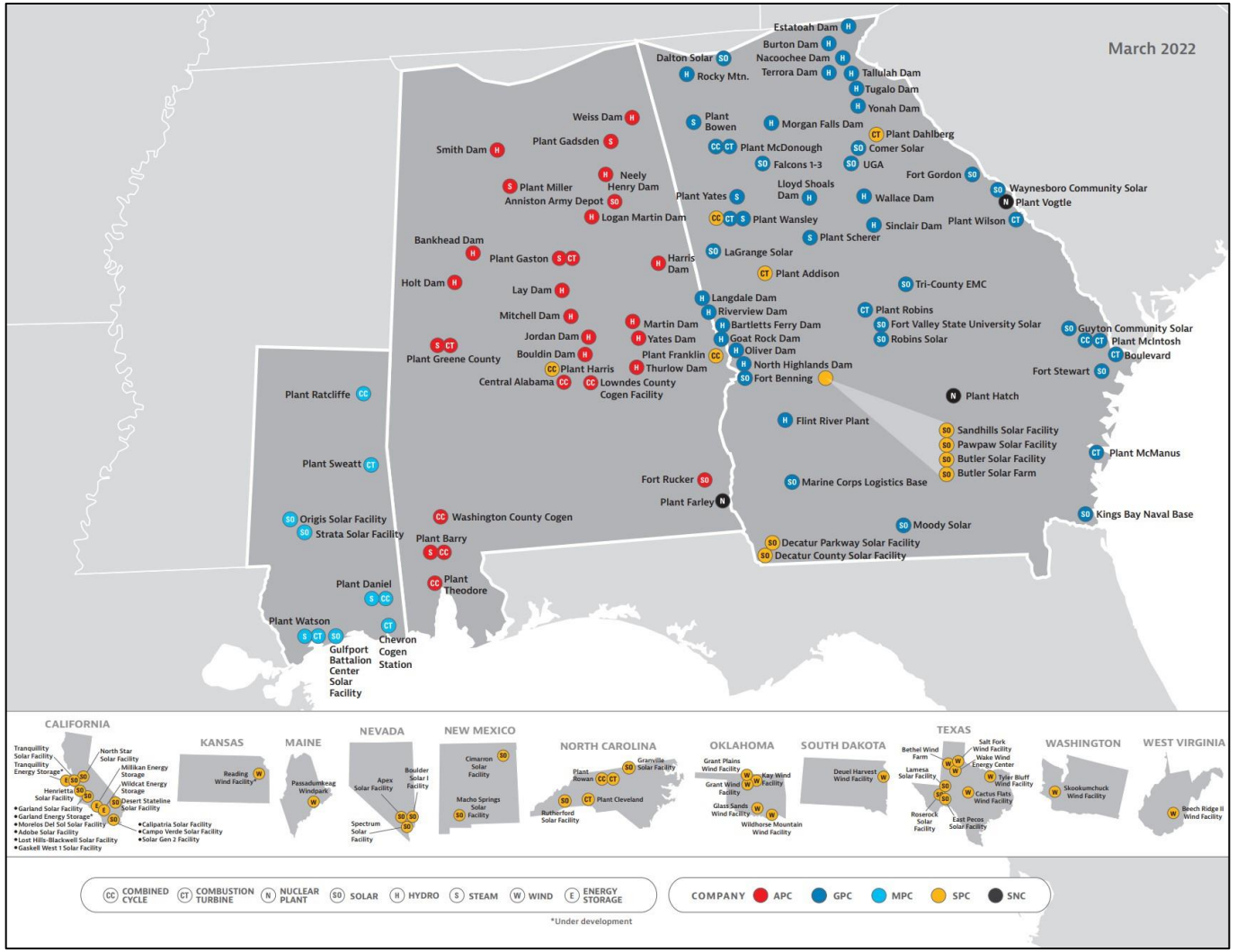
Probabilistic Methods in Operations

Will Hobbs, PE
Southern Company R&D
March 23, 2022

Southern Company

This work focuses on our balancing area in the Southeast



Outline

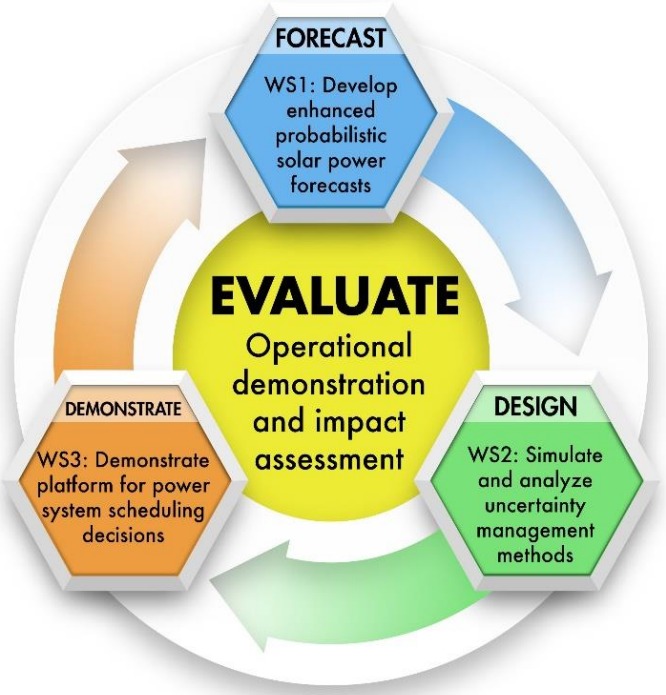
- **OPTSUN**: Using probabilistic information
- **Solar Forecast Arbiter**: Evaluating forecasts (probabilistic or otherwise)
- **Flexible Solar**: Another tool in the toolbelt

OPTSUN Acknowledgments

- Aidan Tuohy
- Dan Kirk-Davidoff
- David Larson
- Miguel Ortega-Vasquez
- Mobs Bello
- Qin Wang
- Russ Philbrick
- (Others I’m forgetting)

EPRI OPTSUN Project

- Operational Probabilistic Tools for Solar Uncertainty
- **Forecast**: improved probabilistic forecasts
- **Design** methods for managing uncertainty (using production cost modeling)
- **Demonstrate** a scheduling management platform (SMP) to support decision making



UL

VT

POLARIS

DUKE ENERGY.

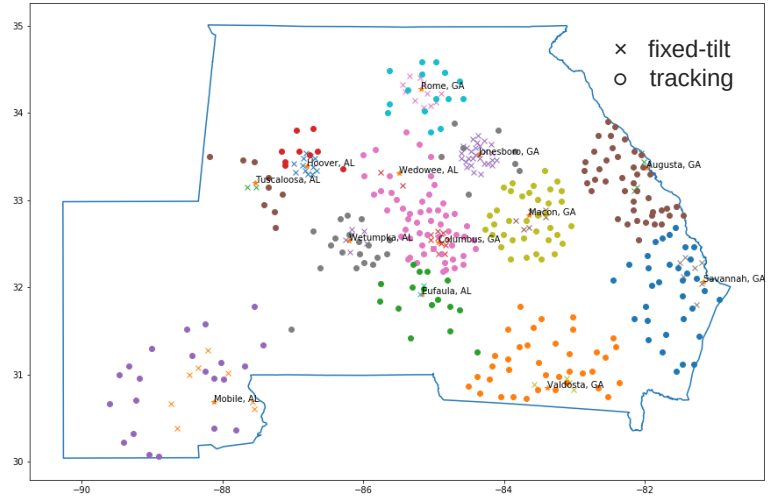
Southern Company

Hawaiian Electric

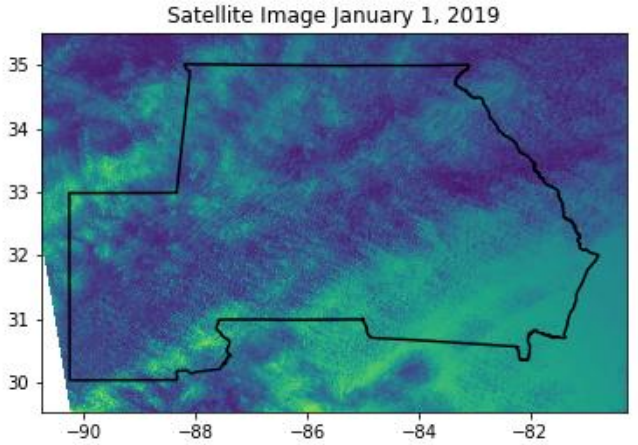
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

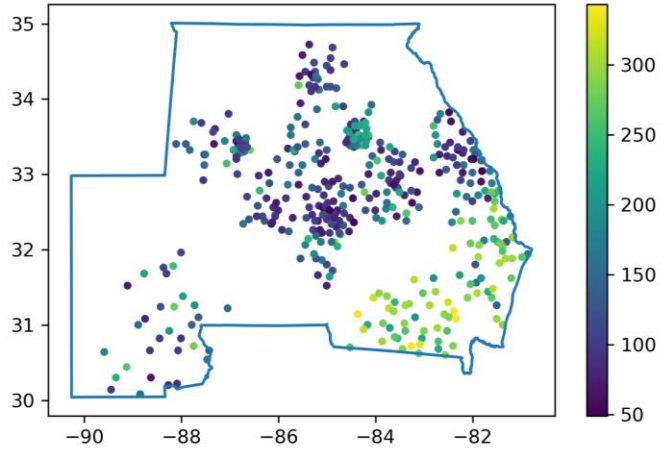
Solar Plants, Power Output

- Solar capacity scenarios:
  - Existing (~2 GW)
  - 7 GW
  - 10 GW
  - 20 GW



1. Select sites
2. Collect satellite data* and tune
3. Model individual plant power
4. Sum



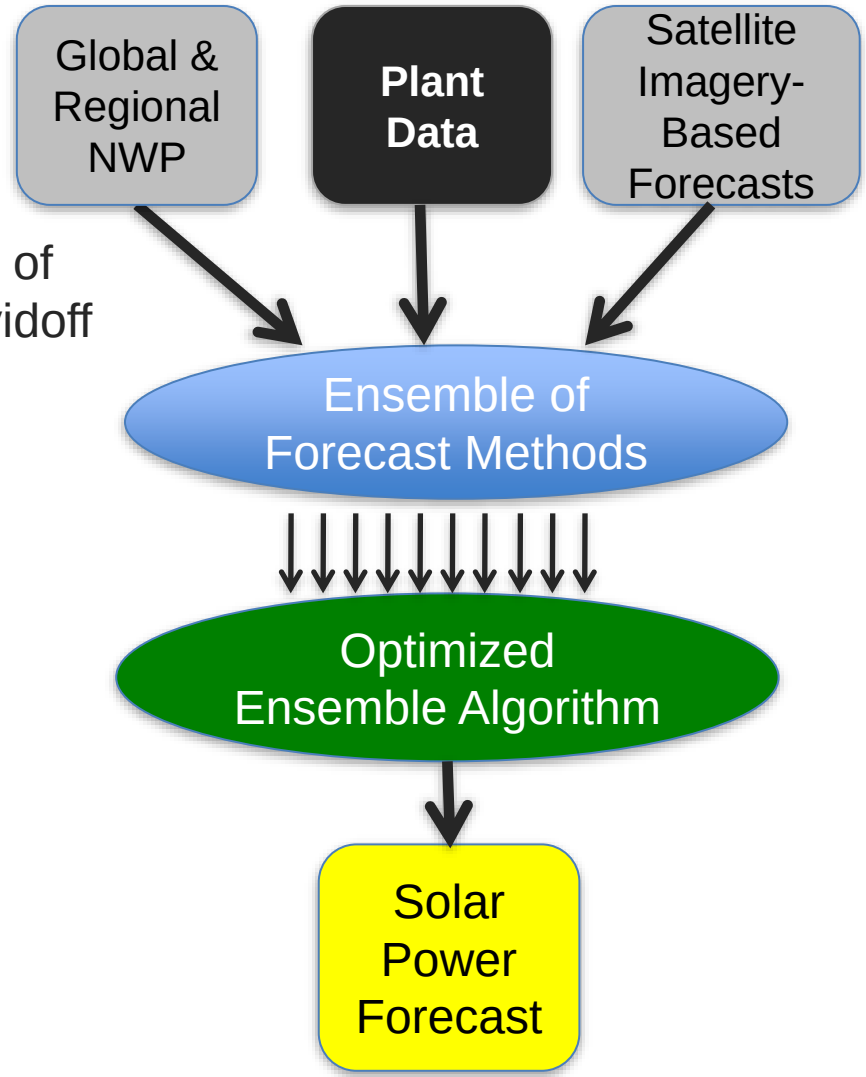


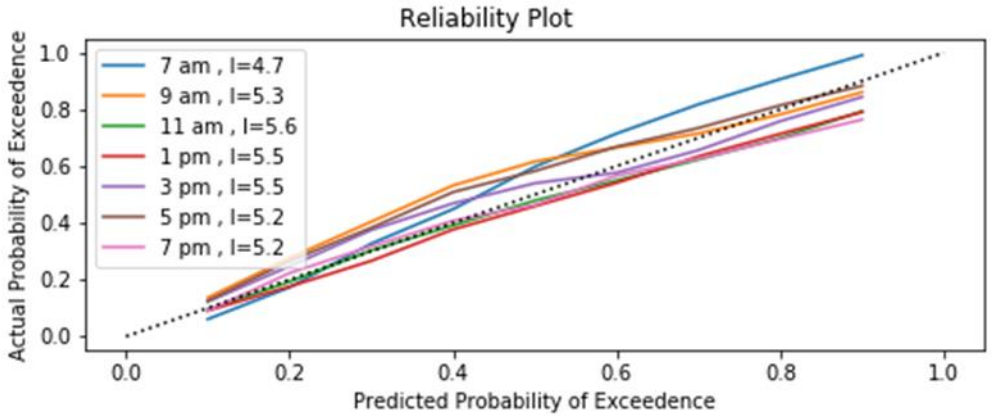
*160,000 visible and IR satellite images from the GOES 16 satellite

Forecasts

- Re-run forecasts from archived NWP and satellite data
- Horizons:
  - Multi-day ahead
  - Day Ahead (DA)
  - 2-Hours Ahead (2HA)
- Tune an ML-based analog ensemble

(big oversimplification of work by Dan Kirk-Davidoff and UL team)

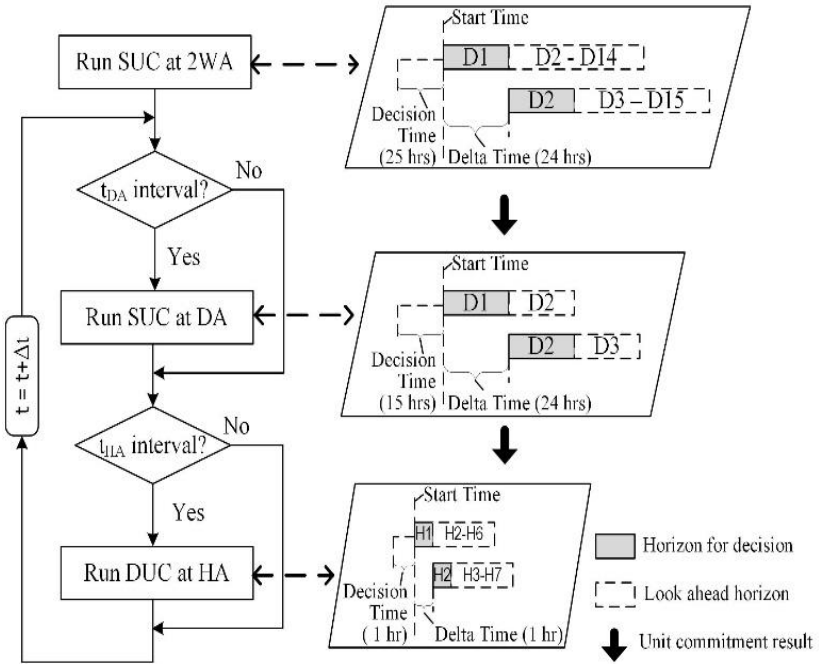


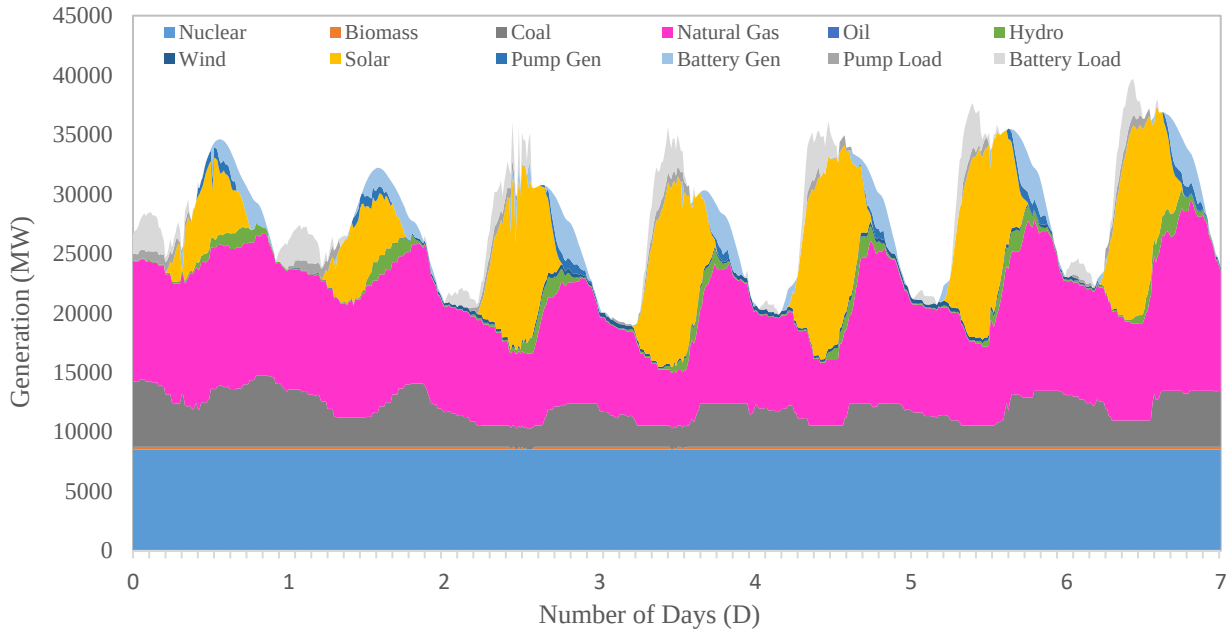


Production Cost Model

- Representative inputs (not a match for future system)
- Multiple commitment cycles
- deterministic unit commitment (DUC)
- stochastic unit commitment (SUC)

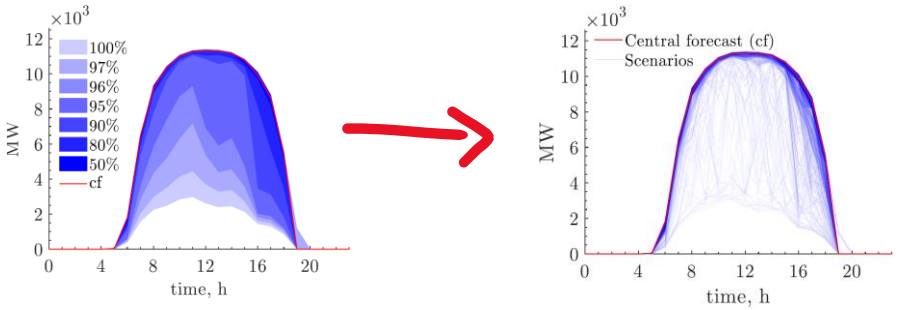
Power System Optimizer





Reserve Determination Methods

- **D** – Deterministic Forecast (Baseline)
- Based on **Historical Observations**:
  - **P1** – All scenarios: Consider all possible conditions from observations
  - **P2** – Extreme scenarios: Consider only worst possible conditions
- Based on **Forecasted Conditions**:
  - **P3** – Bounds of Extreme Scenarios
  - **P4** – Prediction Interval



a) Probabilistic forecast

b) Probabilistic scenarios

(synthetic scenarios)

EPRI's DynaDOR tool

All P Methods: "Robustness" is selectable.
E.g., 0.99 covers 99% of scenarios or 99% f.cast confidence. 0.90 is lower, …

Results

Results (draft)

7 GW Solar

Methods	D	Static	Risk (100MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties ($)	2,997 M	2,997 M (↑0.0%)	2,997 M (↑0.0%)	2,998M (↑.002%)	3,006 M (↑0.3%)	2,997 M (↓.03%)	3,013M (↑0.5%)	3.013 M (↑0.5%)
Annual total cost w/ penalties ($)	3,004 M	3,004 M (↑0.0%)	3,003 M (↓.02%)	2,999 M (↓0.17%)	3,008 M (↑0.13%)	3,001 M (↓.09%)	3,013 M (↑0.3%)	3,013 M (↑0.3%)
Reg. Down vio. (MWh)	3,490	3,522 (↑1%)	2,575 (↓26%)	2,831 (↓19%)	797 (↓77%)	1,934 (↓45%)	896 (↓74%)	163 (↓95%)
Operating reserve vio. (MWh)	1,995	2,404 (↑20%)	2,884 (↑45%)	2,323 (↑16%)	641 (↓68%)	2,048 (↑3%)	229 (↓89%)	139 (↓93%)
Total reserve vio. (MWh)	5,485	5,927 (↑8%)	5,459 (↓0.5%)	5,154 (↓6%)	1,438 (↓74%)	3,983 (↓27%)	1,125 (↓79%)	302 (↓94%)
Balance vio.	None							

20 GW Solar

Methods	D	Static	Risk (160MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties ($)	2,493 M	2,496 M (↑0.1%)	2,491 M (↓0.1%)	2,522 M (↑1.1%)	2,631 M (↑5.5%)	2,594 M (↑4.1%)	2,635 M (↑5.7%)	2,632 M (↑5.6%)
Annual total cost w/ penalties ($)	2,610 M	2,614 M (↑0.16%)	2,608 M (↓0.1%)	2,635 M (↑0.93%)	2,635 M (↑0.96%)	2,628 M (↑0.67%)	2,639 M (↑1.1%)	2,637 M (↑1.01%)
Reserve vio. (MWh)	15,406	14,535 (↓5.7%)	14,562 (↓5.5%)	14,415 (↓6.4%)	3,959 (↓74.3%)	8,411 (↓45.4%)	3,844 (↓75%)	3,854 (↓75%)
Balance vio. (MWh)	19,893	20,383 (↑2.5%)	19,924 (↑0.2%)	19,269 (↓3.1%)	0 (↓100%)	4,745 (↓76.1%)	0 (↓100%)	0 (↓100%)

Results (draft)

= better

= worse

7 GW Solar

Costs

Methods	D	Static	Risk (100MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties ($)								
Annual total cost w/ penalties ($)								
Reg. Down vio. (MWh)								
Operating reserve vio. (MWh)								
Total reserve vio. (MWh)								
Balance vio.	None							

Violations

20 GW Solar

Methods	D	Static	Risk (160MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties ($)								
Annual total cost w/ penalties ($)								
Reserve vio. (MWh)								
Balance vio. (MWh)								

Results (draft)

= better

= worse

7 GW Solar

Costs

Methods	D	Static	Risk (100MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties ($)								
Annual total cost w/ penalties ($)								
Reg. Down vio. (MWh)								
Operating reserve vio. (MWh)								
Total reserve vio. (MWh)								
Balance vio.	None							

Violations

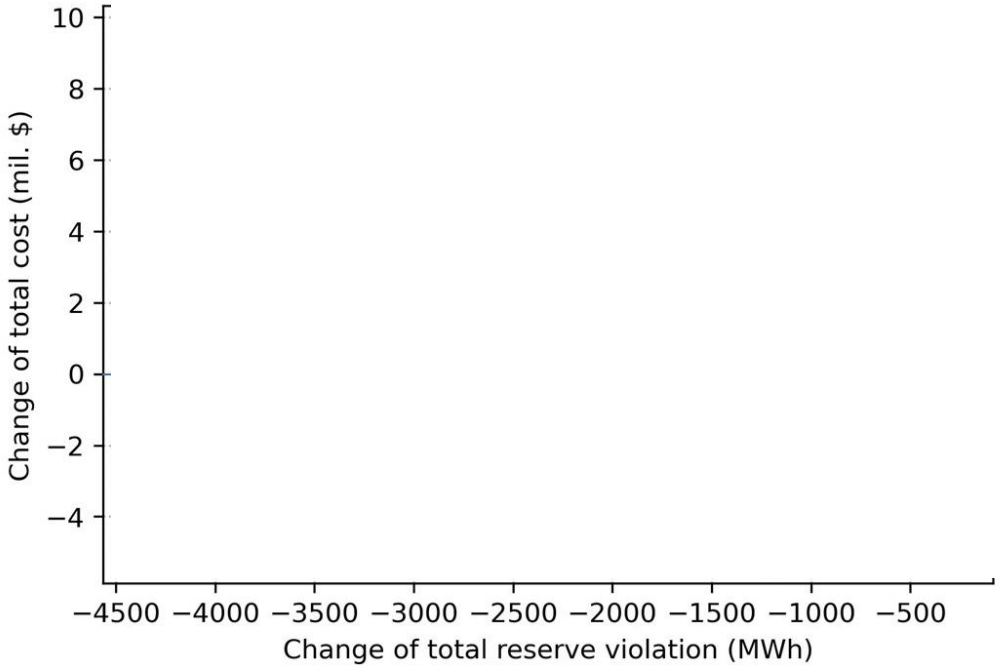
20 GW Solar

Methods	D	Static	Risk (160MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties ($)								
Annual total cost w/ penalties ($)								
Reserve vio. (MWh)								
Balance vio. (MWh)	19,893	20,383 (↑2.5%)	19,924 (↑0.2%)	19,269 (↓3.1%)	0 (↓100%)	4,745 (↓76.1%)	0 (↓100%)	0 (↓100%)

Model is only <u>representative</u>.
<u>Includes no capacity expansion, etc.</u>

Results (draft)

7 GW Solar



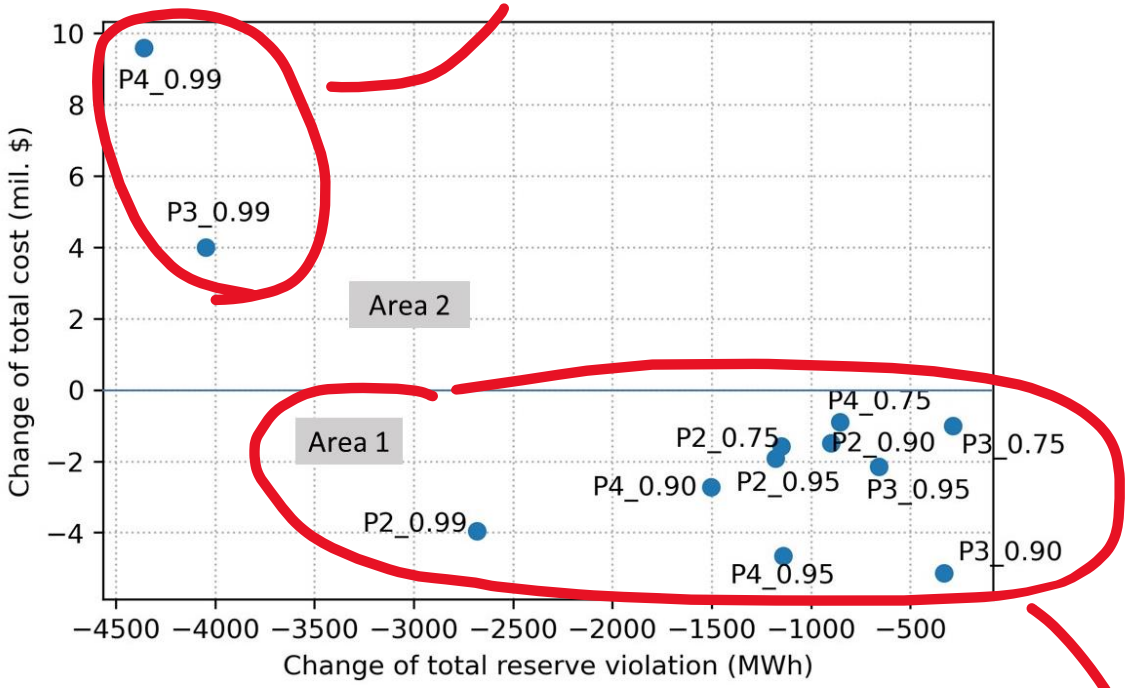
20 GW Solar

Results (draft)

P3 & P4:
- **Help violations most**
- **About equal**

7 GW Solar

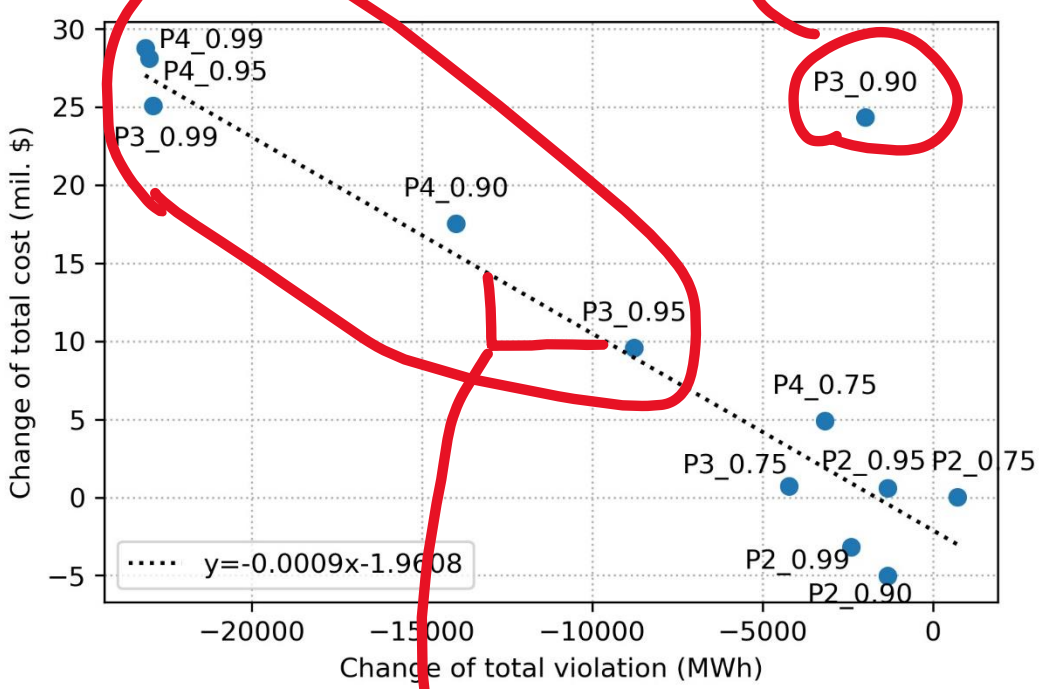
Extreme conditions



Normal conditions

20 GW Solar

Outlier?

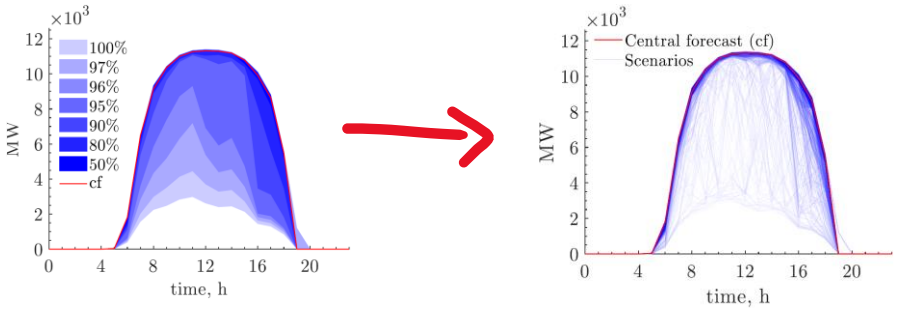


Slope = -$900/MWh

Reserve Determination Methods

- **D** – Deterministic Forecast (Baseline)
- Based on **Historical Observations**:
  - **P1** – All scenarios: Consider all possible conditions from observations
  - **P2** – Extreme scenarios: Consider only worst possible conditions
- Based on **Forecasted Conditions**:
  - **P3** – Bounds of Extreme Scenarios
  - **P4** – Prediction Interval

No synth scenarios



a) Probabilistic forecast

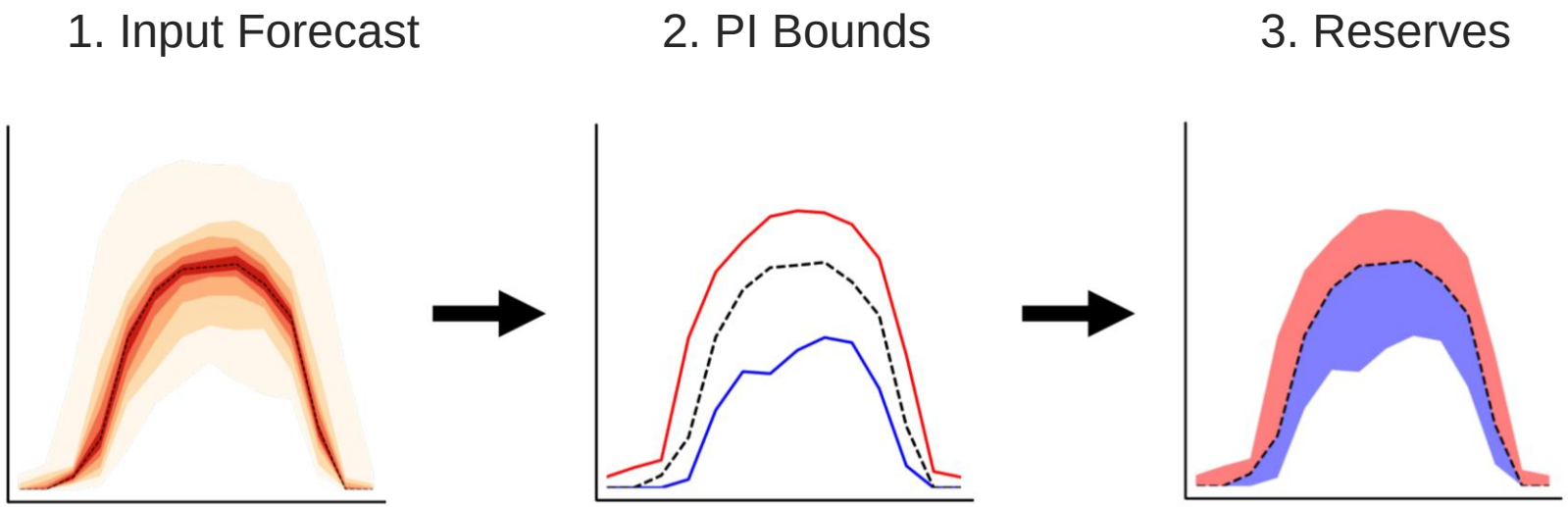
b) Probabilistic scenarios

(synthetic scenarios)

EPRI's DynaDOR tool

All P Methods: "Robustness" is selectable.
E.g., 0.99 covers 99% of scenarios or 99% f.cast confidence. 0.90 is lower, …

P4 – Prediction Interval method



1. Input probabilistic forecast, e.g., day ahead
2. Select prediction interval (PI), e.g., 90% (p5-p95)
3. Determine reserves from PI bounds and p50 forecast
    1. Upward reserves
    2. Downward reserves

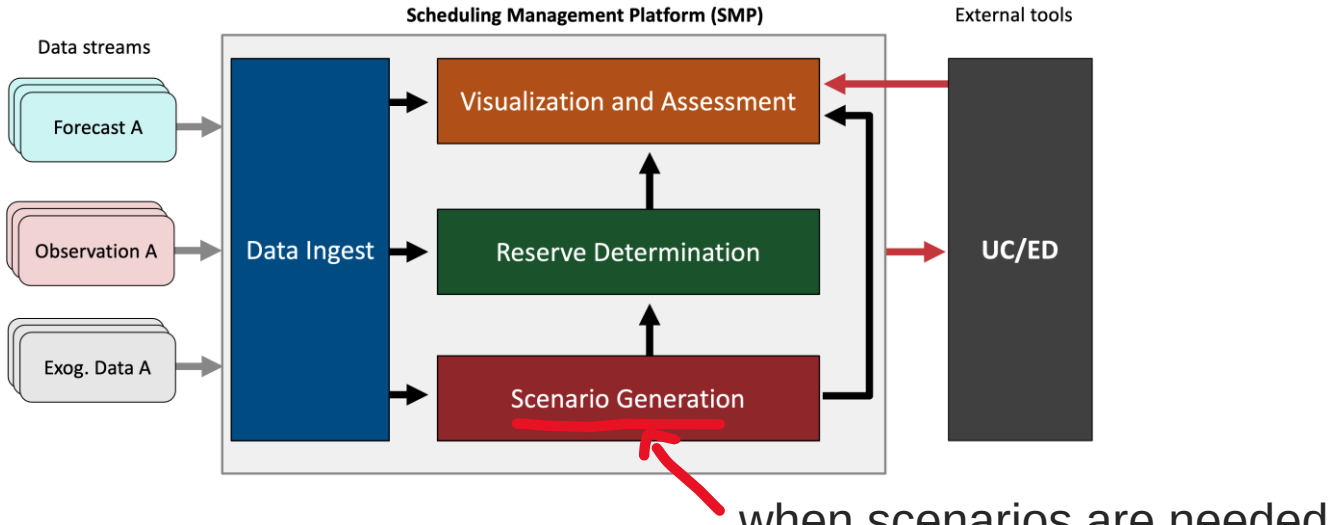
Scheduling Management Platform

(a.k.a., how we might apply this)

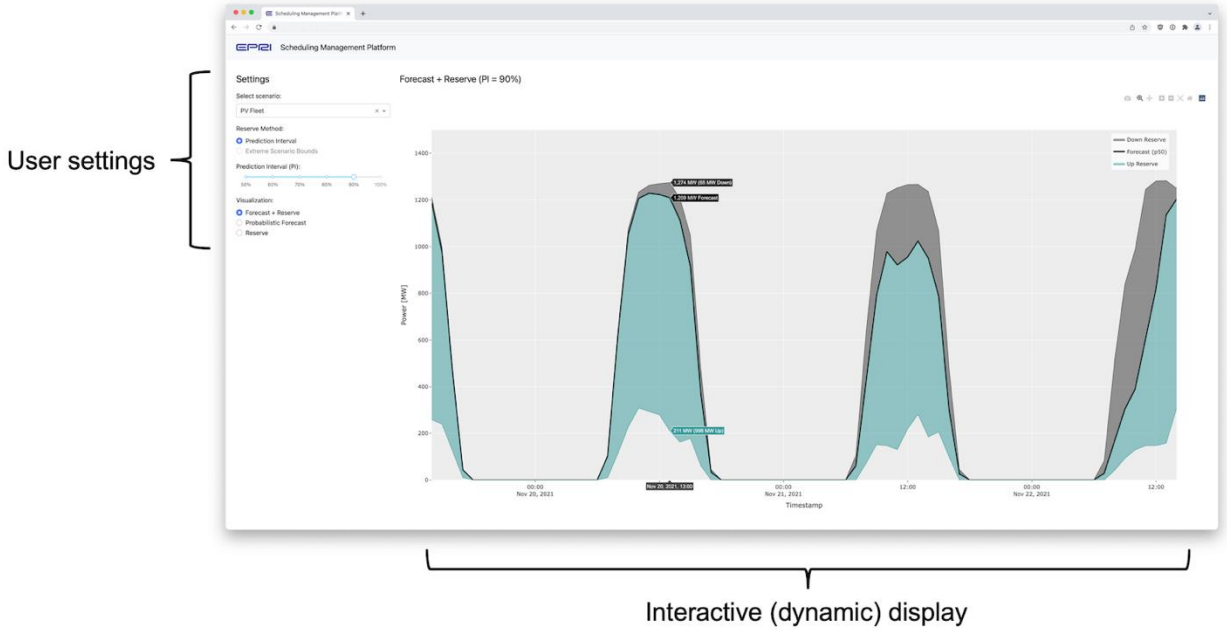
Southern Company

Scheduling Management Platform

- Integrate probabilistic forecasts and scheduling decisions
- Modular and customizable
- Will be open-source
- Browser-based interface




```python
def extreme_bound_reserves(fx, fx_prob, lower_bound, upper_bound,
                           reserve_type="intra-interval"):
    """Reserves based on probabilistic forecasts and extreme scenario bounds.

    Parameters
    ----------
    fx : (m, n)
        Probabilistic forecasts for m timestamps and n CDF intervals.
    lower_bound : (m,) array_like
        Lower bound on the extreme scenarios.
    upper_bound : (m,) array_like
        Upper bound on the extreme scenarios.
    reserve_type : {'intra-interval', 'uncertainty', 'inter-interval'}, optional
        The type of reserve:
        - 'intra-interval':
        - 'uncertainty':
        - 'inter-interval':

    Returns
    -------
    up, down : (m,) array_like
        The upward and downward reserves.

    Notes
    -----
    If 'reserve_type' is set as 'inter-interval', the outputs of this function
    are length 'm-1' (instead of length 'm') as inter-interval reserves
    correspond to ramping between sequential intervals. Also, the output of
    function is the same when the reserve type is set as intra-interval or
    uncertainty.

    See Also
    --------
    :py:func:`smp.scenarios.generate_extreme_bounds`

    """

    # find the MW for the central forecast (CF)
    fx_interp = interp1d(fx_prob, fx, kind="linear", axis=1)
    cf = fx_interp(0.50)

    # force small values (from numerical precision limitations) to zero
    cf[cf < 1e-1 * 100] = 0.0

    if reserve_type == "inter-interval":
        # compute ramps for each reserve requirement
        up = np.maximum(cf[:-1] - lower_bound[1:], 0)
        down = np.maximum(upper_bound[1:] - cf[:-1], 0)
    elif reserve_type in ["intra-interval", "uncertainty"]:
        # compute reserve requirement
        up = cf - lower_bound
        down = upper_bound - cf
    else:
        raise KeyError(
            f"'{reserve_type}' does not match any of the supported reserve "
            "types {'intra-interval', 'uncertainty', 'inter-interval'}"
        )

    return up, down
```



Solar Forecast Arbiter

Evaluating forecasts (probabilistic or otherwise)

Southern Company

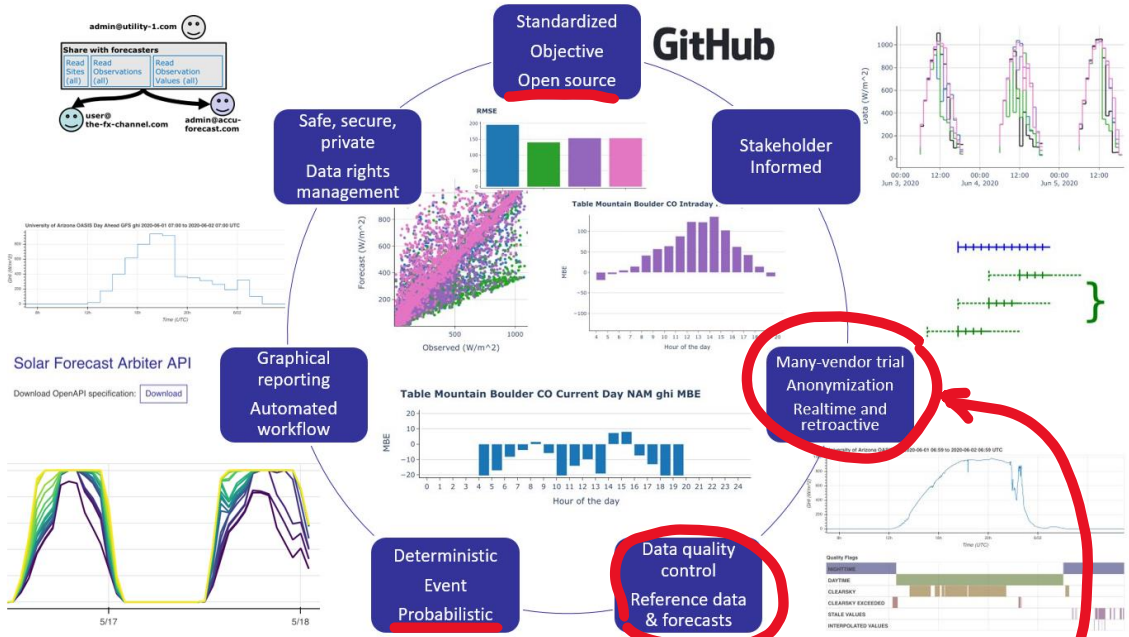
Solar Forecast Arbiter

A paradigm shift in forecast evaluation

- Originally DOE-funded, w/ University of Arizona, EPRI, Sandia, Sharply Focused
- **Open source, standardized, easy trials, good reference forecasts**
- **Probabilistic f.cast evaluation**

At conclusion of DOE work:

- Transitioning to EPRI
- Maintained by working group
- Becoming “Forecast Arbiter” (more emphasis on wind, load, net load)



We plan to join

We plan to run a trial this year

Forecast Arbiter Working Group

- Contact David Larson (dlarson@epri.com) or Aidan Tuohy (atuohy@epri.com) for more info
- Aims to start mid-2022 and will include:
  - annual meetings,
  - updates on performance, and
  - support in benchmarks and use

Flexible Solar

Another tool in the toolbelt

Southern Company

Flexible Solar Study

- Published in JPV
- Used PSO model from OPTSUN
  - deterministic forecasts
  - **5-min** intervals
- Solar: 2, 7, and 20 GW
- **Solar Control Scenarios:**
  - Must-Take
  - Curtailable (limited control)
  - Flexible (economic dispatch, reserves)
- **Results for flexible vs. curtailable:**
  - Similar reduction in violations
  - Reduced cost (~$13M/yr, or 0.5% of total production cost)
  - Cut solar curtailments by about 1/2 (10% → 6% for 20GW)

152 IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 12, NO. 1, JANUARY 2022

Evaluating Potential Benefits of Flexible Solar Power Generation in the Southern Company System

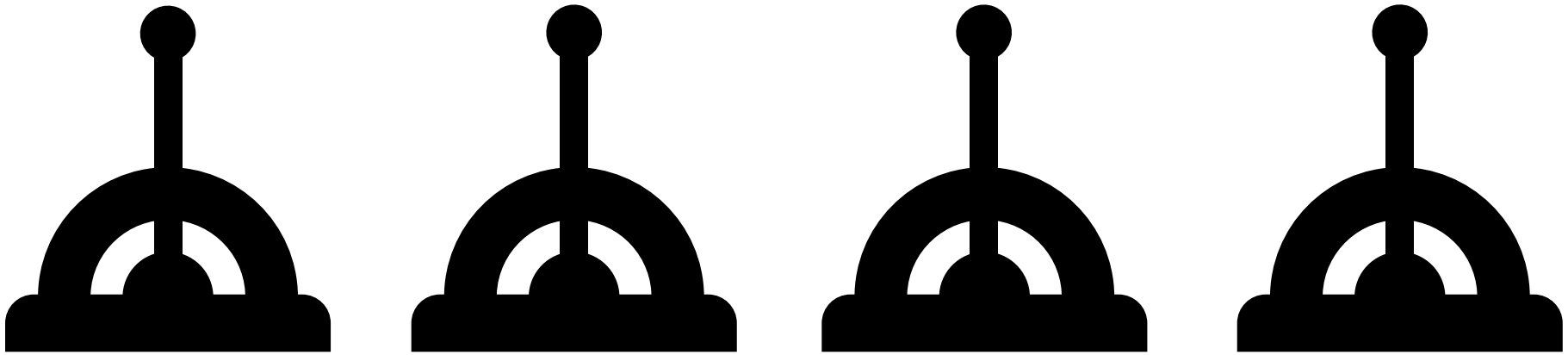
Qin Wang, *Senior Member, IEEE*, William B. Hobbs, *Member, IEEE*, Aidan Tuohy, *Senior Member, IEEE*, Mobolaji Bello, *Senior Member, IEEE*, and David J. Ault

(https://doi.org/10.1109/JPHOTOV.2021.3126118)

Future work:
Storage sensitivity study?
- Adding 4hr ES at 20% of PV (1.4, 4 GW) closed gap between curtailable and flexible
- How much ES is flexible solar "worth"?

Probabilistic Forecasts?

4 (+) levers:



Probabilistic Information

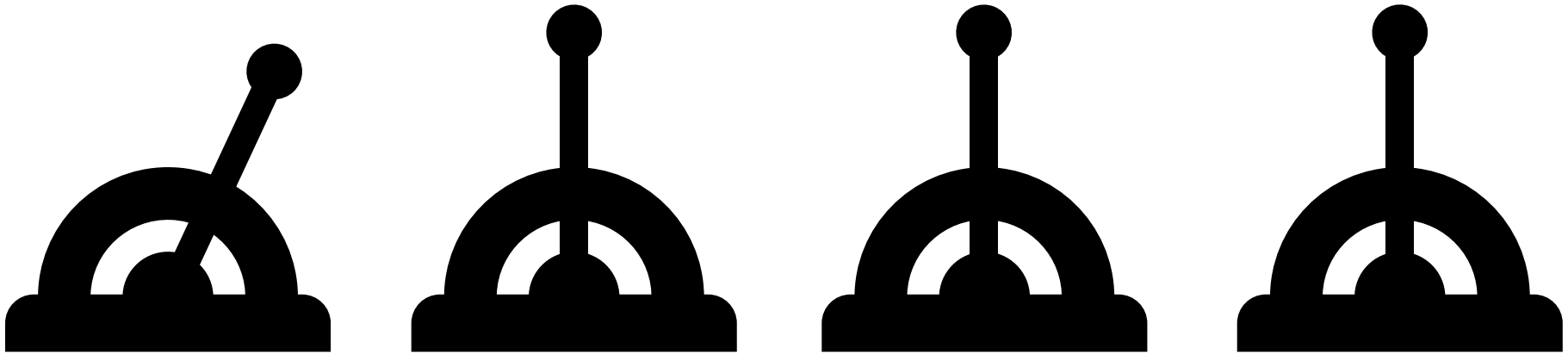
Forecast Accuracy

Renewable Flexibility

Storage (Fleet flexibility)

4 (+) levers:

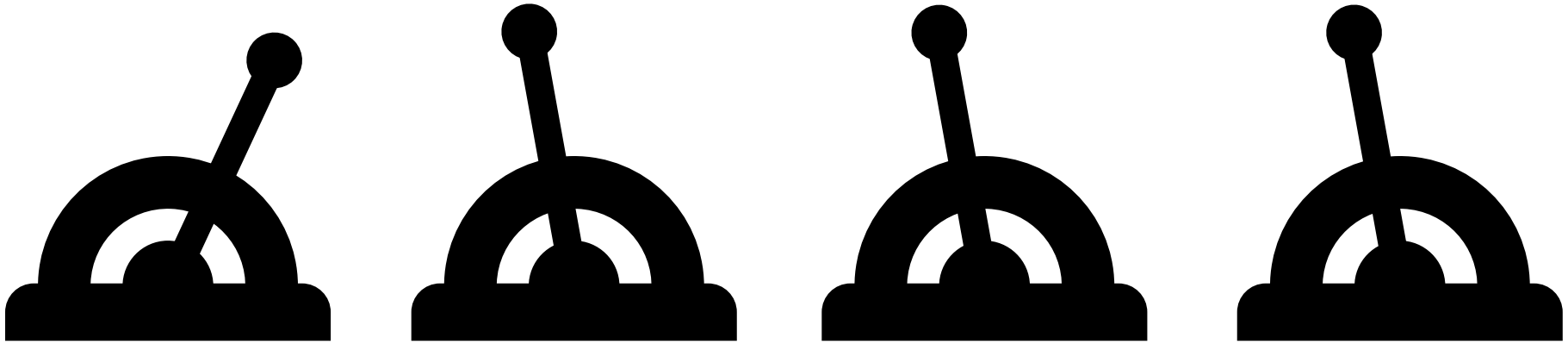
- Improvements in any one…



Probabilistic Information | **Forecast Accuracy** | **Renewable Flexibility** | **Storage (Fleet flexibility)**

4 (+) levers:

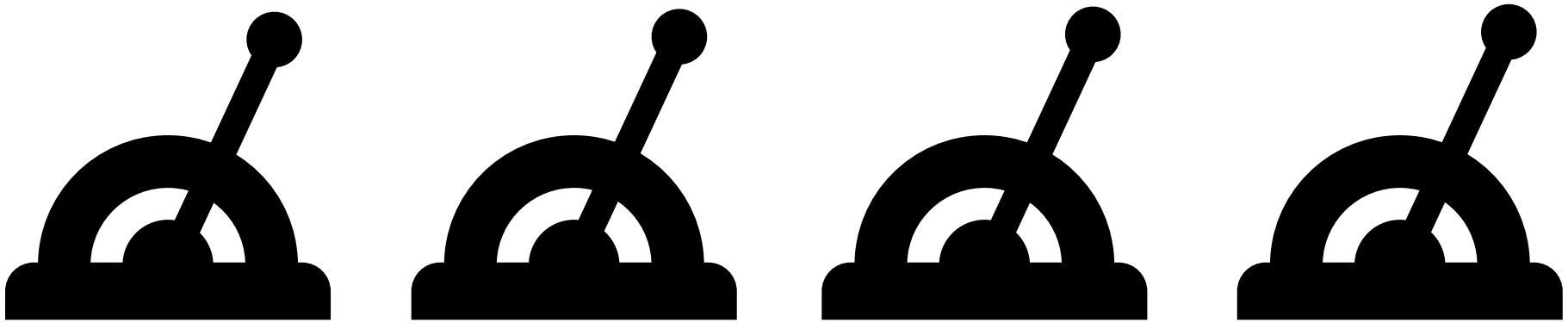
- Improvements in any one… could mean less need for others



Probabilistic Information | **Forecast Accuracy** | **Renewable Flexibility** | **Storage (Fleet flexibility)**

4 (+) levers:

- Improvements in any one… could mean less need for others
- Improvements in all could reduce cost and increase reliability
- (flexible load, others?)



Probabilistic Information | **Forecast Accuracy** | **Renewable Flexibility** | **Storage (Fleet flexibility)**

Understanding how to “actuate” these levers and what their impact will be is key to the future of the grid

Thanks for your time!

Questions: whobbs@southernco.com