Grid Value Potential of Oregon Offshore Wind Energy

Perspective from the Pacific Outer Continental Shelf

June 17, 2020

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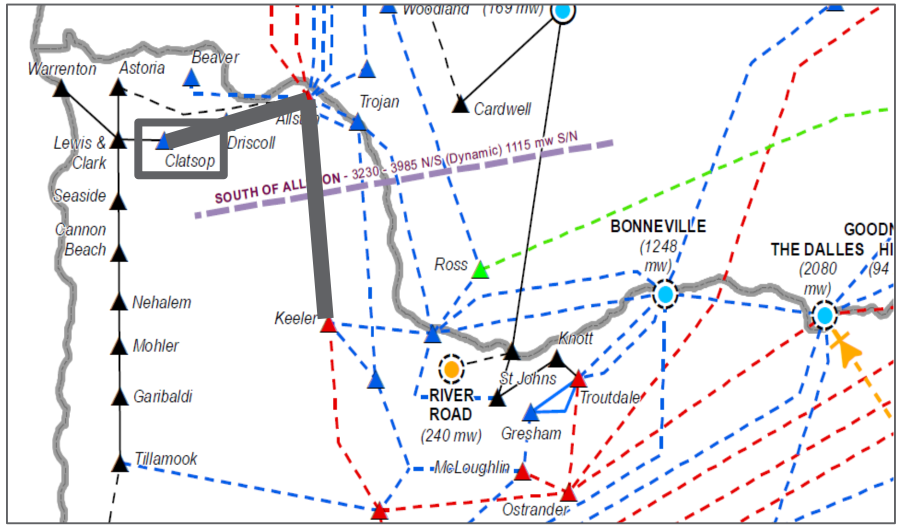
Agenda

- Why Offshore Wind (OSW) in Oregon?
- *Resource Complementarity:* To what degree does OSW complement existing energy resources?
  - Variable Renewable Energy (VRE)
  - Hydropower
- *Load Complementarity:* To what extent does OSW naturally align with load patterns?
- *Locational Value*: What impacts can be expected on coastal and regional transmission grids?
- Summary
- Next Steps
- Questions



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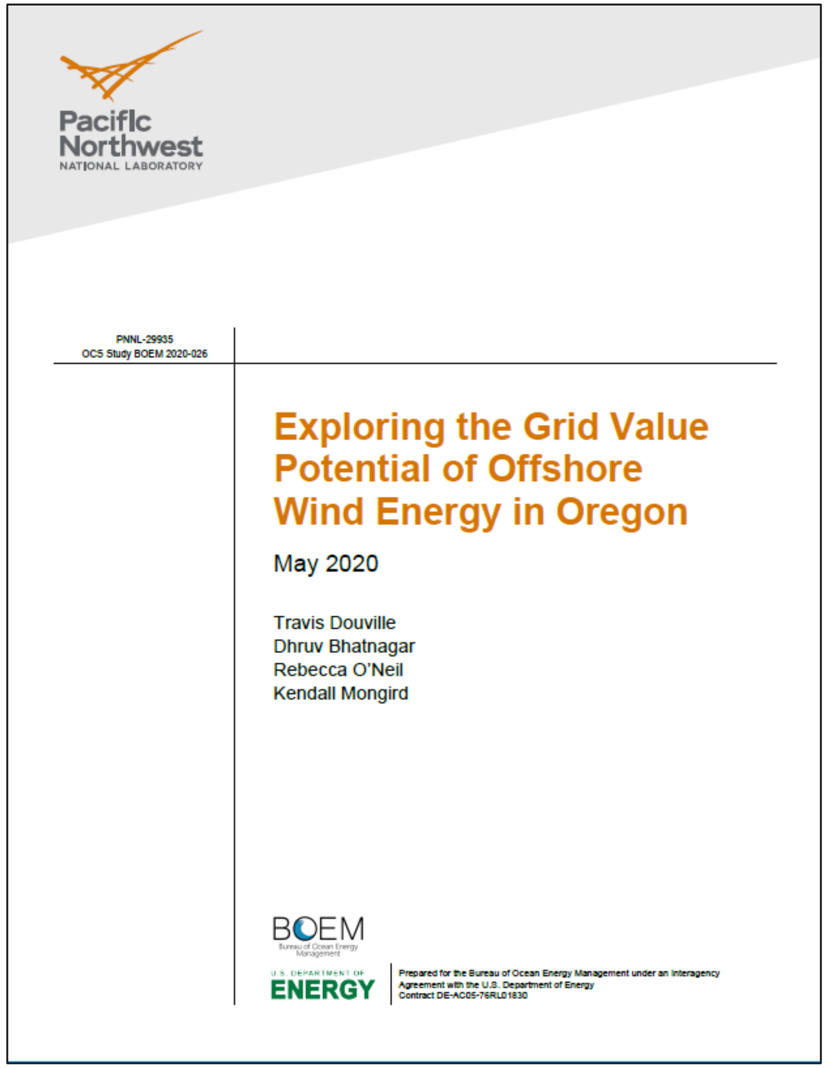
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PNNL-29935
OCS Study BOEM 2020-026

Exploring the Grid Value Potential of Offshore Wind Energy in Oregon

May 2020

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BOEM

U.S. DEPARTMENT OF ENERGY

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Full report available:

https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-29935.pdf

Key Findings

- **Regional transmission may be able to carry significant OSW contributions (2-3 GW) with minimal transmission investment and limited power export**
- **OSW power flows would relieve historic transmission flows**
  - OSW frees east-to-west transmission which may assist additional VRE transmission
  - Coastal loads could be served largely by OSW
- **OSW naturally complements loads better than Northwest onshore wind**
- **OSW could complement regional clean energy sources**
  - Consistency of OSW speeds in late summer may benefit constrained hydropower
  - OSW could help hydropower balance Gorge wind

Oregon’s Offshore Wind Resource—Context

Opportunities

- World-class offshore winds (OSW)
- Oregon’s clean energy targets
- Thermal retirements
- Emergence of solar energy
- Electrification futures
- Changing seasonal water availability for hydropower
- California’s energy prices, duck curve, and clean energy targets

Challenges

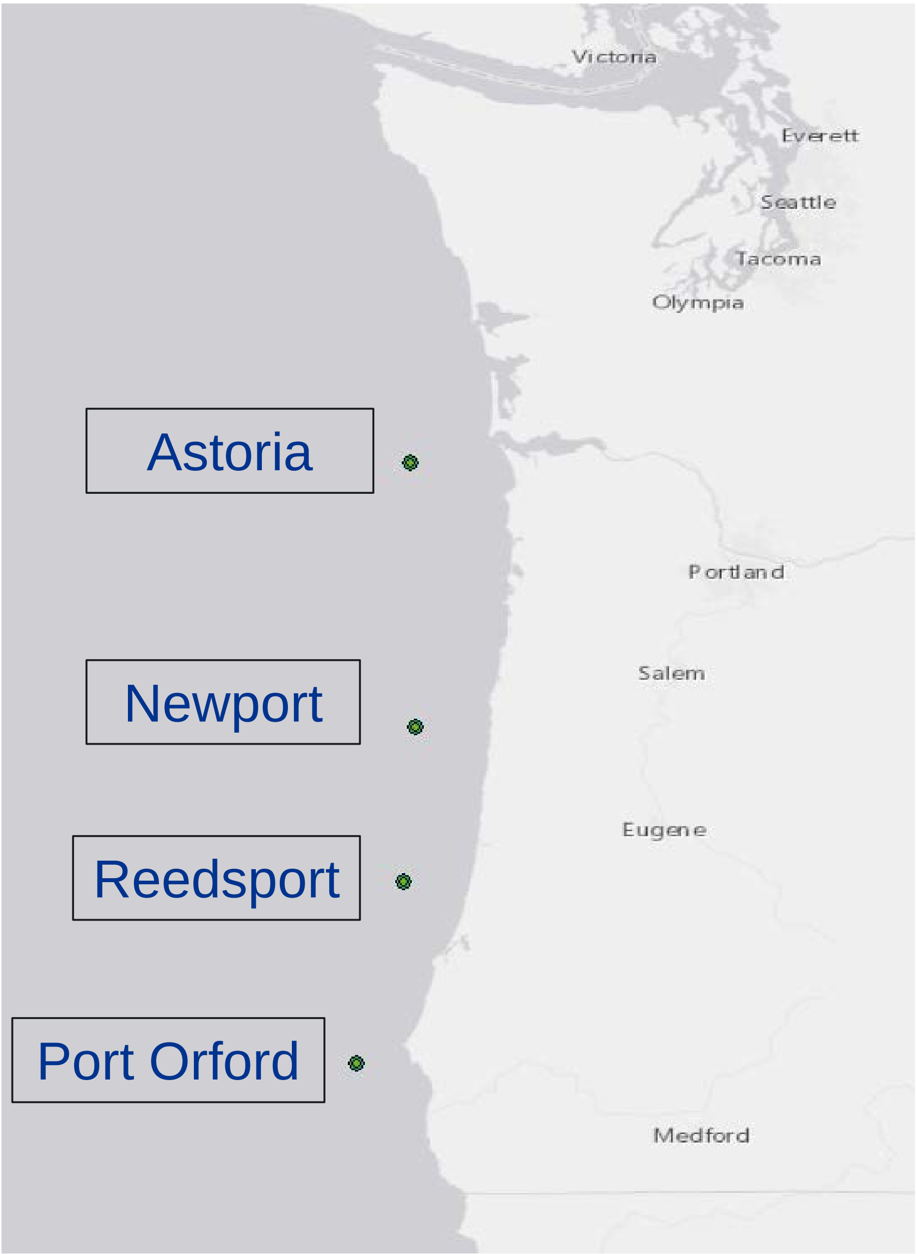
- Low-cost and plentiful hydropower
- Limited load growth
- Natural gas
- Distant load centers
- Coastal range topography
- Undeveloped coastal infrastructure

A comprehensive understanding of OSW value in Oregon electricity grids and the Western Interconnection is necessary to weigh opportunities against challenges.

Wind Resource Characteristics

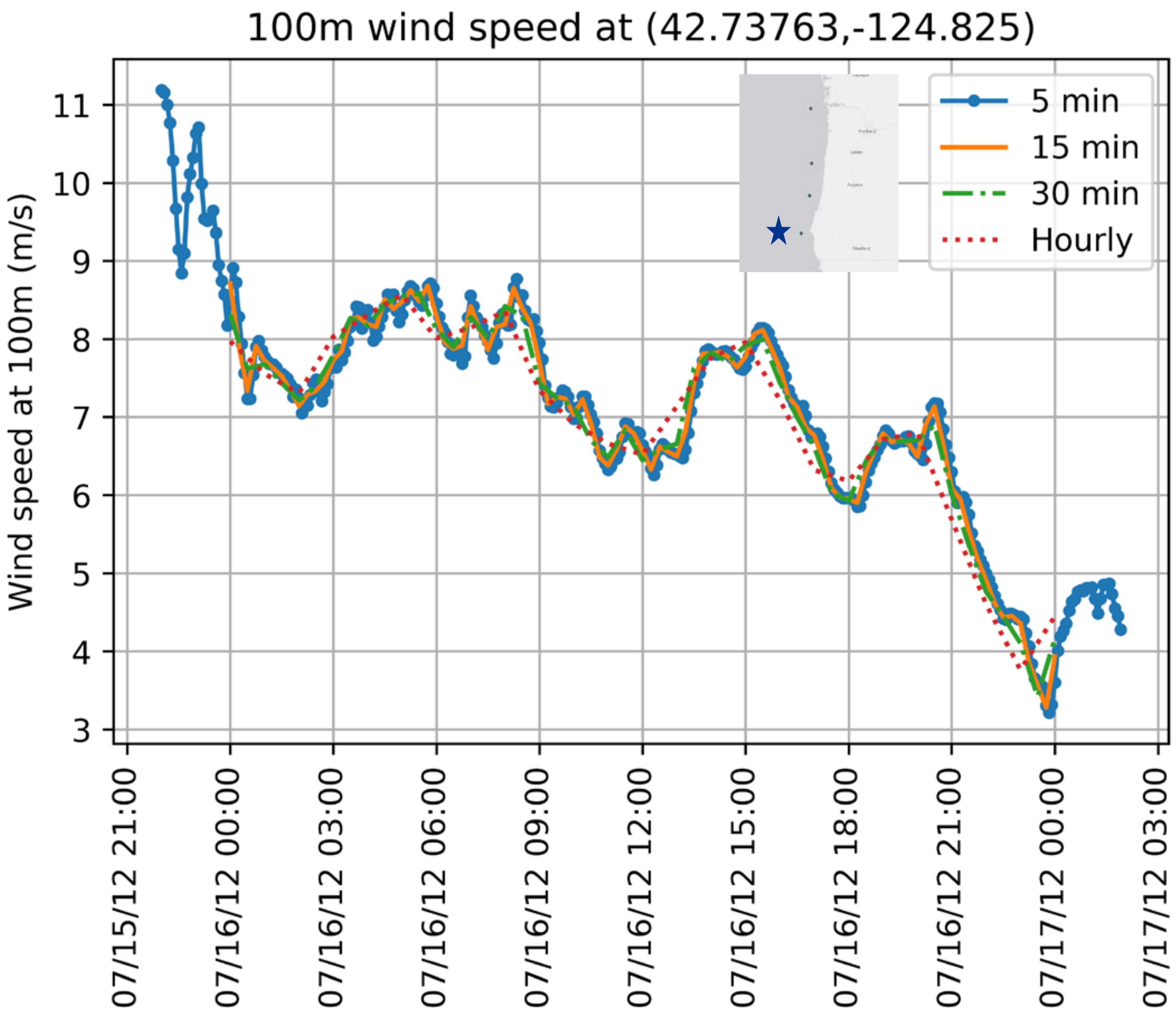
Locations along the OR Outer Continental Shelf:

Location	Distance Offshore (km)	Latitude, Longitude (NAD83)
Astoria	42	(46.13978, -124.5193)
Newport	33	(44.63749, -124.4879)
Reedsport	30	(43.76358, -124.5609)
Port Orford	27	(42.73763, -124.8250)



Wind Resource Characteristics

- Techno-Economic WIND Toolkit (NREL)
- 5-min data for 7 years (2007-2013)* at ~120k points
- Preliminary investigation restricted to 100m wind speeds
- Wind speed use as 1st order proxy for power
- 5 minute data offers insights relevant to ramp rates & balancing reserves
- Data resampled at 15-min, 30-min, and hourly intervals



* Data from 2007-2012 were available for this study

Resource Complementarity—VRE

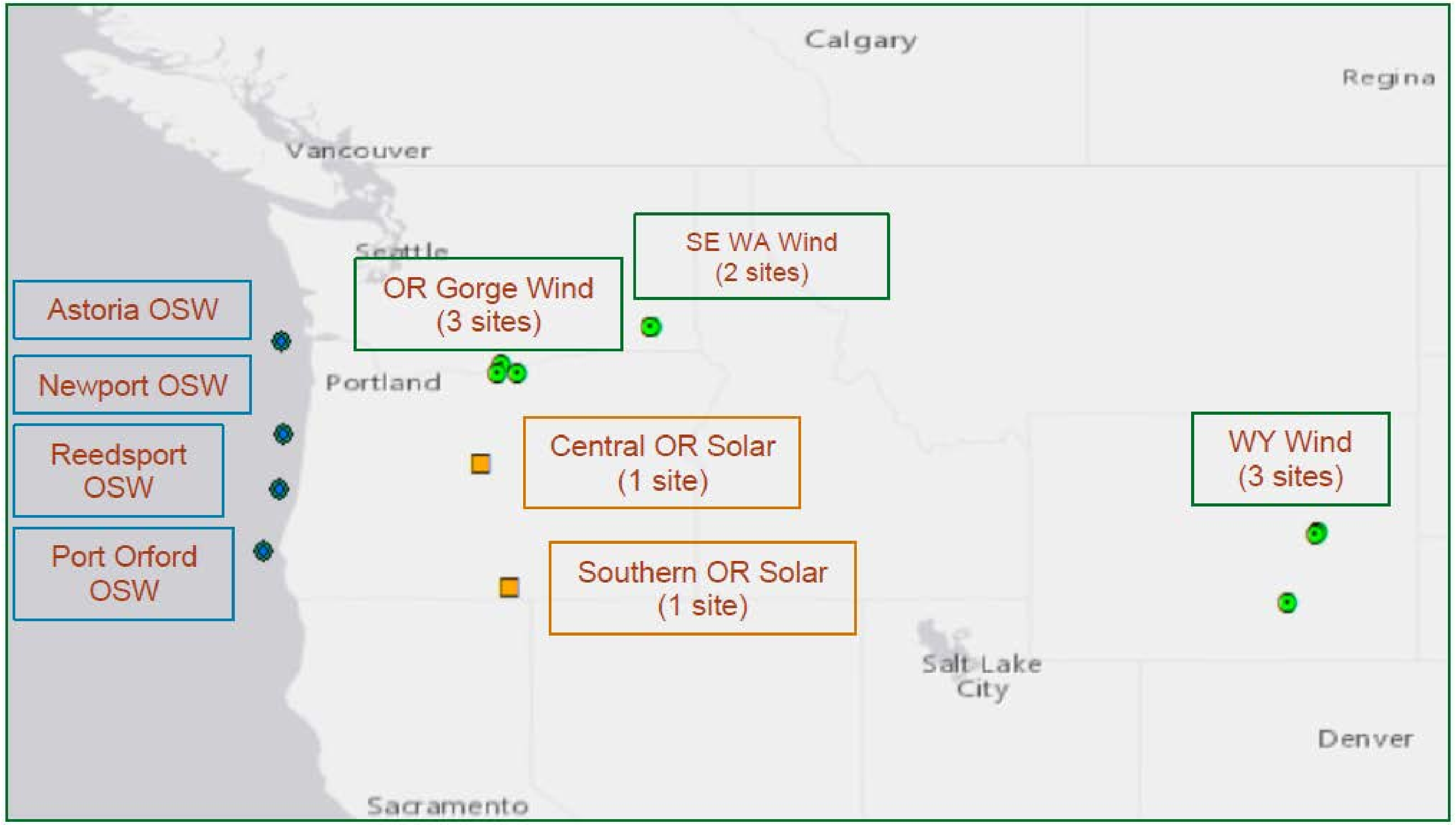
Variable Renewable Energy (VRE) study:

+8 "terrestrial" wind (TW) locations

- All in proximity of PGE/Pacificorp parks:
- 3 in the Columbia River Gorge ("OR Gorge")
- 2 in Southeast Washington (SE WA)
- 3 in Wyoming (power wheeled to region by Pac)

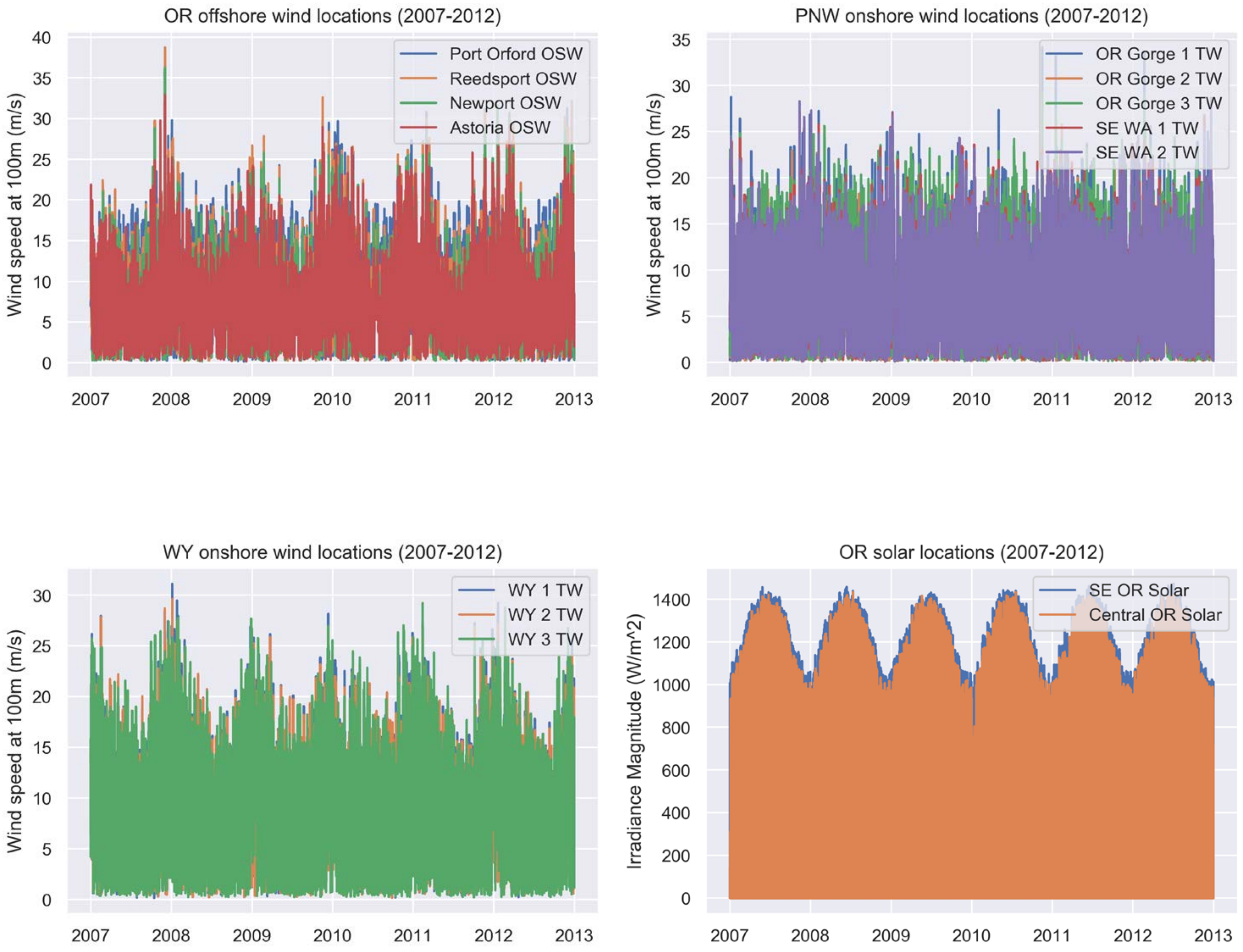
+2 solar farms (OR Solar Dashboard)

- Hourly DNI, GHI data from National Solar Radiation Database (NSRDB)
  - Central OR
  - Southern Oregon
- Irradiance magnitude used as proxy for generation in correlation studies



Resource Complementarity

- Resource data only, all years

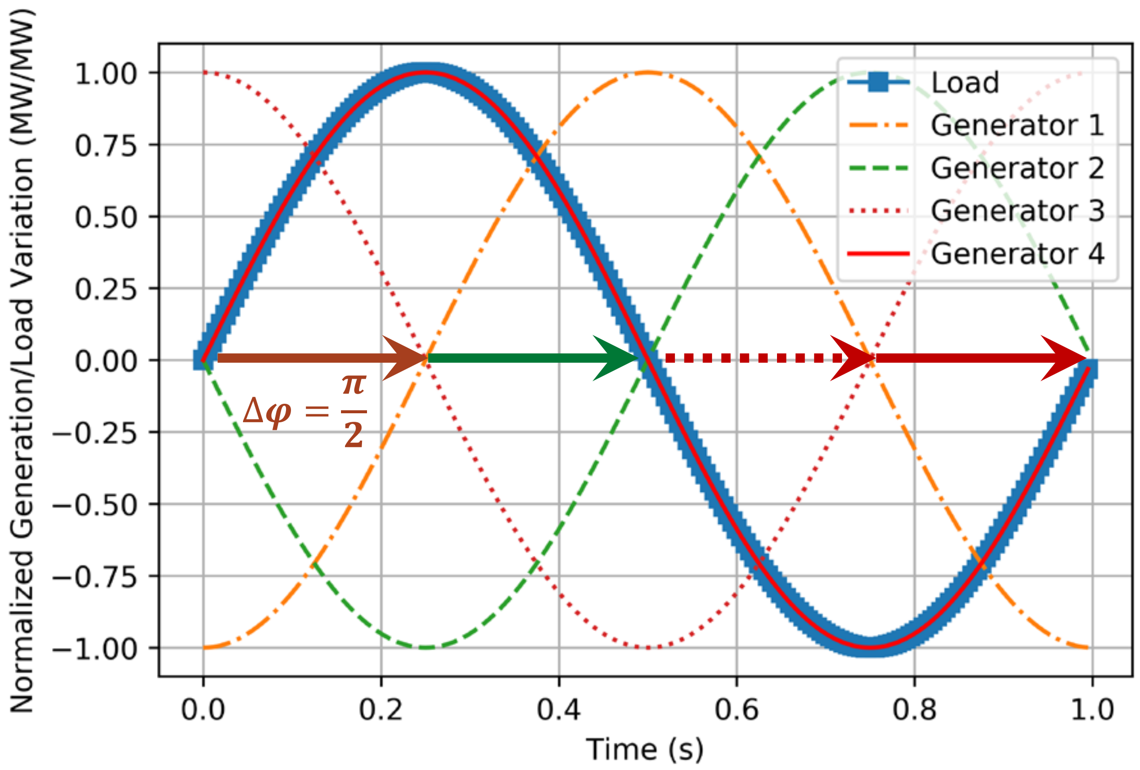


Complementarity

- Pearson's Correlation Coefficient

$$r_{x,y} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

- Hypothetical example (90° phase-shifted sine waves)



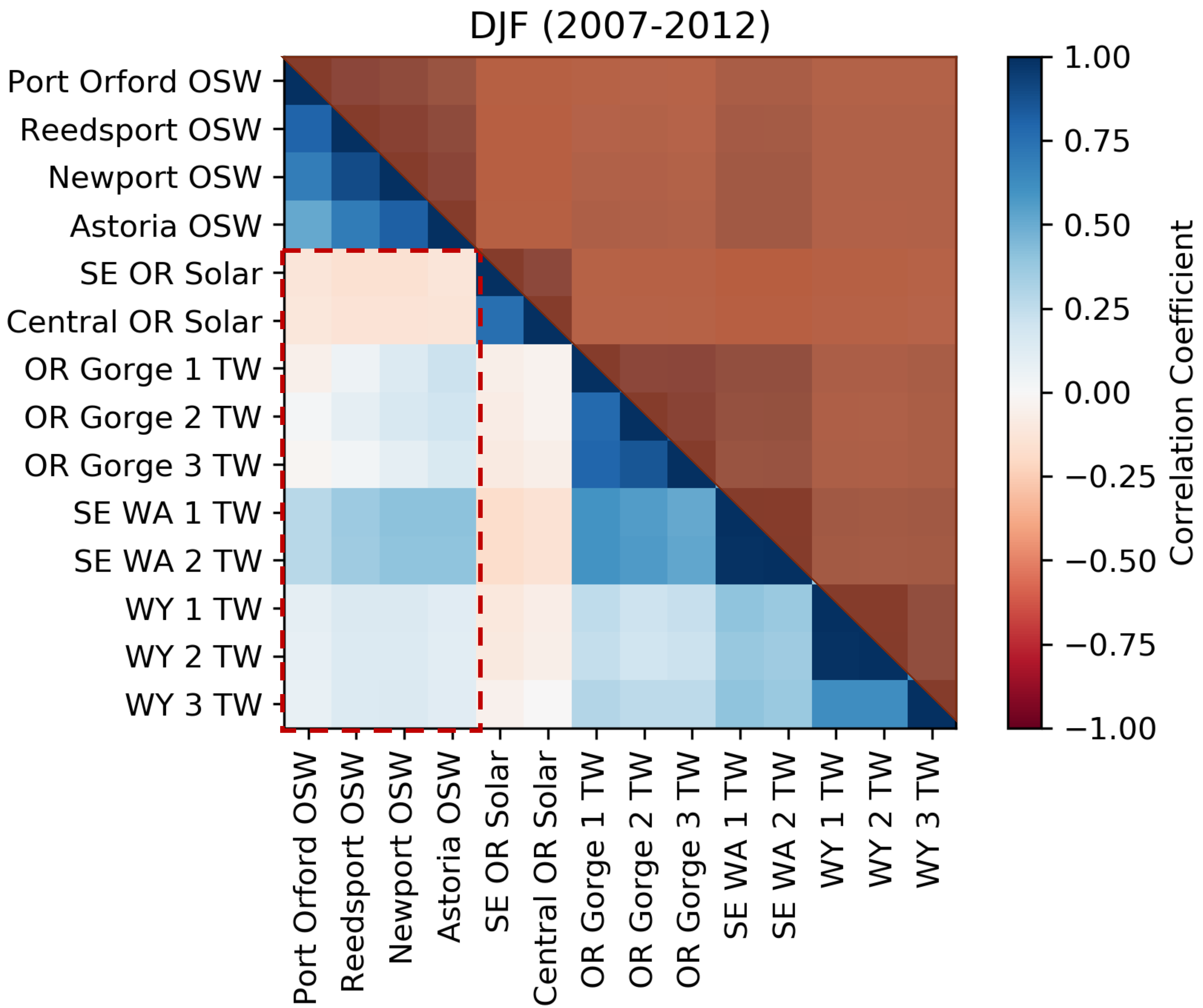
r(i,j)	Load	Gen 1	Gen 2	Gen 3	Gen 4
Load	1	0	-1	0	**1**
Gen 1	0	1	0	**-1**	0
Gen 2	-1	0	1	0	-1
Gen 3	0	**-1**	0	1	0
Gen 4	**1**	0	-1	0	1

Positive correlation desired between generator and load.
Negative correlation desired between generators.

Units of *X*, *Y* cancel in Pearson's calculation.

Resource Complementarity

- Hourly correlations grouped by seasons over all years
- Wind resource correlations a 1st-order proxy for wind power generation
- Solar irradiance magnitude a 1st order proxy for solar power generation



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Resource Complementarity

1. ***r*(OSW, Gorge TW) ~ -0.2 (summer), -0.13 (spring)**

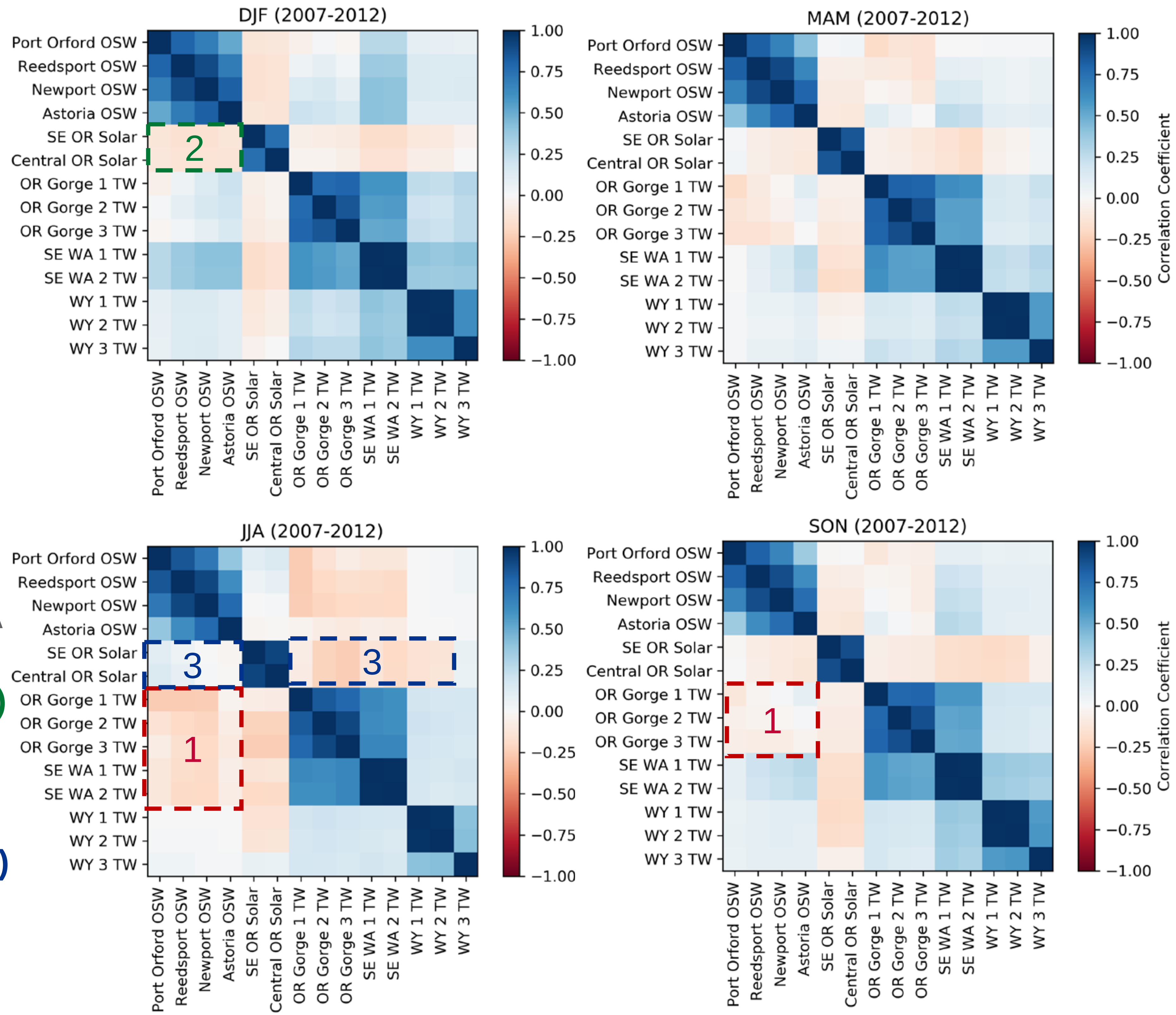
   OSW could help balance Gorge, SE WA wind in the summer

2. ***r*(OSW, OR solar) ~ -0.15 (winter)**

   OSW could complement OR solar to help meet regional peak loads

3. ***r*(TW, OR solar) ~ -0.2 (summer) > *r*(OSW, OR solar) ~ 0 (summer)**

   OSW does not complement solar as well as TW in the summer



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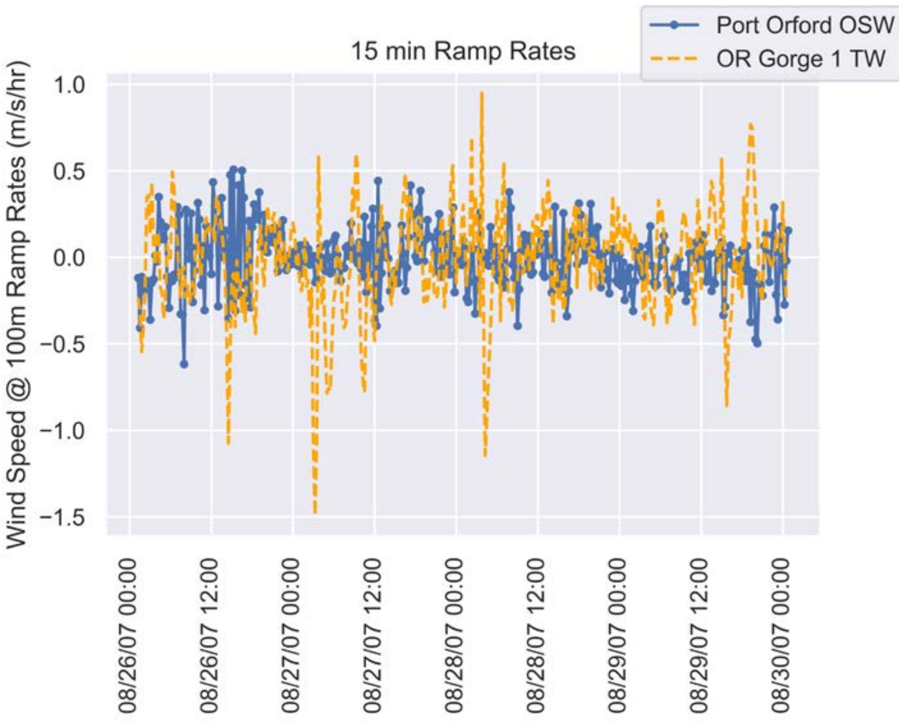
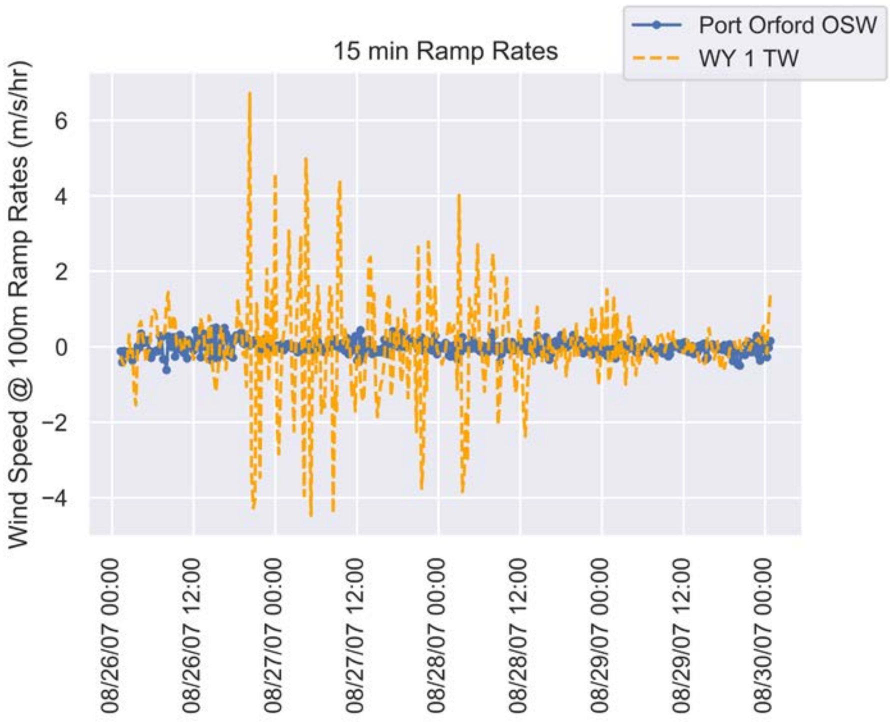
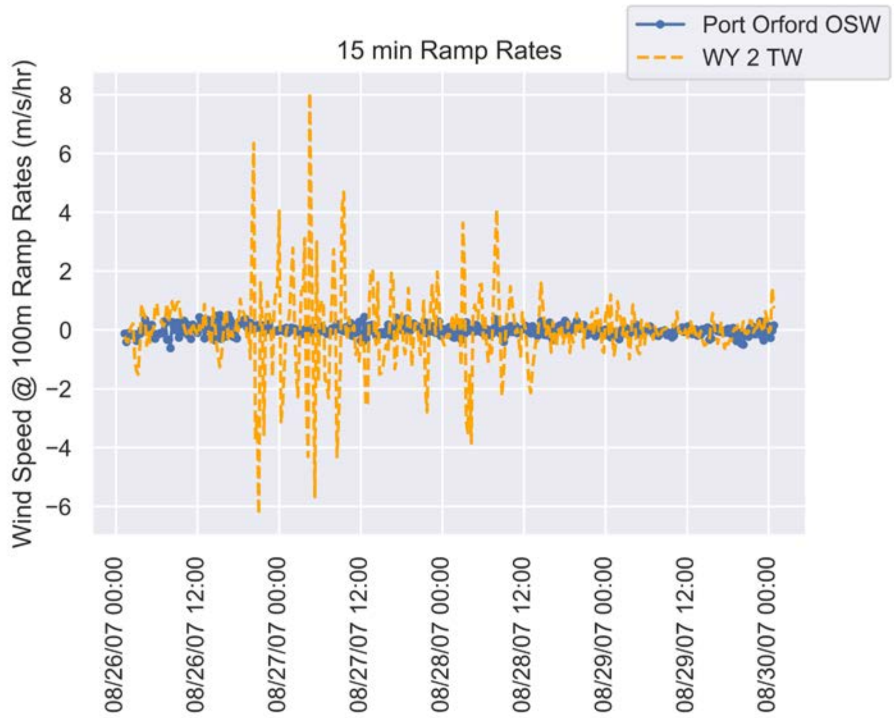
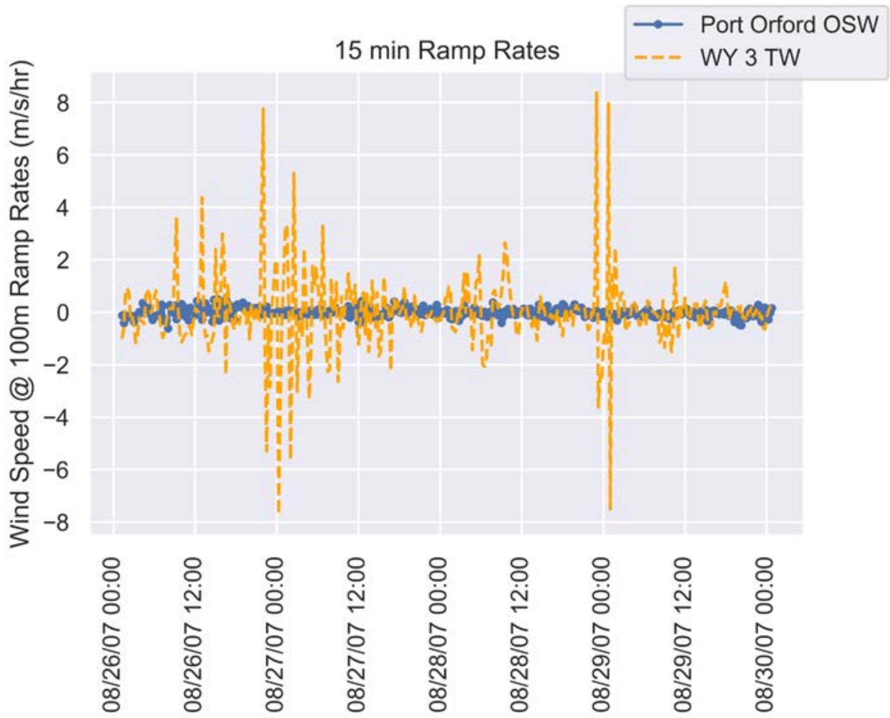
Resource Complementarity

- Sub-hourly, diurnal, seasonal profiles inform additional values
- Beyond the plausibility of “more consistent” offshore winds:
  - Good physical reasons (less thermodynamic variability, terrain complexity)
  - Regionally-specific complications
    - Atmospheric stability variability (Archer 2016, Kettle 2014)
    - Upwelling and unstable ocean water stratification
    - Wave-pumping mechanism
    - Ocean depth & currents



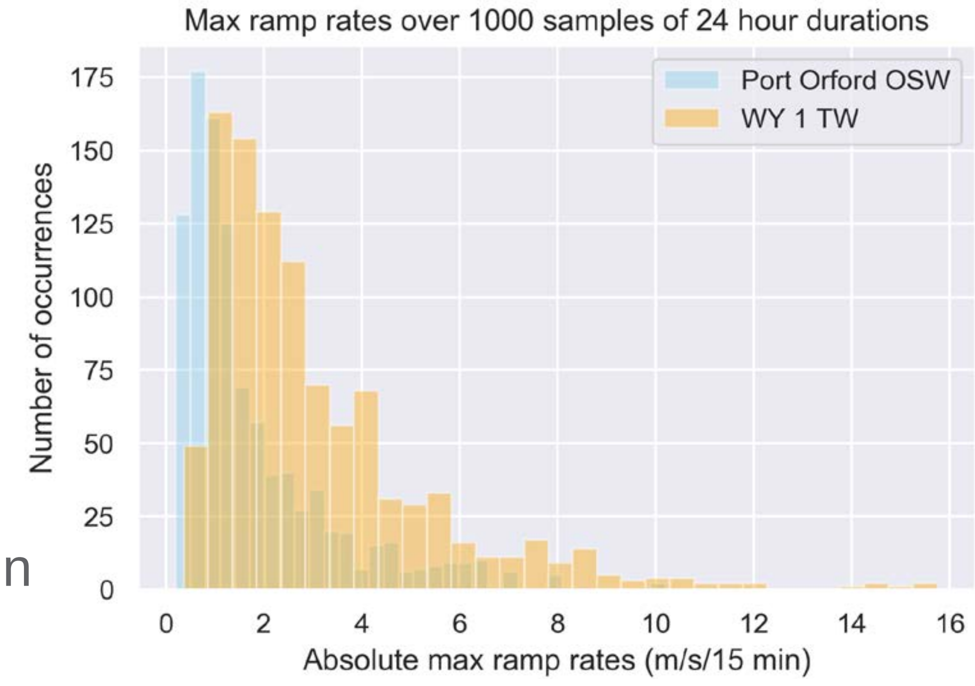


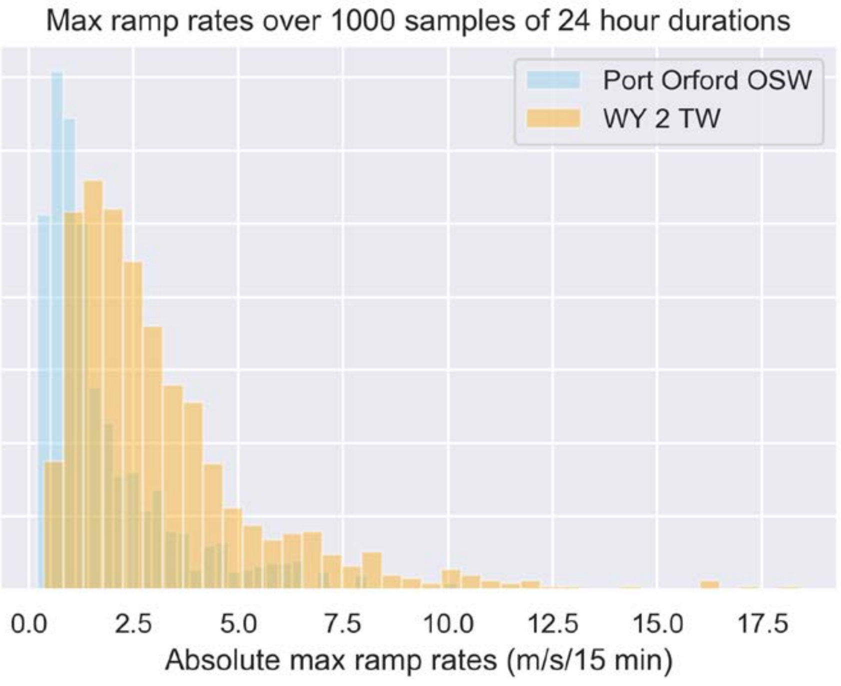


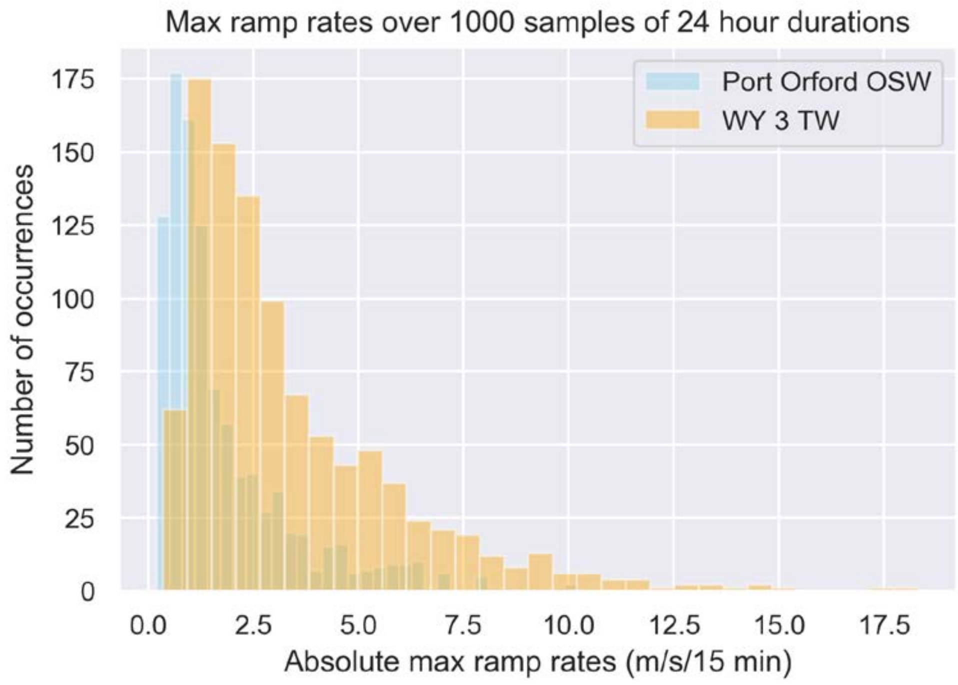


Resource Complementarity
OR OSW / WY TW

- Maximum absolute values of 15-min ramp rates occurring within a 24 hour period
- 1000 24-hour periods randomly selected over 6 years
- Comparisons between OSW (blue) and WY TW (orange)
- OSW indicates a smoother wind resource than Wyoming wind
- *Project LCOE optimization does not account for the system requirements to integrate the resource*



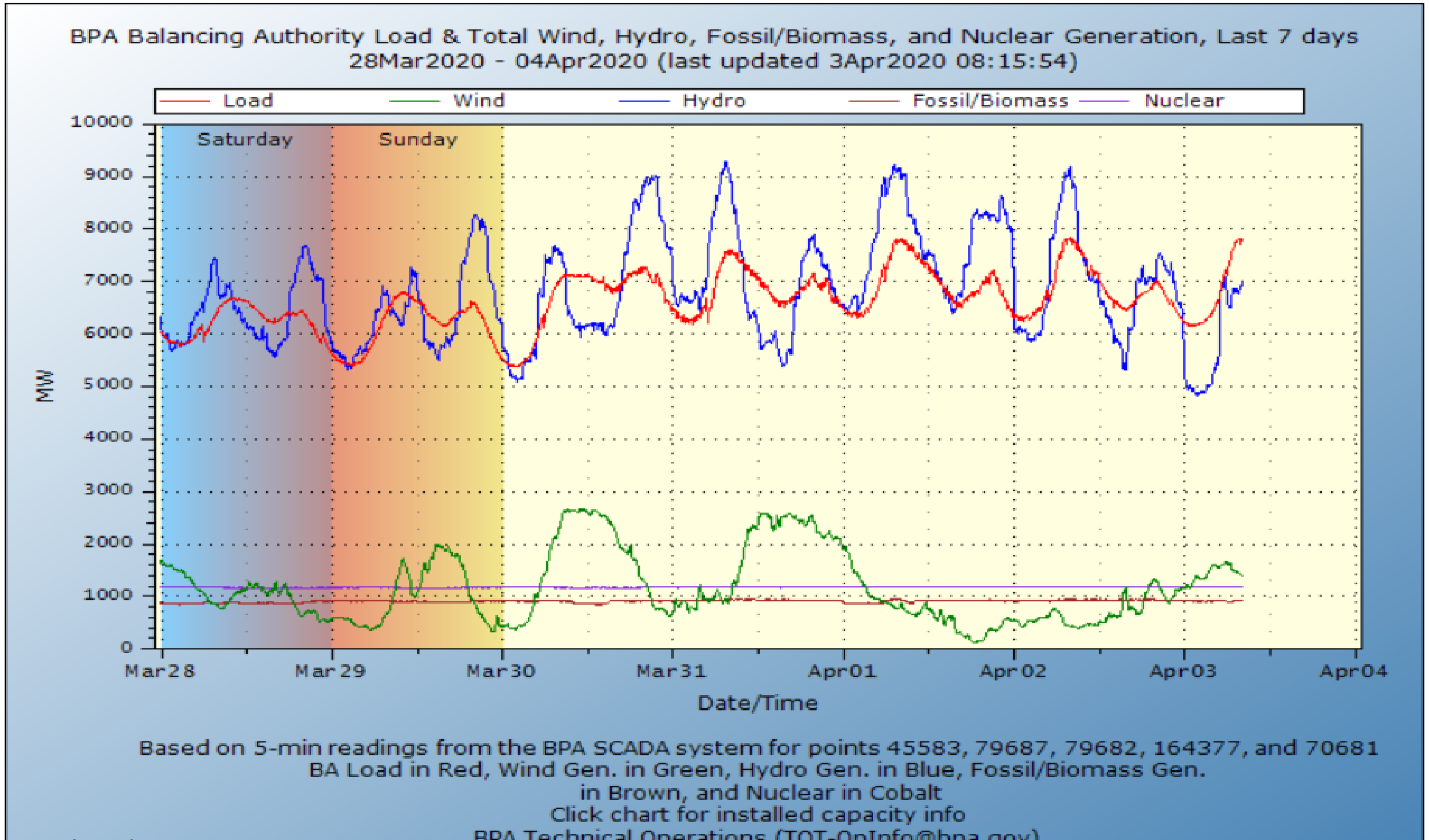




Resource Complementarity—Hydro

- Regional hydropower differs from VRE:
  - Dispatchable
  - Inter-annual variability
  - River management
- Alternate approach needed

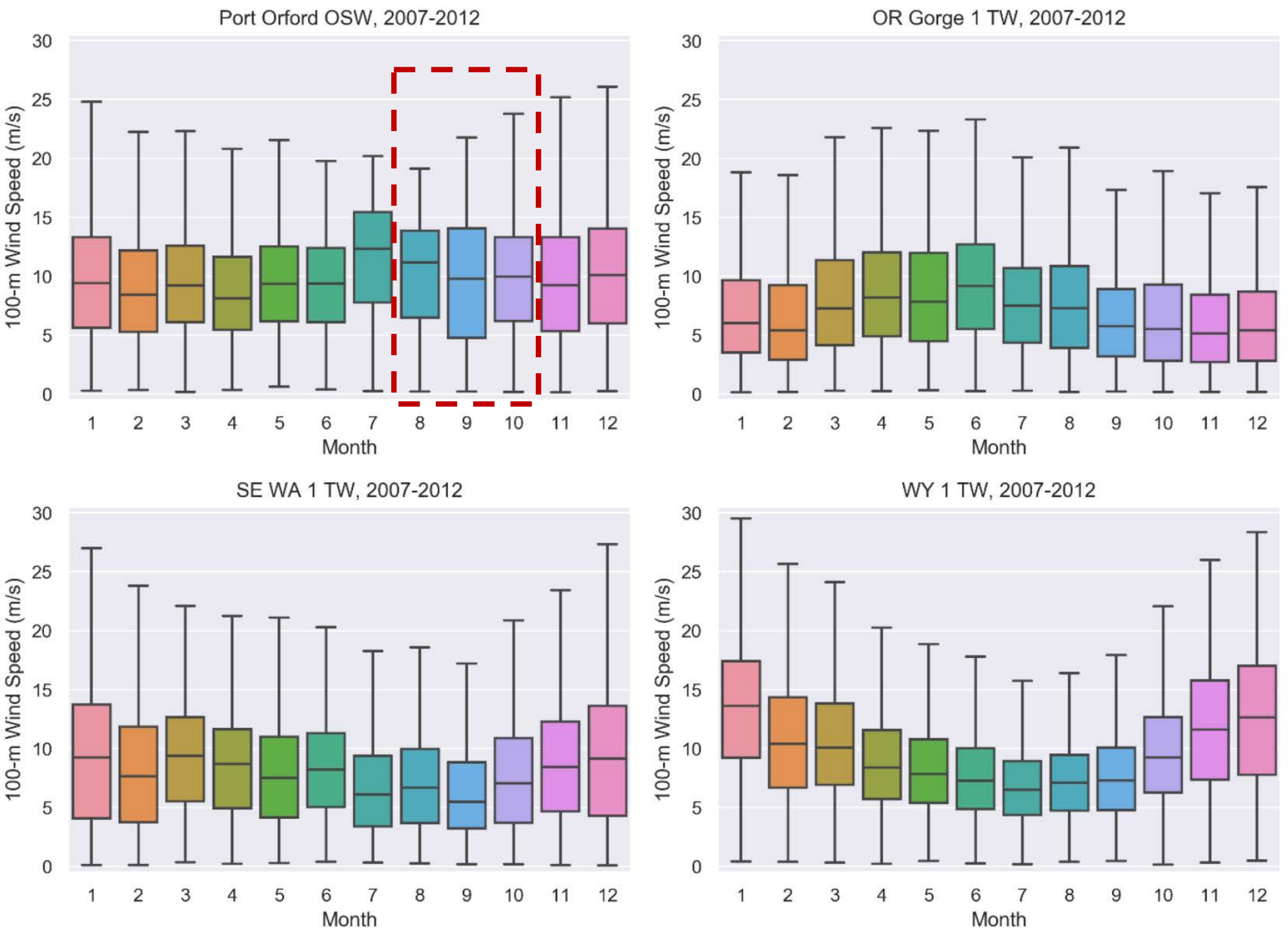
Florescu, & Pead (2018)



BPA (2020)

Resource Complementarity—Hydro

- Late summer constraints:
  - Depletion of water resource
  - Increase in river temperatures mean that the river must flow to preserve habitat
  - Hydropower flexibility is reduced
- OSW holds a more consistent production profile through the summer than TW resources



Resource Complementarity—Hydro

- Late summer constraints:
  - Depletion of water resource
  - Increase in river temperatures mean that the river must flow to preserve habitat
  - Hydropower flexibility is reduced
- These constraints will become more constrictive in dry *and* wet years as temperatures rise
  - More precipitation will fall as rain and less “stored” as snow in the mountains
  - There is limited storage of Columbia River Hydro system to compensate
- OSW late summer consistency becomes even more important under these scenarios
- Resource Adequacy concerns

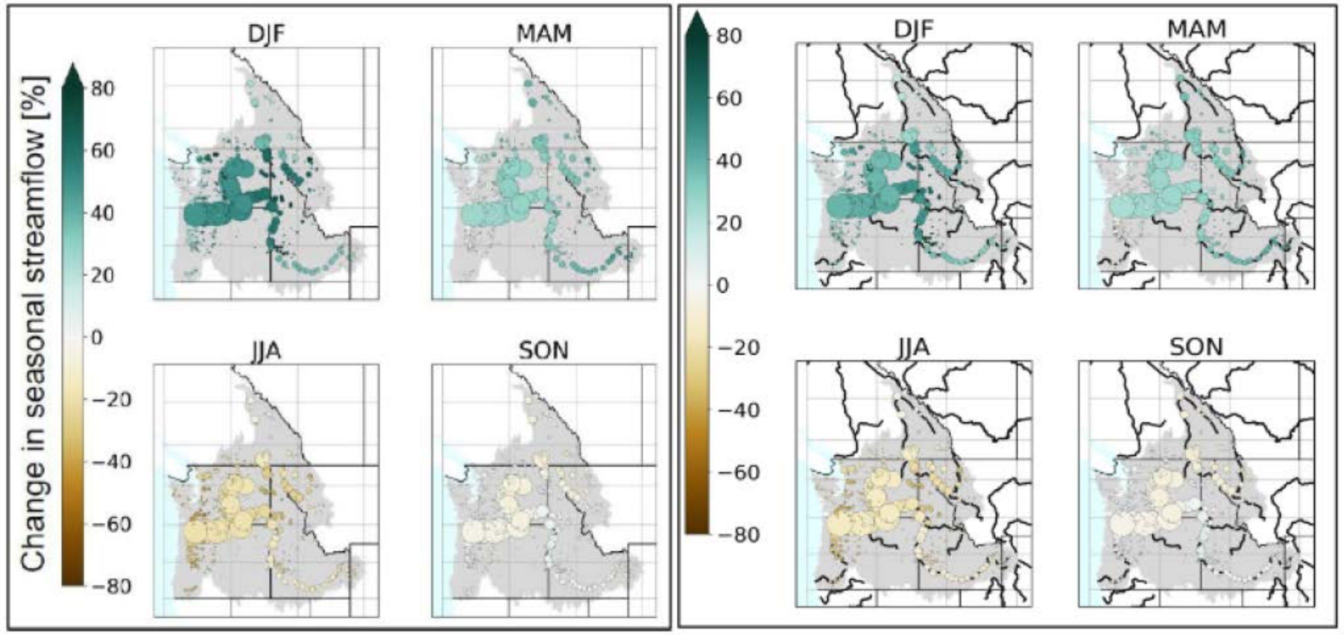


Figure 9. Anticipated shift from historical streamflow (1976-2005) to streamflow futures (2020-2049), by seasons, showing modeled increase in winter flows and decrease in summer flows. The left and right chart represent Representative Concentration Pathways (RCP) 8.5 (watts/square meter) and RCP 4.5 warming scenarios, respectively. Circle size is correlated to volume. FCRPS DEIS, citing University of Washington as the source.[10]

[10] As discussed in Columbia River System Operations Draft Environmental Impact Statement, Chapter 4, Climate, Subsection 4.1.2.4. Streamflow. March 2020. "https://cdm16021.contentdm.oclc.org/utils/getfile/collection/p16021coll7/id/13754"https://cdm16021.contentdm.oclc.org/utils/getfile/collection/p16021coll7/id/13754

Load Complementarity using Production Cost Modeling

- ABB's GridView Model: GridView simulates security-constrained unit commitment and economic dispatch in large-scale transmission networks
- WECC Anchor Data Set Case (2028 ADS V2.0 PCM base case available July 2019)
  - The study uses this case as-is and did not make any changes to resources, transmission, or topology contained within the case. The case includes resource updates in accordance with published integrated resource plans (IRPs) and the addition of transmission projects in the 10-year planning horizon made publicly available to the grid planning community
  - Hourly resolution for a one-year duration of the model year 2028
  - Nodal model: load nodes within each balancing authority
- Regional hydro units are *generally* modeled under the following parameters:
  - No contracts (i.e. with PUDs or CA), set as a "load following" resource
  - Minimum and max generation capacity by month (water flow)
  - Minimum monthly energy (flows)
  - Zero cost resource
  - *Some small hydro resources are set with specific flow shapes*

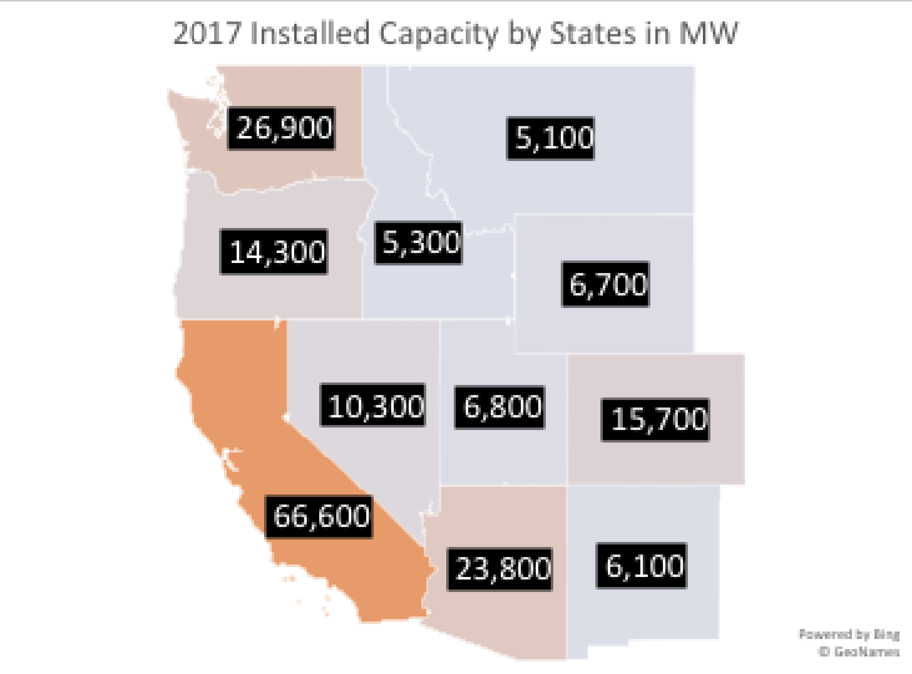
Load Complementarity — WECC Anchor Data Set: What changes in the grid between 2018-2028?

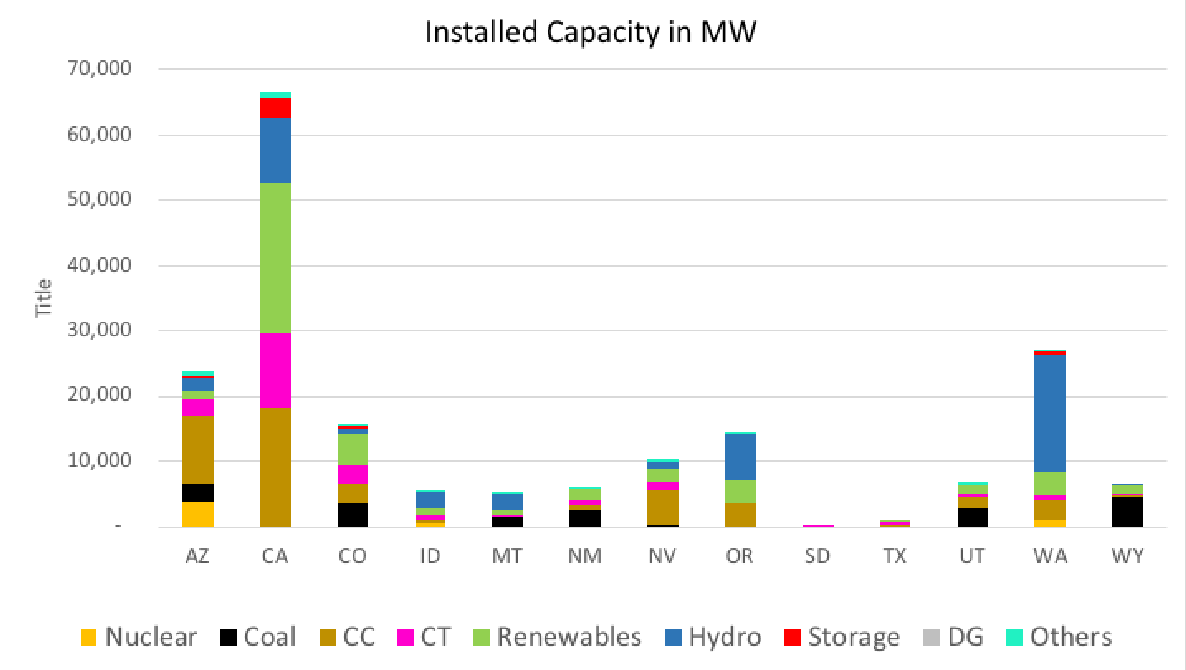
Current Grid

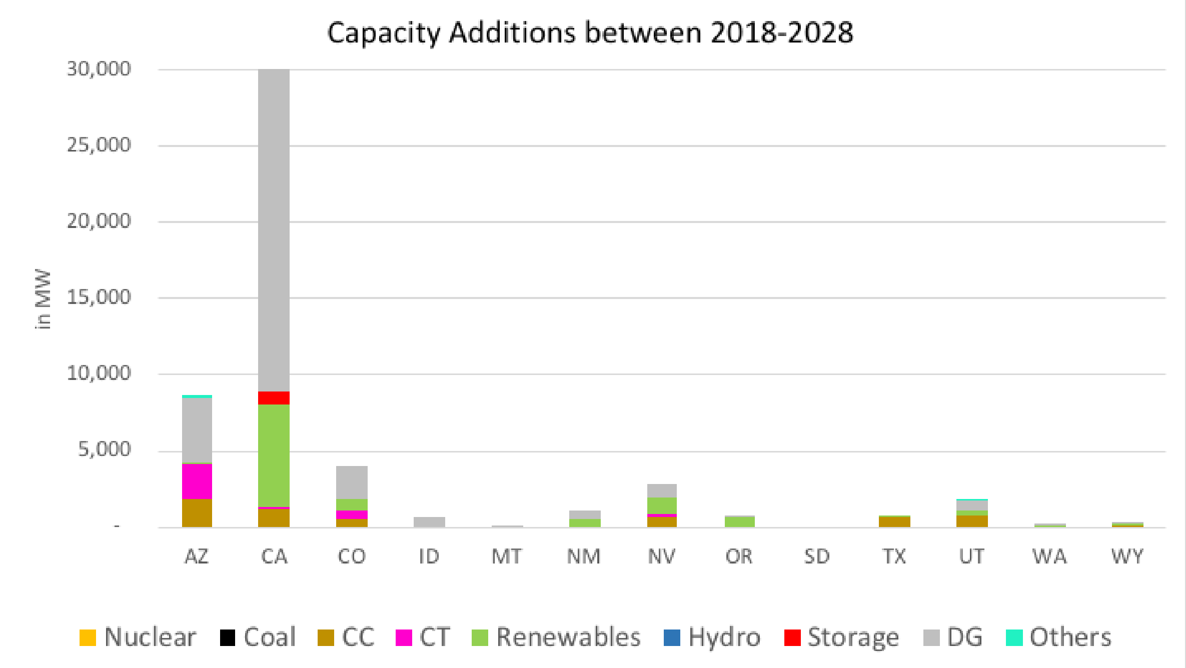
- Most installed capacity along the West Coast (WA, OR, CA)

WECC ADS Updates (IRP based)

- Distributed Generation (DG) predominantly distributed PV in (CA, AZ, CO, NV, UT)
- Renewables (Solar utility scale and wind)
- Natural gas technology (CC, CT)
- Minor transmission upgrades

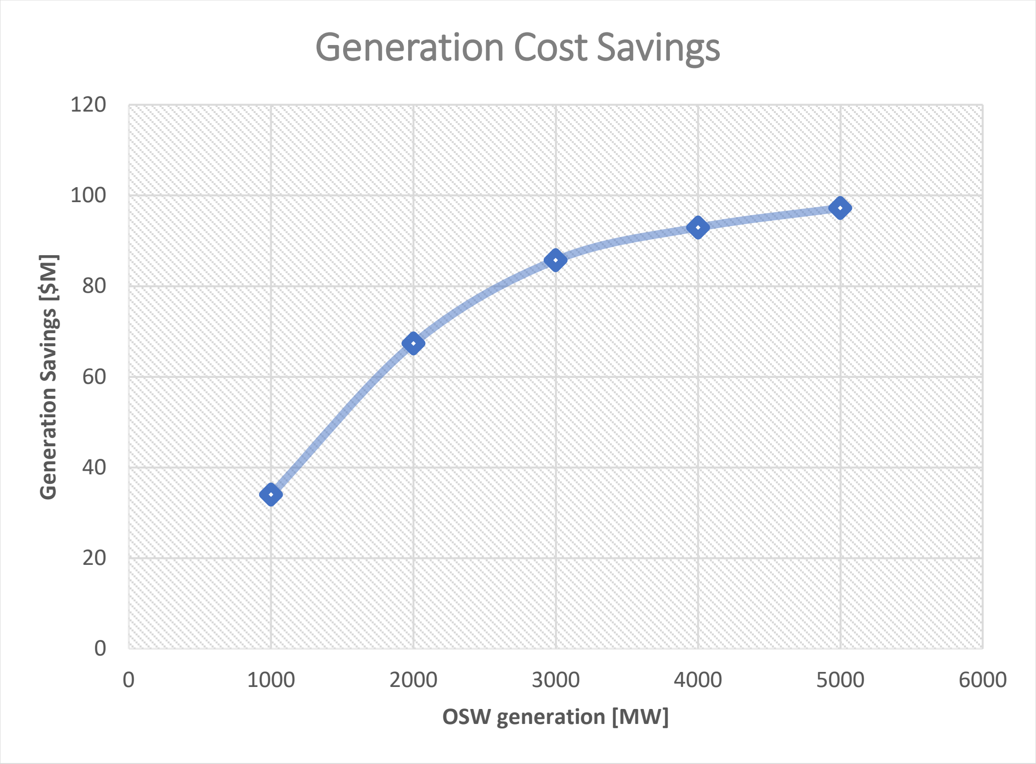






Source:
WECC: 2028 Anchor Data Set.
GridView. Energy Portfolio Management: ABB. 2019. avail: https://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/gridview

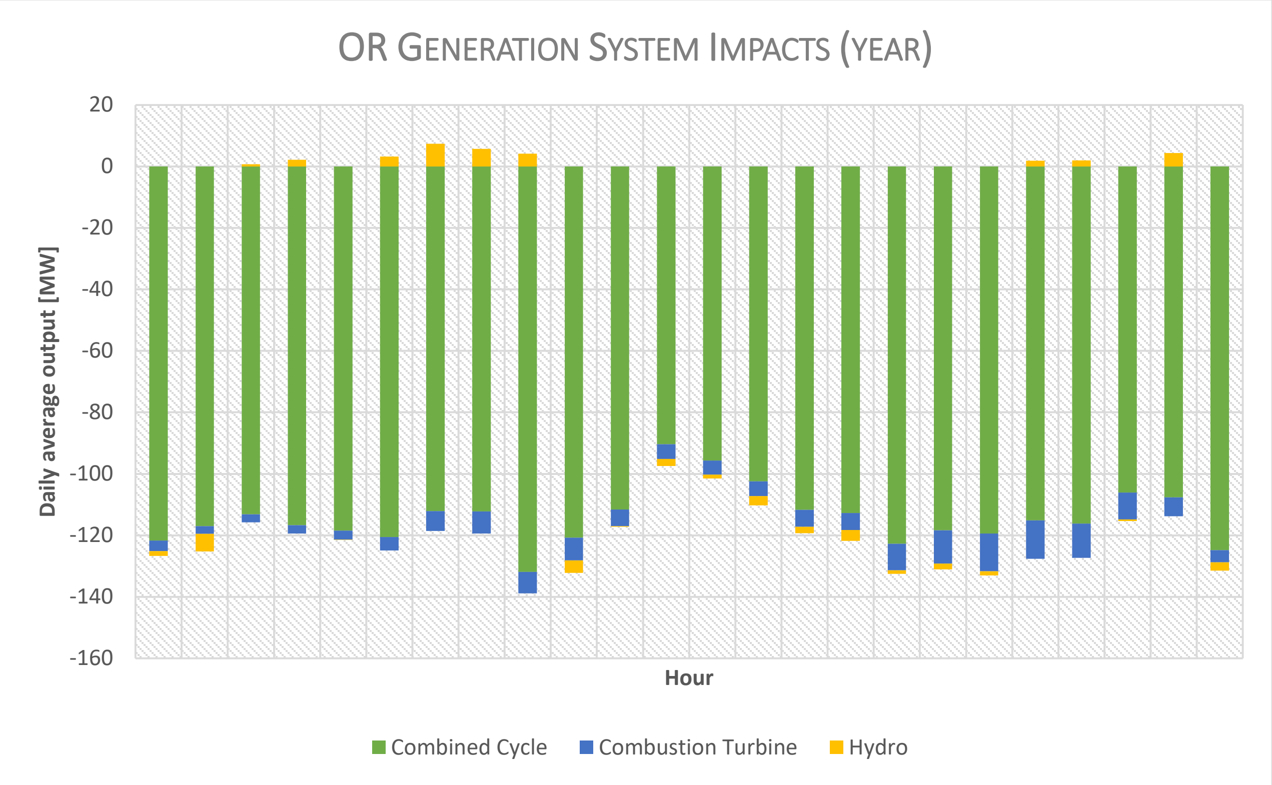
Load Complementarity — System Impacts

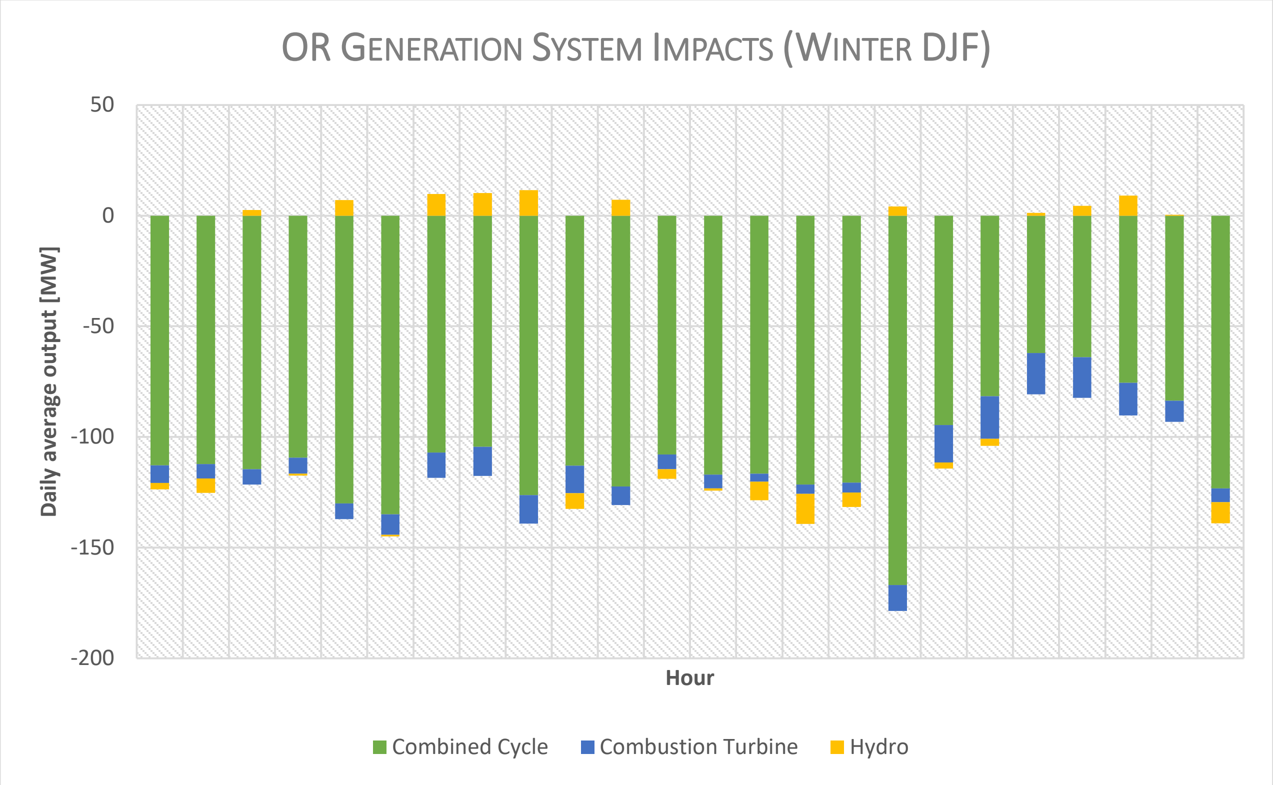


Scenario	Generation Cost ($M)	Average LMP ($/MWh)	CO_2 (st)	NOx (st)	SO_2 (st)
1 GW OSW	-34.00	-0.92	-704,783	-399	-4.1
2 GW OSW	-67.32	-1.84	-1,332,254	-771	-7.6
3 GW OSW	-85.72	-2.64	-1,667,821	-976	-9.5
4 GW OSW	-92.92	-2.88	-1,793,679	-1,055	-10.2
5 GW OSW	-97.21	-3.04	-1,863,317	-1,116	-10.8
3 GW + EV	-89.68	-3.44	-1,783,355	-1,040	-11.9

Notes:
1. Savings are for the BPA, PGE and PACW balancing authorities and are relative to the base case model for 2028, and for the electric vehicle base model (PNNL EV study)
2. Cost savings primarily consist of reduction in fuel use from traditional plants.
3. The EV case assumes the deployment of 24 million light duty vehicles across the WECC.

Load Complementarity — Generation Impacts





- Offshore wind is primarily impacting the use of fossil resources in all months.
- Hydro resources are relatively minimally impacted due to existing contracts and lower cost output.

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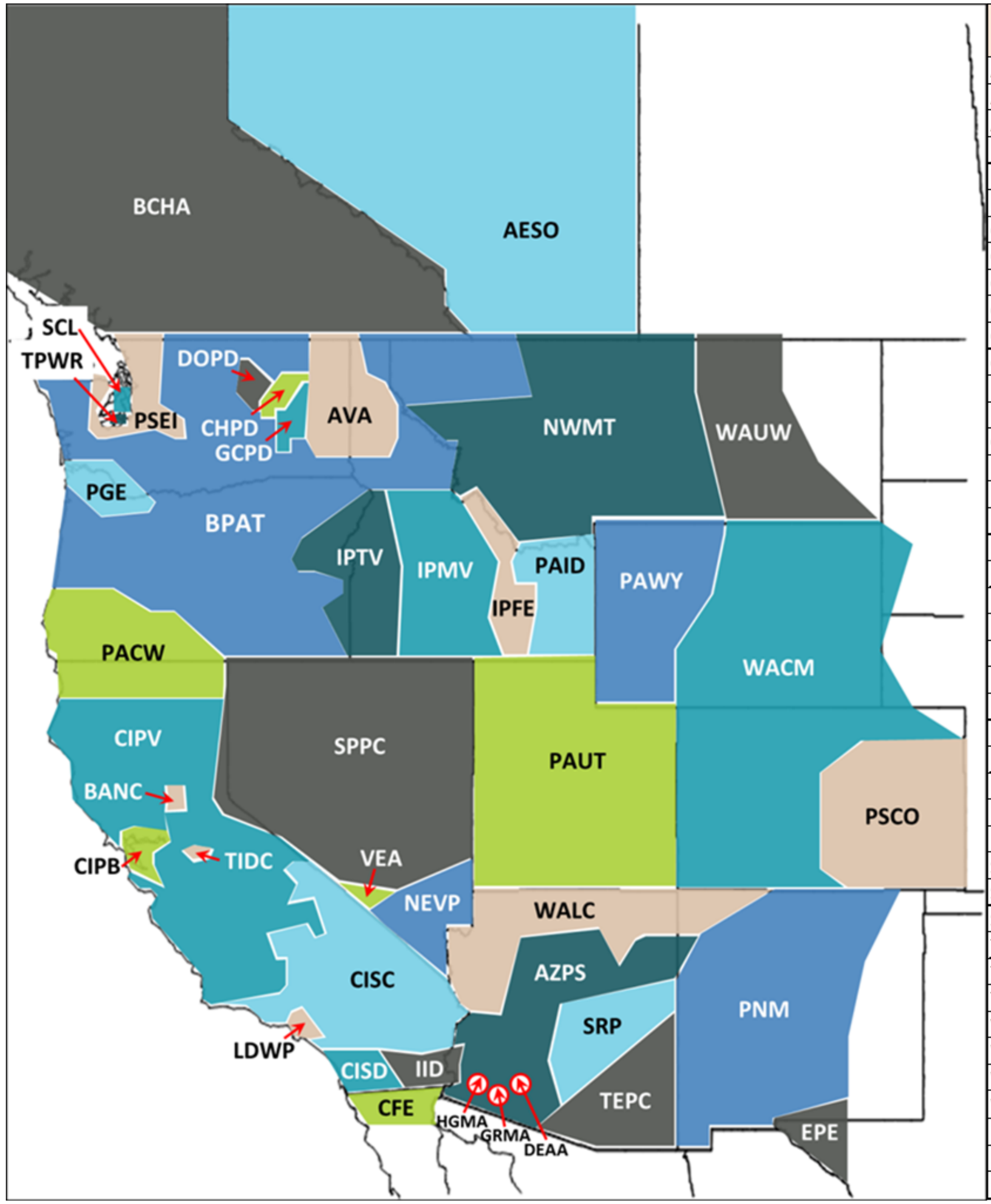
Load Complementarity

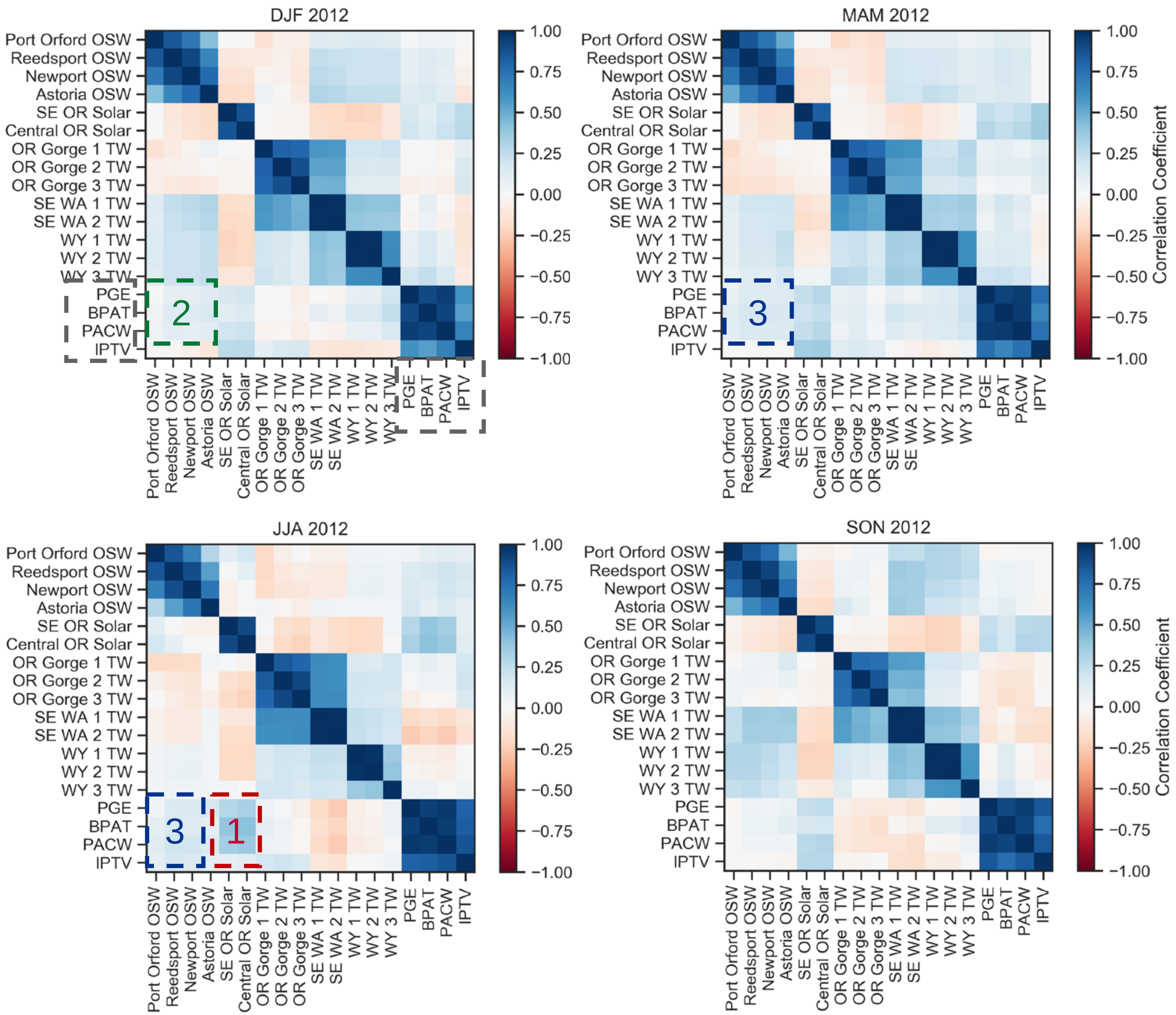
- WECC Balancing Authorities of interest:
  - BPAT, PGE, PACW, IPTV



TEPPC Area	Area Description
AESO	Alberta Electric System Operator
AVA	Avista
AZPS	Arizona Public Service
BANC	Sacramento Municipal District
BCHA	British Columbia Hydro
BPAT	Bonneville Power Administration
CFE	Comision Federal de Electricidad
CHPD	Chelan Co PUD
CIPB	Pacific Gas & Electric Bay Area
CIPV	Pacific Gas & Electric Valley Area
CISC	Southern California Edison
CISD	San Diego Gas & Electric
DOPD	Douglas Co PUD
EPE	El Paso Electric
GCPD	Grant Co PUD
IID	Imperial Irrigation District
IPFE	Far East (Idaho Power)
IPMV	Magic Valley (Idaho Power)
IPTV	Treasure Valley (Idaho Power)
LDWP	Los Angeles Dept of Water & Power
NEVP	Nevada Power
NWMT	Northwestern Montana
PACW	PacifiCorp West
PAID	PacifiCorp East – Idaho
PAUT	PacifiCorp East – Utah
PAWY	PacifiCorp East - Wyoming
PGE	Portland Gen Electric
PNM	Public Service New Mexico
PSCO	Public Service Colorado (Xcel)
PSEI	Puget Sound Energy
SCL	Seattle City Light
SPPC	Sierra Pacific Power
SRP	Salt River Project
TEPC	Tucson Electric Power
TIDC	Turlock Irrigation District
TPWR	Tacoma Power
VEA	Valley Electric Association
WACM	Western Area Power Admin Colorado/Missouri
WALC	Western Area Power Admin Lower Colorado
WAUW	Western Area Power Admin Upper Missouri
N/A	DECA, LLC - Arlington Valley (DEAA)
N/A	Gila River Maricopa Arizona (GRMA)
N/A	Harquahala L.L.C. (HGMA)

WECC (2015)

Load Complementarity



1. ***r*(OR solar, load) ~ 0.4 (summer)**

   Solar load complementarity exceeds all other VRE

2. ***r*(OSW, load) ~ 0.15 (winter)**

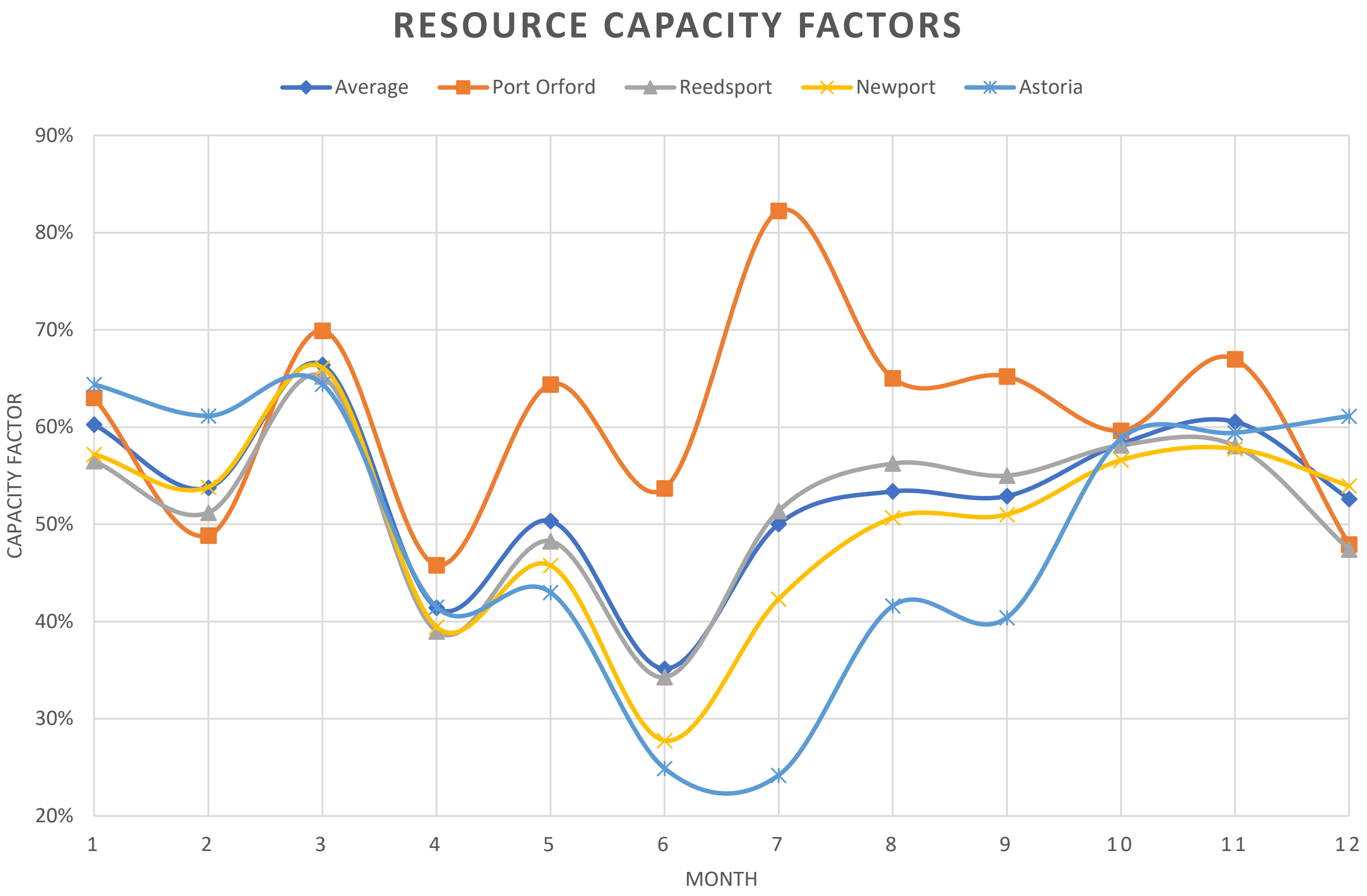
   OSW may help balance loads during regional peaks driven by heating

3. ***r*(OSW, load) ~ 0.17 (summer), 0.18 (spring)**

   In general, OSW complements load better than TW through the year

Load Complementarity — Resource Availability at Peak

Generator capacity factors provide insight to resource availability during peak load hours and shed some light on the positive system impacts (i.e. generation cost savings)

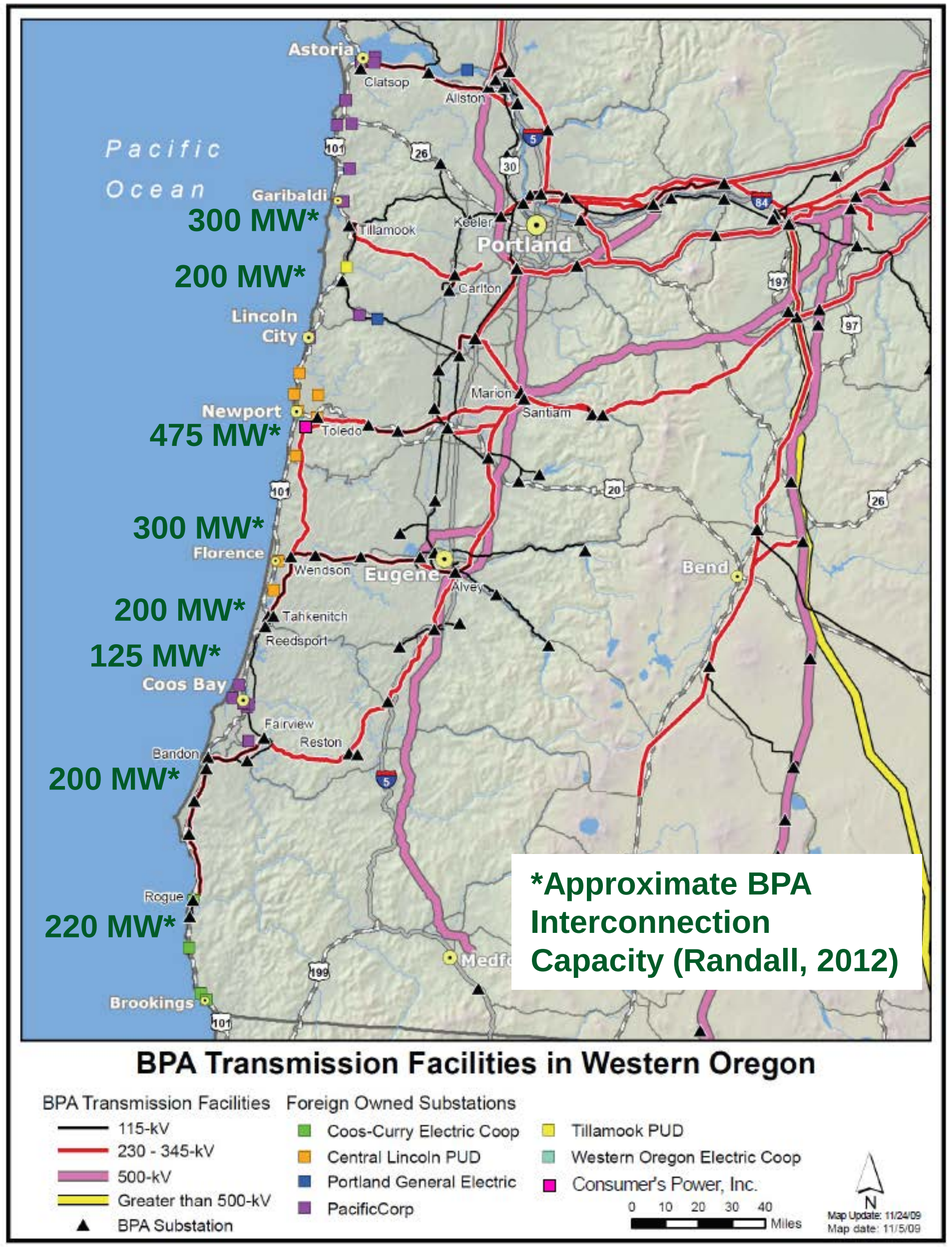


OSW Location	Morning Peak OR Load (9 to 11 AM)	Evening Peak OR Load (6 to 9 PM)	WECC System-wide Peak (3 to 7 PM)
Port Orford	62%	61%	50%
Reedsport	49%	55%	39%
Newport	48%	53%	47%
Astoria	46%	51%	42%
Average	51%	55%	44%

Generator gross capacity factor across peak hours of the year by OSW resource location and peak period.

Locational Value to Support Isolated Grids

- Power Quality. Injection from modern offshore WTGs may stabilize coastal grids
  - Distributed active power injection for frequency response and regulation
  - Reactive power for voltage regulation
  - Fault ride-through
  - Many of these capabilities recently demo'd (CAISO, 2020)
- Resilience benefits
  - Avoided costs of outages
  - Reductions in backup systems
  - Loads which can be served by resilient power, including disaster response
- Reduce power transmission to OR coast
  - 1GW of coastal load frees up coastal transmission to serve additional inland loads



Pacific Energy Ventures (2009)

Wind Integration into the BPA Grid: Curtailment

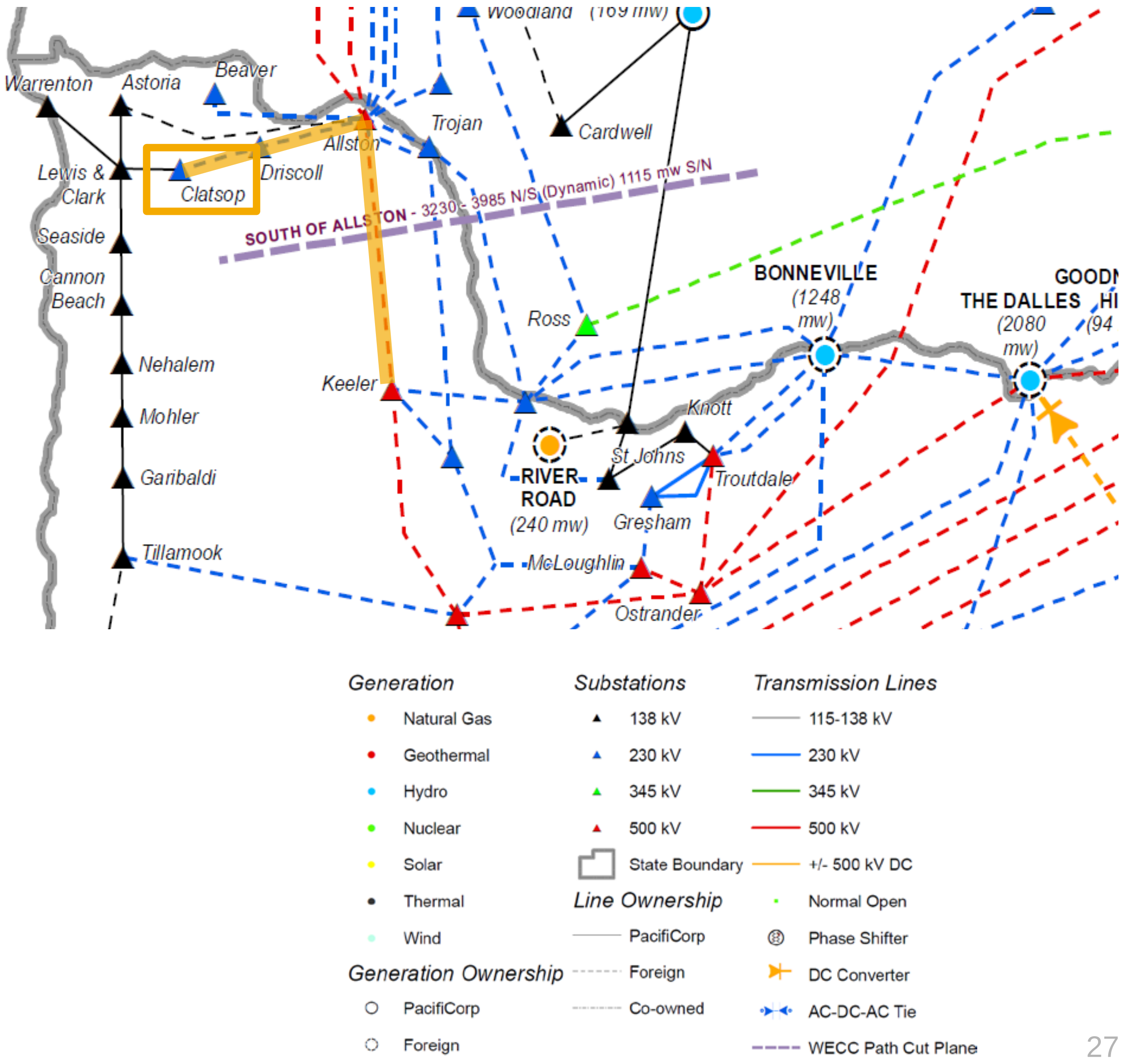
location	latitude	longitude	Substation ID	Sub name
Astoria	46.13978	-124.519	40243	CLATSOP
Newport	44.63749	-124.488	41083	TOLEDO
Reedsport	43.76358	-124.561	41061	TAHKNICH
Port Orford	42.73763	-124.825	40895	ROGUE

OSW Penetration	Port Orford	Reedsport	Newport	Astoria
1 GW	0.2%	0.1%	0.0%	0.1%
2 GW	2.0%	7.2%	0.2%	3.1%
3 GW	20.5%	28.1%	10.3%	14.6%
4 GW	36.8%	42.2%	26.1%	30.1%
5 GW	47.3%	51.5%	37.3%	40.9%
3 GW + Electric Vehicles	19.5%	27.6%	9.3%	14.0%

Locational Value — Localized Transmission

- Coastal transmission loading for Northern Oregon

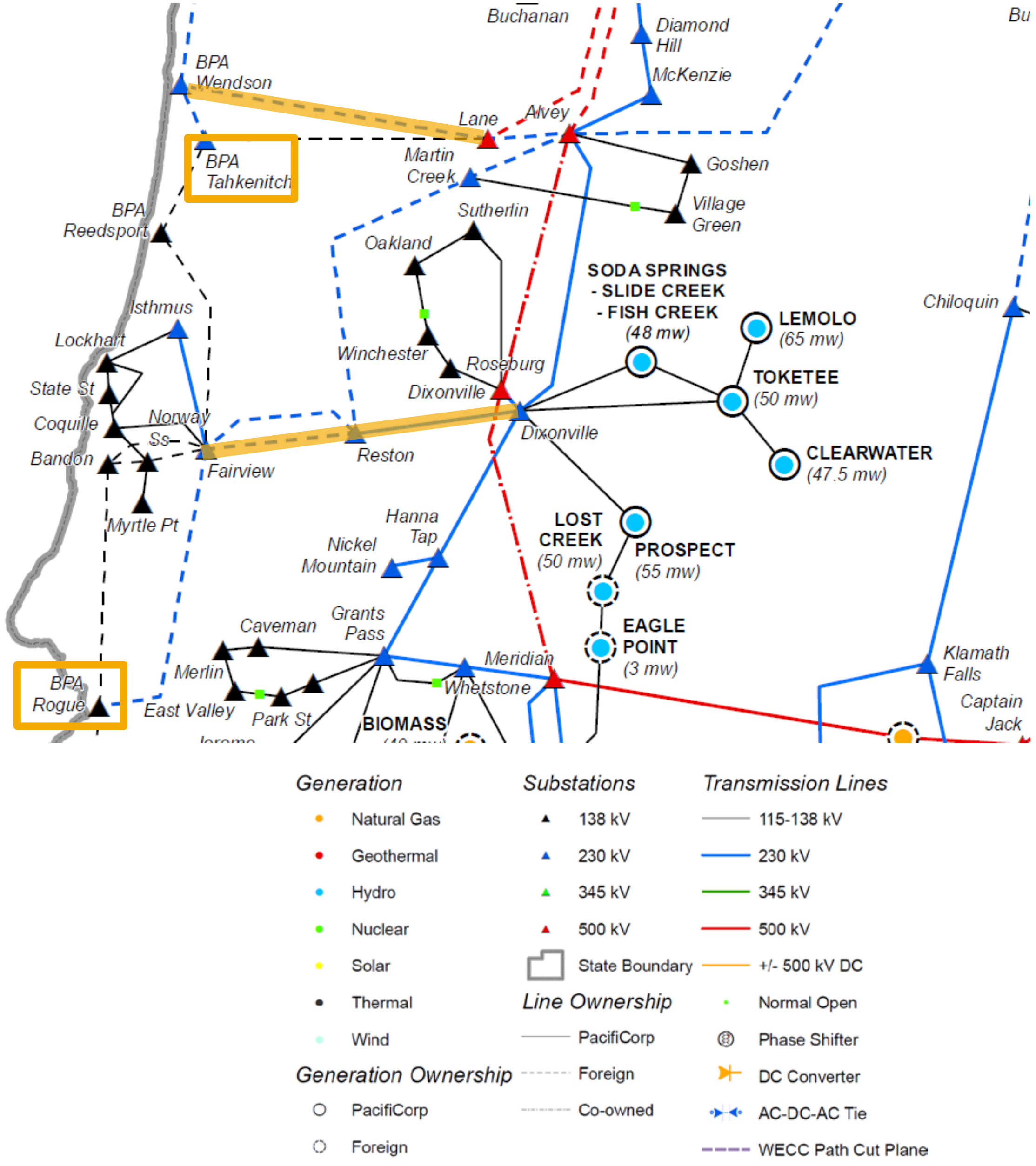
	Clatsop to Driscoll	Allston to Keeler
Normal loading [MW]		
Median	-41.6	259.3
Peak	-77.4	1121.5
3 GW OSW loading [MW]		
Median	225.3	220.4
Peak	488.2	1197.1
positive direction	east	south



Locational Value — Localized Transmission

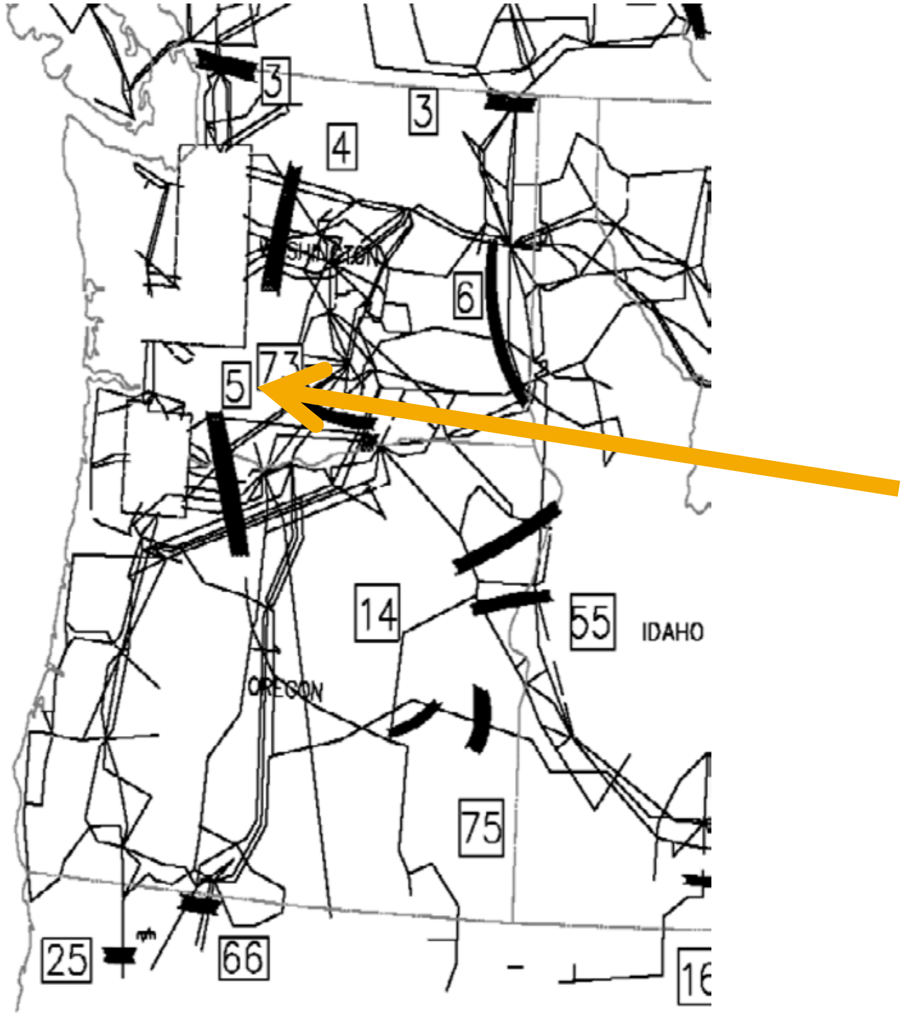
- Coastal transmission loading for Southern Oregon

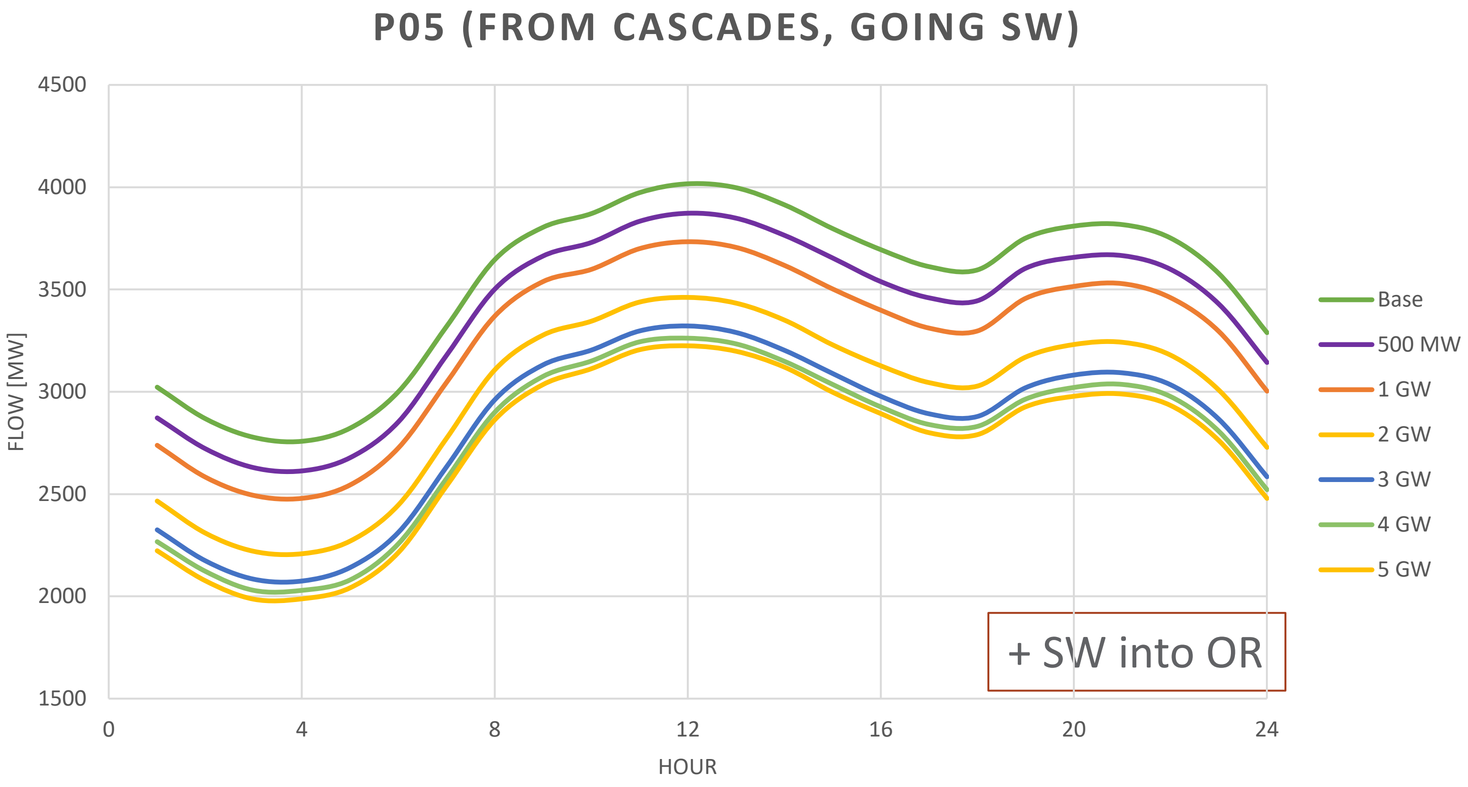
	Fairview to Reston	Reston to Dixonville	Lane to Wendson
Normal loading [MW]			
Median	-79.8	-43.4	46.3
Peak	-199.2	-128.6	90.6
3 GW OSW loading [MW]			
Median	370.9	253.9	-246.4
Peak	636.7	407.7	-476.8
positive direction	east	east	west



Locational Value — Transmission Paths

- An infusion of offshore wind impacts Oregon/regional transmission pathways.





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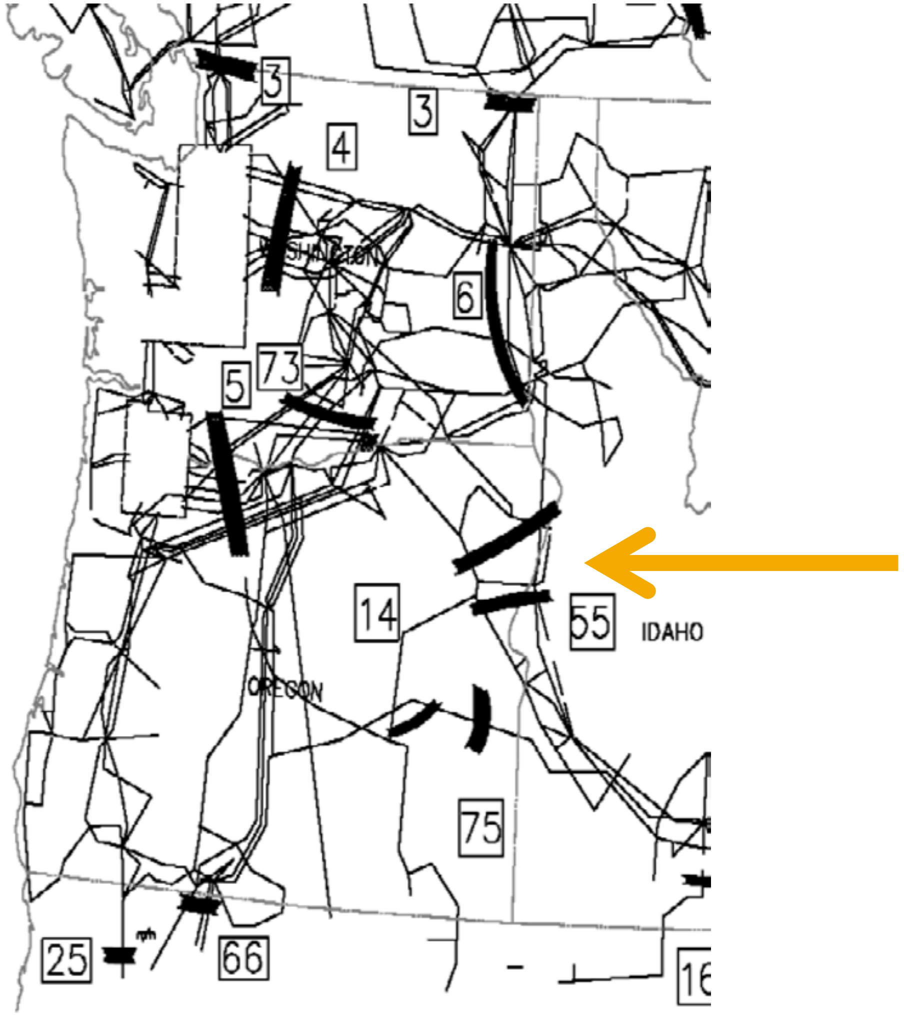
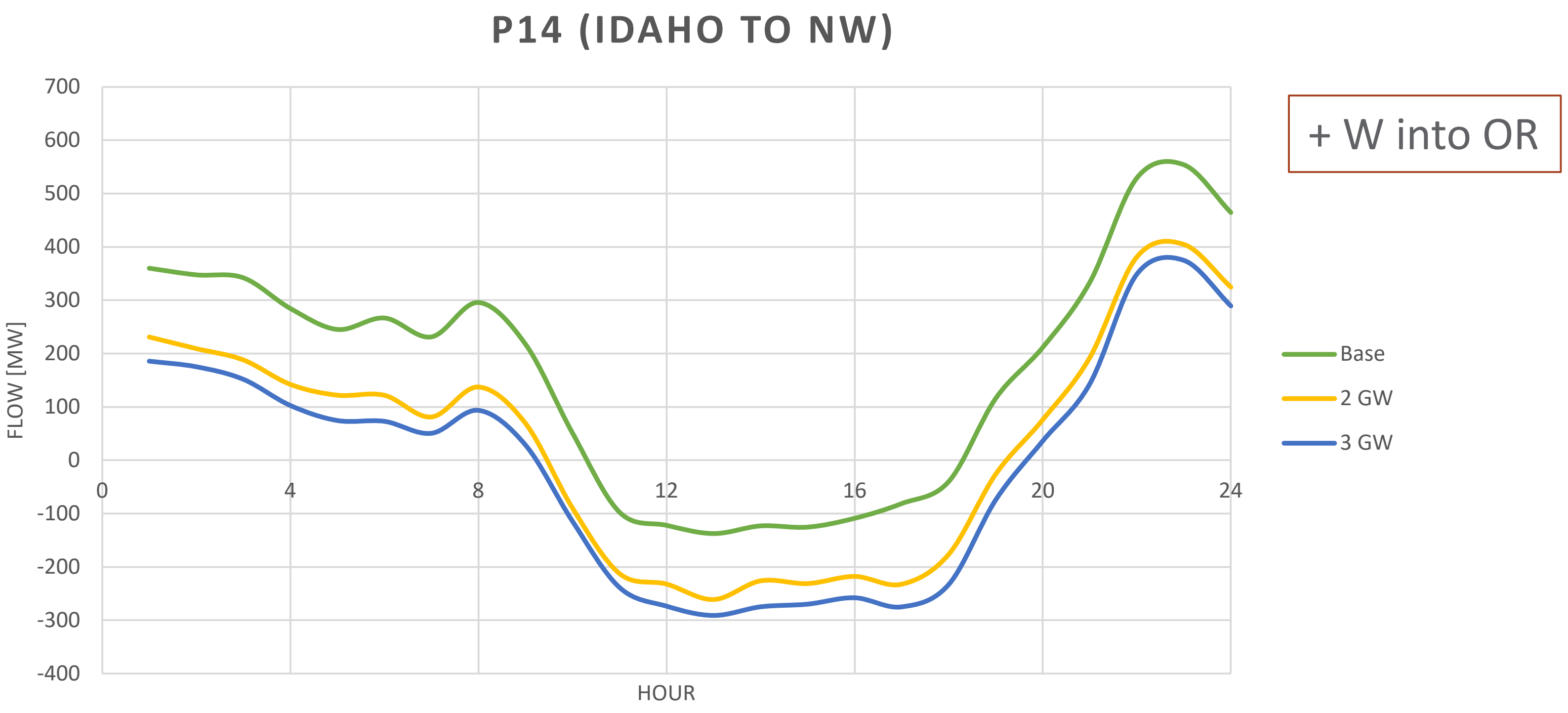
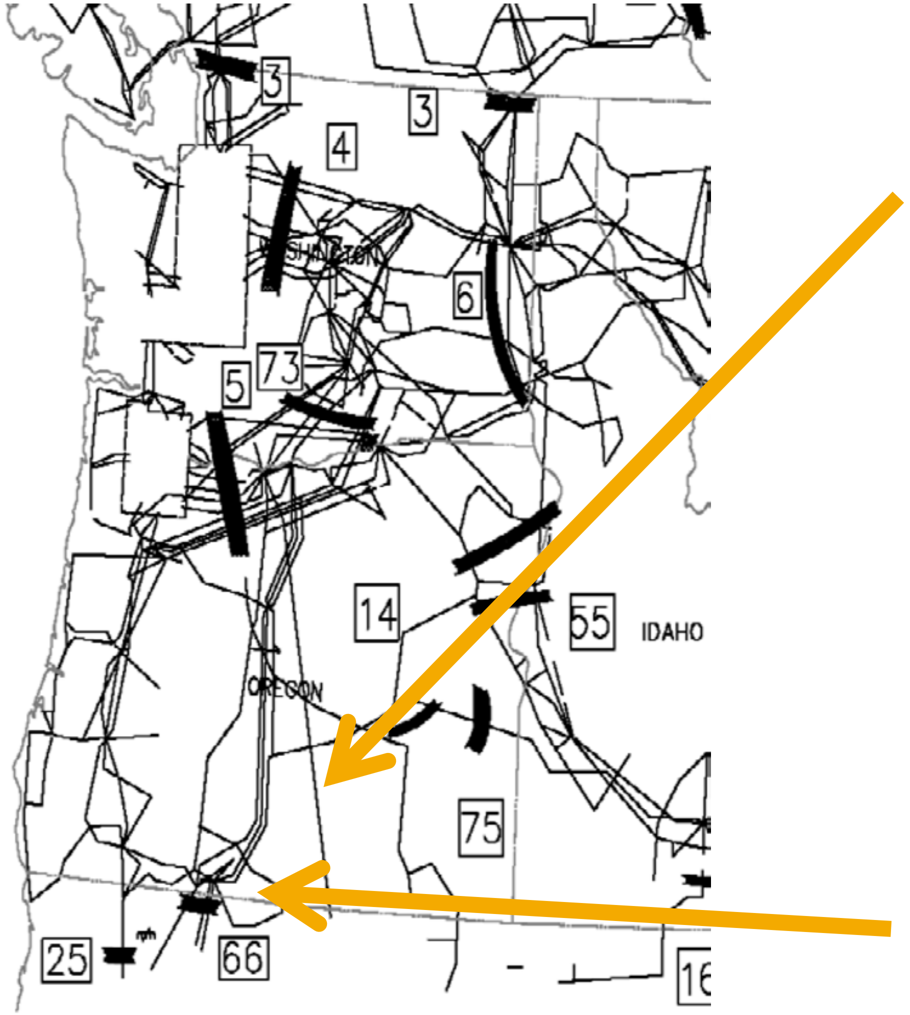
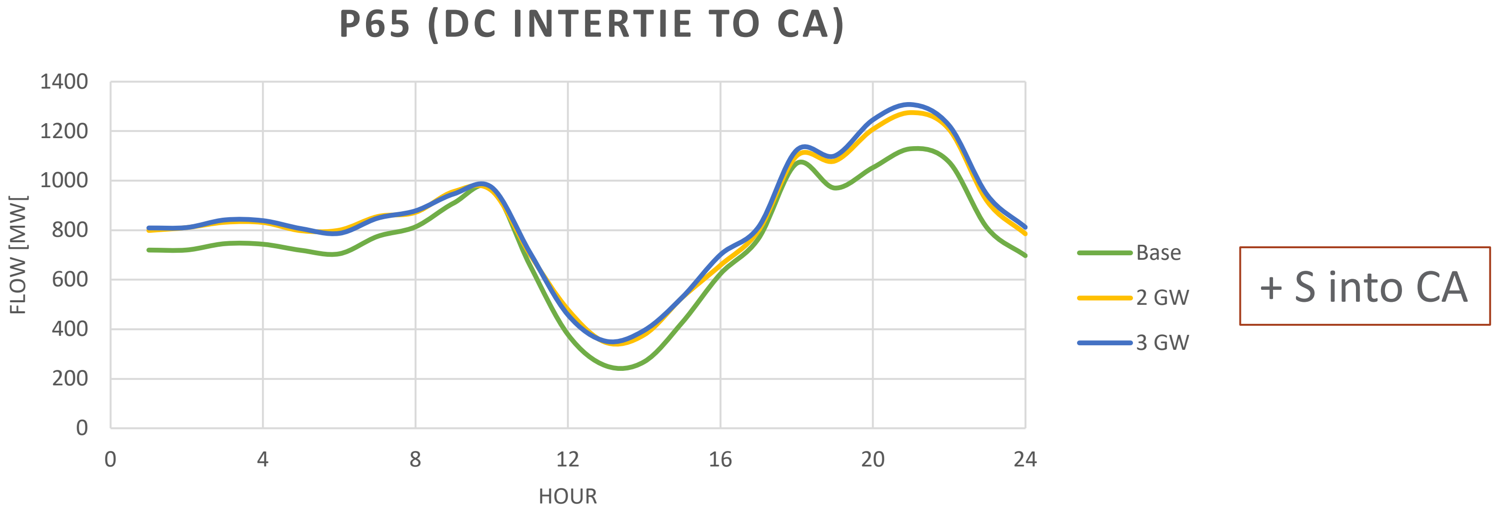


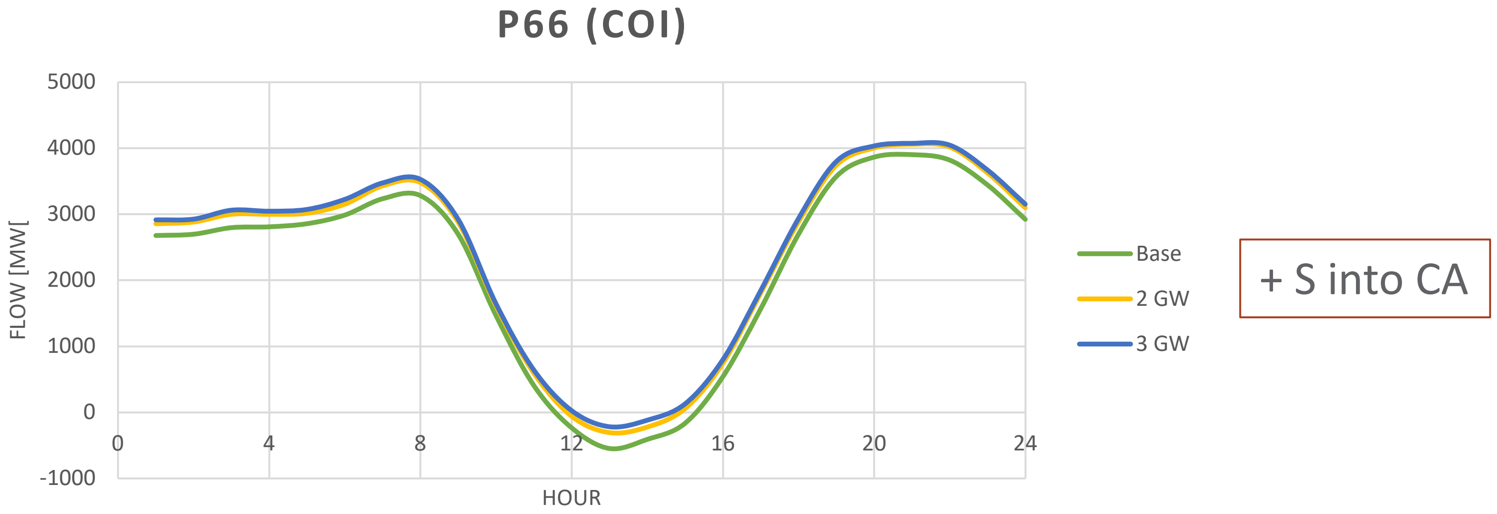


Locational Value — Transmission Paths

- An infusion of offshore wind impacts Oregon/regional transmission pathways.







Summary

Regional transmission can carry significant OSW contributions today

- A Production Cost Model indicates that ~2 GW of OSW could be interconnected and transmitted with minimal investment in today's system
- Under the 2 GW scenario, limited export of electricity from the state on major transmission paths is observed
- System benefits are observed up to 3 GW of OSW, with moderate curtailment
- >3 GW may require transmission investment, particularly in the coastal range

OSW power flows would relieve historic transmission flows

- OSW frees east-to-west transmission which may assist additional VRE transmission
- Coastal loads could be served largely by OSW
- Power quality contributions from modern wind turbines may help stabilize coastal grids
- Decoupling from coastal transmission may offer some degree of resilience to coastal communities

Summary

OSW complements regional clean energy sources

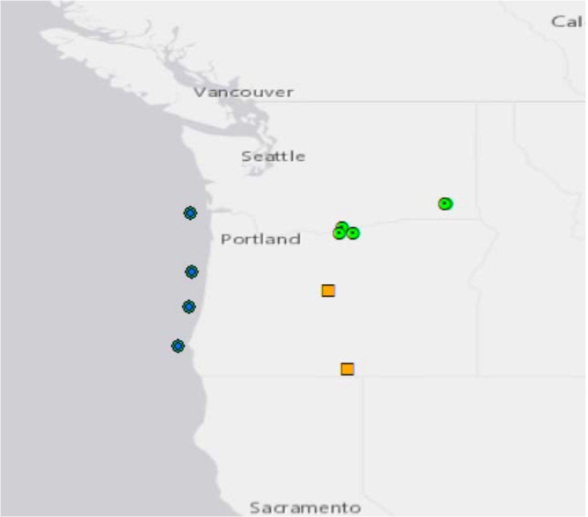
- Consistency of OSW speeds in late summer may benefit constrained hydropower
- OSW could help hydropower balance Gorge wind (and vice versa)
- OSW shows moderate complementarity with solar in winter when loads peak
- OSW indicates similar generation ramp rates to northwest “terrestrial” wind, smoother than WY wind

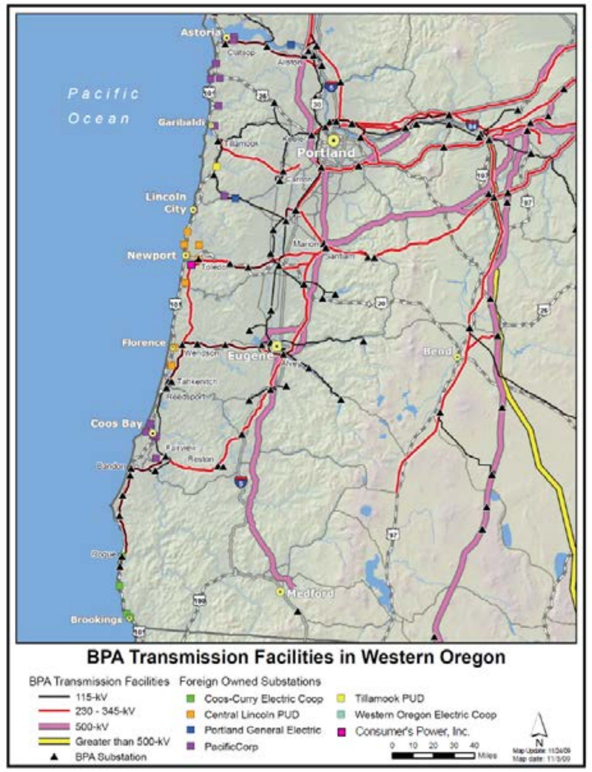
OSW naturally complements loads better than Northwest onshore wind

- Load complementarity is on par with solar in the winter, particularly for northern OSW locations
- Modest complementarity in the spring and summer
- OSW is largely uncorrelated with loads in the fall

Next steps

- Investigate hydropower complementarity within the WECC under multi-objective river management
- Quantify the capacity value of OSW through enhanced hydropower flexibility
- Model in detail coastal power flows and interconnection options
- Extend resource complementarity to generation complementarity and consider impacts on system reserves
- Expand load complementarity to sub-hourly load trends, more years, and additional balancing authorities





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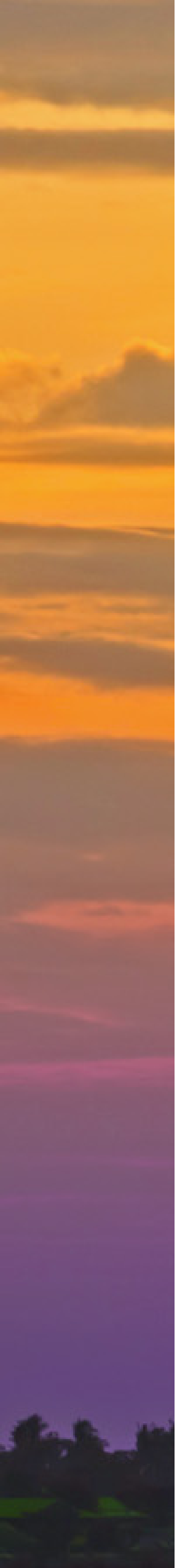

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Thank you