Potential customer benefits of interregional transmission

Memo to

American Council on Renewable Energy (ACORE)

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FOREWORD

This memo was prepared by General Electric International, Inc. (GEII), acting through its Energy Consulting group, based in Schenectady, New York. Questions and any correspondence concerning this document should be referred to:

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Motivation

This memo is being provided to ACORE in support of their comments to FERC's Advance Notice of Proposed Rulemaking: *Building for the Future Through Electric Regional Transmission Planning and Cost Allocation and Generator Interconnection*.

Summary: Interregional transmission can enhance grid reliability, enable consumer benefits

State governments, utilities, and large energy buyers are mandating a shift to carbon-free resources while grid reliability is simultaneously being challenged by extreme weather events. Given their cost-competitiveness compared to alternatives,[1,2] these new carbon free resources will likely be in the form of new wind and solar generation. Reliability can be maintained with high penetrations of variable renewable energy in three ways:

1) *Adequacy*: Long term supply-demand balance resilient to grid uncertainties (e.g. outages, weather)
2) *Operational*: Day-to-day supply-demand balance for all time periods
3) *Stability*: System strength to sustain voltage and frequency

California, Denmark, and SPP are examples of three regions achieving hours of renewable penetration >70% with significant ramping, and high reliance on inverter-based resources. Each of them are leaning into new reliability approaches by utilizing a menu of industry best practices. **One of the most technically impactful and cost-effective best practices they both utilize is regionalization**. Certainly, California remains challenged by the effects of extreme weather but without such regionalization, one could argue, the impacts of prior events would have been even more devastating.

GE Energy Consulting forecasts a 2035 United States that will look similar to the SPP, California and Denmark of 2020. The value of regionalization that has been validated for SPP, California and Denmark should be assessed for the broader US.

GE Energy Consulting has suggested a methodology to assess the incremental transmission requirement for a regionalized future US with higher renewables and extreme weather uncertainty. This incremental requirement would be based on a holistic assessment of three areas of reliability benefit:

1) *Operational:* Incremental interregional transmission can enable lower wind and solar curtailment which results in fuel cost savings.
2) *Adequacy:* Incremental interregional transmission can enable higher generation diversity in the face of uncertainties such as: generation, transmission or fuel outages or extreme weather events.
3) *Stability:* Incremental interregional transmission can enable greater system strength to avoid unintentional unit tripping due to fluctuations in voltage, frequency or unwanted oscillations.

[1] E.g. Lazard LCOE 15.0, https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf

[2] UT Austin, https://calculators.energy.utexas.edu/lcoe_map/#/county/tech (selecting for "availability zones" filter)

Today, there are limited practices in place for each region to evaluate the consumer benefits of interregional transmission on their own. Recent studies modeling the benefits of interregional transmission across the Western and Eastern Interconnects have demonstrated significant cost savings for consumers.[3,4] National-level guidance would help chart the path towards realizing the benefits of greater regionalization.

1 Decarbonization mandates are changing the energy mix

In the United States, and around the world, decarbonization mandates are driving a change in our energy mix. Countries, states, utilities, and companies are all taking on new mandates to decarbonize their operations. While the timing varies, many of these entities have some permutation of net zero carbon goals by 2050 at the latest. Indeed, many have announced more bold near-term goals by 2030 or 2040. We have summarized these goals in Figure 1 along with average electric generation mix.

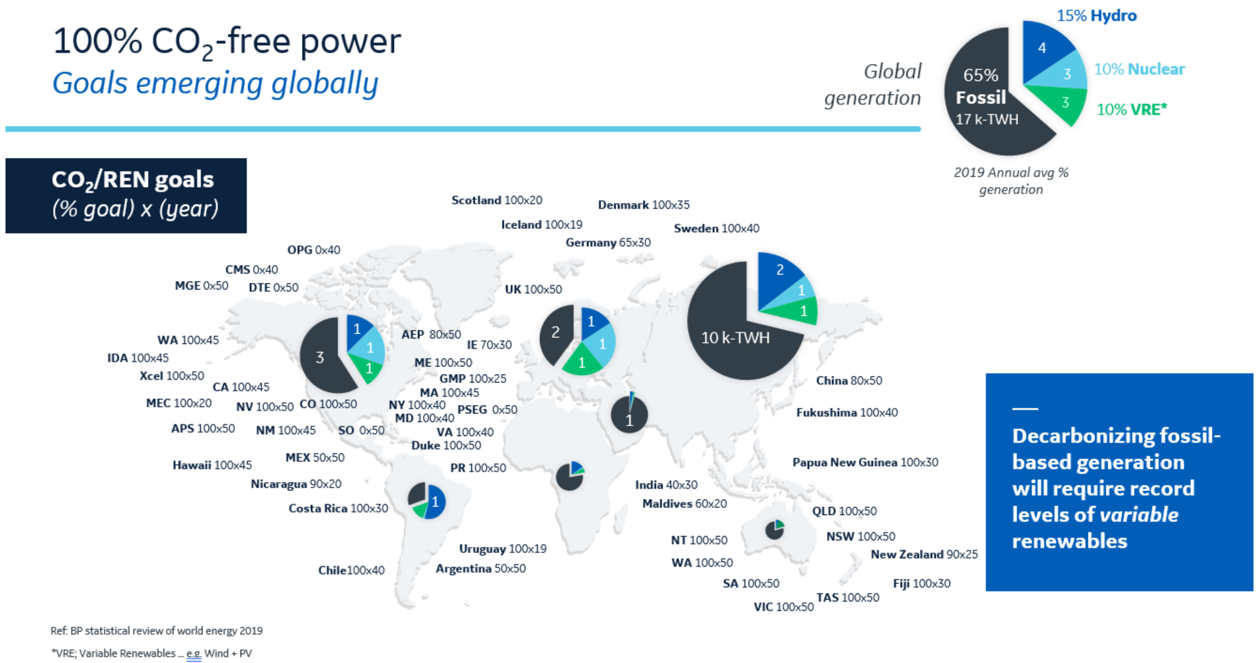

Figure 1 Global electricity generation mix along with decarbonization goals by various types of entities.

While hydro and nuclear form the majority of today's carbon-free forms of generation, given their limited availability, cost, permitting and siting challenges, the future generation mix will likely rely on

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[3] Clack and Goggin, Consumer, Employment and Environmental Benefits of Electricity Transmission in the Eastern U.S., October 2020, (optimizing transmission build across the Eastern Interconnect would save consumers ~$105B through 2050), *available at* https://cleanenergygrid.org/wp-content/uploads/2020/10/Consumer-Employment-and-Environmental-Benefits-of-Transmission-Expansion-in-the-Eastern-U.S..pdf

[4] Energy Strategies and the Western Interstate Energy Board, Western Flexibility Assessment, December 10, 2019 (noting that absent market coordination and increased regionalized transmission, achieving state policy targets in the 2020s becomes more difficult and costly), *available at* https://westernenergyboard.org/wp-content/uploads/2019/12/12-10-19-ES-WIEB-Western-Flexibility-Assessment-Final-Report.pdf

record amounts of new variable renewables … i.e. new wind and solar facilities. **New penetrations of wind and solar energy are central to achieving decarbonization mandates** in the electric power sector and for non-electrical carbon-emitting sectors like transportation and building heating and cooling.

2 Extreme weather events are challenging reliability

The U.S. power sector is increasingly feeling the effects of grid outages due to extreme weather. According to a recent analysis published by the US EIA, extreme events have been the main source of lost hours per customer in 2020.

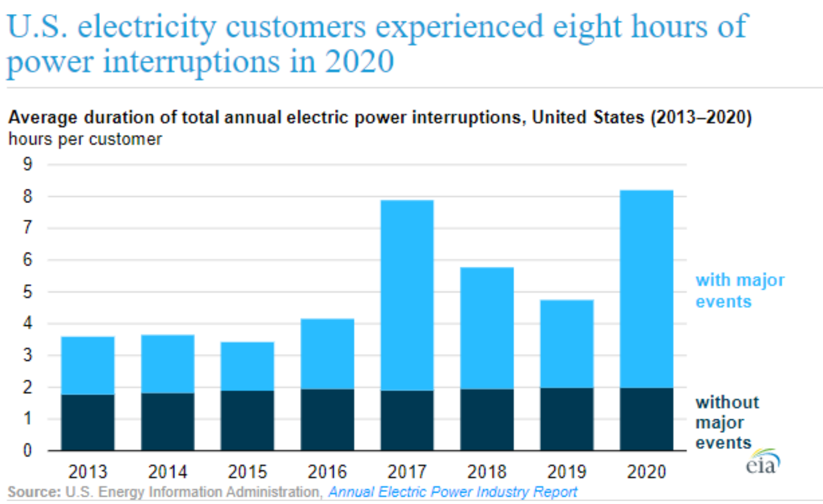


Figure 2 Analysis from the US EIA highlighting how major events accounted for six out of the eight outage hours per customer in 2020.[5]

According to the EIA, **2020 was the highest year of power interruptions since the agency began collecting data back in 2013**.[5] Notable recent storm-related outages included:

- August 2020: Louisiana & Texas—Hurricane Laura
- August 2020: Connecticut--Tropical Storm Isaias
- August 2020: Iowa derecho (extreme thunderstorm)
- August 2020: California heat wave
- October 2020: Oklahoma ice storm
- November-December 2020: Several winter storms in Maine
- February 2021: Texas freeze (Winter Storm Uri)

The key question is: **how do we continue to decarbonize our energy mix in a way that economically benefits consumers while also improving resilience to extreme weather events?**

[5] https://www.eia.gov/electricity/data/eia861/

3 Several regions are already achieving high variable renewable penetrations

While most of the world is currently below 20% variable renewables penetration, if we zoom in on the US and Europe as shown in Figure 3, we can see several examples of countries or regions that are achieving higher levels of renewables penetration.

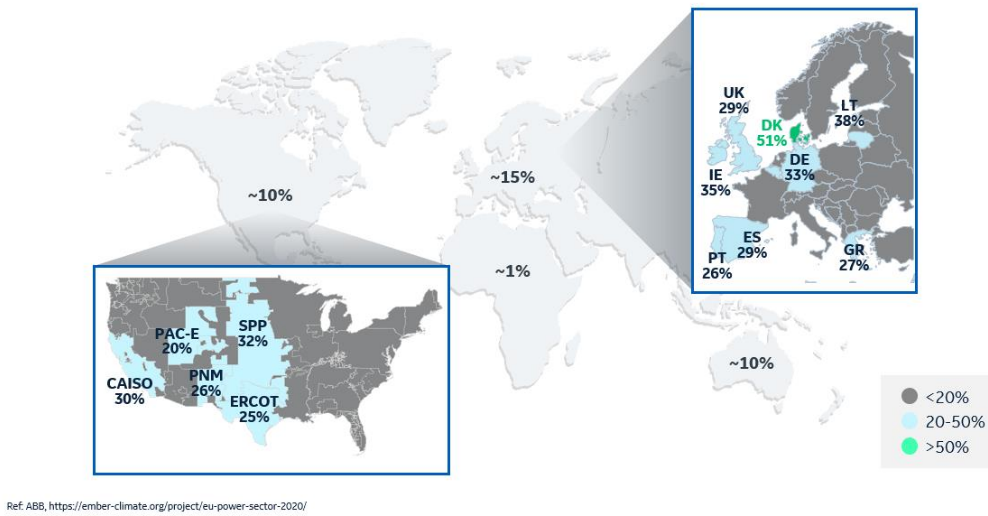


Figure 3 Average 2020 variable renewables penetration across the US and Europe.

In terms of regional penetration, Denmark has achieved 51% annual average variable renewable penetration, while several other regions across the US and Europe have achieved penetration levels in the 20-50% range. We present 2020 hourly penetrations and operations in Figure 4 for three example regions.

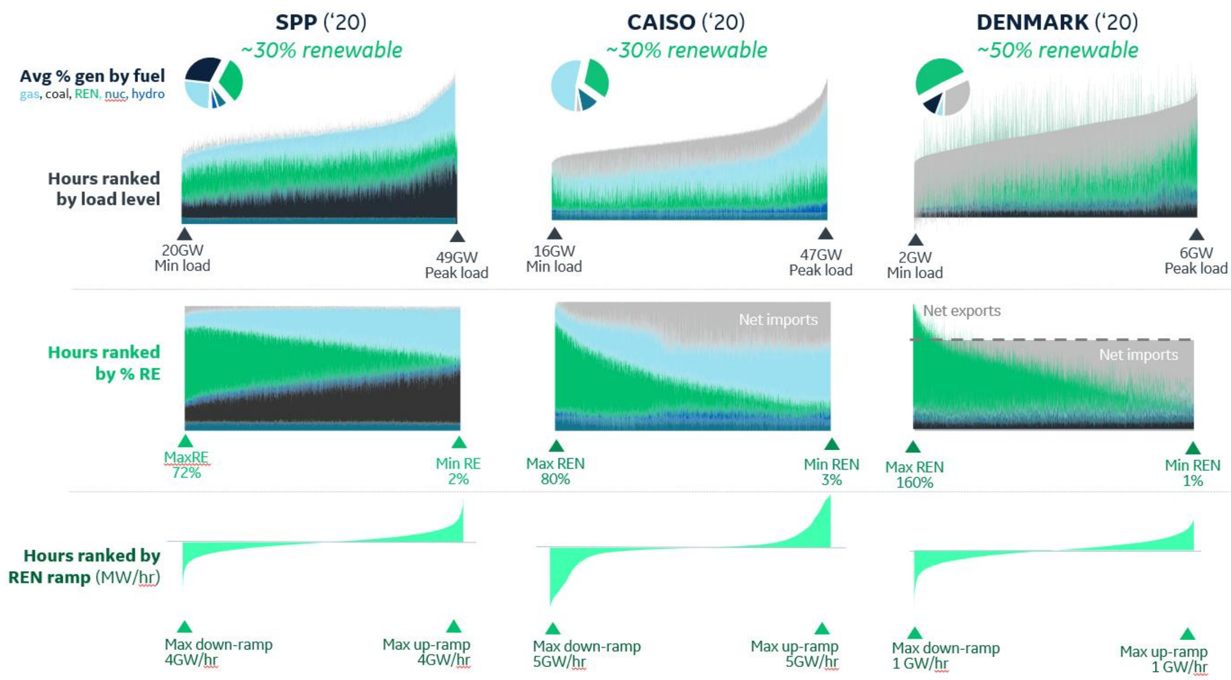


Figure 4 2020 hourly renewable penetration compared between SPP, CAISO, and Denmark.[6]

In Figure 4 and Table 1 we illustrate how hourly operations vary across systems with three different levels of variable renewable energy (VRE) penetration.

2020	PEAK LOAD	AVG %VRE	MIN HOURLY %VRE	MAX HOURLY %VRE	MAX RAMP-DOWN
SPP	49 GW	~30%	2%	72%	4 GW /hr (8% of peak)
CAISO	47 GW	~30%	3%	80%	5 GW/hr (11% of peak)
Denmark	6 GW	~50%	1%	16%	1 GW/hr (17% of peak)

Table 1 Summary of 2020 variable renewables (VRE) penetration levels across SPP, CAISO, and Denmark.[6]

Through this comparison we would like to highlight the following observations that have a direct impact on reliability:

1) **Hourly renewable penetrations can range from zero to over 100%.** In CAISO, hourly VRE penetration can be close to zero or as high as 80% while in Denmark, penetrations are even higher ranging from close to zero to ~160%.
2) **Ramping levels approach ~20% peak load levels.**

[6] ABB Hitachi

3) **Very high average VRE penetrations create periods of over/undersupply**. In the case of Denmark, we see that load levels exceed 100% or can be as low as 1%. In our forward-looking models of the US system, we see similar dynamics emerging within the next 15 years.

How do these systems maintain reliability given these new operating extremes? As we discuss further in this memo, across all three of these regions, **reliability and cost effectiveness in enabled by strong interconnections with their neighbors.**

4 Resilient decarbonization is based on three types of reliability

GE Energy Consulting has supported a wide variety of utilities and grid operators as they plan for reliable and cost-effective integration of renewables. Please see the Appendix for links to ~20 of our publicly available renewable integration study reports.

Given our broad renewable integration experiences, we observe three areas of reliability opportunity as we shift to variable renewables and maintain extreme-weather resiliency:

1. *Adequacy*: Operators are used to generators with fuel sources that are almost always available when needed. However, with the frequency of extreme weather events increasing this dynamic is changing for conventional fuel sources. Similarly, despite the availability of forecasts, wind and solar resource output is not a certainty either. How do we balance the need for adequacy and resilience with the costs to consumers? **In general, portfolio *diversity* benefits adequacy.**

2. *Operations*: Grids were designed assuming large centrally-located generation where power flows are generally flowing in a steady direction from generation centers to load centers. With the growth of highly distributed and variable wind and solar, there are reliability benefits associated with increasing flexibility. For SPP, CAISO and Denmark highlighted in Figure 4, we illustrate that the flexibility of their systems enabled renewables to reliably change their output quite dramatically in the course of one hour. **In general, resource *flexibility* provides reliability benefits to systems with higher variability.**

3. *Stability*: For the last 100 years of our electric system, stable frequency and voltage has been maintained by synchronous machines: rotating turbines that mechanically drive an electrical generator to create electricity. Wind turbines, solar panels, and batteries all drive power electronic, inverter-based electrical generators (i.e. inverter-based resources or IBRs) which provide new opportunities to maintain stable frequency and voltage. **In general, *grid strength* provides frequency and voltage stability benefits.**

5 Resilient reliability has a toolbox of solutions: cost-benefit drives choice

There is no one-size-fits-all solution. As we plan resilient decarbonized systems, **higher reliability is achieved via: 1) higher diversity; 2) flexibility; and 3) stronger grids**. Many times, a given solution can help address all three as we summarize in Table 2. In addition, implementing multiple forms of reliability enhancements can provide consumer benefits as renewable penetrations increase.

RELIABILITY ENHANCEMENTS	**TYPE**	**ADEQUACY:** *DIVERSITY*	**OPERATIONS:** *FLEXIBILITY*	**STABILITY:** *GRID STRENGTH*
Forecasting	PROCESS	✓	✓	✓
Regional coordination/visibility	PROCESS	✓	✓	✓
Geographic diversity	PROCESS	✓	✓	✓
Flexible demand	PROCESS	✓	✓	✓
Faster markets	PROCESS		✓	
Grid forming controls	PROCESS			✓
Interregional imports/exports	ASSET	✓	✓	✓
Storage	ASSET	✓	✓	✓
Lower minimum generation levels	ASSET	✓	✓	✓
Fuel-based synchronous generation	ASSET	✓	✓	✓
Synchronous condensers	ASSET			✓

Table 2 Examples of flexibility to improve diversity, flexibility and grid strength for resilient decarbonized electric systems.

The list in Table 2 represents the most common forms of reliability enhancements GE Energy Consulting recommends in our renewable integration studies. Determining which solutions are most advantageous for each region depends on the availability of solutions, their breadth of impact, along with their cost-benefit to consumers.

In general, process-related enhancements are frequently the lowest cost, and often provide all three types of reliability benefit. However, once process-related enhancements have been exhausted, exploring asset-related enhancements is imperative. Again, **implementation should be driven by the breadth of impact along with the cost to consumers.**

6 Today's best practices depend on interregional transmission & coordination

If we return to our three examples of increasing renewable penetration: SPP, CAISO and Denmark, as we show in Table 3, all three of these jurisdictions utilize reliability enhancements across the full menu of options and reliability types we presented in Table 2.

RELIABILITY ENHANCEMENTS	**TYPE**	**SPP** (~30% VRE)	**CAISO** (~30% VRE)	**Denmark** (~50% VRE)
Forecasting	PROCESS	✓	✓	✓
Interregional coordination /visibility	PROCESS	✓	✓	✓
Geographic diversity	PROCESS	✓	✓	
Flexible demand	PROCESS			
Faster markets	PROCESS	✓	✓	✓
Grid forming controls	PROCESS			
Interregional imports / exports (% of load)	ASSET	~1% (-10% -> +15%)	~40% (5% -> 70%)	~20% avg (-90% -> +80%)
Storage	ASSET		~2GW batteries[7]	

[7] https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/082621-feature-battery-storage-capacity-rapidly-rising-across-california-thermal-remains-strong

Lower minimum generation levels	ASSET	✓	✓	✓
Fuel-based synchronous generation	ASSET	✓	✓	✓
Synchronous condensers	ASSET	✓	✓	

Table 3 Examples of reliability enhancements utilized by SPP, CAISO, and Denmark.

Though this survey is not exhaustive, CAISO and Denmark represent examples of continental jurisdictions that benefit from regionalization to achieve their 2020 penetration levels. Regionalization includes:

- **Interregional transmission** build-out that is relied upon with neighboring jurisdictions. This does not necessarily imply a transfer capacity requirement.
- **Interregional planning**, coordination & visibility with neighboring jurisdictions.

Our work in Hawaii (see references in Appendix) demonstrates how island systems that are unable to regionalize can technically achieve similar levels of renewable penetration. However, such islands would have to rely on other forms of reliability enhancements in order to do so and these reliability enhancements would likely carry a higher cost versus regionalization.

6.1 California renewables expansion benefits from regionalization via the Western Energy Imbalance Market

In 2010, GE Energy and NREL identified the value of greater regionalization to support California's aggressive renewable penetration goals in our Western Wind and Solar Integration Study.[8] For example, Figure 5 shows the results of our analysis highlighting how greater interregional cooperation for 5 minute spinning reserves could save $2B.

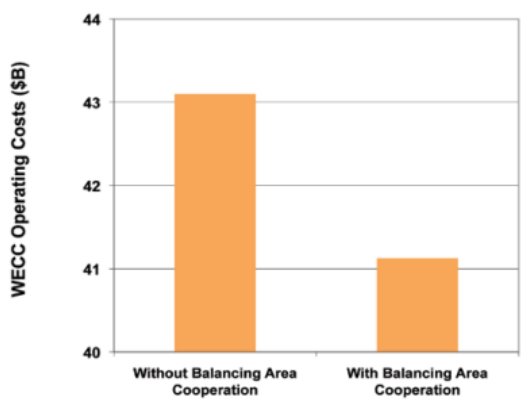


Figure 5 Results from 2010 GE-NREL WWSIS study illustrating the $2B in savings by holding spinning reserves as 5 large regions (right) versus many smaller zones (left).[8]

[8] NREL, "Western Wind and Solar Integration Study,"
http://www.nrel.gov/docs/fy10osti/47434.pdf
http://www.nrel.gov/docs/fy10osti/47781.pdf

This work helped support the 2014 launch of the Western Energy Imbalance Market that is operating today and enables California to benefit from operational flexibility at ~30% variable renewable penetration.[9]

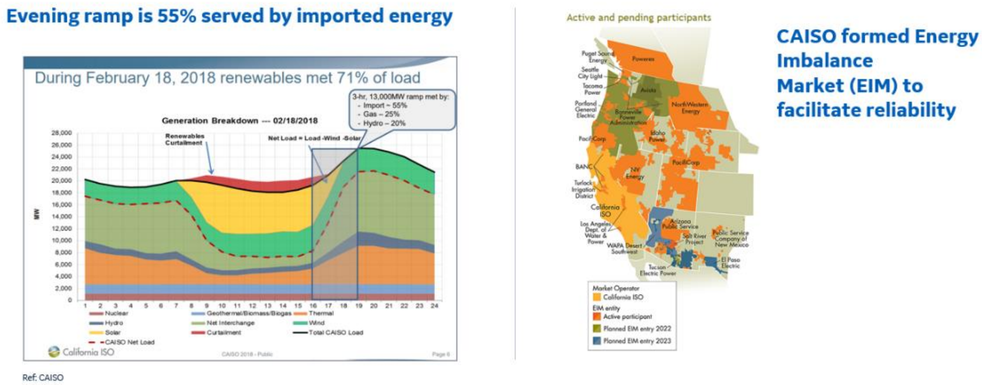
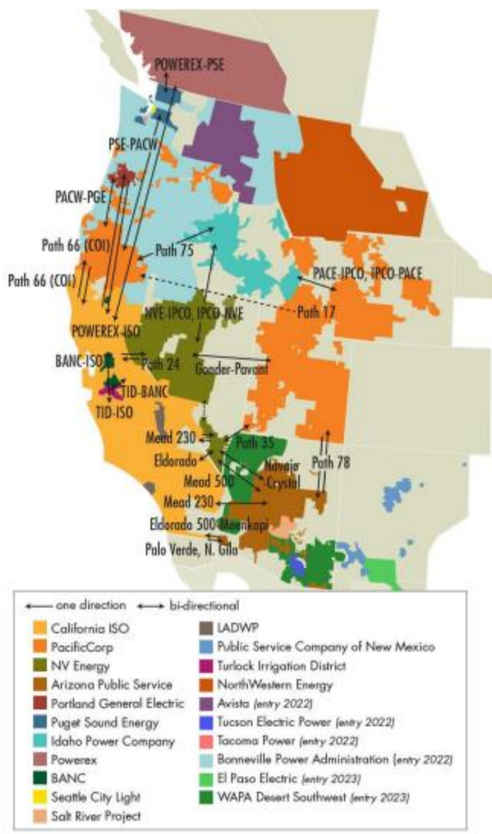


Figure 6 Data and map from CAISO illustrating how imports support the California "duck curve" or evening ramp in net load. These imports have been facilitated by the formation of the Western Energy Imbalance Market.



Path	Estimated Max Capacity (MW)
Path 24 *(west to east)*	100
Path 24 *(east to west)*	35-90
Eldorado	797
Path 35 *(west to east)*	580
Path 35 *(east to west)*	538
Gonder-Pavant	130
PACW to PGE	320
Path 66 *(ISO to PGE)*	627
Path 66 *(PGE to ISO)*	296
Path 66 *(ISO to PACW)*	331
Path 66 *(PACW to ISO)*	432
Path 17	0-400[1] [2]
PSE to PACW	300
Eldorado 500-Moenkopi	732
Palo Verde, N. Gila	3,151
Path 78 *(PACE to APS)*	625
Path 78 *(APS to PACE)*	660
Navajo-Crystal	522
Mead 500	349
Mead 230 *(APS <--> ISO)*	236
Mead 230 *(ISO to NVE)*	3,443
Mead 230 *(NVE to ISO)*	3,476
IPCO to PACW (Path 75)	1,500
PACW to IPCO (Path 75)	400-510
PACE to IPCO	2,557
IPCO to PACE	1,550
NVE to IPCO	262
IPCO to NVE	390-478
Powerex <--> PSE	150
Powerex <--> ISO	150
BANC <--> ISO	2,000-4,000
TID to ISO	1,400
TID to BANC	650

[1] Is an optional path available for PACE-PACW EIM transfers and the capacity is a subset of PACE-IPCO/IPCO-PACE and Path 75 capacity.

[2] When in use, the available capacity on PACE-IPCO/IPCO-PACE and Path 75 will be subsequently reduced by the used amount on Path 17, and not double counted.

Current as of October 2021

Figure 7 Interregional transfer capability utilized by the Western Energy Imbalance market.[10]

[9] https://www.westerneim.com/

[10] https://www.westerneim.com/Pages/About/QuarterlyBenefits.aspx

The Western EIM would not be possible without the physical transmission infrastructure that enables power flows across the Western US. Figure 7 summarizes the inter-regional transmission capability across the EIM footprint. **For example, the largest inter-regional capacity outside California is ~3400 MW between CAISO and NV Energy.**

Benefits

$1.72 billion in gross benefits since Nov 2014 *(as of 10/28/2021)*

(millions $)

EIM PARTICIPANTS	2014-2019	2020	2021 Q1	2021 Q2	2021 Q3	TOTAL
Arizona Public Service Entered 10/2016	$140.32	$48.96	$15.01	$9.25	$24.58	$238.12
BANC Entered 04/2019	$15.86	$30.36	$7.53	$18.12	$72.52	$144.39
California ISO Entered 11/2014	$191.88	$62.04	$8.91	$27.58	$54.01	$344.42
Idaho Power Company Entered 04/2018	$55.11	$26.30	$12.54	$15.23	$17.76	$126.94
LADWP Entered 04/2021				$8.54	$23.57	$32.11
NV Energy Entered 12/2015	$89.03	$24.62	$14.14	$6.20	$18.04	$152.03
NorthWestern Energy Entered 06/2021				$1.06	$5.16	$6.22
PacifiCorp Entered 11/2014	$235.29	$40.63	$20.48	$15.05	$40.12	$351.57
Portland General Electric Entered 10/2017	$73.27	$31.76	$8.80	$7.45	$7.12	$128.40
PNM Entered 04/2021				$2.32	$6.77	$9.09
Powerex Entered 04/2018	$19.78	$4.03	$1.17	$1.01	$0.92	$26.91
Puget Sound Energy Entered 10/2016	$41.25	$13.68	$4.31	$4.16	$6.78	$70.18
Salt River Project Entered 04/2020		$36.06	$5.52	$12.61	$17.78	$71.97
Seattle City Light Entered 04/2020		$6.64	$2.60	$2.75	$3.92	$15.91
TID Entered 04/2021				$1.37	$2.13	$3.50
TOTAL	$861.79	$325.08	$101.01	$132.70	$301.18	**$1,721.76**

Figure 8 Summary of economic benefits from the Western EIM by participant.[11]

While the EIM is aimed at enhancing operational flexibility, it's a great example of how regionalization is an economically efficient form of flexibility—having realized almost $2B in gross benefits since 2014 as summarized in Figure 8. By leaning on a wider footprint across balancing areas to support grid services, this can substantially lower the operational and integration cost. Strengthening interregional ties and deploying capabilities across them via markets and requirements was shown in the above-mentioned GE and NREL studies.

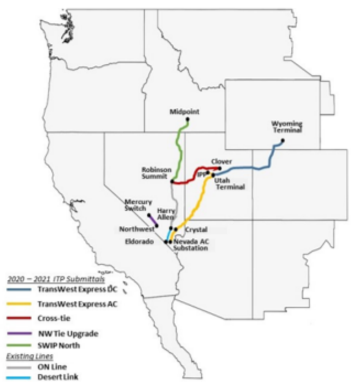
As the same time, **CAISO has been engaged in an interregional transmission planning process since 2015 to support all three areas of reliability.**[12] The CAISO and regional entities throughout the western interconnection collaborate during their transmission planning processes to ensure regional transmission stability and efficiency. These coordination efforts inform each entity's transmission plans. The interregional planning regions are WestConnect, NorthernGrid and California ISO.

[11] https://www.westerneim.com/Pages/About/QuarterlyBenefits.aspx

[12] http://www.caiso.com/planning/Pages/InterregionalTransmissionCoordination/default.aspx

The CAISO interregional transmission planning process (ITP) is performed in a 2 year planning cycle covering all three areas of reliability that we previously outlined:

1) ***Adequacy***: extreme weather assessment (e.g. wildfires), localized capacity evaluation (e.g. storage, gas alternatives)
2) ***Operations***: flexible capacity deliverability
3) ***Stability***: frequency response assessment (e.g. potential tripping effects in case of Palo Verde nuclear outage)



Project Name	Sgmts	Company	CEII or Confidential Data Submitted	Project Submitted to	Relevant Planning Regions	Cost Allocation Requested From	Termination From	Termination to	In Service Date
Cross-Tie Transmission Project		TransCanyon, LLC	Yes	CAISO, NTTG, NG, WC	NG and WC	CAISO, NTTG and WC	Clover, UT (PacifiCorp)	Robinson Summit, NV (NV Energy)	2024
Northwest Tie Upgrade		GridLiance West	No	CAISO, WC	CAISO and WC	CAISO, WC	Innovation (VEA, GLW, CAISO)	Northwest, NV (NVE)	2024
SWIP-North`		Great Basin Transmission LLC	Yes	CAISO, NTTG and WC	NG, WC and CAISO	CAISO, NTTG and WC	Midpoint. ID (IPCO, PAC)	Robinson Summit, NV (NV Energy)	2023
TWE WY-IPP DC Project[149]	1	TransWest Express, LLC	No	CAISO and NTTG	Not an ITP	CAISO	Sinclair, WY (PAC)	Delta, UT (PAC)	2025
TWE WY-IPP DC + IPP-Crystal 500 kV AC Project	1+2	TransWest Express, LLC	No	CAISO and NTTG	NG + (WC)	CAISO	Sinclair, WY (PAC)	No. Vegas (NV Energy)	2025
TWE WY-IPP DC + Crystal - Eldorado 500 kV AC Project	1+3	TransWest Express, LLC	No	CAISO and NTTG	NA – segments not contiguous	CAISO			2025

Figure 9 Interregional transmission projects submitted to CAISO for their 2020-2021 interregional planning cycle.[13]

In Figure 9 we show **six interregional transmission projects that have been submitted to CAISO** as part of this holistic interregional planning process.

6.2 Southwest Power Pool (SPP) renewable penetration benefits from regionalization via continued expansion

The high levels of renewable penetration we observe from SPP has been enabled by their vast geographic footprint along with their continued interregional expansion. Though Table 3 seems to suggest that they do not have heavily reliance on interregional resources today, SPP has been steadily expanding their footprint since 2015 in order to incorporate the value of regionalization into their operations.

[13] http://www.caiso.com/Documents/BoardApproved2020-2021TransmissionPlan.pdf

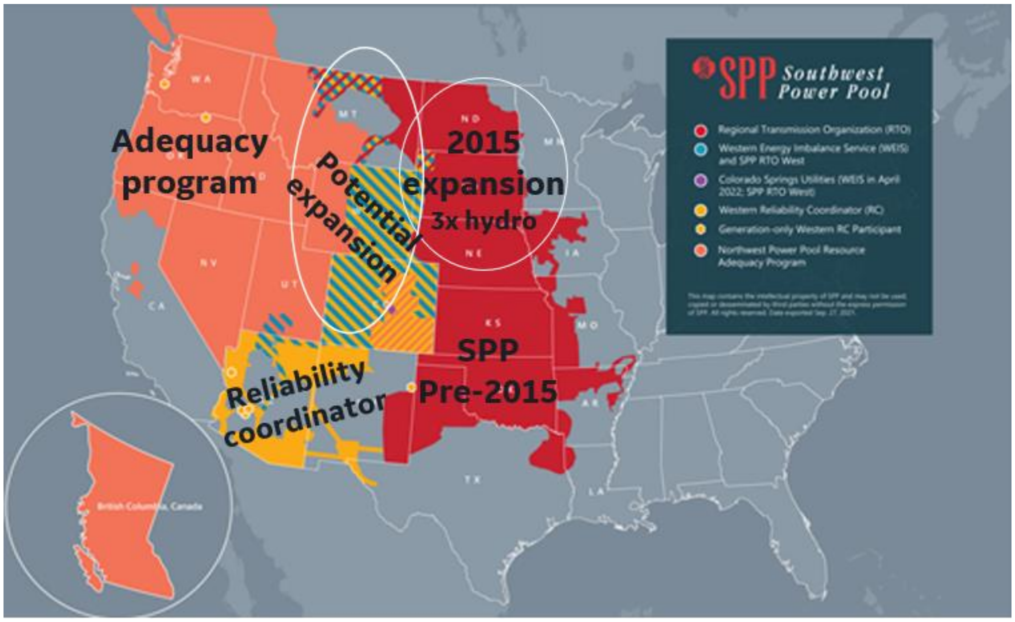


Figure 10 Southwest Power Pool map showing the current range of operational areas and services[14].

SPP is very transparent regarding the value that regionalization has brought to members in its territory. In its "2020 Member Value Statement," [14] SPP shares that it has provided $2B in savings to its members in 2020. **Of this $2B in member savings, transmission was the largest component of value at ~$770M. According to SPP, every dollar SPP directs toward transmission expansion returns at least $3.50 in benefits** via:

- Higher reliability and deliverability
- Lower production costs
- Creating new revenue streams
- Reduced on-peak generation costs
- Reduced planning reserve margins
- Reduced resource adequacy requirements
- Improved siting of new generation
- Accelerated renewable integration

As SPP expands its services across the Northwest Power Pool, the cost-benefits of greater regional coordination are leading the efforts.[15] These benefits are projected to produce ~$50M per year in savings and span all three forms of reliability that we have previously outlined as follows:

- Imbalance services
- Reliability coordination
- Planning coordination
- Unscheduled flow mitigation

[14] SPP.org

[15] https://spp.org/western-services/

6.3 Danish renewable penetration benefits from regionalization via ENTSO-E

The high levels of Danish renewable penetration also heavily rely on regionalization for all three types of reliability: 1) adequacy; 2) operational; and 3) stability via the ENTSO-E (European Network of Transmission System Operators for Electricity).

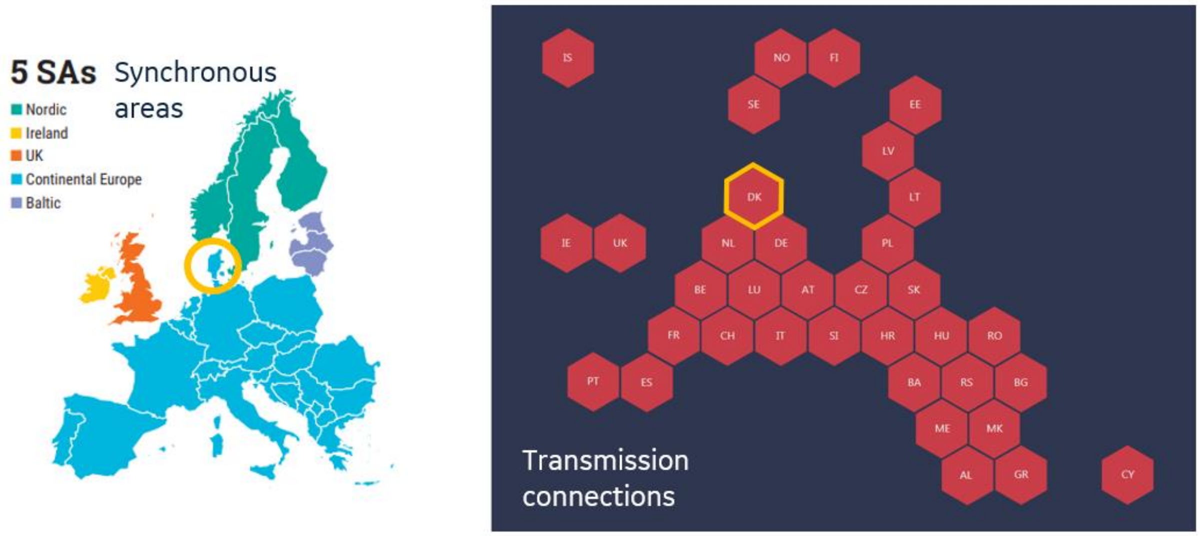


Figure 11 ENTSO-E maps showing the five synchronous areas and inter-country transmission coordination.[16]

The Continental European grid with coordination through ENTSO-E allows Denmark to rely on its neighbors for grid strength, balancing, and sharing of resources to manage uncertainty. Coordination of transmission interconnection and operation is done at the EU Commission level via ENTSO-E, and allows Denmark to achieve instantaneous variable inverter-based resource (IBR) penetrations well above 100%. Modeling and grid planning are coordinated across the EU regions by ENTSOE to maintain sufficient adequacy, resiliency and stability.[12]

The strength of this heavily regional approach is validated by the fact that the January 2021 "European Grid Separation" event did not result in significant blackouts.[17]

7 The rest of the US will need to reflect today's best practices

When we look at where the United States is headed with respect to variable renewables penetration, we see that much of the US in 2035 will look like California, the Great Plains region, and Denmark today.

[16] https://www.entsoe.eu/

[17] https://www.entsoe.eu/news/2021/07/15/final-report-on-the-separation-of-the-continental-europe-power-system-on-8-january-2021/

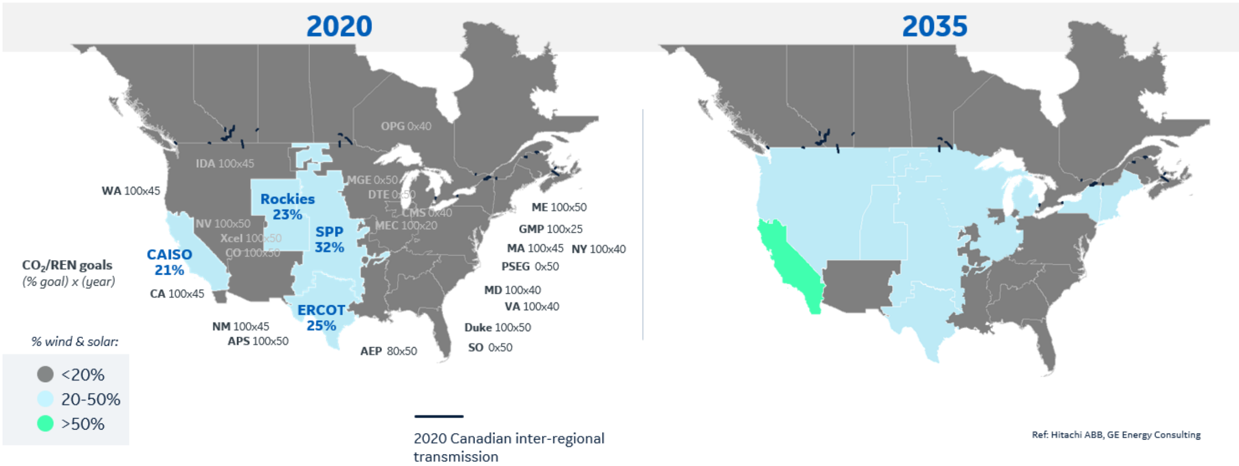


Figure 12 GE Energy Consulting forecast of regional variable renewables penetration in 2035 versus 2020.

In Figure 12, we show GE Energy Consulting's forecast of variable renewables penetration in 2035 versus 2020. Our forecasts are based on utility/grid operator load growth forecasts along with decarbonization policies spanning multiple layers of government. While much of the country is below 20% variable renewables today, **by 2035, much of the country will be between 20-50% VRE penetration**. This means that by 2035:

1. From an *adequacy* perspective: There will be hours where variable renewables within certain regions are close to zero coupled with the uncertainty of extreme weather. **The 2035 US will therefore benefit from the higher *diversity* enabled by regionalization.**
2. From an *operational* perspective: There will be hours where variable renewables approach or exceed 100% within certain regions along with intervals of high ramping. **The 2035 US will therefore benefit from higher *flexibility* enabled by regionalization.**
3. From a *stability* perspective: Each of the three US interconnections will be highly dependent on inverter-based resources to maintain voltage and frequency. **The 2035 US will therefore benefit from the higher *grid strength* enabled by regionalization.**

Given what we have shared regarding the potential reliability challenges, and potential mitigations for CAISO and Denmark today, we believe the rest of the US will need to increasingly leverage the reliability enhancement options we summarized in Table 2. Given the continental nature of the US systems along with our prior study work assessing the cost-benefit tradeoffs of the various solutions, **we contend that greater regionalization can be the most cost-effective mechanism for achieving resilient adequacy, flexibility, and stability in the 2035 US.**

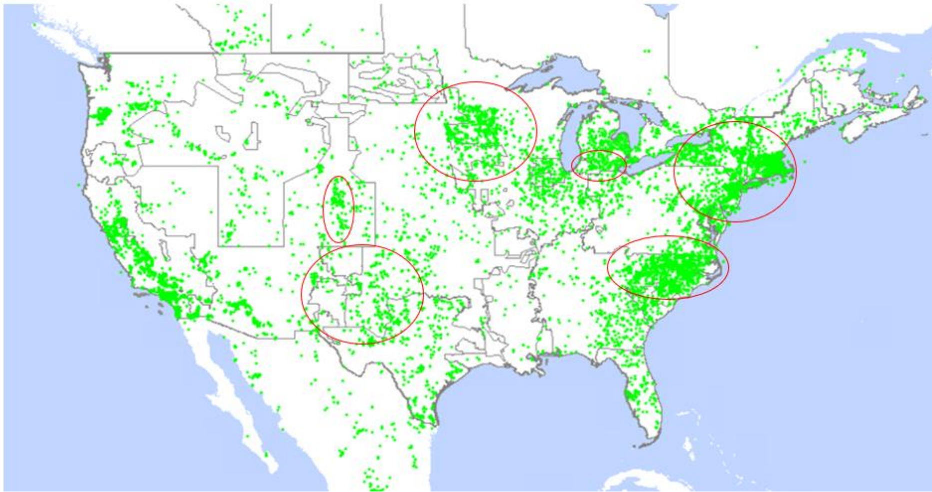


Figure 13 Regional map of the US showing siting of operating and planned wind and solar projects as of 2020. The circled areas highlight areas of high wind and solar siting along interregional interfaces. These are areas that could potentially benefits from greater interregional transfer capacity.[18]

At the same time, even looking at a current map of the US showing siting of wind and solar projects both in operation and under development, show how **projects are often located at the interfaces between two regions.** From our experiences interconnecting many of these projects, we observe that control stability of IBRs continues to be more challenging at regional interfaces. **Strengthening interregional transmission connections across seams where there are growing high-penetration pockets of IBRs can help ensure sufficient power flow during extreme weather events and, in certain cases, assist in resolving weak grid stability constraints** (e.g. between MISO and SPP). In addition, interregional sharing of services around balancing, frequency and voltage support, and managing variability and uncertainty of VER across stronger interregional ties has great benefit to reduce overall integration costs. Interregional assessment and interconnection is therefore also becoming more important as IBR penetration levels grow.

[18] ABB Hitachi

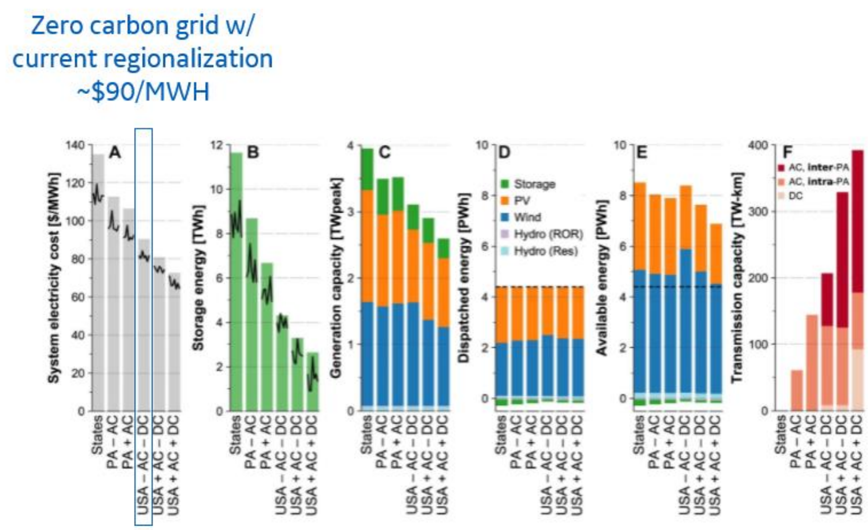


Figure 14 MIT study highlighting the economic benefit of higher regionalization to a zero-carbon grid.[19]

A recent MIT study also pointed to the benefits of higher transmission build-out to a future decarbonized US grid. In Figure 14 we show a summary of their analysis showing how a decarbonized US with higher transmission-enabled regionalization could lower average energy costs by ~$20/MWH (left graph). The areas of value are shown in the graphs to the right:

1. Lower long term storage requirement
2. Lower generation capacity requirement

One important implication of this work is that the economic benefit of greater transmission is higher than the economic benefit of greater storage in a zero-carbon electric mix.

8 Suggesting a requirement for incremental interregional transmission

For the future United States, **how can a minimum interregional transmission requirement be assessed** to reliably and cost-effectively support the anticipated renewables build-out while planning for new extreme weather events? GE team proposes the following *potential* approach to assess the operational, stability and adequacy benefits of increased transmission interconnection. This approach focuses on the technical benefits and should be used as part of a fuller analysis that considers the economics compared to alternatives.

[19] Brown and Botterud. The Value of Inter-Regional Coordination and Transmission in Decarbonizing the US Electricity Grid. MIT. (Dec 2020)

8.1 Operational incremental interregional transmission requirement

In order to assess the operational benefits of increased interregional transmission capacity, we propose simulating the dispatch of the US system under the following two conditions:

1) *Condition 1:* **Unconstrained interregional imports/exports.** We suggest removing the MW limits associated with inter-pool transmission flows to determine the total power flow amounts between pools.

   Output: **Total transmission-unconstrained interregional power flow amounts between pools.**

2) *Condition 2:* **Constrained[20] interregional imports/exports**. We suggest simulating the same system after re-instating the existing/expected MW limits associated with the inter-pool transmission flows. This will allow the determination of the total power flow amounts between pools utilizing the existing/planned transmission system. We would expect renewables curtailment to be higher under this condition.

   Output: **Total transmission-constrained interregional power flow amounts between pools.**

Utilizing simulations under both the constrained and unconstrained EI conditions would allow us to calculate an "operational incremental interregional transmission requirement." These requirements could be calculated on a pool-to-pool basis for each pool across the United States. GE MAPS is an example of a software tool that could be used for this assessment.

8.2 Adequacy incremental interregional transmission requirement

In order to determine the incremental interregional transmission requirement to support future resilience and renewables uncertainty needs. We propose using a similar approach as described in Section 8.1 with the **addition of a stochastic dimension to test for the incremental transmission need given renewables uncertainty, outages, and extreme weather.** These requirements will be calculated on a pool-to-pool basis for each pool across the United States.

Given that recent grid events have highlighted adequacy risks across every type of resource (e.g. frozen cooling water, gas supply outages, transmission outages, extreme temperatures), we suggest:

- **Broadening the potential sources of failure** (e.g. non-electric sources of failure such as gas supply outage)
- **Testing new weather extremes** (e.g. extreme temperatures)
- **Testing coincidence of failures** (e.g. extreme temperatures during gas supply failure, or cyber attacks across multiple resources simultaneously)

GE MARS would be an example software tool that could be used for this assessment.

[20] Note on Constrained and Unconstrained in this section pertains to deliverability of MW based on thermal ampacity of transmission lines. It does not include stability constraints at this stage. Stability would be assessed as part of 8.3 via screening techniques.

8.3 Stability incremental interregional transmission requirement

In order to determine the incremental interregional transmission requirement to support stability needs. We suggest the following steps:

Step 1: Use the dispatch simulation results (see Section 8.1) and transmission maps to downsselect interregional areas of high IBR penetration and series compensation.

Step 2: For each of these areas, we suggest running a production cost (e.g. GE MAPS), stability and short circuit simulations (e.g. in PSSE or GE PSLF) under the following two conditions:

Step 2.1--***Condition 1:*** Current system with current interregional ties and series compensation.
Step 2.2--***Condition 2:*** Add in incremental interregional transmission (MW) and bypass series compensation.

Step 3: Under these two conditions, we suggest testing the following on a pass/fail basis:

- ☐ **Weak grid & voltage stability**: Was the short circuit current ratio acceptable (e.g. SCR>3) in both cases?
- ☐ **Frequency stability**: Was the headroom on committed synchronous units acceptable?
- ☐ **Small signal stability**: Were there unwanted resonances?

Step 4: If any of the tests in Step 3 fail, repeat Step 2.2 with additional incremental transmission until all stability tests pass. The total additional transmission is the interregional requirement.

8.4 Total incremental interregional transmission requirement

We propose that a total incremental interregional transmission requirement would encompass the three reliability benefit components described above. It is important to acknowledge that the technical value of greater interregional transmission may stem from any or all of the three areas of reliability. **In our experience, typical studies focus on one of these three reliability areas while missing the others.** Individual pools across the US may find value from differing areas of reliability given their existing infrastructure combined with their projected expansion.

9 Conclusion: Coordinated interregional transmission is a proven enabler for resilient decarbonization

GE Energy Consulting forecasts a 2035 United States that will look similar to the California, Great Plains region and Denmark of 2020 with high penetrations of variable inverter-based renewables. The value of regionalization for increasing adequacy, operational reliability, and stability, that has been validated for SPP, California and Denmark, should be assessed for the broader US.

GE Energy Consulting has suggested a methodology to assess the incremental transmission requirement for a regionalized future US with higher renewables and extreme weather uncertainty. This incremental requirement would be based on a holistic assessment of three areas of reliability benefit:

1) *Operational:* Incremental interregional transmission can enable lower wind and solar curtailment which results in fuel cost savings.
2) *Adequacy:* Incremental interregional transmission can enable higher generation diversity in the face of uncertainties such as: generation, transmission or fuel outages or extreme weather events.
3) *Stability:* Incremental interregional transmission can enable greater system strength to avoid unintentional unit tripping due to fluctuations in voltage, frequency or unwanted oscillations.

Today, there are limited practices in place for each region to evaluate the consumer benefits of regionalization on their own. National-level guidance would help chart the path towards realizing the benefits of greater regionalization.

APPENDIX: GE ENERGY CONSULTING RENEWABLE INTEGRATION STUDY REFERENCES

Most of GE Energy Consulting's wind and solar integration study work is publicly available at the following links:

- Australian Energy Market Operator, "Technology Capabilities for Fast Frequency Response," https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2017/2017-03-10-GE-FFR-Advisory-Report-Final---2017-3-9.pdf
- Barbados Light & Power Company , "Barbados Wind and Solar Integration Study," http://www.blpc.com.bb/images/watts-new/Barbados%20Wind%20and%20Solar%20Integration%20Study%20-%20Exec%20Summary.pdf
- California Energy Commission's Intermittency Analysis Project Study "Appendix B - Impact of Intermittent Generation on Operation of California Power Grid," http://www.energy.ca.gov/2007publications/CEC-500-2007-081/CEC-500-2007-081-APB.PDF
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- New York State Energy Research and Development Authority's "The Effects of Integrating Wind Power on Transmission System Planning, Reliability, and Operations," http://www.nyserda.ny.gov/-/media/Files/EERP/Renewables/wind-integration-study.pdf
- Nova Scotia Power, Inc., "Nova Scotia Renewable Energy Study," Jun, 2013 https://www.nspower.ca/site/media/Parent/2013COSS_CA_DR-14_SUPPLEMENTAL_REISFinalReport_REDACTED.pdf
- NREL "Eastern Frequency Response Study," June 2013, https://www.elp.com/articles/print/volume-93/issue-1/sections/t-d-operations/eastern-interconnection-offers-positive-outlook-for-wind-generation-with-frequency-responsive-plant-controls.html
- NREL, "Western Wind and Solar Integration Study,"
- http://www.nrel.gov/docs/fy10osti/47434.pdf
- http://www.nrel.gov/docs/fy10osti/47781.pdf
- PJM Interconnection, LLC, "PJM Renewable Integration Study," http://www.pjm.com/~/media/committees-groups/subcommittees/irs/postings/pris-executive-summary.ashx