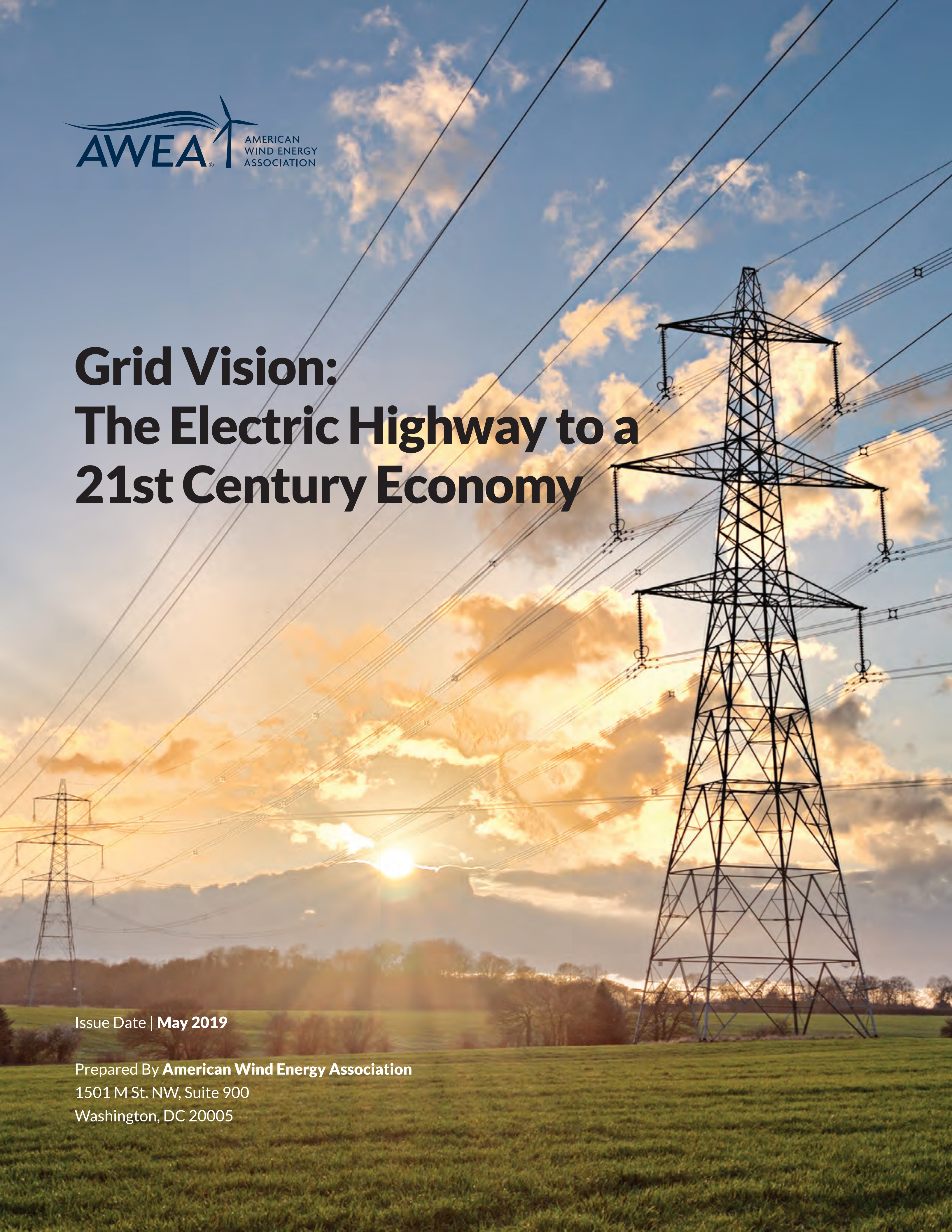

AWEA AMERICAN WIND ENERGY ASSOCIATION

Grid Vision: The Electric Highway to a 21st Century Economy

Issue Date | **May 2019**

Prepared By **American Wind Energy Association**
1501 M St. NW, Suite 900
Washington, DC 20005

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May 2019

Executive Summary

Background:

Electricity is the lifeblood of the modern U.S. economy, yet much of America's electric grid is outdated and in dire need of investment and expansion to bring it into the 21st Century. The American Society of Civil Engineers recently gave America's electricity infrastructure a mark of "D+," and grid congestion and power outages cost American businesses billions of dollars each year.

To better understand the best way to update and invest in the grid, and any associated consumer benefits, the American Wind Energy Association (AWEA) undertook a literature review that examines building out the country's transmission infrastructure. This paper finds investing in upgrading and expanding America's transmission system will improve electric reliability and resiliency, reduce electricity costs for consumers, bolster national security, reduce environmental impacts, and create jobs and economic development. Dozens of studies confirm that an investment in transmission will pay for itself many times over.

Key Findings

- Expanding the current transmission system network could save consumers as much as $47 billion annually – a roughly 10% reduction in electric bills.[1]
- Upgraded transmission networks have been proven to reduce consumers' bills through reduced congestion costs. By expanding transmission, the New England grid operator reduced congestion costs from $600 million per year under $100 million annually following upgrades.[2]
- Regional power providers have found transmission investments provide benefits 2-4 times greater than their costs.[3]
- Strengthening the grid by adding network paths significantly increases the system's resilience to damage and prevents power outages.[4]
- Kansas utility Westar has seen a 40% reduction in transmission-related customer outages as it expanded its grid.[5]

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[1] https://www.utilitydive.com/news/study-deep-decarbonization-of-us-grid-possible-without-energy-storage/412721/, http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2921.html

[2] https://www.iso-ne.com/static-assets/documents/2017/01/20170130_stateofgrid2017_presentation_pr.pdf p.39-40

[3] https://www.spp.org/documents/35297/the%20value%20of%20transmission%20report.pdf p.5

[4] https://public.lanl.gov/rbent/pscc_resilience.pdf

[5] https://www.spp.org/documents/35297/the%20value%20of%20transmission%20report.pdf, page 15

- A more robust grid helps protect against and recover from all types of unexpected events, including deliberate attacks on our infrastructure, while a weak and congested grid makes the system vulnerable to disruption.[6]
- Infrastructure redundancy and regional diversity, both key benefits of transmission expansion, limit the threat posed by cyberattacks.[7]
- Transmission expansion is even more essential with the growth of technologies such as distributed solar, energy storage, and electric vehicles.
    - Significantly increasing our use of solar power, whether utility-scale or distributed, requires a strong transmission system.
    - Battery storage, demand response, and other new technologies are valuable complements to transmission, but cannot substitute for transmission's ability to move large amounts of power long distances.
    - Electrification of transportation and building and water heating is also increasing the demand for a strong transmission system.

Policy Recommendations

Centered around the "Three Ps" of Planning, Paying and Permitting, this paper outlines the policies needed to realize the benefits of an expanded, improved and interconnected transmission system. These initiatives should enjoy support from consumer, pro-market, environmental, national security, and economic development advocates across the country.

- **Planning** – Transmission planning should look further into the future, proactively incorporate expected future generation additions, and simultaneously account for the multiple benefits of transmission. Planners should work together across states and regions to evaluate interregional transmission solutions, coupled with effective means to pay for those upgrades.
- **Paying** – The most important policy solution is broad transmission cost allocation to reflect the broadly distributed benefits of transmission, particularly for high-capacity and interregional transmission.
- **Permitting** – Simplifying the siting of interstate transmission lines. Policies should incentivize states to work together on siting and deploy federal authority where necessary for projects that serve the national interest.

The electric grid underlies nearly all of our modern economy and underpins every aspect of day-to-day American life. We've neglected it for far too long, and a 21st Century update will benefit all American families and businesses.

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[6] http://thehill.com/opinion/energy-environment/365890-a-vulnerable-power-grid-lets-invest-in-critical-national

[7] https://fivethirtyeight.com/features/hacking-the-electric-grid-is-damned-hard/amp/

Introduction

The National Academy of Engineering has concluded that the most important engineering accomplishment of the 20th century was widespread access to electricity through large interconnected power systems. The key factor enabling consumers' access to low-cost, reliable electricity was the aggregation of electricity supply and demand across wide areas. This was chiefly made possible by the innovations of George Westinghouse and Nikola Tesla, who developed the Alternating Current (AC) power transformers and high-voltage electric transmission necessary to efficiently move energy long distances. Our large, aggregated grid provides two critical benefits:

-Economies of scale allow electricity to be cost-effectively generated at large facilities located in favorable locations with low-cost access to fuel.

-Fluctuations in electricity supply and demand from individual power plants and customers are mostly canceled out by opposite changes elsewhere on the network.

These efficiencies explain why Westinghouse's large interconnected AC system won out over Thomas Edison's localized system in the "War of the Currents" more than a century ago. Today, large electric grid networks save consumers billions of dollars per year relative to smaller networks.[1]

The value of a large electricity network can be seen by starting from the extreme case of having no network, which is the case for customers who are "off-grid." Without a network, an individual customer must meet their electricity needs at all times with their own dedicated energy supply. The challenge is that individual residential, commercial, and industrial users' electricity demand fluctuates widely over time depending on what appliances are being used, time of day, weather, etc.

Without aggregation, each customer needs an electricity generation source large enough to meet their personal peak electricity demand, and the vast majority of the time their generation resource would sit idle or minimally utilized. Moreover, when their generation source was down for maintenance, a customer would have to either forego using electricity, or bear the cost of owning a fully redundant backup power source at all times.

A network of many customers and sources of supply greatly reduces costs because changes in individual sources of electricity supply and demand are not perfectly correlated. For example, the odds of one neighbor running their clothes dryer at the same time as another are quite low, and when one considers an entire neighborhood of dryers, the odds of them all running at the same time drop to nearly zero. The total electricity demand is always smaller than the sum of every user's peak demand because these fluctuations are not perfectly correlated and many cancel each other out, reducing the system's need for supply. Similarly, the odds of several power plants experiencing an unanticipated outage at the same time are very low. When millions of customers and hundreds of power plants are aggregated on a large

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[1] For example, the two largest grid operators in the U.S. each save their customers around $3 billion annually. https://www.misoenergy.org/about/miso-strategy-and-value-proposition/miso-value-proposition/, http://www.pjm.com/about-pjm/value-proposition.aspx

power system, the statistical diversity is even greater, significantly reducing the cost of building and operating the power system.

Department of Energy (DOE) data illustrate this benefit of a large power system.[2] The following map shows the individual grid operators and the three main interconnections (East, West, and the Electric Reliability Council of Texas or ERCOT) that make up the U.S. power system. At any point in time, some grid operators are experiencing more electricity demand than was forecast the day ahead (indicated by darker shades of red), while others are experiencing less demand than expected (darker shades of blue). If sufficient transmission capacity is available, grid operators are able to exchange power with their neighbors to net out those deviations, reducing the need for one operator to ramp up its power plants while another ramps down its power plants.

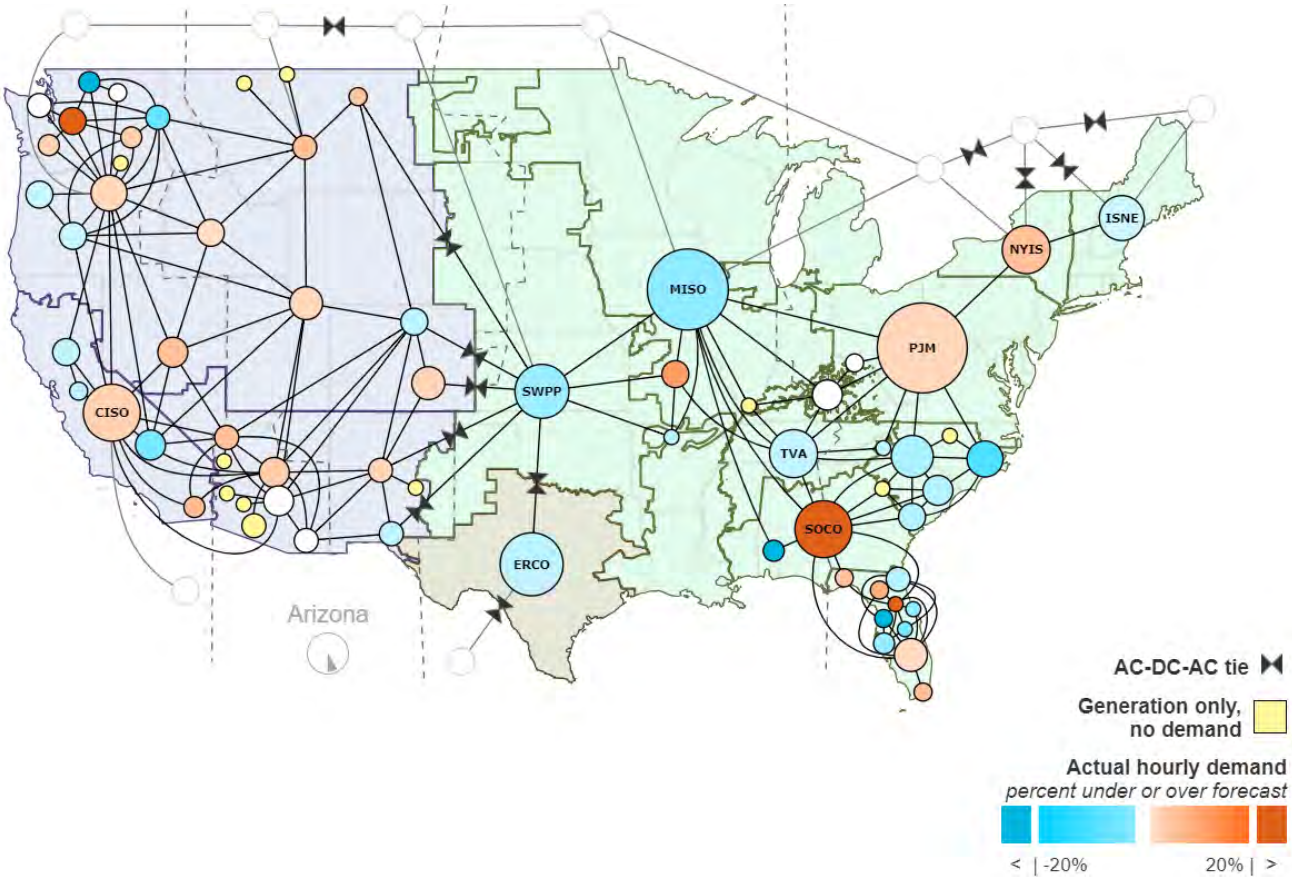

Figure 1: U.S. grid operators are aggregated into three Interconnections, netting out electricity fluctuations

Due to this regional diversity, the total electricity demand forecast error for the whole U.S. power system is typically about 1/5th as large as the sum of the errors for all individual grid operators.

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[2] https://www.eia.gov/realtime_grid/#/status

Transmission connections among regions reduce the amount of spare power plant capacity each grid operator must hold as operating reserves to accommodate those deviations.

An even larger benefit is that not all regions experience peak electricity demand at the same time. For example, many northern regions experience peak demand in the winter, while many southern regions experience their annual peak demand in the summer. This is due to their different weather profiles and use of electricity for heating and cooling. With adequate transmission, grid operators can use imports and exports from their neighbors to help meet peak demand, saving billions of dollars per year by not having to build as many power plants. Transmission also provides this benefit within a single grid operating area. The grid operator for the Mid-Atlantic and Great Lakes region has found that coincident peak demand across its footprint is 33,000 MW less than the sum of the non-coincident peak demands of its individual utility members, and 6,000 MW less than the sum of the peaks across its larger demand zones.[3]

The same principle of statistical aggregation through a market-based network is the foundation of many peer-to-peer businesses, including ride-sharing and car-sharing applications like Uber, Lyft, and car2go. Most cars sit idle the vast majority of the time, wasting expensive resources. To borrow the power system term for the amount of time a resource is utilized relative to its maximum theoretical utilization, the "capacity factor" of cars is very low. In addition, while any one car is occasionally unavailable due to planned or unplanned maintenance, a fleet of cars made available through a network will almost always have a car available. Ride-sharing and car-sharing use the Internet to create networked markets that increase the capacity factors of underutilized assets and reduce the total need for cars and parking spots, just as a networked power grid achieves a higher utilization and reduced need for power plants by netting out fluctuations in individual sources of supply and demand across large geographical areas.

The value of making power systems larger and more integrated is driven by the powerful fundamental principles of statistical aggregation and economies of scale. Efforts to work against those principles by "cutting the cord" from the network will always face an uphill battle, despite advances in technology for energy storage and microgrids. As technology changes our sources of electricity supply and demand, the value of large grids is increasing rather than decreasing, as explained in Chapter 2 below.

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[3] https://pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.ashx?la=en, page 21

Chapter I. Transmission provides consumers more reliable and affordable power

A number of studies have examined the costs and benefits of transmission upgrades, including many after-the-fact analyses of the impacts of actual transmission investment. These studies have found that transmission provides large net benefits to consumers, and the studies note that those estimates are conservative because it is difficult to quantify all of transmission's benefits. Dozens of studies across nearly every region of the country show that investing in transmission pays for itself many times over.

The Southwest Power Pool (SPP), the grid operator for Kansas, Oklahoma, Nebraska, and parts of neighboring states, evaluated the many categories of benefits provided by its recent transmission upgrades.[4] SPP found that the transmission upgrades it installed between 2012 and 2014 will create nearly $12 billion in net benefits for consumers over the next 40 years, or around $800 for each person currently served by SPP, or $2,400 per each metered customer. The $16.6 billion in gross savings is higher than SPP's transmission planning models had initially estimated, and 3.5 times greater than the cost of the transmission upgrades. As shown in the following chart from SPP's report, these upgrades are already yielding large net benefits, and the benefits only grow over time while the costs decline.

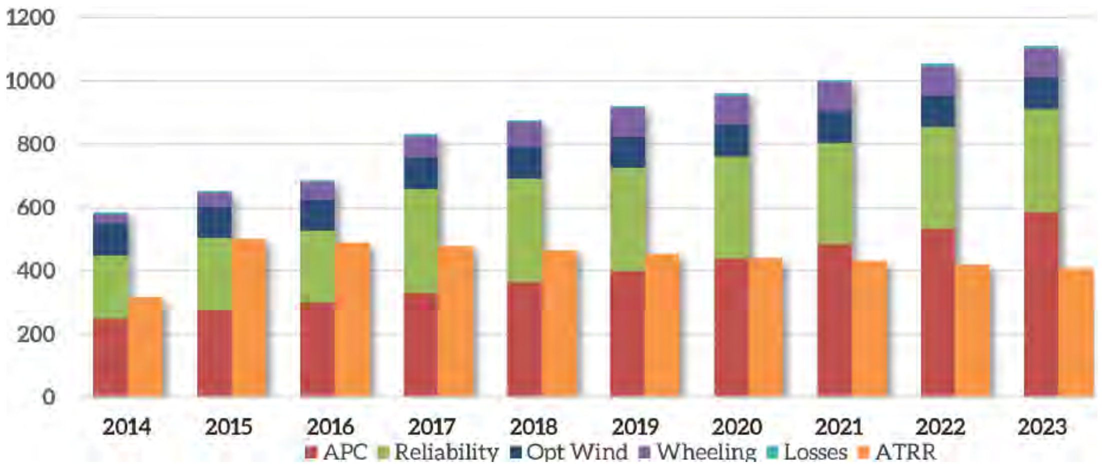

Figure 2: SPP found transmission benefits (left bar) exceed cost (orange bar)

The following table from SPP's report shows the wide range of benefits provided by transmission: it reduces the cost of producing electricity, reduces the need for power plants by improving power system efficiency, increases electricity market competition, improves electric reliability, makes the power system more resilient to unexpected events, reduces environmental impacts, and creates jobs and economic development.

Table 1: SPP calculation of benefits of transmission

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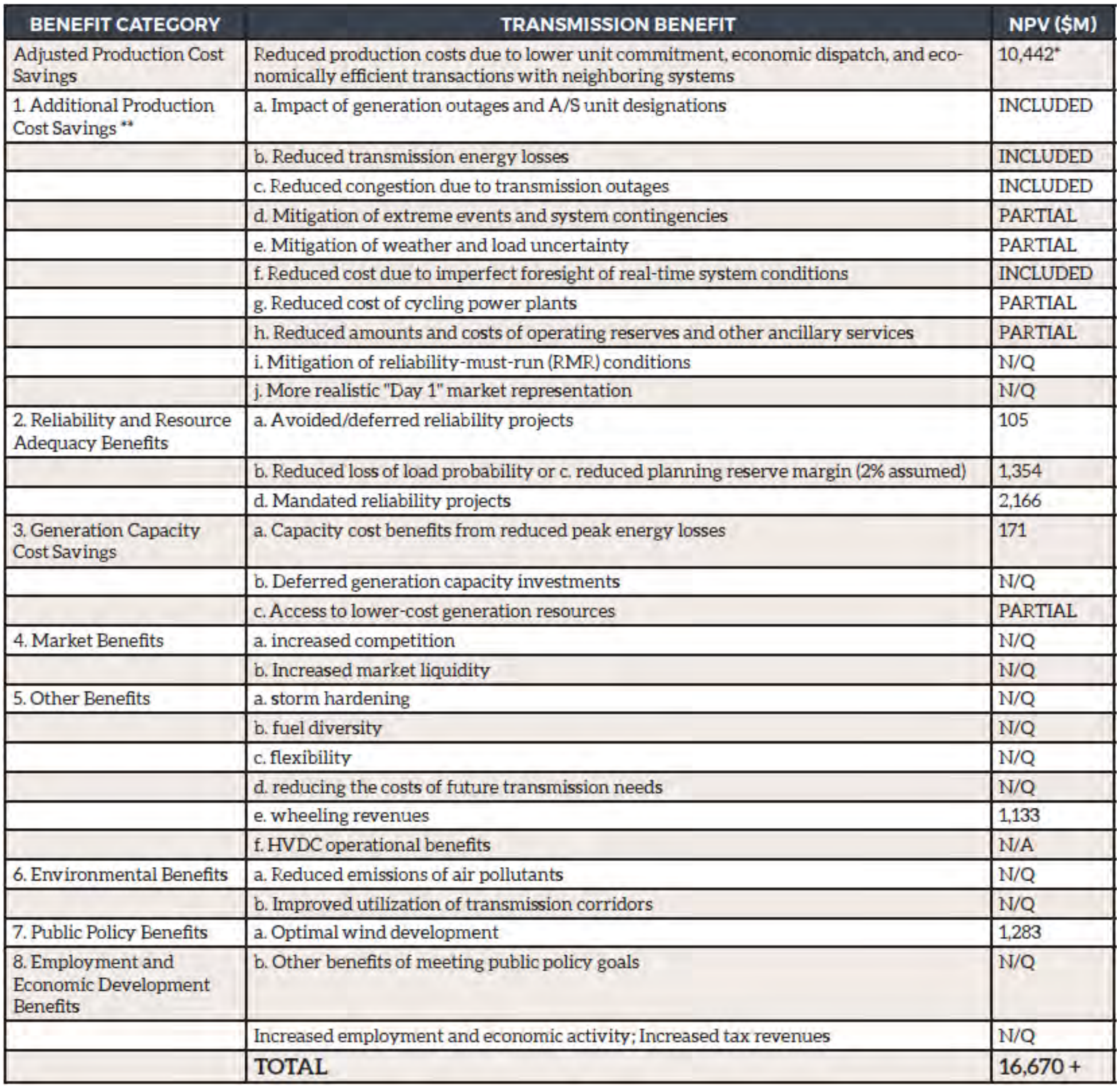
[4] https://www.spp.org/documents/35297/the%20value%20of%20transmission%20report.pdf



BENEFIT CATEGORY	TRANSMISSION BENEFIT	NPV ($M)
Adjusted Production Cost Savings	Reduced production costs due to lower unit commitment, economic dispatch, and economically efficient transactions with neighboring systems	10,442*
1. Additional Production Cost Savings **	a. Impact of generation outages and A/S unit designations	INCLUDED
	b. Reduced transmission energy losses	INCLUDED
	c. Reduced congestion due to transmission outages	INCLUDED
	d. Mitigation of extreme events and system contingencies	PARTIAL
	e. Mitigation of weather and load uncertainty	PARTIAL
	f. Reduced cost due to imperfect foresight of real-time system conditions	INCLUDED
	g. Reduced cost of cycling power plants	PARTIAL
	h. Reduced amounts and costs of operating reserves and other ancillary services	PARTIAL
	i. Mitigation of reliability-must-run (RMR) conditions	N/Q
	j. More realistic "Day 1" market representation	N/Q
2. Reliability and Resource Adequacy Benefits	a. Avoided/deferred reliability projects	105
	b. Reduced loss of load probability or c. reduced planning reserve margin (2% assumed)	1,354
	d. Mandated reliability projects	2,166
3. Generation Capacity Cost Savings	a. Capacity cost benefits from reduced peak energy losses	171
	b. Deferred generation capacity investments	N/Q
	c. Access to lower-cost generation resources	PARTIAL
4. Market Benefits	a. increased competition	N/Q
	b. Increased market liquidity	N/Q
5. Other Benefits	a. storm hardening	N/Q
	b. fuel diversity	N/Q
	c. flexibility	N/Q
	d. reducing the costs of future transmission needs	N/Q
	e. wheeling revenues	1,133
	f. HVDC operational benefits	N/A
6. Environmental Benefits	a. Reduced emissions of air pollutants	N/Q
	b. Improved utilization of transmission corridors	N/Q
7. Public Policy Benefits	a. Optimal wind development	1,283
8. Employment and Economic Development Benefits	b. Other benefits of meeting public policy goals	N/Q
	Increased employment and economic activity; Increased tax revenues	N/Q
	TOTAL	**16,670 +**

The transmission operator for the Mid-Atlantic and Great Lakes region, PJM, completed a similar report in April 2019.[5] As detailed in the following sections, the report found transmission provides PJM consumers with billions of dollars in benefits by reducing the cost of electricity, increasing competition, reducing the need for power plant capacity, increasing power system reliability and resilience, and enabling the region to take advantage of new low-cost gas and renewable resources.

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[5] https://pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.ashx?la=en

In several other studies, utility consultant the Brattle Group has found that transmission provides a similarly wide array of benefits.[6] The Midwest grid operator also analyzed grid upgrades that are currently underway, and found $12 billion to $53 billion in net benefits across many different categories of impacts.[7]

These studies note that these are conservative estimates that do not include many benefits that are difficult to quantify. SPP's analysis was reviewed by the Brattle Group, which noted that the study is likely an understatement of transmission's benefits. SPP's table above lists many benefits that were not accounted for ("N/Q" = not quantified) or that could only be partially quantified. Importantly, many valuable benefits, such as greater market competition and liquidity, a more resilient power system, fuel diversity, and system flexibility, were not quantified. The following sections discuss the benefits of transmission in more detail.

1. Transmission reduces consumers' electric bills

The cost of transmission is a small component of customers' electric bills, around 12 percent in recent years. However, investments in transmission more than pay for themselves by reducing the electricity generation costs that account for the majority of typical electric bills.

The largest benefit of transmission, and one of the easiest to quantify, is that it provides consumers with access to lower-cost sources of energy. Transmission allows consumers to access electricity from where it can be most cost-effectively produced at that point in time. Just like the interstate highway system provides consumers with access to low-cost goods by sourcing them from they are most cost-effectively produced, like Florida oranges or Texas beef or Pacific Northwest lumber products, transmission delivers consumers electricity from where it is most affordably produced. As explained in Chapter 2, this benefit becomes particularly important as renewable energy use grows, given large regional differences in renewable resources.

As shown in Table 1 above, access to lower-cost electricity accounts for most of the benefits of transmission, providing over $10 billion of the $16.6 billion in total benefits SPP found for its transmission upgrades. These benefits are even larger than SPP had estimated when it planned the transmission.[8]

Other grid operators have also found that reduced electricity generation costs account for a large share of the benefits from transmission upgrades. In 2017, the Midcontinent grid operator, MISO, analyzed the cost and benefits of grid upgrades that are nearing completion. As shown in Figure 3 below, MISO found that the new transmission will provide $12 to $53 billion in net benefits over the next 20 to 40 years, or between $250 and $1,000 for each person currently served by MISO. The benefits are 2.2 to

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[6] https://cleanenergygrid.org/uploads/WIRES%20Brattle%20Rpt%20Benefits%20Transmission%20July%202013.pdf page v; http://files.brattle.com/files/6112_recommendations_for_enhancing_ercot%E2%80%99s_long-term_transmission_planning_process.pdf, Appendix B

[7] https://cdn.misoenergy.org/MTEP17%20MVP%20Triennial%20Review%20Report117065.pdf

[8] https://www.spp.org/documents/10047/benefits_of_robust_transmission_grid.pdf

3.4 times greater than the cost of the transmission, an increase from the 1.8 to 3.0 benefit-to-cost ratio that was initially expected when the transmission was planned in 2011.[9] Like SPP, MISO found that congestion and fuel cost savings associated with providing consumers with access to lower-cost energy sources accounted for between $20 billion and $71 billion in benefits, a large share of the total benefits.

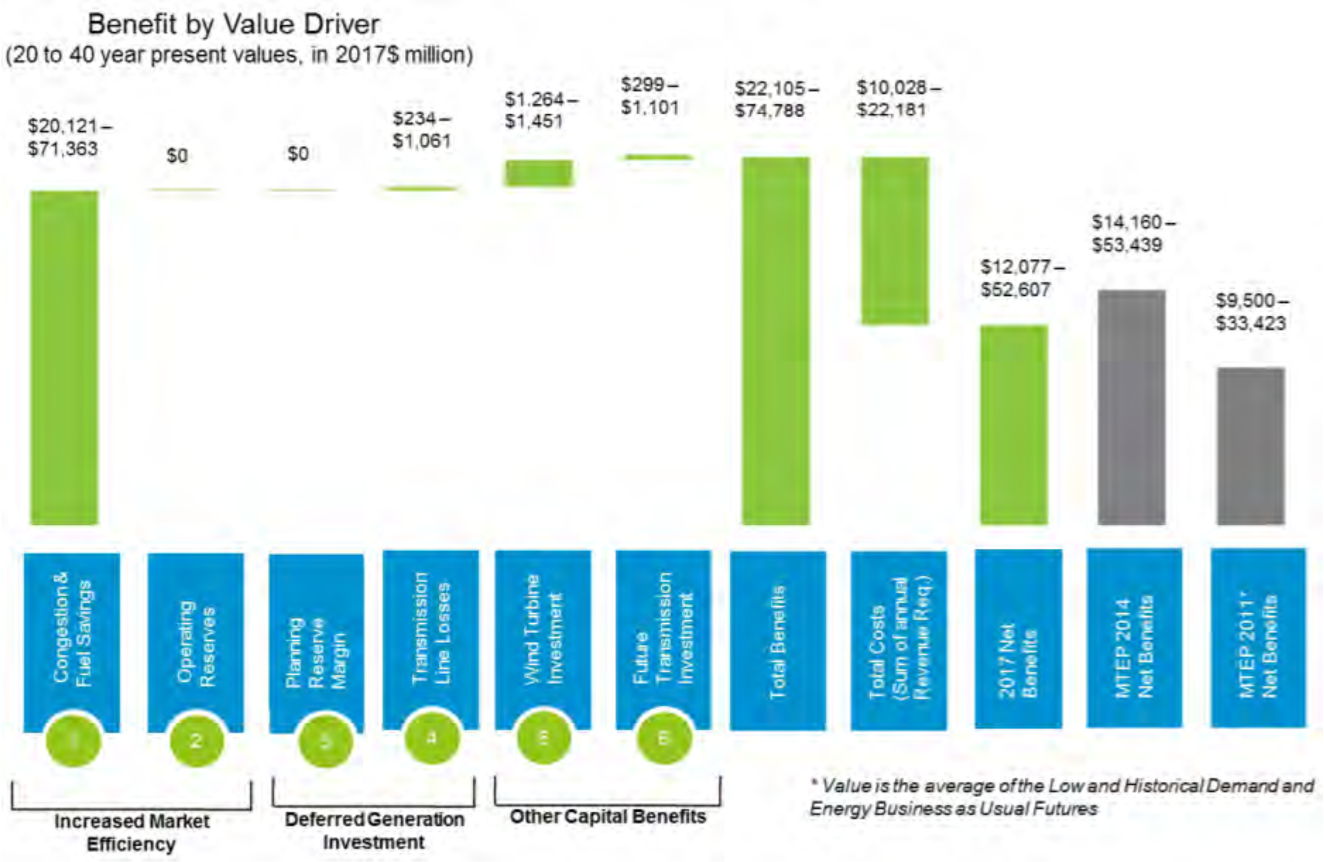

Figure 3: MISO net benefits of transmission, from Triennial MVP Review 2017

Reducing grid congestion is a critical benefit of transmission investment. Transmission congestion occurs when there is insufficient transmission capacity to deliver lower-cost electricity to customers. This increases consumer costs because a higher-cost energy source must be used to replace the low-cost generation that could not be delivered. As discussed in the next chapter, transmission congestion is particularly costly when it prevents consumers from accessing renewable resources with zero fuel cost.

Grid operators have documented how transmission upgrades save consumers money by reducing grid congestion. For example, the New England grid operator saw a large reduction in the congestion-related costs paid by consumers after it made significant investments in transmission upgrades. Specifically, system-wide congestion costs fell from in excess of $600 million per year in 2005 and 2006 to under $100 million annually, mostly as a result of transmission investment.[10] Similar reductions in congestion

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[9] https://cdn.misoenergy.org/MTEP17%20MVP%20Triennial%20Review%20Report117065.pdf

[10] https://www.iso-ne.com/static-assets/documents/2017/01/20170130_stateofgrid2017_presentation_pr.pdf, pages 39-40

costs have been observed in other regions that have invested in transmission. Without enough transmission, congestion on the grid forces consumers to pay higher prices to buy power from more expensive sources of energy, just like bad traffic might lead you to shop at a more expensive store closer to your house.

The consumer savings that can be realized by building transmission are massive. As shown below, transmission congestion increased electricity costs by about $4.6 billion in 2017 across the nation's Regional Transmission Organizations (RTOs), which serve about two-thirds of the nation's population, up from $4 billion in 2016. Most regions have not yet reported congestion cost data for 2018, but the regions that have show an increasing cost trend. For example, PJM congestion costs nearly doubled to $1.485 billion in 2018. The Department of Energy regularly releases transmission congestion studies, which document billions of dollars in additional congestion costs in the one-third of the country outside of these RTOs.[11]

Table 2: Transmission congestion costs (in millions) for RTOs, 2016 and 2017

	2017	2016
MISO	$1,503	$1,400
PJM	$818	$1,024
ERCOT	$967	$497
NYISO	$481	$529
SPP	$506	$280
CAISO	$180	$142
into CAISO	$114	$92
ISO-NE	$41	$39
Total	**$4,610**	**$4,003**

Transmission not only benefits consumers by providing them with access to lower-cost energy, but it also saves them money by improving the efficiency of moving power across the grid. Most directly, higher-voltage, higher-capacity transmission lines greatly improve the efficiency with which power is transmitted by reducing losses relative to lower-voltage lines. In the studies discussed above, SPP calculated that its transmission upgrades are saving consumers around $100 million from reduced transmission losses, while MISO estimated line loss savings of $200 million to $1 billion dollars in net present value due to its upgrades.

These efficiency savings are most pronounced when transmission lines are congested, which is when transmission is most valuable because power prices are high. This is because line losses increase significantly when power lines are being operated close to their maximum capacity and the lines are hot due to heavy use.

Another efficiency benefit is that transmission allows the grid to operate equally reliably with fewer power plants, by allowing the sharing of planning and operating reserves across the power system and with neighboring power systems. Grid operators keep power plant capacity in reserve to ensure there is sufficient power supply to handle fluctuations in electricity supply and demand over the course of a day

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[11] https://www.energy.gov/sites/prod/files/2014/02/f7/TransConstraintsCongestion-01-23-2014%20.pdf

(operating reserves) and from year-to-year (planning reserves). As explained in the introduction, on large power systems and over larger geographic areas, transmission enables fluctuations in supply and demand to cancel each other out, allowing grid operators to keep a smaller share of plants in reserve.

SPP found $1.354 billion in net present value benefits, around 8 percent of the total benefits of its transmission upgrades, were due to transmission enabling a 2 percent reduction in the size of its generating fleet by reducing the need for planning reserves. Similarly, PJM's April 2019 report found that aggregating electricity demand across its footprint saves consumers $3.78 billion annually by reducing the need for power plant capacity by over 33,000 MW.[12] In addition, transmission ties to neighboring power systems saved PJM consumers $1.3-1.7 billion per year. PJM also found that transmission-enabled supply and demand diversity has allowed it to reduce its target planning reserve margin, the amount of power plant capacity that must be kept in excess of expected peak demand, from 22% to 15.7% while maintaining the same level of reliability. A previous iteration of MISO's transmission upgrade analysis, conducted when load growth was expected to drive a need for new power plant capacity, found net present value savings of $1 billion to $5.1 billion from reduced planning reserve needs, and $33 million to $116 million from reduced operating reserve needs.[13]

The aggregation of power plants into the large grid operating areas of MISO and PJM, enabled by existing transmission, respectively saves $2.2 billion to $2.7 billion and $1.1 billion to $1.4 billion annually on planning reserves, while operating reserve savings are around $100 million annually.[14] An Xcel Colorado analysis found that 200 MW of transmission ties with neighboring Balancing Authorities enabled a reserve margin reduction from 19.2% to 16.3% while meeting the same reliability standard.[15] The geographic diversity benefit is particularly large for inter-regional transmission, due to the diversity in weather and climate across large areas. As discussed in Chapter 2, this geographic diversity benefit becomes even more pronounced as wind and solar make up a larger share of our electricity mix.

London Economics recently evaluated the consumer savings of two potential transmission projects, one project better connecting the MISO and PJM regions in the Midwest, and another project connecting the Rocky Mountain region and California.[16] That study found the MISO-PJM project would reduce consumers' electricity costs by around $275 million per year on average, offsetting the $200 million total cost of the transmission project in less than a year, without even accounting for the project's large environmental, electric reliability, and job creation benefits. PJM consumers in particular benefited from greater access to low-cost wind resources in MISO, with annual savings for PJM consumers growing to over $1 billion per year towards the end of the study period. The $3 billion project in the Western U.S.

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[12] https://pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.ashx?la=en , page 21

[13] https://cdn.misoenergy.org/2011%20MVP%20Portfolio%20Analysis%20Full%20Report117059.pdf, page 57

[14] https://www.misoenergy.org/about/miso-strategy-and-value-proposition/miso-value-proposition/, http://www.pjm.com/about-pjm/value-proposition.aspx

[15] https://www.xcelenergy.com/staticfiles/xe/Regulatory/Regulatory%20PDFs/PSCo-ERP-2011/Attachment-2.10-1-LOLP-Study.pdf, p. 2-9.

[16] http://www.wiresgroup.com/docs/reports/WIRES_LEI_TransmissionBenefits_Jan2018.pdf

also provided large net benefits, reducing consumer electricity costs by $1.2 billion annually, with similarly large environmental, electric reliability, and job creation benefits.

2. Transmission helps ensure electricity markets are competitive

Transmission also keeps prices low for consumers by facilitating competition in electricity markets. Just as consumers who lack quality roads to easily access goods from other regions would be at the mercy of the prices charged by a sole supplier in their area, a weak grid makes it possible for power plant owners in constrained sections of the grid to exert market power and charge excessive prices. In any market, the more supply options that are available to an area, the less likely it is that a supplier can take advantage of customers.

Texas has historically had some of the strongest pro-transmission policies in the country because its elected officials understood that a strong grid is essential to its free market for electricity. As a Board member for the Texas grid operator ERCOT explained, "One thing in favor of strengthening transmission … is that it's pro market. It allows a larger set of generators to compete in a more robust marketplace."[17]

The Federal Energy Regulatory Commission (FERC) has also explained that a congested transmission system can constrain electricity market competition. In a landmark order the Commission explained how some power plant owners "can have a disincentive to remedy transmission congestion when doing so reduces the value of their generation or otherwise stimulates new entry or greater competition in their area. For example, a transmission provider does not have an incentive to relieve local congestion that restricts the output of a competing merchant generator if doing so will make the transmission provider's own generation less competitive."[18]

Most of America's transmission system was built before the transition to large interstate electricity markets in recent decades. Before markets, most transmission was built inside a utility's footprint, with only weak ties to neighboring power systems intended mostly for emergency use. Much of the congestion on today's power system exists because the transmission system was not designed for interstate electricity trading. While changes in the electricity generation mix are increasing the demand for new transmission infrastructure, many grid upgrades were already long overdue because of the move to interstate electricity markets.

3. Reliability and resilience

It is widely understood that a more robust transmission system improves electric reliability and resilience, though most transmission planning studies do not quantify that benefit. It is intuitive that a stronger transmission system with more network paths to deliver power will be more reliable. Just as most commuters have a backup route in case their primary road to work is blocked by a traffic accident, grid operators are required to have at least one backup path to get electricity to homes, businesses, and

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[17] https://www.rtoinsider.com/ercot-board-rio-grande-valley-28040/

[18] http://www.nerc.com/files/order_890.pdf

hospitals. However, having multiple backup paths becomes particularly valuable when a disaster takes out multiple power lines simultaneously.

As utilities Xcel and ITC explained in a recent application to build a new transmission line in Minnesota, "the Project will improve the robustness of the regional backbone transmission system by improving the efficient delivery of energy and enabling the system to better withstand contingencies under multiple future scenarios. A robust transmission system is better positioned to deal with unplanned system outages."[19]

Analysis confirms that investing in transmission expansion does improve electric reliability and resilience. Kansas utility Westar has reported that transmission expansion has been associated with a 40% reduction in transmission-related customer outages.[20]

The London Economics analysis mentioned above also evaluated the value of transmission for making the power system more resilient to extreme events. It found that, "Over a single year period, under constrained system operating conditions, electric consumers are projected to save as much as $1.3 billion in PJM and $740 million in MISO with the 1,300 MW Eastern Interconnect project. This is equal to savings of about $20 (in MISO) to $40 (PJM) on a typical household's annual electricity utility bill in the affected regions."[21] The project in the Western U.S. was estimated to save over $100 million per year by making the power system more resilient. The study found additional economic savings of $500 million annually in each of MISO, PJM, and the Western U.S., for total annual savings of $1.5 billion, from the two transmission projects reducing occurrences of widespread blackouts and regional power outages.

Researchers have also modeled theoretical power systems and demonstrated that strengthening the grid by adding network paths significantly increases the system's resilience to damage and prevents power outages.[22] That study also found power flow control devices, which are discussed in more detail in Chapter 3, are highly effective at preventing outages. Similar modeling of the United Kingdom's power system has demonstrated that investing in stronger transmission infrastructure as well as additional backup paths for power significantly reduces the risk of a power outages due to windstorms.[23] If anything that study likely understates the value of additional backup transmission paths because it only looks at wind storm events. With a wind storm there is a very high correlation between the failure of the first circuit and backup circuits because the storm affects a large area. With other events that account for most transmission line outages (equipment failure, human error, wildfire, lightning strike, tower collapse, tree damage, tornado) there would be a much lower correlation for the loss of the two circuits, making additional backup paths much more valuable.

By enabling the delivery of electricity from other regions, transmission plays a particularly important role in keeping electricity reliable and affordable when unexpected events such as extreme weather

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[19] https://www.huntleywilmarth.com/staticfiles/microsites/hw/HW-Certificate-of-Need-Application.pdf, page 8

[20] https://www.spp.org/documents/35297/the%20value%20of%20transmission%20report.pdf, page 15

[21] http://www.wiresgroup.com/docs/reports/WIRES_LEI_TransmissionBenefits_Jan2018.pdf

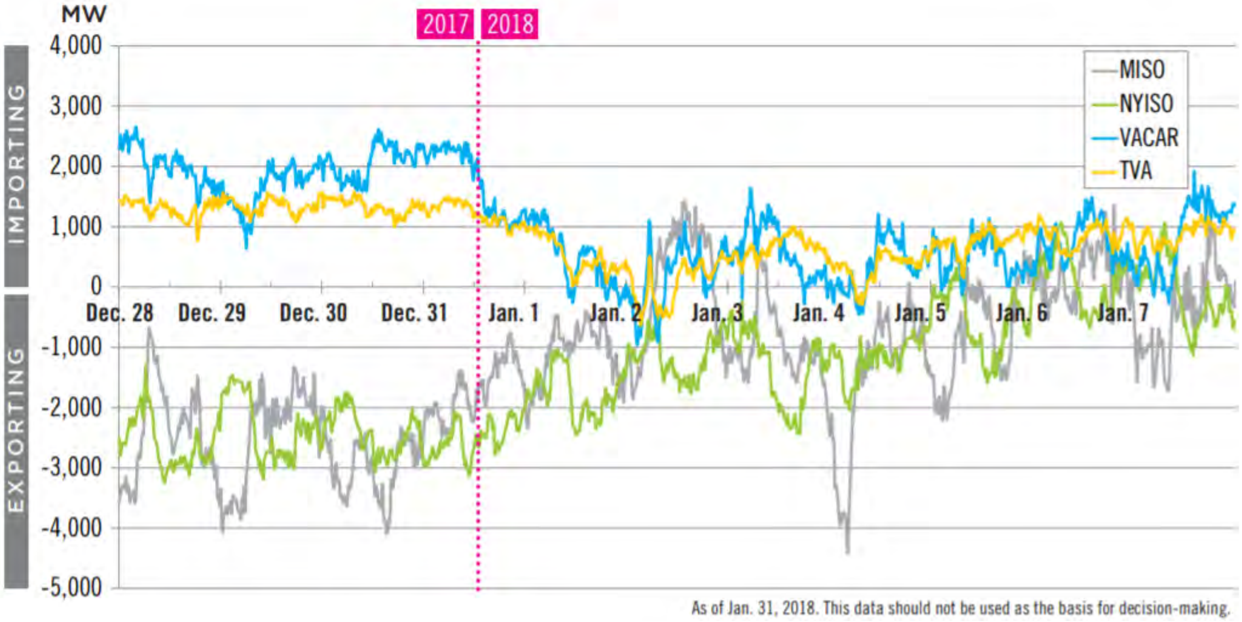
[22] http://public.lanl.gov/rbent/pscc_resilience.pdf

[23] https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7801854

affect part of the system. Weather and other extreme events tend to be geographically limited in scope so one region is almost never experiencing an extreme supply shortfall at the same time as all neighboring regions.

For example, during the Bomb Cyclone event in early January 2018, the low temperatures were far more extreme in eastern PJM than in western PJM, causing wholesale electricity prices in eastern PJM to be about three times higher than in western PJM. Specifically, during the Bomb Cyclone week, power prices in Virginia averaged about $222/MWh, versus $76/MWh in Northern Illinois. Largely as a result, PJM congestion costs in the first half of 2018 tripled to nearly $900 million relative to a year earlier. Greater west-to-east transmission capacity in PJM, and an ability to import more power from MISO, would have saved PJM consumers hundreds of millions of additional dollars during the Bomb Cyclone event alone.

In the following chart, PJM documented how its transmission ties with its neighbors were heavily utilized during the Bomb Cyclone.[24] On January 1-7, PJM was able to export power to its southern neighbors VACAR (Virginia-Carolina) and TVA (Tennessee Valley Authority) as they dealt with record cold, while PJM saw large swings in transfers with MISO and NYISO as those regions experienced high demand at different times.



As of Jan. 31, 2018. This data should not be used as the basis for decision-making.

Figure 4: PJM imports and exports during Bomb Cyclone

In 2019, a polar vortex-related cold snap caused extreme electricity demand and power plant failures in northern MISO. MISO was able to import nearly 12,000 MW over its transmission ties with neighboring power systems. Over half of those imports came from PJM, which was experiencing near-record wind output. The next extreme event might more strongly affect western PJM, causing greater demand and

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[24] https://pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.ashx?la=en, page 37

price spikes and generator unavailability there than in eastern PJM or MISO, so over time transmission expansion will ultimately benefit all.

The reliability cost of an inadequate transmission system can be quite high. The 2003 blackout in the Northeast U.S. and Canada, which largely resulted from a congested transmission system and inadequate transmission maintenance, caused an estimated $7-10 billion in economic losses. A congested transmission system with poor coordination in transmission system planning and operations was also a contributing factor to the 2011 blackout that affected parts of Southern California and Arizona.[25] The costs to consumers and the economy from these transmission-related outages are a significant share of America's total annual spending on transmission, indicating that additional spending to increase transmission system resilience – in addition to transmission's other benefits – would be worthwhile.[26]

The reliability benefits of a more interconnected power system have been apparent for over 50 years. The official report to President Johnson regarding the large-scale 1965 Northeast blackout concluded that "Isolated systems are not well adapted to modern needs either for purposes of economy or service" and recommended "… an acceleration of the present trend toward stronger transmission networks within each system and stronger interconnections between systems in order to achieve more reliable service at the lowest possible cost."[27]

Another reliability concern is that much of America's transmission infrastructure is now reaching the end of its useful life, including transmission lines, towers, transformers, and other substation equipment. Like most infrastructure, this equipment will likely see a higher outage and failure rate as it nears the end of its life, putting reliability at risk. In part due to its obsolescence, the American Society of Civil Engineers recently gave America's power grid infrastructure a "D+."[28]

Grid operators confirm that their transmission infrastructure is reaching the end of its life and must be replaced.[29] PJM recently noted that "Two-thirds of all system assets in PJM are more than 40 years old; over one-third are more than 50 years old. Some local, lower-voltage transmission facilities, especially below 230 kV, are approaching 90 years old."[30]

Nationally, most of our transmission infrastructure was built between 1960 and 1980; according to one estimate, just replacing that infrastructure alone will cost around $8-14 billion per year over the next 25

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[25] https://www.ferc.gov/legal/staff-reports/04-27-2012-ferc-nerc-report.pdf

[26] http://www.eei.org/issuesandpolicy/transmission/Documents/bar_Transmission_Investment.pdf

[27] Federal Power Commission, "Report to the President on the Power Failure in the Northeastern United States and the Province of Ontario on November 9-10, 1965," December 6, 1965. p. 43 (emphasis added). Cited in http://www.wiresgroup.com/docs/reports/Transmission_Resilience_WIRES_FINAL_05092018.pdf p. 2. http://www.wiresgroup.com/docs/filings/WIRES%20Testimony%20ENR%20Senate%20Committee%20071218.pdf

[28] http://www.infrastructurereportcard.org/cat-item/energy/

[29] http://www.nyiso.com/public/webdocs/media_room/publications_presentations/Power_Trends/Power_Trends/2016-power-trends-FINAL-070516.pdf, page 2

[30] https://pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.ashx?la=en, page 5

years.[31] A similar estimate is that the grid will need $57 billion in investment over the next five years alone.[32]

As America undertakes that investment, it should also account for future needs and ensure that the size of transmission investment is optimized to realize the benefits outlined in this section. In addition to their greater efficiency and economies of scale, higher-voltage transmission lines tend to experience fewer outages, suggesting that investment in these higher-capacity lines will improve system reliability. Higher-voltage lines tend to have multiple circuits (or phases), which protects against the loss of a single circuit. As American Electric Power explains, high-capacity "765 kV [kilovolt] circuits experience, on average, 1.0 forced outages per 100 mile-years. A comparable statistic for 500 kV is 1.4 forced outages per 100 mile-years. While single-phase faults are the dominant type of failures for both voltage classes, no multi-phase faults have been recorded at 765 kV in normal operation, short of tower failure."[33] NERC data confirm that higher-voltage transmission lines and infrastructure have a lower outage rate than lower-voltage lines.[34]

Grid operators agree that transmission is important for resilience

In the recent grid resilience proceeding at FERC, the Regional Transmission Organizations unanimously and strongly agreed that transmission should be a primary focus of any efforts to increase resilience. In its comments to the Commission, MISO focused on "Transmission Planning" and "Inter-regional Operations" as two of the three areas the Commission should focus on for improving resilience. As MISO explained, "Continued industry dialogue on more effectively identifying, valuing, and incorporating resilience attributes in transmission planning processes will help the Commission identify further opportunities to support and advance grid resilience."[35]

Similarly, PJM argued that "resilience efforts will require changes to transmission and infrastructure planning," explaining that "the Commission could provide assistance to RTOs by requiring them to plan for and address resilience, and confirm that resilience is a component of regional transmission system planning" and that "Robust long-term planning, including developing and incorporating resilience criteria into the [Regional Transmission Expansion Plan], can also help to protect the transmission system from threats to resilience."[36]

In its comments, NYISO explained that the Commission "must also recognize the critical importance of maintaining and enhancing grid interconnections. These interconnections support and bolster reliability and resilience by creating a larger and more diverse resource pool available to meet needs and address

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[31] http://files.brattle.com/system/publications/pdfs/000/005/190/original/investment_trends_and_fundamentals_in_us_transmission_and_electricity_infrastructure.pdf?1437147799, pages 6-7

[32] http://www.cg-la.com//documents/Maximizing-the-Job-Creation-Impact-of-%241-Trillion-in-Infrastructure-Investment.pdf

[33] https://www.aep.com/newsroom/resources/docs/AEP_Interstate_Project-Technologies.pdf

[34] https://www.nerc.com/pa/RAPA/tads/Key_TADS_Documents/TADS%20Dashboard%20RAW%20Data.xlsx

[35] https://elibrary.ferc.gov/IDMWS/common/opennat.asp?fileID=14837872, page 2

[36] https://elibrary.ferc.gov/IDMWS/common/opennat.asp?fileID=14838232, pages 11, 69, 50

unexpected and/or disruptive events throughout an interconnected region."[37] It provided a detailed explanation of how "The resiliency value of an interconnected grid has been clearly demonstrated during recent periods of system stress," and explained that "Maintaining and protecting existing interconnections between neighboring regions and continually assessing opportunities to improve interregional transaction coordination can bolster the resiliency of the grid throughout an interconnected region. These interconnections foster the opportunity for the Northeast and Mid-Atlantic markets to rely on a broader, more diverse set of resources to meet the overall needs of the region."

ISO-NE discussed the consumer savings and resilience benefits of its recent transmission investments, noting that "As a result of these investments, the region has a robust transmission system that has the ability to operate reliably under myriad operating conditions."[38] SPP also noted how "This additional transmission has enabled resources of all fuel types to help meet customer demand during a range of potential threats to reliability and resilience," and that "The construction of new transmission facilities pursuant to modern design standards enhance the robustness of the system."[39] CAISO explained that a key function of its transmission planning process is "maintaining reliability through a resilient electric system."[40]

Finally, in their comments, ERCOT and the Texas public utility commission explain that "One of the most critical elements of system resilience is ensuring that the transmission system is planned in such a way as to ensure continued operations following an unexpected outage of one or more generators or transmission elements."[41]

In its comments in an earlier resilience proceeding, NERC, the entity responsible for electric reliability for much of North America, also explained the central role of transmission for reliability and resilience and the importance of improved transmission planning methods, noting repeatedly that "The right combination and amount of resources and transmission together maintain adequacy of the system."[42]

Transmission is more effective than generation for increasing reliability and resilience

Despite the primary focus on fuel security and power plant retirements in recent discussions of electricity resilience, generation failures account for an extremely small share of customer electric outages. Over 90 percent of customer outage minutes caused by failures on the low-voltage distribution system that delivers electricity to homes and businesses, while the vast majority of the remainder caused by transmission system failures. As a result, policymakers concerned about resilience should

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[37] https://elibrary.ferc.gov/IDMWS/common/opennat.asp?fileID=14838205, pages 10-12
[38] https://elibrary.ferc.gov/IDMWS/common/opennat.asp?fileID=14837909, page 15
[39] https://elibrary.ferc.gov/IDMWS/common/opennat.asp?fileID=14838087, pages 3, 5
[40] https://elibrary.ferc.gov/IDMWS/common/opennat.asp?fileID=14838234, page 148
[41] https://elibrary.ferc.gov/IDMWS/common/opennat.asp?fileID=14837920, page 7
[42] https://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/Comments%20of%20NERC%20re%20Proposed%20Grid%20Reliability%20and%20Resilience%20Pricing.pdf, page 2

focus far more on strengthening electricity transmission and distribution infrastructure than on measures to increase generating capacity.

The Rhodium Group consulting firm found that generation inadequacy accounted for less than 1/10,000th of all customer-hours of outages, with fuel supply emergencies an even smaller share at fewer than 1 in 1.4 million.[43] Similarly, analysis in Public Utilities Fortnightly found that "distribution system outages appear to impose roughly two orders of magnitude more minutes of outage on customers than does resource adequacy … 146 compared to 1.2 minutes a year."[44] That analysis went on to note that even that is likely to be an overestimate of outages caused by generation shortfalls, as Balancing Authorities can typically resort to steps such as leaning on neighboring power systems or reducing system voltage in the event of a generation shortfall and avoid resorting to customer outages.

As documented in a recent report, of the 27 major U.S. blackouts that have caused outages to more than 1 million customers since 2002, only four were due to factors other than severe weather – three started on the transmission system (the 2003 Northeast Blackout, the 2008 Turkey Point blackout, and the 2011 Southwest Blackout) and one was due to a power plant fire (Puerto Rico 2016).[45] Only the ERCOT 2011 rolling blackouts, mostly caused by inadequate equipment weatherization for extremely cold weather, were related to a generation shortfall. It should also be noted that, due to their larger size and geographic diversity, the Eastern and Western Interconnections (which are subject to FERC jurisdiction) tend to be more resistant to generation shortfalls than ERCOT.

The reliability value of additional generation is also extremely low at the current high levels of excess power plant capacity in most regions. PJM analysis has demonstrated that once generating capacity planning reserve margins exceed 20 percent, the marginal benefit of additional reserve capacity for reducing customer outages is negligible.[46] Analysis by Xcel's Colorado utility reached the same conclusion.[47] The Brattle Group similarly calculated that 9 percent is the economically optimal reserve margin for ERCOT, as above that level the cost of extra generating capacity outweighs the benefits.[48] Instead of focusing on generation, federal policymakers and regulators concerned about resilience should focus on strengthening and expanding transmission, while state regulators who also have jurisdiction over distribution infrastructure should focus on both transmission and distribution.

4. National security

Strengthening America's power grid will always help keep the lights on, but especially when disaster strikes. A more robust grid helps protect against and recover from all types of unexpected events,

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[43] https://rhg.com/research/the-real-electricity-reliability-crisis-doe-nopr/
[44] https://www.fortnightly.com/fortnightly/2010/04/reconsidering-resource-adequacy-part-1
[45] https://gridprogress.files.wordpress.com/2018/05/customer-focused-resilience-final-050118.pdf, Appendix A
[46] https://www.pjm.com/~/media/planning/res-adeq/2017-pjm-reserve-requirement-study.ashx, page 39
[47] https://www.xcelenergy.com/staticfiles/xe/PDF/Attachment%20AKJ-2.pdf, page 391
[48] http://www.ercot.com/content/wcm/lists/143980/10.12.2018_ERCOT_MERM_Report_Final_Draft.pdf, p. iv.

including deliberate attacks on our infrastructure, while a weak and congested grid makes the system vulnerable to disruption.[49]

Transmission expansion helps limit the potential impact of intentional attacks on the power system, whether caused by cyber-attacks, small-scale sabotage, or large-scale physical attacks. Power system cybersecurity experts have explained that infrastructure redundancy and regional diversity, both key benefits of transmission expansion, limit the threat posed by cyberattacks.[50] For any unexpected event that affects either generation or transmission infrastructure, a strong network of inter-regional transmission allows power to be instantly re-routed to the affected region.

Keeping the electricity on following a disaster can be a matter of life and death. For many Americans, electricity not only powers luxuries like flat screen TVs, but also critical equipment like kidney dialysis machines. Water and communications networks rely on electricity, refrigeration is critical for keeping food and medical supplies usable, and emergency responders need electricity to do their jobs.[51]

Military installations, hospitals, emergency services, and critical data and financial networks have invested in backup power supplies, indicating the value of reliable electricity to many public services and sectors of the economy.

Just as Eisenhower's interstate highway system was primarily built for national security reasons but has since paid for itself many times over by allowing low-cost transport of goods and people, investing in America's grid will pay dividends for both our economic and national security.

5. Job creation and economic development

Investing in transmission creates jobs and provides economic development benefits. MISO has evaluated the impact its transmission investment had on jobs, economic development, and tax revenue over the 2002-2015 period. [52] It found over 114,000 job-years were created from MISO transmission investment over that period, with a peak of 16,700 to 25,800 total jobs in 2014. That provided $5 to $8 billion of labor income from 2002 to 2015. Economic activity spurred by that investment totaled $6.7 to $11.3 billion over that period. The transmission projects also drove $457 to $765 million of state and local tax revenue, and $935 million to $1.5 billion of federal tax revenue from 2002 to 2015.

Iowa State University recently calculated the job creation and economic development that would be driven by a large-scale investment in transmission, and the renewable energy deployment that would result.[53] It found that investing in the grid and renewable generation would increase net employment by around 200,000 jobs on average for the first decade, with sustained higher employment after that, even

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[49] http://thehill.com/opinion/energy-environment/365890-a-vulnerable-power-grid-lets-invest-in-critical-national

[50] https://fivethirtyeight.com/features/hacking-the-electric-grid-is-damned-hard/amp/

[51] https://www.thechicagocouncil.org/sites/default/files/working_paper_grid_security_weigert_171214.pdf

[52] https://cdn.misoenergy.org/Economic%20Impact%20of%20MTEP%20In-Service%20Projects271136.pdf

[53] https://register.extension.iastate.edu/images/events/transgridx/Economic-Benefits-and-Job-Creation-from-the-Interconnection.pdf

after accounting for the displacement of other generation sources. Another study projected that a large-scale investment in transmission, and the resulting generation additions, would create between 649,010 and 936,111 jobs for 30 years.[54]

The London Economics study mentioned above also evaluated the job creation and economic development impact of two potential transmission projects. It estimated that the $3 billion transmission investment and resulting renewable deployment in the Western U.S. would create 9,400 new jobs per year in the medium term and increase GDP by around $700 million annually.[55] That study also found the smaller $200 million project in the Eastern U.S. would create up to 3,000 new jobs annually in the medium term and increase GDP by $22 million per year in the short-term and up to $11 million per year in the medium term.

The National Renewable Energy Laboratory (NREL) has similarly estimated the jobs and economic development benefits from several planned transmission projects to access Wyoming wind resources.[56] The analysis found the transmission investment alone would create 2,100 jobs on average over the first ten years, and 520 ongoing jobs after that. Property tax payments were estimated at $11 million per year, landowner payments at $1.8 million per year, and sales taxes potentially totaling tens of millions of dollars during the construction phase. Separately, the Center for Rural Affairs has compiled case studies on the positive impact from increased tax revenue and other payments to rural communities from transmission investment.[57]

Transmission that will access renewable energy also brings the large job creation and economic development benefits associated with renewable plant development and operations. The transmission developer Clean Line estimated that building each of its proposed long-distance transmission lines and the associated renewable projects would create around 5,000 jobs, with 500 ongoing operating and maintenance jobs.[58]

Transmission investment also creates jobs and spurs economic development by providing industries and businesses with access to low-cost, reliable electricity. Keeping electricity reliable and affordable is one of the best ways to maintain American competitiveness. Businesses must pass higher electricity costs on to their customers, and electricity-intensive industries have a strong incentive to relocate to locations with lower electricity costs, taking jobs with them. Low-cost, reliable power is essential for data centers, factories, and other businesses, and companies take that into account when choosing where to locate new facilities. Because of the low and stable price of renewable energy, as well as its environmental benefits, some companies have decided to locate facilities where they have better access to renewable energy, and transmission is key to delivering renewable energy to those facilities.[59]

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[54] http://cleanandsecuregrid.org/2017/11/28/economic-advantages-and-financial-feasibility/

[55] http://www.wiresgroup.com/docs/reports/WIRES_LEI_TransmissionBenefits_Jan2018.pdf

[56] https://www.nrel.gov/docs/fy11osti/50577.pdf

[57] https://www.cfra.org/sites/www.cfra.org/files/publications/GenerationAndDelivery.pdf

[58] https://www.grainbeltexpresscleanline.com/site/page/benefits

[59] http://windenergyfoundation.org/2017/05/24/new-report-wind-energy-setback-policy-will-cost-ohio-4-2-billion-unless-changed/

6. Transmission protects against uncertainty

As utilities and state regulators confront growing uncertainty due to fuel price volatility, uncertain policy changes, rapid technology improvements, and large changes in the generation mix, transmission provides valuable flexibility to respond to unexpected changes. A robust network ensures customers can access low-cost power under a wide range of scenarios.

Every year, utilities invest tens of billions of dollars in power plants that will cost an additional tens of billions of dollars to operate over their multi-decade lifetimes. Those irreversible investments are made in the face of massive uncertainty about future fuel prices, costs of other generating technologies, policies, electricity demand, and other factors. Transmission provides valuable optionality that hedges against those large uncertainties, any of which can result in billions of dollars in additional costs if consumers have insufficient transmission to access cheaper energy sources. As utilities Xcel and ITC noted in an application to build a transmission line in Minnesota, "A robust regional transmission system is also key to enabling access to a diverse mix of generation resources, which in turn allows customers to access the least expensive power available at any given time."[60]

Transmission is an important mechanism to protect consumers against the inherent but unpredictable volatility in the price of fuels used to produce electricity. Transmission can alleviate the negative impact of fuel price fluctuations on consumers by making it possible to buy power from different generators in other regions if it is cheaper than running a closer generator. This increased flexibility also helps to modulate swings in fuel price, as it makes demand for fuels more responsive to price because utilities can respond to price signals by decreasing use of an expensive fuel and instead importing cheaper power produced from other sources. PJM notes how a strong transmission system and additional transmission investment enabled the reliable and cost-effective replacement of over 30,000 MW of generating capacity over the last decade while providing access to lower-cost gas and renewable resources.[61]

Transmission also enables new power plants to be built to take advantage of unexpected shifts in the economics of different energy sources. Over the last decade, transmission has not only allowed customers to benefit from the large cost reductions for wind and solar generation, but also the increased availability of low-cost shale natural gas in many regions where gas resources were not previously available. Because it takes much longer to plan, permit, and build transmission than generation, it is often not possible to wait for economic and policy shifts to occur before investing in the transmission needed to optimally respond to them. The SPP and Brattle studies mentioned earlier documented the value of transmission for providing optionality to hedge against uncertainty in future fuel prices, the generation mix, and other factors.[62] Additional analysis has shown the optionality value

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[60] https://www.huntleywilmarth.com/staticfiles/microsites/hw/HW-Certificate-of-Need-Application.pdf, page 8

[61] https://pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.ashx?la=en, page 23

[62] http://wiresgroup.com/docs/reports/WIRES%20Brattle%20Report_TransmissionPlanning_June2016.pdf and

of transmission to be very large and found that standard transmission planning methods greatly underestimates the value of transmission.

Specifically, analysis by Dr. Ben Hobbs at Johns Hopkins University and his graduate student Francisco Espinoza shows that current transmission planning methods, which at best use several deterministic scenarios to highlight ranges of future outcomes for the power system, are "a weak tool for decisions under uncertainty" and "don't account for flexibility."[63] Relative to standard deterministic methods that do not account for uncertainty, probabilistic transmission planning methods that account for uncertainty by simultaneously evaluating a large number of possible scenarios result in both a larger and more optimal transmission build, potentially saving consumers tens or even hundreds of billions of dollars.[64]

Other recent analysis found that the consumer savings from use of such probabilistic (stochastic) tools in the Western U.S. "can be as much as or even exceed the cost of the recommended transmission facilities themselves. Furthermore, we provide evidence that the transmission recommendations of stochastic programming models are more robust to scenarios that haven't been considered than recommendations by deterministic models. That is, stochastic plans appear to make the network more adaptable in the face of all uncertainties, not just those that were included as specific scenarios."[65]

Unfortunately, most grid planners do not currently account for this value of transmission, aside from limited analysis of a few potential scenarios. MISO does account for some uncertainty, noting that it "uses its value-based planning approach to proactively identify infrastructure that is valuable under a number of long-term future scenarios."[66]

Just as the interstate highway system made the American economy more efficient and flexible by facilitating interstate trade, a more robust transmission system will save consumers money and enable a more efficient transition to whatever direction that future takes. When transmission provides access to stably-priced renewable generation that provides even greater protection to consumers because renewable resources are not subject to fuel price risk.

Many of the benefits discussed in this section and the preceding sections are difficult to quantify. The unfortunate result is that in most transmission planning efforts, unquantified benefits are not accounted for. Even for benefits that can be quantified, it is common to underestimate benefits. As noted above, SPP and others have found that the benefits of transmission they observe in the real-world are even larger than they anticipated in their initial plans.

Given that transmission infrastructure typically remains in service for 40 years or more, it is likely to provide many benefits that cannot be anticipated when it is built. Even though they were planned only

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[63] https://www.sciencedirect.com/science/article/pii/S1040619015001025,
http://energy.gov/sites/prod/files/2013/09/f2/1-2013RMReview-Hobbs.pdf

[64] http://hobbsgroup.johnshopkins.edu/docs/FD_Munoz_Dissertation.pdf, page 102.

[65] https://www.wecc.biz/Reliability/Planning-for-Uncertainty-Final-Report.pdf

[66] https://elibrary.ferc.gov/idmws/common/OpenNat.asp?fileID=14837832, pages 15-16.

10 years ago, the Texas grid operator ERCOT has documented how the Competitive Renewable Energy Zone (CREZ) transmission upgrades have already had the unexpected benefit of addressing reliability concerns caused by the potential retirement of fossil generators.[67] Additionally, former Public Utilities Commission of Texas Chair Barry Smitherman has explained how those grid upgrades also addressed unexpected reliability concerns caused by a surge in electricity demand from oil and gas production in West Texas.[68]

The economist Larry Summers has explained that, as a general matter, "improved infrastructure has benefits that go well beyond what is picked up in standard rate of return on investment calculations," including "spurring investment and promoting agglomeration by increasing the range over which the best companies can expand and compete." Networks like the power grid function in non-linear ways including economies of scale, with initial investments reducing the cost and increasing the benefits of subsequent investments, so investments yield positive externalities that are difficult to quantify. For example, once a region's power system has overcome the initial cost hurdle of adding substations and power lines that operate at a higher voltage, the cost of connecting additional lines to those substations is reduced because a significant share of the needed substation equipment already exists. Similarly, moving from two to three parallel transmission lines increases the amount of transmission capacity that can be safely used by 100% for only a 50% increase in transmission costs; with only two lines, their total utilization would be limited to the capacity of a single line because the other line's capacity must be held in reserve to prevent an overload in case one of the lines failed.

As discussed in Chapter 3, transmission planning processes can be improved to better account for benefits that are difficult to quantify and are therefore often ignored. The under-investment in transmission due to a failure to account for these benefits leaves billions of dollars in consumers' money, electric reliability value, and other benefits on the table.

The vision for a stronger, more connected grid

Over the last decade, grid operators and other researchers have released dozens of conceptual transmission plans to achieve the benefits highlighted above. These plans were all calculated to provide benefits many times larger than their cost.

As one example, a large consortium of grid operators, DOE national laboratories, and other researchers developed an optimized national transmission expansion through the Interconnections Seam Study.[69] The study examines a range of possible transmission upgrades:

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[67] http://www.ercot.com/content/news/presentations/2013/2012%20Long%20Term%20System%20Assessment.pdf, pages 33-35

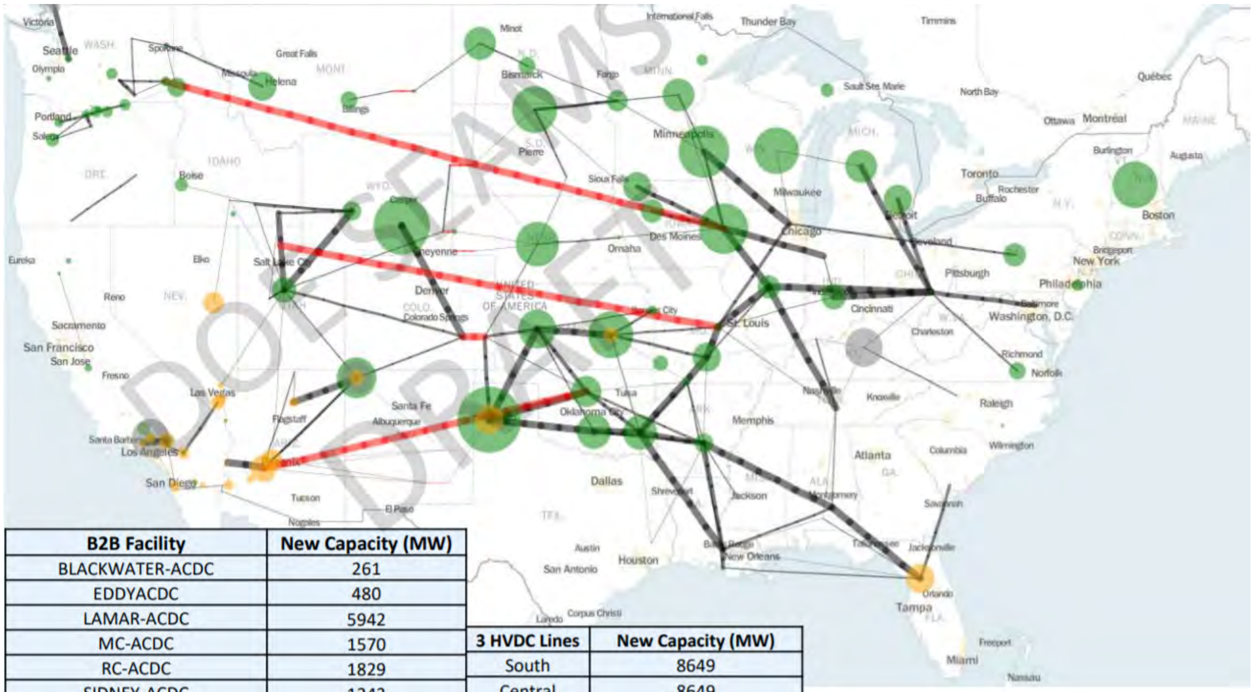
[68] Texas Energy Report (subscription) article referenced here https://www.sierraclub.org/texas/blog/2014/10/comptroller-s-anti-renewables-report-gets-swift-rebuke

[69] https://www.nrel.gov/analysis/seams.html; results from "Interconnection Seams Study," presented at Energy Systems Integration Group spring meeting, March 2018, and at Iowa State Transgrid-X Symposium, July 2018, https://iastate.box.com/s/vfgn9nikl1rz7r8x0vaoauzpm2210t35; Also presented at https://cigre-usnc.org/wp-content/uploads/2017/10/3-Interconnection-Seams-Study-Update-101817-CIGRE-GOTF.pdf

-Modest grid upgrades and a slight increase in transfer capacity between the two primary power systems in the U.S., the Eastern and Western Interconnects (map not shown below)

-The addition of high-capacity DC lines and supporting AC infrastructure to more strongly connect the East and West (first map shown below, with red lines indicating new DC transmission, gray lines indicating new AC transmission, wind resource additions indicated by green circles, and solar resource additions indicated by yellow circles)

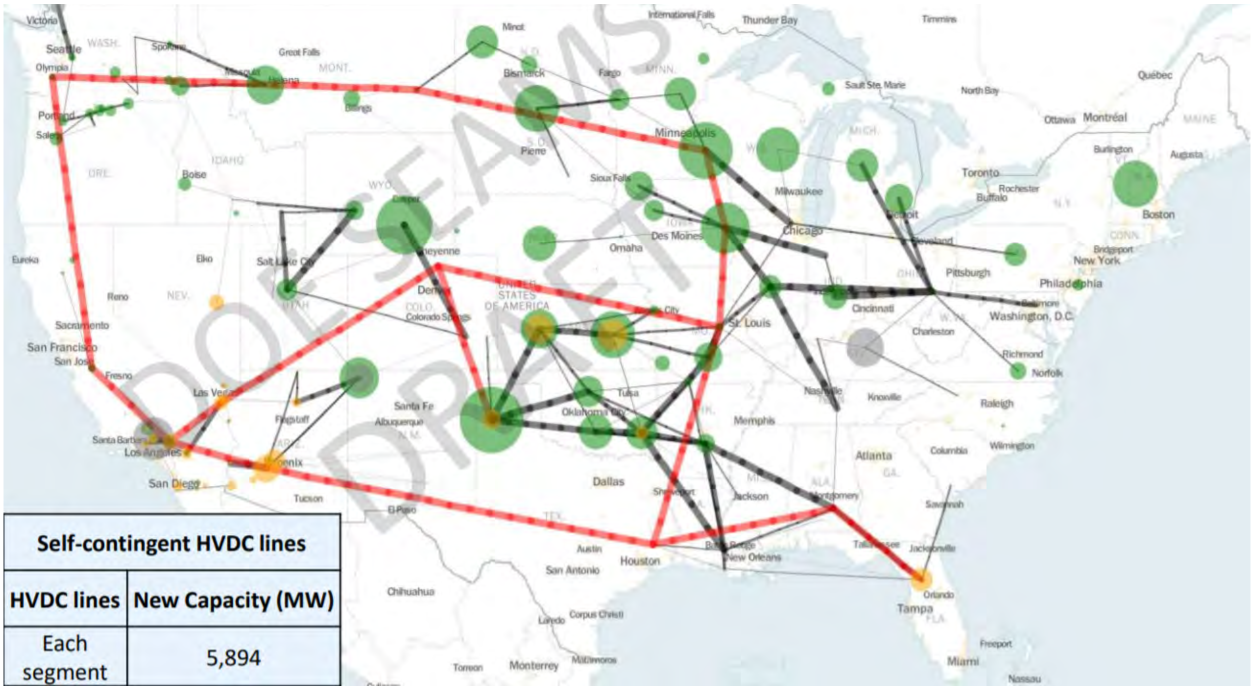
-The addition of a nationwide high-voltage DC transmission network (second map below)



B2B Facility	New Capacity (MW)
BLACKWATER-ACDC	261
EDDYACDC	480
LAMAR-ACDC	5942
MC-ACDC	1570
RC-ACDC	1829
SIDNEY-ACDC	1243
STEGAL-ACDC	1422
TOTAL B2B	**12,747**

3 HVDC Lines	New Capacity (MW)
South	8649
Central	8649
North	8649
TOTAL DC LINE	**25,947**

Figure 5: Medium transmission upgrade scenario in Interconnections Seam Study



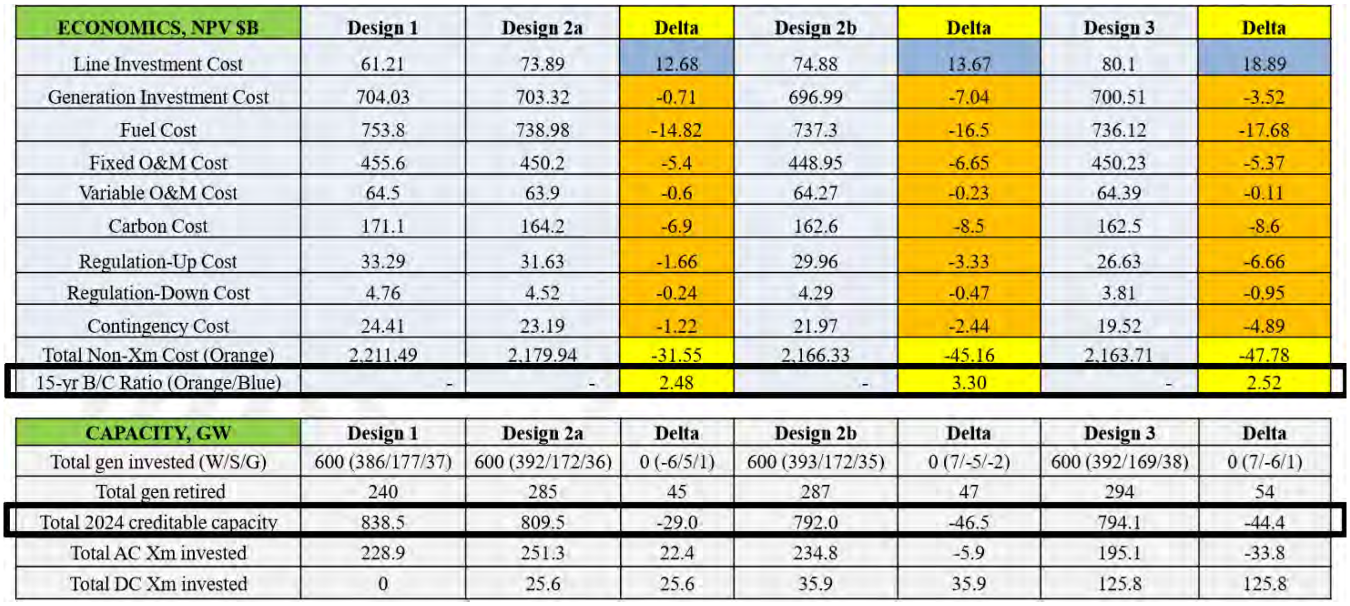
Self-contingent HVDC lines	
HVDC lines	**New Capacity (MW)**
Each segment	5,894

Figure 6: Largest transmission upgrade scenario in Interconnections Seam Study

As indicated in the following table from a presentation of the study's preliminary results, these transmission investments yield benefits that are many times larger than their cost. The blue cells show the cost of each transmission addition, while the orange cells tally the benefits of that transmission. The bottom yellow cell calculates the benefit-to-cost ratio for each design, which range from $2.50 to $3.30 per $1 invested over a 15-year period, depending on the design.

In addition, the study found ongoing annual savings of $1.4 to $4.2 billion beyond that 15-year period; many transmission investments are expected to have a lifetime of 40 or more years. Even without accounting for the cost of carbon emissions, the transmission investments were found to have a positive benefit-to-cost ratio.

Table 3: Benefit-to-cost results of Interconnections Seam Study



ECONOMICS, NPV $B	Design 1	Design 2a	Delta	Design 2b	Delta	Design 3	Delta
Line Investment Cost	61.21	73.89	12.68	74.88	13.67	80.1	18.89
Generation Investment Cost	704.03	703.32	-0.71	696.99	-7.04	700.51	-3.52
Fuel Cost	753.8	738.98	-14.82	737.3	-16.5	736.12	-17.68
Fixed O&M Cost	455.6	450.2	-5.4	448.95	-6.65	450.23	-5.37
Variable O&M Cost	64.5	63.9	-0.6	64.27	-0.23	64.39	-0.11
Carbon Cost	171.1	164.2	-6.9	162.6	-8.5	162.5	-8.6
Regulation-Up Cost	33.29	31.63	-1.66	29.96	-3.33	26.63	-6.66
Regulation-Down Cost	4.76	4.52	-0.24	4.29	-0.47	3.81	-0.95
Contingency Cost	24.41	23.19	-1.22	21.97	-2.44	19.52	-4.89
Total Non-Xm Cost (Orange)	2,211.49	2,179.94	-31.55	2,166.33	-45.16	2,163.71	-47.78
15-yr B/C Ratio (Orange/Blue)	-	-	2.48	-	3.30	-	2.52

CAPACITY, GW	Design 1	Design 2a	Delta	Design 2b	Delta	Design 3	Delta
Total gen invested (W/S/G)	600 (386/177/37)	600 (392/172/36)	0 (-6/5/1)	600 (393/172/35)	0 (7/-5/-2)	600 (392/169/38)	0 (7/-6/1)
Total gen retired	240	285	45	287	47	294	54
Total 2024 creditable capacity	838.5	809.5	-29.0	792.0	-46.5	794.1	-44.4
Total AC Xm invested	228.9	251.3	22.4	234.8	-5.9	195.1	-33.8
Total DC Xm invested	0	25.6	25.6	35.9	35.9	125.8	125.8

Another study published in the journal *Nature Climate Change* examines the benefits of building an even larger nationwide transmission network that could save consumers as much as $47 billion annually, a roughly 10 percent reduction in electric bills.[70] As shown below, the network taps into the best renewable resources (green represents wind deployment, red shows solar deployment) to produce around 60 percent of America's electricity from renewable resources (the outer circle in the lower right shows generation by energy source, the inner circle shows power plant capacity by energy source). The network would cut carbon dioxide emissions by 80 percent while saving consumers money.

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[70] http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2921.html, https://www.utilitydive.com/news/study-deep-decarbonization-of-us-grid-possible-without-energy-storage/412721/

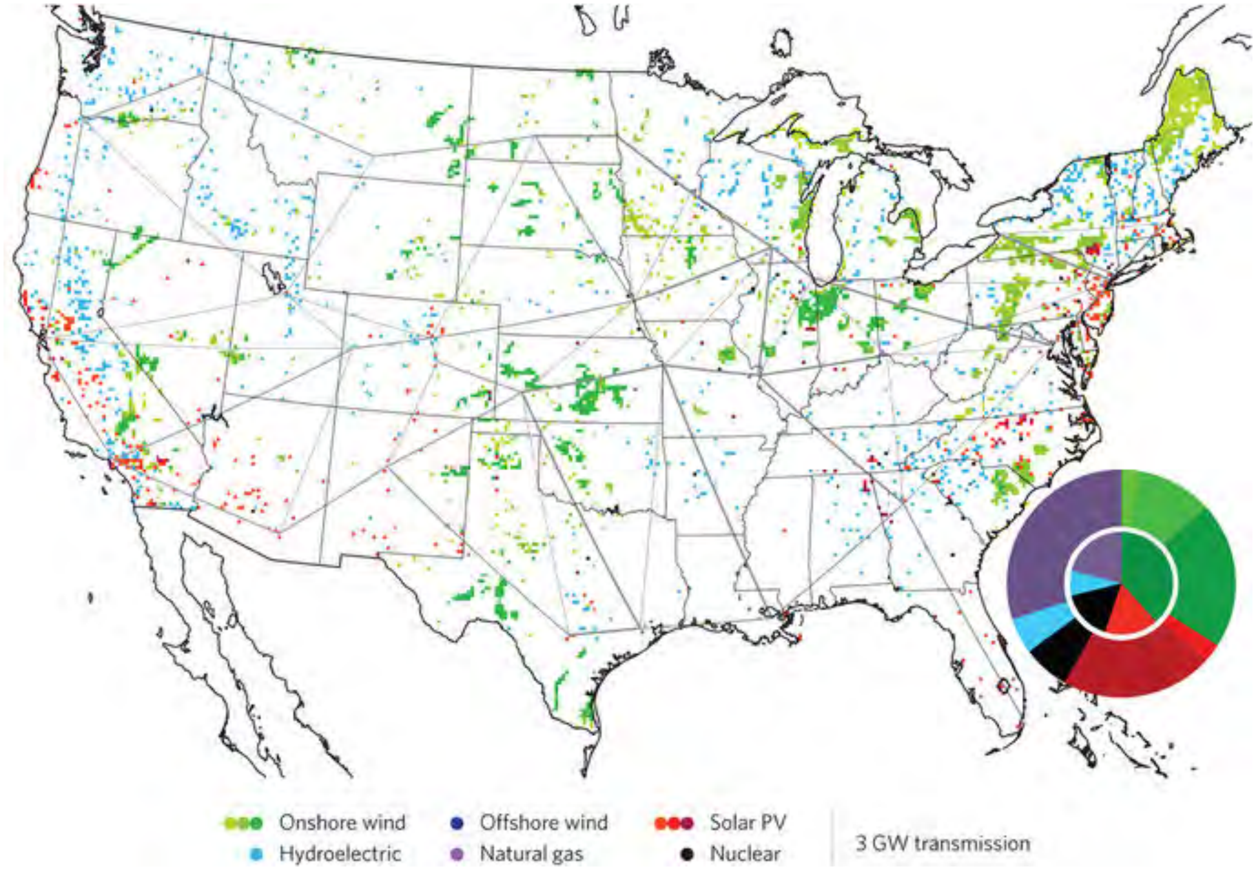

Figure 7: Transmission network and generating resource map, *Nature Climate Change* study

Other studies have looked at regional transmission investments. In 2017, the National Renewable Energy Laboratory (NREL) released detailed analysis of several proposed transmission lines in the Western U.S., shown below. It found that these lines would cost $10 billion but save $2.3 billion per year,[71] which indicates the lines themselves would have a payback period of around 4 years.

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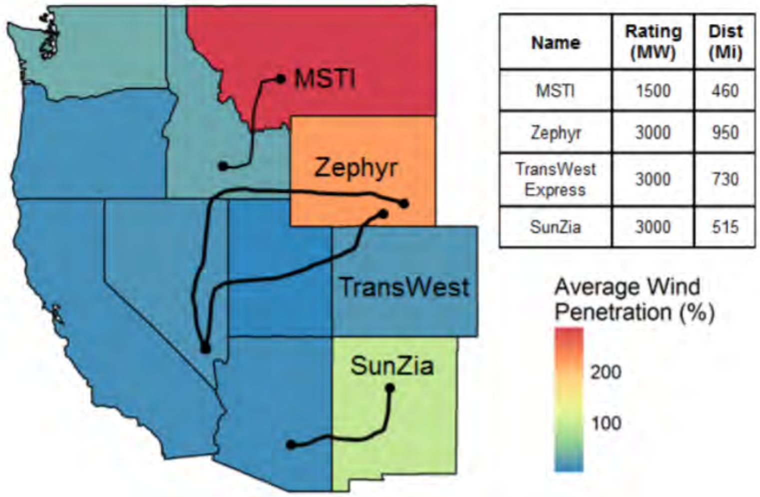
[71] https://www.nrel.gov/docs/fy17osti/67240.pdf



Name	Rating (MW)	Dist (Mi)
MSTI	1500	460
Zephyr	3000	950
TransWest Express	3000	730
SunZia	3000	515

Figure 8: Proposed transmission additions in Western U.S. studied by NREL

Analysis conducted for MISO found that significant transmission expansion was economical under all future scenarios, with the largest transmission expansion needed in Minnesota, the Dakotas, and Iowa. In the carbon reduction case, transmission provided $3.8 billion in annual savings, reducing total power system costs by 5.3%.[72] Recent analysis using the same model for the state of Minnesota found that "the increased spending on transmission and sub-transmission (along with implicit distribution costs) was strongly outweighed by the decreased generation costs."[73] Specifically, expanded transmission connections to other states saved Minnesota consumers $86 million annually in a case without a limit on carbon. Those savings rose to $1.25 billion and $2.8 billion annually in cases in which Minnesota decarbonized.[74] The Great Plains Institute also recently analyzed future scenarios with very high levels of renewable generation, and concluded that "Efficient transmission expansion can also better integrate increases in renewable generation and avoid curtailments."[75]

In another regional study, Charles River Associates, International examined the potential for a high-voltage transmission overlay in SPP.[76] It concluded that the investment would provide economic benefits of around $2 billion per year for the region, more than four times the $400-500 million annual cost of the transmission investment. Of these benefits, $900 million would be in the form of direct consumer savings on their electric bills, with $100 million of these savings coming from the significantly higher

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[72] http://www.vibrantcleanenergy.com/wp-content/uploads/2016/05/VCE_MISO_Study_Report_04252016.pdf, page 23

[73] http://www.vibrantcleanenergy.com/wp-content/uploads/2018/07/MNSmarterGrid-VCE-FinalVersion-LR.pdf, page 4

[74] *Ibid.,* page 18

[75] http://roadmap.betterenergy.org/wp-content/uploads/2018/08/GPI_Roadmap_Web.pdf, page 28

[76] CRA International, "First Two Loops of SPP EHV Overlay Transmission Expansion: Analysis of Benefits and Costs," available at http://www.spp.org/documents/8272/analysis_of_benefits_two_loop_sppfinal.pdf

efficiency of high-voltage transmission. The remainder would stem from reduced congestion on the grid allowing customers to obtain access to cheaper power.

Synapse Energy Economics also analyzed the net benefits of a large transmission upgrade in the MISO footprint. This analysis found significant net savings for consumers from this transmission expansion, between $3 billion and $9.4 billion in net savings per year, or $63-200 in annual benefits per household in the region.[77]

ERCOT, the Texas grid operator, has also evaluated the transmission expansions that would be needed under a range of future scenarios.[78] Notably, it found that many transmission lines were needed across a range of the scenarios, a finding confirmed by more recent ERCOT analysis.[79]

There are many more transmission plan concepts that could have been included here; a lack of transmission plans is not the obstacle to achieving the benefits outlined in this chapter. As explained in Chapter 3, the primary obstacles are regulatory policies that prevent private developers from obtaining the permits and cost recovery necessary to build these transmission lines.

A common element across these plans is the use of high-voltage transmission lines to increase the power than can transmitted through a single line. As shown below, high voltage lines carry far more power than lower-voltage lines, and are far more cost-effective due to economies of scale.[80]

Transmission Voltage (kV)	Cost per Mile ($/mile)	Capacity (MW)	Cost per Unit of Capacity ($/MW-mile)
230	$2.077 million	500	$5,460
345	$2.539 million	967	$2,850
500	$4.328 million	2040	$1,450
765	$6.578 million	5000	$1,320

Figure 9: Economies of scale for high-voltage transmission

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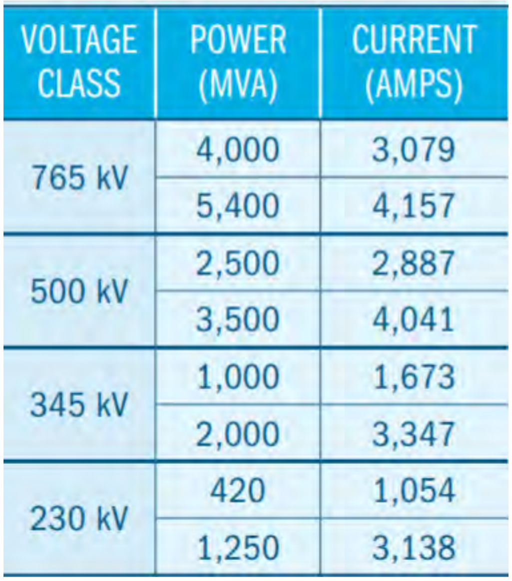
[77] http://www.synapse-energy.com/sites/default/files/SynapseReport.2012-08.EFC_.MISO-T-and-Wind.11-086.pdf

[78] http://www.ercot.com/content/committees/other/lts/keydocs/2013/DOE_LONG_TERM_STUDY_-_Draft_V_1_0.pdf

[79] http://www.ercot.com/content/wcm/lists/89476/2016_Long_Term_System_Assessment_for_the_ERCOT_Region.pdf

[80] http://image.sustainablemfr.com/a/sage-supplier-wind-power-transmission-provides-manufacturing-opportunities-cost-voltage-wind-powerjpg.jpg

As mentioned above, high-voltage lines also greatly reduce losses compared to lower-voltage lines, with 765-kV AC lines, the highest voltage in operation in the U.S., experiencing one-eighth to one-quarter the losses of more common 345-kV transmission lines per amount of power transferred.[81] This is possible because the power transfer capacity of a line is determined by the voltage times the current (or amperage), while losses generally increase in proportion to the square of the current. As shown in the following table created by PJM, increasing the voltage allows far more power to be transmitted at the same current, and thus a comparable amount of losses.[82] In the table, two numbers are shown for each voltage class to represent lower and upper bounds for power and current.



VOLTAGE CLASS	POWER (MVA)	CURRENT (AMPS)
765 kV	4,000	3,079
	5,400	4,157
500 kV	2,500	2,887
	3,500	4,041
345 kV	1,000	1,673
	2,000	3,347
230 kV	420	1,054
	1,250	3,138

Figure 10: Higher voltage increases power transfer while minimizing current, and thus losses

The vision of a high-capacity transmission network is being realized in other countries like China, India, and Europe. As shown below, China is building a network of extra-high-voltage AC and DC transmission lines.[83] The 800kV DC links have a capacity of around 8,000 MW, and China recently completed a 12,000 MW, 2,050 mile, 1,100 kV DC line, a world record for all three metrics.[84] For comparison, the DC Pacific Intertie that ties the U.S. Pacific Northwest to Southern California can carry up to 3,100 MW across an 846 mile 560kV line.

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[81] https://web.ecs.baylor.edu/faculty/grady/_13_EE392J_2_Spring11_AEP_Transmission_Facts.pdf, page 4

[82] https://pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.ashx?la=en, page 9

[83] https://www.windpowermonthly.com/article/1361466/analysis-china-adds-uhv-network-transfer-surplus-wind-energy

[84] https://spectrum.ieee.org/energywise/energy/the-smarter-grid/chinas-state-grid-corp-crushes-power-transmission-records

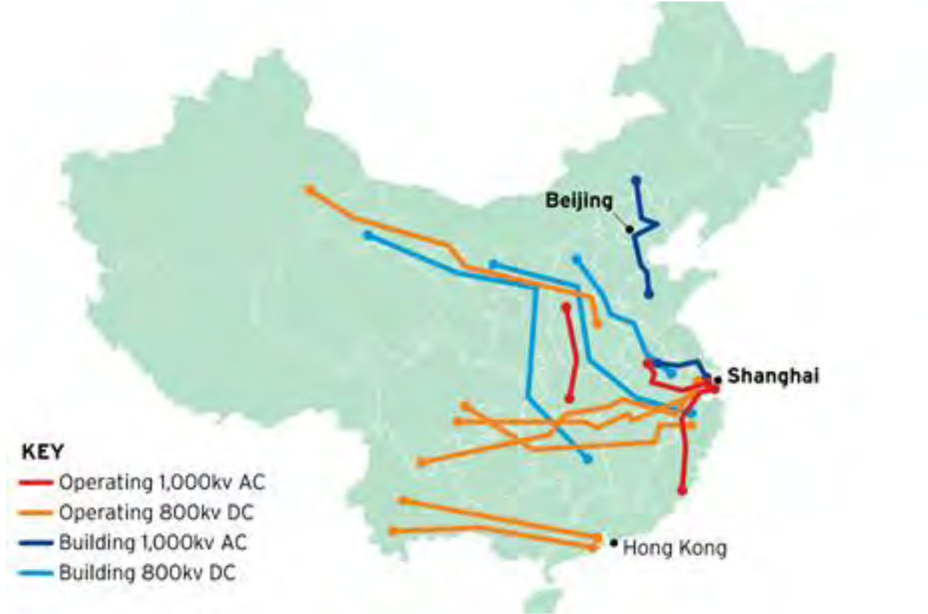

Figure 11: High-voltage transmission operating and under construction in China

Chapter II. Renewable and distributed resources make a large interconnected grid even more valuable

Some have argued that distributed energy resources like small-scale solar, distributed storage, microgrids, and demand response will obviate the need for transmission expansion. This is not an either/or choice. Distributed resources can play a valuable role in the future generation mix, and given the magnitude and urgency of the need to move to cleaner forms of energy, we should pursue both distributed and utility-scale resources. A large and strongly networked transmission system is essential regardless, and will become even more valuable as renewable and distributed resources become a larger part of the power system.

The following three insurmountable physical and economic principles dictate that large-scale generation and transmission will continue to play the largest role in powering America's future. Each of these principles strongly applies to all energy sources, but even more so to solar and wind. These principles are so strong that working against them will always be a costly uphill battle, as Edison learned in his local network's loss to Westinghouse's regional power network.

1. America's lowest-cost energy sources are distant from population centers

The fundamental value of electricity is that it allows energy to be transmitted efficiently from where it is most cost-effectively produced, saving dollars and energy relative to shipping the fuels or using lower-quality resources closer to demand. For all energy sources, both renewable and conventional, the best resources tend to be located far from where people live. Westinghouse built his first transmission line to deliver hydropower from Niagara Falls to New York City. Coal is expensive to transport, and sparsely-populated states like Wyoming produce the majority of the nation's coal.[85] It is cost-prohibitive to build almost any type of large power plant in an urban area due to land costs and siting concerns.

The cost of wind and solar energy varies even more drastically from region to region. This is mostly due to large differences in resource quality among regions, and to a lesser degree due to regional differences in the cost of land and other cost inputs associated with deploying renewable resources. Even within a region, the most cost-effective wind and solar resources are almost always located at a significant distance from electricity demand centers. As a result, transmission is essential for accessing cost-effective renewable resources, and the relatively small cost of transmission is outweighed by the greater savings realized by accessing lower-cost renewable resources. As mentioned in Chapter 1, generation costs make up around 60% of a typical consumer's monthly electric bill, five times greater than the 12% of the bill that goes to transmission costs.

The best wind resources are concentrated in the Interior region of the U.S., while the best solar resources are concentrated in the Southwest region. For both wind and solar, the low cost and high output of these resources results in a much lower levelized cost than is obtainable in other regions, as shown in the following chart from Wall Street investment firm Lazard.[86] Comprehensive DOE data confirms this is true for both wind[87] and solar[88] pricing, with wind projects in the Interior region able to sell power at about half the price of wind projects farther east or west, and Southwest solar prices coming in at a similar discount relative to other regions. Because the lowest-cost renewable resource regions tend to have lower electricity demand, transmission is critical for delivering this low-cost power to customers.

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[85] http://www.wsgs.wyo.gov/energy/coal-production-mining

[86] https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf

[87] https://emp.lbl.gov/projects/wind, page 59

[88] https://emp.lbl.gov/utility-scale-solar, page 33

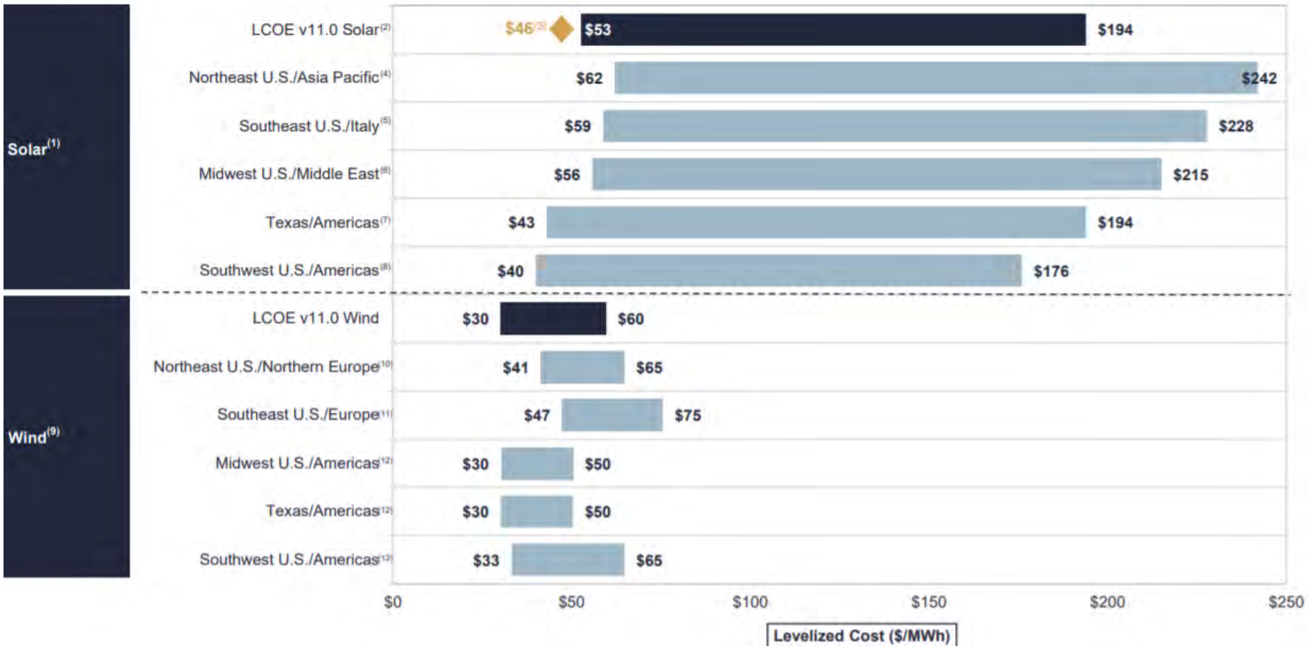

Figure 12: Lazard unsubsidized levelized cost of energy range for solar and wind, by region

This cost difference is primarily driven by insurmountable physical principles that dictate that high-resource wind and solar areas have far greater productivity than areas with lower-quality resources. Wind energy output is proportional to the cube of wind speed, while solar output is much higher in southern regions and desert climates with few clouds**.** In the following wind map from NREL, the darker purple areas in the interior of the country average 8-9 meter/second wind speeds, while the darker brown and orange areas that represent the best wind resources in most other regions average 6-7 meters/second.[89] While a difference of 2 meters/second may seem small, the purple areas are more than twice as productive as the brown and orange areas because the power of wind is proportional to the cube of wind speed. In the second NREL map showing solar resources, the orange areas in the desert southwest offer solar PV resources that are nearly twice as productive as those in the densely populated Northeast.[90]

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[89] https://windexchange.energy.gov/maps-data/319

[90] https://www.nrel.gov/gis/images/map_pv_us_annual10km_dec2008.jpg

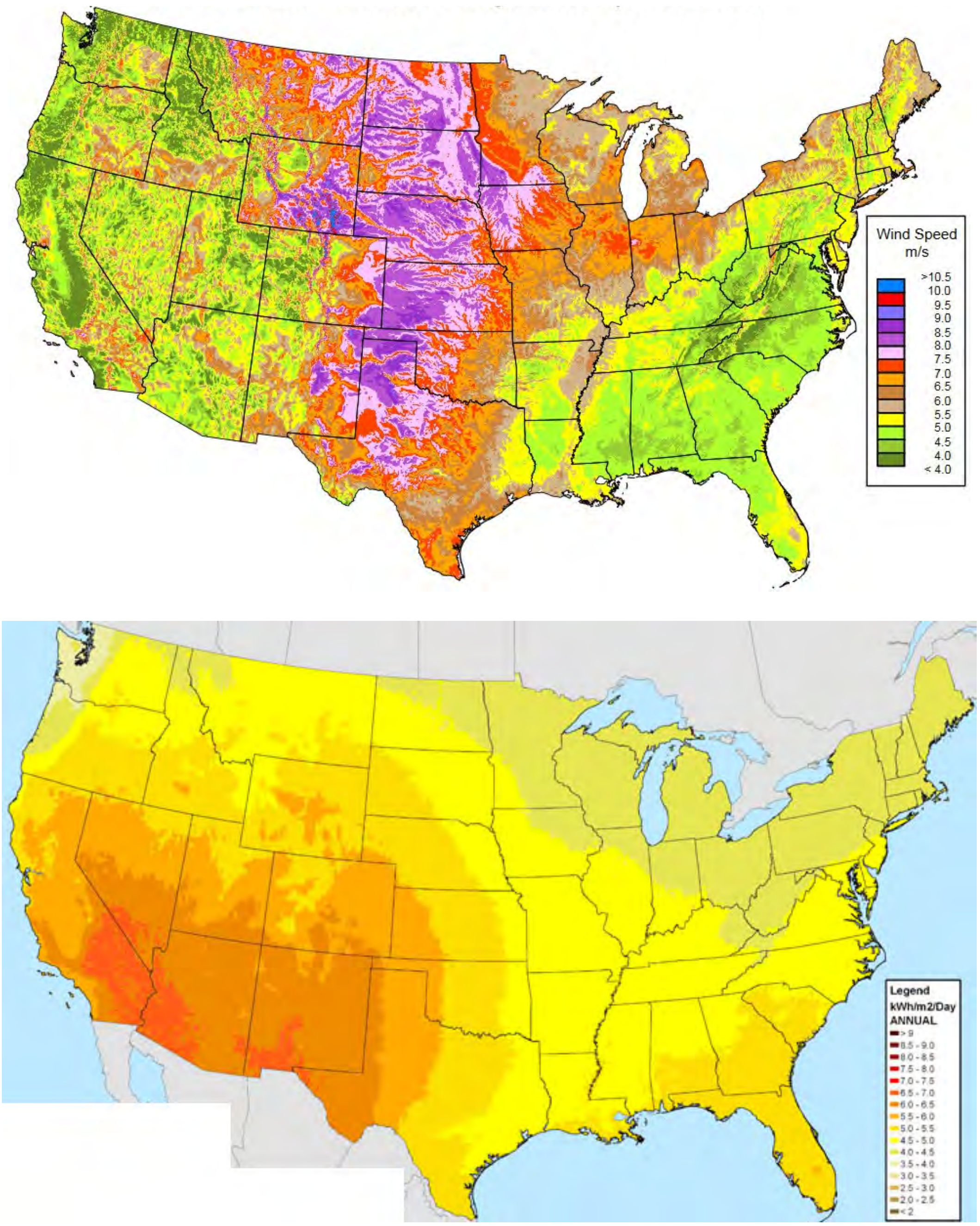

Figure 13: NREL wind and solar resource maps

The large impact on renewable energy output is confirmed by the following charts from Lawrence Berkeley National Laboratory (LBNL) showing wind[91] and solar[92] plant output by region (output is measured by capacity factor, which is actual output divided by the maximum potential output if the plant always ran at 100% output).

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[91] https://emp.lbl.gov/projects/wind, page 46

[92] https://emp.lbl.gov/utility-scale-solar, page 26

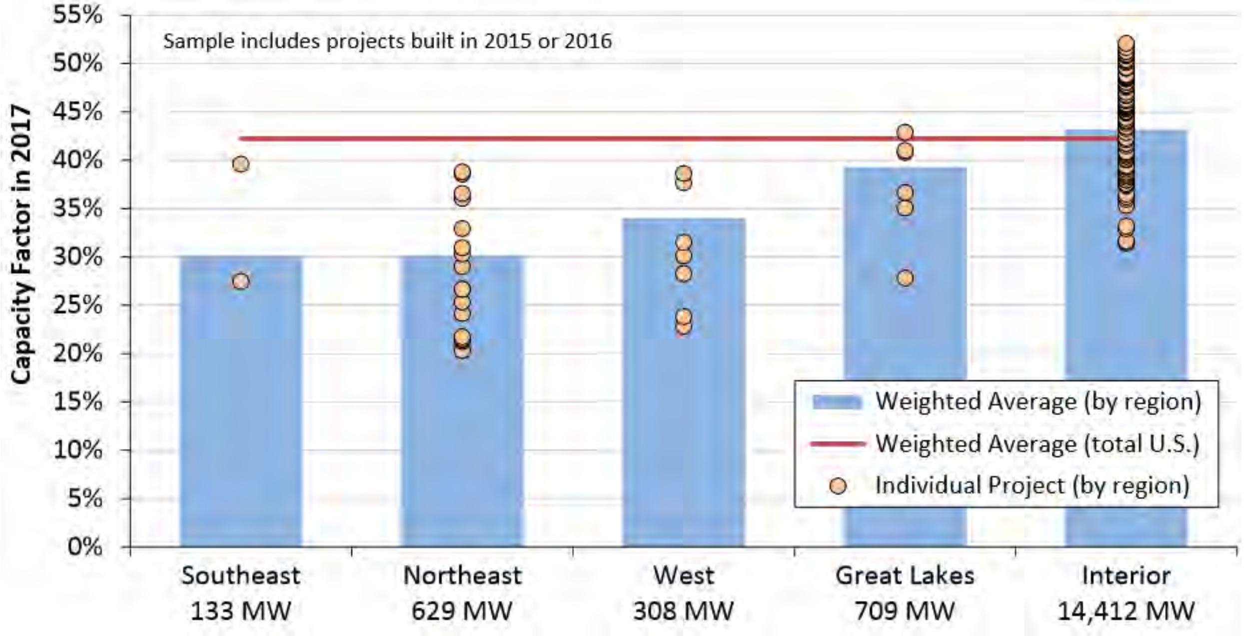

Figure 14: LBNL wind capacity factor by region

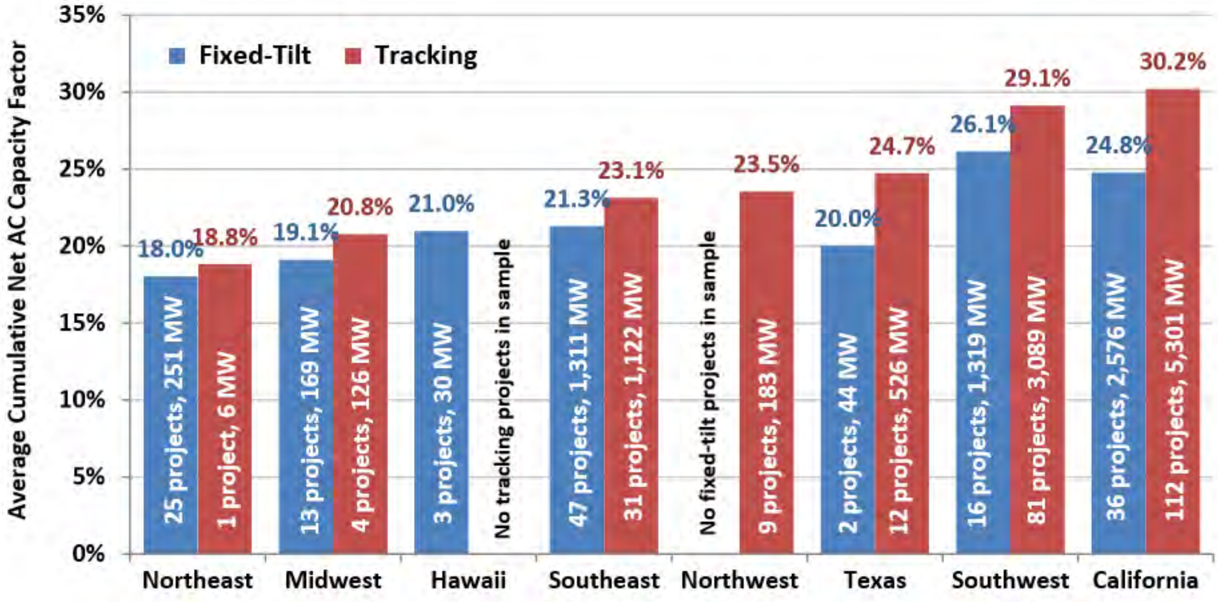

Figure 15: LBNL utility-scale solar capacity factor by region

While new technology can help make other regions viable for wind and solar development, renewable resources in those regions will always be more expensive than those in the best renewable resource areas. Technologies to boost the output of wind and solar resources in less productive areas, such as taller wind turbine towers, come at significant cost.[93] Land costs are also significantly lower in sparsely populated areas, which reduces the cost of wind and particularly solar energy by reducing the cost of land leases.[94]

Inter-regional transmission is particularly valuable for regions without abundant low-cost renewable resources. Transmission allows those regions to access renewable resources with significantly lower cost than those available in their region, and in sufficient quantities to meet their needs. As noted above, wind and solar prices in the Interior and Southwest regions are often half those available from resources in more densely populated regions. As those more densely populated areas seek to greatly expand their use of renewable energy, inter-regional transmission will be critical for keeping the cost acceptably low.

This does not mean that wind and solar plants should only be built in the very best resource areas. As discussed below, geographically diverse renewable resources provide less variable output, so accessing renewable resources from diverse regions will become even more important at very high levels of renewable use. Most regions have access to very good renewable resources within their region that can be economically utilized with intra-regional but not inter-regional transmission. Given the scale of America's transition to renewable resources, we need to build both. Investing in the transmission needed to access better renewable resources, both intra-regional and inter-regional, will save consumers tens of billions of dollars per year.

A lack of transmission is greatly constraining development of both wind and solar resources, as evidenced by interconnection queue backlogs. At the end of 2017, over 188 GW of proposed solar and 180 GW of proposed wind projects were waiting in queues to connect to the grid after having applied for interconnection. Solar's interconnection queue backlog is growing faster than wind's, with solar adding 99 GW of new projects in 2017 versus 81 GW of new wind projects.[95] Historically the vast majority of queue projects have failed to proceed to development, in many cases because of the costs and delays associated with interconnecting to the grid.

A large body of analysis has demonstrated that the savings from building transmission to access lower-cost renewable energy, along with the other benefits of transmission, more than pays for the transmission. Earlier this decade, a DOE-funded effort brought together a large group of stakeholders to plan transmission for the Eastern U.S. through the Eastern Interconnection Planning Collaborative (EIPC). This group developed transmission plans for several scenarios, including the plan shown below to

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[93] Wind projects in the Eastern U.S. have a 30-50% higher average installed cost than those in the Interior region, partially due to the use of 100+ meter towers versus 80 meter towers in the Interior region https://emp.lbl.gov/projects/wind, page 52

[94] Average land costs in some of the best wind and solar resource states are more than a factor of ten lower than more densely populated states, perhttps://www.nass.usda.gov/Publications/Todays_Reports/reports/land0818.pdf, page page 5

[95] https://emp.lbl.gov/projects/wind, page 9

utilize the best renewable resources in the Eastern U.S., as well as a smaller transmission investment to utilize more local renewable resources.[96]

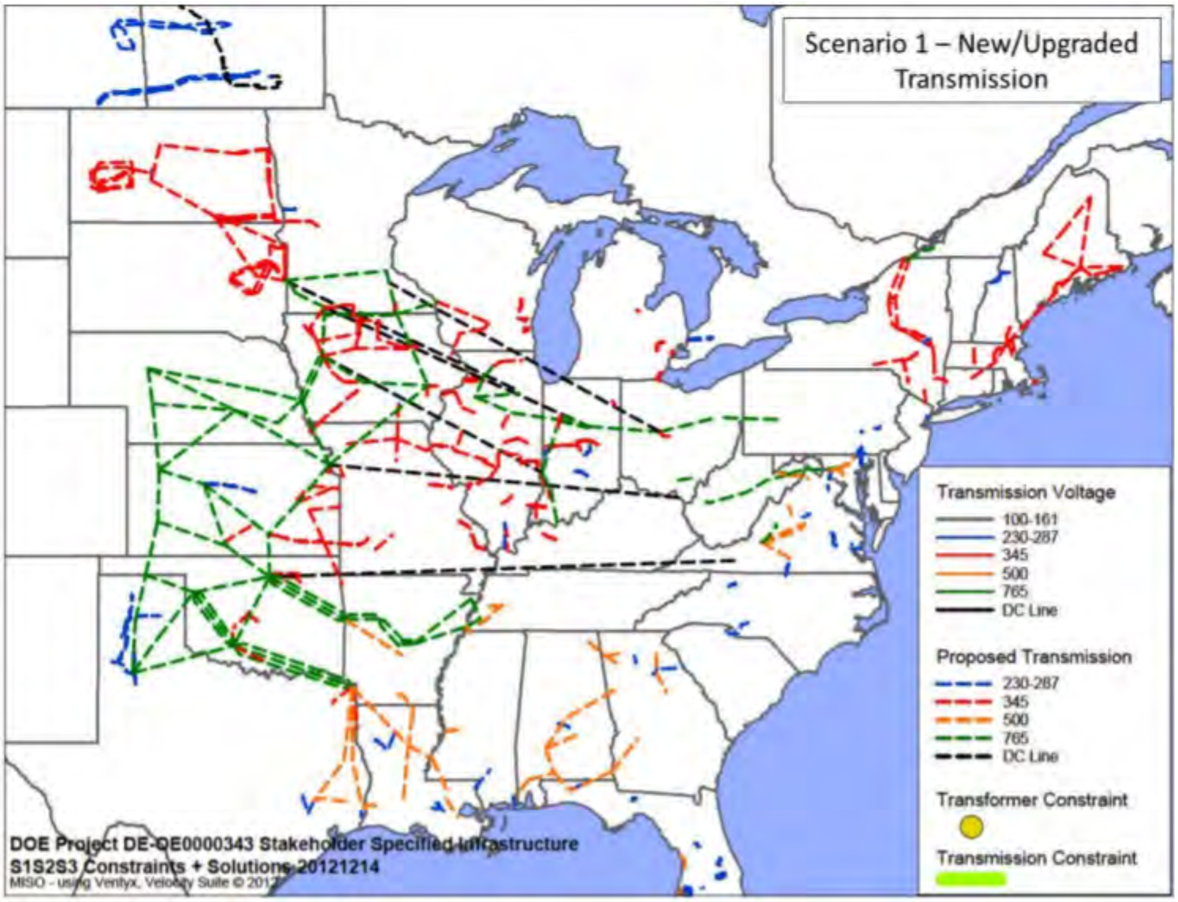

Figure 16: EIPC transmission plan for high renewable scenario

EIPC found a large transmission investment to access the best renewable resources in the Eastern U.S. produced significant consumer savings relative to the smaller investment to utilize local resources. Specifically, a $206 billion larger upfront investment yielded additional savings of over $41 billion per year, indicating that the investment would pay for itself in 5 years.[97] The magnitude of these savings, tens of billions of dollars annually for the Eastern U.S. alone, confirms the critical importance of inter-regional transmission to access the best renewable resources. As discussed in Chapter 1, these calculated savings, as in all transmission cost-benefit studies, should be viewed as conservative because the analysis was unable to quantify many of the benefits of transmission.

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[96] http://nebula.wsimg.com/c4e982819ff6b85ceffa0f6c124760f6?AccessKeyId=E28DFA42F06A3AC21303&disposition=0&alloworigin=1, page 10

[97] http://www.synapse-energy.com/sites/default/files/SynapseReport.2013-07.Sust-FERC.EIPC-Expanded-Analysis.13-047-Report.pdf, page 9

Analysis the Department of Energy conducted several years ago of the Clean Power Plan also illustrates the value of transmission for enabling cost savings. The scenario with national trading enabled more efficient use of all energy sources, including both emitting and non-emitting resources, achieving $1-2/MWh lower electricity costs relative a scenario in which each state was forced to rely on its own resources.[98]

NREL recently completed analysis confirming the critical role of transmission in cost-effectively achieving high renewable penetrations.[99] The analysis found that renewable resources can reliably and cost-effectively provide 70% of electricity in the Eastern U.S. under all scenarios, but that the cost would be higher if there were constraints on the flow of electricity. The study included two scenarios that constrained the flow of electricity, one in which 25% of electricity demand within a zone had to be met by local thermal or hydropower resources, while another imposed a $10/MWh cost for moving power between market regions. These scenarios increased the annual cost of operating the Eastern U.S. power system by $3.2 billion and $2 billion respectively, or cost increases of 7% and 4%.

The MISO and SPP analyses discussed in Chapter 1 also found significant net savings from building transmission to access the best renewable resources within those regions. SPP found the transmission investment would save $1.28 billion by enabling more optimal wind deployment, while MISO similarly found about $1.26-1.45 billion in net present value savings from utilizing more cost-effective wind resources.

2. Economies of scale in electricity generation and transmission

All forms of electricity generation experience significant economies of scale, which is a primary reason why Westinghouse's large power plants won against Edison's smaller, local power plants.[100] Large wind and solar deployments are also far more cost-effective than smaller projects. DOE/Lawrence Berkeley National Laboratory data conclusively show this to be the case for both wind[101] and solar,[102] as shown below. The solar chart only shows costs for non-residential distributed PV projects; the downward cost trend continues for utility-scale PV projects, with 20-50 MW projects averaging $2.05/W, and 50-100 MW projects averaging $1.92/W;[103] while the upward cost trend continues off the left side of the chart for smaller residential PV projects, reaching $4.5/W for residential installations under 2 kW.[104] For both wind and solar, small projects cost more than twice as much per Watt as large projects, although the size at which solar projects achieve economies of scale is smaller than for wind.

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[98] https://www.eia.gov/analysis/requests/powerplants/cleanplan/pdf/powerplant.pdf; for analysis of EIA's results, see page 10 at http://awea.files.cms-plus.com/AWEA%20report%20on%20EIA%20CPP%20analysis%20July%202015.pdf

[99] https://www.nrel.gov/docs/fy18osti/71465.pdf

[100] https://www.citylab.com/life/2017/03/how-the-war-of-currents-brought-power-to-cities/519402/

[101] https://emp.lbl.gov/projects/wind, page 51

[102] https://emp.lbl.gov/sites/default/files/tracking_the_sun_2018_edition_final_0.pdf, page 30

[103] https://emp.lbl.gov/utility-scale-solar, page 17

[104] https://emp.lbl.gov/sites/default/files/tracking_the_sun_2018_edition_final_0.pdf, page 30

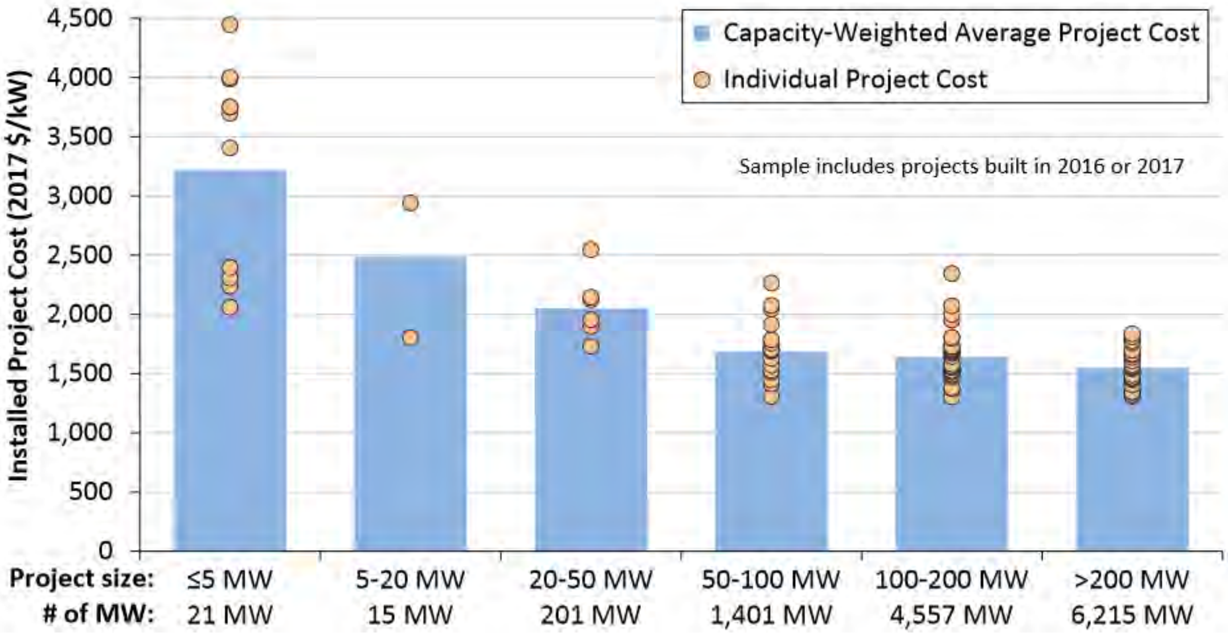

Figure 17: LBNL data showing wind installed cost by project size

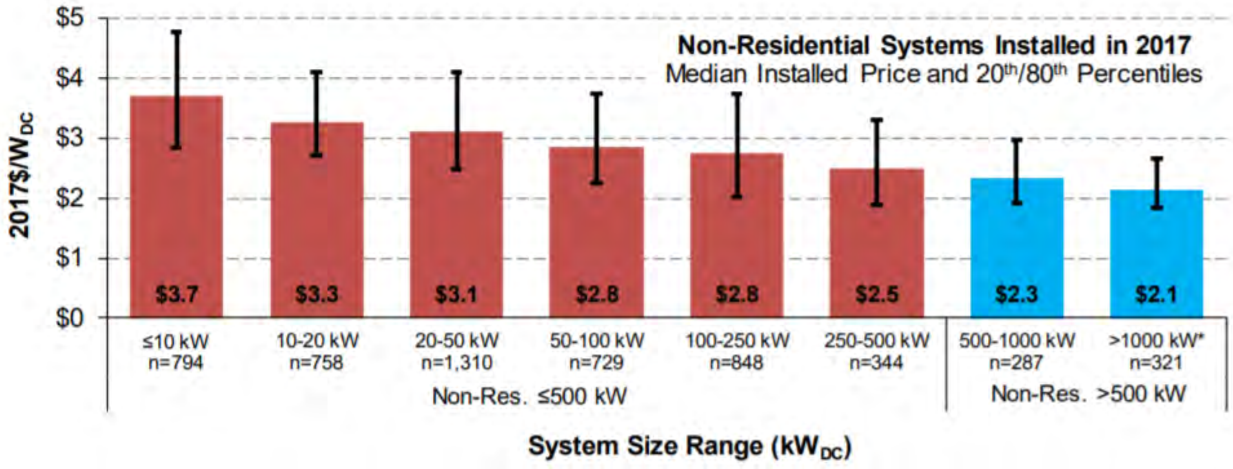

Figure 18: LBNL data on non-residential distributed PV cost by project size

The cost multiple for small PV installations relative to large-scale projects has actually increased over time, as shown below.[105] This is because installation, balance-of-system, and other "soft" costs have decreased more slowly than PV module costs.[106] Because there will always be some "fixed" costs to solar installation that increase less than proportionally with project size, large-scale solar will always be significantly cheaper than small-scale solar.[107]

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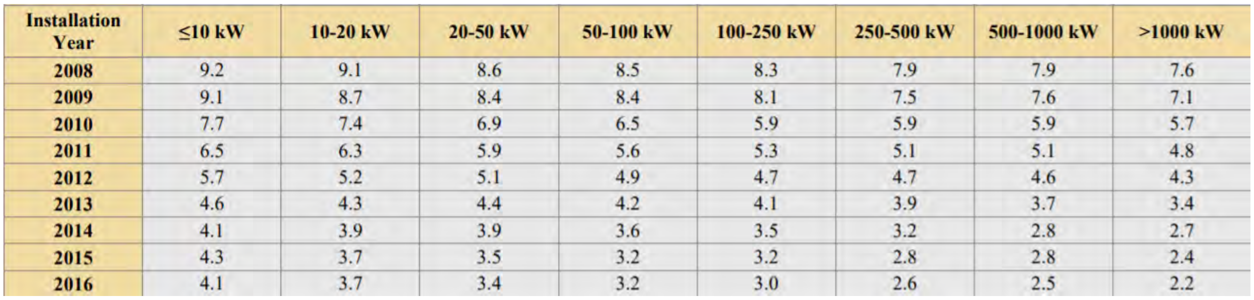
[105] http://eta-publications.lbl.gov/sites/default/files/tracking_the_sun_10_report.pdf, Appendix B

[106] *Ibid.*, page 15

[107] https://emp.lbl.gov/sites/all/files/lbnl-188167.pdf, https://emp.lbl.gov/sites/all/files/lbnl-1000917.pdf, https://emp.lbl.gov/sites/all/files/lbnl-188238_1.pdf,

Table 4: Non-residential distributed PV, $/W cost by year and size



Installation Year	≤10 kW	10-20 kW	20-50 kW	50-100 kW	100-250 kW	250-500 kW	500-1000 kW	>1000 kW
2008	9.2	9.1	8.6	8.5	8.3	7.9	7.9	7.6
2009	9.1	8.7	8.4	8.4	8.1	7.5	7.6	7.1
2010	7.7	7.4	6.9	6.5	5.9	5.9	5.9	5.7
2011	6.5	6.3	5.9	5.6	5.3	5.1	5.1	4.8
2012	5.7	5.2	5.1	4.9	4.7	4.7	4.6	4.3
2013	4.6	4.3	4.4	4.2	4.1	3.9	3.7	3.4
2014	4.1	3.9	3.9	3.6	3.5	3.2	2.8	2.7
2015	4.3	3.7	3.5	3.2	3.2	2.8	2.8	2.4
2016	4.1	3.7	3.4	3.2	3.0	2.6	2.5	2.2

Large-scale wind and MW-scale solar projects cannot typically be cost-effectively built in close proximity to electricity demand centers due to land costs and siting issues. While some distributed PV installations are economic because they help defer the need for local distribution system upgrades or provide other local benefits, those opportunities are typically quickly depleted as solar resources push the local system's peak net demand to later in the day when solar output is much lower.[108] Similarly, of the distribution system circuits where it was possible to cost-effectively deploy MW-scale distributed PV projects, many are already approaching saturation by PV deployment.[109] This is because areas that have abundant low-cost land are low density, and therefore tend to have less electricity demand and distribution infrastructure to accommodate PV deployment. As a result, transmission is essential if wind and all types of solar are to continue their growth.

It is also worth noting the magnitude of U.S. energy consumption, and why that necessitates using all renewable resources, both distributed and large-scale. Arguing that distributed resources alone are adequate and that new transmission is not needed reflects a fundamental misunderstanding of the magnitude of our energy use. Even the most aggressive scenarios for deployment of rooftop solar PV only meet a small share of current U.S. electricity consumption. For example, even with deployment of solar on every feasible rooftop in Washington DC, the district could only get 18% of its electricity from rooftop solar.[110] These constraints are compounded by other limiting factors such as many roofs being unsuitable for solar due to shading or layout, many renters being unable to invest in solar, etc. As a result, New York has confirmed that without transmission investment, the state will be unable to meet its clean energy goals. In a recent report, the grid operator concluded that "In order to achieve its objectives for renewable energy and carbon emissions, New York will need additional transmission capability to deliver renewable resources from upstate New York to consumers throughout the state."[111]

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http://brattle.com/system/publications/pdfs/000/005/188/original/Comparative_Generation_Costs_of_Utility-Scale_and_Residential-Scale_PV_in_Xcel_Energy_Colorado%27s_Service_Area.pdf?1436797265

[108] http://ei.haas.berkeley.edu/research/papers/wp260.pdf, page 2

[109] https://www.utilitydive.com/news/how-californias-utilities-are-mapping-their-grids-for-distributed-resource/436899/

[110] https://www.mapdwell.com/en/solar/dc/stats, https://www.eia.gov/electricity/state/DistrictofColumbia/

[111] https://www.nyiso.com/documents/20142/2223020/2019-Power-Trends-Report.pdf/0e8d65ee-820c-a718-452c-6c59b2d4818b, page 44

NREL recently calculated the economically optimal deployment of different renewable resources across different U.S. regions, the results of which are shown below.[112] The results strongly demonstrate several reasons why transmission is essential for realizing a renewable future: 1. The total technical potential for distributed PV (DPV) generation was less than 40% of current U.S. electricity demand, and the economic potential was about 7%,[113] with utility-scale wind and solar providing about 5 times more generation; and 2. Some regions mostly deploy wind while other regions mostly deploy solar, which makes transmission essential for the reasons discussed in the preceding section (delivering power to customers in other regions) and following section (power system balancing).

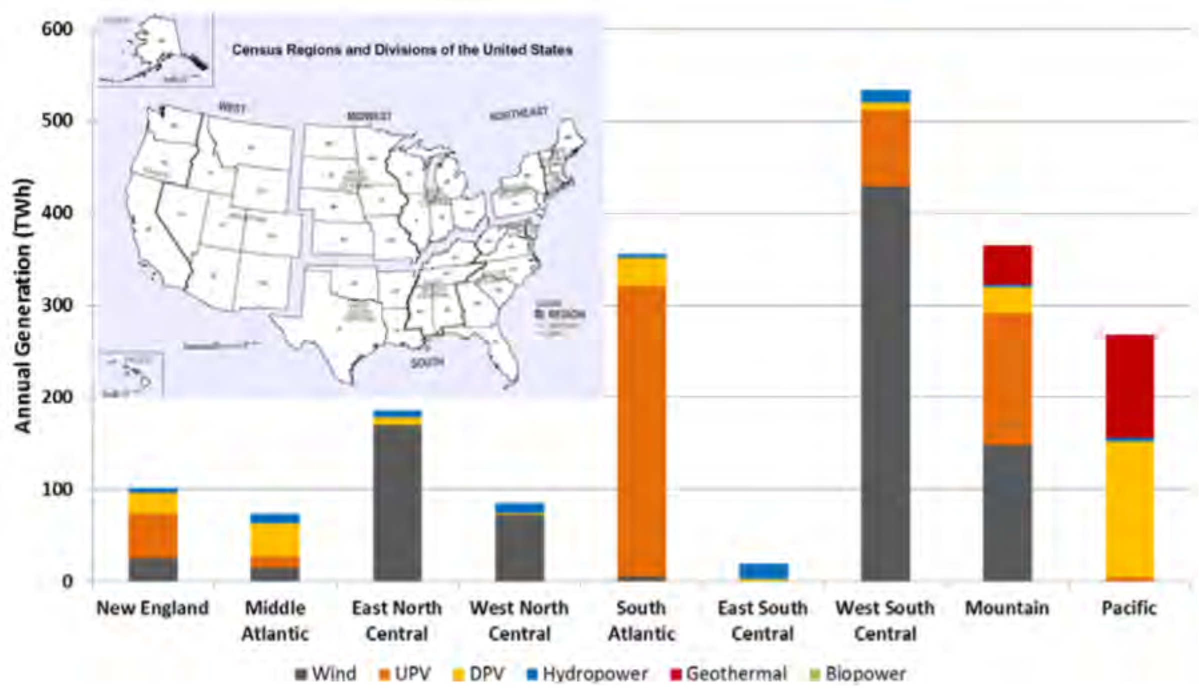

Figure 19: NREL modeling of economically optimal renewable deployment by region

Electricity demand will also increase as we electrify other sectors of the economy like transport, industrial processes, building and water heating, and even using electricity to produce synthetic fuels. Projections are that electricity demand will double by 2050 due to electrification, even with aggressive assumptions for energy efficiency deployment.[114] If renewables are to make a large contribution to meeting that growth, we will need both small- and large-scale renewable deployment, which requires

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[112] https://www.nrel.gov/docs/fy15osti/64503.pdf, page xix

[113] *Ibid.,* page xvi

[114] https://riskybusiness.org/site/assets/uploads/sites/5/2016/10/RiskyBusiness_FromRiskToReturn.pdf; https://unfccc.int/files/focus/long-term_strategies/application/pdf/mid_century_strategy_report-final_red.pdf; http://www.innovationreform.org/wp-content/uploads/2018/02/EIRP-Deep-Decarb-Lit-Review-Jenkins-Thernstrom-March-2017.pdf

transmission. As one of the 2050 studies concluded, “In each of our four pathways, a clean energy economy requires significant new investment in transmission and distribution.”[115]

Cost-effectively meeting that large need also argues for heavily using large-scale renewables. Large-scale renewables offer a much larger resource at lower cost than distributed renewables. For example, analysis of California 50% RPS compliance scenarios by consulting firm E3 found that scenarios using a diverse mix of renewable resources resulted in the lowest consumer electricity prices, followed by a heavy large-scale solar deployment case, followed by a scenario with small-scale solar deployment, followed by a rooftop solar case.[116]

Much like the logic and analysis that underpins the greenhouse gas abatement supply curve developed by McKinsey & Company,[117] it makes sense to keep the cost of electricity low by mostly using low-cost resources that can make large contributions rather than high-cost resources that can only make small contributions. At the scale of wind and solar deployment envisioned under most future energy mix scenarios, transmission to access large-scale resources will be critical for keeping the total cost low. Deploying wind and solar in high-quality resource areas in the Interior U.S. has other advantages as well. The Interior region’s electricity generation mix is several times more pollution-intensive than that along the coast, so renewables’ public health benefit is much higher there than along the coasts.[118]

There are also considerable economies of scale for other resources like energy storage, with large-scale installations coming in at one-third the cost of behind-the-meter installations,[119] making a strong transmission system critical for efficiently realizing storage’s value. Battery storage is relatively modular beyond a certain size, but the cost of the communications and control infrastructure is relatively fixed, making larger installations more cost effective. Battery storage deployment at ground-mounted solar deployments can also yield cost savings because the battery and the solar modules can share the same inverter, which is often not feasible for rooftop solar installations. Many of the larger energy storage technologies, like pumped hydropower and compressed air, can only be deployed as utility-scale resources and require direct transmission interconnection.

As noted in Chapter 1, there are also significant economies of scale for transmission, with the cost per-MW of higher-voltage, higher-capacity lines a fraction of that of lower-capacity lines. These factors strongly indicate large-scale renewables and high-capacity transmission must form the foundation of the clean energy revolution. As utility ComEd’s CEO recently explained, “network economies rule… The grid

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[115] https://riskybusiness.org/site/assets/uploads/sites/5/2016/10/RBP-FromRiskToReturn-WEB.pdf, page 53

[116] https://www.ethree.com/wp-content/uploads/2017/01/E3_Final_RPS_Report_2014_01_06_with_appendices.pdf, page 22

[117] https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability%20and%20Resource%20Productivity/Our%20Insights/Pathways%20to%20a%20low%20carbon%20economy/Pathways%20to%20a%20low%20carbon%20economy.ashx

[118] https://www.epa.gov/statelocalenergy/avoided-emission-factors-generated-avert

[119] https://www.lazard.com/perspective/levelized-cost-of-storage-2017/

can get you to clean and green faster, more affordably and more equitably than any other mechanism out there."[120]

3. Diversity benefits of a large, integrated power system

Even in the absence of renewable resources, large integrated power systems provide billions of dollars in benefits by aggregating diverse sources of electricity supply and demand.[121] As noted in the introduction, much of this benefit comes from the fact that different sources of electricity demand are weakly correlated, as are outages at sources of electricity supply, so larger aggregations require less expense for capacity and reserves than smaller aggregations. This fundamental principle of statistical aggregation was the primary driving factor behind the success of large AC power systems over small DC power systems more than a century ago, and is even more relevant today.

The benefits of aggregating become even larger as the penetration of variable renewable resources like wind and solar increases on the power system due to the geographic diversity in the output of these resources. As NREL and others have documented, the lowest-cost solution for power system flexibility is typically expanding the footprint of grid operating areas through operational changes and infrastructure additions, which reduces the variability in electricity supply and demand through aggregation and provides greater access to existing sources of flexibility.[122]

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[120] https://www.eenews.net/energywire/2015/07/23/stories/1060022279

[121] https://www.misoenergy.org/about/miso-value-proposition/; http://www.pjm.com/about-pjm/value-proposition.aspx

[122] https://www.nrel.gov/docs/fy16osti/64864.pdf, page 7, citing Cochran et al., 2014

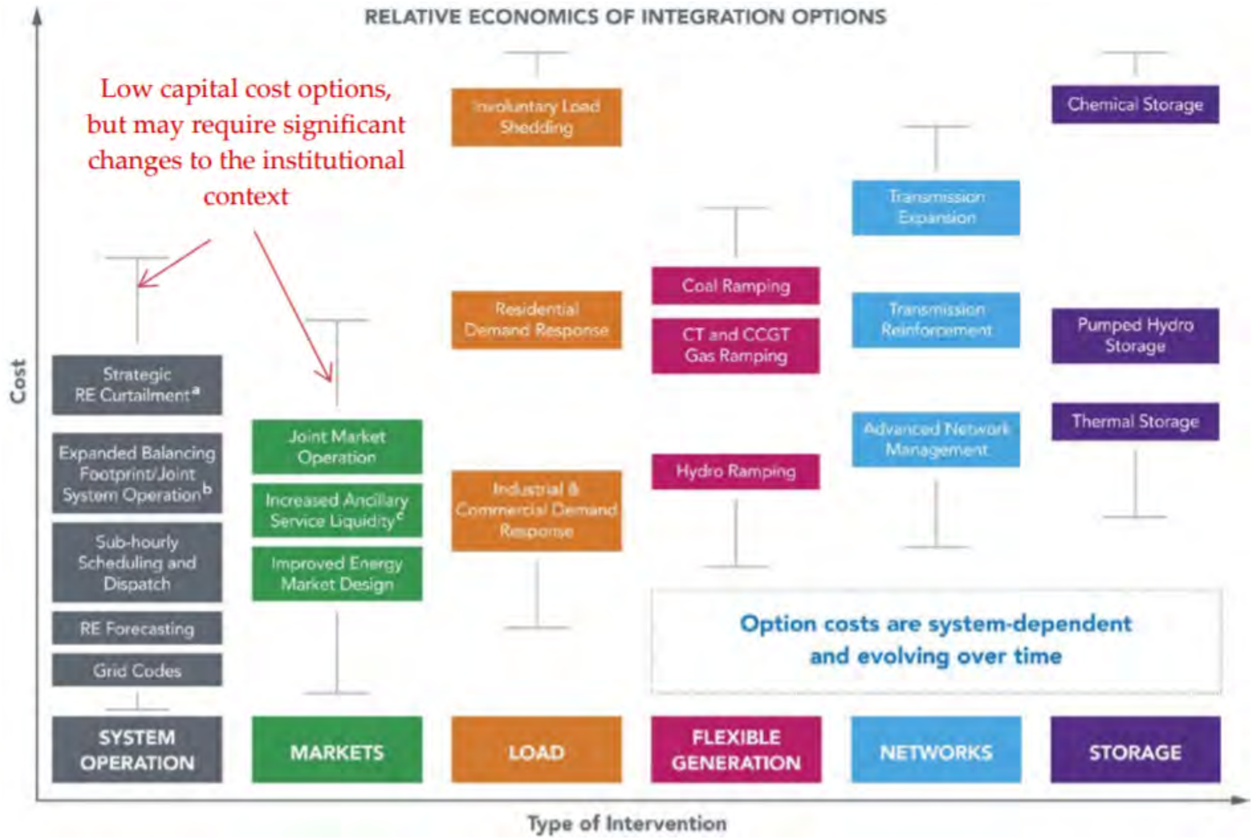

Figure 20: NREL supply curve of flexibility solutions

For example, the high-voltage Pacific Intertie transmission lines allow large power flows between the Pacific Northwest and California, making it possible for California generation to help meet the Northwest's peak demand during the winter and Pacific Northwest generators to help meet California's peak demand during the summer. Those lines also now allow California to export solar generation when output is high and import Pacific Northwest's hydropower and wind generation at other times.

As mentioned in Chapter 1, recent analysis published in the journal *Nature Climate Change* developed a transmission plan to cost-effectively expand wind and solar use to 38 percent and 17 percent of America's electricity use, respectively.[123] That article found that a major benefit of transmission is capturing the geographic diversity in wind and solar output due to the fact that "the average variability of weather decreases as size increases; if wind or solar power are not available in a small area, they are more likely to be available somewhere in a larger area." The study notes that "paradoxically, the variability of the weather can provide the answer to its perceived problems."

Even with a 14 percent increase in electricity consumption from current levels, the study found that demand can still be reliably met in all hours with the removal of all coal generating capacity and a

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[123] http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2921.html, https://www.utilitydive.com/news/study-deep-decarbonization-of-us-grid-possible-without-energy-storage/412721/

significant reduction in gas generating capacity from what we have today. This is possible because geographically diverse renewable resources provide more output that can be depended on to meet peak electricity demand.

The fundamental physical factors behind the geographic diversity in renewable output are well-documented and strong.[124] As shown below, NREL's analysis of high wind and solar levels in the Western U.S. showed that while wind and solar can significantly increase power system variability in a single grid operating area, if sufficient transmission capacity is built to allow the aggregation renewable output across the Western U.S., then power system variability actually decreases.[125]

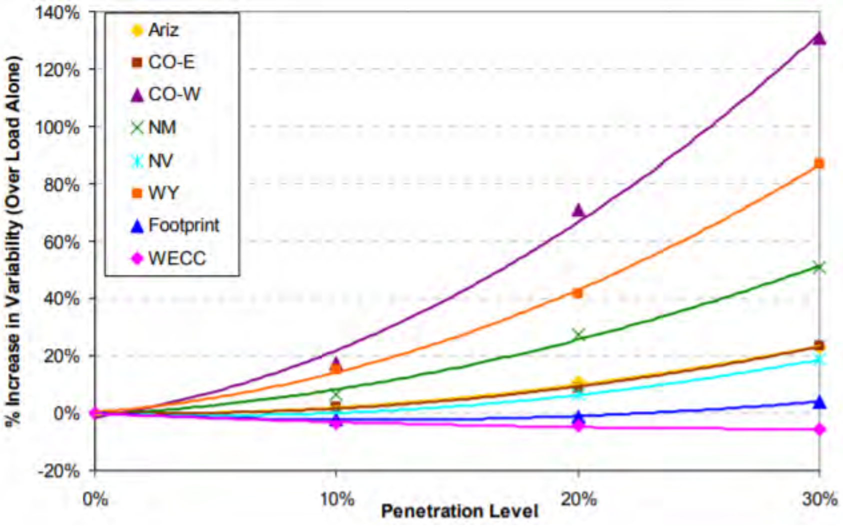

Figure 21: NREL shows geographic diversity in wind and solar output reduces system variability

There is not only geographic diversity in wind and solar output variability, but there is also geographic diversity in their output uncertainty. Over larger regions, wind and solar forecast error as a percentage of capacity is reduced, as shown below,[126] because a low forecast in one area is often offset by a high forecast in another area.

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[124] http://iopscience.iop.org/article/10.1088/1748-9326/10/4/044004

[125] https://www.nrel.gov/docs/fy10osti/47434.pdf, page 83

[126] https://community.ieawind.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=c7a0f97c-b01c-713b-b51a-46f33d62b5db&forceDialog=0, page 28

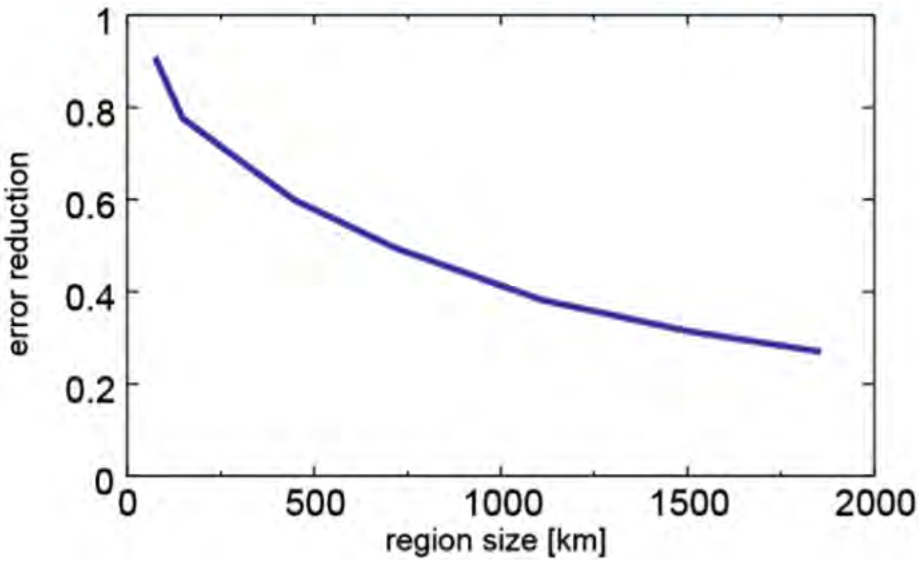

Figure 22: IEA: Wind forecast error as a share of wind capacity declines over larger regions

Wind and solar are also complementary resources on both an hourly and seasonal basis. As shown in the figures below, in most regions there is a strong negative correlation between wind and solar output. This complementarity is particularly valuable during unusual weather events, such as large atmospheric high-pressure systems that can suppress wind output across multiple regions but tend to coincide with clear conditions and therefore above average solar output.[127] However, that complementarity can only be realized through a large transmission system, given that most wind and solar resources are typically deployed in different regions.

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[127] https://www.vaisala.com/en/press-releases/2018-08/heatwave-hits-european-wind-energy-boosts-solar-production

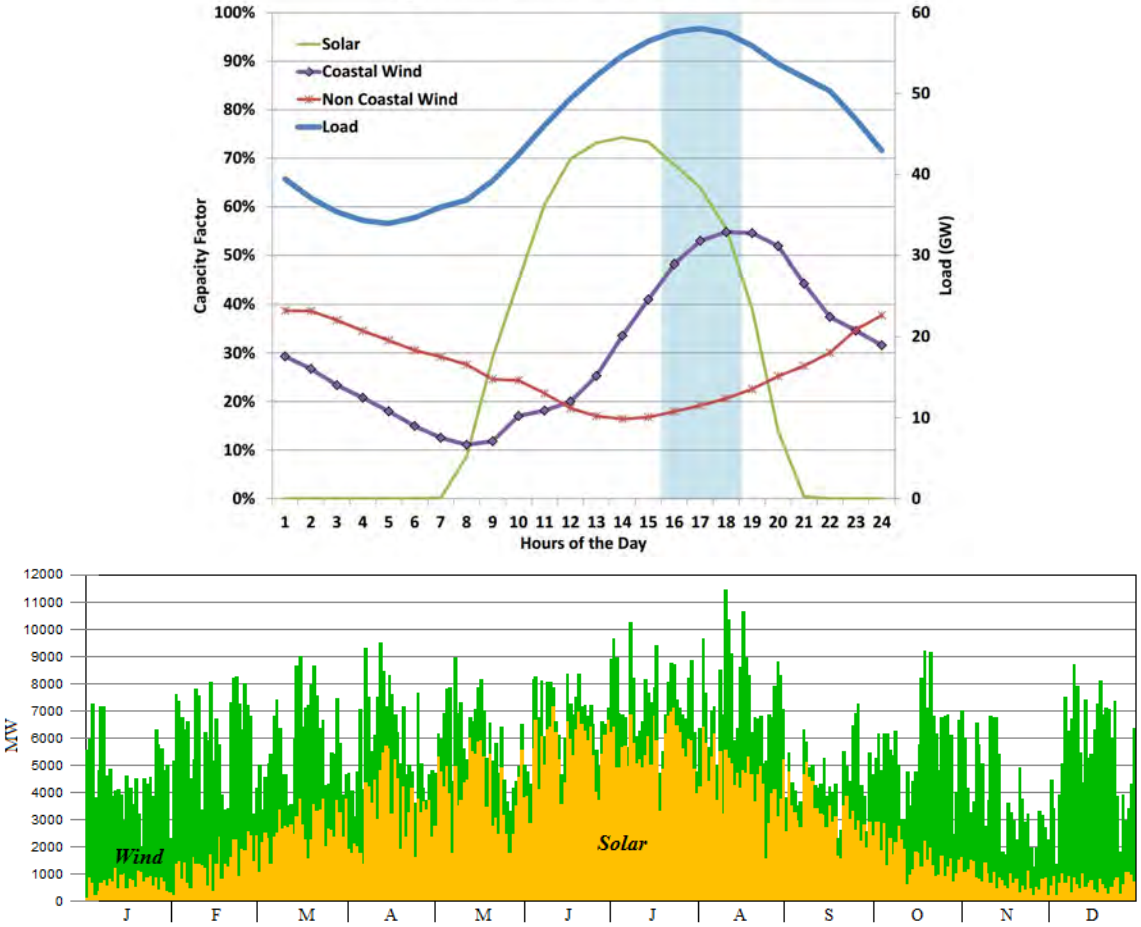

Figure 23: Complementary daily (top)[128] and seasonal (bottom)[129] output profiles for wind and solar

The big grid is valuable and essential for both wind and solar

Access to consumers is paramount for zero-marginal-cost, location-constrained, and variable-output resources like wind and solar. Production curtailment and low power prices caused by a lack of transmission capacity has already begun to affect wind and solar, though in different ways. NREL has documented two primary types of curtailment: localized and system-wide.[130] The following box conceptually explains how wind and solar are affected differently by the two different kinds of curtailment, and why.

Table 5: Differences in primary cause of curtailment for wind and solar

	Wind	Solar
Curtailment tends to be …	Localized	System-wide
Because the resource is more …	Location-constrained	Concentrated in specific hours

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[128] http://rameznaam.com/2015/04/28/solar-wind-more-than-the-sum-of-their-parts/
[129] http://euanmearns.com/hinkley-point-c-or-solar-which-is-cheaper/
[130] https://www.nrel.gov/docs/fy14osti/60983.pdf

As a general matter, wind curtailment tends to be more localized because wind is more location-constrained than solar, while solar curtailment tends to be more system-wide because solar output is more concentrated into a smaller number of hours. Of course, wind and solar are both location-constrained and variable, and both can be affected by localized constraints and system-wide constraints. For example, solar has faced localized curtailments in California, while wind has faced system-wide curtailments in SPP and ERCOT. System-wide curtailments are emerging as a bigger issue for both resources, with the number of system-wide low prices steadily increasing on power systems with high renewable penetrations like CAISO, SPP, and ERCOT.

Solar is heavily exposed to system-wide curtailment, particularly at higher penetrations. For example, analysis of a 50% RPS scenario in California found that solar would be curtailed at a three times higher marginal rate than wind, with 65% curtailment of the incremental solar generation added to grow from a 40% RPS to a 50% RPS, versus 22% for wind.[131] The following chart from the California grid operator's Independent Market Monitor report shows that negative prices have increased the most during daylight hours as solar has grown, with prices now going negative in more than 15% of late morning and midday hours.[132]

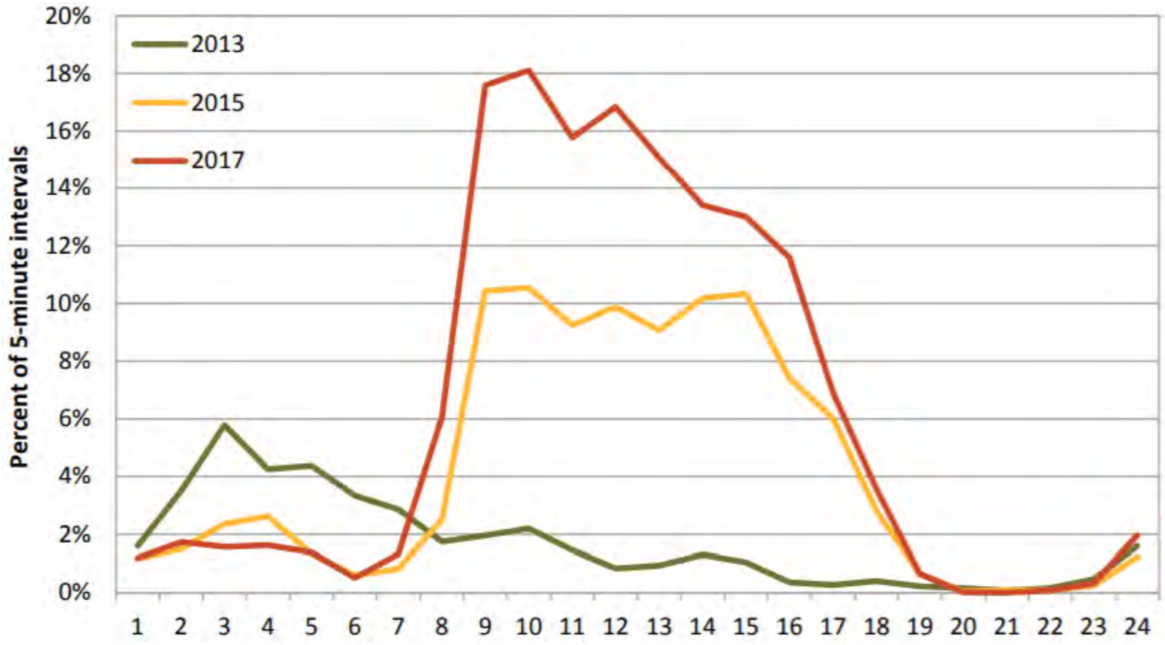

Figure 24: Time intervals with negative prices in CAISO, by hour of day

While distributed solar resources are often immune to localized curtailment, distributed resources are affected by the same system-wide drops in solar value as utility-scale resources.[133] If anything,

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[131] https://www.ethree.com/wp-content/uploads/2017/01/E3_Final_RPS_Report_2014_01_06_with_appendices.pdf, page 15

[132] http://www.caiso.com/Documents/2017AnnualReportonMarketIssuesandPerformance.pdf, page 86

[133] http://ei.haas.berkeley.edu/research/papers/wp260.pdf

distributed solar is likely to be even more strongly affected by this drop in value as its output is concentrated into fewer hours than utility-scale output. Most rooftop PV installations do not use trackers or a high inverter-loading ratio,[134] and because of trees and other obstructions they tend to have more shading during lower-output hours and seasons when the sun is lower in the sky, so their output is likely to be more concentrated into a few hours than utility-scale generation. While distributed solar generators may think transmission congestion and curtailment does not affect them, the resulting drop in solar value from system-wide constraints will abruptly set in as solar penetrations increase.

In California, the value of solar has already dropped by around half over the last few years alone due to constraints on solar exports from the state,[135] and that drop in value must eventually be reflected in the rates received by all existing and future solar owners, including net metering customers. As other regions expand their use of solar they will see a similar drop in value, with the drop occurring even more quickly in the small grid operating areas of the Western and Southeastern U.S.,[136] which happen to have some of the country's best solar resources.[137]

A lack of inter-regional transmission is the most important ceiling on the growth of solar

Solar is more acutely affected than wind by the challenge that its output is concentrated into a relatively small number of hours. As a result, increasing solar penetrations fairly rapidly result in generation oversupply in the midday hours, a drop in capacity value as solar pushes peak net load later into the evening by reducing net load during the day, a need for generation and capacity during the nighttime hours, and large generation ramps in between.[138] European analysis concluded that relative to wind, "Solar loses value quicker because solar power is concentrated in a few hours: 80% of all solar power is produced in 26% of all hours of the year, while 80% of all wind power in 47% of all hours."[139] In other papers, the same author found that the value of solar declines two to three times faster than that of wind with increasing penetrations.[140] Solar's drop accelerates at higher penetrations, decreasing by 50% or more at a 15% market share,[141] versus a drop of only 25% for wind penetrations of up to 40%.[142]

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[134] A high "inverter-loading ratio" refers to oversizing the DC solar modules relative to the AC inverter capacity, which is primarily done to save on inverter costs. This causes some "clipping" of generation when the DC output exceeds the inverter capacity during peak output hours, which results in somewhat less concentration of solar output into a small number of hours.

[135] https://emp.lbl.gov/utility-scale-solar, page 37

[136] For example, the drop in solar value occurred quickly on the relatively small Tampa Electric system https://www.ethree.com/wp-content/uploads/2018/10/Investigating-the-Economic-Value-of-Flexible-Solar-Power-Plant-Operation.pdf

[137] https://www.eia.gov/todayinenergy/detail.php?id=27152

[138] https://ecee.colorado.edu/~ecen5009/Resources/Photovoltaics/Denholm2016a.pdf

[139] https://www.neon-energie.de/Hirth-2015-Market-Value-Solar-Power-Photovoltaics-Cost-Competitive.pdf

[140] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2724826, https://www.strommarkttreffen.org/1.1-2016-09-30-Hirth-System-friendly_renewables_Strommarkttreffen.pdf

[141] http://hayek.diw.de/documents/dokumentenarchiv/17/diw_01.c.506693.de/hirth_belec.pdf

[142] https://www.neon-energie.de/Hirth-2013-Market-Value-Renewables-Solar-Wind-Power-Variability-Price.pdf, page 10

The following chart from Lawrence Berkeley National Laboratory highlights solar energy's rapid drop in energy and capacity value, as well as the faster increase in forecast error cost, from increasing solar penetration relative to wind.[143] As discussed below, inter-regional transmission helps preserve solar's energy and capacity value by taking advantage of time zone and seasonal diversity, while even intra-regional transmission provides enough geographic diversity to cancel out forecast error caused by clouds and other local weather.

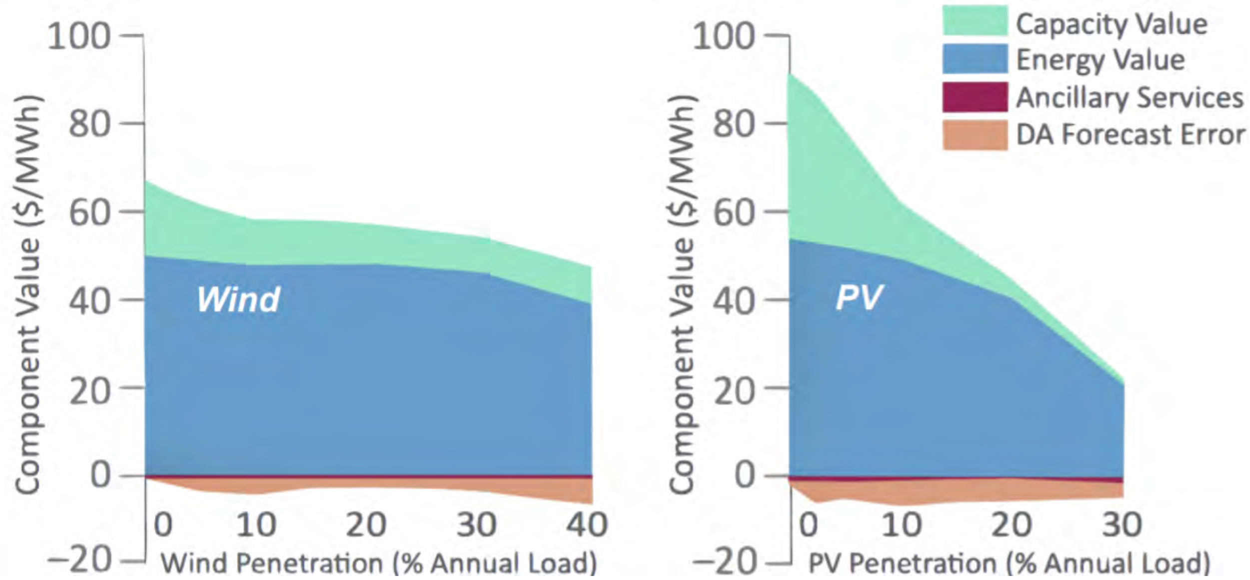

Figure 25: LBNL modeling of decline in wind and solar value with increasing penetration

A recent study by First Solar, Tampa Electric Company, and consulting firm E3 confirms that on Tampa Electric's power system, the value of solar drops rapidly at higher penetrations.[144] Specifically, without using solar to provide needed system flexibility, the marginal value of solar to the Tampa Electric power system approaches zero as solar penetrations exceed 20% of annual energy, with average curtailment exceeding 15% of total potential solar production. Even with solar providing flexibility, the marginal value of solar drops by nearly half at penetrations above 20% of annual energy, confirming that expanding transmission ties to export and import power and achieve greater geographic diversity must play a key role in achieving high solar penetrations.

As noted above, the value of solar PV energy in California has already dropped by around half,[145] and will continue to fall as more distributed and utility-scale solar is added.[146] New LBNL analysis shows that across the country, solar tends to reduce prices more quickly than wind, and that solar's impact grows

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[143] https://www.nrel.gov/docs/fy17osti/67467.pdf, page 12, cited to Wiser and Mills 2012

[144] https://www.ethree.com/wp-content/uploads/2018/10/Investigating-the-Economic-Value-of-Flexible-Solar-Power-Plant-Operation.pdf

[145] https://emp.lbl.gov/utility-scale-solar, page 37

[146] https://www.greentechmedia.com/articles/read/what-happens-when-renewables-eat-their-own-profits#gs.x0B1l9I

even larger at higher renewable penetrations.[147] Analysis has shown that technological and deployment innovations to expand the output of solar PV across more hours, such as the use of trackers, west-facing installations, and higher inverter loading ratios, have a minimal impact on the drop in the value of solar, as shown below.[148] In contrast, the decline in wind energy value can be greatly mitigated by the use of longer turbine blades, taller towers, and other technologies, even at relatively high penetrations.

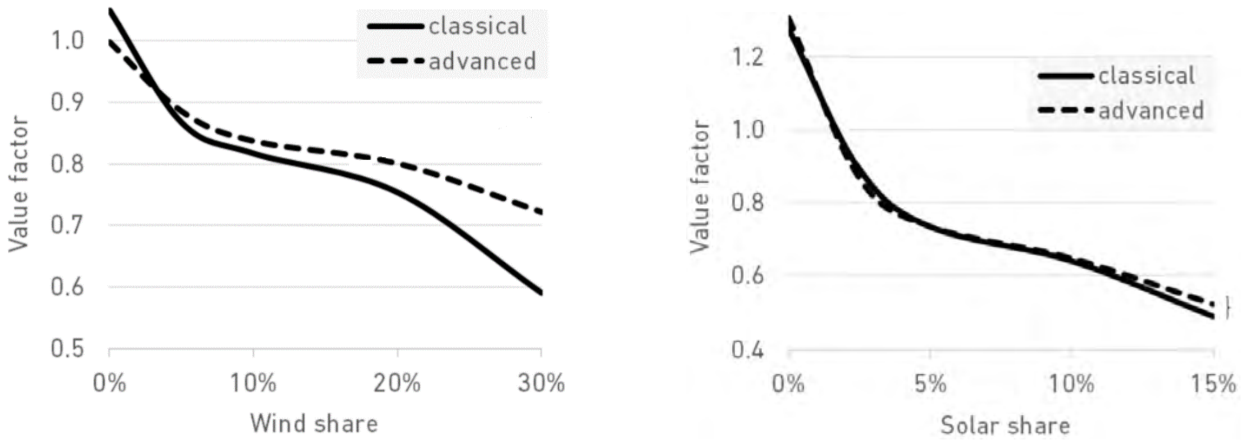

Figure 26: Technological mitigation of drop in wind and solar value at increasing penetrations
(note different x- and y-axes; the wind chart goes to 30% penetration, versus 15% in the solar chart)

Inter-regional transmission helps address solar's challenges in several ways. First, it allows exporting solar to neighboring balancing areas that have lower penetrations. Second, it provides weather diversity. For solar, weather-related variability and uncertainty can be significant, particularly if the balancing area's solar output comes from a small number of plants that can be simultaneously affected by clouds. Cloud-related solar variability is much faster than fluctuations in wind output. While still far slower and less costly than the instantaneous failures of large conventional power plants, large swings in output over a matter of minutes can be challenging. Fortunately, hundreds or even dozens of miles of geographic separation between solar plants is typically enough to cancel out the impact of clouds and local weather.

However, small-scale geographic separation offers almost no diversity in the fundamental output profile caused by the sun's daily track across the sky. Within hundreds of miles one can typically find wind resources that have a low or even negative correlation in output profile, such as mountain passes or coastal areas that have their highest output on hot summer afternoons due to the sea-breeze effect. However, for solar one must go thousands of miles away to find solar resources that have a significantly different output profile.

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[147] http://eta-publications.lbl.gov/sites/default/files/report_pdf_0.pdf, pages 23-24
[148] http://hayek.diw.de/documents/dokumentenarchiv/17/diw_01.c.506693.de/hirth_belec.pdf

A large-scale inter-regional transmission network can do that, greatly benefiting solar by spreading solar output over a larger number of hours and reducing midday overgeneration. A large transmission network provides time zone diversity and seasonal north-south diversity, which are particularly beneficial for solar output diversity but also electricity demand diversity.

Some of this benefit results from time zone diversity as the sun moves east to west across the U.S. With a national transmission network, the sun ramping to peak output during late morning on the East Coast could help meet the morning demand ramp up on the West Coast, while mid-afternoon West Coast sun could help meet East Coast population centers' evening peak demand after the sun has already set there. Such benefits can even be realized within the existing Interconnections. For example, animations from NREL's recent modeling of the Eastern U.S. show how solar resources along the East Coast help complement those in the Plains states and smooth out the solar output profile.[149]

An additional under-appreciated benefit is seasonal north-south diversity in solar resources. While any Northern snowbird who winters in Florida can tell you that southern areas receive more sun in the winter, it is also true that during the summer northern parts of the U.S. have nearly two more hours of daylight than southern areas, with the sun rising over an hour earlier and setting over an hour later. Using north-south and east-west diversity to expand the solar output profile by several hours, particularly into the peak demand evening hours, is critical for preserving the value of solar at higher penetrations.

How congestion harms the economics of renewables

Just as transmission congestion harms consumers by denying them access to low-cost energy sources, congestion harms cost-effective renewable development by reducing the value of renewable energy produced in constrained parts of the grid. Extreme congestion causes wind or solar energy production to be reduced, called curtailment. Transmission benefits consumers and facilitates renewable development by reducing the curtailment of renewable generation, providing them with greater access to low-cost wind and solar energy. As MISO and the Texas grid operator (ERCOT) have added transmission, they have seen a large decline in the curtailment of wind generation (blue bars) even though wind continues to be added (green dots).[150]

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[149] https://www.nrel.gov/grid/ergis.html

[150] https://emp.lbl.gov/wind-technologies-market-report, page 40

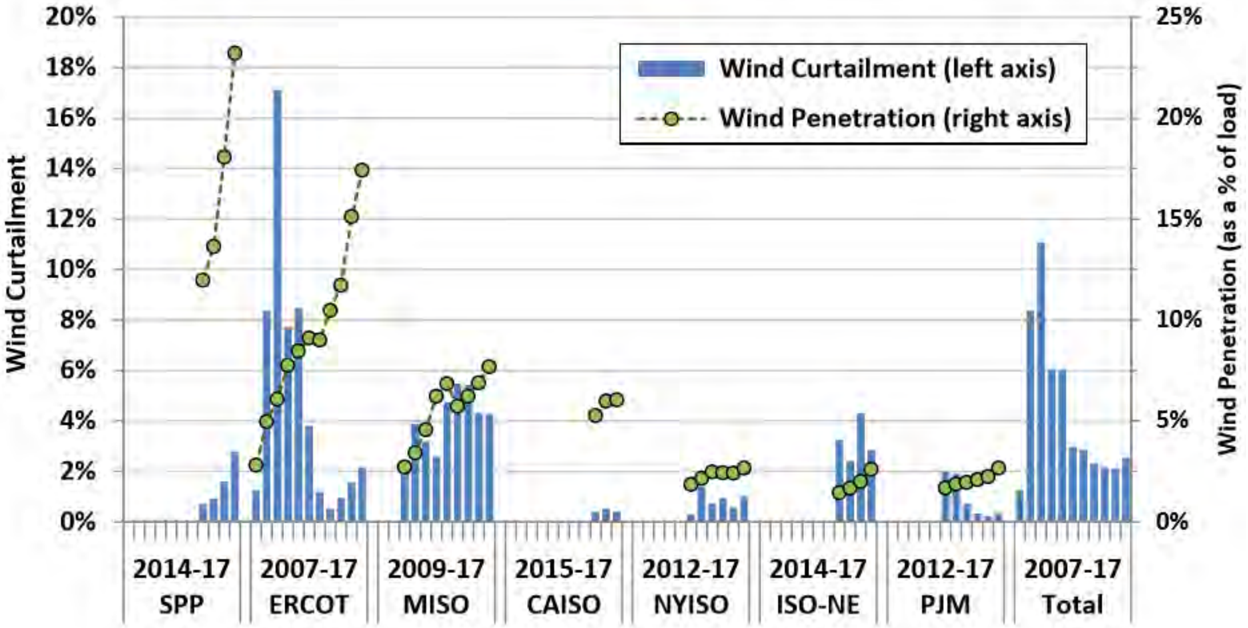

Figure 27: Wind curtailment by grid operator

Curtailment data alone understates the impact of congestion on consumers, as well as renewable plant revenue and profit. This is because in electricity markets, all resources and consumers participating in the market receive the market clearing price set by the marginal cost of producing electricity at the most expensive power plant that was needed to meet electricity demand. Many studies only focus on the cost of the generation lost to curtailment, which is a fraction of the total cost to consumers and renewable plant owners because congestion affects the price of all electricity purchased and sold in the wholesale market, not just the generation that is curtailed.

Transmission congestion results in lower electricity market prices (known as Locational Marginal Prices or LMPs) on the renewable plant side of a transmission constraint and higher prices on the customer side of the constraint. The higher LMP on the consumer side reflects the higher marginal cost of the energy source closer to load that must be used to replace the low-cost generation that could not be delivered due to the congestion. The LMP on the renewable plant side often drops to zero or below because the wind plant becomes the marginal generator in the congested area, reflecting the zero-fuel cost of renewable generation. Importantly, the local LMP clearing price applies to all megawatt-hours (MWh) sold into and procured from the market in those areas, not just the smaller quantity of MWh that are being curtailed. As a result, the cost of this congestion for consumers and renewable producers can be much higher than just the cost of generation lost to curtailment.

To illustrate the outsized impact of congestion on renewable plants, assume a power system that has the transmission capacity to deliver 5,000 MW of output from a renewable resource area experiences 5,100 MW of renewable output in that area. Even though only 100 MW or roughly 2% of output is curtailed, all 5,000 MW of renewable output receives zero profit. This occurs because the market clearing price in that area drops to the marginal cost of producing renewable energy, which is $0/MWh due to the lack of fuel cost. This outsized effect on marginal pricing relative to average curtailment can be seen in the California solar value data discussed earlier. While only around 1% of solar generation was curtailed in 2017 and the first half of 2018, the electricity market value for solar generation had dropped by around half.[151]

The E3 study of California similarly found that in a 50% RPS scenario with 8.9% total curtailment, overgeneration would drive prices to zero or below in 23% of hours.[152] The impact on renewable economics is even larger if one weights those hours based on renewable production, because most overgeneration occurs during the highest renewable output hours; even limiting the analysis to daylight hours when PV is producing, given that PV is driving most overgeneration hours in this scenario, would indicate that prices would likely be near-zero in nearly half of daylight hours. This rapid drop in pricing occurs with both localized congestion and system-wide congestion.

When transmission congestion reduces LMPs in a renewable generating area, or there is risk of that occurring over a prospective renewable project's life, that significantly reduces the value of wind to customers and makes them less willing to sign Power Purchase Agreements (PPAs) at pricing and other terms that are acceptable to the renewable developers. This inhibits renewable development as long-term PPAs with customers, either utilities or corporations that use large amounts of electricity, are typically essential for obtaining the investment necessary to finance a renewable project.

When congestion is so extreme that it results in renewable curtailment, there is an additional economic cost to renewable plant owners, output purchasers, consumers, and the environment from "throwing away" zero-fuel-cost, zero-emission energy that would have been used by consumers if sufficient transmission capacity were available. Generation lost to curtailment forces the renewable plant owner to amortize its fixed costs across fewer MWh, which increases the price per MWh that the renewable plant owner can offer to utilities and other purchasers, a cost increase that is directly passed on to consumers.

While historically a large share of curtailment risk was borne by utilities purchasing wind energy, wind power purchase agreements (PPAs) increasingly require wind project owners to shoulder a significant share of wind energy curtailment risk. The cost of this lost revenue, as well as the risk of experiencing this cost, significantly deters wind energy development and reduces the willingness of lenders or investors to finance wind energy development in constrained areas. As most PPAs pass some curtailment cost and risk to the purchaser, and the value of wind generation is reduced utilities are also hesitant to sign PPAs for wind projects that they expect will face significant congestion or curtailment.

Without adequate transmission, renewable curtailment will continue to increase and reach levels that prevent new development. Recent analysis in MISO found that without additional transmission expansion, expected renewable deployment by the year 2031 will result in more than 18 million MWh of

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[151] https://emp.lbl.gov/utility-scale-solar, page 37

[152] https://www.ethree.com/wp-content/uploads/2017/01/E3_Final_RPS_Report_2014_01_06_with_appendices.pdf, page 18

renewable curtailment in Minnesota, North Dakota, South Dakota, and Iowa alone.[153] For reference, that is nearly half the roughly 45 million MWh of wind generation those states produced in 2017.

Finally, transmission congestion, curtailment, and interconnection upgrade costs tend to force wind energy development into lower quality wind energy resource areas with lower wind capacity factors. Most directly, wind projects with lower output have smaller environmental benefits, and reduce electricity production costs and wholesale market LMPs less than more productive projects. That higher PPA price is directly passed on to the utility's customers, and also impedes renewable development by making it less attractive relative to other options.

Congestion and curtailment risk is particularly harmful to the business certainty needed to develop capital-intensive renewable projects because it is often caused by the actions of others, occurs abruptly when the threshold of available transmission capacity has been exceeded, and typically cannot be fully hedged. To describe how adding a new renewable project can cause congestion that ruins the market for all existing projects in an area, some in the renewable industry have used the analogy of a boat sinking because one last person jumped in and overloaded it, equally harming all of those who had boarded the boat when it was not overloaded. As shown in the examples above, exceeding the capacity of a transmission line by only a small amount abruptly crosses a threshold that depresses power prices and profits for all to zero.

The impact on renewable economics can be dramatic. As shown below, a lack of transmission capacity out of renewable-heavy western SPP has pushed the annual average market price as low as $12/MWh across a large area, half the SPP-wide average of $23/MWh,[154] even though less than 3% of wind generation was curtailed in SPP in 2017.[155] Consumers in central Oklahoma who are paying as much as $42/MWh for electricity generation would also benefit from greater access to the low-cost wind resources just a short distance to the west. While to date this congestion has primarily affected wind generation, it is now also affecting the prospects for solar deployment in western SPP, which offers the best solar resource in the Eastern Interconnect. As solar grows, this more localized type of transmission congestion is likely to also significantly affect the economics of both distributed and utility-scale solar.

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[153] https://www.huntleywilmarth.com/staticfiles/microsites/hw/HW-Certificate-of-Need-Application.pdf, page 95
[154] https://www.spp.org/documents/57928/spp_mmu_asom_2017.pdf, page 134
[155] https://emp.lbl.gov/sites/default/files/2017_wind_technologies_market_report.pdf, page 40

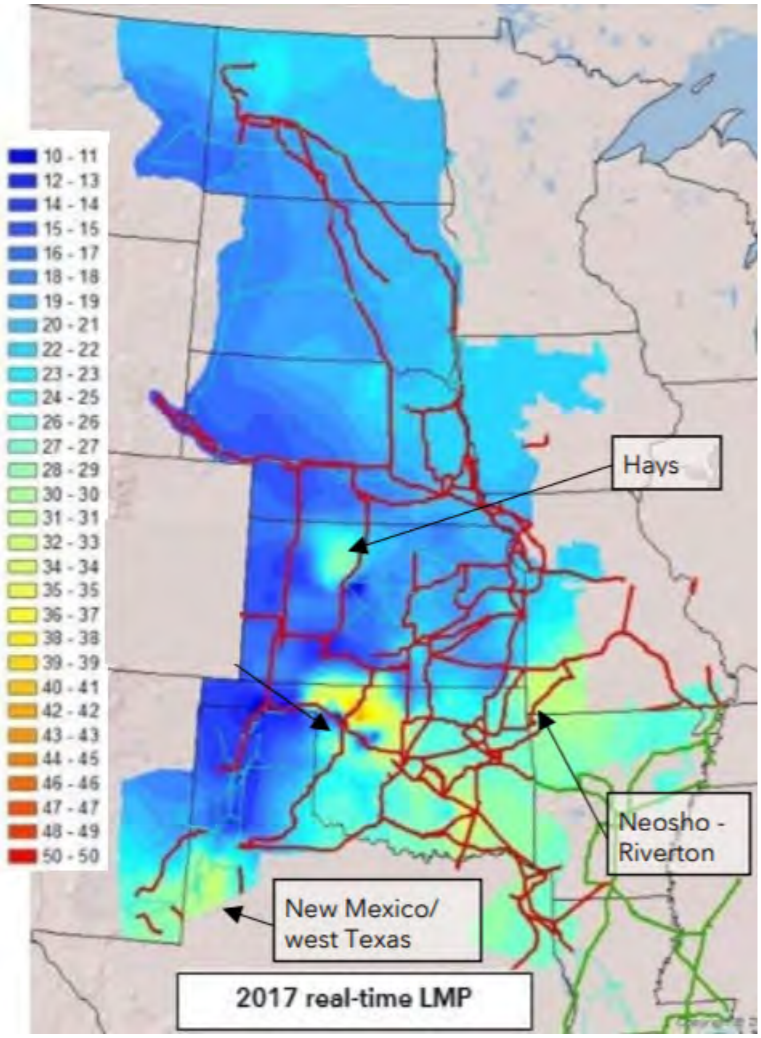

Figure 28: SPP Market Monitor map showing low prices in renewable-heavy western SPP

The following LBNL chart showing the vastly different wholesale energy market value of wind generation across different regions in 2017[156] illustrates the value of both intra-regional and inter-regional transmission for consumers and renewable generators. First, inter-regional transmission provides consumers in high-priced areas with access to low-cost electricity and abundant renewable resources in other regions. Second, intra-regional transmission helps alleviate the localized congestion that has reduced the value of wind generation in regions like ERCOT and SPP.

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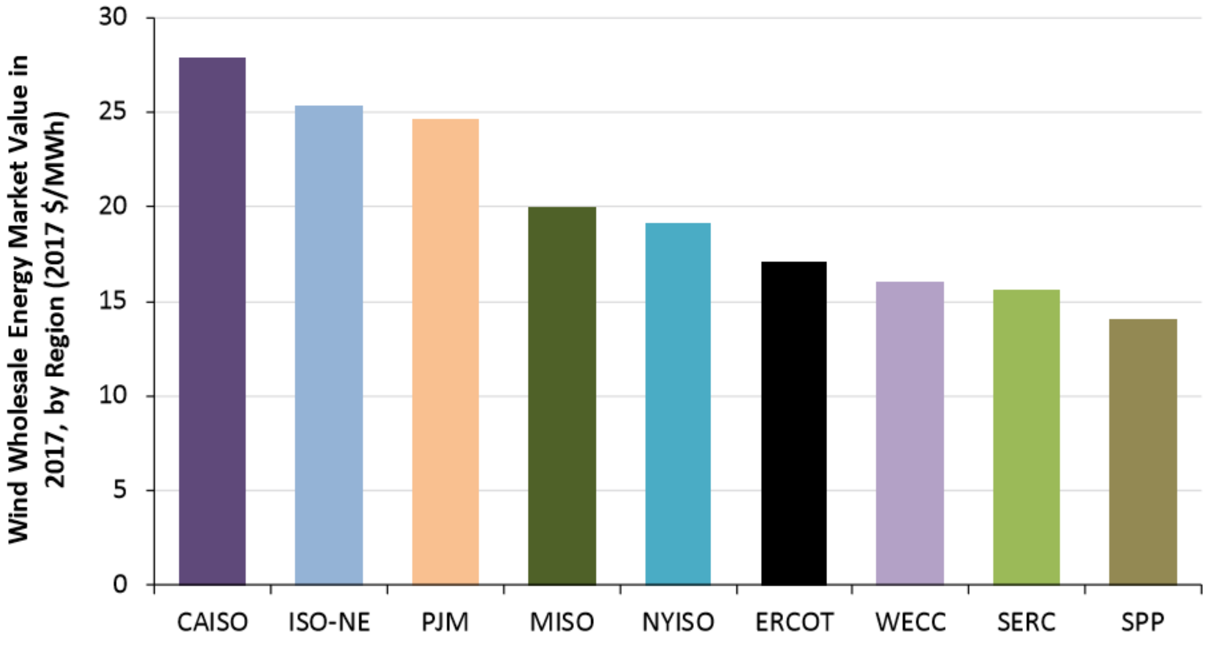
[156] https://emp.lbl.gov/projects/wind, page 62



Sources: Berkeley Lab, ABB

Figure 29: LBNL chart showing market value realized by wind by region in 2017

<u>Many "transmission alternatives" are useful complements to transmission, but not alternatives</u>

Some have argued that batteries and demand response will address all challenges related to integrating larger amounts of renewables, so transmission to access a diverse mix of resources is not needed.[157] While demand response and energy storage provide many valuable grid services and are a key part of our future power system, it is important not to lose sight of the continued importance of transmission.

Energy storage and demand response offer valuable services to the grid by moving power from one time period to another. However, achieving each of the three fundamental principles outlined at the beginning of this chapter (access to low-cost location-constrained resources, access to economies of scale, access to geographic diversity) requires moving electricity from one location to another, something that only transmission can do.

In addition, while energy storage and demand response can move power across time, it is not on the scale needed for today's power system, let alone a future power system with higher levels of variable renewable resources and greater electrification. Demand response and energy storage are highly effective at providing MW or power for short durations, but are generally poor at storing MWh or energy. Analysis by London Economics shows that transmission excels at providing a wide range of services to meet a variety of power system needs, exceeding the capabilities of energy efficiency,

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[157] https://sandiegofreepress.org/2018/05/california-should-not-risk-its-clean-energy-future-on-extreme-strategies/

demand response, and distributed generation.[158] Most notably, energy storage and demand response resources can typically only absorb or discharge electricity for a few hours, while transmission is able to absorb or discharge power indefinitely. In a localized area, periods of renewable generation abundance or scarcity can persist for many hours or even days or weeks, something that transmission's sustained duration can accommodate but energy storage and demand response's limited duration response cannot. Moreover, because all demand response deployed at a commercial scale today is used to reduce electricity consumption, not increase it, current demand response technologies are unable to reduce renewable curtailment by increasing demand on the renewable project side of a transmission constraint.

At very high penetrations of wind and solar energy, it becomes necessary to move very large quantities of energy in time and space, on the magnitude of moving dozens of Terawatt-hours across weeks. The magnitude of this energy and duration need is many times greater than can be provided by any technology other than transmission delivering electricity to long-duration storage resources, like hydroelectric reservoirs and the use of electricity to synthetically produce storable fuels, as explained in more detail below.

Other inherent limits prevent demand response and distributed energy storage resources from alone facilitating a renewable future, without the addition of transmission. Demand response and distributed storage are by definition located in electricity demand centers, which tend to be far from where renewable resources are located. These resources cannot move energy in time to help alleviate a localized transmission constraint because the distributed resource is located on the demand side of the constraint and not the renewable resource side of the constraint. As utilities Xcel and ITC explained in proposing a transmission line in Minnesota, "Because the need for the Project is driven by increased amounts of wind generation along the Minnesota/Iowa border rather than increased demand, conservation and demand-side management programs are not effective alternatives to meet the identified need."[159]

Utility-scale energy storage deployed on the same side of the transmission constraint as the renewable resource can help alleviate the constraint, however. The primary author of the *Nature Climate Change* paper discussed above has done additional analysis examining the value of energy storage in a variety of scenarios for the state of Minnesota. That analysis found that energy storage was a useful complement to transmission, with more storage built in scenarios with more transmission build because storage was useful for increasing the utilization and efficiency of the transmission investments.[160] Storage works with transmission to absorb shorter-duration fluctuations in supply and demand, moving excess energy to a period when the transmission line has excess capacity. The analysis also found that storage plays an

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[158] https://www.energy.senate.gov/public/index.cfm/files/serve?File_id=8BFFFDEE-9C26-448F-8285-5B672B0EF2B0, page 70

[159] https://www.huntleywilmarth.com/staticfiles/microsites/hw/HW-Certificate-of-Need-Application.pdf, page 122

[160] http://www.vibrantcleanenergy.com/wp-content/uploads/2017/07/Modernizing_Minnesotas_Grid_LR.pdf, page 260

important role on the power system in all scenarios, particularly in displacing the need for fossil-fired peaker power plants.

Transmission also provides value to energy storage and demand response resources by providing them with greater access to markets. This can become particularly valuable as their penetrations increase and they begin to saturate their local markets. For example, states like California that are aggressively deploying energy storage and demand response are likely to find that the value provided by those resources begins to decline as they saturate markets for power system flexibility and other ancillary services. Already some deployments of energy storage technologies have quickly saturated their local markets. After deploying a large battery, South Australia has seen the price of some ancillary services drop by as much as 90%,[161] and many larger markets for high-revenue services are expected to quickly saturate as energy storage grows.[162] Thus demand response and storage developers in states like California will increasingly find it desirable to export their services via transmission to other parts of the grid where their services are still needed. A recent book argues that even if microgrids and other efforts to decentralize the grid through distributed resources are successful, a large-scale transmission network will still be critical for those decentralized resources to realize their value.[163]

A number of recent studies confirm that transmission is essential for reaching a high renewable future. Consulting firm E3 examined a host of potential solutions to solar curtailment under a 50% Renewable Portfolio Standard (RPS) in California, and found that some of the most effective solutions were regional coordination and access to a diverse mix of resources, both of which are enabled by transmission.[164] The study found that around 5,000 MW of energy storage, several times greater than the level envisioned under current policy, would be necessary to reduce solar curtailment as much as using regional coordination or a diverse mix of resources. The E3 report also concluded that today's demand response provides little help with renewable curtailment because it is used to reduce energy consumption at times of peak demand and not increase consumption during times over oversupply, though the study did find that future demand response resources that offer long-duration increases in consumption could be useful.

A recent study found that a package of flexibility solutions, including expanded imports and exports, would greatly reduce curtailment as California increases its use of renewable energy. In a high solar case, curtailment fell from 9.5% to less than 0.5% with the package of flexibility solutions in place, while in the case with less solar and more wind generation, curtailment fell from over 4% to 0.2%.[165] The analysis found that among the flexibility solutions in the package, removing restrictions on electricity imports and exports from California and removing requirements for local generation "drives" the

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[161] https://www.utilitydive.com/news/south-australias-grid-service-costs-slashed-90-by-tesla-battery/523436/

[162] https://utilityweek.co.uk/frequency-response-market-nearing-saturation-industry-warned/

[163] Sivaram, Varun. Taming the Sun: Innovations to Harness Solar Energy and Power the Planet (MIT Press), 2018, pp. 215-218

[164] https://www.ethree.com/wp-content/uploads/2017/01/E3_Final_RPS_Report_2014_01_06_with_appendices.pdf

[165] https://www.nrel.gov/docs/fy16osti/64884.pdf, pages v-vii

amount of curtailment. The primary role of imports and exports in providing flexibility was confirmed in the study's ramping analysis, which found that "the primary resources ramping to meet the 11 GW hourly ramp include physical imports (4.5 GW ramp), storage (3.2 GW), the gas fleet (3.2 GW), and demand response (0.2 GW)."[166]

European countries like Germany and Denmark, which respectively achieved 22% and 46% annual penetrations of wind and solar last year, have also found that transmission plays the most important role in accommodating high levels of renewable energy. A German energy official recently noted that Germany's investment in larger transmission ties to Scandinavia is "the cheapest flexibility you can think of. We don't need to build, for that, storage facilities which are much more expensive."[167] As he further explained, "I don't know whether the demand for storage will increase. What I know is the demand for flexibility will increase, will increase dramatically... and if storage proves to be the cheapest flexibility, and the market chooses storage, then of course storage will increase… It's always coming down to flexibility. That's what we need and storage is one sort of that."

Other technological changes are increasing, not decreasing, the need for transmission. The electrification of other sectors of the economy, such as transportation, building heating, water heating, and industrial processes, will also increase the value of transmission. Greater use of electricity for building heating will increase the value of transmission for accessing the load diversity that results from regional differences in climate and weather, which today is mostly just driven by diversity in summer air conditioning needs. By increasing electricity consumption in population centers, electrification will also increase the need for transmission to deliver electricity from remote resources of all types into those areas.

Recent analysis from the Brattle Group confirms that transmission expansion will be essential for electrification. That report found that, in addition to upgrades needed anyway, "$30–90 billion dollars of incremental transmission investments will be necessary in the U.S. by 2030 to meet the changing needs of the system due to electrification, with an additional $200–600 billion needed from 2030 to 2050."[168]

Regardless of electrification, population and economic growth are expected to drive increased demand for electricity, which will increase the need for transmission. National electricity consumption increased 2.1% in 2018.[169] The American population is increasingly moving to urban areas for a variety of socioeconomic factors, also increasing the need for transmission to deliver energy from all types of power plants to customers.

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[166] *Ibid.*, page viii

[167] http://www.eesi.org/briefings/view/060818germany, https://www.forbes.com/sites/jeffmcmahon/2018/06/10/baseload-is-poison-and-5-other-lessons-from-germanys-energy-transition/

[168] https://wiresgroup.com/new/wp-content/uploads/2019/03/Electrification_BrattleReport_WIRES_FINAL_03062019.pdf

[169] https://www.eia.gov/electricity/monthly/archive/february2019.pdf, page 135

Transmission-related technologies are also increasing the value of transmission. Chapter 3 discusses the value of several innovative technologies that serve as complements to transmission by increasing the utilization of those lines. For example, dynamically rating transmission lines based on ambient weather conditions instead of worst-case assumptions, optimizing power flows using network topology optimization and power flow control devices, and other solutions all offer considerable economic promise as complements to transmission.[170] While these solutions are sometimes presented as interim “transmission alternative” measures because they can be deployed quickly on an interim basis to defer expansion needs while new transmission is being planned and built, they are best viewed as transmission complements because they only work when deployed in conjunction with the transmission system.

However, “transmission alternatives” that attempt to work against the fundamental principles outlined at the beginning of this chapter, including microgrids that permanently operate in isolation from the bulk power system, customers using distributed generation and storage to disconnect from the grid, the direct pairing of flexibility resources to even out the variability of individual sources of supply and demand, and the claim that a networked grid with centralized electricity markets is unnecessary because of bilateral energy transactions facilitated by blockchain technology, will inexorably result in costly redundancy and inefficiency relative to a large integrated power system.

What batteries can and cannot do

Energy storage, and particularly battery storage, offer transformational value to the power system. Aside from powering electric vehicles, batteries can also provide a range of reliability services to the grid far better than any other resource. For example, battery storage can and will replace conventional power plants built to meet peak demand, can provide fast power injection to stabilize voltage and frequency following a grid disturbance, can quickly charge and discharge to regulate frequency, and can charge or discharge over several hours to accommodate fluctuations in supply and demand, including morning and evening solar output ramps. However, it is important to keep perspective of what batteries can and cannot do. At high penetrations of wind and solar energy, it becomes necessary to move large quantities of energy across time and space. Energy storage cannot move electricity from one place to another; only transmission can do that.

Batteries also have limited ability to store large amounts of energy for significant durations. The argument that storage can meet future needs without a need for transmission and large regional markets[171] misses the fundamental distinction that, due to inherent physical limits, batteries excel at providing MW or power, but are generally poor at storing MWh or energy. All of the services that batteries excel at providing, as listed in the paragraph above, are short-duration injections or withdrawals of MW, not storing large quantities of MWh for long durations. Batteries are ideal for use in electric vehicles and as a replacement for peaker power plants, as both applications require short-

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[170] https://watttransmission.files.wordpress.com/2018/03/watt-living-grid-white-paper.pdf

[171] https://sandiegofreepress.org/2018/05/california-should-not-risk-its-clean-energy-future-on-extreme-strategies/#.XD_egFxKg2w

duration injections of MW. However, attempting to use batteries for longer-duration storage of MWh is exorbitantly expensive, as several recent studies from MIT and national laboratories have illustrated.[172]

California grid operator data confirm that the state's grid-connected batteries are almost exclusively being used to accommodate fast intra-hour fluctuations in electricity supply and demand, often switching from charging in one 5-minute period to discharging in the next 5-minute period.[173] Rather, imports on the state's large transmission ties with neighboring regions, chiefly from the large flexible hydropower fleet in the Pacific Northwest, are the primary tool being used to accommodate the multi-hour ramps in net load. As shown in the following chart for a typical day, imports are dialed back midday when California solar generation is abundant, and then ramped back up as solar output wanes and electricity demand peaks in the evening.

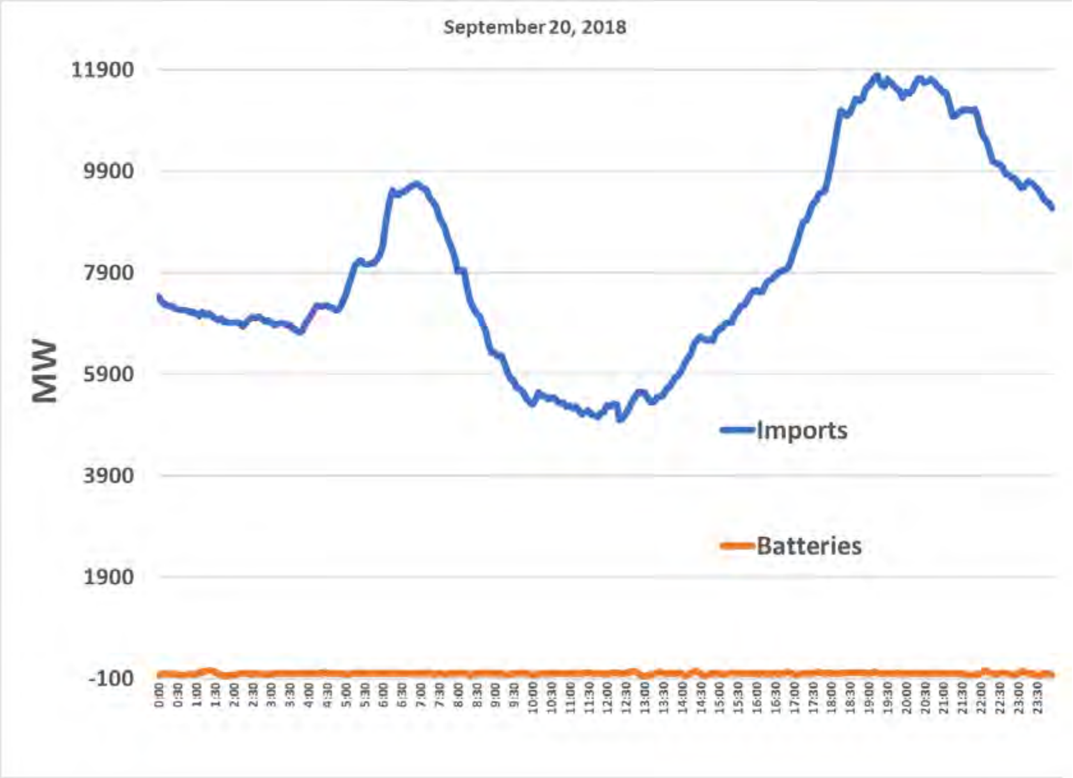

Figure 30: California grid operator data showing a typical daily generation profile for battery storage and transmission imports

NREL analysis of high solar penetrations in California confirms that transmission is much more valuable than storage for alleviating solar curtailment.[174] While storage is able to reduce curtailment by about one-third at 33% and 40% renewable penetrations, increasing exports from the state via transmission completely eliminates curtailment. Like the Minnesota study discussed earlier, the California analysis

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[172] https://www.technologyreview.com/s/611683/the-25-trillion-reason-we-cant-rely-on-batteries-to-clean-up-the-grid/

[173] http://www.caiso.com/TodaysOutlook/Pages/supply.aspx

[174] https://www.nrel.gov/docs/fy16osti/65061.pdf, pages 63-66

also showed a complementarity between storage and transmission, with the largest cost savings realized in scenarios that increased both exports and storage.

In addition to transmission's unique ability to move electricity from one place to another, transmission is also capable of moving very large amounts of energy for an indefinitely sustained period at a relatively low cost. A single 765-kV AC transmission line can carry 5,000 MW or more, and as noted earlier China has just completed an 1100 kV DC line that can carry up to 12,000 MW. The group of AC transmission lines that currently connect California with Arizona and Southern Nevada can carry over 10,600 MW of power, while the AC and DC lines that connect California with the Pacific Northwest total 6,775 MW of capacity.[175]

The efficiency at which transmission moves energy is also very high, which becomes important given the scale of energy that must be moved, particularly in a high-renewable future. The existing PJM system typically experiences transmission losses of well under 1%,[176] and losses can be kept to a few percent even over extremely long distances, especially with extra-high-voltage transmission,[177] and particularly DC transmission.[178] In contrast, lithium ion batteries experience round-trip losses of around 14%, while other battery chemistries can be as high as 33%.[179]

The *Nature Climate Change* paper discussed above, which developed a nationwide transmission network to net out most fluctuations in renewable output through geographic diversity, also examined the potential use of storage to provide that same service, but found it would have "a higher cost than HVDC transmission lines," even with aggressive assumptions for storage cost reductions, and was not necessary.

A recent study to compare the "flexibility cost-benefits of geographic aggregation, renewable overgeneration, storage, and flexible electric vehicle charging, and (2) compare pathways to a fully renewable electricity system" found that "Geographic aggregation provides the largest flexibility benefit with ~5–50% cost savings."[180] The study found that "With a major expansion of long-distance transmission interconnection to smooth renewable energy variation across the continent, curtailment falls to negligible levels"[181] at a 60% renewable penetration, from 5% in the case without transmission. In the 80% renewable case, transmission reduced curtailment from 12% to 5%.

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[175] https://www.wecc.biz/Reliability/TAS_PathReports_Combined_FINAL.pdf

[176] http://www.pjm.com/markets-and-operations/ops-analysis/gld.aspx

[177] https://web.ecs.baylor.edu/faculty/grady/_13_EE392J_2_Spring11_AEP_Transmission_Facts.pdf

[178] https://www.siemens.com/press/pool/de/events/2012/energy/2012-07-wismar/factsheet-hvdc-e.pdf

[179] https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf, https://www.renewableenergyworld.com/ugc/articles/2015/01/calculating-the-true-cost-of-energy-storage.html, https://www.greentechmedia.com/articles/read/the-grim-details-lurking-in-lazards-energy-storage-analysis#gs.5bh6diA

[180] https://www.sciencedirect.com/science/article/pii/S0360544216300032

[181] http://www.innovationreform.org/wp-content/uploads/2018/02/EIRP-Deep-Decarb-Lit-Review-Jenkins-Thernstrom-March-2017.pdf

Recent NREL analysis of the Texas market found that relatively small additions of energy storage could help significantly reduce curtailment in a scenario in which 55% of energy was provided by renewables, but that the incremental value of deploying additional storage for reducing curtailment rapidly diminished. This occurred because many periods of excess renewable output persisted for days, exceeding the MWh storage and duration capability of batteries. As a result, even very large additions of energy storage were only effective for eliminating about half of curtailment, leaving curtailment at high single-digit levels, which would likely be unacceptably high for renewable energy developers.[182]

As noted above, batteries generally excel at providing MW, but are poor at providing MWh. The following EPRI chart shows the MW and duration offered by different energy storage technologies, with MWh being the product of MW and duration.[183] A primary challenge in a very high renewable future will be moving tens of thousands of GWh by days or weeks in time. The scale of this need falls several orders of magnitude off the upper right end of this chart. As discussed below, there are solutions that can work together with transmission to provide this service, such as conventional hydroelectric reservoirs and using electricity to produce synthetic fuels that can be stored. Transmission plays a key role in enabling a very high renewable future by moving large quantities of power across long distances to reach those long-duration MWh storage resources and realizing the geographic diversity benefits of renewable resources.

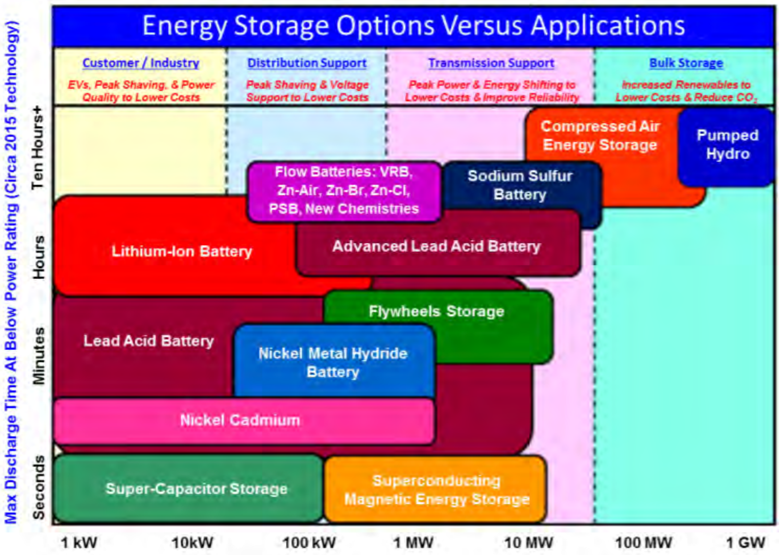

Figure 31: EPRI chart showing MW versus duration for different types of energy storage

All of the battery options in the chart fall many orders of magnitude short of the MWh scale needed in a high renewable future.[184] Analysts have calculated that meeting future US energy needs only using Tesla Powerwalls and renewable energy would require 37.8 billion of the 13.5 kWh Tesla Powerwall 2.0, or

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[182] https://www.nrel.gov/docs/fy17osti/68960.pdf, page vi

[183] http://www.energy.ca.gov/renewables/tracking_progress/documents/energy_storage.pdf

[184] https://www.fool.com/investing/general/2015/10/11/energy-storage-needs-to-think-bigger-than-batterie.aspx

over 100 for each person in the United States.[185] While debates about 100% renewable energy futures are generally a distracting strawman argument,[186] the point about the technical limits of batteries for MWh storage is valid and is already a significant factor even at lower renewable penetrations. Lithium ion batteries are typically most cost-effectively deployed in a way that scales their maximum MW power output in proportion to their MWh energy content, so increasing the charge and discharge duration to increase MWh storage can only be achieved by underutilizing their MW capability to charge and discharge.[187] There are insurmountable physical and economic limits that limit the role batteries can play in meeting the long-duration MWh-shifting needs of a high renewable power system.

A recent book explains why battery storage alone cannot solve the challenges associated with high renewable penetrations, particularly the need for very long duration energy storage, even at a seasonal timescale. It noted that "seasonal storage is an extremely uneconomical way to run a storage resource. Storing energy in the summer and discharging it in the winter cycles the storage resource only once a year, making it virtually impossible to earn enough revenue to defray its capital costs." As a result, it concludes that "grid-scale energy storage technologies cannot be the only solution for coping with the intermittency of solar energy;" rather, "extending the geographical reach of the grid" will play an important role.[188]

That said, batteries will continue to play an increasingly important role in providing valuable short duration MW-related services to the grid, a need that will grow as renewable penetrations increase. The studies discussed above found an important role for energy storage, which is increasingly economic for providing a variety of services on the grid, most notably-the short-duration MW injections currently provided by fossil peaker plants. Storage can also complement transmission by increasing the amount of energy that can be delivered across a given line and even optimizing power flows by regulating voltage. However, it is important that those making decisions that affect the future of the grid do not get distracted by energy storage's exciting advances and cost reductions, and lose sight of the continued importance of transmission and other resources for serving the large-scale, long-duration MWh-shifting needs of the future power system.

How transmission works with other resources to move and store energy in quantities batteries cannot

Water, as an abundant and high-density substance, is extremely effective at storing large quantities of MWh over long periods of time. At high renewable penetrations, this long-duration MWh resource will likely be a critical complement to the short-duration MW services provided by battery storage. North America has already deployed hydroelectric dam reservoir storage on a massive scale, so regions looking to increase their access to long-duration energy storage only need to expand their transmission ties to regions with that hydroelectric storage capacity.

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[185] http://www.innovationreform.org/wp-content/uploads/2018/02/EIRP-Deep-Decarb-Lit-Review-Jenkins-Thernstrom-March-2017.pdf

[186] https://www.aweablog.org/may-cooler-heads-prevail-debate-renewable-energys-role-providing-clean-electricity/

[187] Sivaram, Varun. Taming the Sun: Innovations to Harness Solar Energy and Power the Planet (MIT Press), 2018, page 229

[188] *Ibid.,* pp. 231-232

Most of this hydroelectric storage capacity is not the U.S.'s 22 GW of pumped hydroelectric power plants, which like batteries were mostly designed to provide MW and not MWh. Most pumped hydro plants have reservoirs large enough to provide between 6 and 20 hours of storage. Assuming 12 hours of storage at the average U.S. plant indicates our pumped hydro fleet has around .250 TeraWatt-hours (TWh) of energy storage, which if it could all be used to generate power at once could power the U.S. for around half an hour. Europe has quantified that it could build 2.3 TWh of pumped hydro storage, seven times greater than its existing amount of pumped hydro storage, and enough to power the U.S. for about 5 hours if it could all be used at once.[189]

Most of North America's energy storage can be found in the large reservoirs behind conventional hydropower dams, many of them in Canada. Quebec's reservoirs have 176 TWh of energy storage, enough to meet the province's electricity needs for a year, or U.S. electricity needs for 16 days.[190] Two massive reservoirs in British Columbia possess an additional 10-25 TWh of storage, and further operating reservoir capacity exists in Manitoba.[191] The 55 trillion gallons of reservoir capacity in Quebec provide 455 trillion pounds of potential energy stored behind dams, energy storage on a scale that batteries cannot provide.

For comparison, the U.S. had about .002 TWh of grid-connected battery storage by the end of 2018, which can hold enough energy to meet U.S. electricity demand for about 15 seconds if it could be discharged that quickly.[192] Canada's existing hydroelectric reservoirs are able to store over 100,000 times more energy than that. Replacing the entire 120 GW US combustion turbine fleet with 4-hour batteries would provide only 0.480 TWh of energy storage, enough for about an hour of U.S. electricity consumption or less than 1/400th of Canada's reservoir capacity.

Europe has 180 TWh of total hydroelectric reservoir capacity, with 82 TWh in Norway and 34 TWh in Sweden.[193] This is approaching the scale needed for a power system that relies heavily on renewable energy.[194] Increasing renewable generation will automatically facilitate existing reservoir dams' transition from primarily serving as energy generation resources to serving as capacity, flexibility, and storage resources. By displacing dams' need to produce as many MWh to meet energy needs, renewable generation allows more water to be stored during periods of renewable abundance. Using renewables to maintain higher reservoir levels can actually make hydropower dams more productive, as the power produced by a dam is proportional to the square of the height from the bottom of the dam to the water level of the reservoir, likely offsetting modest increases in evaporation from slightly increasing the surface area of the reservoir.

Doing the math for other innovative forms of energy storage also illustrates that, while they can help with MW needs and some shorter-duration MWh needs, they are not up to the task of moving the

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[189] https://www.hydroworld.com/articles/2016/05/estorage-project-report-quantifies-2-291-gwh-of-new-pumped-hydro-possible-in-europe.html

[190] http://www.hydroquebec.com/learning/hydroelectricite/gestion-eau.html

[191] www.regie-energie.qc.ca/audiences/3398-98/memoires/aqcie/evidenc.doc

[192] https://www.woodmac.com/news/editorial/global-energy-storage-market-takes-off/

[193] https://deepresource.wordpress.com/2013/06/26/hydro-power-storage-in-europe/, https://cdn.eurelectric.org/media/1141/fact_sheet-hydropower-web-2013-160-0002-01-e-h-0862EB73.pdf

[194] http://www.innovationreform.org/wp-content/uploads/2018/02/EIRP-Deep-Decarb-Lit-Review-Jenkins-Thernstrom-March-2017.pdf, page 5

massive quantities of long-duration MWh storage that will be necessary at high renewable penetrations. One newer energy storage technology is heating molten salt at solar thermal power plants during the day, and then using the heat to produce electricity at night. A large solar thermal power plant in Nevada can store .0011 TWh using 70 million pounds of molten salt.[195] An innovative proposal involves storing and generating electricity over a matter of minutes by driving a train filled with 10,000 tons of rock and concrete up and down a hill, which has the potential to store .0000125 TWh.[196] Another idea involves using a crane to stack and unstack large concrete blocks, with a storage potential of a few dozen MWh per site.[197] In short, while batteries and innovative technologies like these can help with the power system's need for MW, they should not be viewed as MWh solutions.[198]

At very high renewable penetrations, electrification and using electricity to produce synthetic fuels will also help provide the critical MWh complement to the short-duration MW services provided by battery storage. Electrification to replace fossil fuel consumption in other sectors of the economy must play a key role in meeting carbon reduction goals regardless. As an additional benefit, electrification provides additional controllable sources of electricity demand to help balance power system supply and demand and cost-effectively provide some energy storage over shorter periods of time. Water heating, space heating, industrial processes, and plug-in vehicle charging all represent large loads that can to a large extent be controlled and shifted a few hours in time or more. This can provide fast ancillary services like frequency regulation at the minute-to-minute timescale, as well as longer-duration shaping of the diurnal load profile to better match demand to supply, such as moving electric vehicle charging to during the day when solar output or at night when wind power is abundant. As noted above, electrification will require a strong transmission system.

Addressing the challenge of shifting energy by days, weeks, or even months will likely require production of storable gas, liquid, or even solid fuels using electricity, in addition to the greater utilization of existing hydroelectric reservoirs discussed above. Most storable fuel production will likely incorporate hydrogen produced via the electrolysis of water using excess renewable electricity.[199] The storable fuel could be hydrogen itself, which holds promise for some forms of transportation, can be injected at low levels into existing natural gas transport and storage infrastructure to provide significant fuel storage,[200] and can be used as a feedstock for carbon-based fuel production at refineries,[201] though hydrogen's low-density and small molecule size makes hydrogen itself a poor fuel for transport and long-term storage. Hydrogen production can be combined with the capture of carbon dioxide from ambient air or flue gases for net-zero-carbon production of carbon-based fuels,[202] other production of fuels that can be

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[195] http://www.eenews.net/greenwire/2016/03/29/stories/1060034748

[196] https://www.wired.com/2016/05/forget-elons-batteries-fix-grid-rock-filled-train-hill/

[197] https://qz.com/1355672/stacking-concrete-blocks-is-a-surprisingly-efficient-way-to-store-energy/

[198] http://www.thetimes.co.uk/article/we-shouldnt-pin-our-hopes-on-battery-power-g7h67k393

[199] http://science.sciencemag.org/content/sci/360/6396/eaas9793.full.pdf

[200] Blending hydrogen into natural gas at up to 15% penetrations can be accommodated in some existing gas infrastructure with minor modifications: http://www.nrel.gov/docs/fy13osti/51995.pdf. This has been implemented at significant scale using existing natural gas infrastructure in Germany. http://www.helmeth.eu/

[201] http://www.eia.gov/todayinenergy/detail.php?id=24612, http://www.eia.gov/dnav/pet/pet_pnp_feedng_k_a.htm 180 BCF of natural gas is used annually in the U.S. to meet refinery hydrogen demand. Wind and solar in Texas and California are ideal electricity sources for producing hydrogen that can be provided to those refineries.

[202] For example, see https://en.wikipedia.org/wiki/Power_to_gas, http://onlinelibrary.wiley.com/doi/10.1002/slct.201601169/full

readily stored,[203] or even fertilizer production.[204] A major advantage is that society can use existing infrastructure for storing, transporting, and consuming many of those fuels. Strong electricity transmission infrastructure will play a key role in delivering excess renewable generation to the electrolyzers and other equipment used to produce these fuels.

Don't cut the cord; build more of them

At the logical extreme of the argument for decentralization and distributed generation, some have argued that customers should "cut the cord" from the bulk transmission system. While this is taking an argument to its logical extreme, the severe economic and technical challenges to cutting the cord result from the same fundamental principles of statistical aggregation that make a strong transmission grid essential to cost-effectively operating the power system. As a result, it is enlightening to examine such extreme cases.

Microgrids have niche applications and can complement the bulk grid, but are not a substitute

Some have argued that, by taking advantage of improvements in the economics of solar and storage, microgrids operated in complete isolation from the bulk power system offer the promise of more affordable and reliable power.[205] However, due to the fundamental principles outlined above, power produced on a microgrid that is disconnected from the bulk power system is inherently more expensive and less reliable than bulk grid power. As electricity expert Steve Huntoon has observed, "Integration is what maximizes the ability of least-cost resources to reach load. By interfering with least-cost dispatch, microgrids can only raise energy costs. It's just math."[206] Throwing away 100 years of investment in building a large interconnected grid and repeating the mistake of Edison's local DC power system is not a roadmap for the future.

However, microgrids can have niche applications for customers who must be able to operate without a central grid. This includes customers who: 1. Require extremely high levels of reliability and therefore need to separate from the bulk grid when it fails, or 2. Are located in remote areas without a central grid. In the first circumstance, the facility should use grid power the vast majority of the time as that will always be cheaper, and only fall back on the microgrid when the bulk power system or the facility's connection to it fails. In this case the microgrid can provide value because some aggregation is better than none, so a microgrid of a few sources of supply and demand provides more diversity than each individual building relying on its own backup generator.

Pew has documented that microgrids can provide value for military bases, which are a perfect niche for microgrids because they consist of many separate buildings and require high levels of reliability but tend to be located on remote parts of the grid where reliability is lower. Some aggregation is better than none, as the load diversity among buildings on a military base allows more efficient sizing of backup

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[203] https://www.ecn.nl/news/item/power-to-ammonia-from-renewable-energy-to-co2-free-ammonia-as-chemical-feedstock-and-fuel/

[204] https://www.iea.org/media/news/2017/Fertilizer_manufacturing_Renewables_01102017.pdf

[205] http://www.wired.co.uk/article/microgrids-wired-energy

[206] http://energy-counsel.com/docs/Microgrids-Wheres-the-Beef-Fortnightly-November2015.pdf, https://www.rtoinsider.com/microgrids-national-security-40055/

generators, and having multiple connected sources of supply also improves reliability. For example, if the probability of an individual backup generator failing to start up when the grid goes down is 20%, the odds of three backup generators connected via a microgrid all failing to start is less than 1%.

However, for a microgrid to increase reliability, the power lines and other equipment that connect different facilities on the microgrid must also be resilient to whatever threats are likely to take down the bulk grid. If these power lines are just as vulnerable to a weather event as the power lines delivering bulk power to the base, the microgrid may not significantly improve reliability.

Microgrids can sometimes make sense in areas without a bulk grid, as the aggregation of a village into a microgrid is more efficient than each building having its own power supply. However, even for microgrids in developing areas with low electricity usage and a high tolerance for outages, it is extremely difficult to efficiently balance supply and demand without a tie to the central grid.[207] A 2015 article noted that in India "only a small number of villages are too remote to be hooked to the central grid," and over the last several years India has in fact successfully connected essentially all remote villages to the central grid.[208] In all developing areas where it is technically and politically feasible to build a bulk grid, a large transmission network will offer a more economical path to electricity access than microgrids.

Customers going off-grid with distributed generation and storage is not economic

Even more extreme than small microgrids is having no grid at all and becoming totally self-reliant, which is almost never economic unless there is no grid to connect to. Some utility officials have expressed concerns about current customers going off-grid with distributed solar PV and battery storage. However, investment bank UBS found that the cost of customers doing so is extremely high relative to maintaining the existing grid connection (which costs very little to maintain), and the cost will still be prohibitive even under the most optimistic cost reduction assumptions for PV and battery storage.[209] The PV array must be greatly oversized to ensure adequate production under the least favorable weather conditions, requiring massive cost and so much roof and ground space that such an installation would not be feasible for most homeowners. Even then a backup generator is needed to cover the household's full power needs due to weather tail events that cause an extended lack of solar resources, like persistent clouds or snowfall. The required oversizing of the PV array also causes the majority of spring and summer solar output to be wasted due to a lack of seasonal storage.

Electrification is likely to make this nearly-impossible challenge even more difficult. Electric water heaters, building heating, and electric vehicles impose large energy consumption and instantaneous power demand that must be met. Some of those needs, like building heating and cooling, are not fully dispatchable as they cannot be delayed indefinitely, making larger investments in storage or backup generators necessary.

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[207] http://www.scientificamerican.com/article/coal-trumps-solar-in-india/\

[208] http://www.iea.org/newsroom/news/2018/june/commentary-electricity-in-every-village-in-india.html

[209] https://neo.ubs.com/shared/d1Jb7ND94gkz67W/

In short, the value of transmission is only increasing as new technologies like wind, solar, energy storage, demand response, and electrification transform America's power system.

Chapter III. The policy roadmap

Continued development of a robust, interregional transmission network has stalled in recent years because transmission policies have not kept pace with changes in how electricity is produced and sold. Many of these transmission policies are relics of an era when utilities primarily served customers in their state using generation in that state, so there was little need for strong transmission links to other states. With the expansion of competition through wholesale electricity markets in recent decades, electricity is increasingly sold across multiple state lines and balancing area interconnections, yet the regulatory framework remains focused on state boundaries. As one would expect, a balkanized patchwork of regulations has produced a balkanized patchwork of an electric grid.

FERC Order 1000 was a well-intentioned attempt to fix two of the main obstacles holding back transmission investment, barriers to planning and paying for regional and inter-regional transmission. However, unintended consequences and lackluster implementation, particularly for inter-regional transmission, have left all sides unhappy. It's been 8 years since Order 1000 was passed and the time is ripe for FERC to fix what is clearly broken transmission policy.

As explained in Chapter 1, expanding transmission infrastructure provides a wide range of benefits. Like many forms of infrastructure, the benefits of transmission are typically dispersed across all electricity consumers and accrue over many decades. This aspect of transmission, along with transmission being what economists term a "natural monopoly" due to the inefficiency of building redundant competing systems, make transmission and similar types of infrastructure "public goods." As a result, there is an essential role for government policy in ensuring that adequate transmission is built to realize these benefits. However, these policies can and should be implemented in a way that preserves the efficiencies associated with market-based investment by leaving transmission development to the private sector.

The policy solutions lie in better planning, broad cost allocation, and streamlined permitting for transmission.

Planning

FERC, RTO and utility staff, and state regulators have an important role to play in ensuring that the benefits of transmission are fully accounted for in transmission planning processes and that plans are being developed to meet anticipated future scenarios and deliver desired outcomes.

Key transmission planning reforms that are needed in many regions include:

1. Integrated transmission planning should consider all benefits together. Many regions have segregated transmission planning studies for economic, reliability, public policy, and generator interconnection transmission projects. Requiring a transmission project to be categorized as only one type of project fails to recognize all of the values and benefits of a transmission investment since the system ends up being used for various purposes, like reliability or economics, at different times.[210] Regions that have taken an integrated approach to planning a network that optimizes across all categories of benefits have seen far better results.

2. Plan pro-actively. Pro-active transmission planning solves the so-called "chicken and egg" problem in which renewable generators are not built because there is no transmission, and transmission is not built because generators aren't built yet. This problem results from the timing mismatch for building generation versus transmission. It takes a few years at most to plan and build a renewable power plant, while it takes many years to plan, permit, and build transmission.

Due to advances in computing power and modeling techniques, it is now possible to co-optimize transmission and generation planning.[211] Regions should be looking at where new generation is expected to be developed over a at least a 15-year horizon and co-optimizing transmission to enable the lowest cost expansion of new generation.

3. Plan for a long-time horizon. Traditionally, transmission planners have chosen short-time horizons, often 10 years, to calculate the benefits of transmission because of future uncertainty around generation and load. With renewable resources, however, future generation additions will occur in the locations with the best resources, and those locations are known today and do not change over time. Transmission assets typically have a useful life of 40 years or more, and that lifetime can often be extended indefinitely with some replacement of equipment. Because transmission investments are mostly up-front capital expenditures with few ongoing costs, using a short-time horizon for transmission benefit-cost analysis results in a significant under-investment in transmission. Imagine if everyday infrastructure like houses or roads had to have a payback period of 10 years or less to be built. Those critical investments would either not be built or be woefully undersized despite knowing that these investments will deliver benefits for decades if not centuries. The same is true of shortsighted transmission benefit analysis. Planning horizons and cost benefit analysis should be consistent with the expected useful life of transmission.

4. Better sync interregional planning among regions. The current interregional transmission planning processes under Order No. 1000 are not properly planning for and identifying projects across regions that give economic, reliability, operational, and public policy benefits to consumers.[212] This is largely due to the fact that, although Order No. 1000 requires neighboring transmission planning regions to

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[210] http://files.brattle.com/files/5907_eei_2015-08-21_transmission_planning.pdf,pdf, http://45.33.88.170/system/publications/pdfs/000/005/180/original/Scenarios-Based_Transmission_Planning_for_Texas.pdf?1435671047

[211] https://www.researchgate.net/publication/281123009_Co-optimization_of_electricity_transmission_and_generation_resources_for_planning_and_policy_analysis_review_of_concepts_and_modeling_approaches

[212] For more detail, see AWEA Post-Technical Conference Comments to FERC on Order 1000, Docket AD16-18-000, October 3, 2016

coordinate planning, it does not require a joint process or evaluation of interregional solutions and their benefits.

A significant hurdle for many interregional transmission planning processes is that regions use different planning assumptions, categories, and methods. Consistency and standardization between neighboring regions for interregional planning would help avoid the "triple hurdle" – the situation where proposed interregional transmission projects must first meet the requisite interregional criteria then again qualify under each transmission planning region's planning criteria – subjecting interregional projects to three or more distinct approval processes. In the alternative, one interregional process with a common model and assumptions should replace the "triple hurdle."

Interregional planning could also be improved by enabling projects to address different needs in different regions, such as reliability benefits in one region but economic or public policy in another. Once benefits are considered and findings of benefits are agreed to in an interregional study, these determinations should not be subject to reassessment by a subsequent regional evaluation. Further, there should not be exclusions on projects of certain voltage levels, project costs, or location constraints as all options should be on the table.

5. Quantify all benefits. Benefits that are widely acknowledged as real but that are too difficult to quantify are typically ignored in transmission planning and benefit-cost assessments. A failure to fully account for these benefits harms consumers by under-investing in transmission, leaving economic, reliability, and other benefits on the table.[213] To remedy this, grid planners should quantify as many benefits as possible. A recent Brattle study provides a useful guide to studies and approaches that have attempted to quantify almost all of transmission's benefits.[214] In cases in which precise quantification is not possible, using an estimate will result in a more optimal level of transmission investment than giving zero value to a benefit that is widely acknowledged to be large. If benefits are not quantified, they should be at least qualitatively taken into account in the planning process.

6. Account for hedging and resilience value of transmission using probabilistic analysis. As discussed in Chapter 1, researchers have found that traditional planning methods do not account for the hedging and optionality value that transmission provides, which leads us to underinvest in transmission by tens of billions of dollars. Advances in computing power now make it possible to run transmission planning models iteratively to evaluate the benefits of transmission under a wide range of possible scenarios rather than just a handful of scenarios, as is commonly done today. Probabilistic analysis is able to identify common and no-regrets solutions that will provide system value under a range of possible futures.

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[213] http://www.utilitydive.com/news/should-have-started-yesterday-why-better-transmission-planning-is-urgent/420754/

[214] See Appendix B at http://files.brattle.com/files/6112_recommendations_for_enhancing_ercot%E2%80%99s_long-term_transmission_planning_process.pdf

Given the recent focus on electric resilience, there also may be an opportunity to better plan for extreme events under the reliability standards that apply to transmission planners. While it is not always possible to ensure zero loss of load from an extreme event, there is still value in planning for extreme events and making the power system more resilient to them by reducing the magnitude and duration of their impact.

7. Evaluate upgrades that can be implemented more quickly, in addition to new transmission. There are many solutions that can be quickly implemented to reduce transmission constraints. Smaller upgrades and technological solutions will not eliminate the need for new transmission expansion in the long term but can provide short-term solutions that avoid the time delays of siting and cost allocation.

Examples of solutions that can significantly increase power transfer on existing transmission line rights-of-way include:

-Upgrading substation equipment to higher capacity[215]

-Re-conductoring existing transmission paths with advanced materials[216]

-Adding second circuits to existing transmission towers

-Rebuilding existing transmission paths with new towers and conductors[217]

-Installing series compensation[218]

-Installing synchronous condensers[219]

-Installing storage as a transmission asset[220]

Grid operators can also adopt innovative technologies that allow more optimal power flows,[221] such as:

-Dynamic line rating

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[215] Real-world examples of a range of substation upgrades, including replacing circuit breakers and transformers, can be found in the list here: http://www.pjm.com/planning/rtep-upgrades-status/construct-status.aspx

[216] http://www.energy.ca.gov/2013publications/CEC-500-2013-030/CEC-500-2013-030.pdf concludes that thermal rating limits for existing transmission pathways can be increased by more than 50% through the use of advanced conductors alone.

[217] http://www.boldtransmission.com/projects/

[218] http://www.spp.org/documents/22902/17_ju4715%20-%20spp%20-%20review%20of%20series%20compensation%20-%20final%20-%202.1.pdf

[219] http://www.ercot.com/content/news/presentations/2014/Panhandle%20Renewable%20Energy%20Zone%20Study%20Report.pdf finds that, in the Texas Panhandle, the deployment of a synchronous condenser and the addition of a second circuit to existing transmission towers on a single transmission path can support the addition of 2,800 MW of additional wind capacity in the region.

[220] https://www.misoenergy.org/stakeholder-engagement/issue-tracking/energy-storage-as-transmission-reliability-asset/

[221] https://watttransmission.files.wordpress.com/2018/03/watt-living-grid-white-paper.pdf

-Network topology control

-Flexible AC Transmission (FACTs) and other power flow control devices[222]

While building new transmission lines on new rights-of-way is still an essential part of the solution, particularly for accessing renewable resources in areas where there is currently little to no grid, these other types of transmission system upgrades can cost-effectively alleviate congestion and maintain reliability in many locations while new lines are being planned, permitted, and built.

Cost allocation

Even though the net benefits of transmission are well-established, determining how to allocate the cost of transmission is the single largest obstacle to building transmission. The solution has been well-established by the success of transmission policies in regions like ERCOT, SPP, and MISO, that broadly allocate the cost of high-voltage transmission to all consumers across the region. Broadly allocating the cost of transmission to ratepayers across a large region recognizes that the benefits of transmission are widely distributed, as discussed in Chapter 1. Interestingly, the more robust a region's transmission system is, the more the value of new transmission and low-cost generation is able to flow to all customers.

Broad cost allocation simply creates a mechanism by which the costs of transmission investment are allocated to those who benefit from transmission, consistent with FERC's long-standing principle that those who benefit from investments should pay for them. The money recovered from those consumers is then paid to private transmission developers who build the transmission. This mechanism incentivizes private developers to make investments in transmission that benefit consumers. Cost allocation methods should recognize that transmission is a natural monopoly and not require interconnecting generators to pay for large pieces of the network, even though their competitors and consumers would be the primary beneficiaries of those upgrades.

An analogy to the policy that an interconnecting generator pay the full cost of grid upgrades would be requiring the last vehicle entering a congested highway to pay the full cost of adding another lane to the highway. As one would expect, most generators balk at paying for these upgrades and instead drop out of the generator interconnection queue, then the next generator in line does the same thing after a lengthy re-study process, and nothing gets built.

Interregional cost allocation

Although FERC Order No. 1000 required neighboring transmission planning regions to coordinate cost allocation, it has resulted in very little expansion of interregional transmission capacity. The cost allocation of interregional projects should reflect the benefits recognized in the interregional benefit

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[222] http://www.gridtech.eu/project-scope/technologies/12-technologies/21-facts-flexible-alternating-current-transmission-system

calculation.[223] Those benefits should fully reflect the economic and policy benefits as well as other quantifiable benefits that will accrue. Interregional projects could be facilitated by cost allocation methodologies based on pre-specified qualification criteria and pre-specified formulas applied to projects that meet those criteria. For instance, if a project meets the benefit-to-cost ratio in each region, it would not require an additional step of passing a combined cost-benefit ratio, assuming it meets the prespecified threshold. Further, the benefit-to-cost thresholds for interregional projects should not be any more stringent than those applied within each region.

Permitting

Transmission siting is a problem caused by an overlapping patchwork of federal, state, and local regulatory rules that apply to the construction of transmission projects in many regions of the country. State siting can be efficient at siting projects built by a single state utility to serve its retail customers, but state siting processes have not proved effective in siting long-haul transmission projects that traverse multiple states and whose benefits are regional in nature.

Reliance on state siting processes for transmission lines traces backs decades, when there was essentially no interstate power grid, no interstate commerce in electricity, and electricity delivery was local in nature, with power plants close to load. That electricity structure is no longer the dominant landscape. Currently, state and local governments continue to site long-haul electric transmission facilities, whose benefits are regional and interstate in nature, but often with lengthy delays and, in some cases, individual state holdouts despite approvals by several other states.

State and local siting is so difficult to navigate that the real impact is likely unknown, as many projects are aborted in the beginning stages due to perceived difficulties, not to mention the ones that are never even proposed because of the recognized unfeasibility of state siting. These projects with regional benefits are the transmission projects with the greatest national interest and where federal siting is most appropriate.

These proposed lines are likely to traverse multiple states and may only have opposition in one state, which would still result in denial of any benefit to all of the willing states. This type of backbone transmission project typically delivers multiple benefits to many states – benefits that should not be necessarily denied based on one state’s rejection of that project.

Permitting Solution: Revisiting the Federal Role in Transmission Siting

In the Energy Policy Act of 2005 (EPAct),[224] Congress recognized the national interest in a strong grid, and also acknowledged that the transmission siting process that has been used in the United States since 1935 was no longer working. To that end, Congress changed the law governing federal transmission siting, thereby establishing a new federal role.

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[223] For more detailed recommendations, see AWEA Post-Technical Conference Comments to FERC on Order 1000, Docket AD16-18-000, October 3, 2016.

[224] Energy Policy Act of 2005, § 1221, Pub. L. No. 109-58, 119 Star. 594 [hereinafter “EPAct”].

EPAct was intended to provide an effective federal siting process to supplement state and local siting. The new law gave DOE the authority to conduct studies of electric transmission congestion, and then designate NIETCs--areas experiencing electric energy transmission constraints or congestion that adversely affected consumers.[225] Separately, FERC was given authority to issue permits within NIETCs for the construction of electric transmission facilities as a "backstop" to state siting activities under certain circumstances (known as backstop siting).

This siting process established by EPAct was regrettably cumbersome in its approach. The law unnecessarily bifurcated the federal role between two agencies, DOE and FERC, which complicated implementation and served to block the effectiveness of the federal siting process. In addition, although the new process was intended to preempt state siting in some respects, unclear statutory language opened up FERC's siting authority to legal challenge regarding that scope.

As a likely result of these challenges to implementing federal transmission authority, to date, no construction permits for projects in NIETCs have been issued. In fact, only one applicant proposing to site a project within a NIETC even began the pre-filing process at FERC, and that applicant subsequently withdrew from the process.[226] Clearly, this Congressionally-established federal siting authority has not worked.

The importance of ensuring that a federal siting role for transmission that is in the national interest has only increased since the EPAct established, as long-haul interstate lines continue to be significantly delayed due to the current state siting processes. Therefore, the transmission siting process of EPAct should be reinvigorated in a way that establishes effective federal siting and overcomes the difficulties that have until now plagued the process.

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[225] Corridor designation is somewhat of a misnomer, since DOE does not designate a route, and corridor designation is more properly seen as equivalent to a need finding, a finding that some increased transfer capacity is needed somewhere in a region. However, there is a perception in areas included in large corridors that DOE corridor designation will result in a lattice work of new transmission projects across the entire footprint of a corridor.

[226] Southern California Edison sought FERC backstop siting when Arizona Corporation Commission rejected its proposed Devers-Palo Verde 2 line, but three months after the Piedmont decision, Southern California Edison withdrew the Arizona section of its proposal. *See Edison Drops Plan for Power Line in Arizona*, L.A. Times, May 16, 2009, at B2.

Grid Vision: The Electric Highway to a 21st Century Economy

Prepared By
American Wind Energy Association
1501 M St. NW, Suite 900
Washington, DC 20005

AWEA.org