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## PNNL Methodology and Results

# Evaluating Balancing Reserve Requirements for WECC 2034 ADS Case

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**WECC Production Cost Data Subcommittee Meeting**

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U.S. DEPARTMENT of ENERGY BATTELLE

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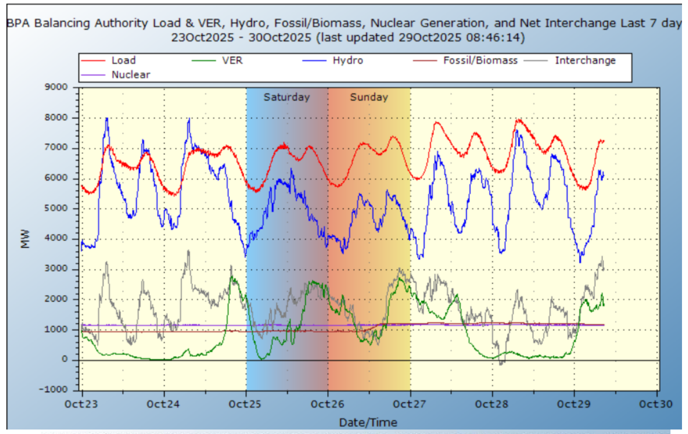
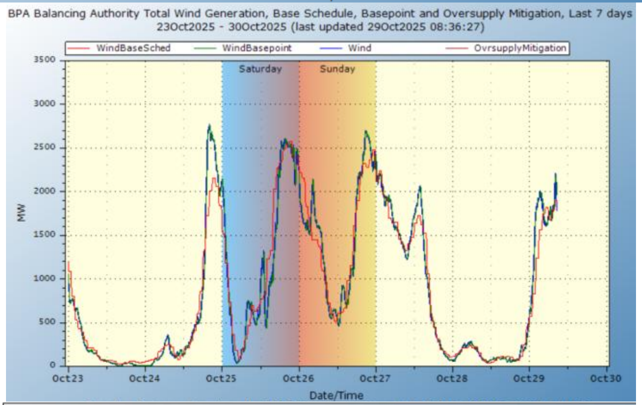
# Agenda

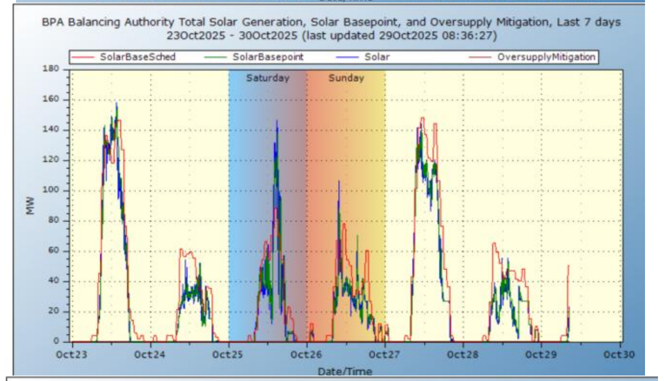
- Main Take-Aways from 2034 Balancing Reserve Calculations
- PNNL Balancing Reserve Calculation Approach
- Data Collection and Processing for WECC ADS PCM 2034 Reserve Calculations
- Sample of Reserve Calculations Results for Selected BA
- Conclusions for 2034 Balancing Reserves
- Appendix
  - Data processing
  - Modeling of Load Following and Regulation Constraints in GridView



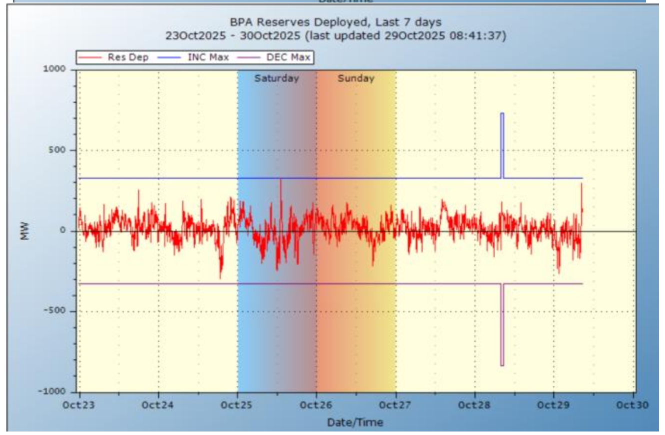

Load (red)




Wind




Solar




Reserve deployment

https://transmission.bpa.gov/business/operations/wind/

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# Main Take-Aways from 2034 Balancing Reserve Calculations

# 2034 Balancing Reserve Results

- High increase of solar (utility and BTM) and wind installed capacity in the the WECC 2034 ADS case compared to the WECC 2032 ADS case
- New hourly utility scale solar and wind profiles are created based on 2018 weather models for new plants that did not exist in the 2032 case
- High-resolution time series (at least 5-min) is key for estimating flexibility requirements
- PNNL calculated Load Following (LF) and Regulation (Reg)  up and down capacity requirements
  - Results to be incorporated in WECC ADS 2034 case at the BA level in Hitachi GridView
- As an example, in CAISO,
  - LF requirements increased by ~1000 MW up/down (January).
  - Reg requirements shifted towards off-peak and mid-day time periods, that would require further investigation and may suggests the need for improvement in the methodology used to create 1-min data.

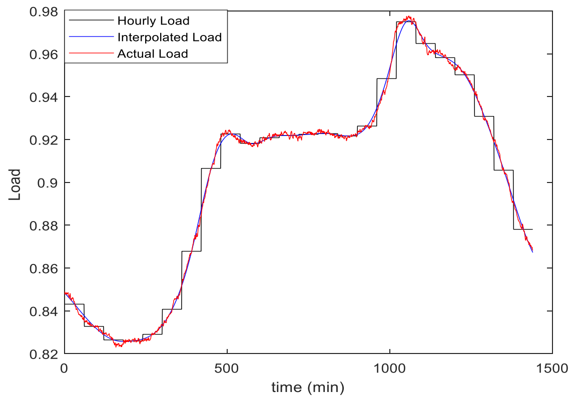
# PNNL Balancing Reserve Calculation Approach

# Generation Flexibility Assessment as Input to Production Cost Model

## PNNL's Grid Reserve and Flexibility Planning Tool (GRAF-Plan)

**Scenarios** of wind and solar generation existing + planned

**Operational practices** – dispatch, scheduling, forecasts, and reserves

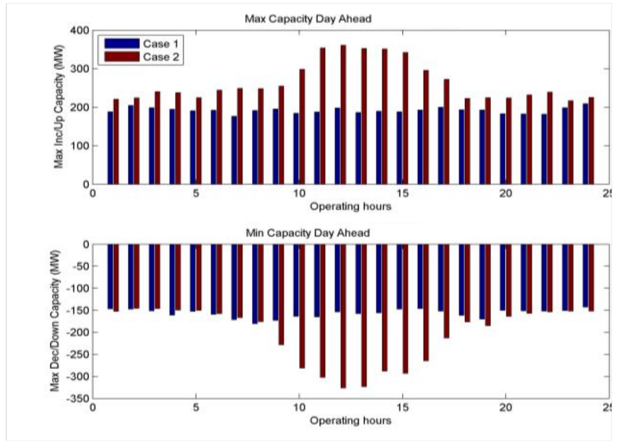



**Forecast and reserve management models**

- Minute by minute load, wind and solar data
- Forecasting practices for wind, solar, and loads
- Available flexible generation
- Balancing timeseries signal
- Swinging-door algorithm

**Calculation of flexibility requirements**

- Capacity
- Ramp rate
- Ramp duration




**Hitachi GridVIEW**

- Production cost model
- Generation and transmission planning

GRAF-Plan methodology has been applied in several studies in U.S., including CAISO and WECC, and internationally.
Studies are linked in appendix slides.


M. Ghosal *et al.*, "Grid Reserve and Flexibility Planning Tool (GRAF-Plan) for Assessing Resource Balancing Capability Under High Renewable Penetration," in *IEEE Open Access Journal of Power and Energy*, vol. 10, pp. 560-571, 2023, doi: 10.1109/OAJPE.2022.3169729
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9762001

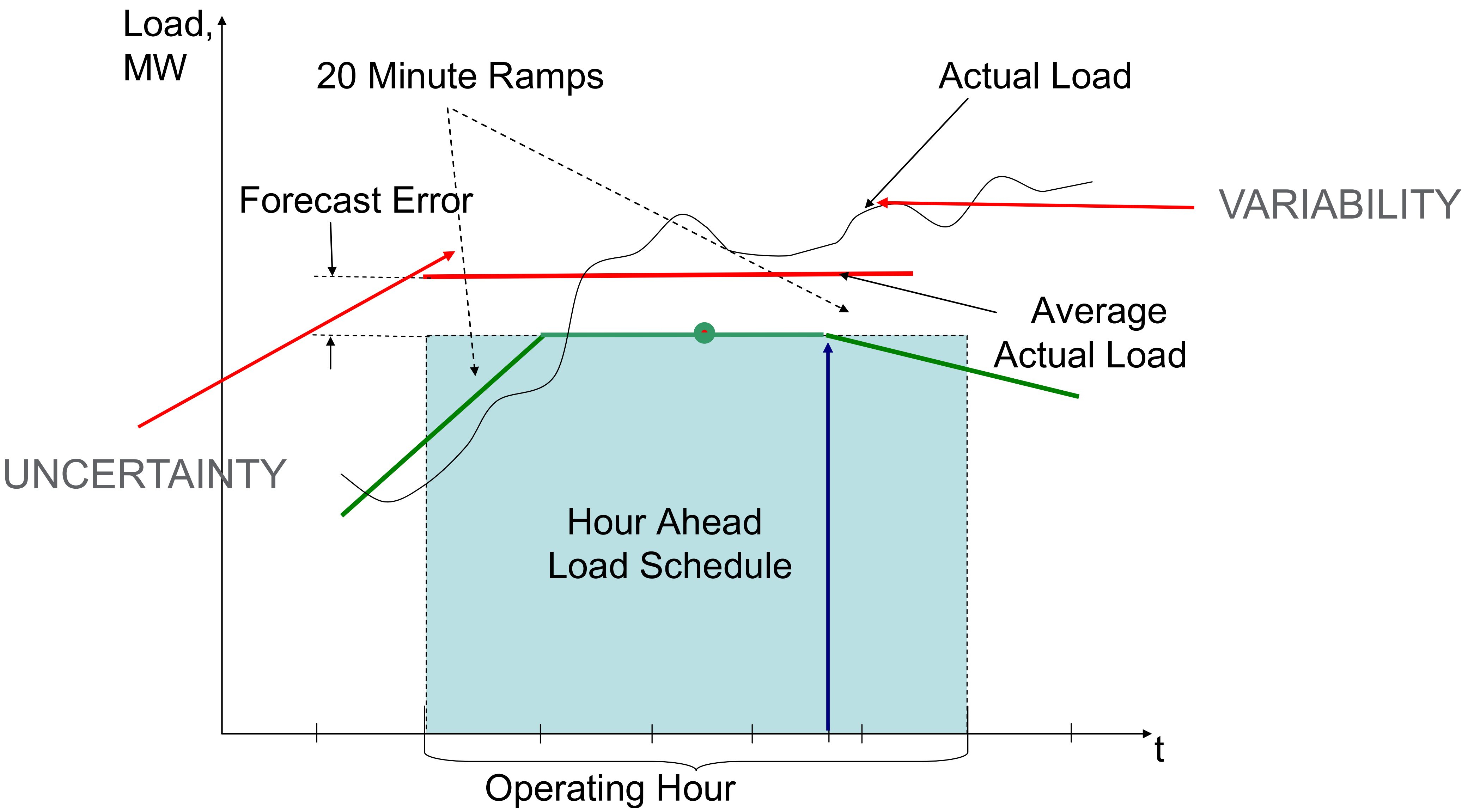
# Summary of PNNL's Reserve Calculation Methodology

- Mimics real balancing process, including scheduling and real-time dispatch
- Incorporates both variability and uncertainty factors
- Includes all sources of uncertainty (native load, wind, solar, behind-the-meter solar)
    - Reflects forecast errors and their impact on balancing requirements
- Evaluates both capacity requirements and ramping requirements
- Flexible to reflect differences between balancing processes in different systems
- Has been benchmarked against actually observed balancing requirements
- Has been used in multiple studies

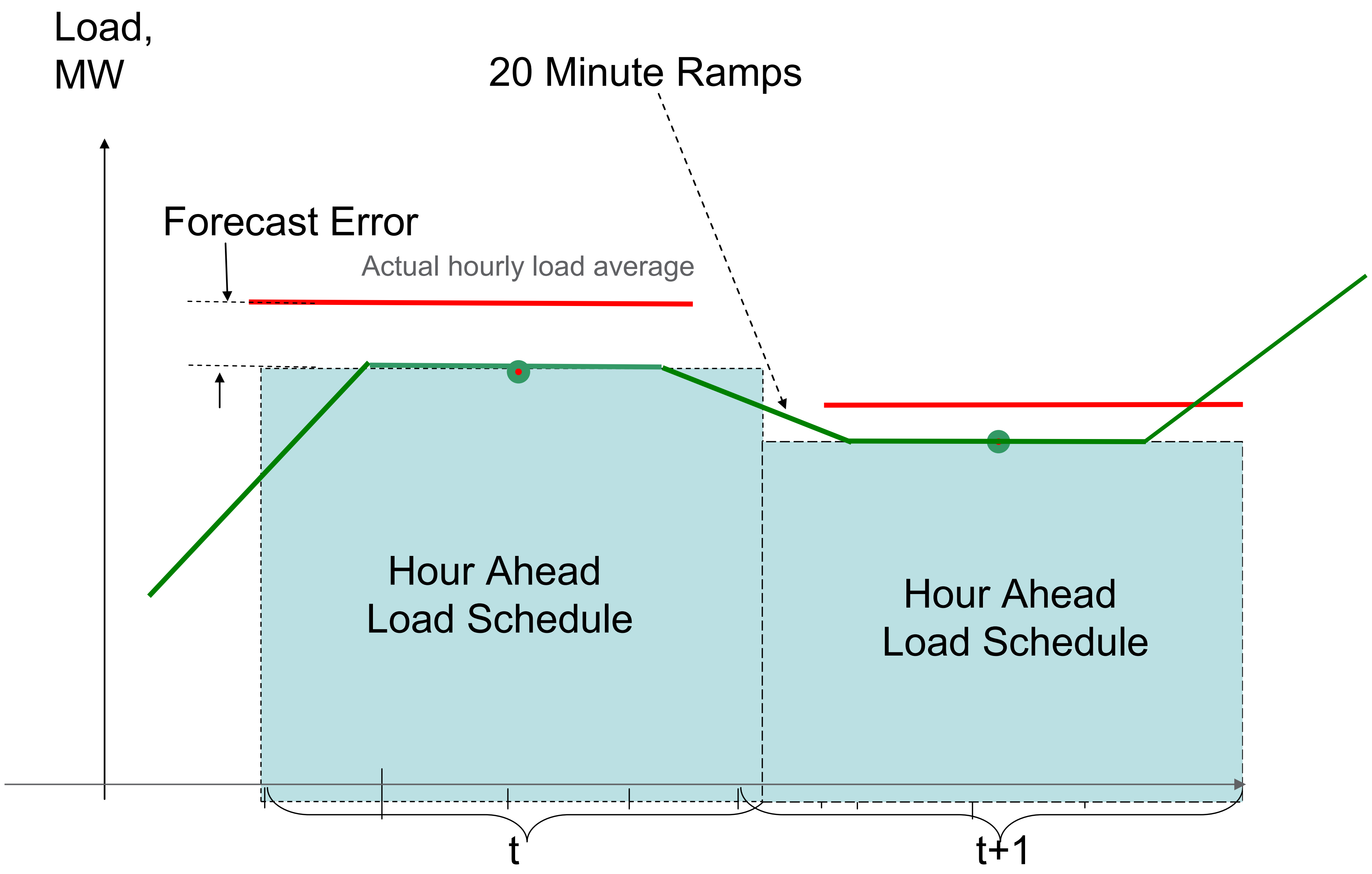
# Net Load and Generation Requirement

- BA Hourly Net Load = Load – Wind – Solar + Interchange
- Net Load = Generation Requirement
- Scheduled Generation Requirement = Forecasted Net Load
- Actual Generation → Actual Net Load ± Δ
- Generation Requirement:
  - Energy schedules
  - Real time dispatch (load following)
  - Regulation

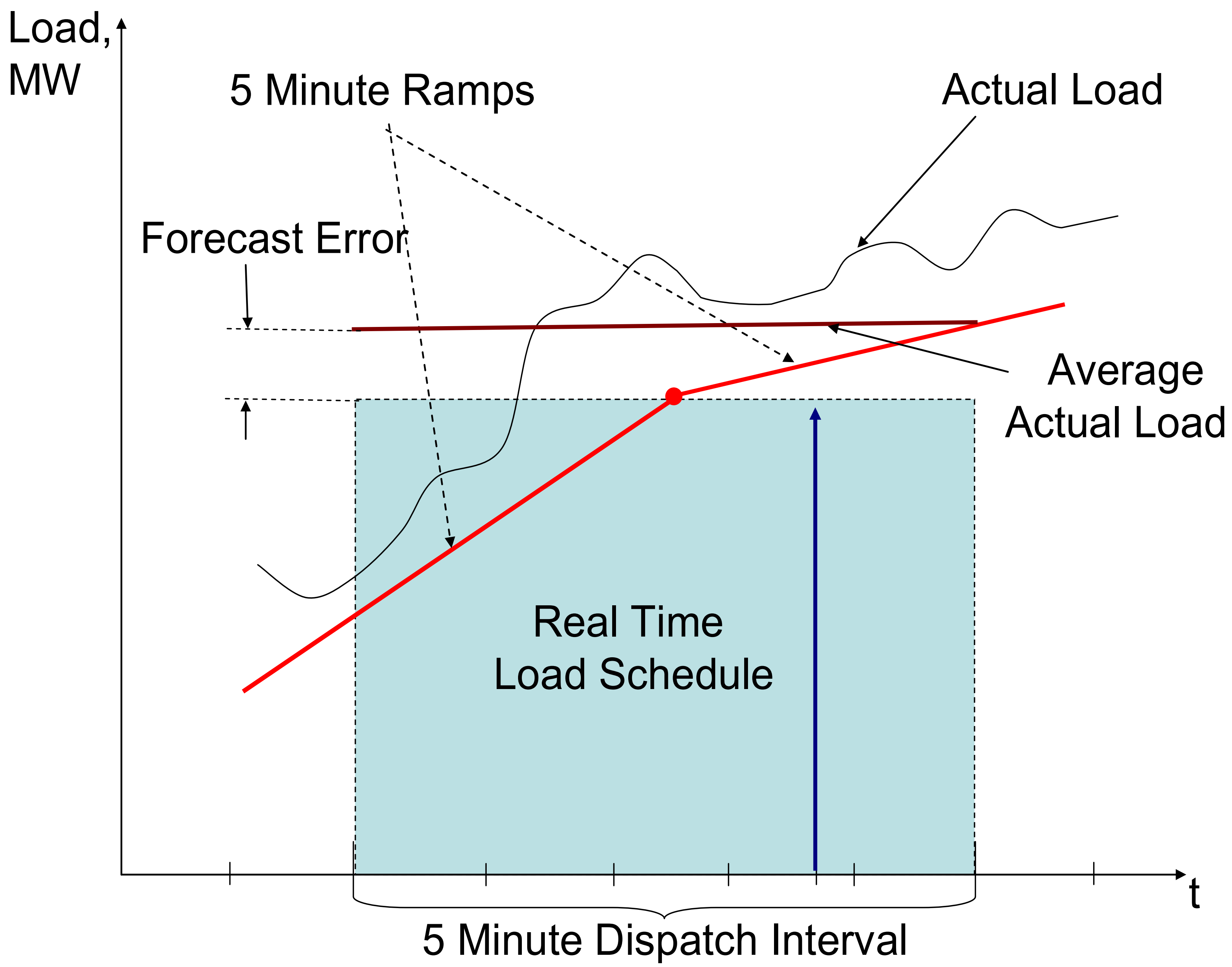
# Modeling Variability and Uncertainty
## (Hour-Ahead Forecast)



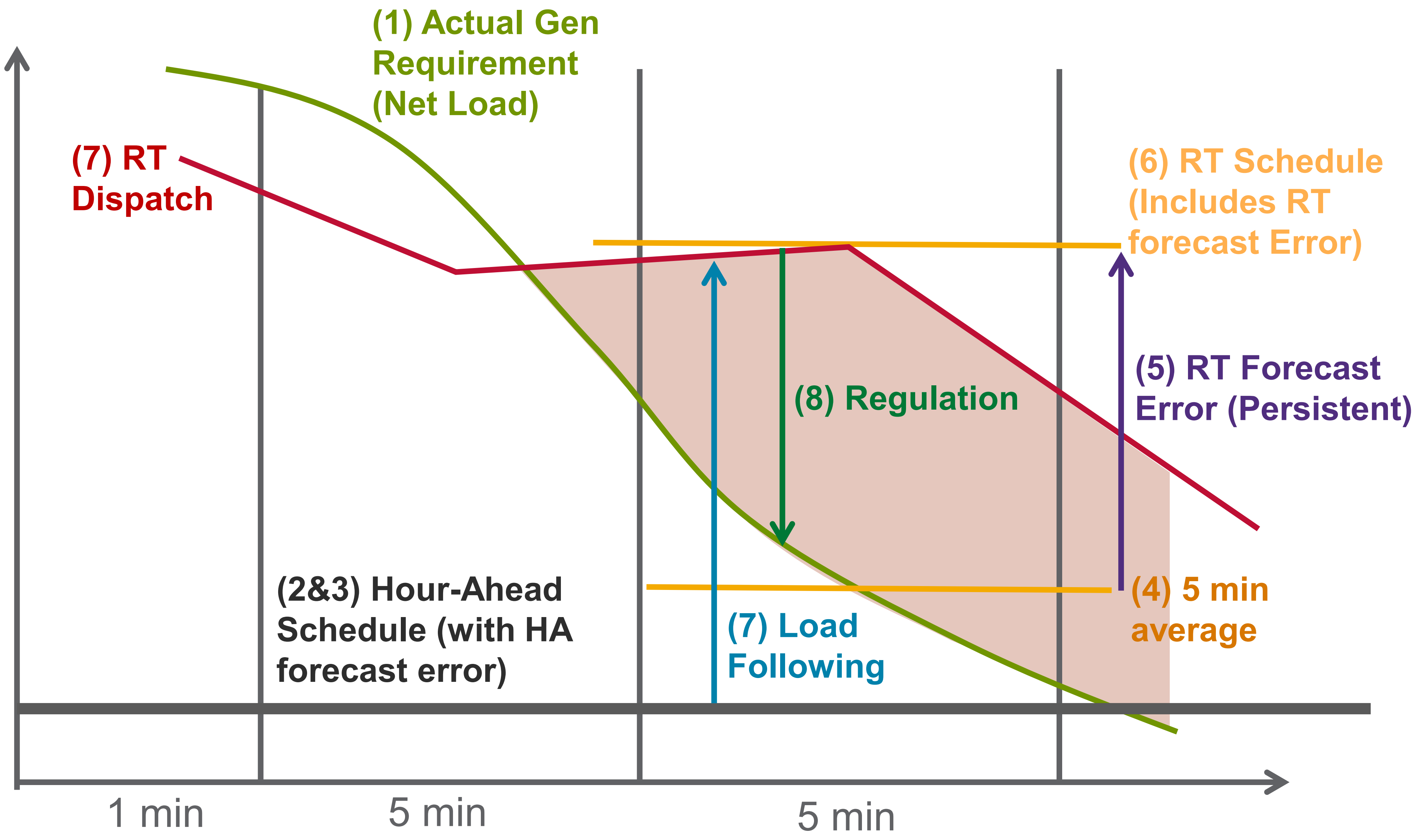
# Block Hour-Ahead Net Load Schedules



# Real-Time Scheduling

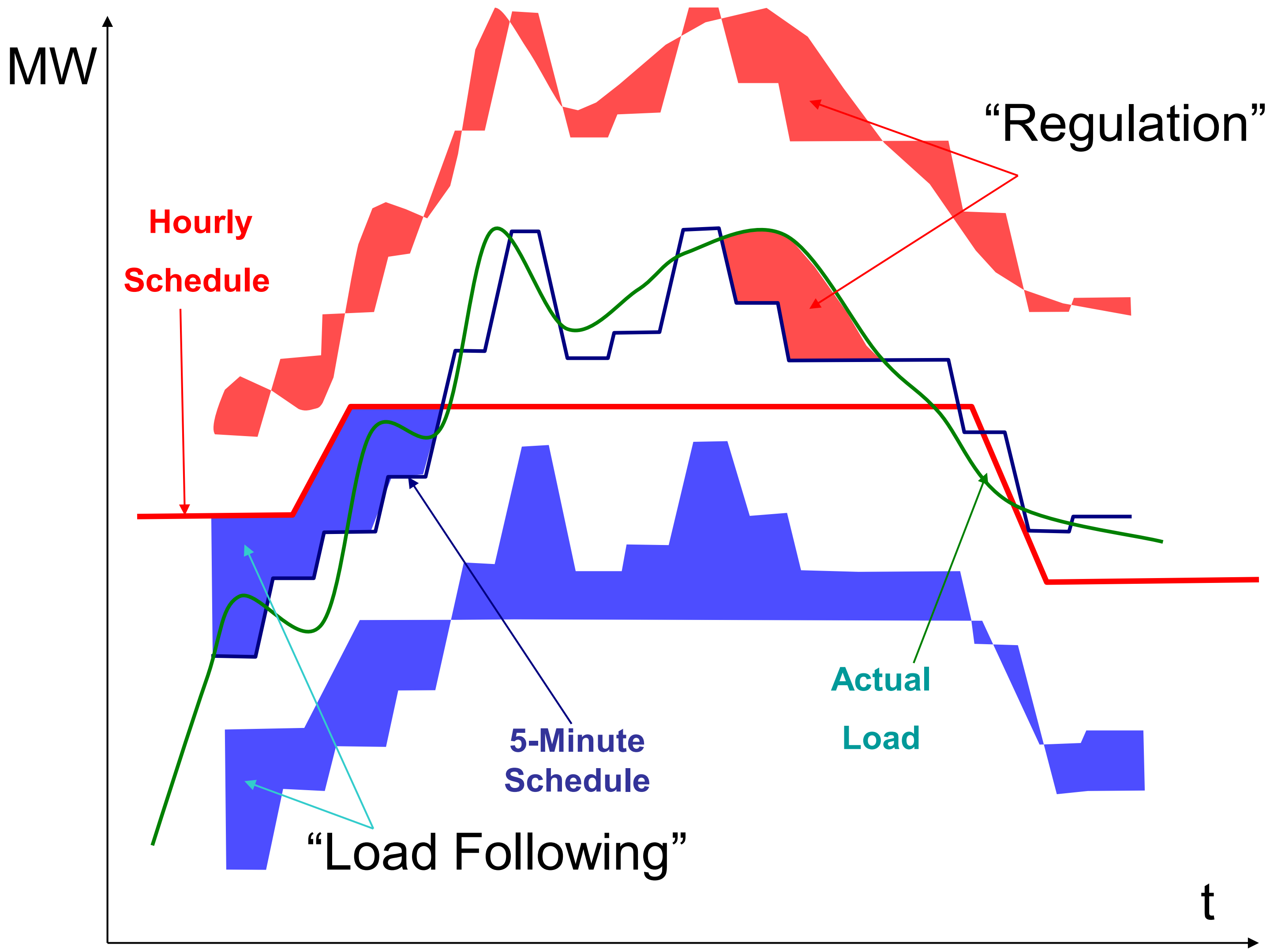


# Balancing Reserves Components



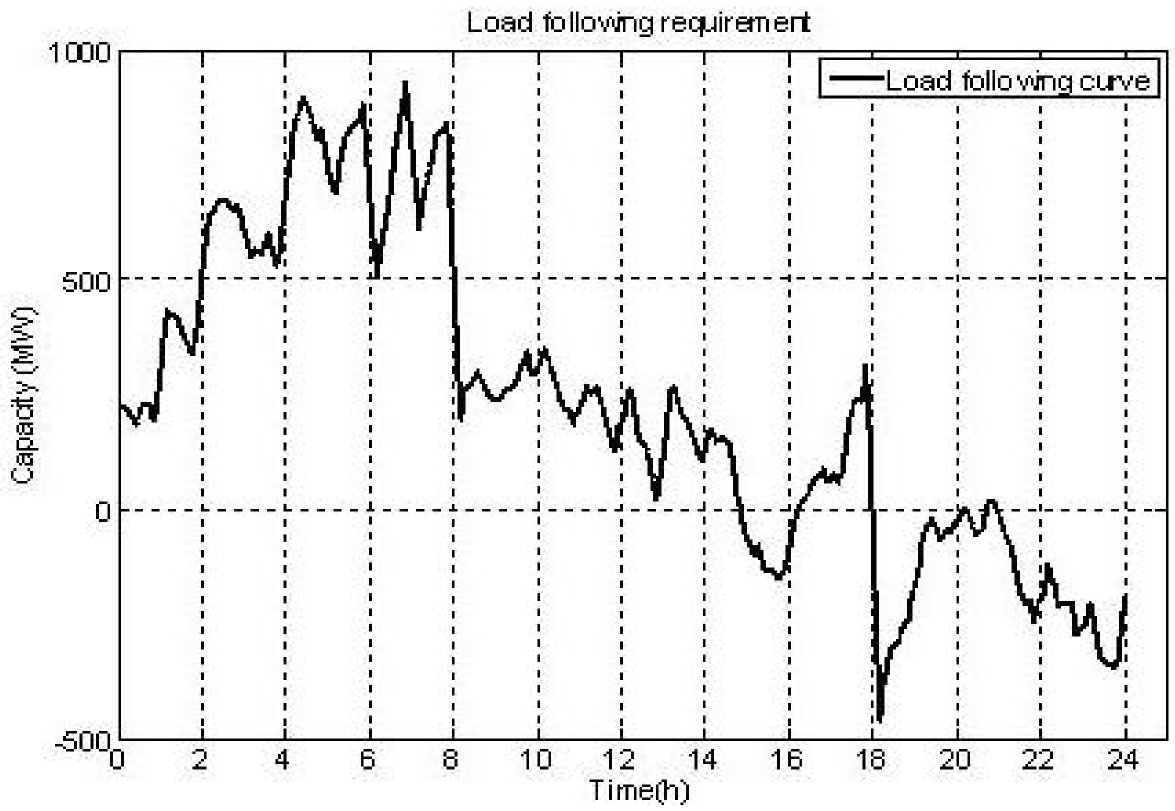
# Load Following and Regulation

- **Load Following:** difference between hourly energy schedule including 20-min ramps (red line) and short-term 5-min forecast/ schedule and applied "limited ramping capability" function (blue line)
- **Regulation:** difference between actual generation requirement and short-term 5-minute dispatch (red area between blue and green lines)

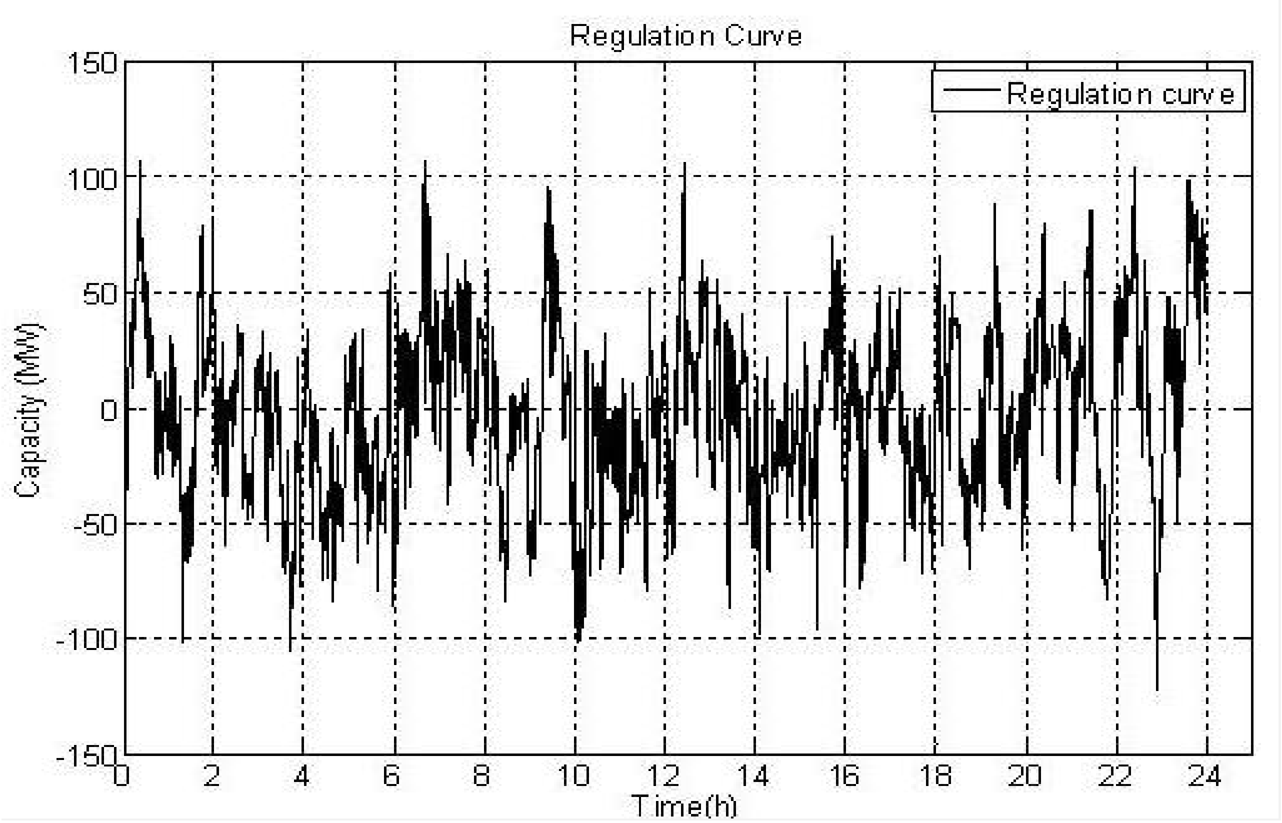


# Example of Load Following and Regulation Requirements

- Generate hour-ahead and 5-min ahead forecast errors for load, wind and solar.
- Use actual and forecast data to derive minute-by-minute load following and regulation requirements for each BA.




Load following requirements




Regulation requirements

# Data Collection and Processing for WECC ADS PCM 2034 Reserve Calculations

# WECC 2034 ADS PCM Planning

- WECC develops Anchor Data Set for 2034 model, including Production Cost Model case in Hitachi GridView software tool
- PNNL supports this planning activity by:
  - Providing utility scale wind and solar hourly profiles based on 2018 weather models for new plants that were not in the 2032 case
  - Applying PNNL-developed methodology to calculate flexibility reserves for the year of 2034
- Variability from wind and solar generators creates the need for operating reserves. This operating reserve calculation work is necessary to mitigate impacts of variability from these resources.

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# Wind and Solar Summary in WECC 2034

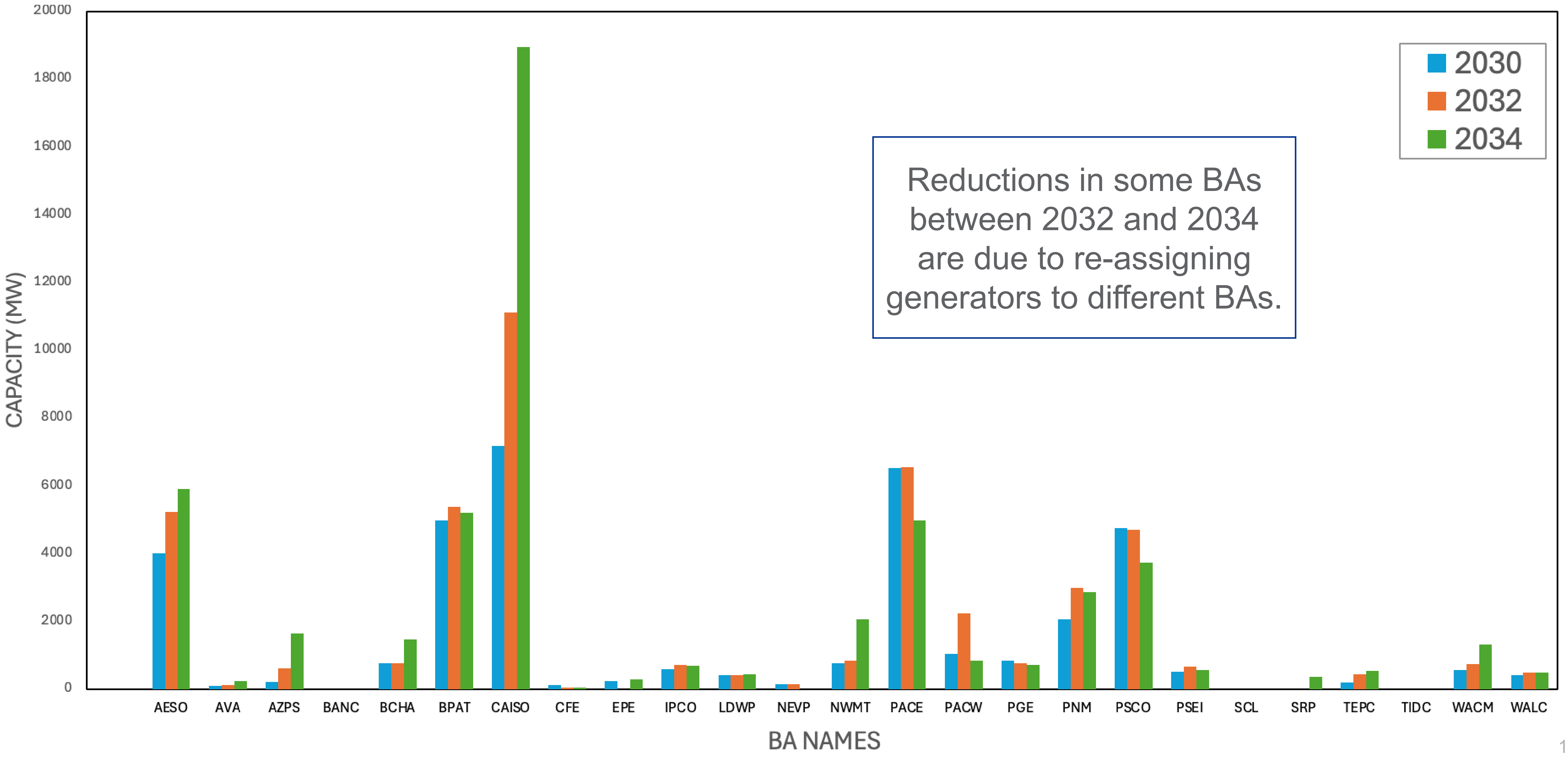
| Data Resource | Wind Capacity (MW) | Solar Capacity (MW) |
|---|---|---|
| 2022 capacity (WECC 2022 State of Interconnection Report) | 29,000 | 30,000 |
| GridView database for WECC 2030 (v. 2.3) | 35,723 | 39,908 |
| GridView database for WECC 2032 (v. 2.1) | 45,092 | 62,403 |
| GridView database for WECC 2034 (v. 3.1) | 53,301 | 86,677 |

## Summary at the BA level:

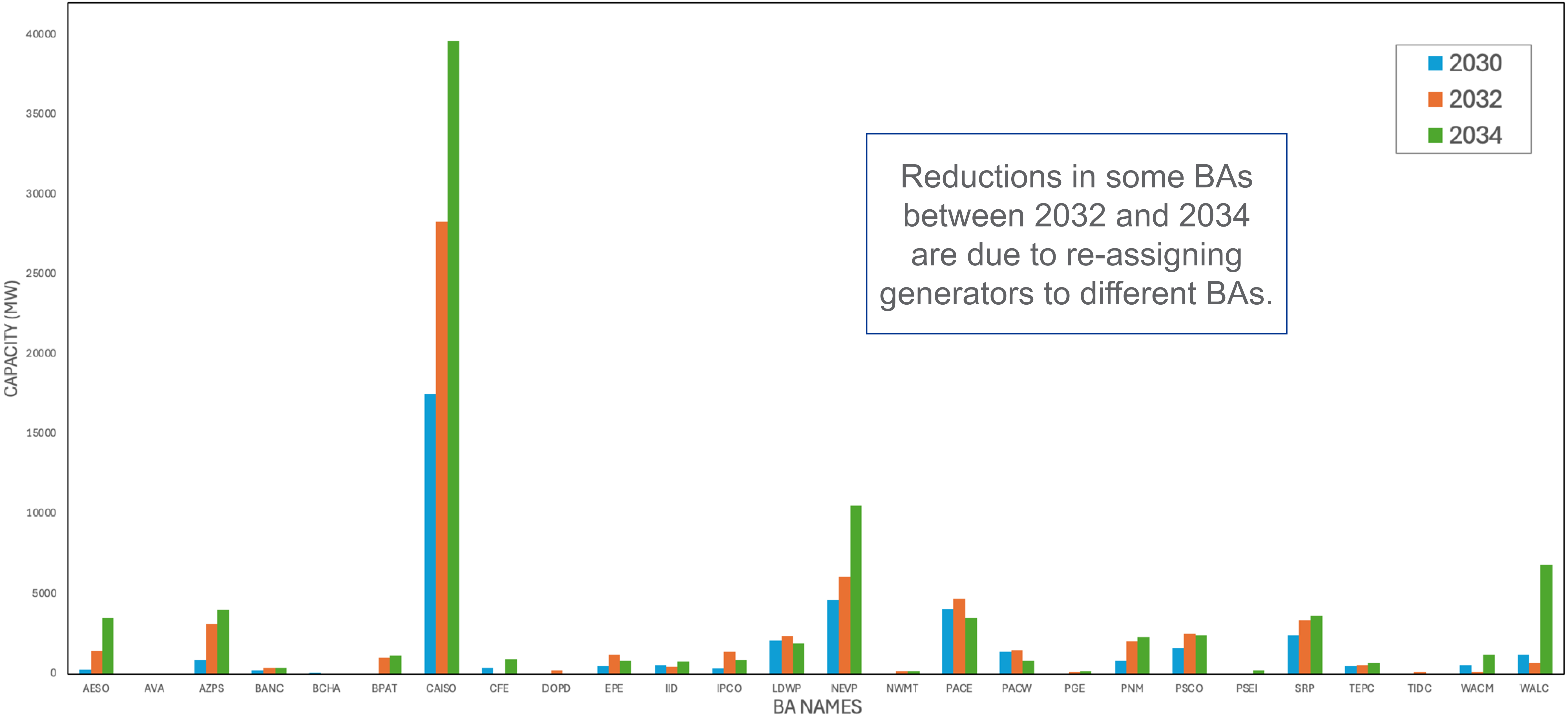
| Types of installed capacity | AESO | AVA | AZPS | BANC | BCHA | BPAT | CAISO | CFE | CHPD | DOPD | EPE | GCPD | IID | IPCO | LDWP | NEVP | NWMT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Onshore Wind (MW) | 5893 | 249 | 1635 | 0 | 1455 | 5200 | 15083 | 40 | 0 | 0 | 300 | 0 | 0 | 692 | 435 | 0 | 2072 |
| Offshore Wind (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 3855 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PV (MW) | 0 | 0 | 2068 | 0 | 0 | 201 | 17109 | 900 | 0 | 0 | 0 | 0 | 0 | 40 | 2 | 2 | 0 |
| SolarPV-Tracking (MW) | 965 | 0 | 687 | 385 | 17 | 819 | 4469 | 0 | 0 | 0 | 840 | 0 | 237 | 745 | 800 | 4233 | 0 |
| SolarPV-NonTracking (MW) | 2544 | 19 | 1019 | 0 | 15 | 131 | 17116 | 50 | 0 | 0 | 3 | 0 | 546 | 116 | 1072 | 6296 | 177 |
| Solar CSP (MW) | 0 | 0 | 250 | 0 | 0 | 0 | 917 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BTM (MW) | 583 | 56 | 3764 | 1360 | 0 | 128 | 37740 | 0 | 0 | 1 | 159 | 1 | 109 | 106 | 850 | 1817 | 173 |
| Peak Load (MW) | 13076 | 2466 | 10947 | 5417 | 12995 | 13435 | 57945 | 5391 | 777 | 805 | 2587 | 1438 | 1206 | 5543 | 8251 | 10767 | 2247 |
| Net Peak Load (Peak Load - BTM) (MW) | 13076 | 2447 | 10410 | 5000 | 12995 | 13434 | 53536 | 5391 | 777 | 805 | 2501 | 1438 | 1170 | 5516 | 8033 | 10566 | 2230 |

| Types of installed capacity | PACE | PACW | PGE | PNM | PSCO | PSEI | SCL | SRP | TEPC | TH_M | TH_P | TIDC | TPWR | WACM | WALC | WAUW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Onshore Wind (MW) | 4973 | 836 | 717 | 2861 | 3729 | 565 | 0 | 356 | 554 | 0 | 0 | 0 | 0 | 1315 | 485 | 0 |
| Offshore Wind (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PV (MW) | 6 | 284 | 48 | 470 | 292 | 0 | 0 | 1525 | 100 | 0 | 0 | 0 | 0 | 273 | 0 | 0 |
| SolarPV-Tracking (MW) | 2984 | 299 | 0 | 1741 | 1842 | 200 | 0 | 1800 | 508 | 0 | 0 | 0 | 0 | 674 | 6867 | 0 |
| SolarPV-NonTracking (MW) | 491 | 267 | 128 | 110 | 297 | 0 | 0 | 353 | 55 | 0 | 0 | 0 | 0 | 274 | 0 | 0 |
| Solar CSP (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BTM (MW) | 2080 | 945 | 145 | 527 | 2768 | 498 | 43 | 426 | 479 | 0 | 0 | 113 | 13 | 164 | 78 | 3 |
| Peak Load (MW) | 11445 | 4943 | 5201 | 3192 | 9950 | 5474 | 1712 | 11576 | 4318 | 0 | 0 | 785 | 795 | 6803 | 1600 | 167 |
| Net Peak Load (Peak Load - BTM) (MW) | 10658 | 4839 | 5150 | 3026 | 9227 | 5474 | 1712 | 11421 | 4163 | 0 | 0 | 753 | 795 | 6729 | 1554 | 166 |

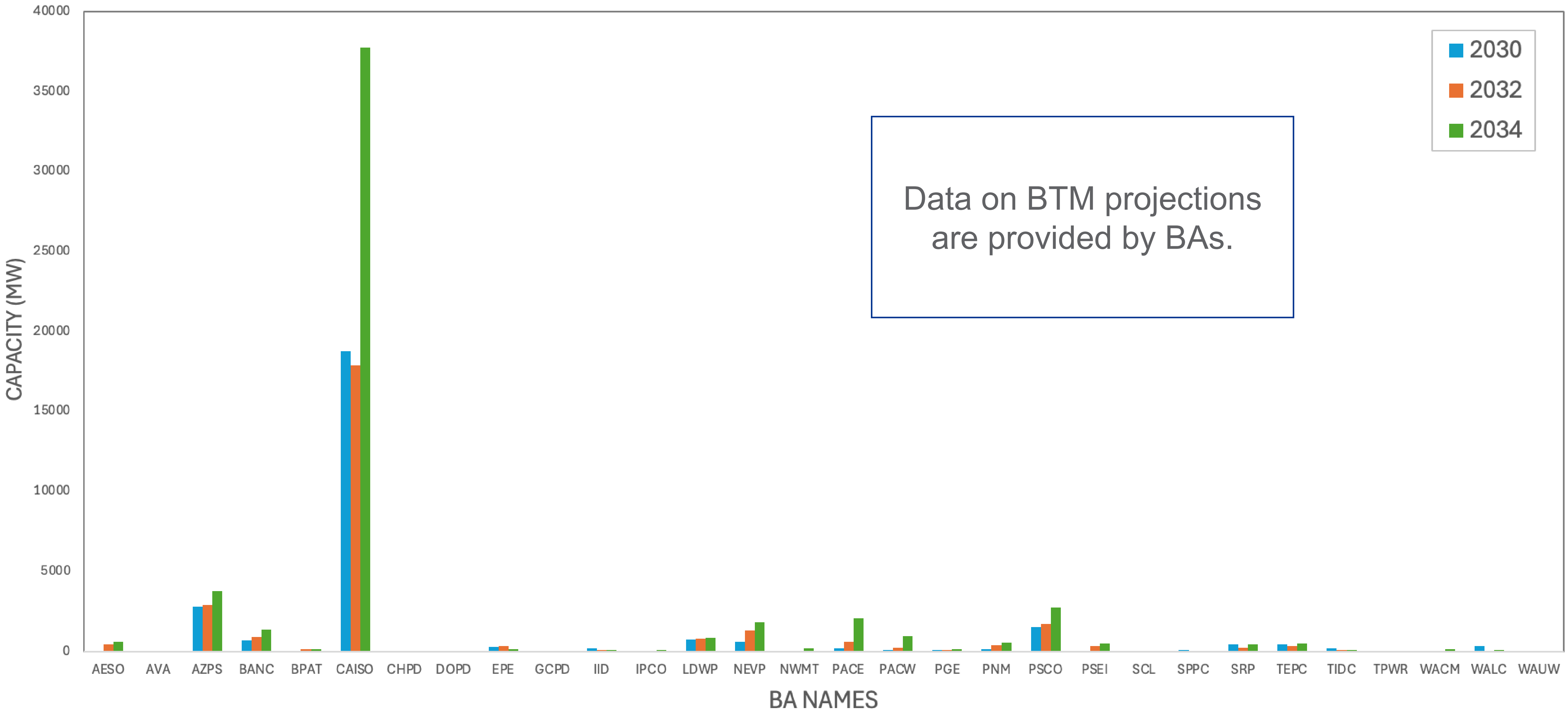
# Wind Capacity Comparison between 2030, 2032, and 2034 Cases



# Utility Scale Solar Capacity Comparison between 2030, 2032, and 2034 Cases

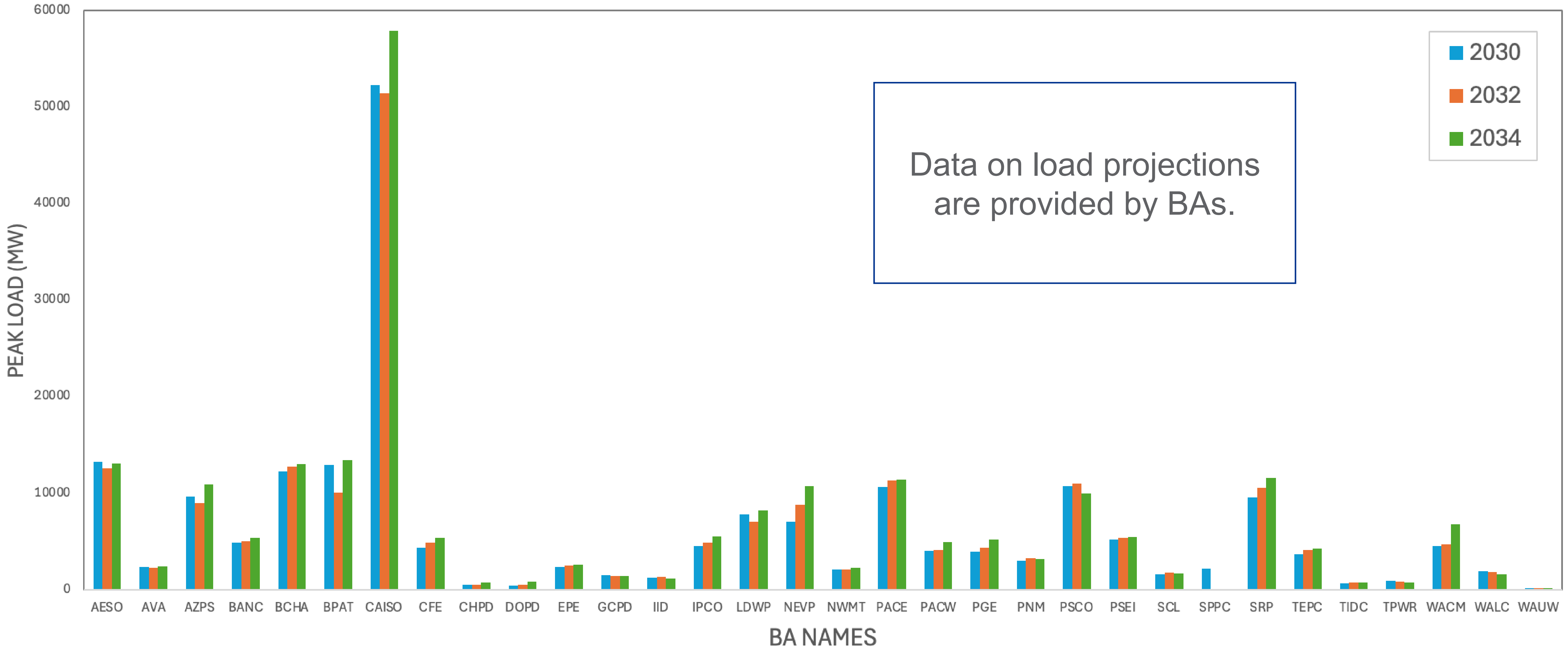


# BTM Solar Capacity Comparison between 2030, 2032, and 2034 Cases

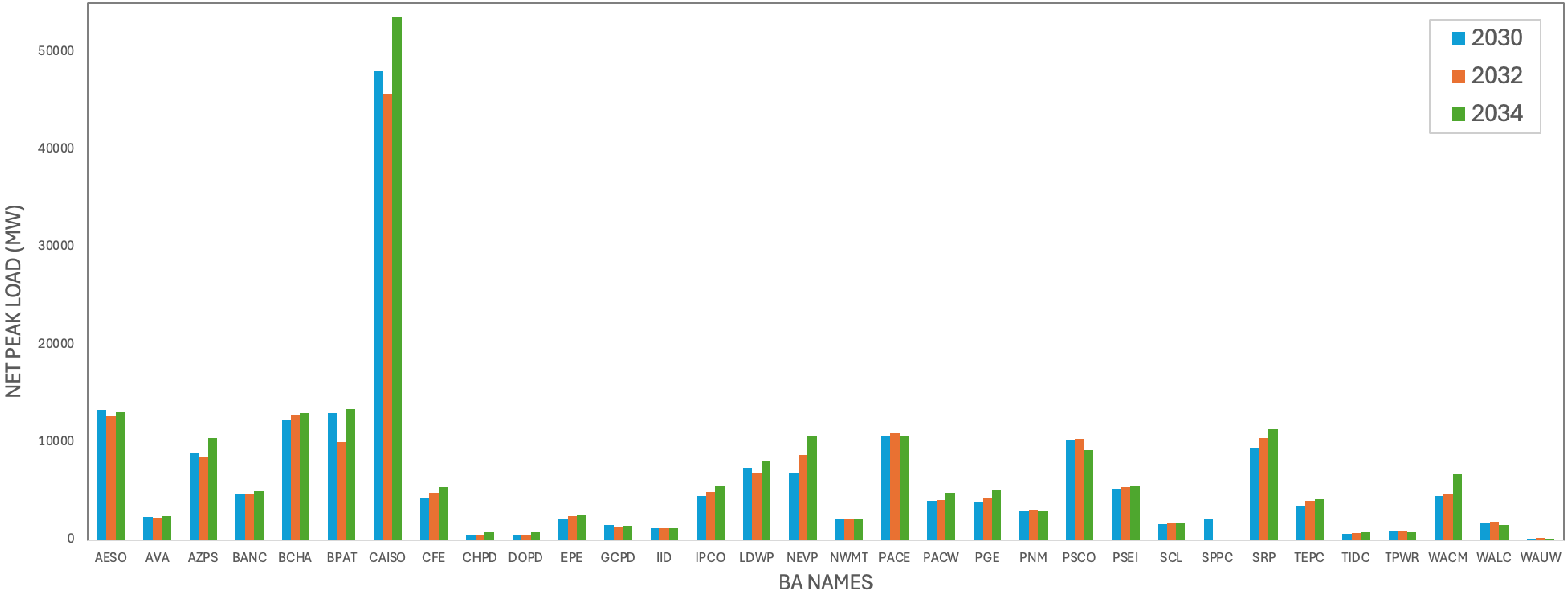



Data on BTM projections are provided by BAs.

# Peak Native Load Comparison Between 2030, 2032, and 2034 Cases



# Net Peak Load (Native Load – BTM) Comparison Between 2030, 2032, and 2034 Cases



# Data Needs for PNNL Flex Reserve Calculation Tool (GRAF-Plan)

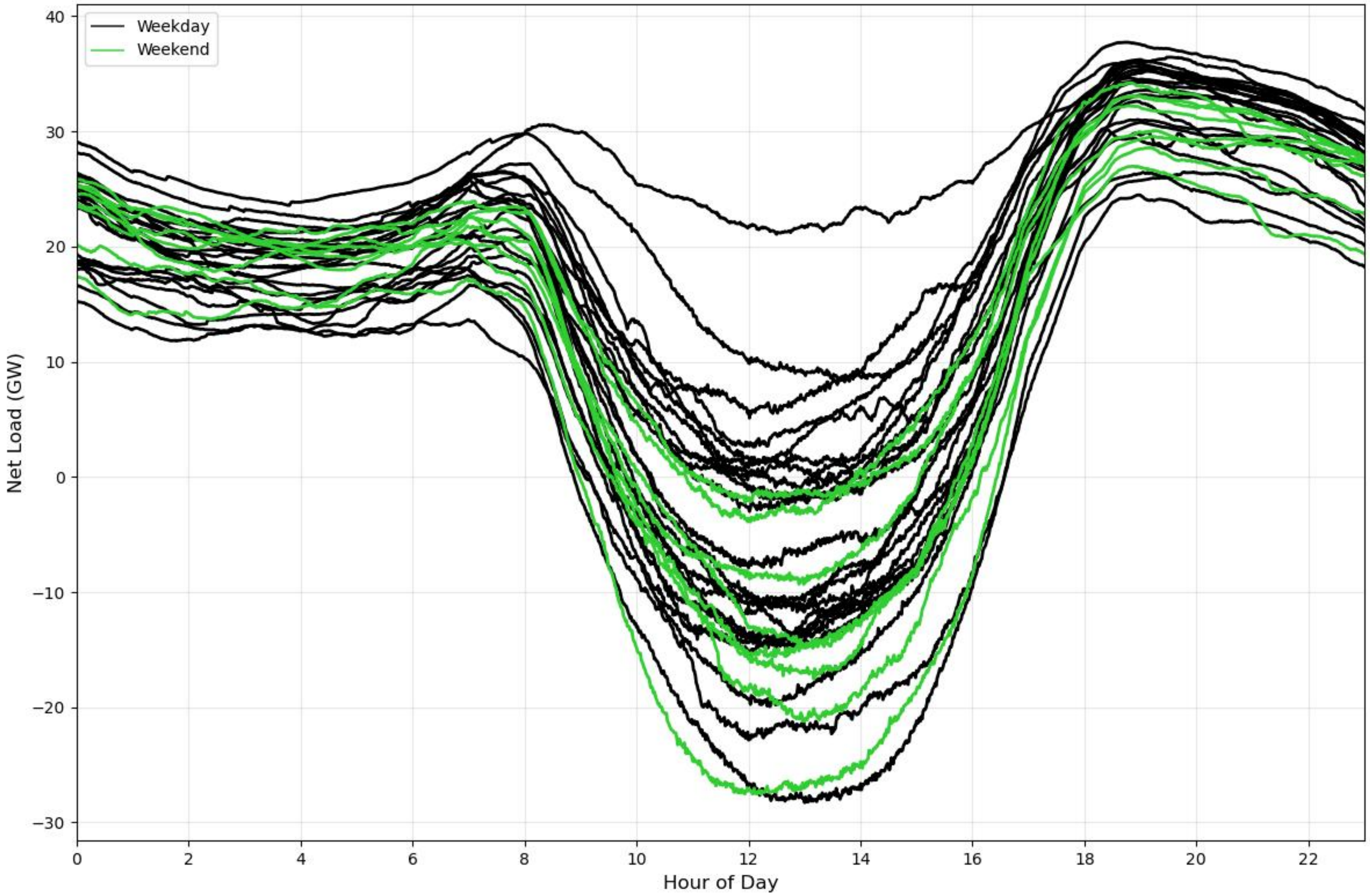
- 1-min net load (native load – BTM solar), wind and utility scale solar
- PNNL converted WECC ADS 2034 hourly native load data into 1-min resolution
- PNNL converted WECC ADS 2034 hourly BTM solar data into 1-min resolution
- NREL team developed 1-hour and 5-min solar data from separate models
- NREL team developed 1-hour wind data, 5-min wind data
- PNNL developed 1-hour and 1-min solar and wind data for new projects that did not exist in the 2032 case

# Data Processing Methodology

- Full discussion of data processing methodology, which takes the 5-min wind, load, and solar data, and converts them into 1-min, can be found in the appendix.

# CAISO Net load (Native Load — BTM_Solar — Utility Scale Solar — Wind) (Jan 2034 days)

The resulting time series, which are fed into GRAF-Plan for processing, look similar to this; 1 minute resolution, with a clear diurnal shape due to BTM Solar and Utility Solar.



# Forecast Error Statistics Collection

- Analyze data from EIA (load and day-ahead load forecast)
- Analyze data from CAISO OASIS for:
  - Hour-ahead, real-time, and actual load
  - Hour-ahead and actual utility scale solar
  - Hour-ahead and actual wind  data
- Analyze data from BPA for:
  - Hour-ahead and actual wind data

# Forecast Error Statistics and Other Assumptions

| Parameter | | Value | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| L10 (used for each BA) | | Example **CAISO 97.4 (2020)** | | | | | | | | |
| | | https://www.nerc.com/comm/OC/Documents/BAL-003_Frequency_Bias_Settings_02Jun2020.pdf | | | | | | | | |
| Swing Door Tolerance (regulation) | | 0.3 L10 | | | | | | | | |
| Swing Door Tolerance (load following) | | 0.6 L10 | | | | | | | | |
| | | PV | | | CSP0 | | | CSP6 | | |
| Solar - HA | | Mean | StdDev | autocorr | Mean | StdDev | autocorr | Mean | StdDev | autocorr |
| | 0<CI<=0.2 | 0 | 2.5% | 0.8 | 0 | 2.5% | 0.8 | 0 | 2.5% | 0.8 |
| | 0.2<CI<=0.5 | 0 | 10% | 0.8 | 0 | 10% | 0.8 | 0 | 10% | 0.8 |
| | 0.5<CI<=0.8 | 0 | 7.5% | 0.8 | 0 | 7.5% | 0.8 | 0 | 7.5% | 0.8 |
| | 0.8<CI<=1.0 | 0 | 2.5% | 0.8 | 0 | 2.5% | 0.8 | 0 | 2.5% | 0.8 |
| Wind - HA | | 0 | 8% | 0.9 | | | | | | |
| Net Load - HA | | 0 | 2% | 0.9 | | | | | | |
| Wind and Solar - RT | | Persistence model Forecast at time T = actual value at T-7.5 min, or average from -12.5 to -7.5 | | | | | | | | |
| Load - RT | | 0 | 0.15% | 0.6 | | | | | | |
| Confidence Level | | BA will Hold Capacity to Balance 95% of load following and regulation needs | | | | | | | | |

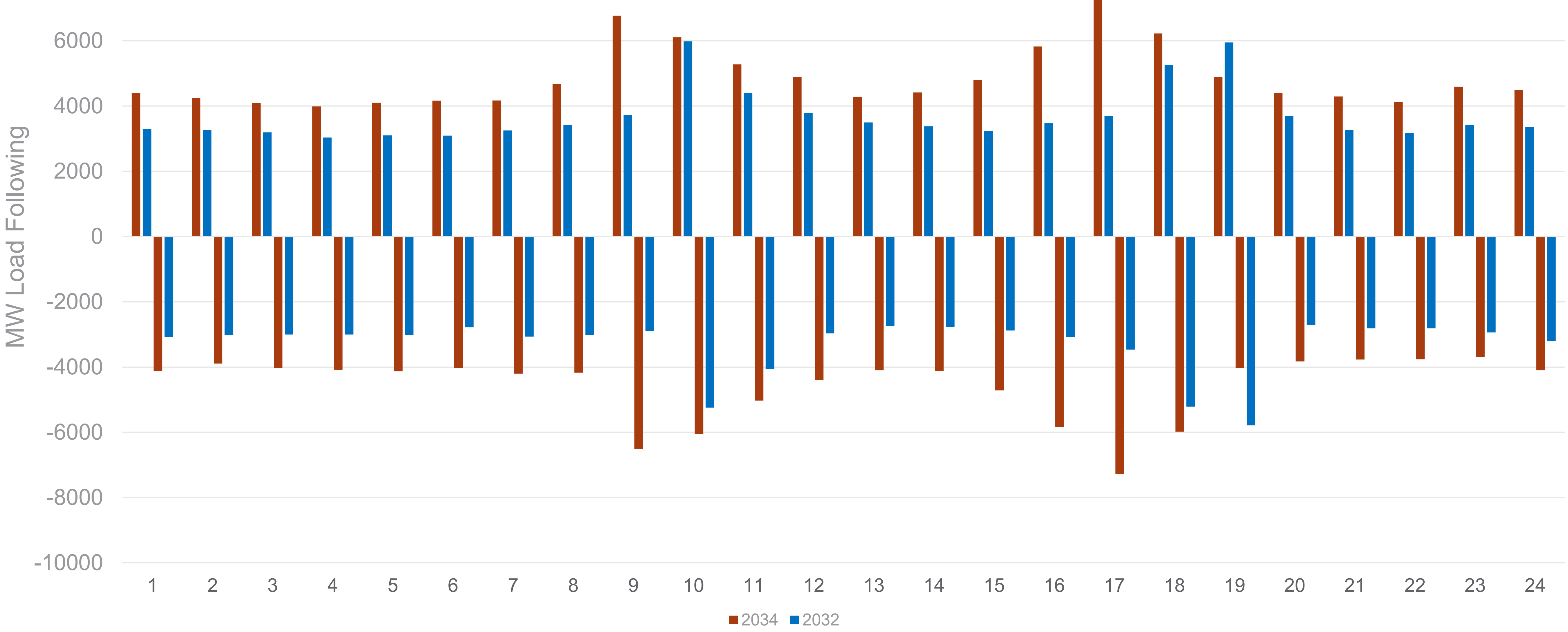
# Forecast Error Statistics and Other Assumptions

| Parameter | | Value |
|---|---|---|
| Truncation of Normal Distribution | Load Truncation | +/- 3 std aggregated at BA level |
| | Wind Truncation | +/- 4.5 std std aggregated at BA level |
| | Solar | 0 and max value from clear sky curve at this hour for the plant |
| Load Following Occurrence | Every 5-min | |
| Number of Monte Carlo runs | 30 | |
| Monte Carlo random seed value, $s$, for current run, $n$, out of total runs, $N$ | • $s = (m - 1) \times 2 \times N + 2 \times (n - 1) + 101$<br>• $s$ = seed value for this Monte Carlo iteration<br>• $m$ = month number (1 to 12)<br>• $N$ = total number of Monte Carlo runs (30)<br>• $n$ = current Monte Carlo run (1 to 30) | |

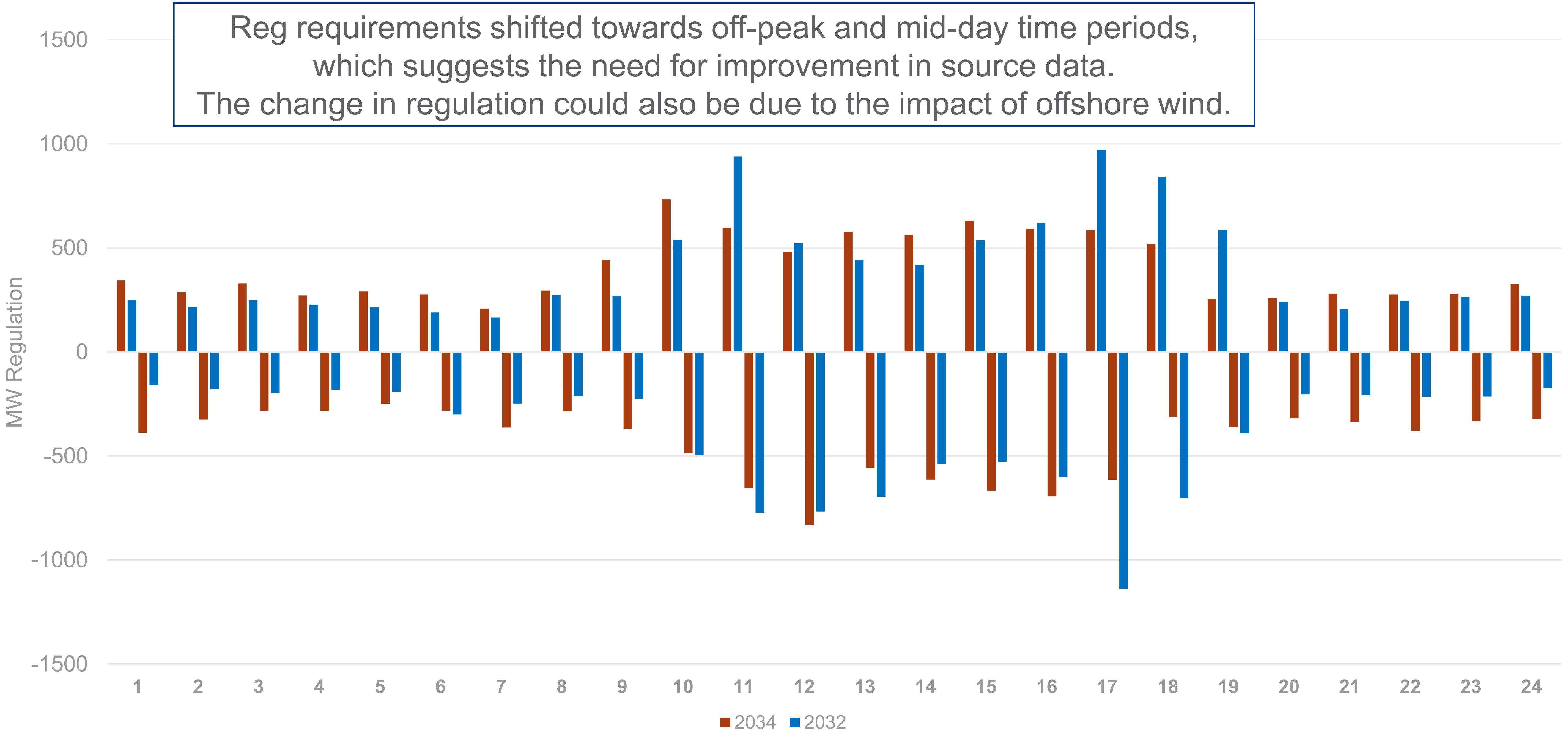
# Sample of Reserve Calculations Results for Selected BA

# CAISO 2032 vs. 2034 Load Following Requirements
## (January)

LF requirements increased by ~1000 MW up/down



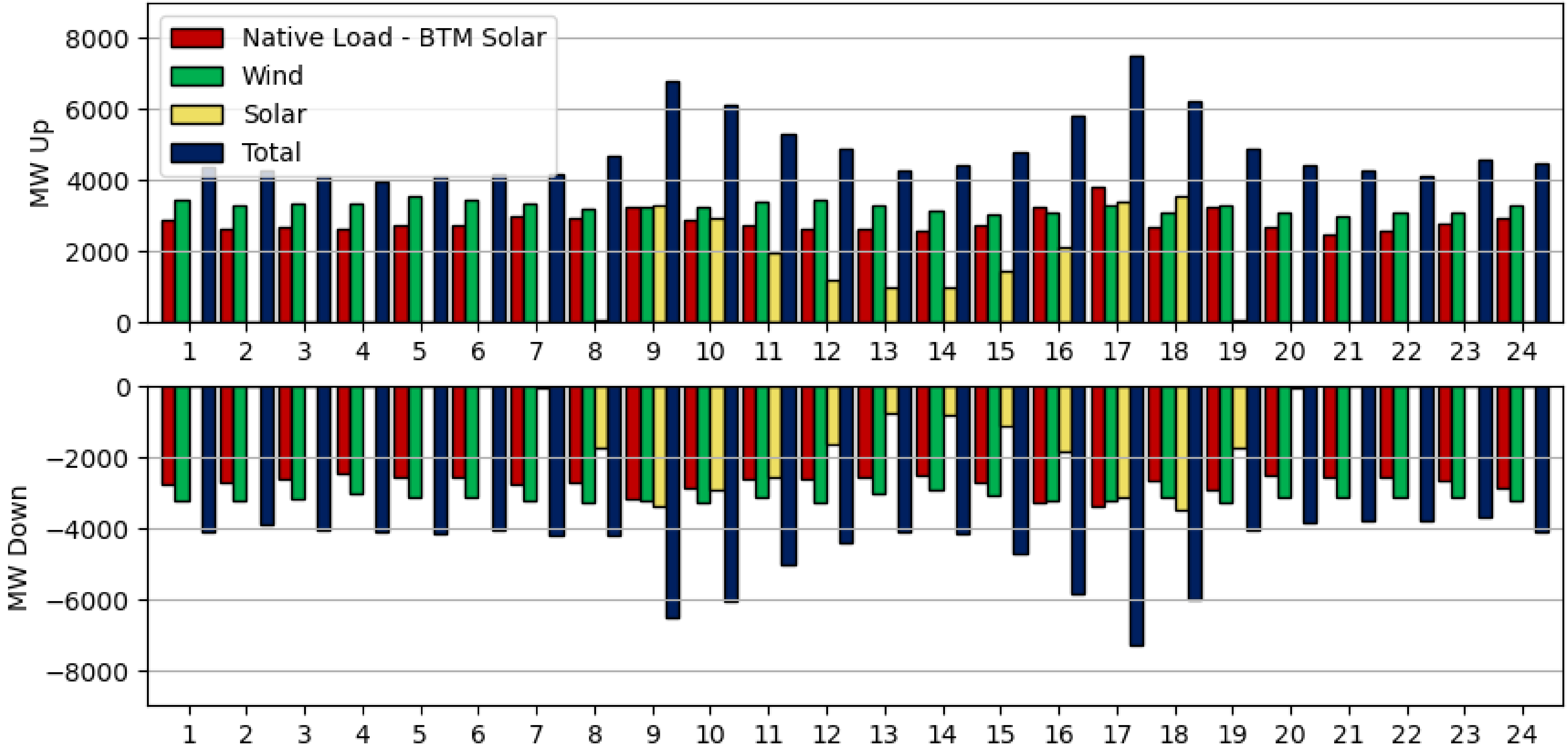
# CAISO 2032 vs. 2034 Regulation Requirements
## (January)



# CAISO 2034 Reserve Results by Source

- January Load Following
- July Load Following
- January Regulation
- July Regulation

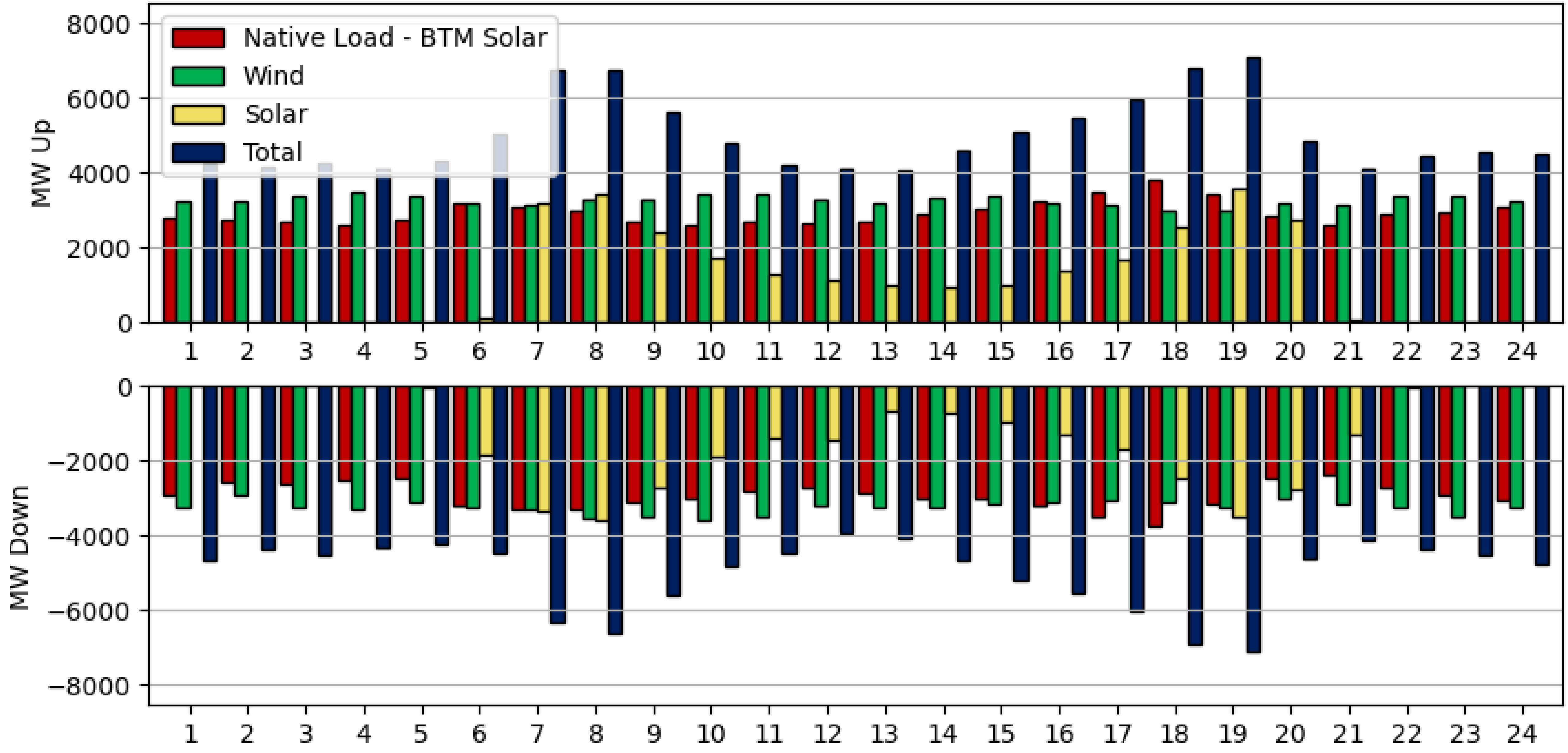
# CAISO January 2034 Load Following decomposed
## (LF capacity needs by each individual resource)




Note: the total requirement (dark blue in the graph) is not a simple linear addition of individual components

# CAISO July 2034 Load Following decomposed

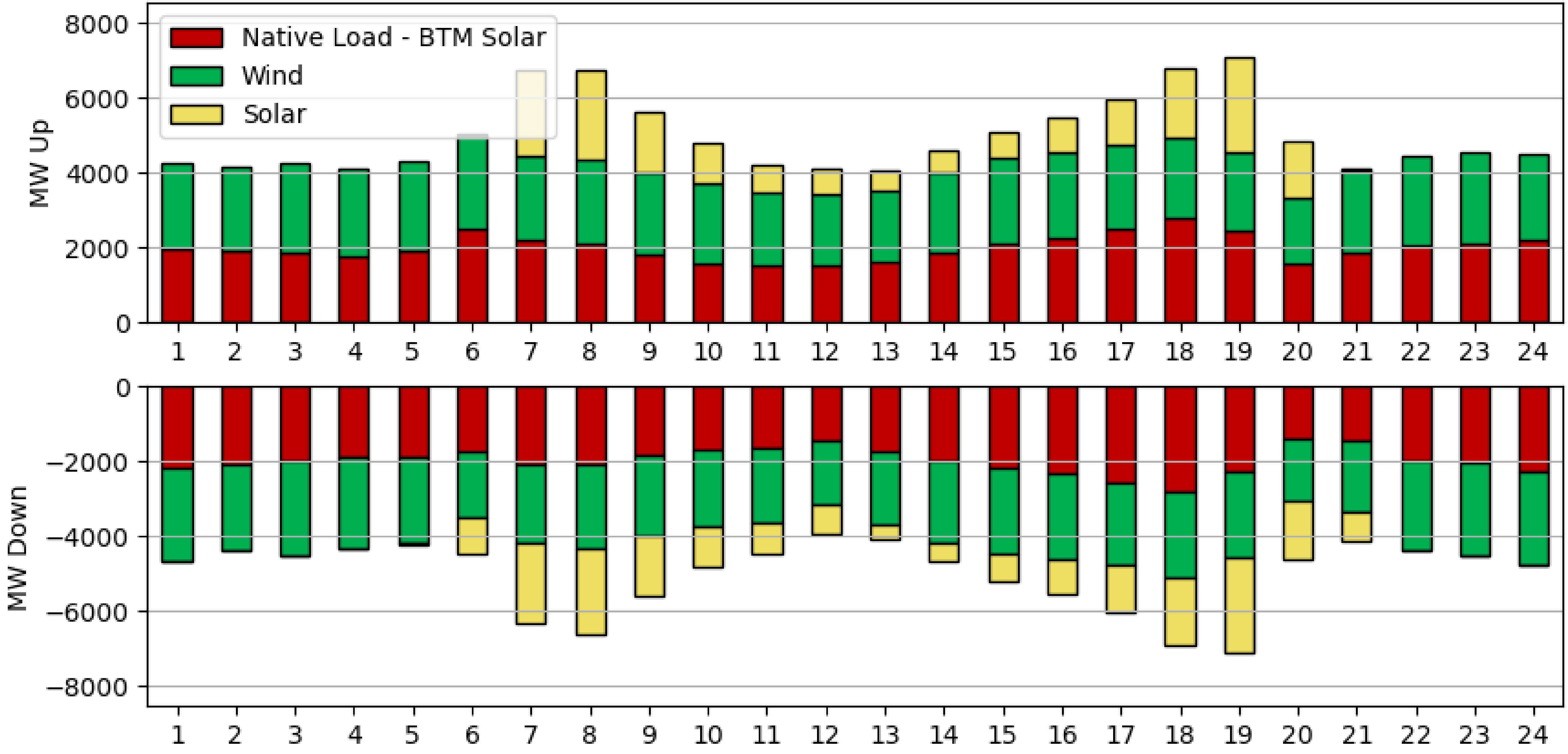
## (LF capacity needs by each individual resource)




Note: the total requirement (dark blue in the graph) is not a simple linear addition of individual components

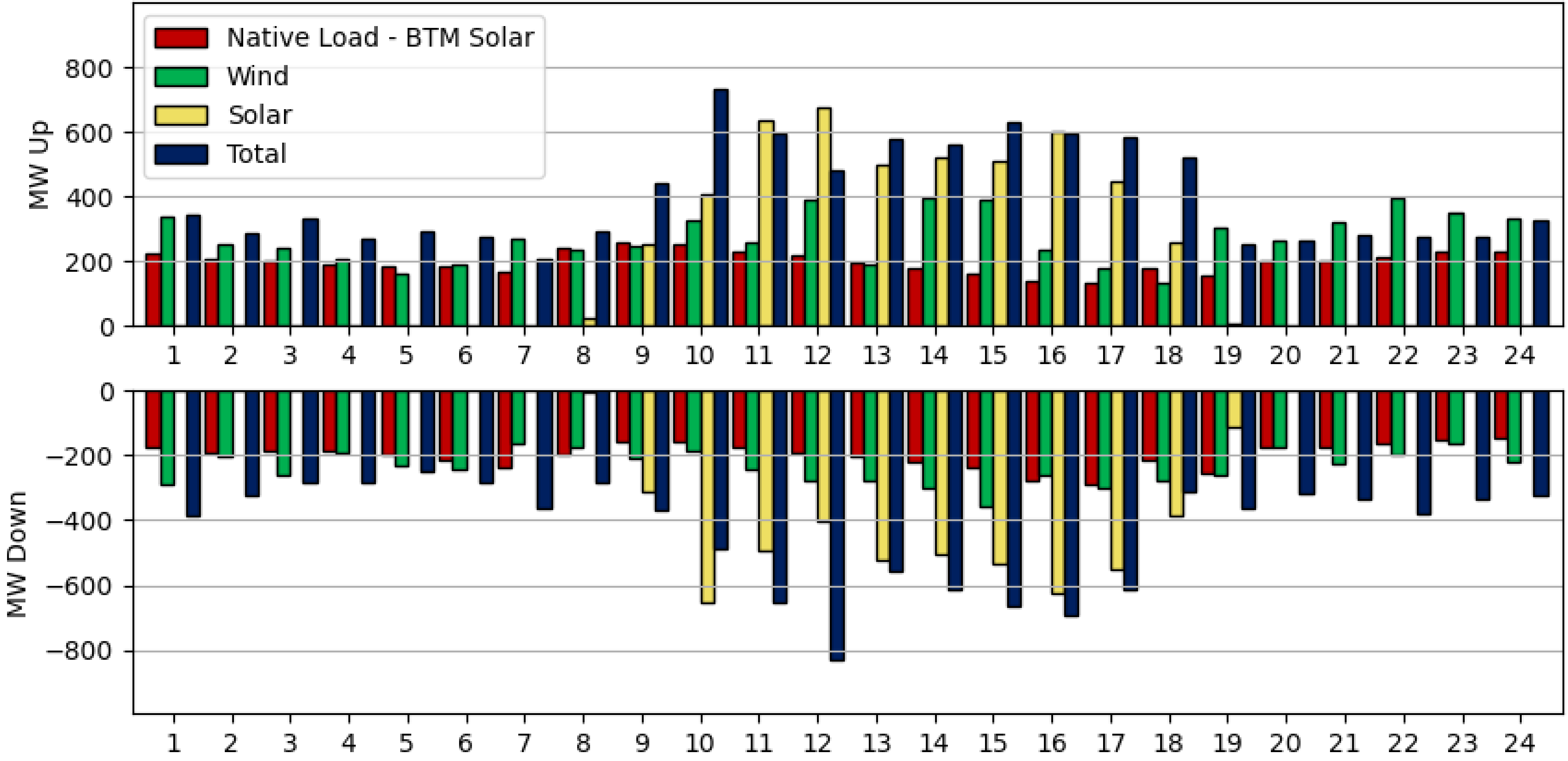
# CAISO July 2034 Load Following decomposed

## (Percent of each resource of total LF capacity)



# CAISO January 2034 Regulation decomposed

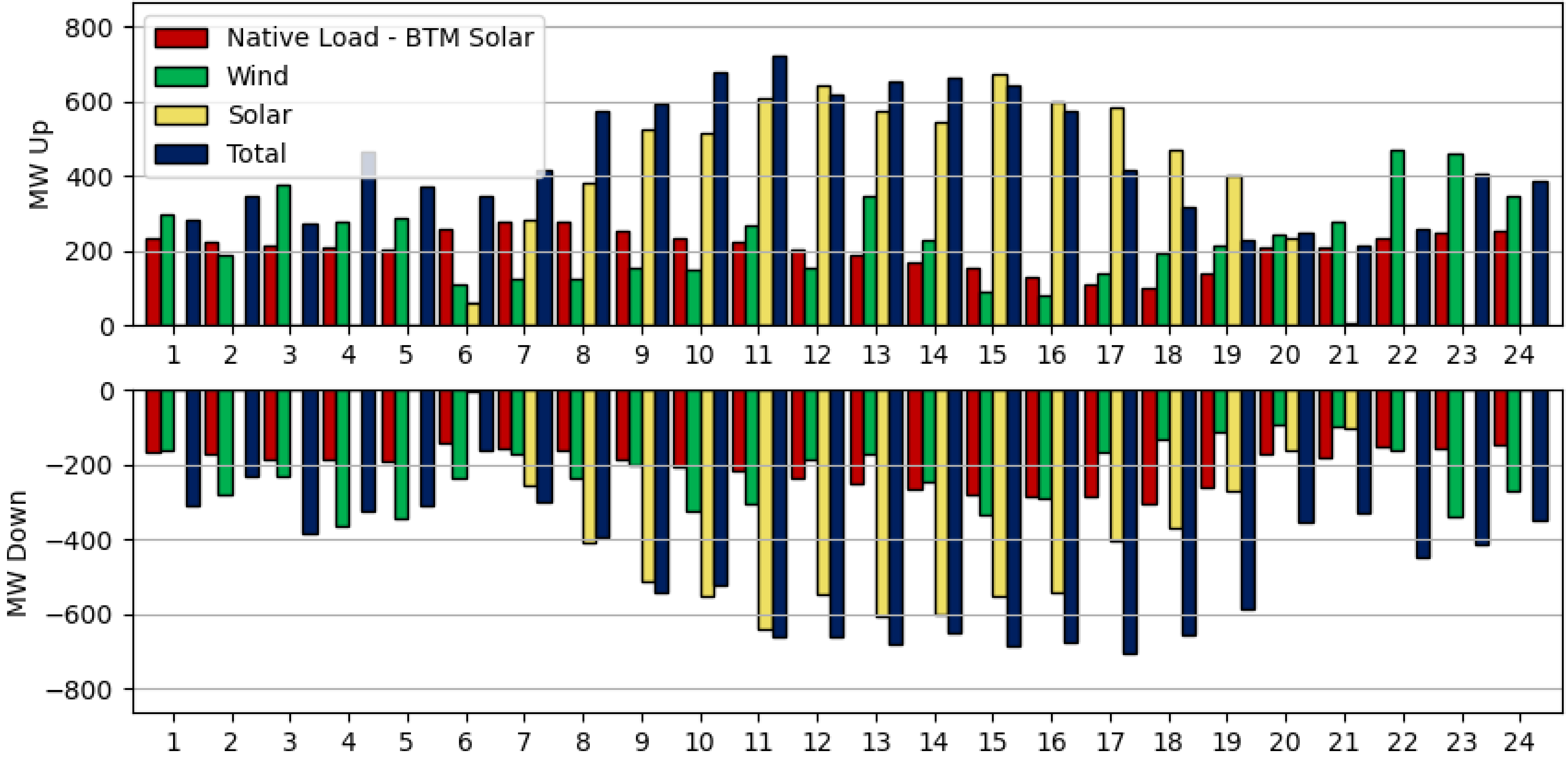
## (REG capacity needs by each individual resource)




Note: the total requirement (dark blue in the graph) is not a simple linear addition of individual components

# CAISO July 2034 Regulation decomposed

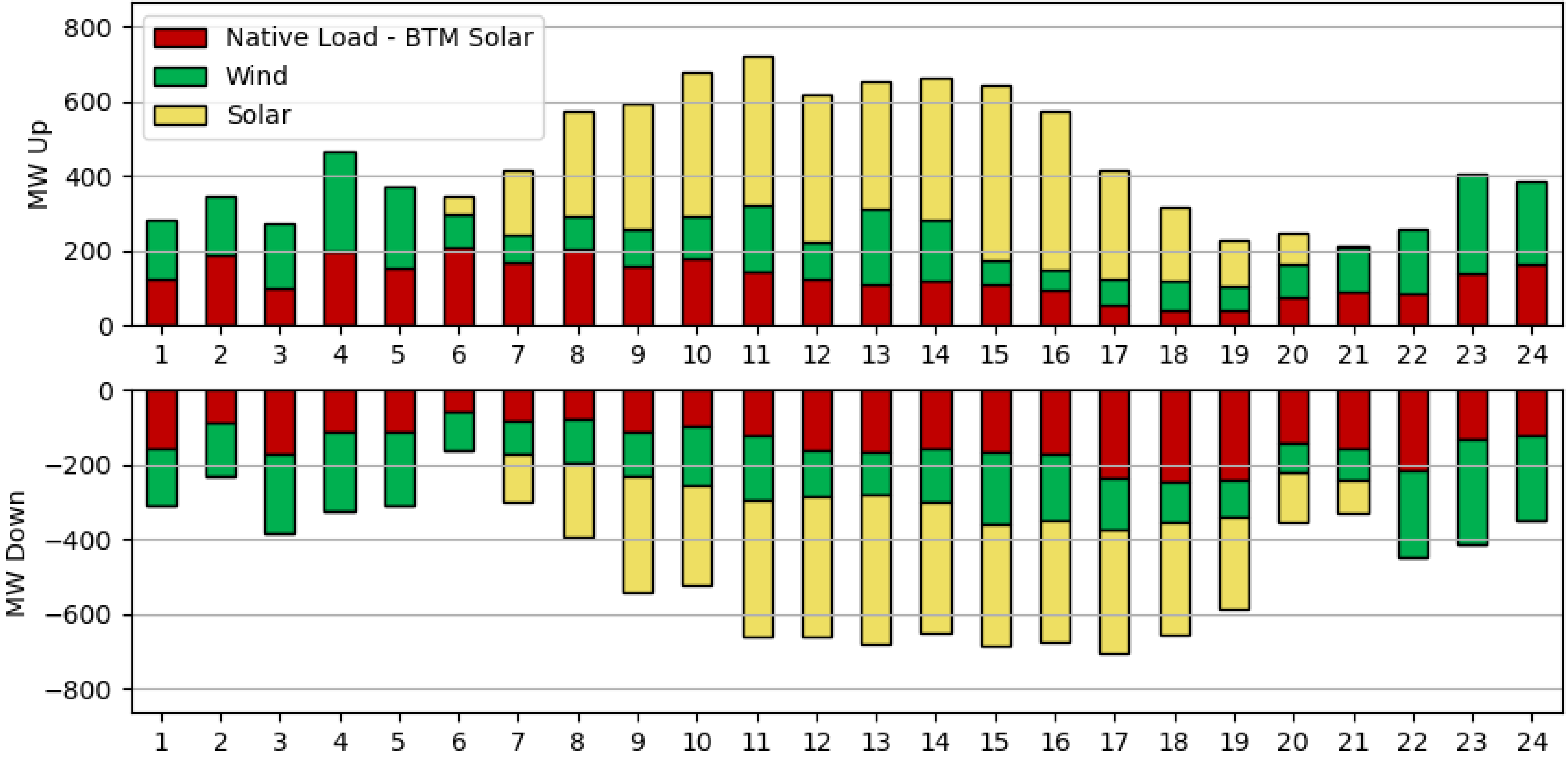
## (REG capacity needs by each individual resource)




Note: the total requirement (dark blue in the graph) is not a simple linear addition of individual components

# CAISO July 2034 Regulation decomposed

## (Percent of each resource of total Reg capacity)



# Conclusions for 2034 Balancing Reserves

# Summary and Conclusions

- High increase of solar (utility and BTM) and wind generation expected in WECC by 2034
- WECC prepares datasets for Production Cost Model in GridView software, ADS 2034 case to support generation, transmission planning
- PNNL supports WECC by calculating generation flexibility requirements used as input in GridView
- High-resolution time series is key for estimating flexibility requirements
  - Native load, BTM, wind and utility scale solar must be all time synchronized - 2009 data adapted to 2034 scenario
  - 1-minute data generated for load, solar (BTM and plants), and wind, based on available profiles – interpolation and noise added to create realistic 1-min data
  - Forecast errors assumed based on EIA data and operational data from California ISO and BPA
- Load following and regulation results incorporated in WECC ADS 2034 case at the BA level in Hitachi GridView

# Thank you

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# GRAF-Plan Client Projects: Successful Implementation of the Tool in Operational Planning

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# Projects (1)

Load following and regulation requirements calculated by this methodology were benchmarked against actual load following and regulation applied in CAISO, BPA, PSE, NV Energy and Duke Energy

| No. | Project Titles | Funding Sources | Project Duration |
|---|---|---|---|
| 1 | Integration of Wind Plant Output Forecasting into Utility Energy Management Systems (EMS) | DOE's Office of EERE | 2008-2009 |
| 2 | Developing Tools for Online Analysis and Visualization of Operational Impacts of Wind and Solar Generation | CEC | 2009-2011 |
| 3 | Predict Day-ahead Regulation Requirements for CAISO | CEC | 2010-2011 |
| 4 | Assessing the Value of Regulation Resources Based on Their Time Response Characteristics | CEC | 2007-2008 |
| 5 | Operational Impacts of Wind Energy Resources in the Bonneville Power Administration (BPA) Control Area | BPA | 2008 |
| 6 | CAISO 20% and 33% Renewables Penetration Study | CAISO | 2007, 2009 |
| 7 | Large-Scale PV Integration Study for NV Energy | NV Energy and DOE | 2010-2012 |
| 8 | WECC BA Consolidation Study | DOE | 2009-2012 |
| 9 | Energy Storage for Power Systems Applications: A Regional Assessment for the Northwest Power Pool (NWPP) | DOE | 2009-2010 |

# Projects (2)

Load following and regulation requirements calculated by this methodology were benchmarked against actual load following and regulation applied in CAISO, BPA, PSE, NV Energy and Duke Energy

| No. | Project Titles | Funding Sources | Project Duration |
|---|---|---|---|
| 10 | NWPP EIM Study | NWPP | 2012-2013 |
| 11 | Duke Energy PV Integration Study | Duke Energy | 2013-2014 |
| 12 | Honduras PV integration Study | DOS | 2015-2016 |
| 13 | Reserve Calculation Study: Guatemala, Nicaragua, Costa Rica, Panama, El Salvador, Honduras | DOS | 2015-2019 |
| 14 | WECC 2030 ADS Reserves | DOE | 2020 |
| 15 | Integrate GRAF-Plan into ABB GridView PCM | DOE | 2020-2021 |
| 16 | WECC 2032 ADS Reserves | DOE | 2022 |
| 17 | Reserve Calculation Study: Vietnam | DOS | 2021-2023 |

# Projects (2)

GRAF-Plan is used by the U.S. Western Interconnection to calculate operational planning reserves, and has been integrated into ABB/Hitachi Gridview Production Cost Model

| No. | Project Titles | Funding Sources | Project Duration |
|---|---|---|---|
| 10 | NWPP EIM Study | NWPP | 2012-2013 |
| 11 | Duke Energy PV Integration Study | Duke Energy | 2013-2014 |
| 12 | Honduras PV integration Study | DOS | 2015-2016 |
| 13 | Reserve Calculation Study: Guatemala, Nicaragua, Costa Rica, Panama, El Salvador, Honduras | DOS | 2015-2019 |
| 14 | WECC 2030 ADS Reserves | DOE | 2020 |
| 15 | Integrate GRAF-Plan into ABB GridView PCM | DOE | 2020-2021 |
| 16 | WECC 2032 ADS Reserves | DOE | 2022 |
| 17 | Reserve Calculation Study: Vietnam | DOS | 2021-2023 |

# PNNL-ABB/Hitachi Technology Commercialization Project (TCF)

- Title: Deploying Intra-hour Uncertainty Analysis Tools to ABB/Hitachi's GridView,
- Duration: Two years from 1/2020 to 12/2021
- Tasks: This project will incorporate the following incremental capabilities to GridView,
  - PNNL forecast error generator functionality to model uncertainty associated with day-ahead, hour-ahead and real-time forecasts of solar, wind and load at the balancing authority level (BA)
  - Balancing reserve requirement calculation using PNNL “Swing Door” algorithm to add load following and regulation constraints at the BA level
  - Sub-hourly database and optimization capability using selected functions from PNNL System Intra-hour Operation Simulator (ESIOCS) to model 5-min market operations

- https://www.energy.gov/articles/department-energy-announces-2019-technology-commercialization-fund-projects

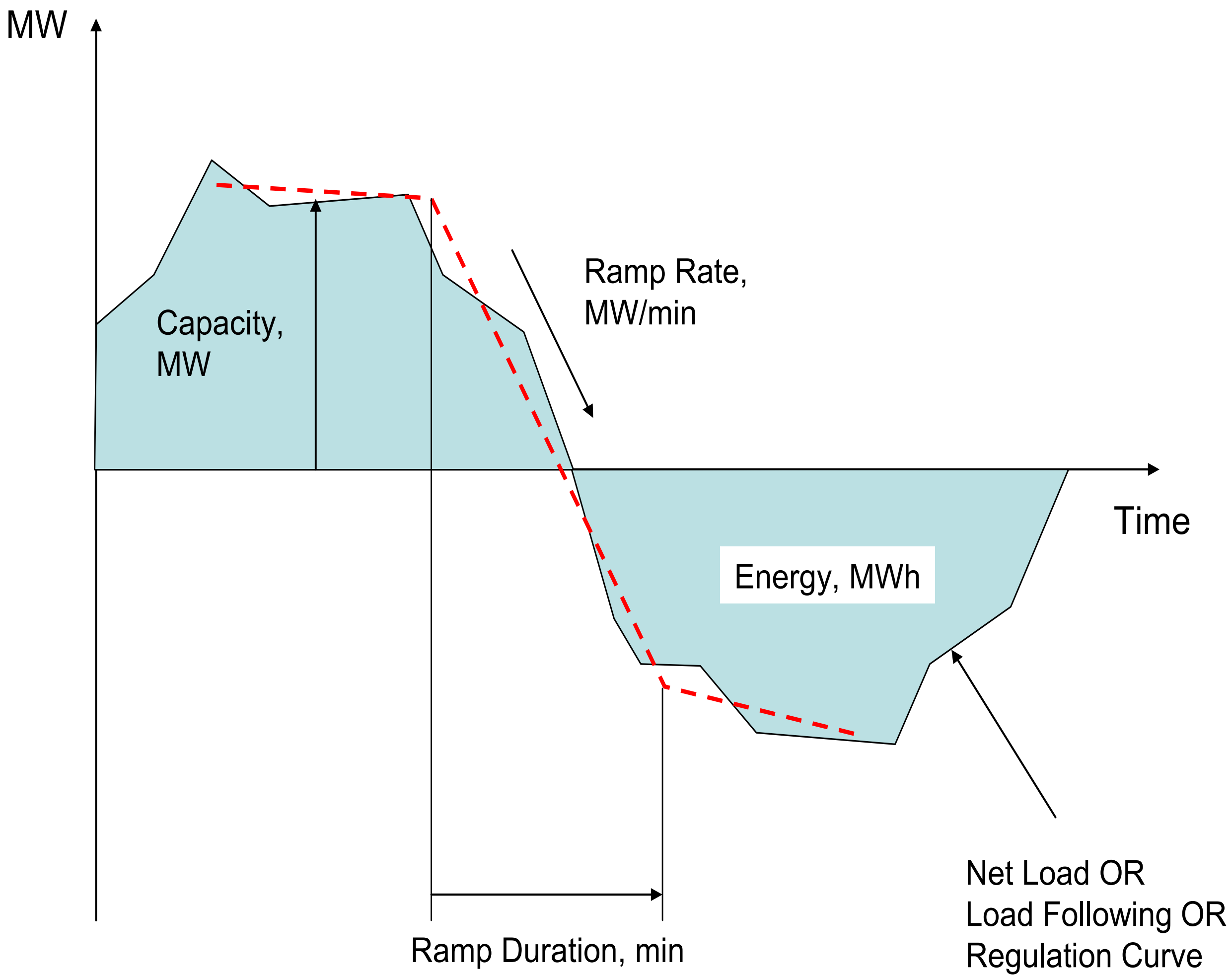
# Projects (2)

GRAF-Plan has been applied in networked countries (Central America) and islanded countries (Vietnam)

| No. | Project Titles | Funding Sources | Project Duration |
|---|---|---|---|
| 10 | NWPP EIM Study | NWPP | 2012-2013 |
| 11 | Duke Energy PV Integration Study | Duke Energy | 2013-2014 |
| 12 | Honduras PV integration Study | DOS | 2015-2016 |
| 13 | Reserve Calculation Study: Guatemala, Nicaragua, Costa Rica, Panama, El Salvador, Honduras | DOS | 2015-2019 |
| 14 | WECC 2030 ADS Reserves | DOE | 2020 |
| 15 | Integrate GRAF-Plan into ABB GridView PCM | DOE | 2020-2021 |
| 16 | WECC 2032 ADS Reserves | DOE | 2022 |
| 17 | Reserve Calculation Study: Vietnam | DOS | 2021-2023 |

# Models for Balancing Requirements Uncertainty: Multidimensional Uncertainty Analysis

- In existing approaches, analysis is frequently limited to just one dimension of the uncertainty problem–capacity
- But capacity is not a single sufficient descriptor of the problem
- Demonstrate operational performance of power system through four basic metrics, forming “performance envelope”
  - *Capacity* (π): required minute-to-minute amount of generation or change in generation output to meet variations in balancing requirements
  - *Ramp rate* (ρ): slope of the ramp
  - *Ramp duration* (δ): duration of a curve’s ramp along the time axis
  - *Energy* (Є): integration of capacity over time; calculate as area between analyzed curve and time axis

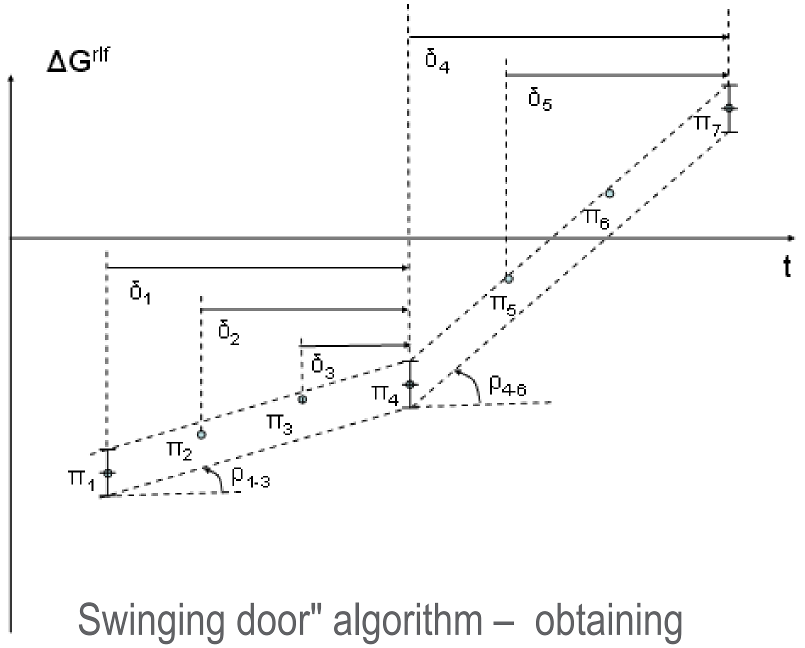



***Discussion of performance envelope**: Makarov, Yuri V, Etingov, Pavel V, Ma, Jian, et al., "Incorporating Uncertainty of Wind Power Generation Forecast into Power System Operation, Dispatch, and Unit Commitment Procedures," IEEE Transactions on Sustainable Energy 2, no. 4 (2011), https://doi.org/10.1109/TSTE.2011.2159254*

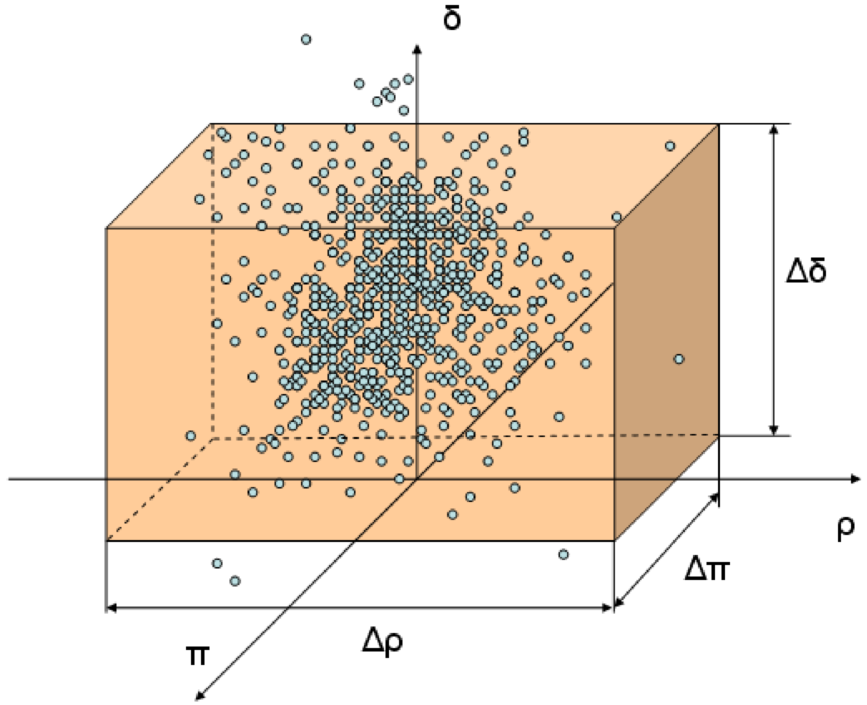
# Assessment of Ramping Requirements

- Use swinging door algorithm to derive required capability (π), ramp rate (ρ), and ramp duration (δ).
- Populate triads ($\pi_i$, $\rho_i$, $\delta_i$) into three-dimensional space.
- Determine boundary values for (π, ρ, δ) that specify the probability of being outside the box:

$$p_{out} = \frac{N_{out}}{N_{out} + N_{in}}$$



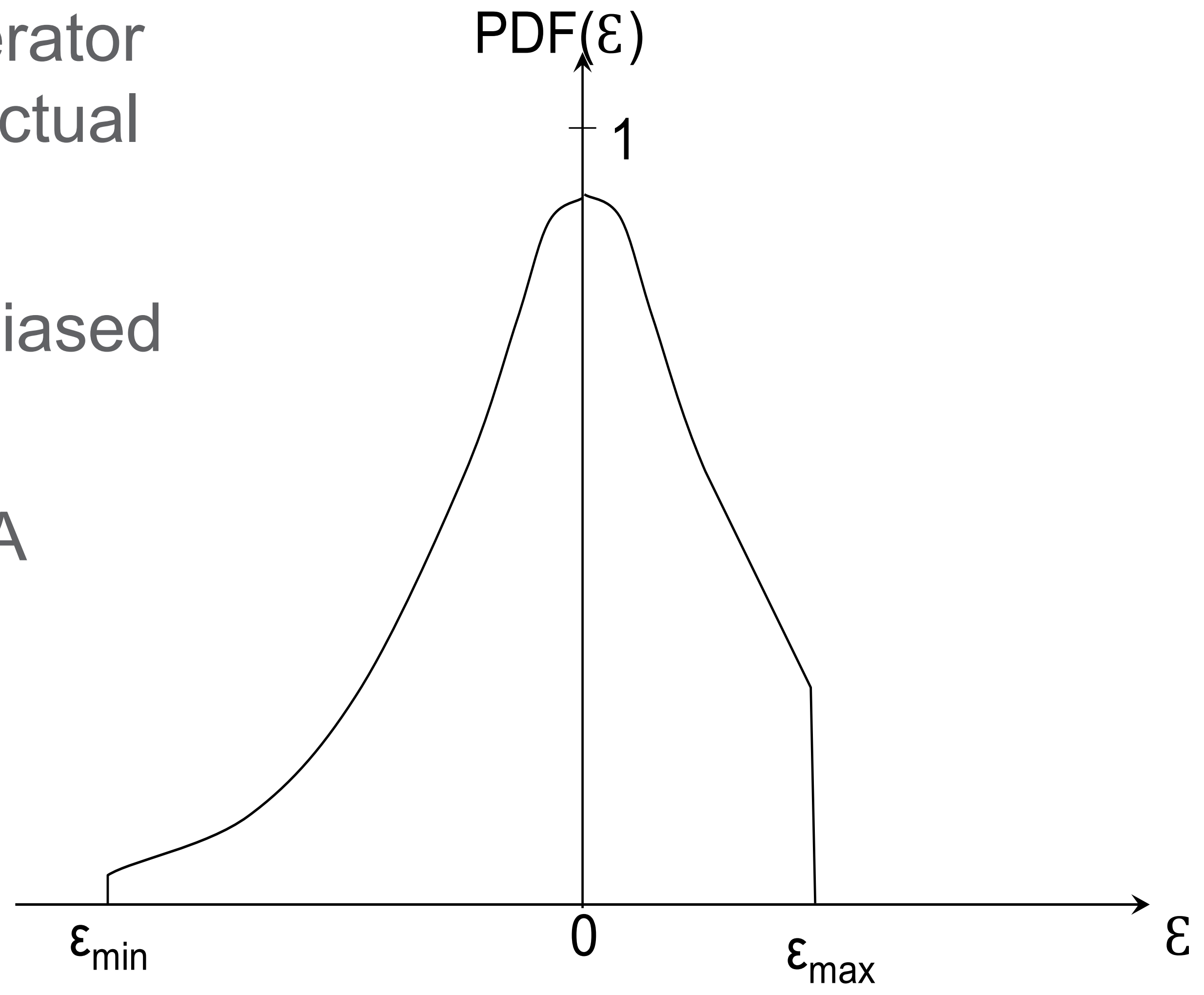

Swinging door" algorithm – obtaining capacity, ramp rate and duration.




Concurrent consideration of the capacity, ramp rate and duration requirements.

# Simulate Hour Ahead (HA) Forecast Errors – Load and Wind

- Simulate using a random number generator based on statistical characteristics of actual forecast errors
- Distribution of forecast errors is an unbiased Truncated Normal Distribution (TND)
- Calculate wind HA forecast errors at BA level (not wind plant level)

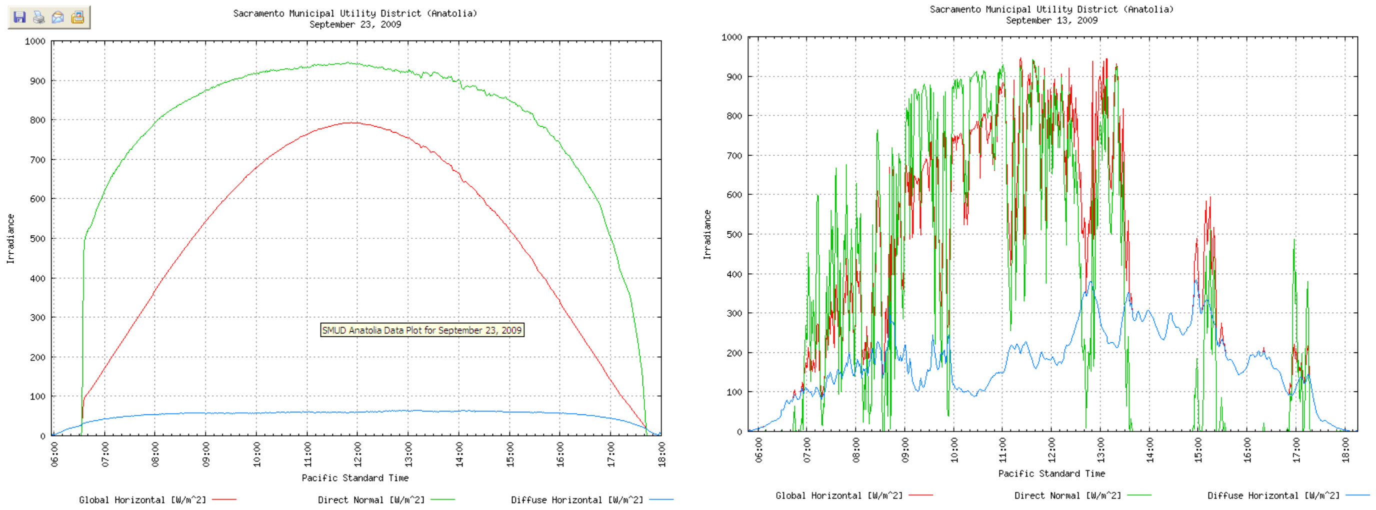


# Simulated Solar Forecast Errors

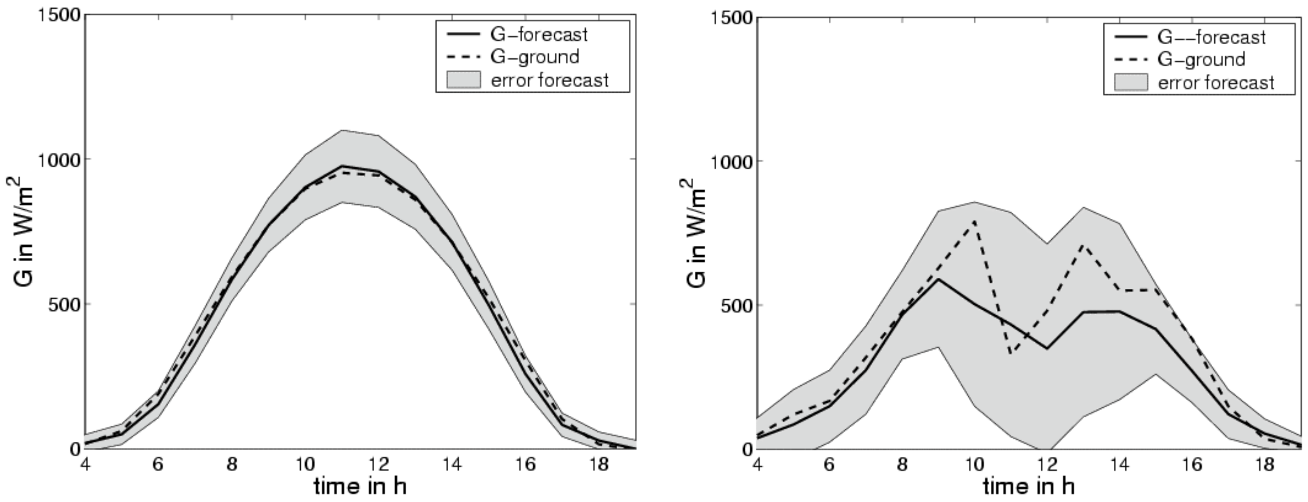
- Behavior of solar is different than wind:
  - In absence of clouds and fog, solar output is very predictable.
  - Cloud and fog impacts are less predictable and act quickly.
  - Many days have little appreciable variation caused by cloud cover.
  - For days with cloud cover, some hours are cloudless.
- Obtain clearness index (*CI*) by dividing observed horizontal global solar radiation $R_g$ by horizontal extraterrestrial solar radiation $R$:

$$k = R_g/R$$

- Solar forecast errors vs. clearness index




Daily pattern of the solar radiation of clearness index.



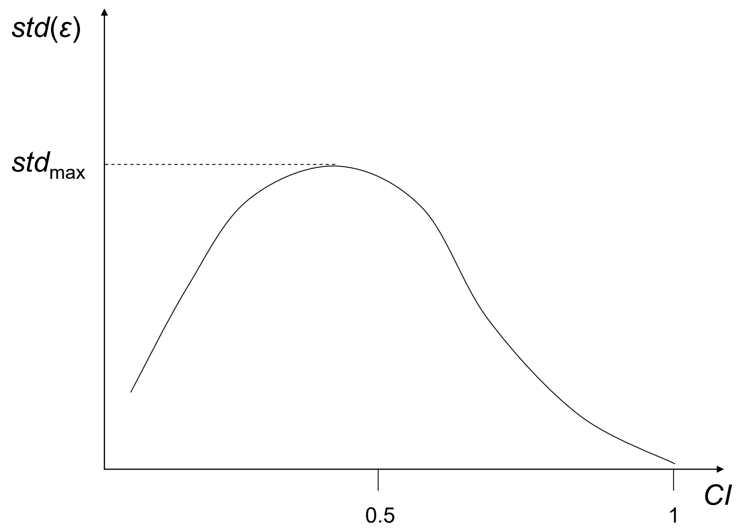

Solar forecast errors vs. clearness index.

# Simulated Solar Forecast Errors (cont.)

- Time and weather conditions during a day can result in different solar forecast errors patterns:
  - Night Time — forecast error is zero, $\varepsilon = 0$
  - Sunny Day — forecast error is small or close to 0, $\varepsilon \to 0$, when $CI \to 1$
  - Very Cloudy Day — forecast error is limited or close to 0, $\varepsilon \to 0$, when $CI \to 0$
  - Partly Cloudy Day — forecast error varies in wide range for intermediate values of *CI*
- Standard distribution of solar forecast errors can be described as a function of *CI*.
- Use solar generation profiles, including actual solar generation and ideal solar generation, to calculate CI:

$$CI(t) = \frac{G_a^s(t)}{G_{max}^s(t)}, (t = 1,2,..,n)$$

- Calculate solar HA forecast errors at solar plant level (not BA level)




Hypothetical distribution of the standard deviation of solar forecast errors depending on the clearness index.

| CI | $\sigma_{HA}$ |
|---|---|
| 0 < CI ≤ 0.2 | 5% |
| 0.2 < CI ≤ 0.5 | 10% |
| 0.5 < CI ≤ 0.8 | 7.5% |
| 0.8 < CI ≤ 1.0 | 5% |

**Table 1**. Standard Deviation of HA Solar Forecast Errors Based on Clearness Index Level.

# Methodology

***Create 1-min load data series for future year from estimated hourly load for that year and historical actual 5-min load series***

- WECC ADS 2034 has hourly native load for 39 load areas, how to calculate 1-min native load?
  - 1-min net load (1-min native load – 1-min BTM solar)
- Ideally, would like to have 2024 5-min load data for each WECC BA and impose this data variability on WECC 2034 hourly data
- Only BPA and CAISO post 5-min load data publicly
  - Superimposed this 5-min variability on other WECC BAs
    - ✓ Impose CAISO load variability on BAs with high BTM solar
      - All load areas in CA, NVE, AZPS
    - ✓ Impose BPA load variability on the remaining load areas with limited BTM solar

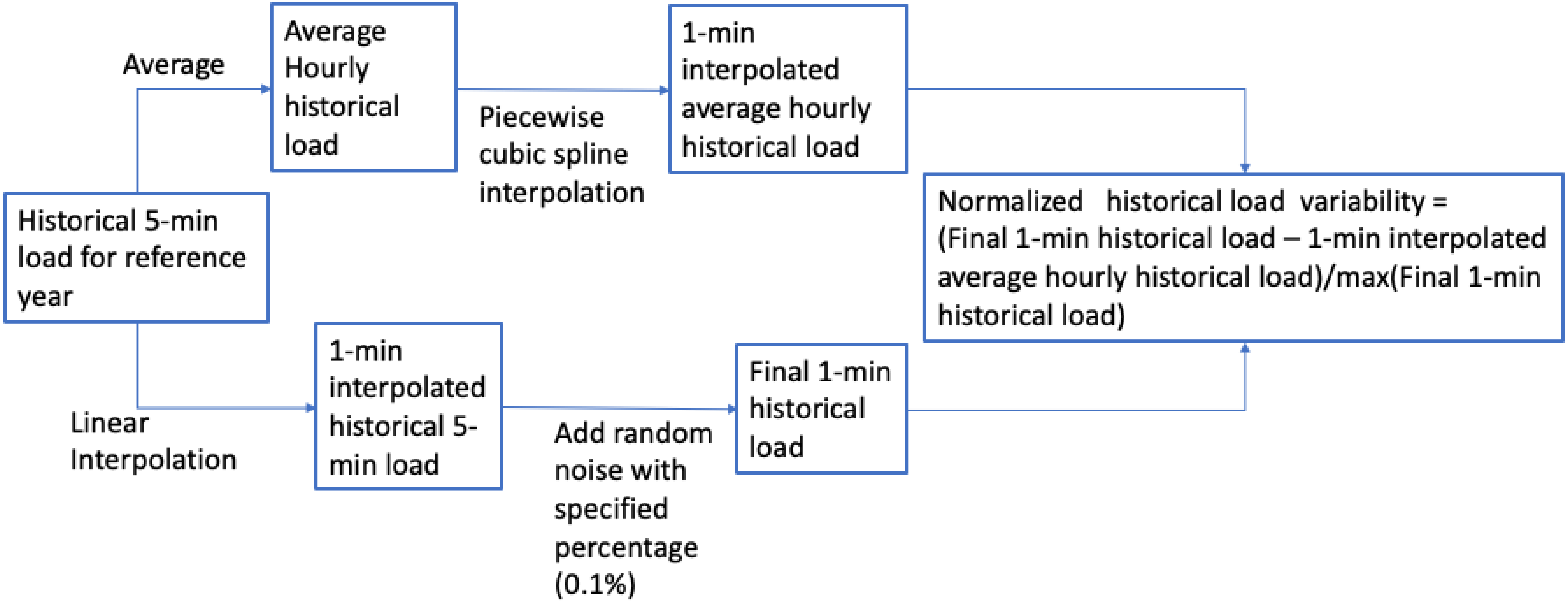
# Methodology – Load Data Preparation

***PNNL approach to calculate 1-min load from estimated future hourly load and historical actual 5-min load***

- Calculate area 1-min normalized variability from historical 5-min area load
- Calculate area final 1-min ADS load
- Repeat process for load areas where 5-min historical load is available.
  - Currently, there are only two BAs (CAISO and BPA) with 5-min historical data available publicly.
- To calculate 1-min actual load for the future year of interest, consider using CAISO normalized error for load areas within CAISO footprint and BPA normalized error for remaining load areas in WECC system

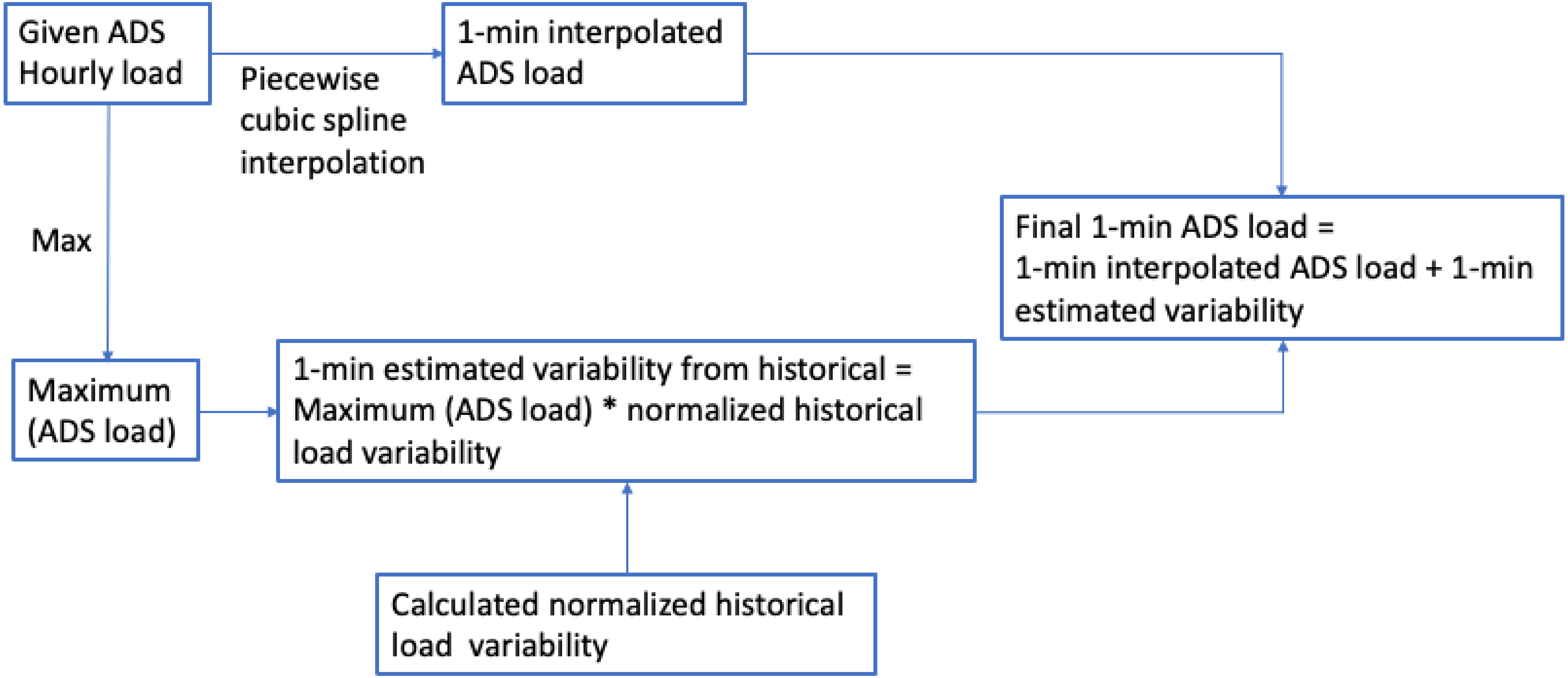
# Methodology

## Calculate the area 1-min normalized variability from historical 5-min area load



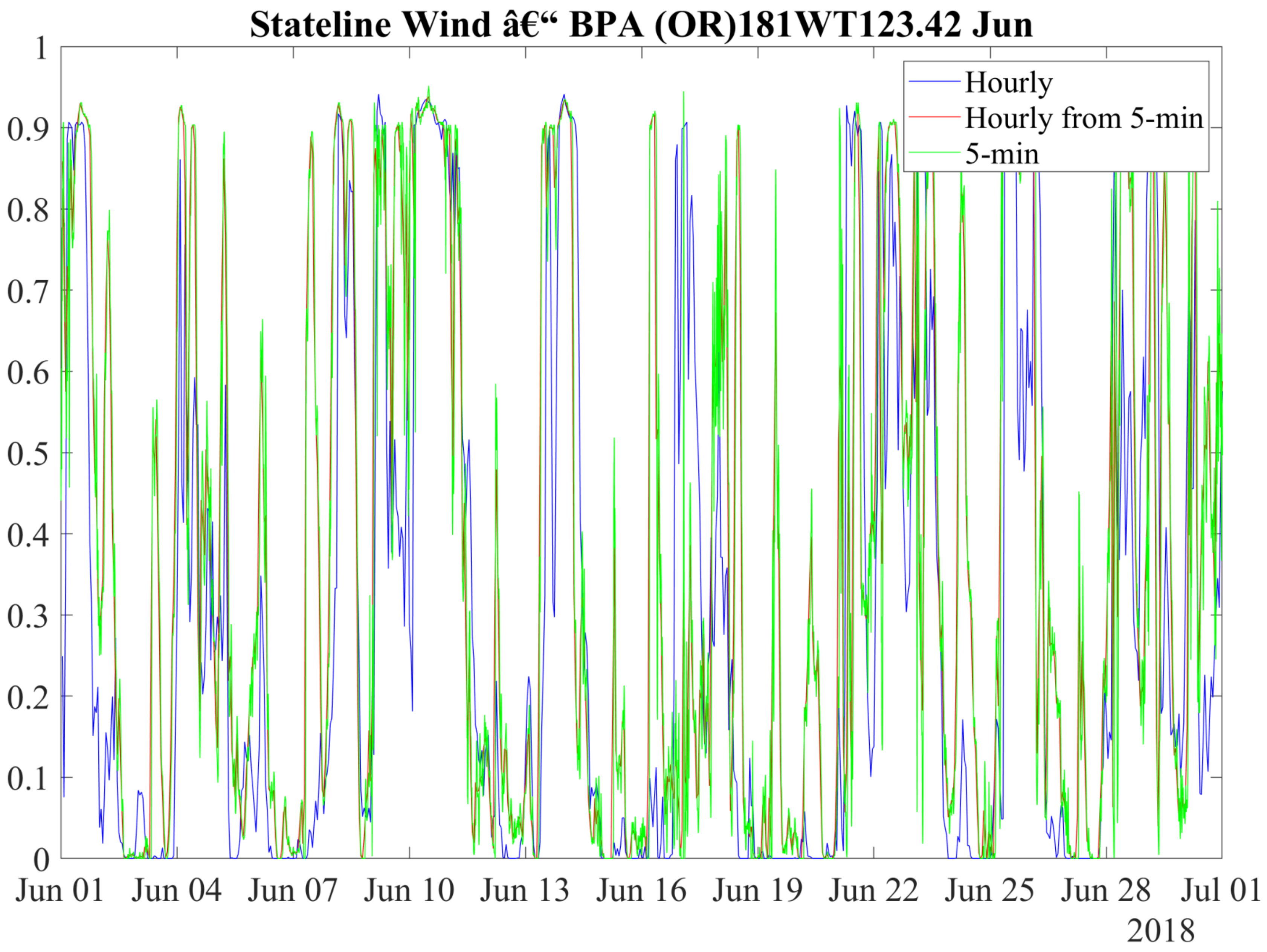
# Methodology

## Calculate the area final 1-min ADS load



# Wind Data Hourly vs. 1-min

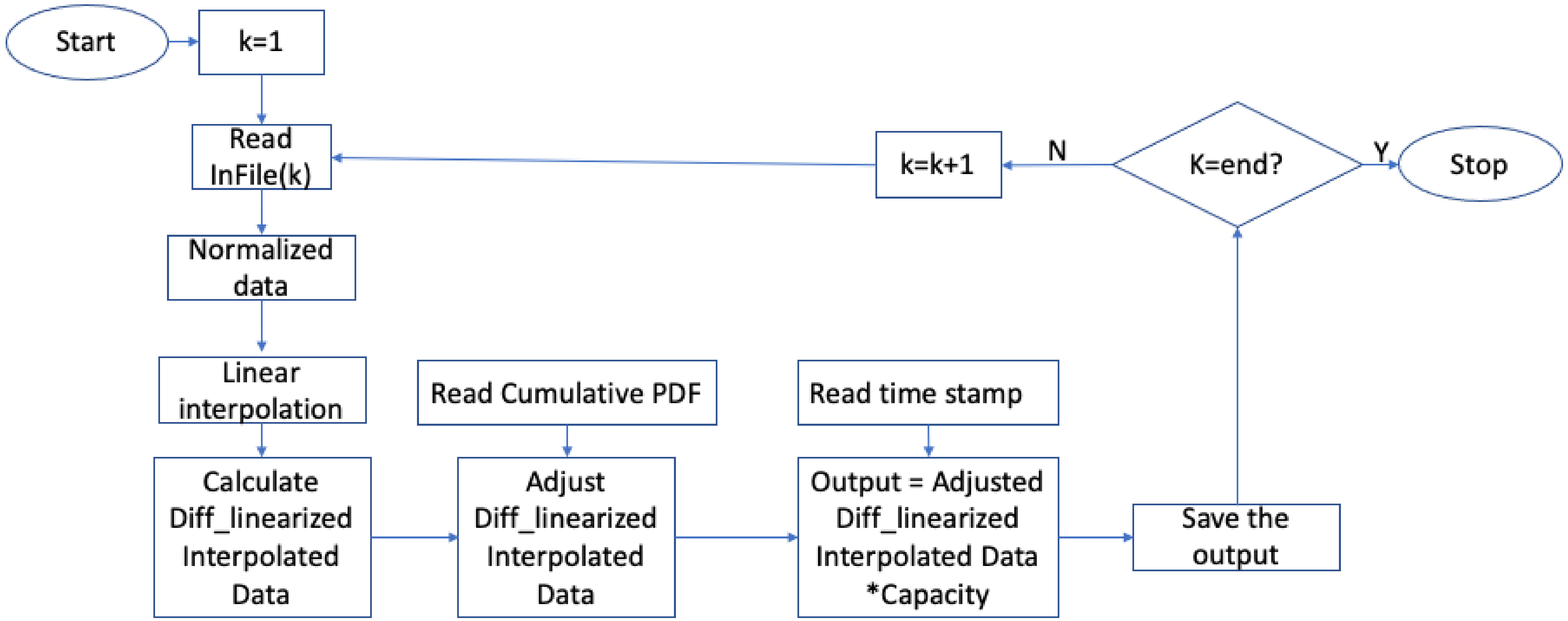
- NREL provided 5-min and 1-hour wind power data for each wind project.
- For most of the projects, there is a good match between the two data sets.



# Methodology

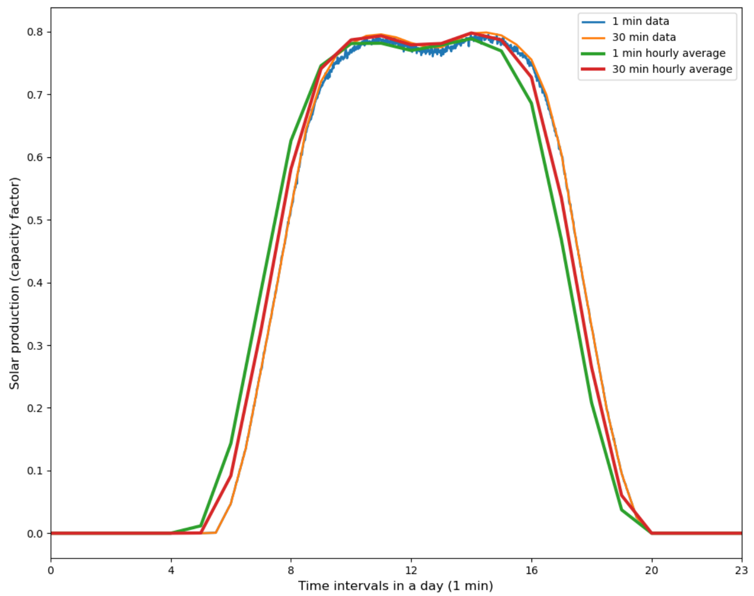
## *Calculate 1-min wind data from 5-min simulated actual*

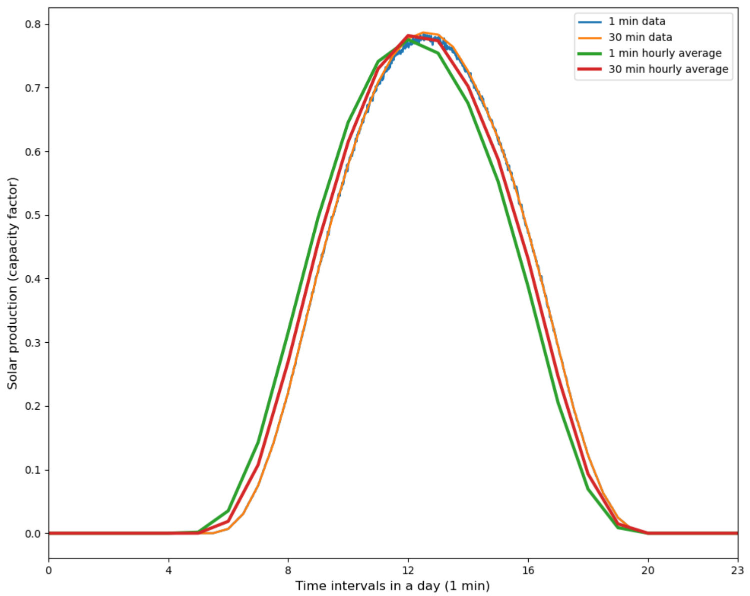
- NREL 5 min wind data (WTK-LED CONUS)
  - https://developer.nrel.gov/docs/wind/wind-toolkit/wtk-conus-5min-v2-0-0-download/
- 3Tier code to convert from 5-min to 1-min, modified from 5-min to 1-min
  - 3TIER. 2010. Development of Regional Wind Resource and Wind Plant Output Datasets. NREL/SR-550-47676. Work performed by 3TIER for the National Renewable Energy Laboratory, Golden, Colorado. Accessed September 15, 2014, at http://www.nrel.gov/docs/fy10osti/47676.pdf



# PNNL's Utility Scale 30-min Solar for New Projects

- Started with 2018 weather dataset from NSRDB (https://nsrdb.nrel.gov/data-viewer)
  - Downloaded the USA & Americas 4km dataset
  - Used the 30-minute resolution to generate solar profiles for new projects
  - Converted to power using several assumptions for each project (see table at right)
- Interpolated 30-min data to 1-min for reserve calculations (cubic spline)
- Compare to hourly average of 30-min data and hourly average of 1-min data
- For most projects, there is a good match between 1-min and averaged hourly data




| Assumptions |
|---|
| DC/AC ratio = 1.3 |
| Azimuth = 180° |
| *Tilt = 0° |
| Inverter efficiency = 96% |
| System losses = 11% |
| Ground coverage ratio = 0.1 |
| Constant loss adjustment = 0 |

*In SAM, 1-axis PV systems are modeled with tilt = 0°, where the "tilt" parameter refers to the horizontal rotation axis.

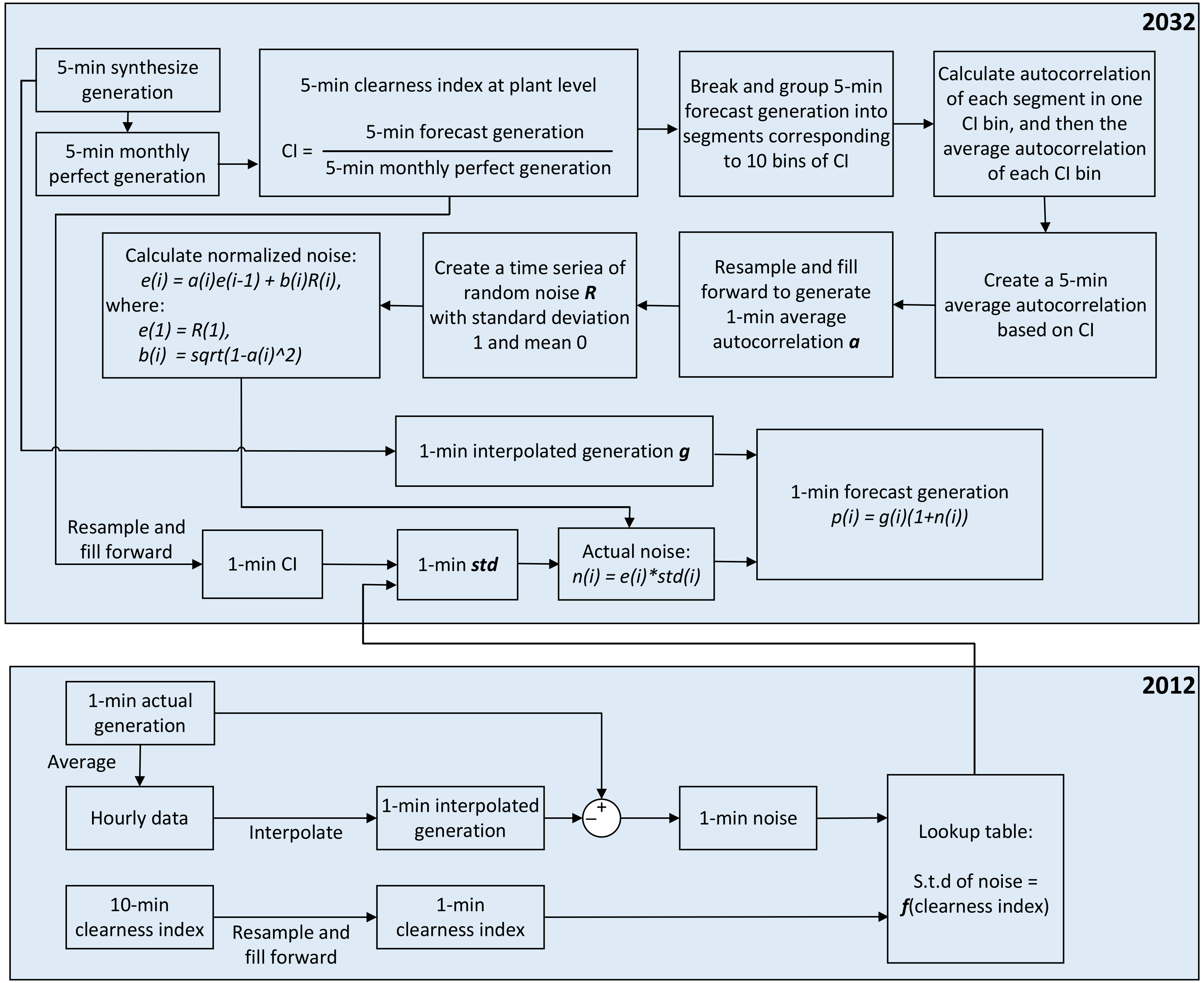
# Methodology

***Calculate 1-min utility scale and BTM solar from 5-min synthetic generation and 1-min historical actual generation***

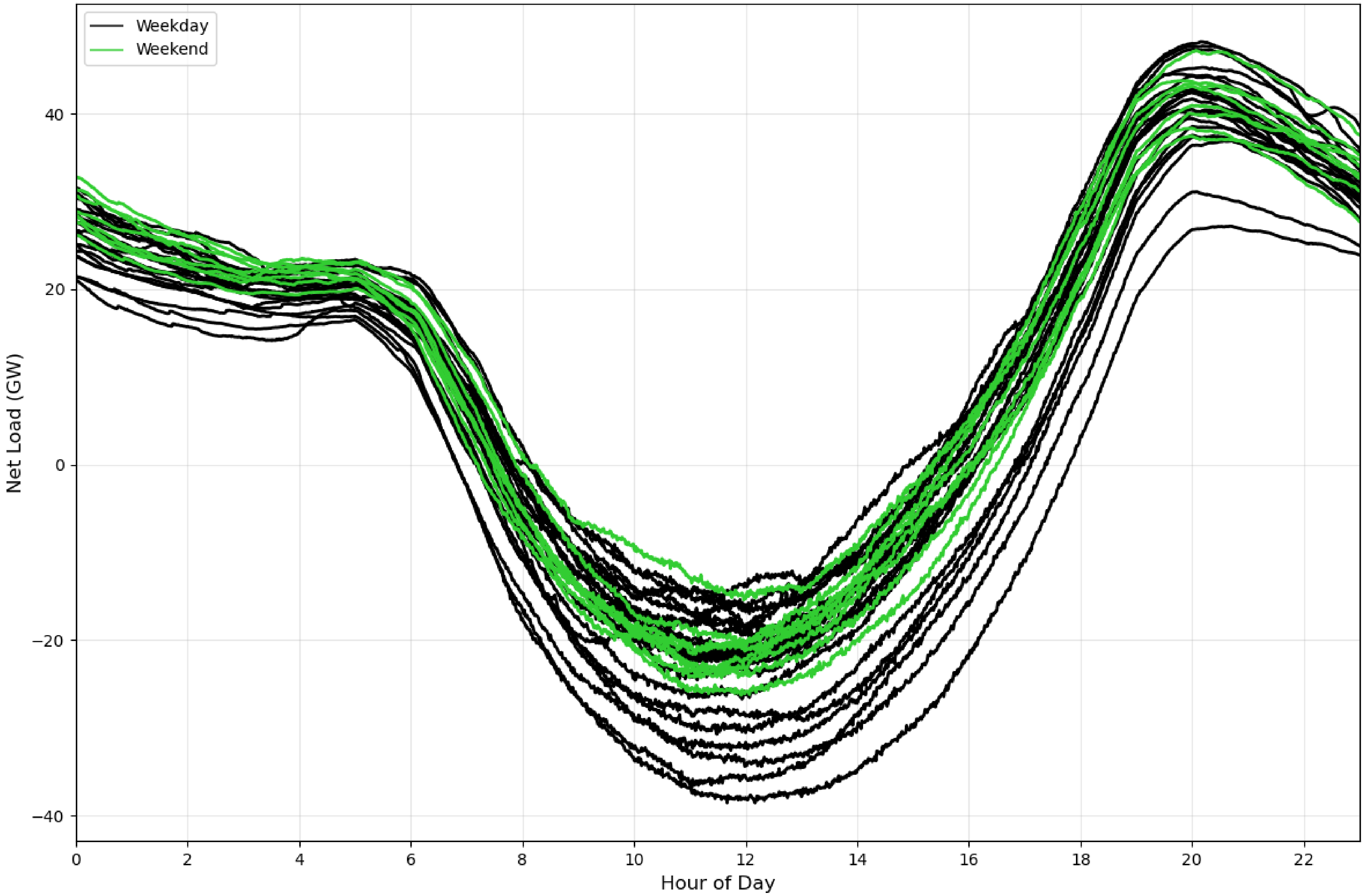
- Start with historical actual 2012 data:
  - Based on 1-min actual generation, create a look-up table for the standard deviation of noise as a function of clearness index
- Apply to synthetic 2034 data:
  - Based on synthetic 5-min generation data, linearly interpolate to 1-min and calculate the clearness index at plant level
  - Based on the calculated clearness, determine the standard deviation of noise for 2034 using look-up table from 2012
  - Calculate the autocorrelation and normalized noise, which is combined with the standard deviation to produce actual noise
  - Use the interpolated 1-min generation and actual noise to get the actual 1-min generation

# Methodology

***Calculate 1-min utility scale and BTM solar from 5-min synthetic generation and 1-min historical actual generation***



# CAISO Net load (Native Load — BTM_Solar — Utility Scale Solar — Wind) (July 2034 days)



# Modeling of Load Following and Regulation Constraints in GridView

- Hourly load following (up/down) and regulation requirements (up/down) at BA level
- Which gen units can provide load following and/or regulation, it can be set at the following levels:
  - Global level: Unit sub-type at system level or units sub-type at BA level
  - Local level: Individual units (will overwrite global level if provided unless global level is smaller)
- Units excluded in ADS 2032 model from providing flex reserve:
  - Wind and Utility Scale Solar
    - ✓ Could provide 100% of their current simulation hour $P_{gn}$ as load following down
    - ✓ Could provide load following up and spinning reserve if curtailed
    - ✓ Not currently used in the model
  - Nuclear (needs to be set at unit level)
  - Run of the river hydro (reserve contribution factor in GridView is set to zero)
  - Most coal units (exceptions for few BAs like PACE and PACW)

# How to Set Limits of How Much Reserve can be Provided by Hydro Gen Units in GridView

**GridView enforces 3 constraints for each unit to provide reserve:**

1. Reserve Contribution Factor (for Hydro units only)
   - How much reserve the unit can provide Up and Down as percentage of the unit Pmax, in the WECC ADS 2030 case
   - 0 for run of river hydro units
   - 0.1 for small hydro units
   - Min(0.5,1/# of units) for dispatchable large hydro units
   - As an example 0.25 Reserve Contribution Factor for a 100 MW unit means this unit can provide:
     - ✓ 25 MW up (LF_up + reg_up + Spinning)
     - ✓ 25 MW down (LF_down + reg_down)
2. Unit Pmax
   - If this 100 MW unit is operating at 90 MW, it can only provide 10 MW up and 25 MW down

# How to Set Limits of How Much Reserve can be Provided by Hydro Gen Units in GridView

3. Limits set by unit ramp rate
   - LF_up and LF_down is bounded by ramp rate per min * 20min
   - Reg_up and Reg_down is bounded by ramp rate per min *10min
   - If this same 100 MW unit can only ramp 60 MW per hour, it can only provide:
     - ✓ 1MW/min *20min = up to 20 MW LF up or down and
     - ✓ 1MW/min *10min = up to 10 MW Reg up or down or spinning
     - ✓ If it provides 10 MW for Reg up reserve, it cannot provide spinning but can provide up to 10 MW for LF up

# How Much Reserve can be Provided by Thermal Gen Units in GridView

- Thermal units can provide reserve based on minimum of:
  - Bid Amount (MW)
  - Ramping Up/Down Rate * Min(AS)
  - Upward: Cap – Dispatch
  - Downward: Dispatch – Pmin
- WECC 2034 ADS can provide up to 100% capacity for reserves
  - Bid amount is not defined in the database (e.g., Nuclear or some coal units can be adjusted by unit bids if don't want to provide reserves)
  - Ramping rate and ramping minutes are defined in the database

# How Much Reserve can be Provided by Wind and Solar Gen Units in GridView

- BTM Solar cannot provide reserve in WECC 2034 ADS
- Wind and Utility Solar can provide downward reserve based on
  - Hourly generation Amount (MW)
- Wind and Utility Solar can provide upward reserve based on
  - Hourly curtailment Amount (MW)
- Wind and Utility Solar can provide up to 100% of hourly generation for downward reserves
- Wind and Utility Solar cannot provide upward reserves

# Backup Slides on 2030 and 2032 ADS case efforts

Pacific Northwest NATIONAL LABORATORY

# Wind and Solar Summary in WECC 2030

| Data Resource | Wind Capacity (MW) | Solar Capacity (MW) |
|---|---|---|
| 2022 capacity (WECC 2022 State of Interconnection Report) | 29,000 | 30,000 |
| GridView database for WECC 2030 (v. 2.3) | 35,723 | 39,908 |
| GridView database for WECC 2032 (v. 2.1) | 45,092 | 62,403 |

## Summary at the BA level:

| Types of installed capacity | AESO | AVA | AZPS | BANC | BCHA | BPAT | CAISO | CFE | CHPD | DOPD | EPE | GCPD | IID | IPCO | LDWP | NEVP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind (MW) | 3,870 | 105 | 227 | 0 | 779 | 4,970 | 7,188 | 130 | 0 | 0 | 247 | 0 | 0 | 601 | 424 | 0 |
| Solar (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 0 |
| SolarPV-Fixed (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 |
| SolarPV-Tracking (MW) | 247 | 0 | 310 | 186 | 2 | 0 | 10,626 | 0 | 0 | 0 | 504 | 0 | 122 | 180 | 855 | 2,662 |
| SolarPV-NonTracking (MW) | 0 | 0 | 343 | 20 | 93 | 5 | 5,626 | 401 | 0 | 0 | 5 | 0 | 442 | 110 | 1,270 | 457 |
| SolarCSP0 (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 481 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SolarCSP6 (MW) | 0 | 0 | 250 | 0 | 0 | 0 | 641 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 64 |
| BTM (MW) | 0 | 12 | 2,815 | 716 | 0 | 44 | 18,771 | 0 | 0 | 2 | 316 | 4 | 199 | 39 | 745 | 599 |
| Peak Load (MW) | 13,291 | 2,376 | 9,687 | 4,844 | 12,234 | 12,958 | 52,320 | 4,361 | 501 | 464 | 2,336 | 1,501 | 1,266 | 4,536 | 7,830 | 7,045 |
| Net Peak Load (Peak Load - BTM) (MW) | 13,291 | 2,375 | 8,866 | 4,678 | 12,234 | 12,956 | 48,037 | 4,361 | 501 | 464 | 2,188 | 1,500 | 1,172 | 4,510 | 7,409 | 6,825 |

| Types of installed capacity | NWMT | PACE | PACW | PGE | PNM | PSCO | PSEI | SCL | SPPC | SRP | TEPC | TIDC | TPWR | WACM | WALC | WAUW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind (MW) | 760 | 6,525 | 822 | 717 | 1,860 | 4,752 | 664 | 0 | 150 | 0 | 190 | 0 | 0 | 566 | 425 | 0 |
| Solar (MW) | 0 | 0 | 145 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SolarPV-Fixed (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SolarPV-Tracking (MW) | 0 | 2,265 | 505 | 0 | 695 | 988 | 6 | 0 | 1,158 | 2,331 | 335 | 0 | 0 | 547 | 1,213 | 0 |
| SolarPV-NonTracking (MW) | 17 | 1,830 | 728 | 0 | 154 | 648 | 0 | 0 | 153 | 91 | 177 | 0 | 0 | 20 | 0 | 0 |
| SolarCSP0 (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SolarCSP6 (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BTM (MW) | 29 | 188 | 73 | 79 | 132 | 1,513 | 24 | 6 | 83 | 438 | 433 | 192 | 1 | 60 | 324 | 2 |
| Peak Load (MW) | 2,090 | 10,700 | 4,033 | 3,914 | 3,053 | 10,741 | 5,230 | 1,612 | 2,176 | 9,606 | 3,658 | 680 | 927 | 4,505 | 1,893 | 163 |
| Net Peak Load (Peak Load - BTM) (MW) | 2,090 | 10,584 | 4,033 | 3,874 | 2,997 | 10,266 | 5,230 | 1,611 | 2,164 | 9,447 | 3,494 | 637 | 927 | 4,470 | 1,782 | 162 |

# Wind and Solar Summary in WECC 2032

| Data Resource | Wind Capacity (MW) | Solar Capacity (MW) |
|---|---|---|
| 2022 capacity (WECC 2022 State of Interconnection Report) | 29,000 | 30,000 |
| GridView database for WECC 2030 (v. 2.3) | 35,723 | 39,908 |
| GridView database for WECC 2032 (v. 2.1) | 45,092 | 62,403 |

## Summary at the BA level:

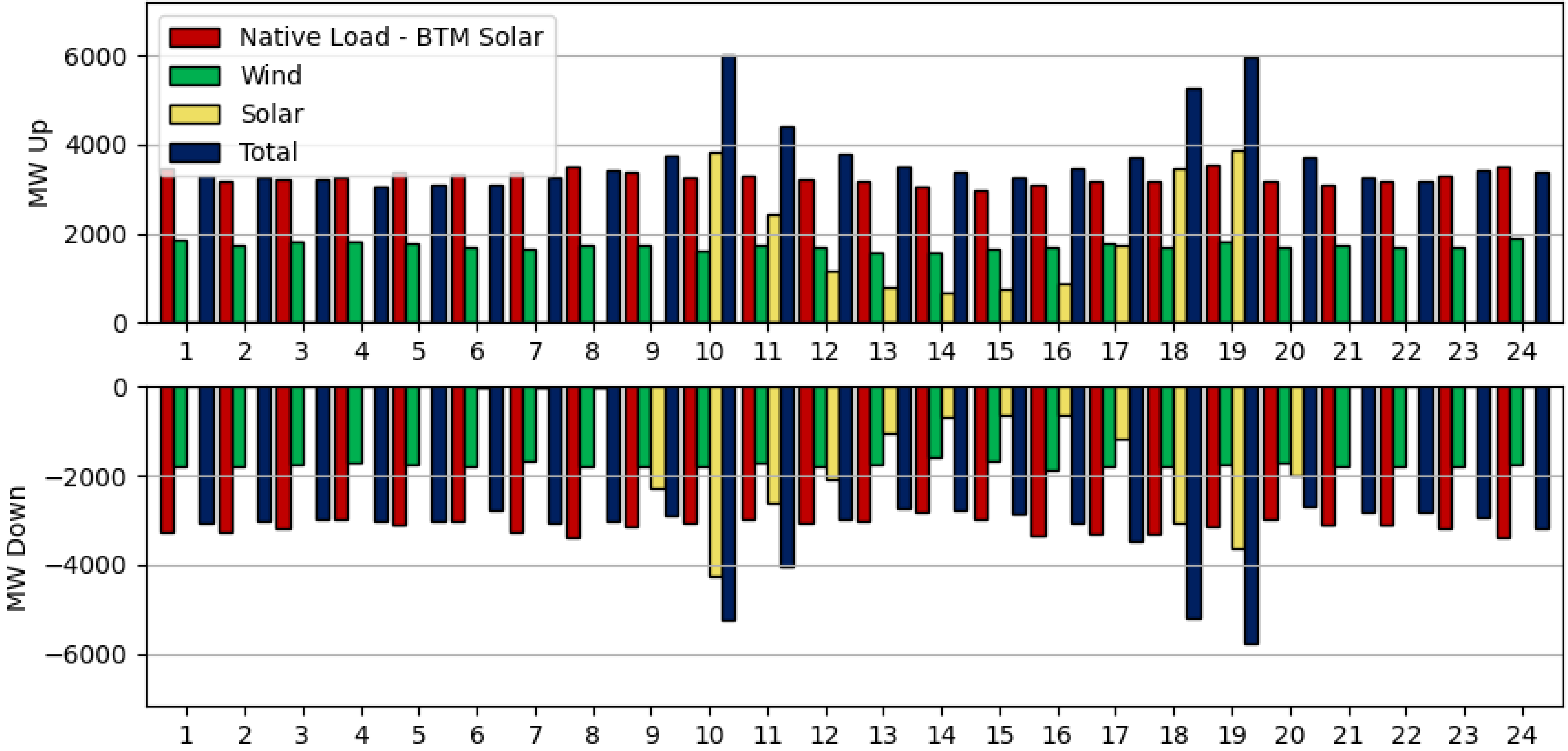
| Types of installed capacity | AESO | AVA | AZPS | BANC | BCHA | BPAT | CAISO | CFE | CHPD | DOPD | EPE | GCPD | IID | IPCO | LDWP | NEVP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind (MW) | 5,240 | 119 | 624 | 0 | 761 | 5,378 | 11,102 | 40 | 0 | 0 | 0 | 0 | 0 | 718 | 420 | 149 |
| SolarPV-Tracking (MW) | 1,069 | 0 | 870 | 254 | 17 | 791 | 5,980 | 0 | 0 | 200 | 1,222 | 0 | 134 | 1,285 | 410 | 5,114 |
| SolarPV-NonTracking (MW) | 350 | 29 | 2,025 | 112 | 15 | 234 | 21,416 | 46 | 0 | 0 | 5 | 0 | 349 | 116 | 2,000 | 785 |
| SolarCSP0 (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 275 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SolarCSP6 (MW) | 0 | 0 | 250 | 0 | 0 | 0 | 642 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 190 |
| BTM (MW) | 456 | 16 | 2,888 | 915 | 0 | 118 | 17,912 | 0 | 1 | 1 | 332 | 1 | 109 | 51 | 800 | 1,330 |
| Peak Load (MW) | 12,622 | 2,290 | 9,016 | 5,016 | 12,763 | 10,049 | 51,469 | 4,864 | 513 | 529 | 2,538 | 1,409 | 1,319 | 4,900 | 7,037 | 8,849 |
| Net Peak Load (Peak Load - BTM) (MW) | 12,622 | 2,289 | 8,534 | 4,672 | 12,763 | 10,046 | 45,684 | 4,864 | 513 | 529 | 2,438 | 1,408 | 1,276 | 4,889 | 6,832 | 8,695 |

| Types of installed capacity | NWMT | PACE | PACW | PGE | PNM | PSCO | PSEI | SCL | SRP | TEPC | TIDC | TPWR | WACM | WALC | WAUW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind (MW) | 847 | 6,561 | 2,248 | 766 | 2,978 | 4,697 | 658 | 0 | 0 | 437 | 0 | 0 | 748 | 485 | 0 |
| SolarPV-Tracking (MW) | 0 | 3,097 | 167 | 0 | 1,906 | 1,842 | 0 | 0 | 2,241 | 418 | 0 | 0 | 134 | 682 | 0 |
| SolarPV-NonTracking (MW) | 177 | 1,625 | 1,306 | 149 | 154 | 699 | 2 | 0 | 1,110 | 150 | 120 | 0 | 4 | 8 | 0 |
| SolarCSP0 (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SolarCSP6 (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BTM (MW) | 21 | 627 | 255 | 85 | 409 | 1,720 | 346 | 63 | 264 | 341 | 74 | 9 | 25 | 52 | 1 |
| Peak Load (MW) | 2,121 | 11,331 | 4,116 | 4,331 | 3,262 | 11,006 | 5,395 | 1,777 | 10,543 | 4,136 | 756 | 868 | 4,687 | 1,887 | 188 |
| Net Peak Load (Peak Load - BTM) (MW) | 2,108 | 10,947 | 4,114 | 4,301 | 3,113 | 10,374 | 5,395 | 1,777 | 10,422 | 4,022 | 731 | 868 | 4,664 | 1,850 | 188 |

# CAISO 2032 Reserve Results

- January Load Following
- July Load Following
- January Regulation
- July Regulation

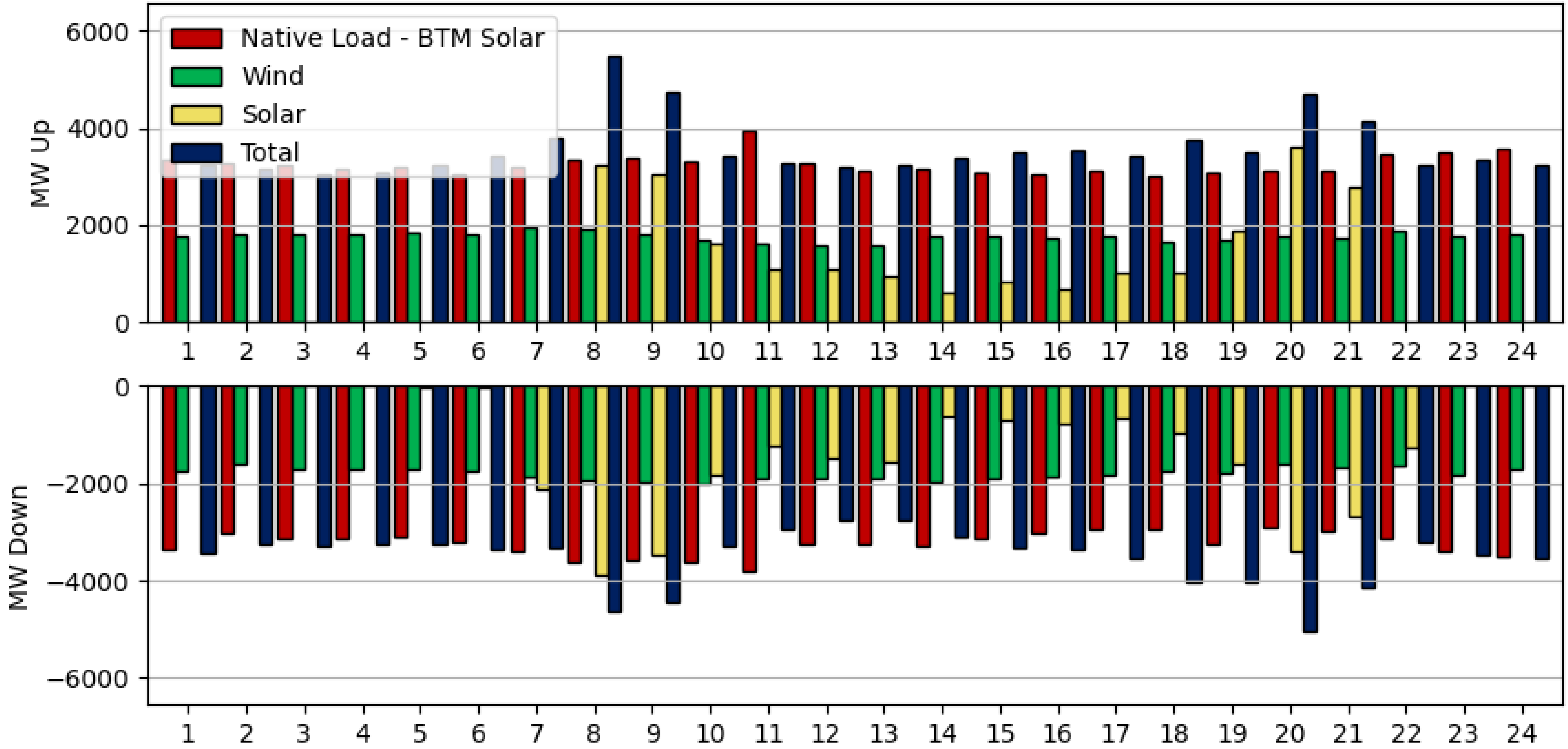
# CAISO January 2032 Load Following decomposed (95% case)
## (LF capacity needs by each individual resource)




Note: the total requirement (dark blue in the graph) is not a simple linear addition of individual components

# CAISO July 2032 Load Following decomposed

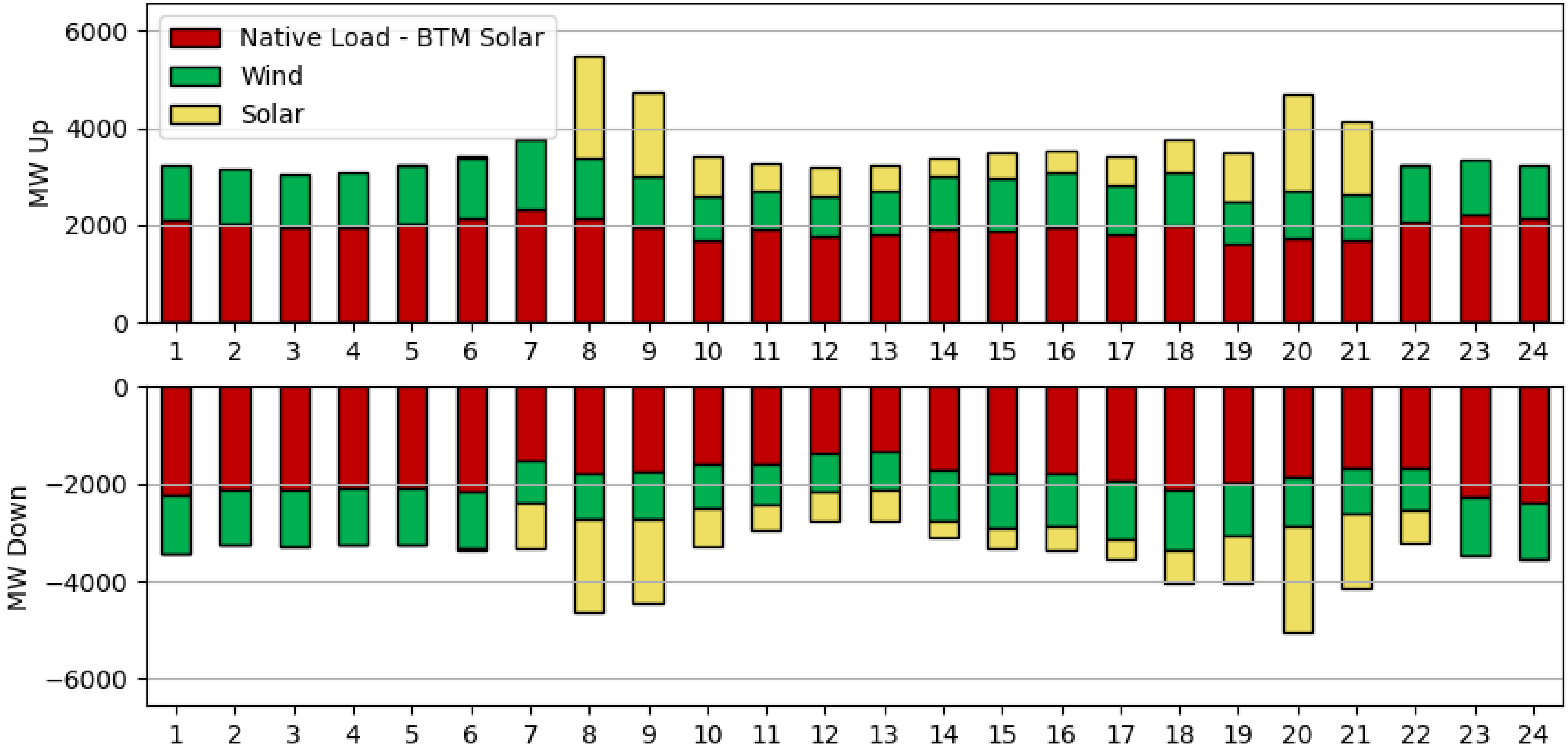
## (LF capacity needs by each individual resource)



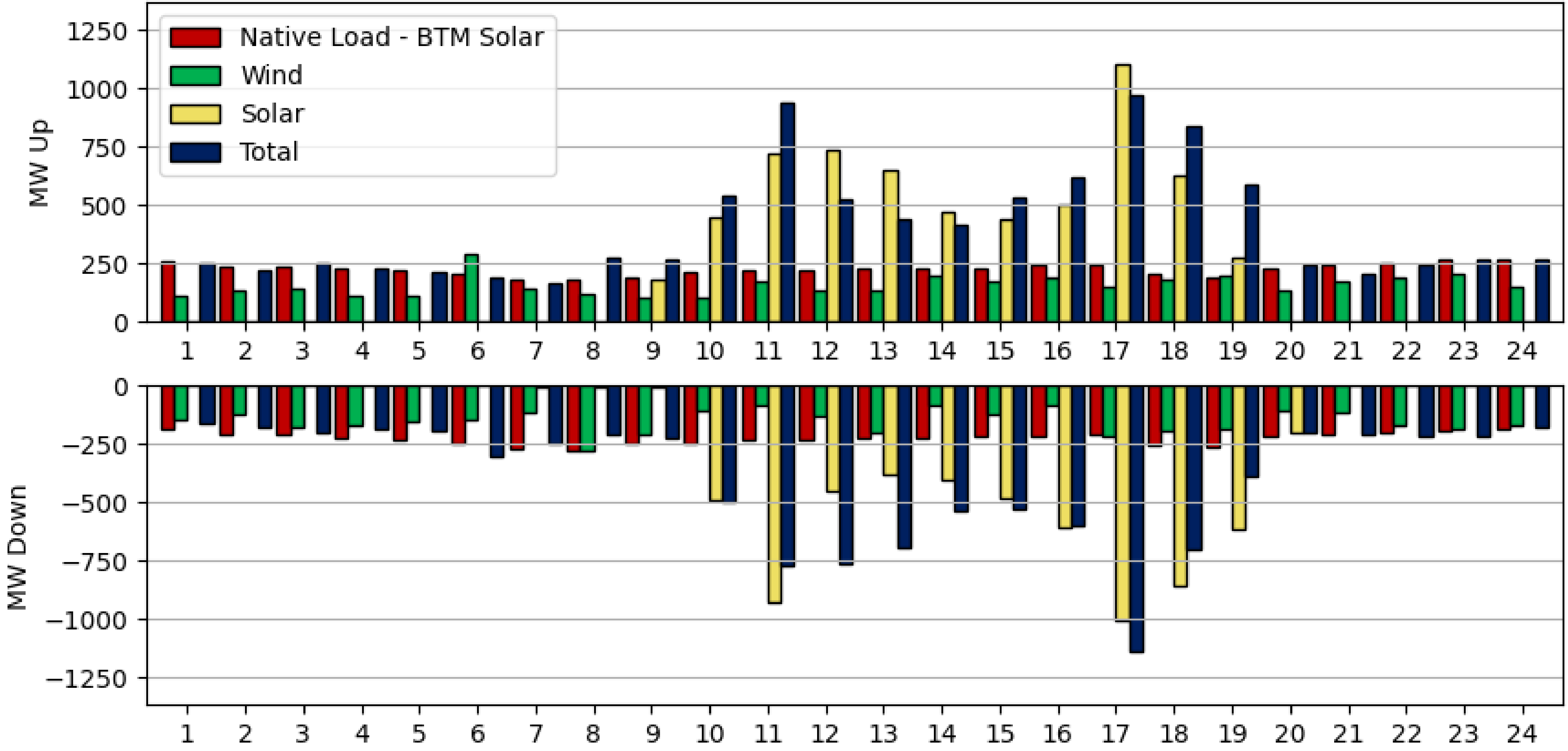

Note: the total requirement (dark blue in the graph) is not a simple linear addition of individual components

# CAISO July 2032 Load Following decomposed

## (Percent of each resource of total LF capacity)



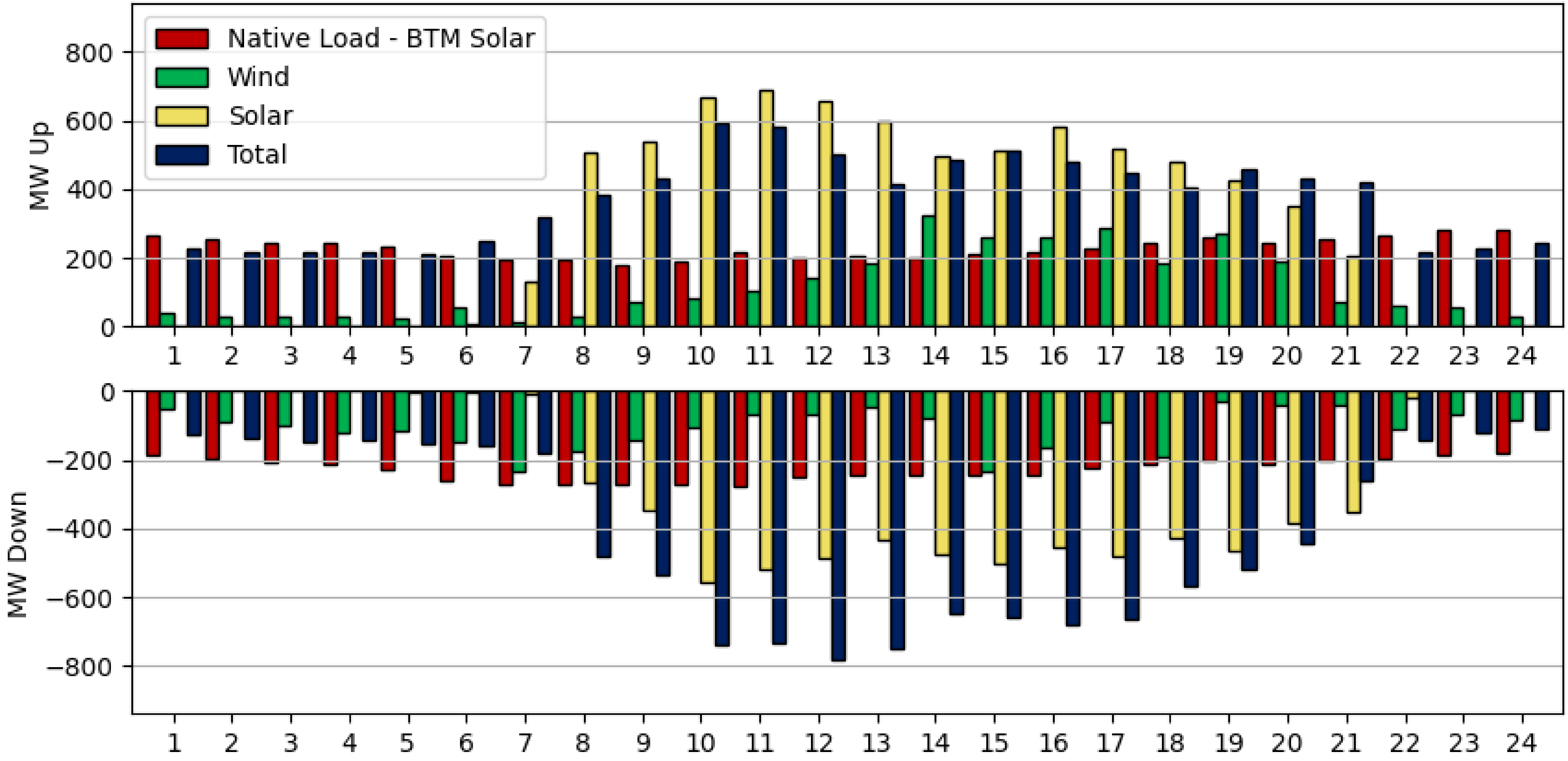
# CAISO January 2032 Regulation decomposed (95% case)
## (RL capacity needs by each individual resource)




Note: the total requirement (dark blue in the graph) is not a simple linear addition of individual components

# CAISO July 2032 Regulation decomposed

## (RL capacity needs by each individual resource)




Note: the total requirement (dark blue in the graph) is not a simple linear addition of individual components

# CAISO July 2032 Regulation decomposed

## (Percent of each resource of total Reg capacity)