



Anchor Data Set (ADS) 2032 Hydropower

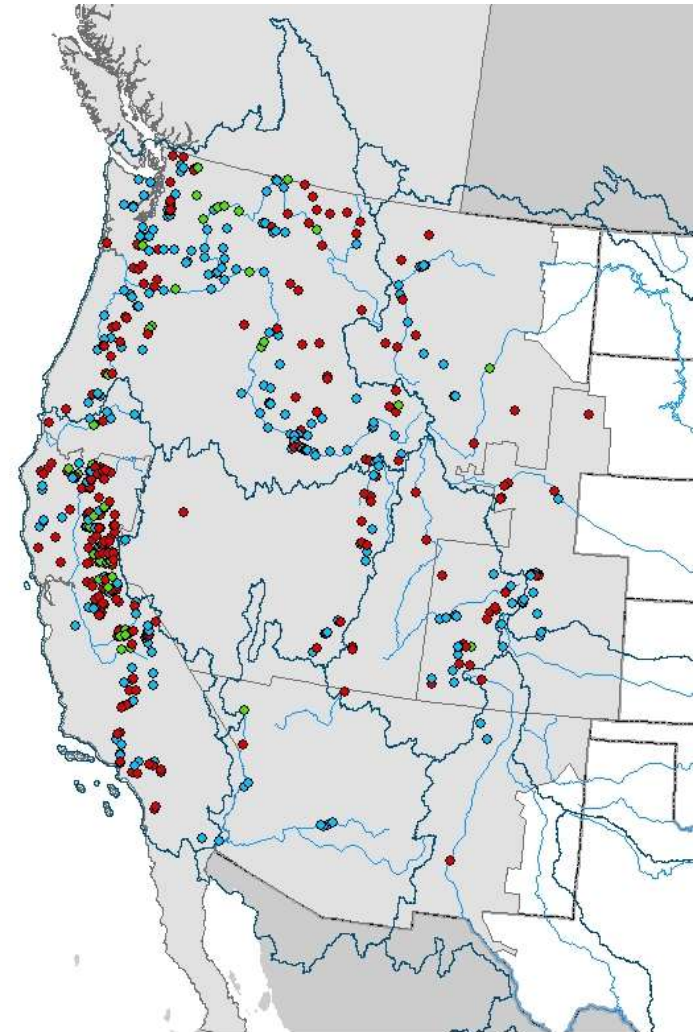
April 5, 2022

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PNNL is operated by Battelle for the U.S. Department of Energy

Voisin N., K.M. Harris, K. Oikonomou, and S. Turner. 04/05/2022. "WECC 2032 Anchor Dataset - Hydropower." Presented by N. Voisin, K. Oikonomou at WECC Production Cost Model Dataset Subcommittee Meeting, Online, Utah. PNNL-SA-171897



Objective of 2032 Case Hydropower Dataset

A hydropower dataset that is representative of normal operations (non-extreme events) and overall hydropower contribution amidst an evolving generation portfolio by 2032.

The objective is to be flexible on the water operations associated with hydropower within the existing or near-term multi-objective water management that cannot be changed without an act of Congress.

Water Availability – a median year

Water Management – inter-annual,
seasonal and monthly representative
of today and near future

Power plant operations – flexible to
contribute to new power grid



Partnering with DOE to leverage recent technical advances in the representation of hydropower in production cost model for resources adequacy

- Supported by US DOE Water Power Technology Office – HydroWIRES Initiative
- Leverage “HydroWIRES B1” project team’s expertise in large scale hydrology, water management, hydro-scheduling and integration in production cost models:
 - Demonstration that the monthly hydropower representation is infeasible from a water perspective due to environmental regulation and multi-objective multi-horizon water management operations
Magee T., S. Turner, M. Clement, K. Oikonomou, E. Zagana, and N. Voisin. 2022. "Evaluating power grid model hydropower feasibility with a river operations model." Environmental Research Letters. PNNL-SA-169958. (submitted, Environmental Research Letters)
 - Demonstration that a weekly representation alleviates the computational burden of a hydropower scheduler while maintaining the representativeness of hydropower at the asset
Ploussard, Q., K. Oikonomou, T. Veselka, N. Voisin 2022. "Hydro-Economics Tradeoff Surfaces to Guide Unit Commitment in Production Cost Models". (submitted, Applied Energy)
 - “B1 datasets”:
 - ✓ Coincidence in space and time across regions
 - ✓ Weekly time step that represents environmental constraints on hydro operations while maintaining flexibility to address power grid needs
 - ✓ GridView software updated with those new datasets
Voisin et al. (in prep, Environmental Research Letters)

Approach

2030 ADS Case

- Observed operations, 2008/09
- Flexibility parameterization: PLF allocation and daily fluctuations
- Reduced number of power plants with fixed schedule wrt 2028 ADS
- GridView software update for flexibility

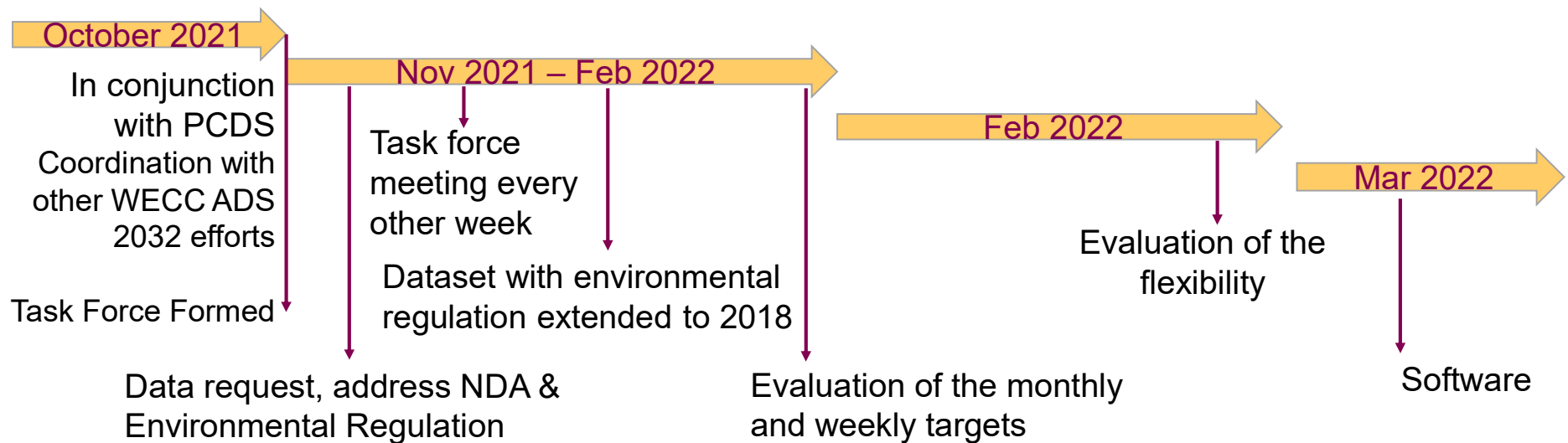
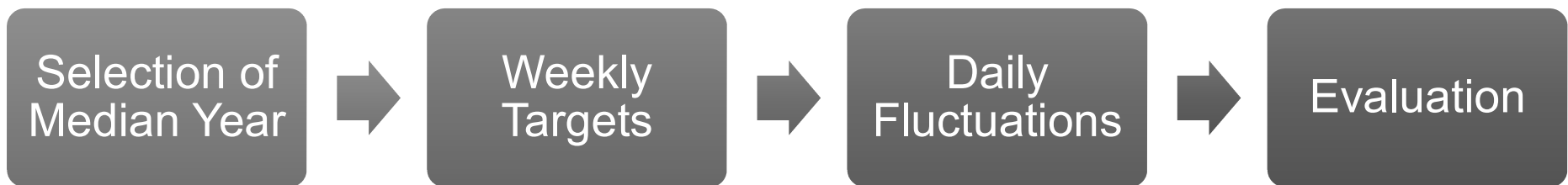
HydroWIRES datasets based on 2028 ADS Case

- Simulated historical hydrology
- Coincident in space and time
- Weekly hydro targets, Pmin and Pmax
- Flexibility parameterization: maintain monthly k and p
- GridView software for weekly targets

WECC ADS 2032 Coordination:

- Observed hydrology/operations
- Coincidence
- Weekly targets
- PLF allocation & daily fluctuations
- Software update

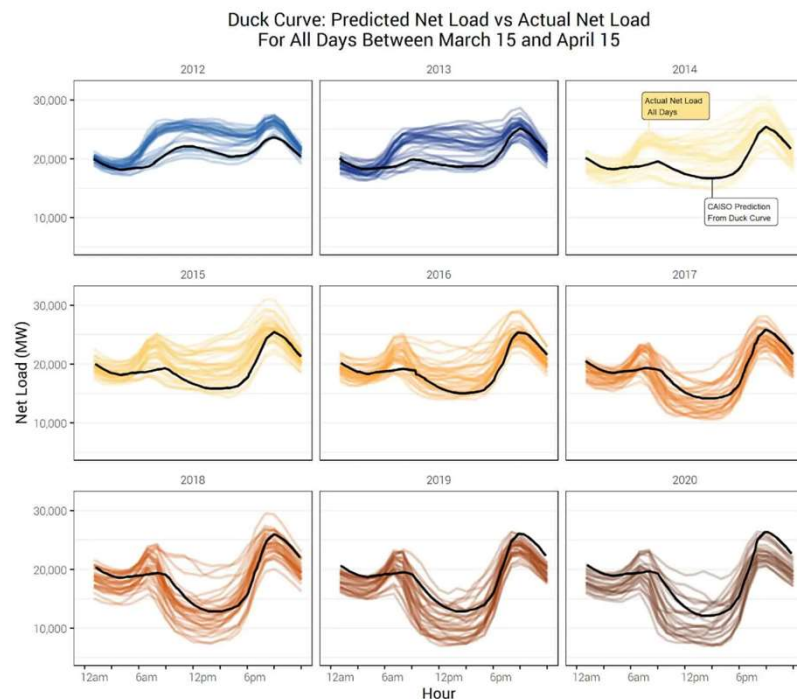
Project Overview



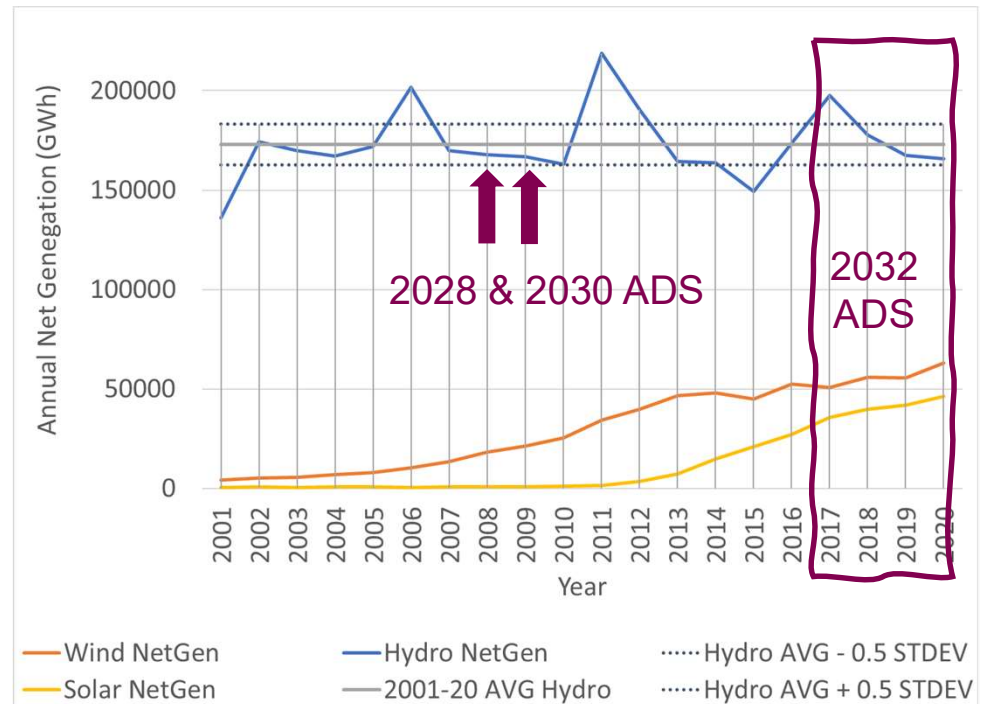
Fast integration of wind and solar motivates selecting a recent year to represent the new hydro

And the need for coincidence in wind and solar and load ...

Ramping needs have changed substantially in the last 9 years



If relying on observed hydro operations, a recent year is needed to be representative of those new operations.

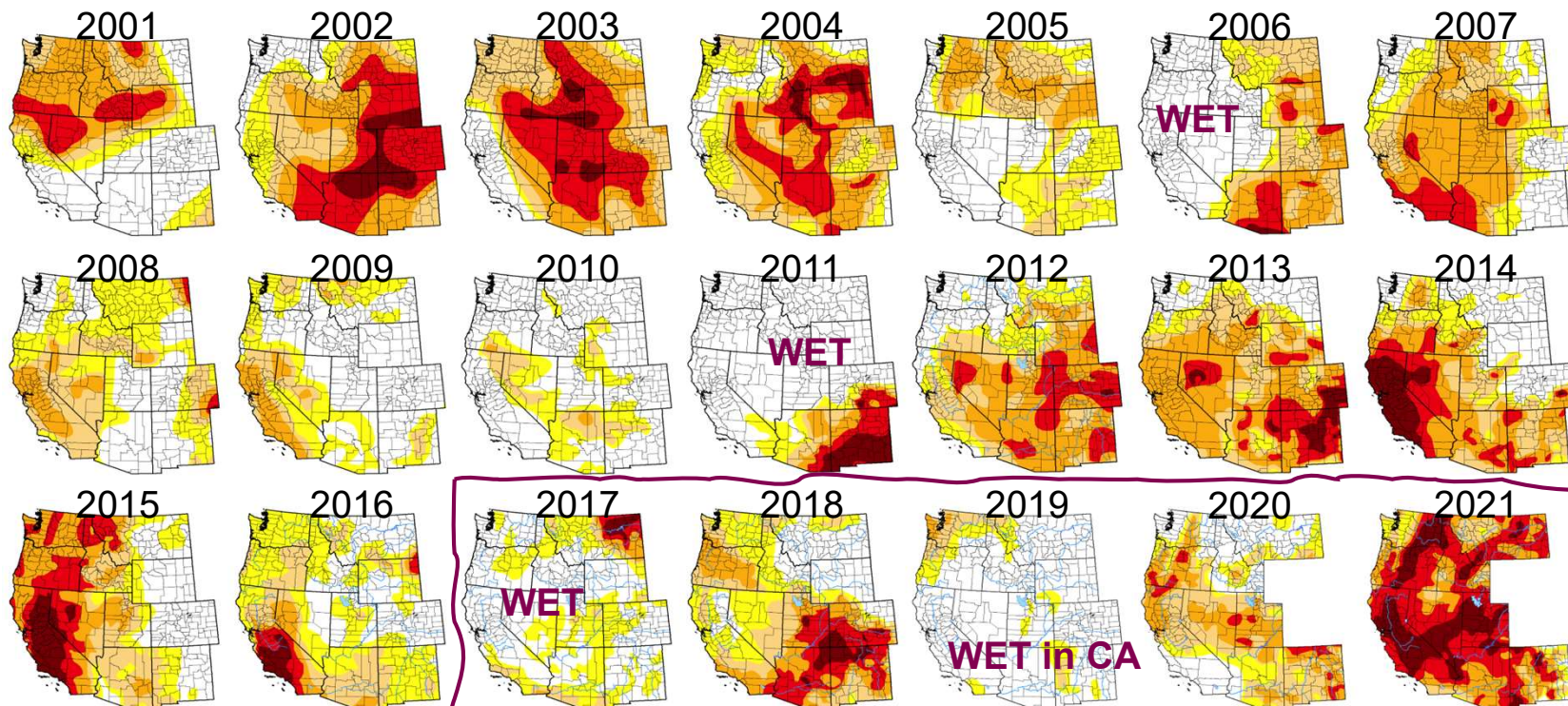


Evolution of the CAISO duck curve. [Source: Gong, A. 2020: The Duck Curve. A review of California's daily load predictions. Available at: <https://www.aurorasolar.com/blog/the-duck-curve-a-review-of-californias-daily-load-predictions/>]

Selection of Median Year considers coincidence with net load datasets

None
D0 (Abnormally Dry)
D1 (Moderate Drought)
D2 (Severe Drought)

U.S. drought monitor for final week of July in each year



Q&A on choice of year

1. Could we mix and match 2019/2020 if data is available?
 - Weekly hydro dataset represent both sub-monthly changes in load and sub-monthly changes in water operations
 - Coincidence in load, wind, solar and hydro is key to have representative regional power flows
2. What if storage is substantial – could we keep the monthly representation and a different year?
 - Storage exceeds annual inflow by design in regions where inter-annual variability is very large. Those reservoirs are managed for end-of-summer carry-over storage.
 - Due to the water supply role of those reservoirs, a weekly flat release is more realistic than a monthly representation with a disaggregation to weekly using perfect load forecast.
 - The weekly coincidence provides the realistic contribution of those plants to the grid

The dataset is based on 2018 water availability throughout the regions



Method 1: 2018 hourly plant-scale data requested, received and processed to a weekly time scale

Method 2: 2018 weekly plant-scale data received

Method 3: 2018 operations are not representative of present nor future operations due to new environmental regulation over the Northwest (EIS2020). Use simulation of reservoir operations with EIS2020 based on 2018 modified flow and statistical relationships for daily fluctuations.

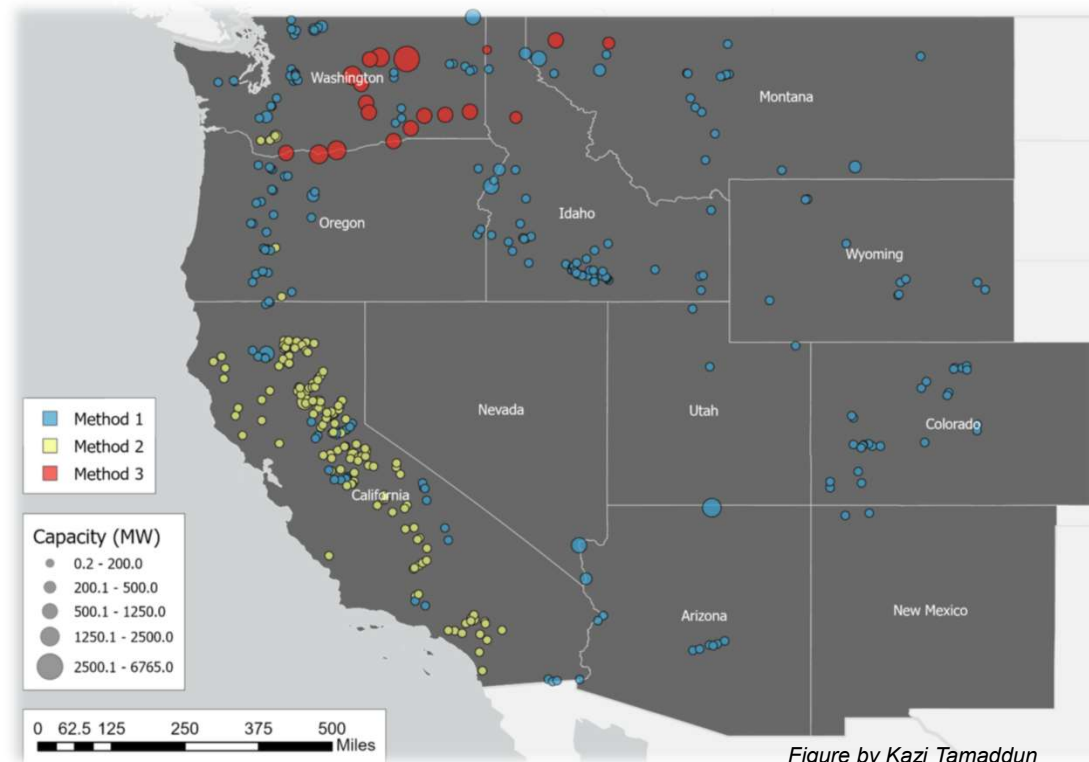
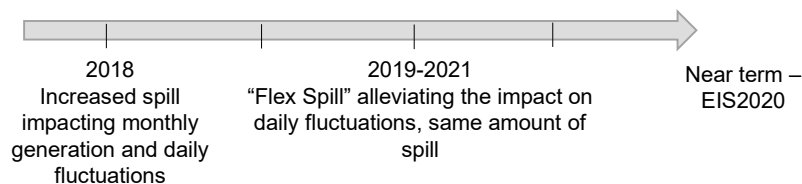
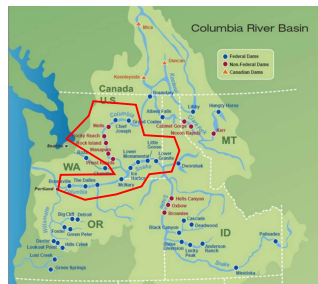


Figure by Kazi Tamaddun

Weekly targets over the Columbia River projects marketed by BPA need to represent EIS2020

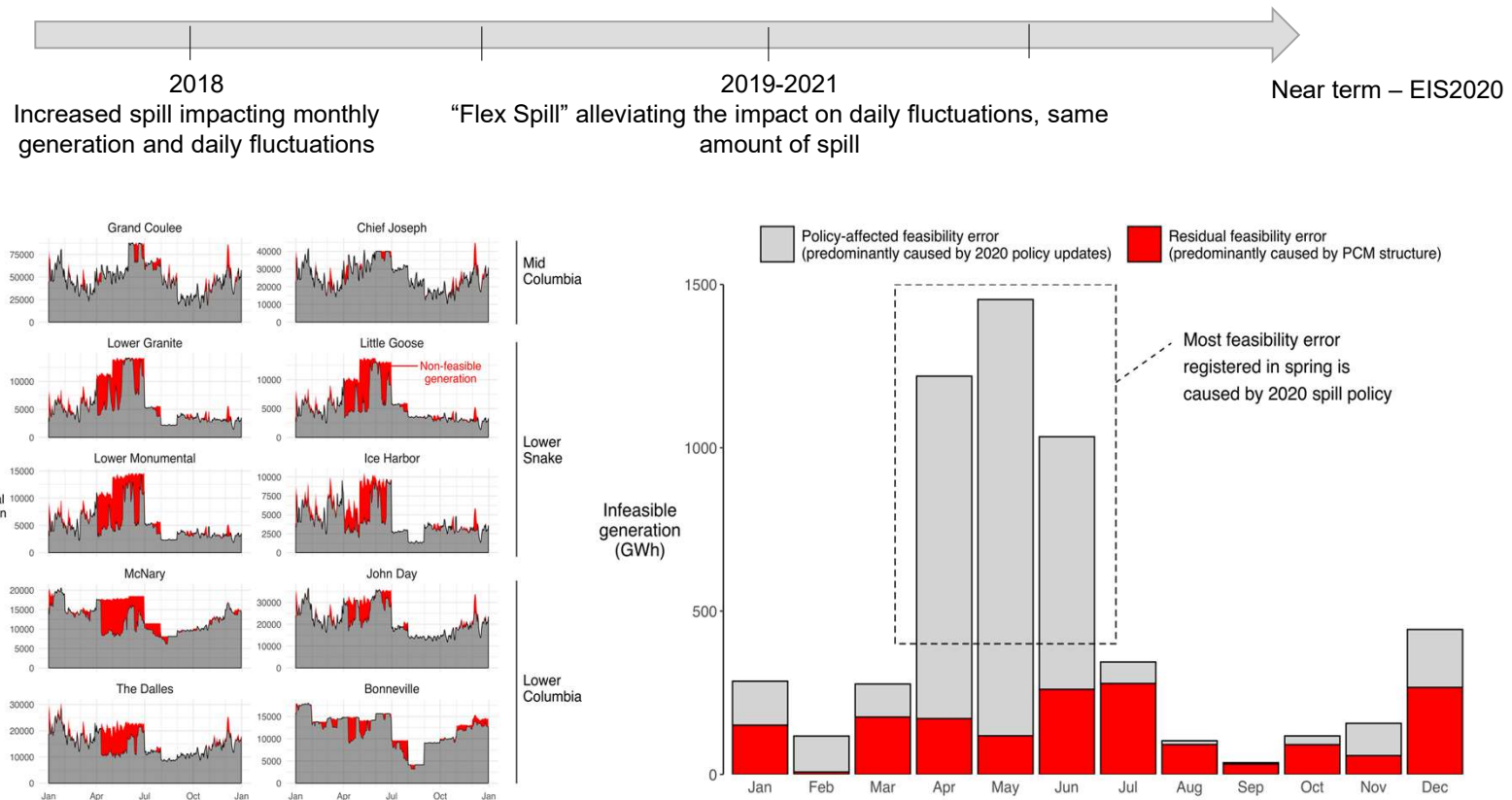
2018 river operations not representative of the current and future operations



WECC ADS 2028 -
GridView Hydro
Dispatch

RiverWare Model with
Flex Spill Operations

Daily total
generation
(MWh)



Magee T., S. Turner, M. Clement, K. Oikonomou, E. Zagana, and N. Voisin. 2022. "Evaluating power grid model hydropower feasibility with a river operations model." *Environmental Research Letters*. PNNL-SA-169958. (submitted, *Environmental Research Letters*)

Study based on 2009 water conditions

Integration of new environmental regulation into the hydropower datasets

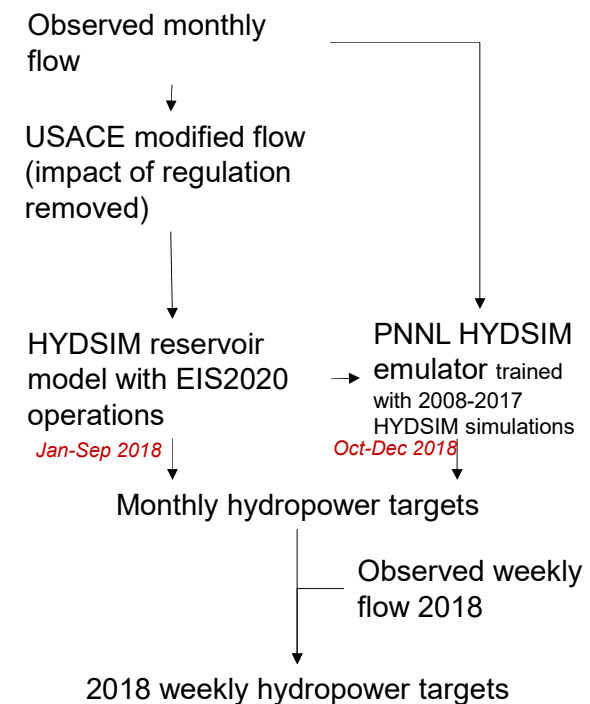
Selection of
Median Year

Weekly
Targets

Daily
Fluctuations

Evaluation

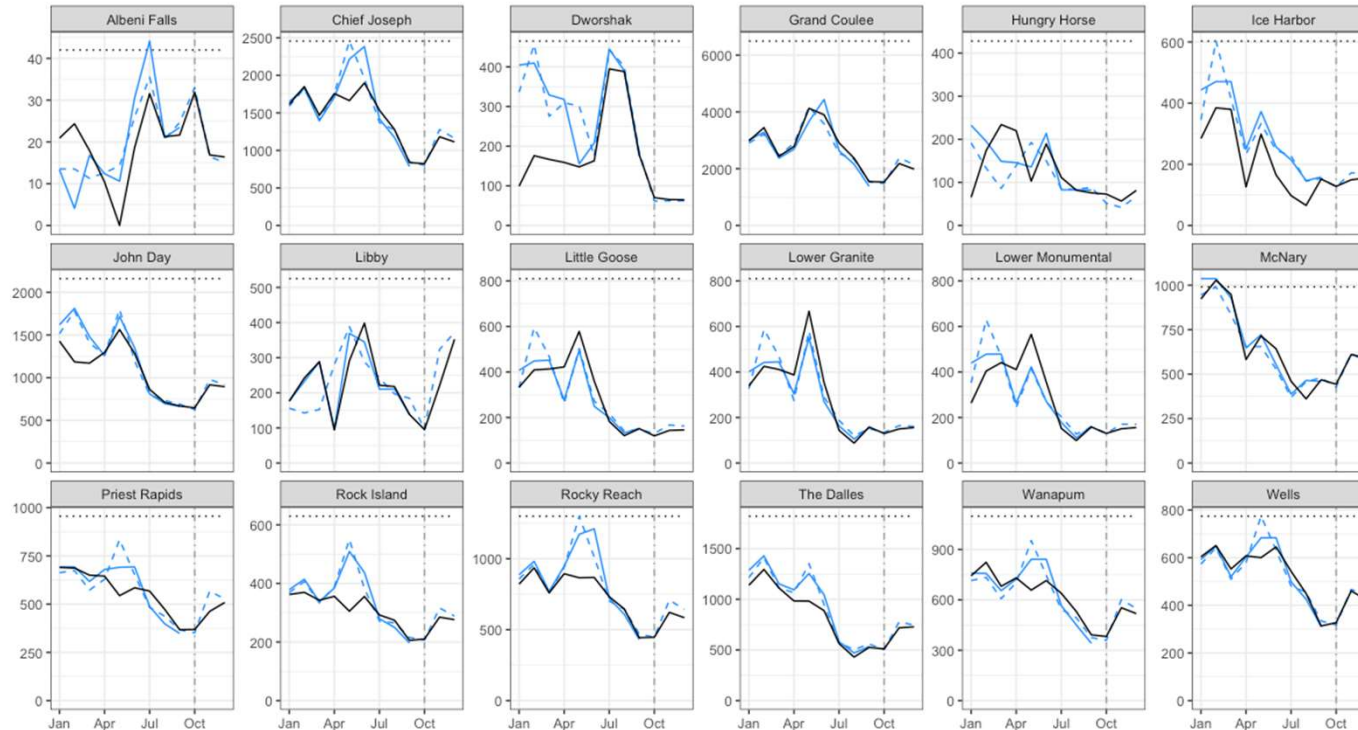
- The new EIS2020 operating rules are represented in the BPA HYDSIM model. Existing historical simulations were available for an 80-year period ending in September 2016
- 2018 water year USACE “modified flow” needed for HYDSIM simulations became available in December. BPA extended their HYDSIM simulations to 2018 water year (e.g., until September)
- PNNL developed a HYDSIM emulator applied to 2018 observed flow to emulate the new EIS2020 operations for 2018 Oct-Nov
- The team evaluated the combined monthly HYDSIM-HYDSIM emulator simulations
- Weekly targets are derived from disaggregating the (bi) monthly targets with 2018 weekly flow observations to conserve coincidence at weekly scale



Integration of new environmental regulation into the hydropower datasets

Average generation (MW)

..... Capacity (nameplate) — hydsim - - - hydsim_emulator — Observed



- (1) "Observed" data from USACE
- (2) HydSim simulations are monthly and bi-monthly (14 periods)
- (3) Flex spill results in more generation than 2018 conditions
- (4) HydSim emulator is used for Oct-Dec



Daily Fluctuations – Flexibility Parameterization

Method 1: 2018 hourly plant-scale data requested, received, and used to develop weekly daily fluctuations

Method 2: 2018 weekly parameterization received directly

Method 3: Use 2018 (median-wet), 2019 (median-dry), 2021 (very dry) hourly data to develop quarterly statistical relationship between flow and daily fluctuations, further applied to HYDSIM 2018 flow.

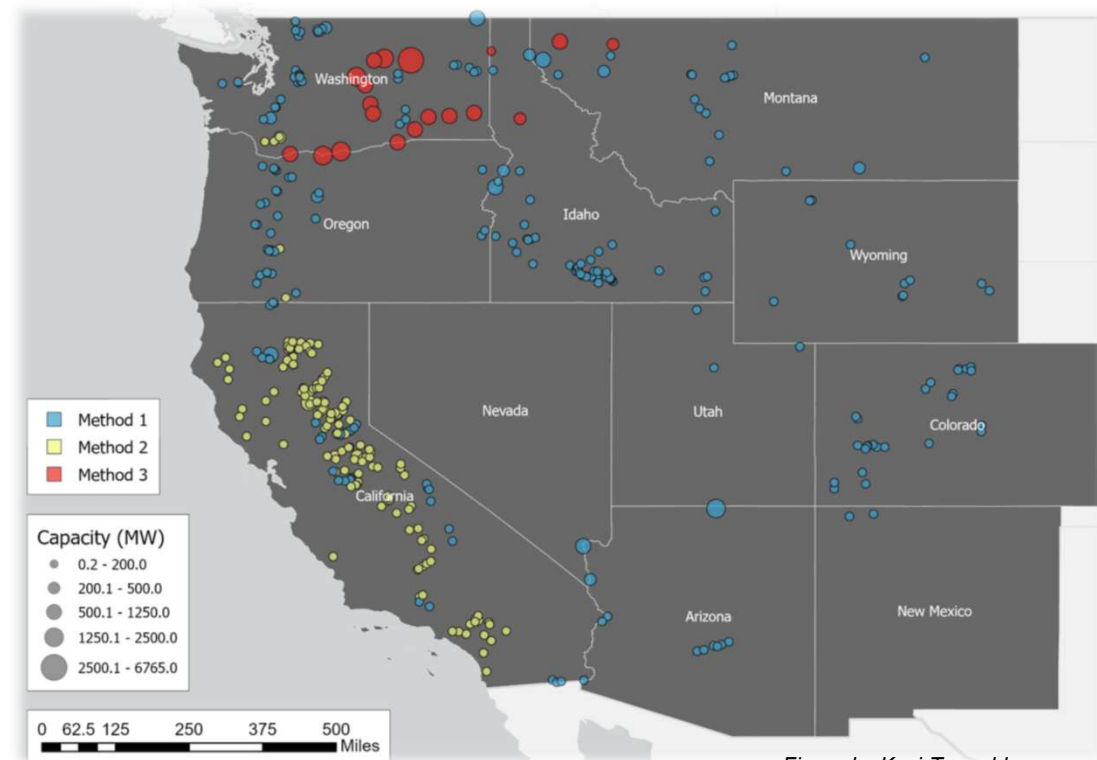


Figure by Kazi Tamaddun

Integration of new environmental regulation into the parameterization of hydro flexibility

- WECC ADS 2030: for cascading reservoirs, used a statistical relationship between mean daily flow and daily fluctuations over **3 clusters** (Mid Upper Columbia, Lower Columbia and Lower Snake). The approach ensures consistency in the daily fluctuations.
- WECC ADS 2032 → need to represent post-2018 flex spill
 - Daily fluctuation range is not available from HYDSIM simulations.
 - Use 2019-2020-2021 to develop statistical relationship?
 - 2020 cannot be used due to non – representative operations associated with COVID19 lockdowns
 - 2019 and 2021 are medium and dry not providing robust statistical relationship for 2018 high Spring flows (with and without EIS2020)
 - Use 2018-19-21 as representative of daily fluctuations as function of 2018 HYDSIM flow

Columbia River Basin Projects

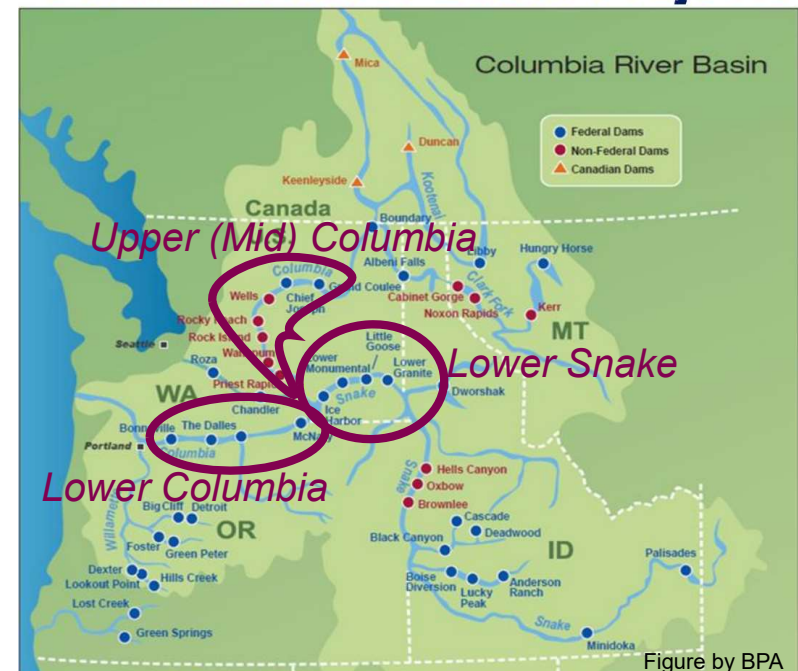


Figure by BPA

For each cluster, 2018-19-21 data are used to develop quarterly statistical relationships

Upper (Mid) Columbia

Lower Columbia

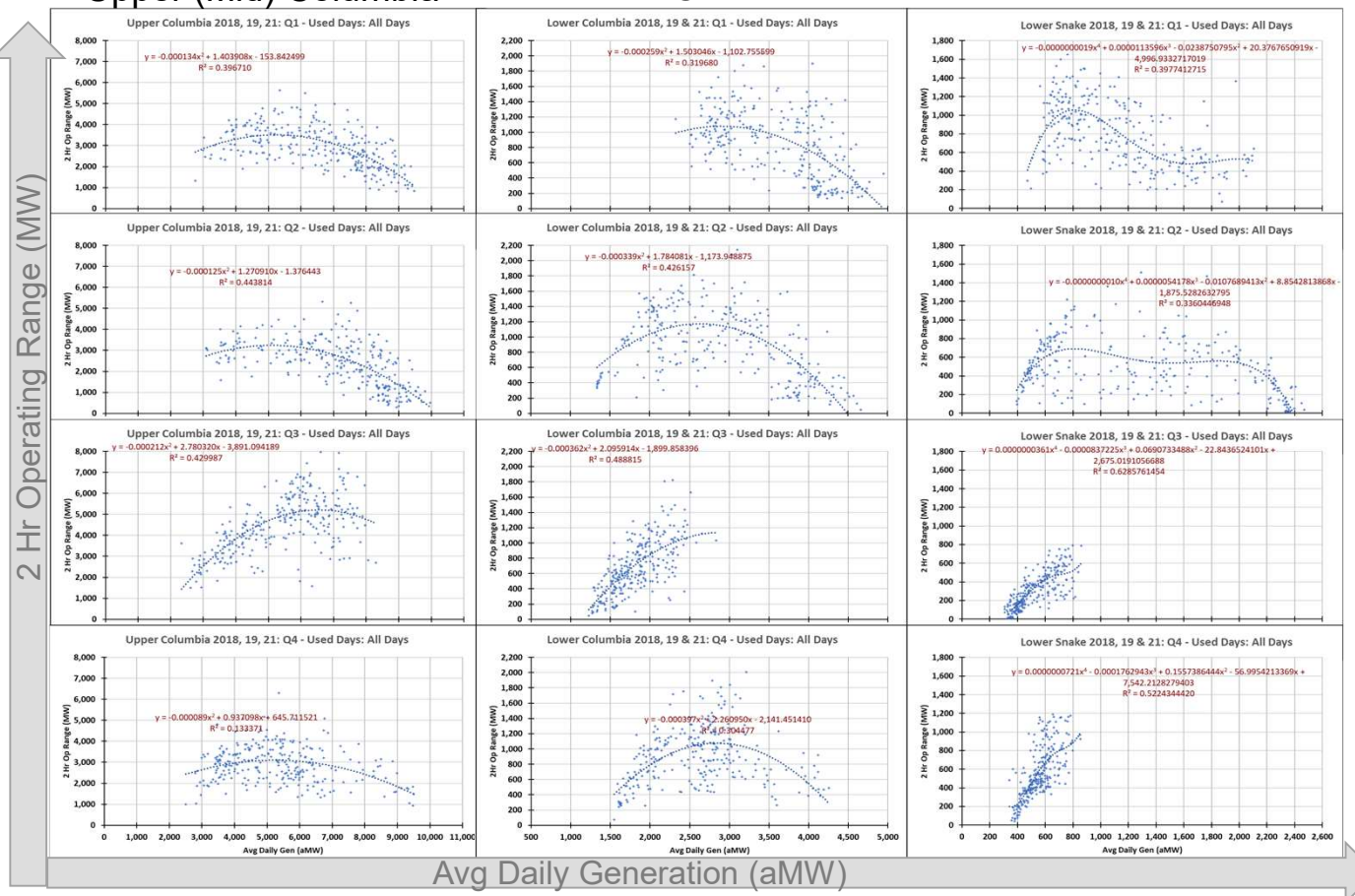
Lower Snake

Operating range =
 $f(\text{daily flow})_{\text{quarter}}$

3 years of diverse water availability conditions are used to isolate flex spill operations and obtain stronger relationships across flow conditions

Polynoms are fitted up to order 4 for the Lower Snake. The large spread has implications for the use of the dataset: it is for normal operations.

Relationships are applied to 2018 weekly HYDSIM-based flow



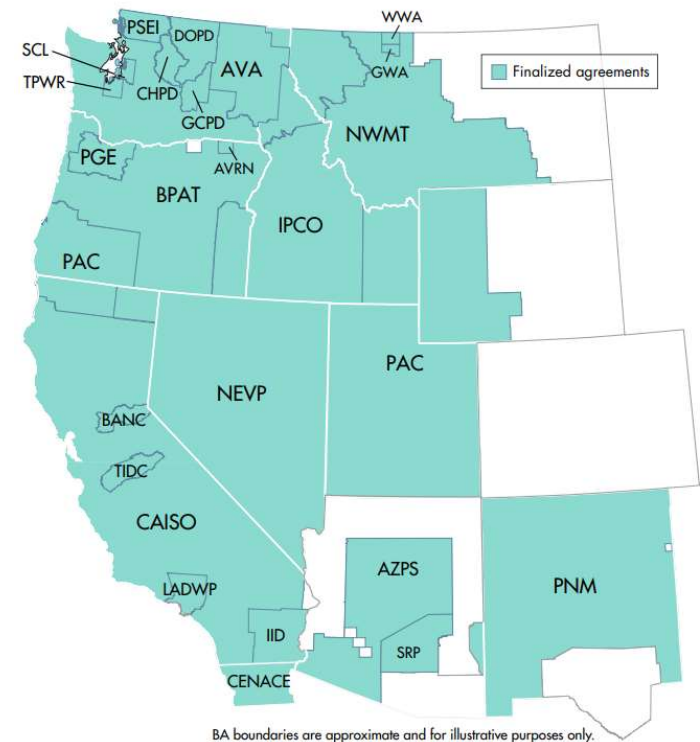
Finalizing the dataset

- Pmax – all methods: set to nameplate capacity
- Pmin - method 3: use similar polynom approach
- Bells and whistle: the datasets need to comply with the following rules for all 53 weeks:
 1. $P_{min} < P_{max}$
 2. $P_{min} \geq 0$
 3. Daily Operating Range > 0
 4. Weekly Target > 0
 5. $P_{max} * 168 \geq \text{Weekly Target}$
 6. $P_{min} * 168 \leq \text{Weekly Target}$

Evaluation prior to GridView simulations

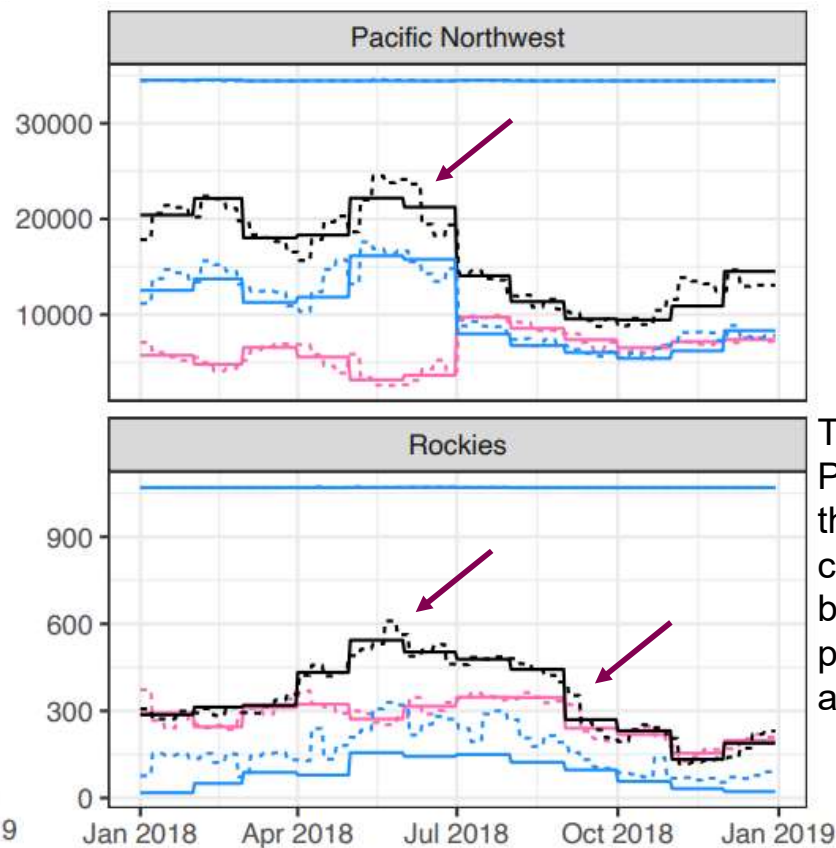
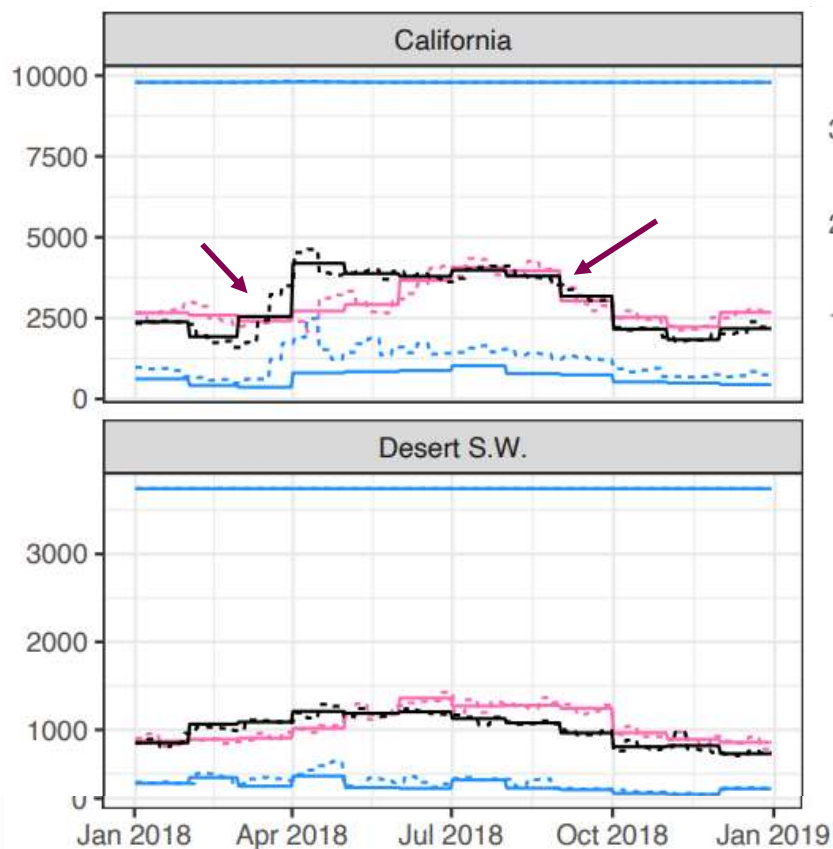
- 16TWh of additional hydro compared to ADS2030
- Major advances are a finer temporal resolution, coincidence and environmental regulation.

Evaluation is performed next across scales (regions and balancing authorities). We show both monthly and weekly to demonstrate the value of the weekly dataset.



Weekly dataset by regions

Smoother transitions between months



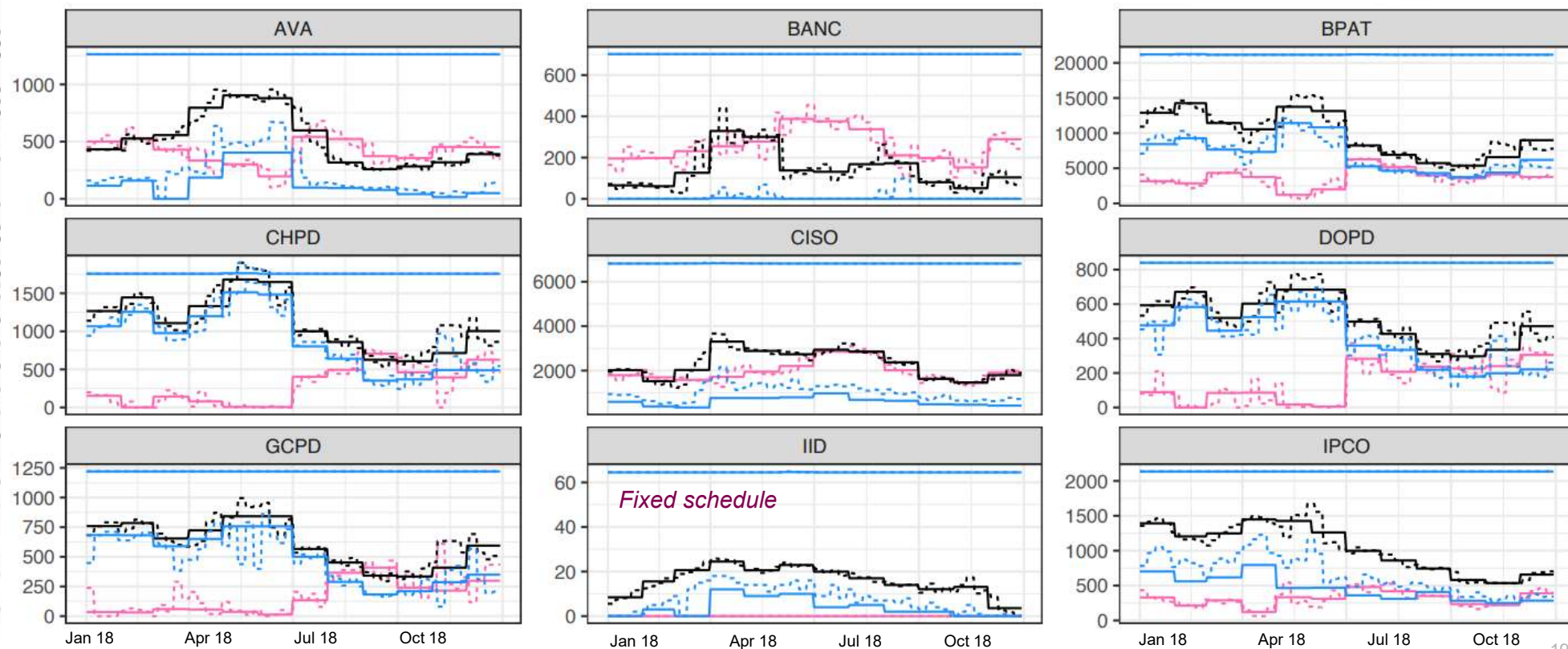
— Target (MW)
— Daily Operating Range (MW)
— Pmax
— Min

Monthly / weekly
— monthly
- - - weekly

The difference in Pmin demonstrates the importance of coincidence between power plants even within a same region

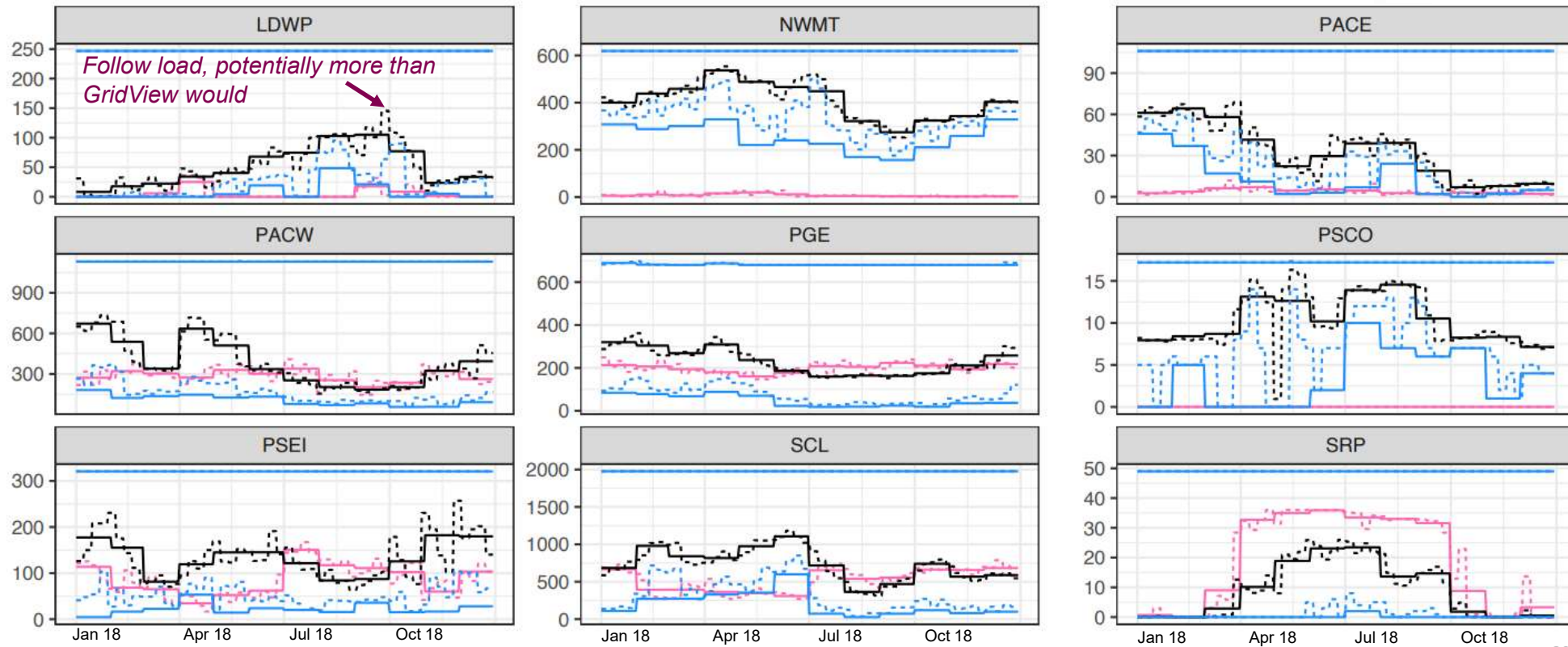


Weekly dataset by balancing authorities



Weekly dataset by balancing authorities

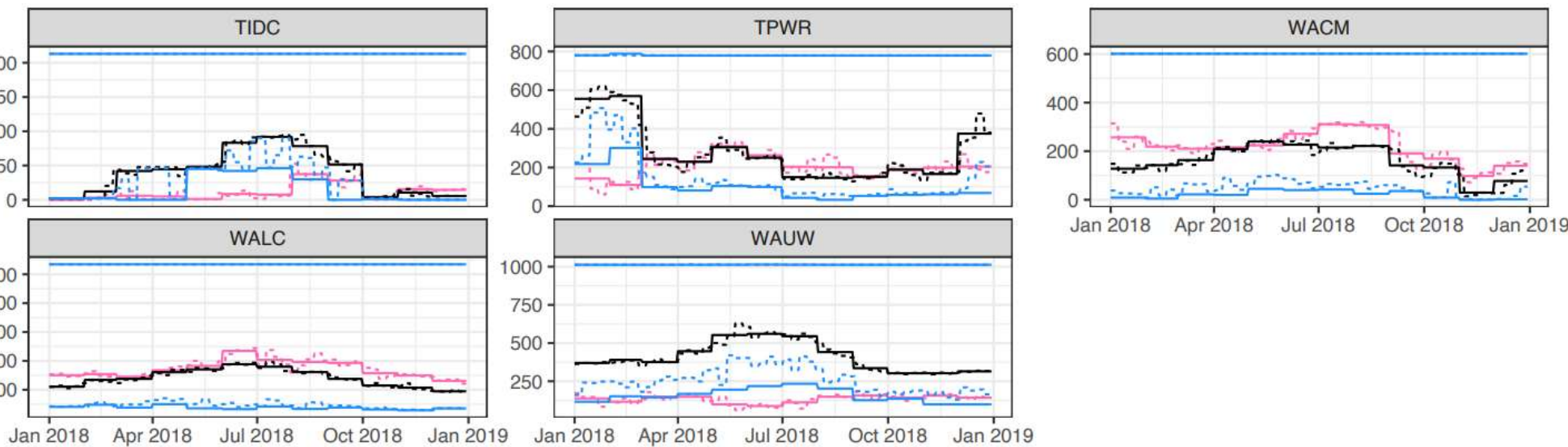
Monthly / weekly
 — monthly
 - - - weekly
 — Target (MW)
 — Daily Operating Range (MW)
 — Pmax
 — Min



Weekly targets by balancing authorities

Monthly / weekly

- Target (MW)
- Daily Operating Range (MW)
- Pmax
- Min
- monthly
- weekly



Achievements

A hydropower dataset:

- Coincident in space and time with wind, solar, and temperature-driven load variations
- With a finer temporal resolution to represent water management driven operations
- Represent normal operations and near-term environmental regulation

The framework to develop the dataset is consistent with:

- ongoing efforts on water availability scenarios under climate change conditions that support the Reliability Study Committee scenarios
- potential future efforts to evaluate ensembles of hydro, wind, solar and load conditions

Limitations

Limitations include:

- Feasibility errors on the water side: the weekly representation likely reduces the “hydropower feasibility errors” in GridView during the Spring freshet and in late Summer. Not all feasibility errors are prevented.
- Optimality errors on the water side: the current representation still do not reflect all the complex operations from the utilities. Complex operations include unit loading (number of units on and loaded, or spinning and offline units), and day-ahead scheduling practices to buy and sell on the market.
- Computational tradeoffs between hydropower operations driven by other water objectives (feasibility) and by power grid needs (optimality from the power side)

Do's and don'ts in using the dataset for other studies outside of WECC resource adequacy effort

- The cluster-approach for parameterizing the flexibility in the Columbia River cascading system needs to be maintained
- The flexibility is parameterized for normal operations. Experiments for extreme events would need to revisit this parameterization for an appropriate representation of hydropower contribution
- We recommend maintaining the coincidence between wind, solar, hydro and load at the regional and balancing authority scales as much as possible



Questions?



GridView Software Update: Hitachi Evaluation of dataset + software : PNNL

- Software Development
- GridView Simulation Evaluation
 - Software validation
 - Comparison between monthly 2030 and 2032 weekly hydro datasets

Hydro Power Weekly Logic Model

- GridView weekly engine schedules hydro generation based on weekly energy budgets, weekly minimum and maximum capacity, weekly daily average operating range, and weekly PLF allocator
 - Automatically computes K (Load following) and P (Price following) values.
- There are 53 weeks of data for an entire year: Jan.1st to Jan.7th uses the first week data, Jan.8th to Jan.14th uses the second week data, etc.
- GridView uses the 53rd week to represent the last day or last two days (leap) of the year
 - The user must import the total energy target corresponding to the 53rd week and GV engine will use one day or two days (leap year) of energy to schedule the hydro resources
- Hydro plants not modeled with the weekly logic will continue to be modeled with the monthly logic

First week of hydro data starts on Monday – Initial design based on budget availability. Future versions can be more versatile.

GV Software Bugs and Errors to Avoid

- Ensure all data quality check criteria are met (“*Bells and whistle*” from previous slide)
- Memory issue (ensure there is enough memory on the hard drive that GV stores the outputs)
- Iterations with ABB Hitachi:
 - In the beginning of each simulation, GV calls all 53 weeks datasets to create the initial schedule – Ensure that the 53rd week has non-zero values
- Simulation time of the weekly logic does not increase the simulation time significantly (increase was in the range of <3 hours).

Modes of Operation: 2030 vs. 2032 Hydro Datasets

#Number of Plants	Fixed Schedule	HTC/PLF*	Total
2030 Hydro datasets	69	1,086	1,155
2032 Hydro datasets	45	1,110	1,155
Difference	24 Plants		

Installed Capacity (MW)	Fixed Schedule	HTC/PLF
2030 Hydro datasets	2,299	68,653
2032 Hydro datasets	2,068	68,884
Difference	231 MW	

* Proportional load following

* Hydrothermal coordination

Name	Area Name	Installed Capacity(MW)
Tiber_Dam	WAUW	7.5
Alcova 1	WACM	21.8
Alcova 2	WACM	21.8
Boysen1	WACM	7.5
Boysen2	WACM	7.5
Buffalo Bill 1	WACM	6.67
Buffalo Bill 2	WACM	6.67
Buffalo Bill 3	WACM	6.67
Estes 2	WACM	15.7
Estes 3	WACM	15.7
Flatiron 3	WACM	8.5
Green Mountain 1	WACM	14.44
Green Mountain 2	WACM	14.44
Towaoc	WACM	12.1
MoraDrop	IPTV	1.85
Etiwanda_Hydro	CISC	24
Hell_Hole	CIPV	0.5
Quinten Luallen	CIPV	6.9
San_Joaquin_2_1	CIPV	3.2
San_Joaquin_3_3	CIPV	4.2
SanJoaquin1A	CIPV	0.4
Big_Cliff_1	BPAT	18
New Hogan 1	BANC	2.2
New Hogan 2	BANC	2.2
Total		230.44

Evaluation



- Weekly dispatch
 - Is the model doing what it is supposed to do? (Input-Output Comparison)
 - ✓ Plant level (Core Columbia and Lower Snake River plants)
 - ✓ Balancing authority level
- 2030 vs 2032 hydro data sets
 - Annual generation portfolio mix
 - Total operating cost
 - Locational marginal prices
 - Solar and wind curtailment
 - CO₂ emissions

Software Validation - Core Columbia and Lower Snake Plants

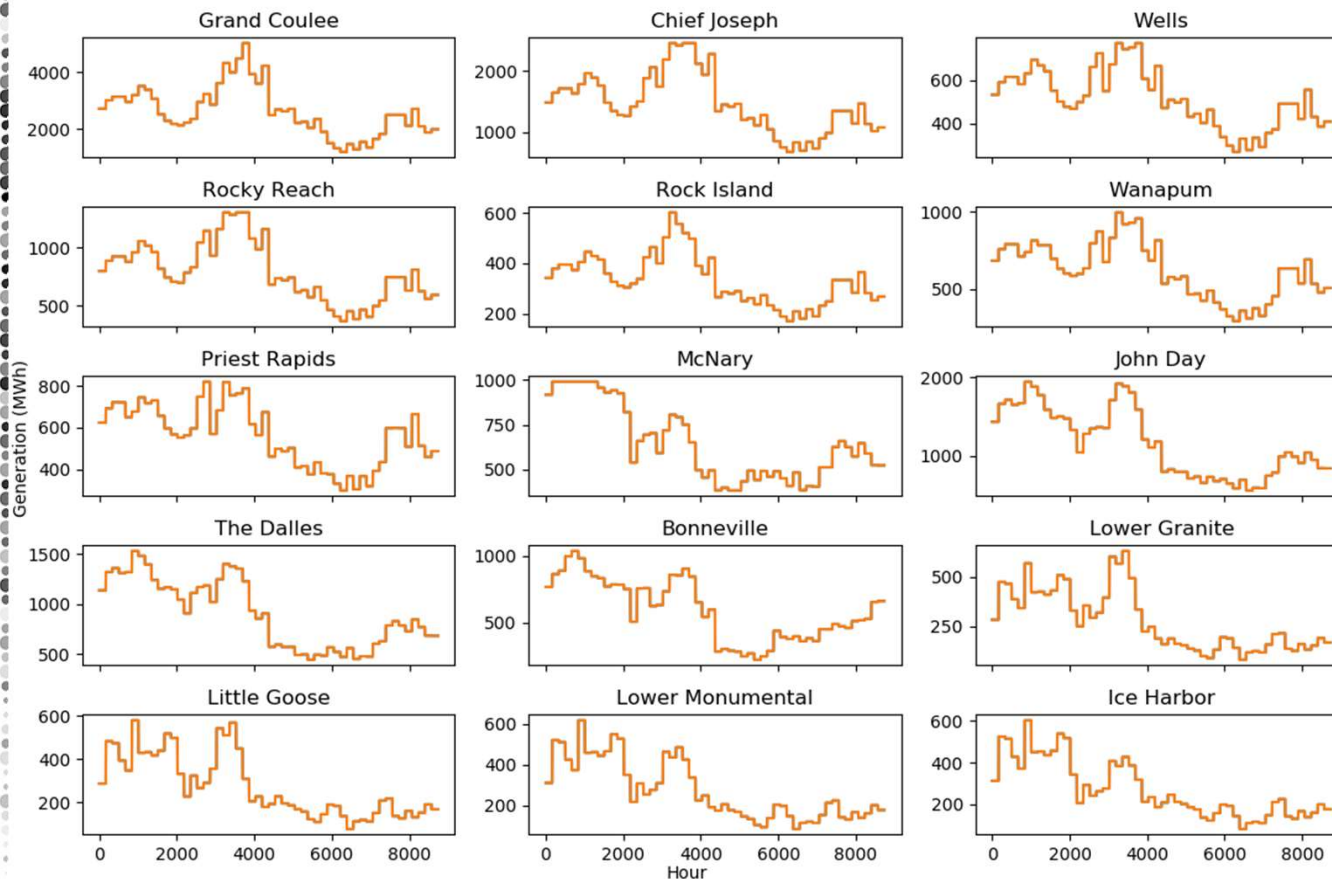
Selection of
median year

Weekly
targets

Daily
Fluctuations

Evaluation

- Weekly average energy **output** vs. Weekly energy **input**



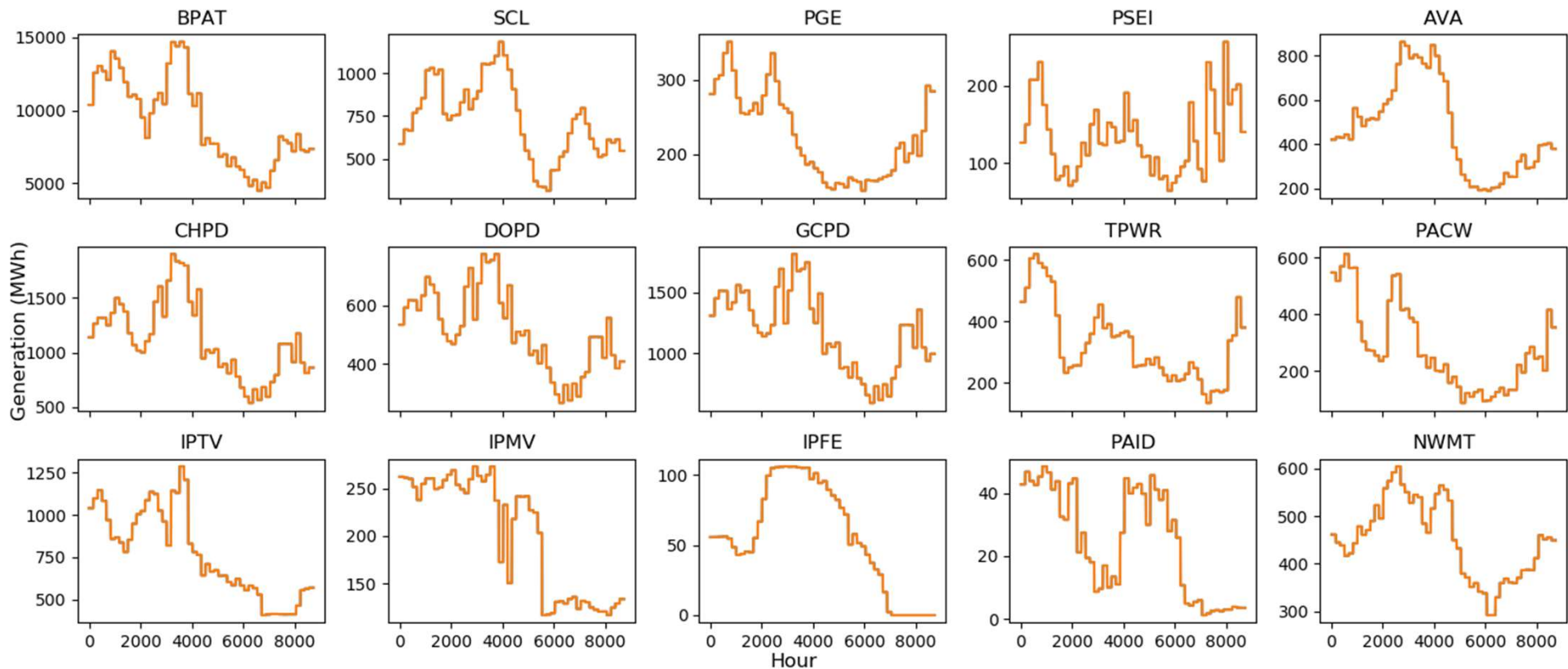
— Energy Input
— Energy Output

We observe a perfect match between the energy output and energy input values

Software Validation – Balancing Authorities (1)

- Aggregated weekly average energy output vs. input for select BAs

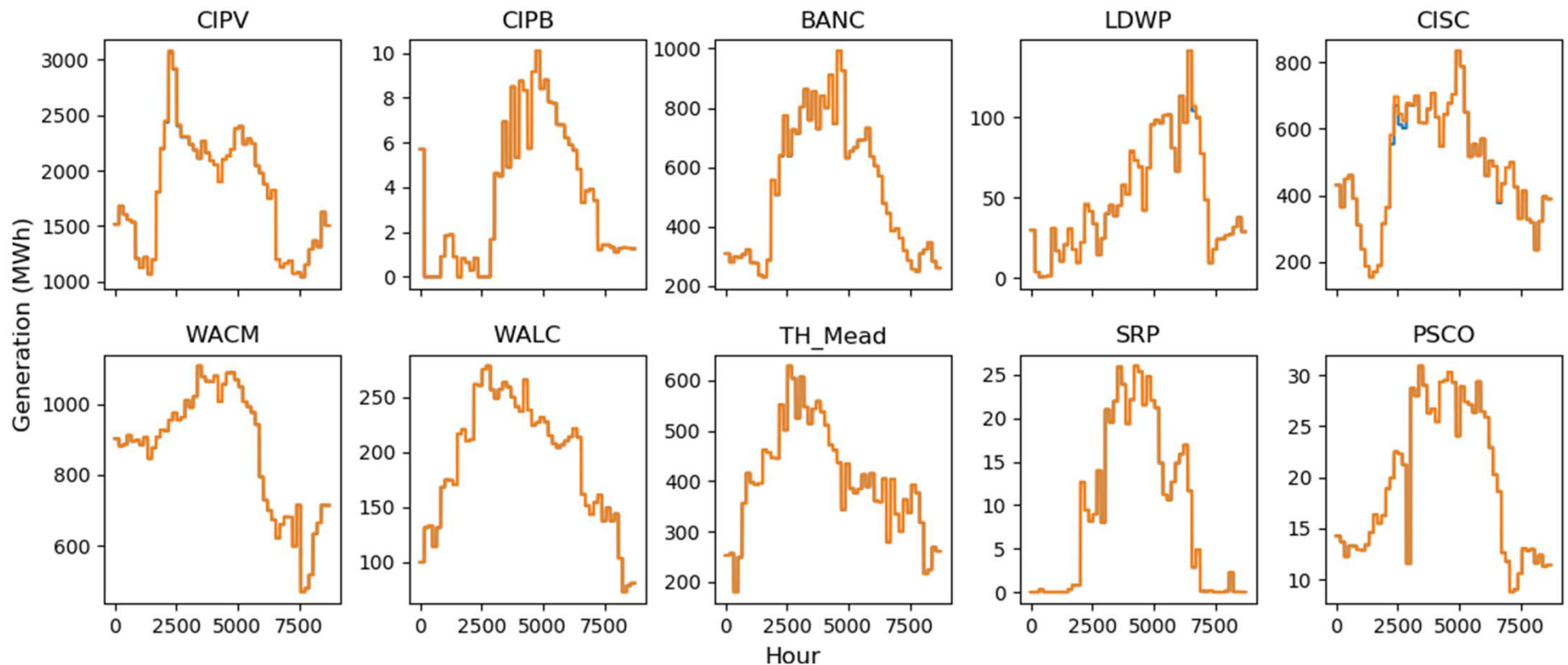
— Energy Input
— Energy Output



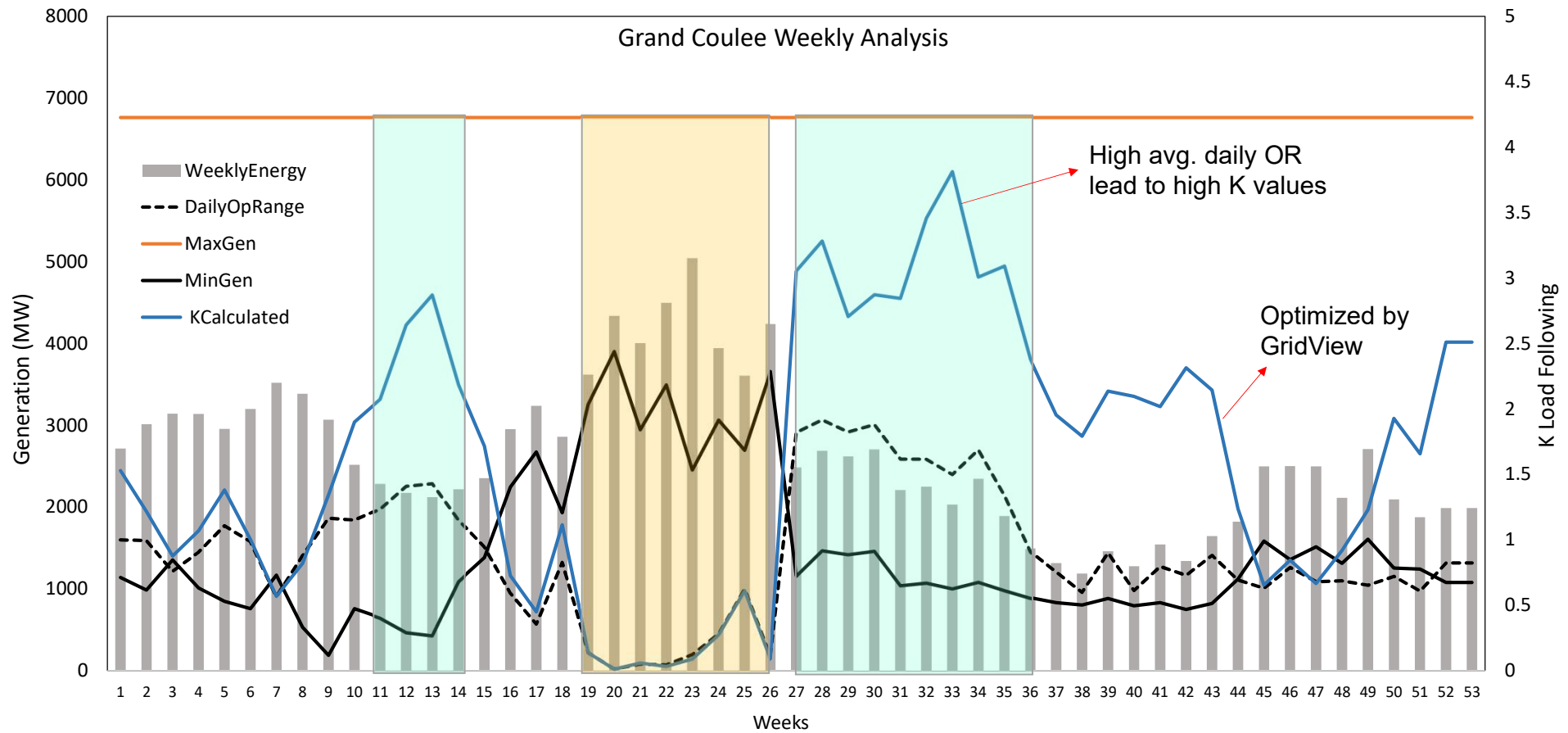
Software Validation – Balancing Authorities (2)

- Aggregated weekly average energy output vs. input for select BAs

Energy Input
Energy Output

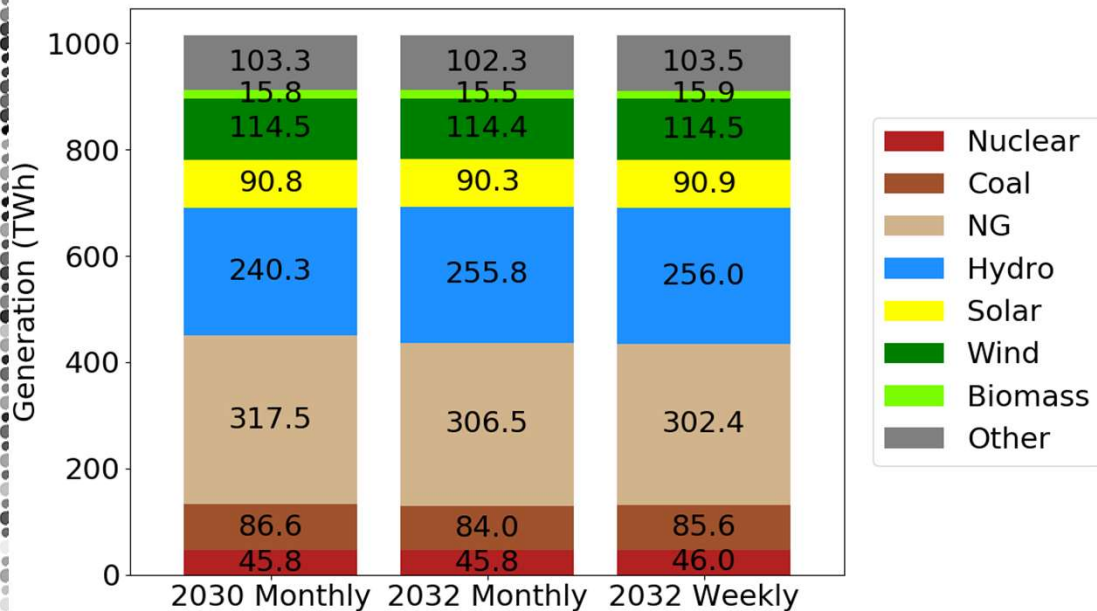


Relationship Between Key Optimization Parameters

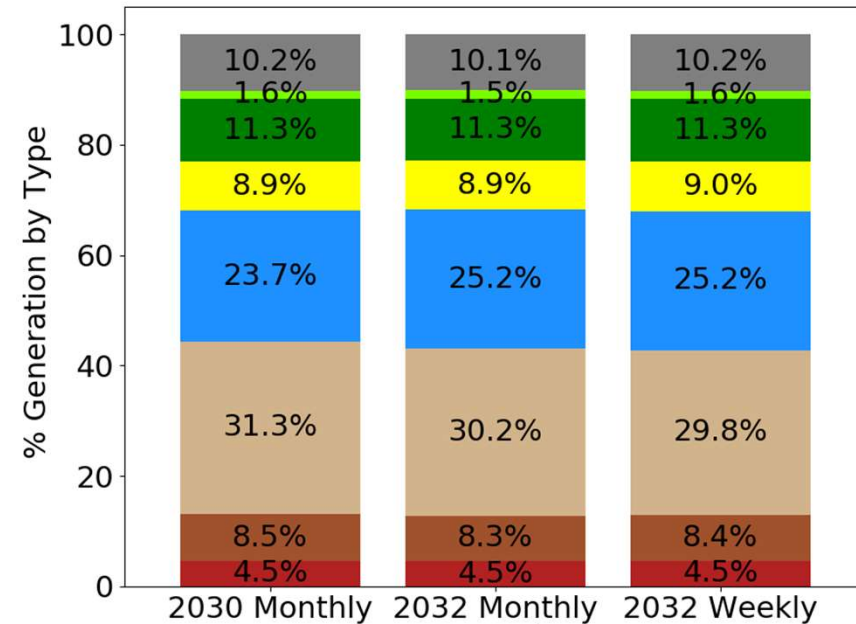


2030 vs. 2032 Annual Generation – Total WECC

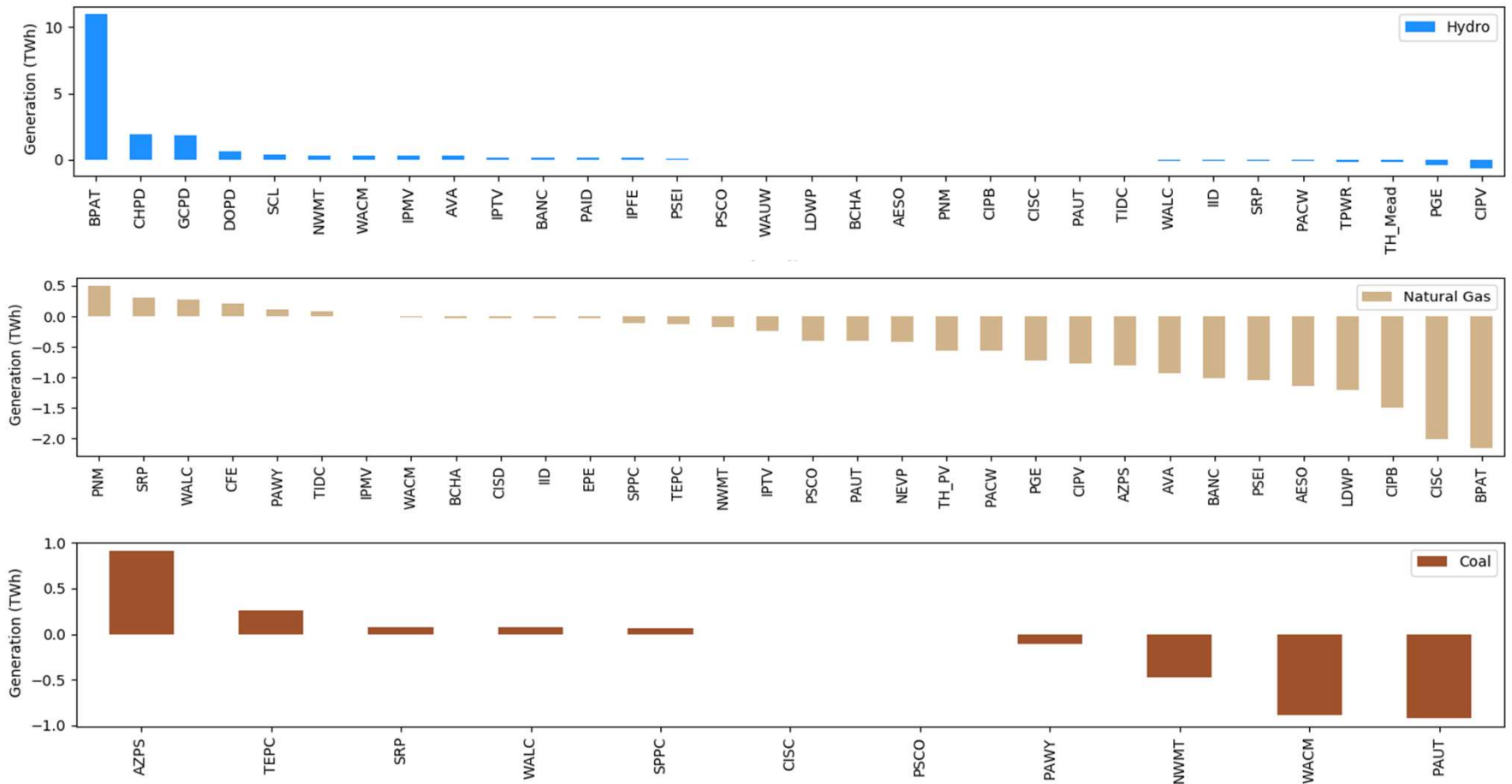
Annual Generation by Technology (TWh)



% Generation by Technology

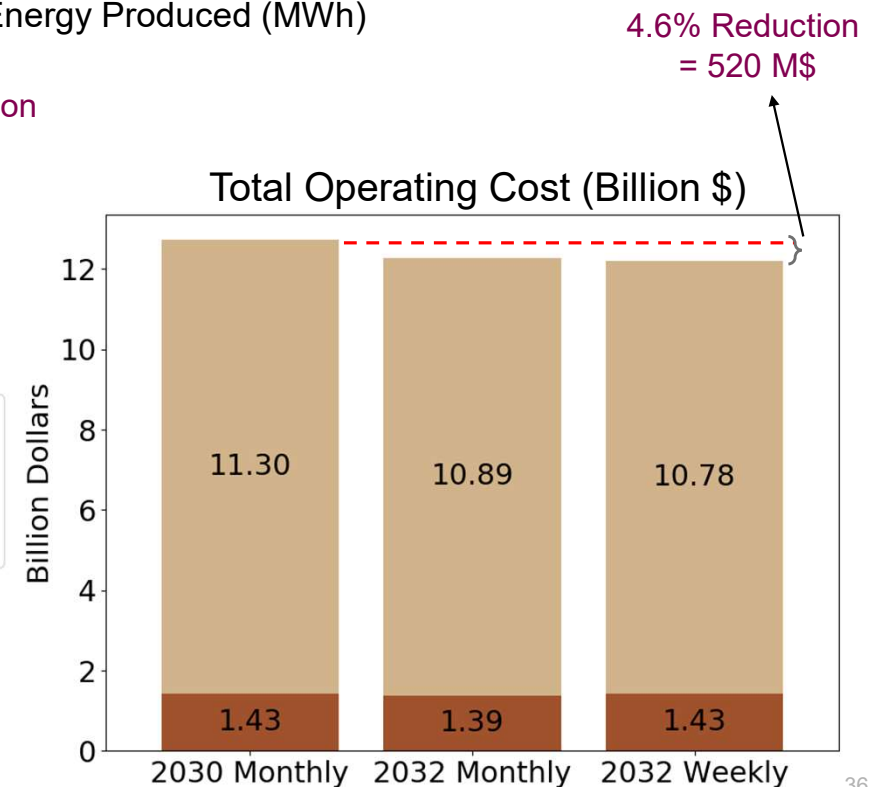
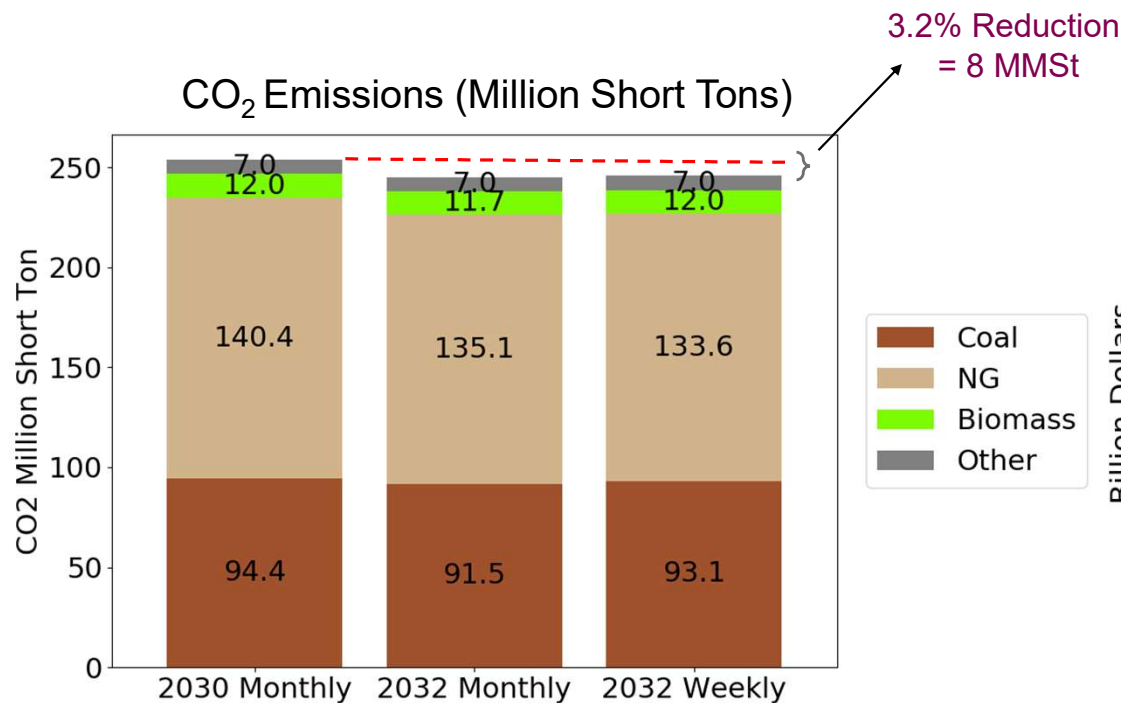


Annual Generation Difference by BA: 2032 Weekly - 2030 Monthly

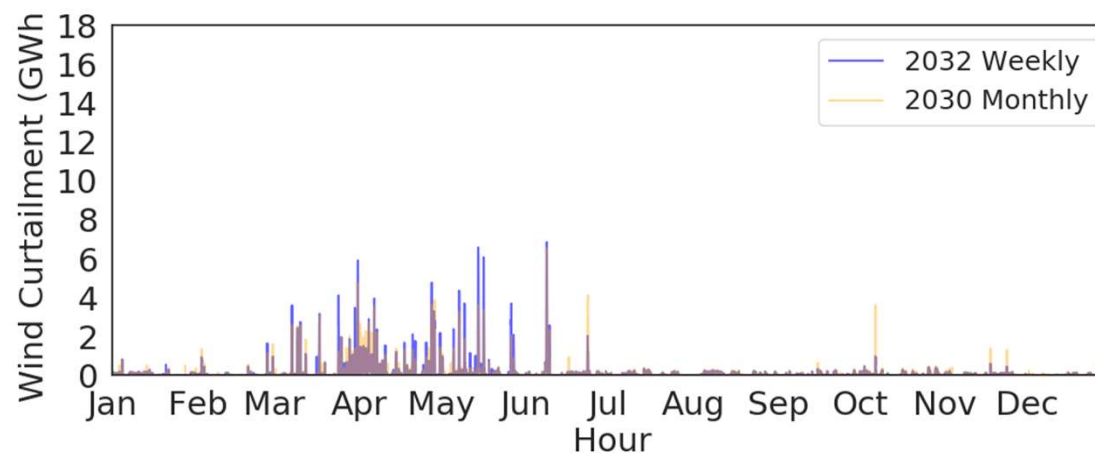
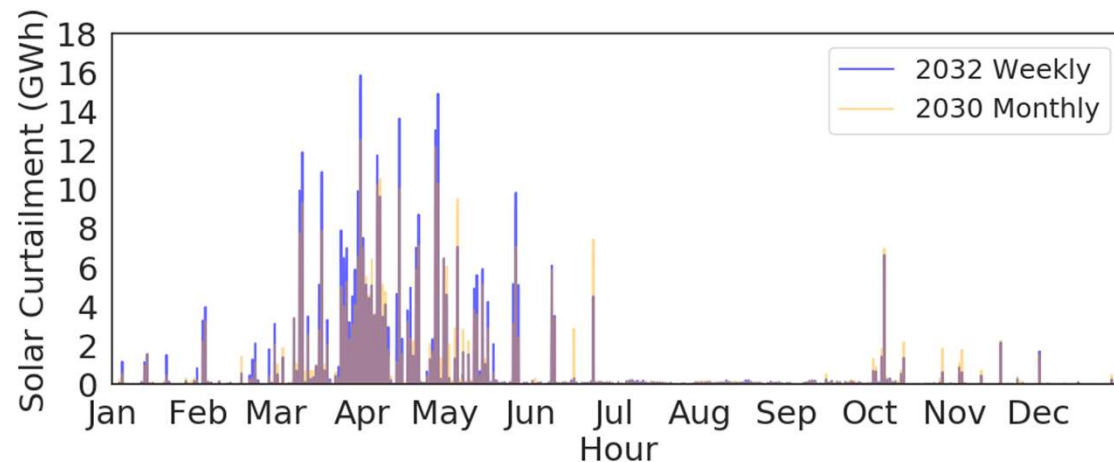
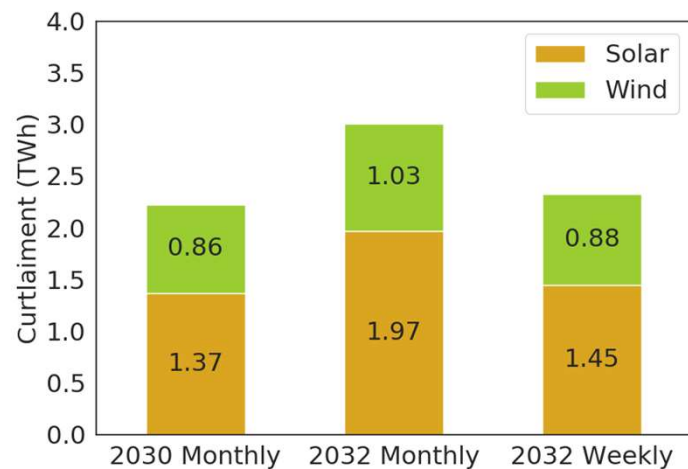


2030 vs. 2032 Operating Costs & Emissions —Total WECC

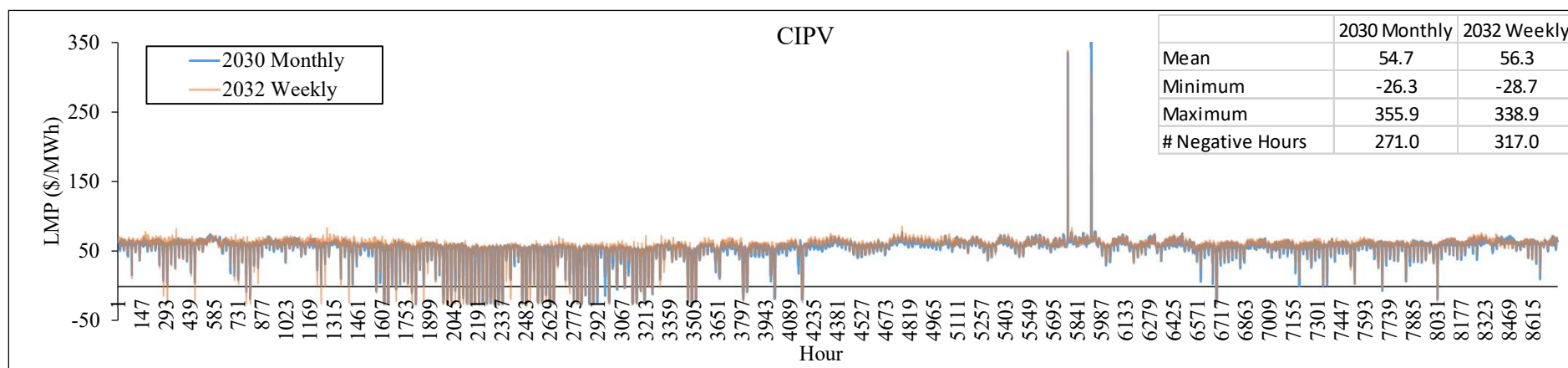
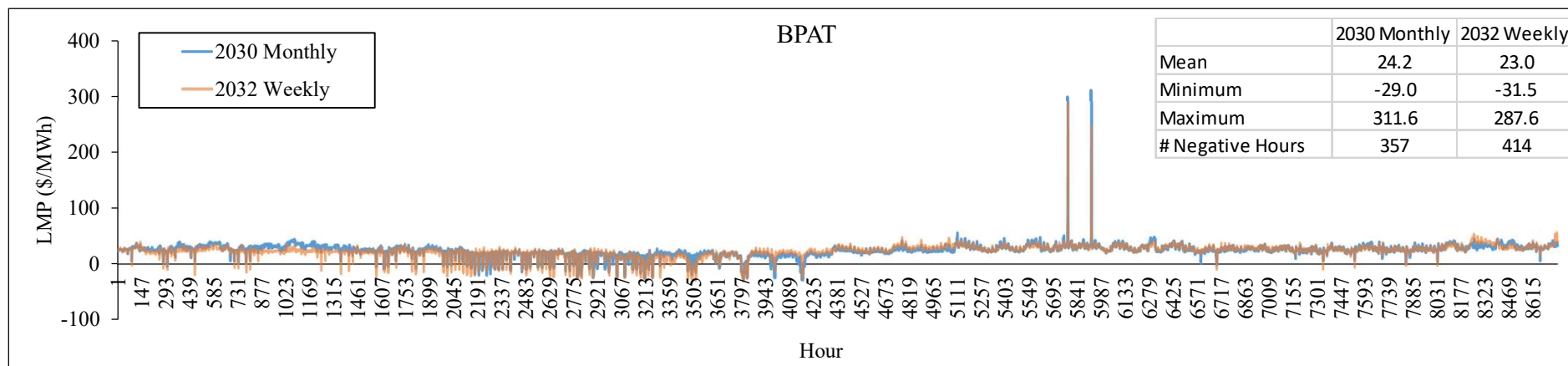
- Emissions = Heat Rate (MMBtu/MWh) × CO₂ Emission Rate (lb/MMBtu) × Energy Produced (MWh)
- Total Operating Cost = Fuel Cost + Start Up Cost + O&M Cost
- Fuel Cost = Heat Rate (MMBtu/MWh) × Fuel Price (\$/MMBtu) × Energy Produced (MWh)



2030 vs. 2032 Curtailment – Total WECC



2030 Monthly vs. 2032 Weekly Prices — BA Level



Conclusion - Combined evaluation of the GridView software for hydro and hydro datasets

- Software update evaluated (weekly constraints are conserved)
- Impact on the GridView simulations:
 - 16 TWh of additional hydro associated with changes in water conditions
 - ~16 TWh less of Natural Gas in the generation portfolio
 - LMPs prices are slightly lower
 - CO2 emissions are 3.2% lower
 - Operating cost is 4.6% lower
 - Curtailment of wind and solar slightly increases – the increase is largely contained by the weekly logic
 - The increase in hydro generation mainly occurs in the BPA and Northwest regions, reducing natural gas reliance in the Northwest and California regions. LMP prices reduction are mostly located in the Northwest.
- PNNL has formatted the 2032 weekly hydro datasets to be compatible with GridView import format:
 - *Hydro weekly variable schedule* file (contains information about the weekly hydro parametrization)
 - *Hydro general* file (contains information about modes of operation and ramp rates)



Thank you

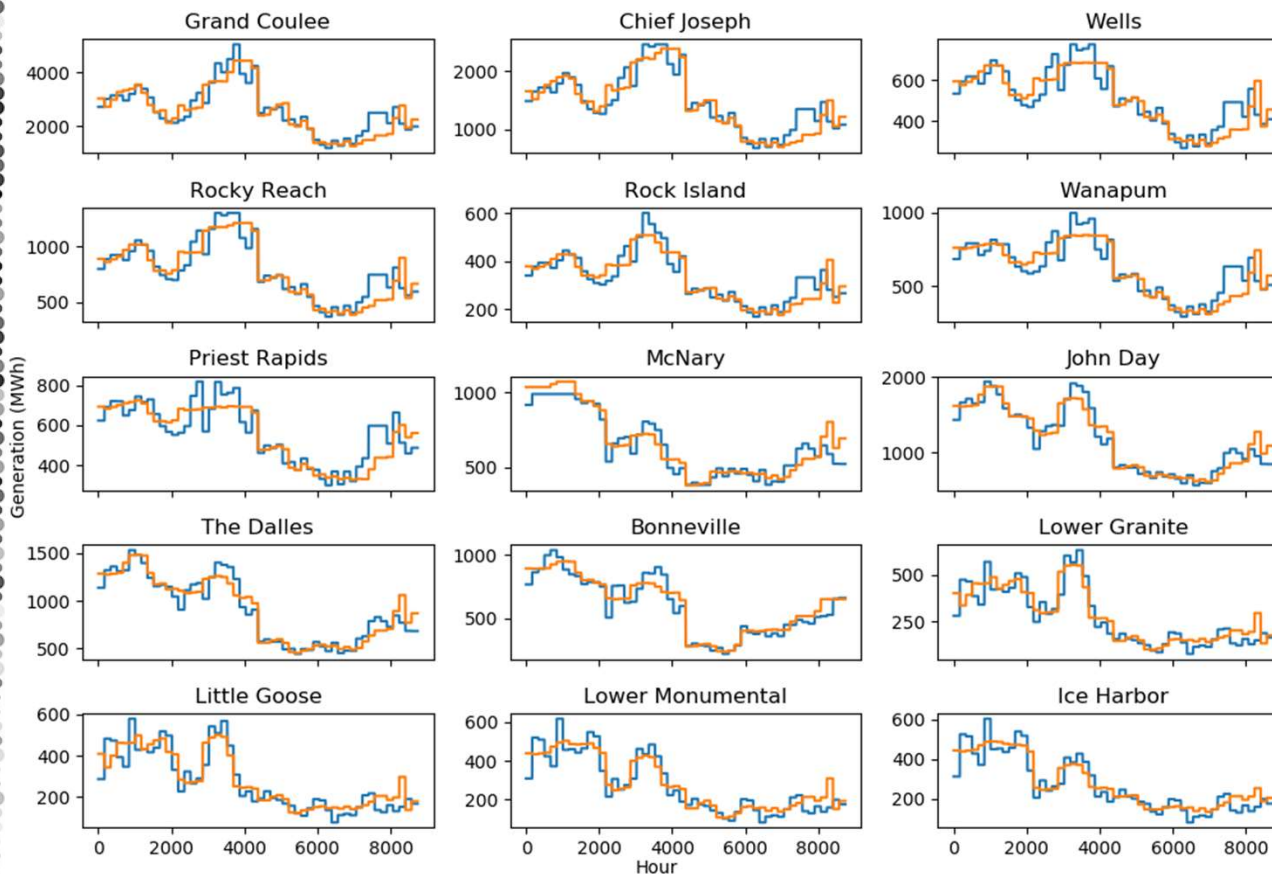
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Validation – Monthly vs. Weekly Logics by Plant

- Monthly vs. Weekly Logics Dispatch Comparison for Core Columbia and Lower Snake Plants



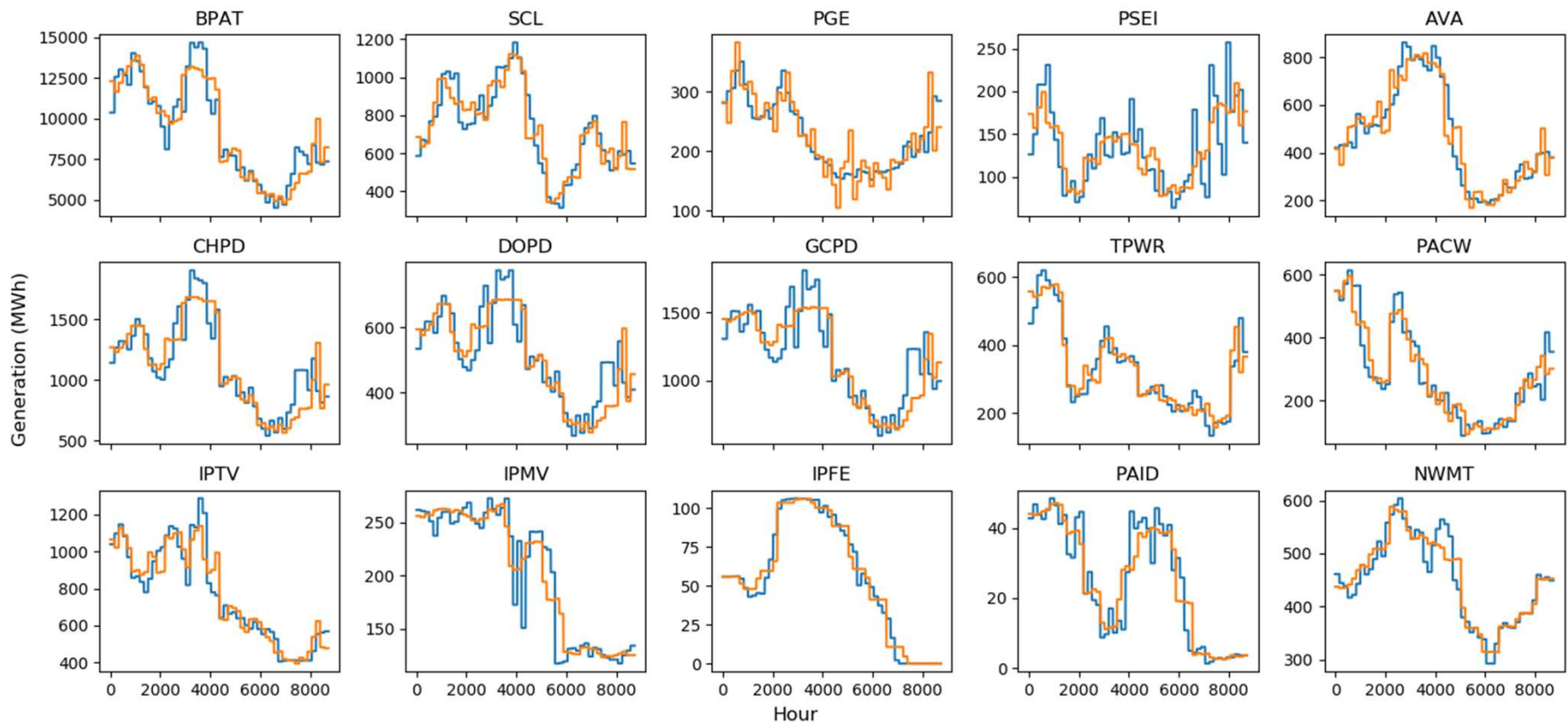
— Monthly
— Weekly

Weekly logic more flexibly responds to system net load variations leveraging the automatic computation of K,P **weekly** parameters

Validation – Monthly vs. Weekly Logics by BA

- Monthly vs. Weekly Logics Dispatch Comparison by Balancing Authority

Monthly
Weekly



Validation – Monthly vs. Weekly Logics by BA (2)

- Monthly vs. Weekly Logics Dispatch Comparison by Balancing Authority

— Monthly
— Weekly

