries
- **Renewable Portfolio Standards & Net-Zero Constraints**
  - In the LT phase, enforced west-wide clean energy constraint getting model to 68% clean by 2035 and 78% clean by 2040
- **Updated capital costs consistent with NREL ATB 2023 & to reflect IRA ITC**

Assumed Transmission Upgrades

Production Cost Modeling Load & Operating Reserves

- **Hourly load profiles scaled to represent load electrification**
  - Performed analysis to determine 12x24 load scalars to represent a variety of electrification technologies in 2035
  - Increases load peaks (MW) and energy (MWh) by ~30% and ~12%, respectively
- **2035 PCM included detailed operating reserve modeling**
  - BA-level regulation reserves
  - Spinning reserves held at a reserve-sharing group footprint

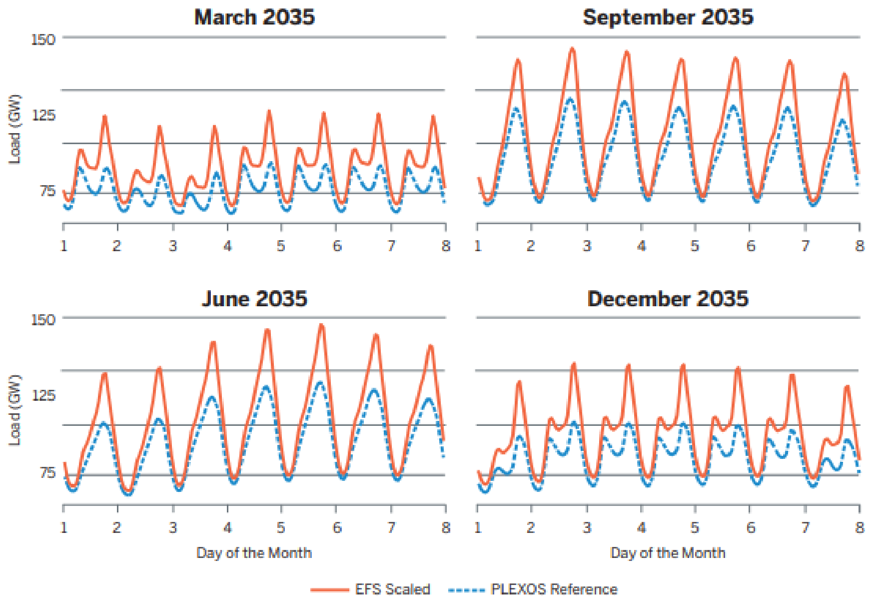
NREL Electrification Futures Scenarios

		Sensitivity Cases (this report)		
		Slow Technology Advancement Sensitivity Case (Slow Advancement)	**Moderate Technology Advancement Sensitivity Case** (Moderate Advancement)	**Rapid Technology Advancement Sensitivity Case** (Rapid Advancement)
Adoption Scenarios (future report)	**Reference**	Slow Advancement, Reference Adoption	Moderate Advancement, Reference Adoption	Rapid Advancement, Reference Adoption
	Medium	Slow Advancement, Medium Adoption	Moderate Advancement, Medium Adoption	Rapid Advancement, Medium Adoption
	High	Slow Advancement, High Adoption	Moderate Advancement, High Adoption	Rapid Advancement, High Adoption

Increasing Electrification

Increasing Load Efficiency

WECC Load Under the Medium EFS Scalar Approach



Study Results

Summary of buildouts during 2030-2040

At moderate levels, distributed generation and storage can replace some transmission.

	Centralized Scenario	Hybrid Scenario	Distributed Scenario
Zonal transmission expansion candidates	11 projects total 18 GW (238 GW-miles)	8 projects totaling 12 GW (166 GW-miles)	11 projects totaling 16 GW (526 GW-miles)
Generation nameplate capacity	431 GW	418 GW	537 GW
Total storage capacity	252 GWh	328 GWh	1,090 GWh

Tradeoff between storage and transmission

Distributed resources reduce some transmission investments

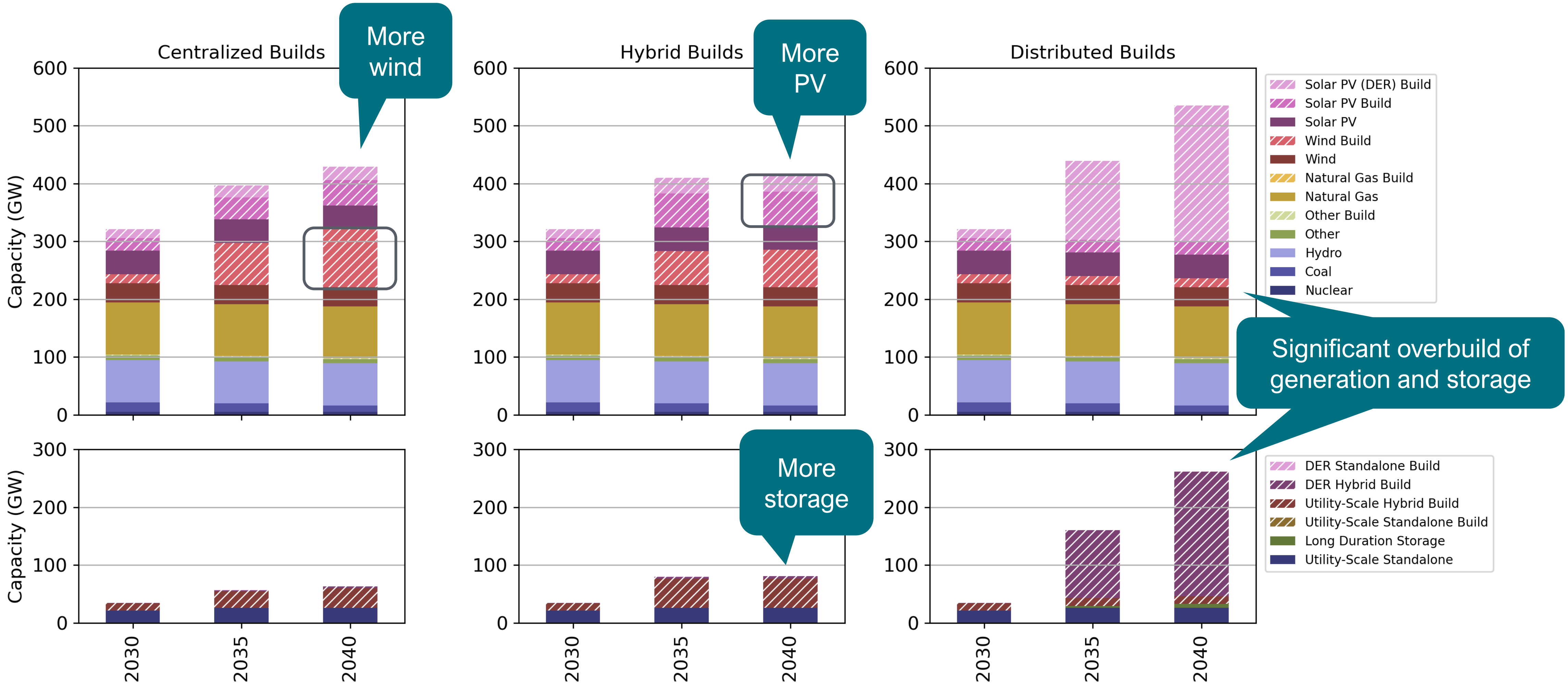
Summary of buildouts during 2030-2040

But taken further, if you try to decarbonize with significant distributed resources, both transmission and storage needs skyrocket.

	Centralized Scenario	**Hybrid Scenario**	**Distributed Scenario**
Zonal transmission expansion candidates	11 projects total 18 GW (238 GW-miles)	8 projects totaling 12 GW (166 GW-miles)	11 projects totaling 16 GW (526 GW-miles)
Generation nameplate capacity	431 GW	418 GW	537 GW
Total storage capacity	252 GWh	328 GWh	1,090 GWh

Relative to Centralized scenario, approximately 4x storage and 2x transmission are required to serve load

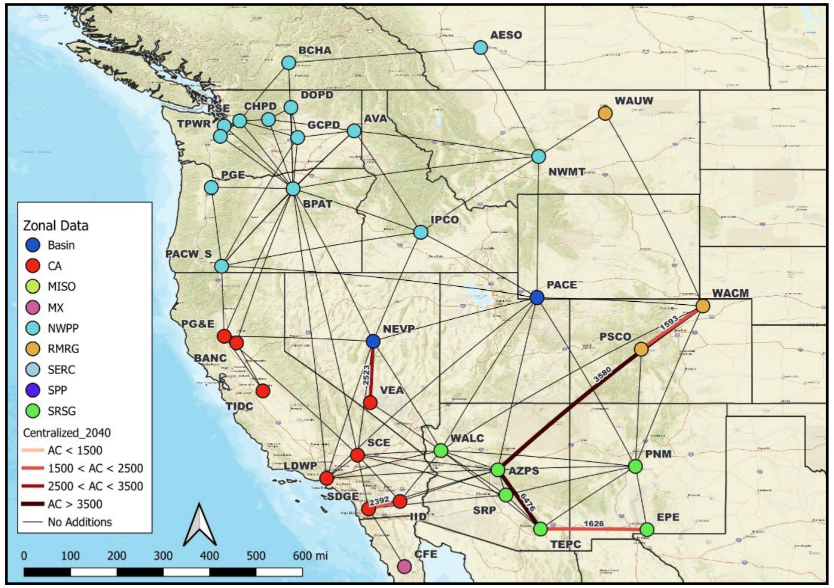
Results of generation/storage for each scenario



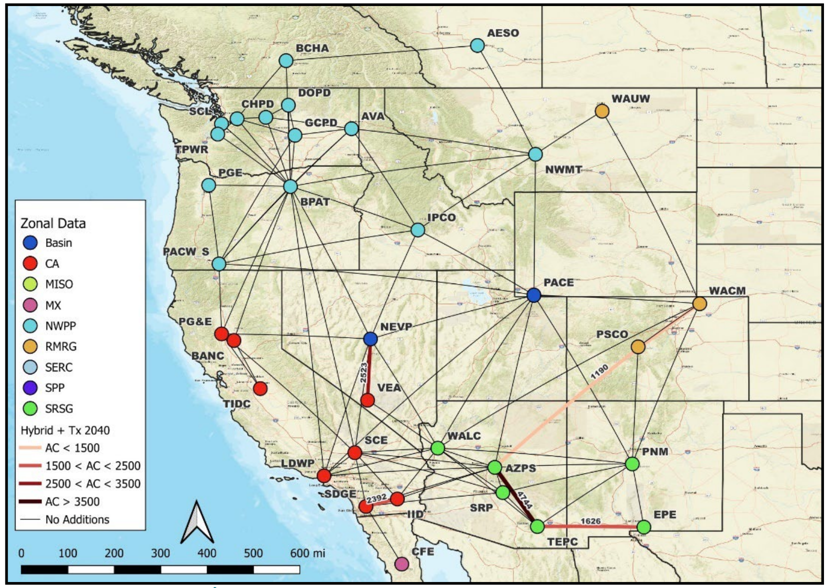
Transmission buildouts 2030-2040

Transmission provides more cost-effective dispatch across regions, sharing of firm capacity across regions, and reduces curtailment of renewables. Solutions feature a combination of reconductoring and new lines.

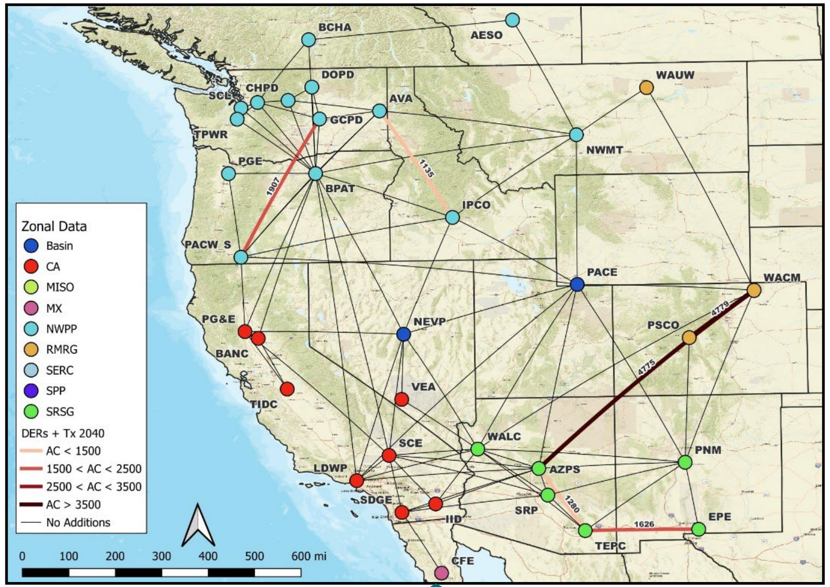
Centralized



Hybrid



Distributed

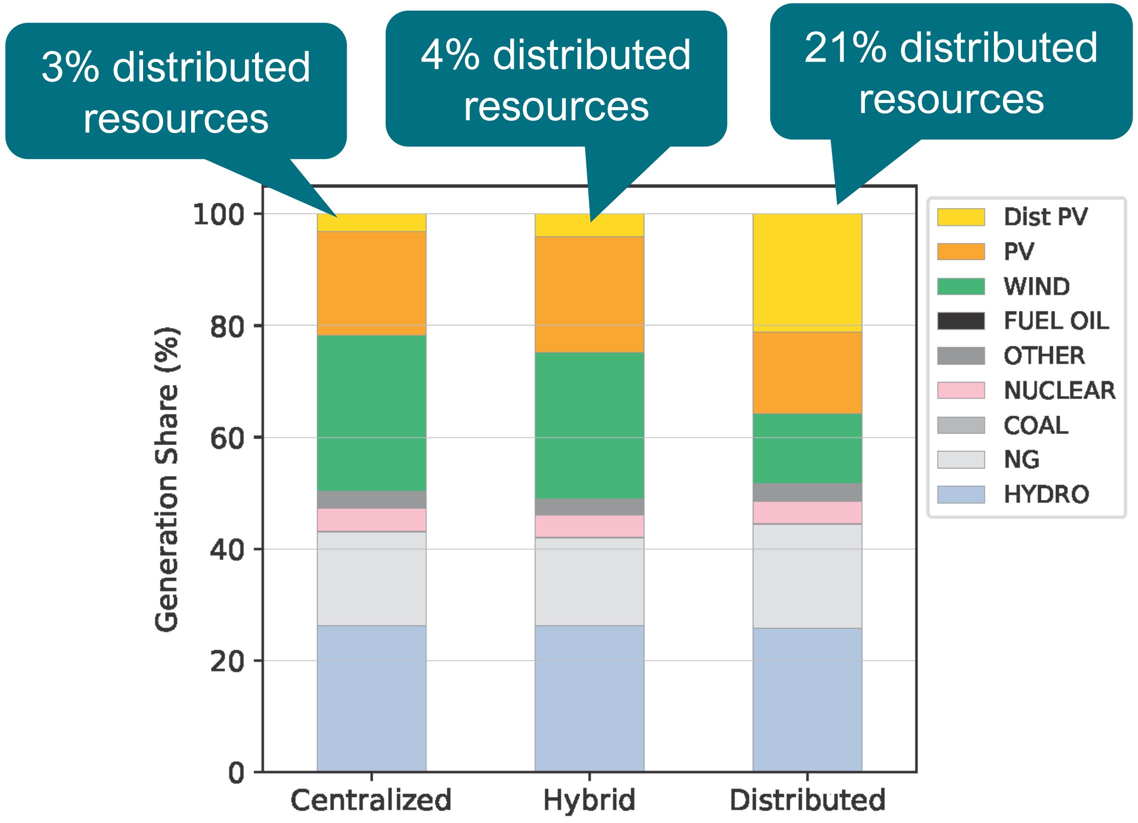


Hybrid scenario defers 3 of 11 transmission projects built in the Centralized scenario

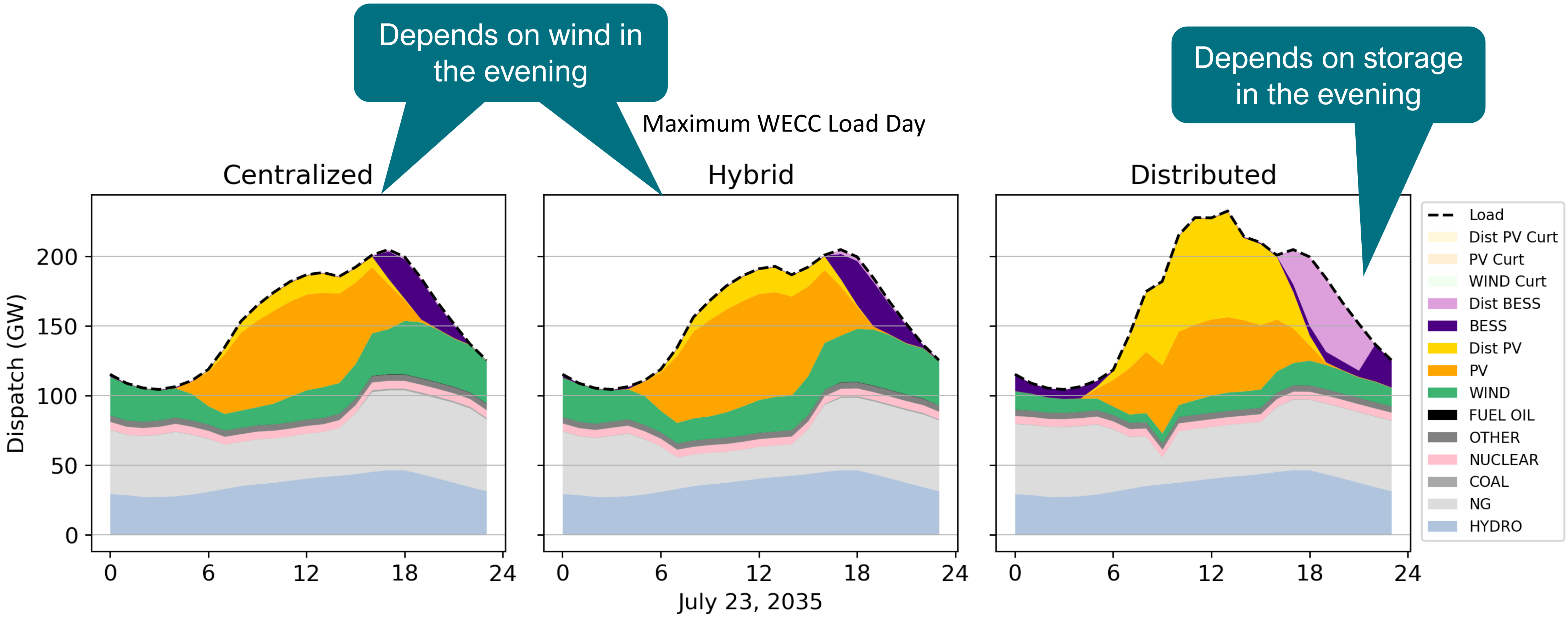
Distributed scenario builds more GW-miles of transmission to better facilitate transfer of power between regions with geographic diversity

Energy Served by Generation Type in 2035

- **Western system able to reach significant penetrations of clean energy due to diverse resource options**
  - Enabled also by the planned transmission builds
- **Approximately 1/5th of energy in distributed case is served by distributed solar and storage resources**
- **Hybrid scenario reduces emissions by 6% whereas distributed scenario increases emissions by 11%, relative to Centralized**
  - Distributed case exhibits more gas generation because the scenario uses primarily gas, wind, and storage to serve load in non-daylight hours

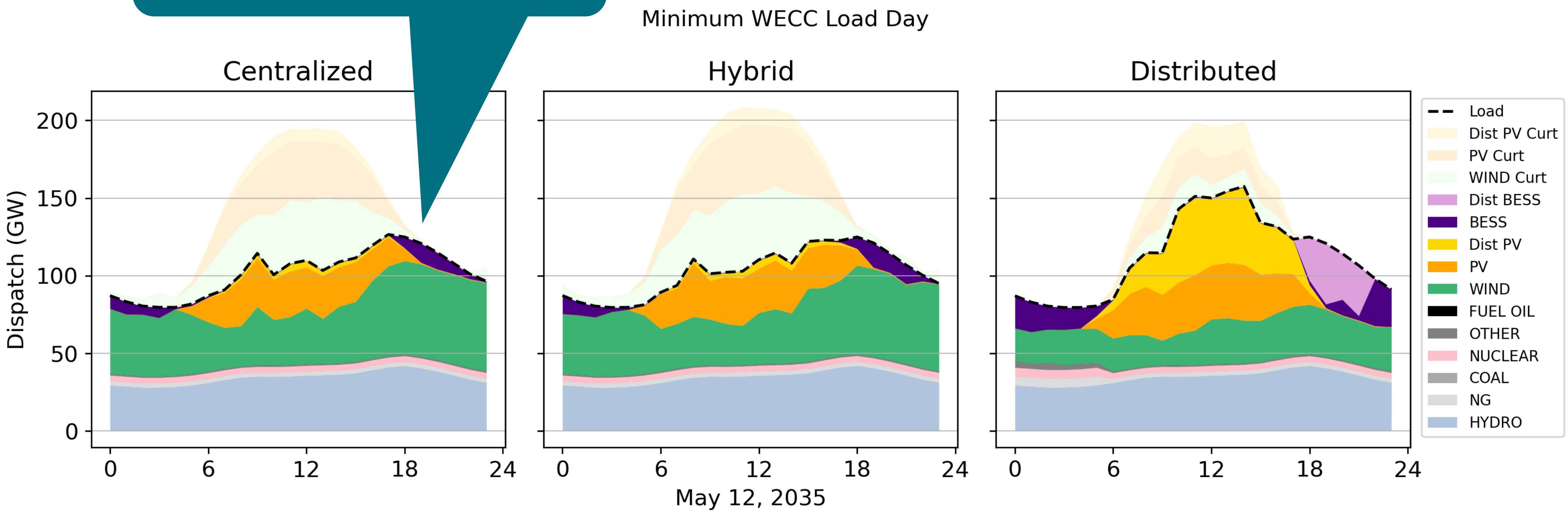


Western System Dispatch (Max Load Day)



Western System Dispatch (Minimum Load Day)

Unstorable energy is curtailed
(2-5% of RE curtailment)



Study Findings

Study Findings (1 of 2)

- **Distributed generation can significantly impact inter-zonal transmission flows.**
  - The modeled adoption of distributed solar and batteries across the Western Interconnection changed diurnal transmission flow and generation patterns. Specifically, it tended to create a midday nadir in net load, and a need for morning and evening flexibility that must be served by storage and other generators on the system.
  - **Shifts in generation dispatch had corresponding impacts on zonal transmission flows as power is moved from where it is generated to where it is needed in response to this new system dynamic.**
- **At moderate levels, distributed generation adoption could cause certain inter-zonal transmission investments to be delayed or avoided.**
  - Relative to the centralized scenario, the hybrid scenario, which has a distributed generation adoption rate doubling the study's status quo (centralized) trajectory from 2031 onward, required about **30% less inter-zonal transmission** in terms of both GW and GW-miles
  - The hybrid scenario also exhibited a lower overall generation nameplate capacity but required about 30% more storage capacity than the centralized scenario.

	Centralized Scenario	Hybrid Scenario	Distributed Scenario
Zonal transmission expansion candidates	11 projects totaling 18 GW (238 GW-miles)	8 projects totaling 12 GW (166 GW-miles)	11 projects totaling 16 GW (526 GW-miles)
Generation nameplate capacity	431 GW	418 GW	537 GW
Total storage capacity	252 GWh	328 GWh	1,090 GWh

Study Findings (2 of 2)

- **The status-quo (centralized) and accelerated (hybrid) distributed generation adoption scenarios shared many common inter-zonal transmission investments.**
  - Notably, the eight inter-zonal transmission candidates selected in the hybrid scenario were also all selected in the centralized scenario, though often in different years.
  - The centralized scenario required three additional inter-zonal transmission projects—for a total of 11 projects—that were not required in the hybrid scenario. These three projects were avoided in the hybrid scenario during the study horizon because of the increased distributed generation levels in this scenario.
- **High levels of distributed generation could increase the need for inter-zonal transmission investment.**
  - While significant inter-zonal transmission is selected in all three study scenarios, the transmission built in the distributed scenario was almost double that of the centralized scenario as measured by GW-miles.
    - The large increase in transmission GW-miles in the distributed scenario illustrates the need for longer lines to help transport high levels of solar and balance the system between regions where existing inter-zonal capacity is limited.
  - The distributed scenario also required more than four times the storage capacity of the centralized scenario, although these two scenarios met the same system planning and policy requirements over the study horizon.

Takeaways

- **With moderate levels of distributed generation, the study finds that transmission investments can be reduced, and more storage is required.**
  - More solar and less wind gets built.
  - There are slight benefits in production costs and CO_2 emissions.
  - This shows competition between transmission and storage infrastructure.
- **At high levels of distributed generation, transmission, storage, and generation investments all increase significantly.**
  - The intermittent & time-of-day limitations on distributed solar generation require other capital investments to store energy and serve load
- **There are common transmission builds in the Centralized and Hybrid scenarios, which could be a starting point for “no-regrets” paths.**
- **The need for transmission is sensitive to many other factors related to DGs including time, location, capacity, and participation behavior.**
- **Opportunities for future research include:**
  - There may be an optimal buildout of distributed vs utility-scale resources but we did not attempt to find that here
  - Additional studies on distribution system impacts are required for a better understanding of system benefits and impacts
  - Location-specific and nodal analyses should be performed to better understand the relationships explored in this study

Thank You. Questions?

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