

# GRACE

a grid that is risk aware for clean electricity

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Duke University

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Denver, CO, June 15, 2023

# PERFORM

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## Performance-based Energy Resource Feedback, Optimization, and Risk Management

• Grid

PRINT

Our group received 3 years of funding (\$ 2.5 M)

We are beginning year 3

\* Status:

Active

### Contact

👤 Program Director:

Dr. Joseph King

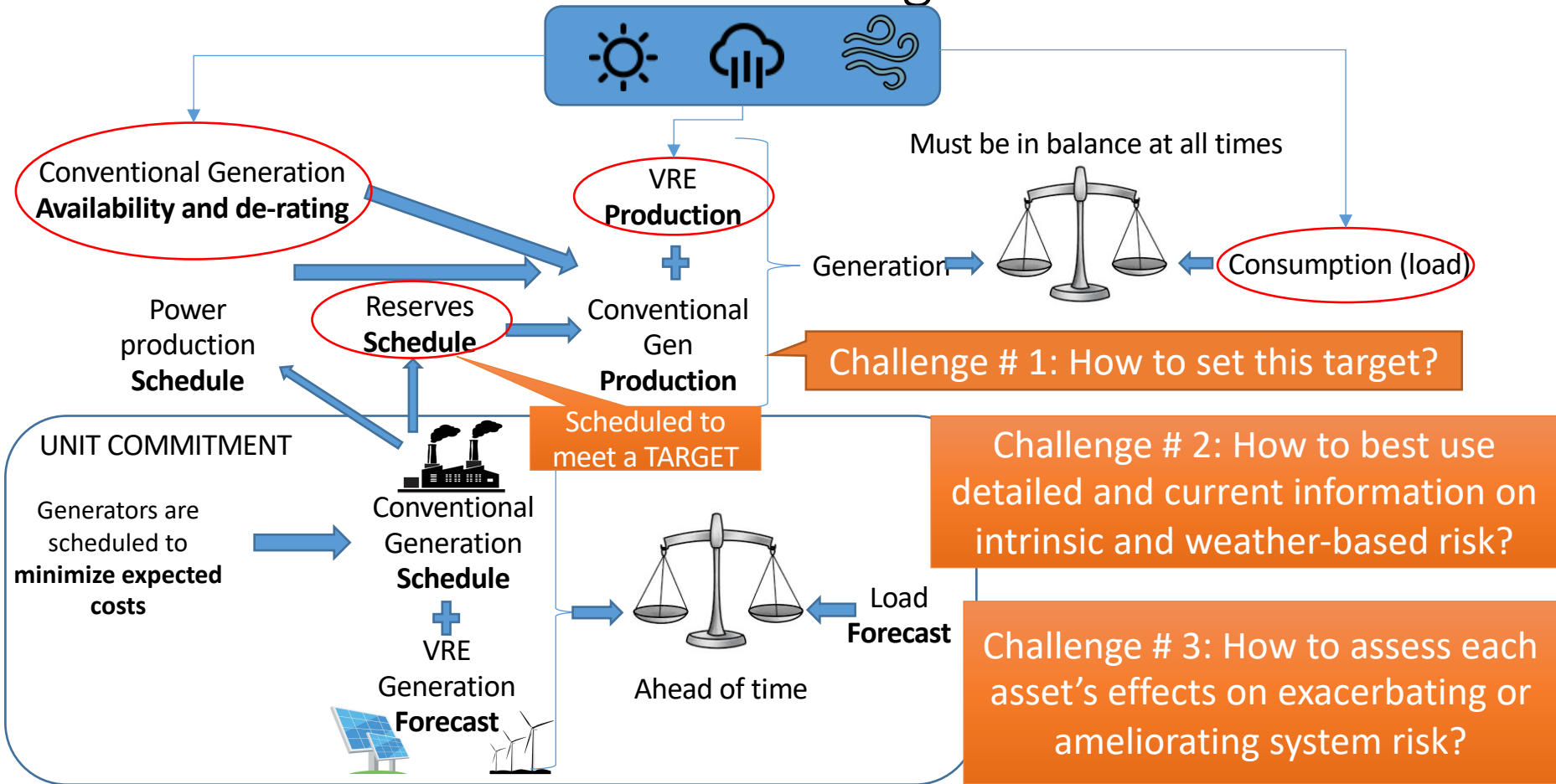
✉ Press and General Inquiries Email:

ARPA-E-Comms@hq.doe.gov

### Project Listing

- Boston University (BU) - A New Risk Assessment and Management Paradigm (NewRAMP) in Electricity Markets
- Castalune - Predicting Events to Enable Robust Renewable Grids
- Columbia University - Risk-Aware Power System Control, Dispatch and Market Incentives
- Duke University - Grid that's Risk-Aware for Clean Electricity - GRACE
- E3 - Deploying E3's RESERVE Tool to Enable Advanced Operation of Clean Grids
- Energy Trading Analytics - Stochastic Market Auction Redesigned Trading System (SMARTS)
- Georgia Tech Research Corporation - Risk-Aware Market Clearing for Power Systems (RAMC)
- Lehigh University - Application of Banking Scoring and Rating for Coherent Risk Measures in Electricity Systems
- National Renewable Energy Laboratory (NREL) - An Integrated Paradigm for the Management of Delivery Risk in Electricity Markets: From Batteries to Insurance and Beyond
- Princeton University - Stochastic Models, Indices & Optimization Algorithms for Pricing & Hedging Reliability Risks in Modern Power Grids
- Rensselaer Polytechnic Institute (RPI) - Risk segmentation and Portfolio Analysis for Pareto Dominance in High Renewable Penetration and Storage Reserves
- Tabors Caramanis Rudkevich (TCR) - Stochastic Nodal Adequacy Platform (SNAP)

# Three Challenges





a grid that is risk aware for clean electricity

## Objective

To develop a scheduling & dispatch approach that effectively considers the risk posed by weather-based and intrinsic uncertainty, and is computationally tractable so it can be implemented now.

GRACE will

- minimize operating **costs**,
- maintain or improve **reliability**,
- maintain or improve utilization of **low-carbon** resources
- quantify the impacts of grid resources on **system risk**

Duke  
UNIVERSITY



THE OHIO STATE  
UNIVERSITY

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 GRACE

a grid that is risk aware for clean electricity

NC STATE  
UNIVERSITY



Pacific Northwest  
NATIONAL LABORATORY



DARTMOUTH

# Risk measures – Risk Scores



**James Smith**

- Distinguished Professor in Decision Science
- Tuck School of Business



DARTMOUTH

# Risk-adjusted stochastic UC model libraries & Integration of all modules



**Kyle Bradbury**

- Assistant Research Professor
- Electrical & Computer Engineering



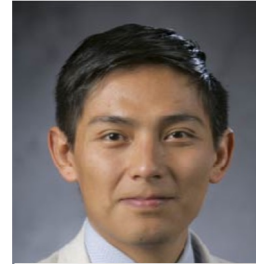
**David Brown**

- Profesvsor
- Fuqua School of Business



**Dimitrios Floros**

- Postdoctoral Fellow
- NSOE



**Mauricio Hernandez**

- Ph.D. Student
- NSOE



**Dalia Patino-Echeverri**

- Associate Professor
- NSOE



**Xiaodong Zhang**

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# Uncertainty Characterization



**Jordan Kern**

- Assistant Professor
- Department of Forestry and Environmental - Civil, Construction and Environmental Engineering and Operations Research



**Luis Prieto**

- Ph.D. Student
- Civil, Construction and Environmental Engineering



**Henry Ssembatya**

- Ph.D. Student
- Forestry and Environmental Resources

# Stochastic Model



THE OHIO STATE  
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## Antonio Conejo

- Professor
- Integrated Systems Engineering and Electrical and Computer Engineering



## Gonzalo Constante

- Ph.D. Student
- Electrical and Computer Engineering



## Xuan Liu

- Ph.D. Student
- Electrical and Computer Engineering

# Uncertainty Characterization



**Veronica Adetola**

- Chief Research Scientist in the Electricity Infrastructure and Buildings Division



**Arnab Bhattacharya**

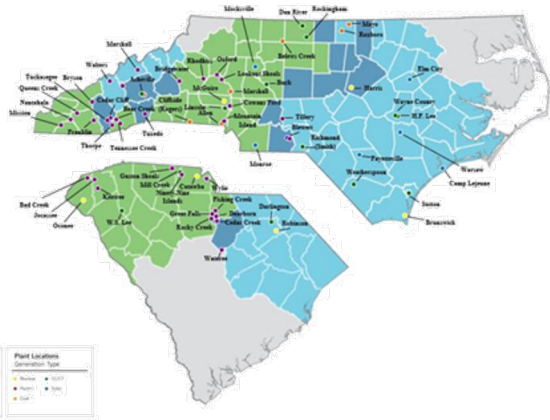
- Operations Research Scientist



**Wei Wang**

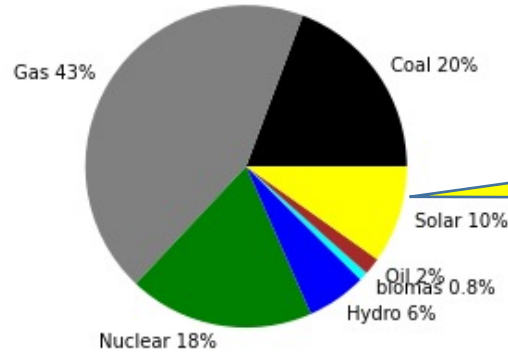
- Postdoctoral Fellow

# Industry Partner :



Duke Energy Carolinas + Duke Energy Progress East + Duke Energy Progress

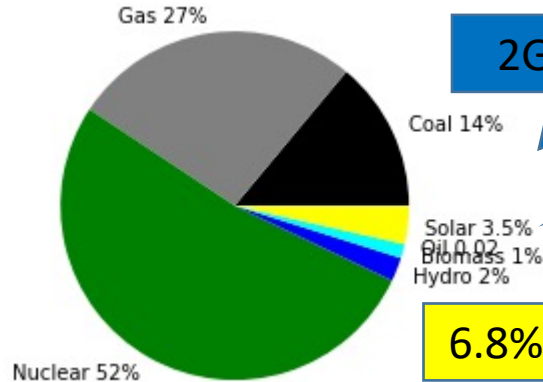
Capacity: DEC+DEP in 2020 = 62.6 GW (eGRID 2020)



6 GW

6.6% of US Solar Capacity

Generation: DEC+DEP in 2020 = 171 TWh (eGRID 2020)

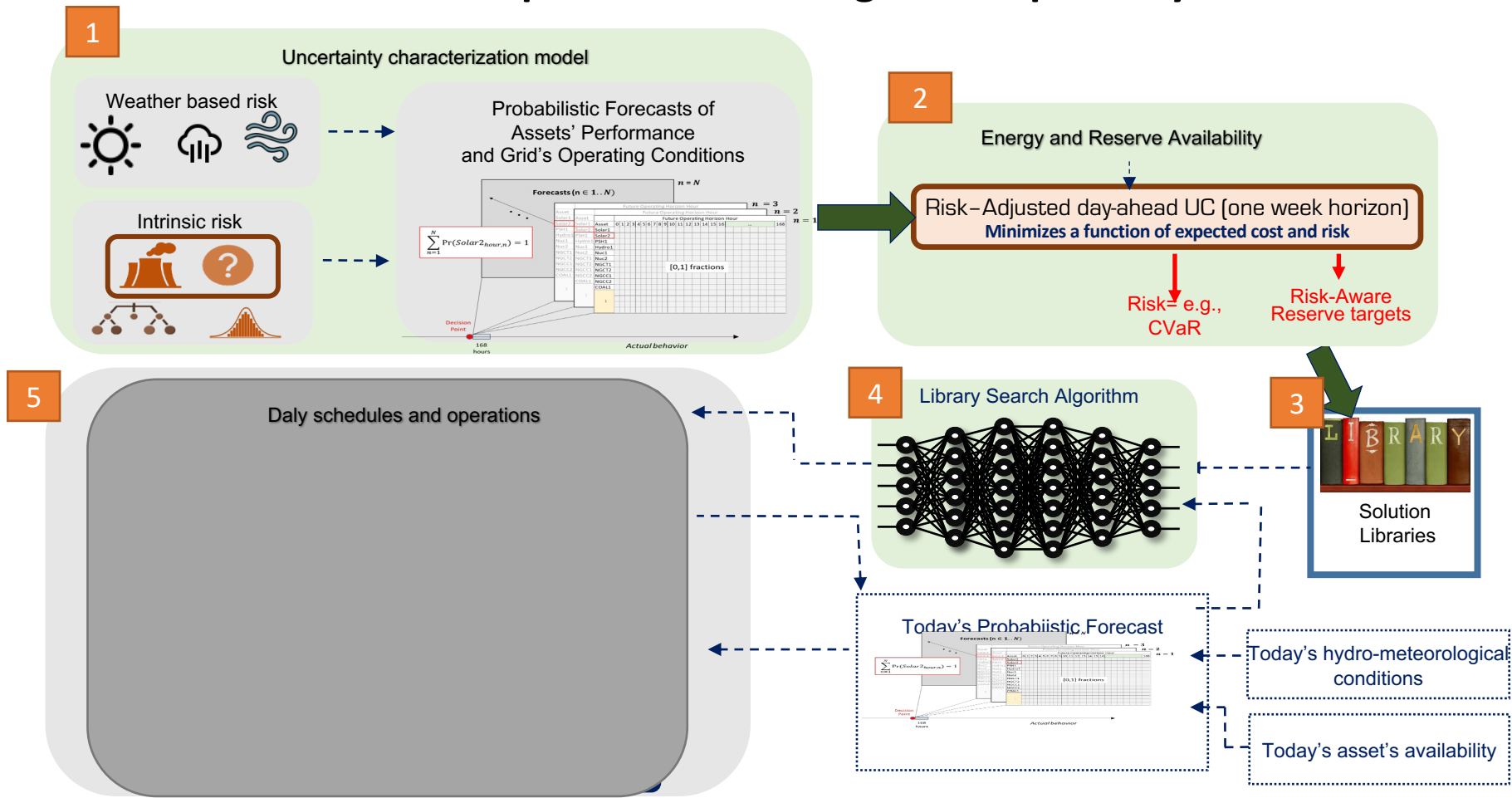


2GW or Pumped Hydro ES

6 TWh

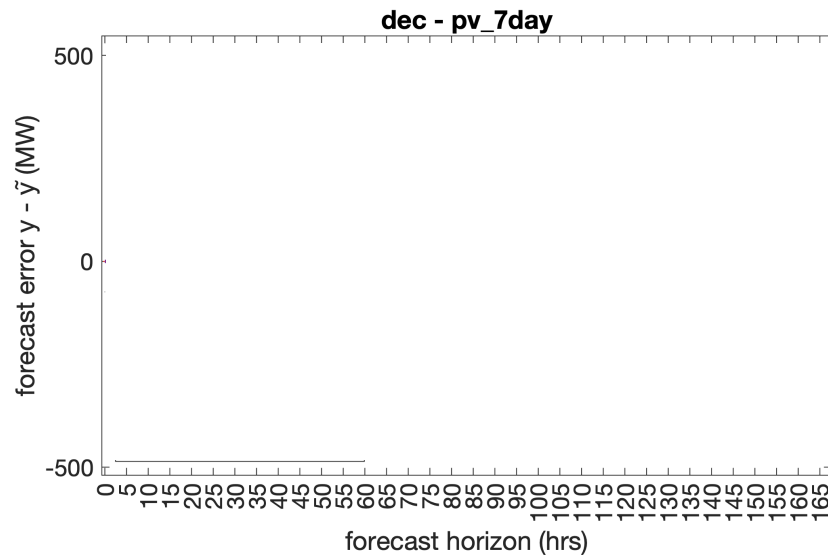
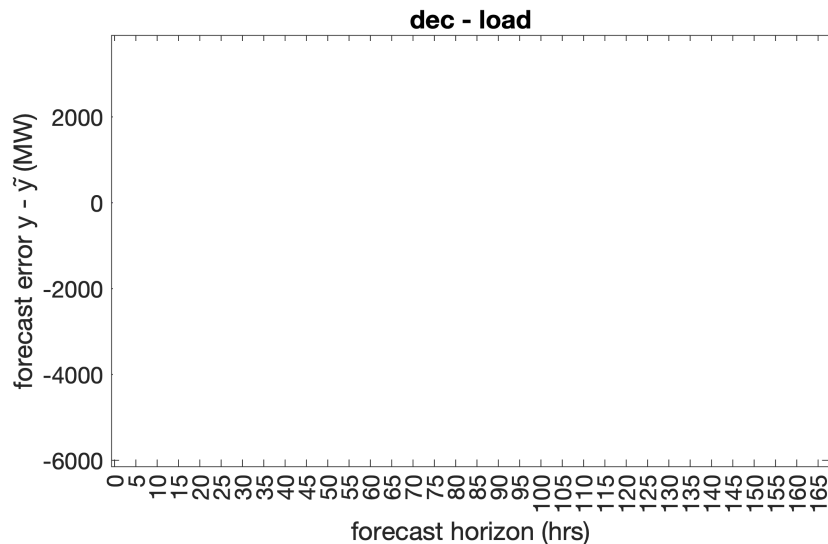
6.8% of US Solar Generation

# GRACE's Improved Scheduling and Dispatch System



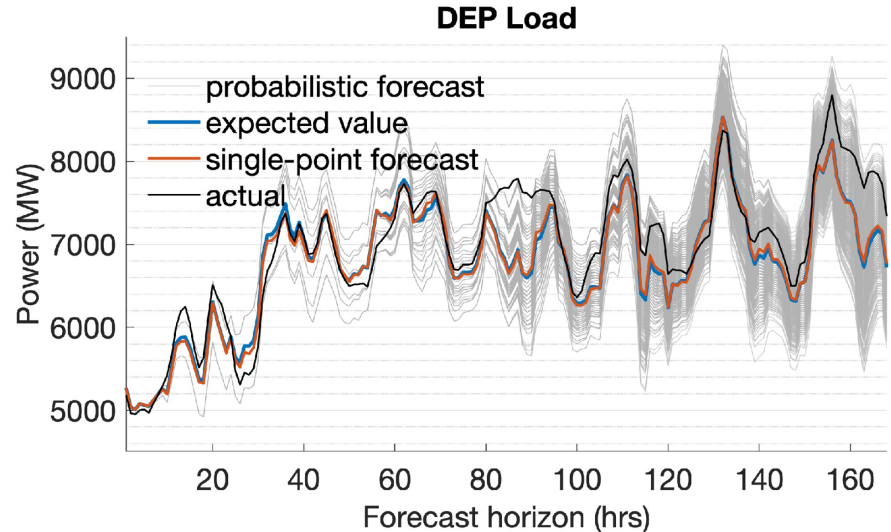
# Uncertainty Characterization

## Forecast errors of load and solar



# Probabilistic forecasts

- 3 components to investigate the GRACE benefits
  - Actual time series (observations)
  - Single-point (deterministic) forecast
  - Probabilistic forecast
- $E[\text{Probabilistic}] = \text{deterministic}$
- Actual can be historical or synthetic



The DEP load for the first 7 days of 2019

# Generation of probabilistic forecasts

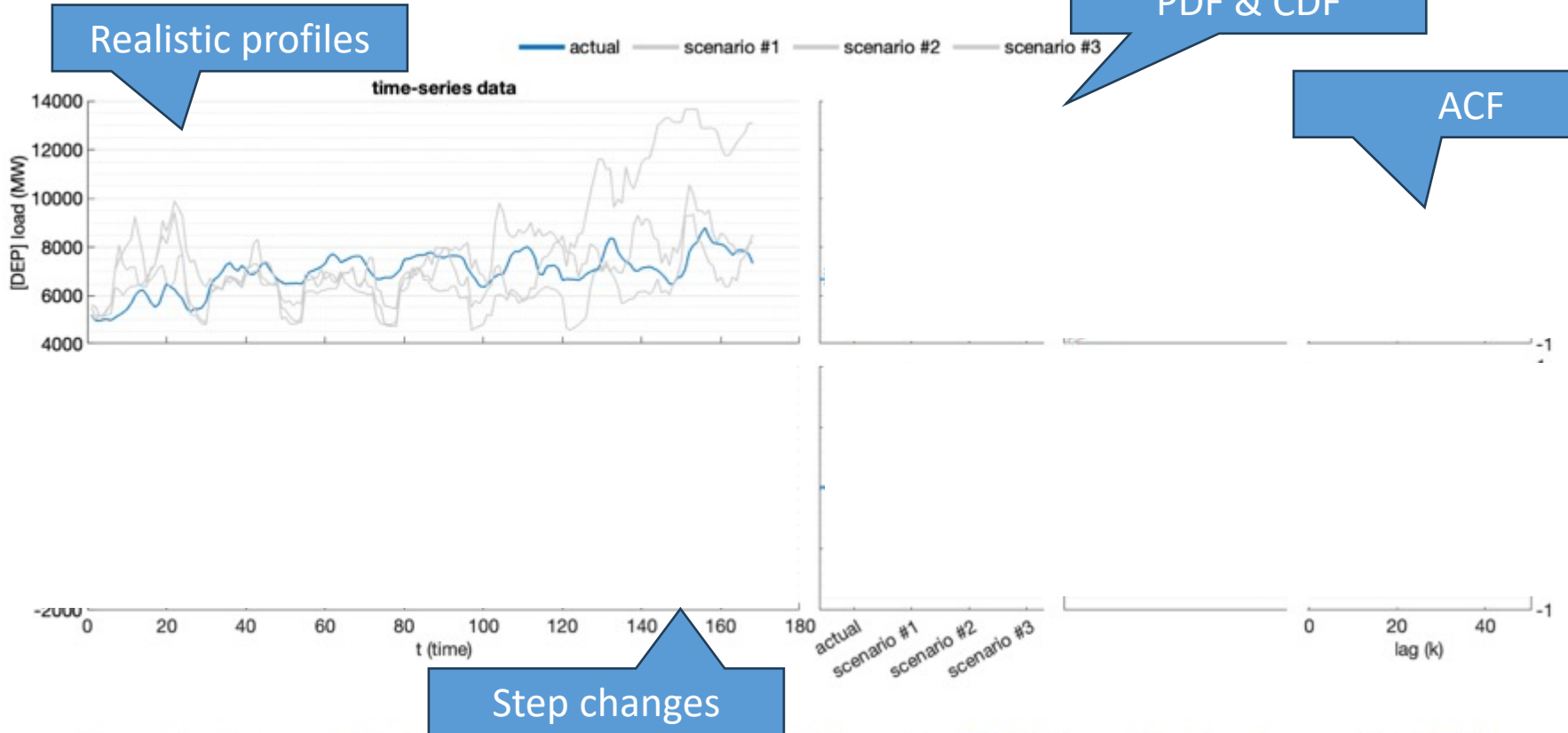
## **Methods**

- Historical sampling
- Monte-Carlo approaches
- Lattice scenarios (baseline)

## **Quality assessment**

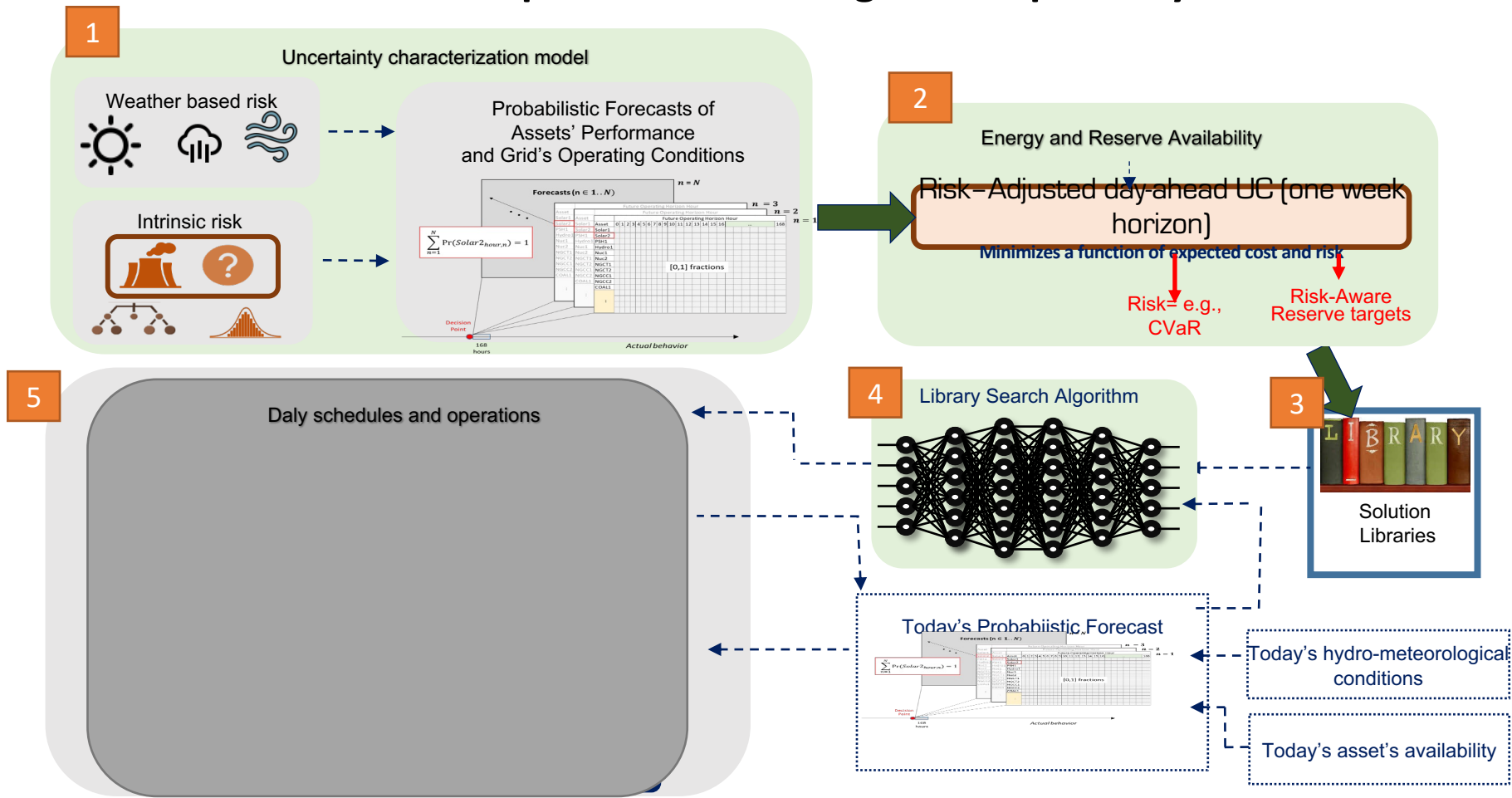
- Are the scenarios realistic?
- How do the different methods compare in realism and forecast accuracy?

# Quality assessment of synthetic data



Comparison between historical observation and probabilistic forecasts of DEP demand load on January 1st, 2019.

# GRACE's Improved Scheduling and Dispatch System



# Risk-adjusted stochastic UC model

Uncertainty characterization from

1

2

Energy and Reserve Availability

Risk-Adjusted day-ahead UC for 168 hours  
Minimizes a function of expected cost and risk

Expected Value of Cost

Risk-Aware Reserve Targets

Risk= e.g., CVaR

$\min_{\underline{x}}$

$(1 - \beta)$  Expected Cost +  $\beta$  CVaR of Cost:

$$(1 - \beta) \left[ \sum_{t \in T} \left( \sum_{j \in J^{\text{coal}} \cup J^{\text{gas}}} (c_j(p_j(t)) + c_j^U y_j(t) + c_j^D z_j(t)) + \sum_{j \in J^{\text{ng}}} c_j(p_j(t)) + \sum_{j \in J^{\text{w}}} c_j(p_j^{\text{w}}(t)) \right) + \sum_{\omega \in \Omega} \pi_{\omega} \sum_{t \in T} \left( \sum_{j \in J} (c_j^{\text{RU}} r_{j\omega}^{\text{U}}(t) - c_j^{\text{RD}} r_{j\omega}^{\text{D}}(t)) + \sum_{i \in \Lambda^{\text{D}}} c_i^{\text{LOL}} D_{i\omega}^{\text{shed}}(t) \right) \right] + \beta \left( \zeta + \frac{1}{1 - \alpha} \sum_{\omega \in \Omega} \pi_{\omega} \eta_{\omega} \right)$$

Optimization of conditional value-at-risk,  
Rockafellar & Uryasev, 2001

1<sup>st</sup> stage: No load, start-up and shut-down costs

2<sup>nd</sup> stage: start-up of peakers, production costs, cost of load shedding

**Minimize**

$(1 - \beta)$  Expected Cost +  $\beta$  CVaR of Cost

**Subject to:**

**First Stage:**

Start-up/shut-down logic  
Min up/down time  
Power generation limits  
Pumped-hydro storage constraints  
Production = Expected net demand

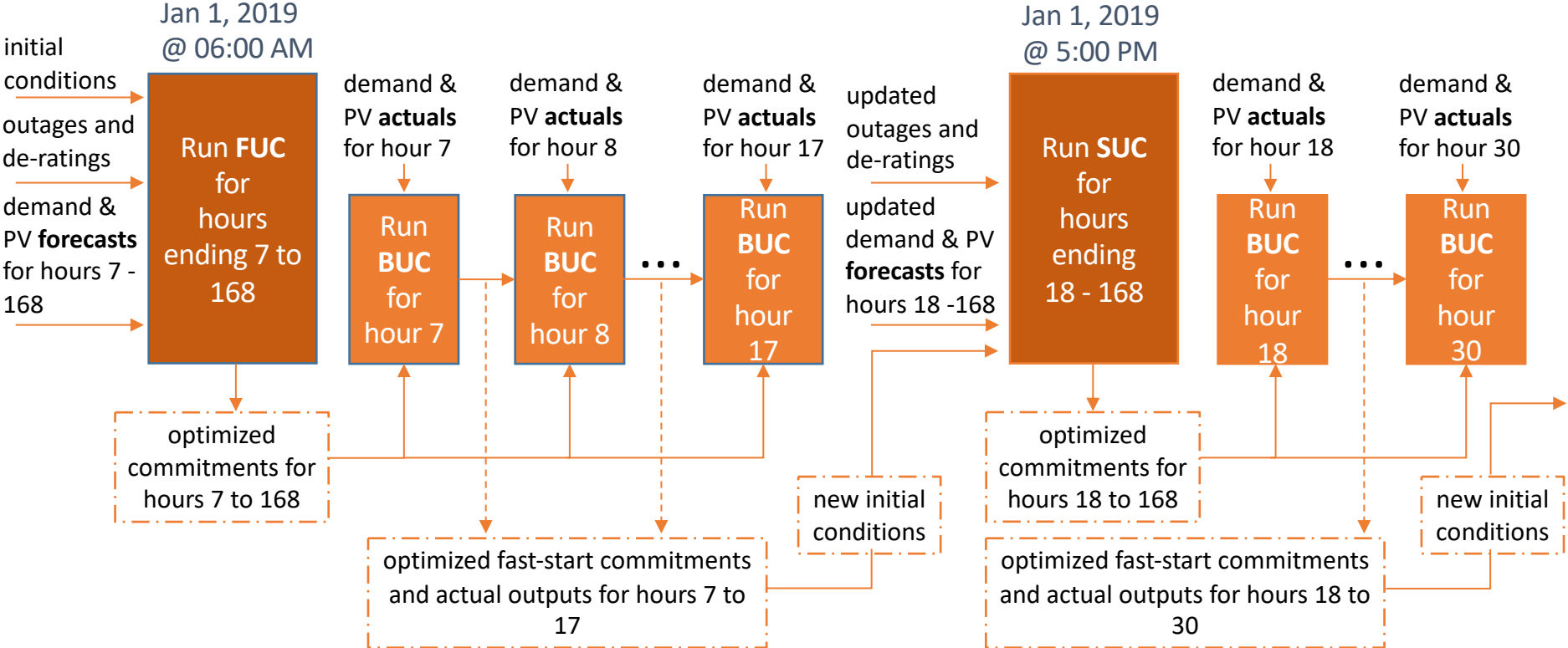
For all units and time periods

**Second Stage:**

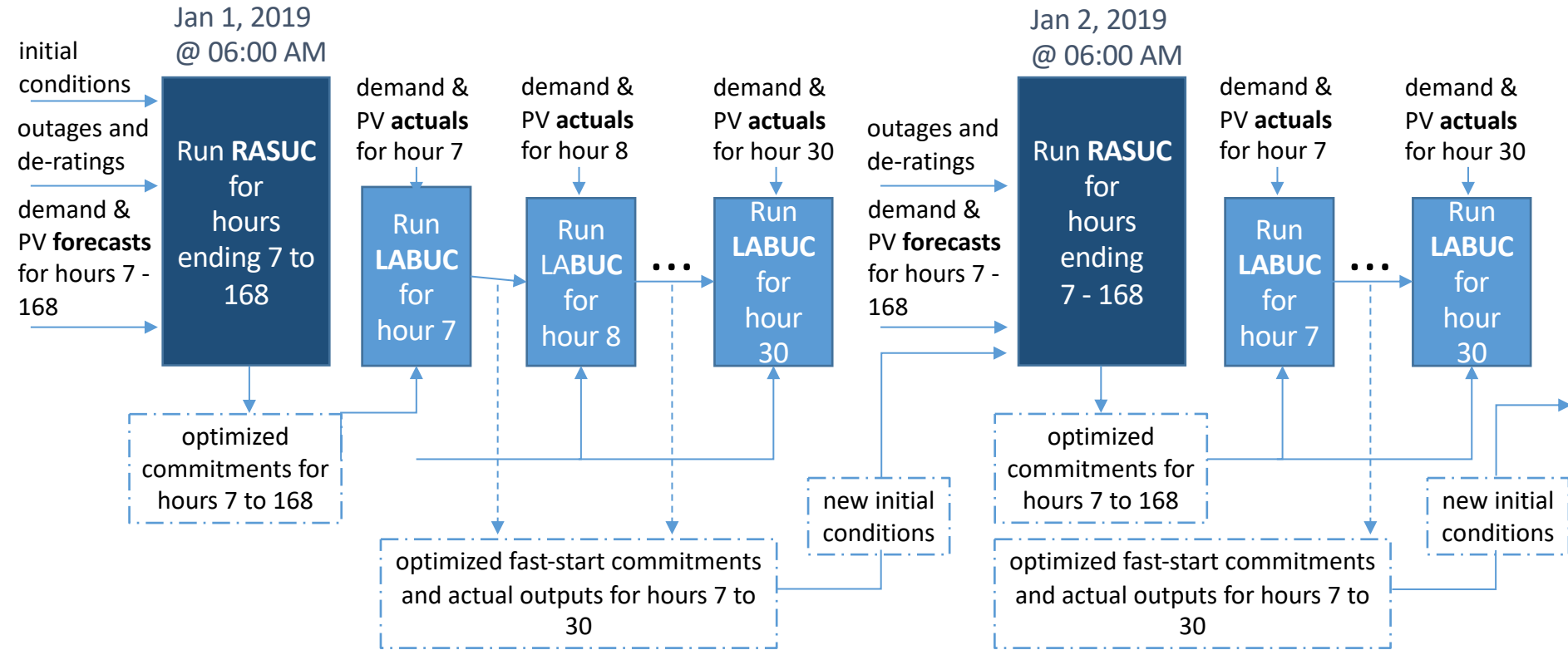
Ramping up/down limits  
Min / max generation limits  
power balance constraints per area  
transmission capacity limits  
VRE curtailment limits  
Unreserved demand limits  
(CVaR constraints)

For all scenarios and time periods

# Duke Energy's Energy Management System (CP-EMS)



# Overview of the RA-EMS

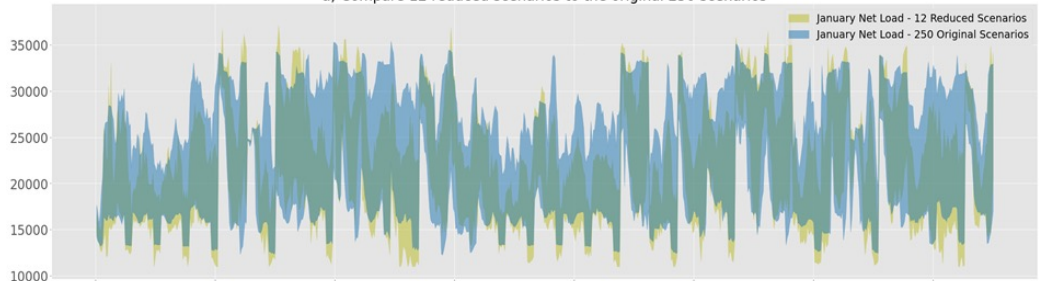


# Risk-adjusted stochastic UC model vs CP-deterministic

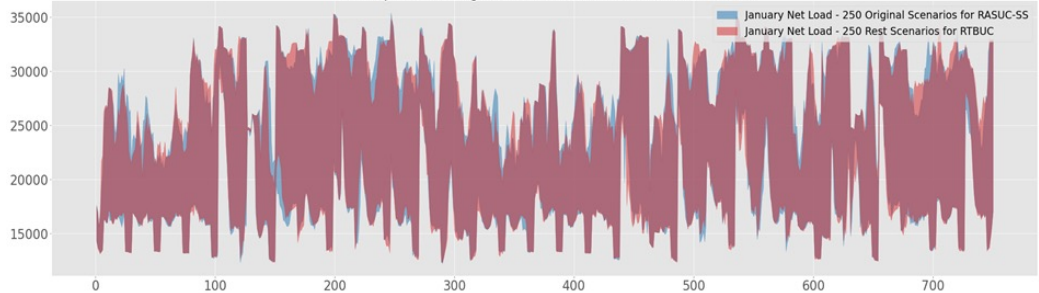
Probabilistic da- forecasts taken from 250 scenarios

Real time 250 actuals

a) Compare 12 reduced scenarios to the original 250 scenarios

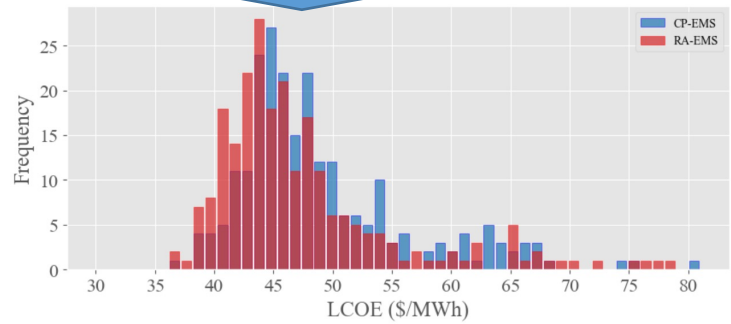


b) Compare 250 original scenarios to the rest 250 scenarios

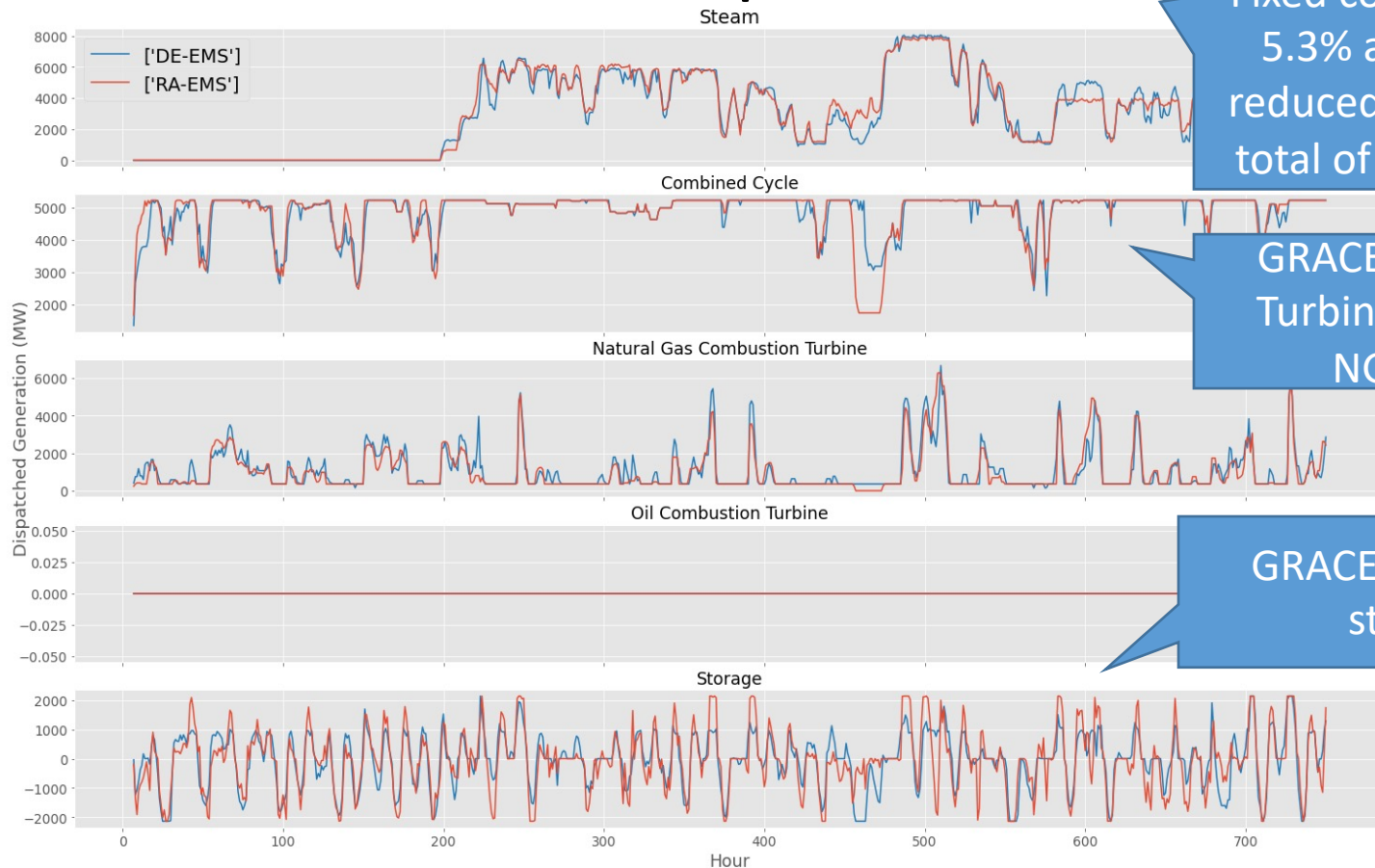


System costs are on average 2% lower than current practice for 2019 fleet

Cost reductions vary from 0% to 5%



# Differences in operations

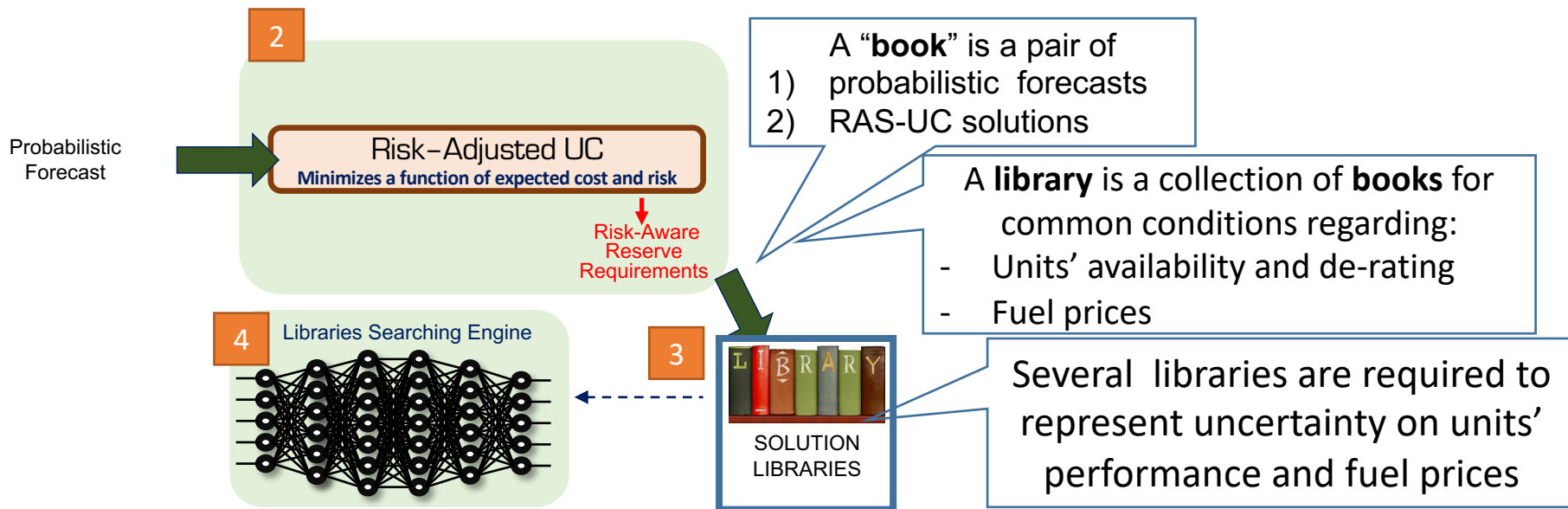


Fixed cost reduced by 5.3% and fuel cost reduced by 1.3% for a total of 2% reduction

GRACE uses Steam Turbines more and NGCTs less

GRACE uses more storage

# GRACE's Improved Energy Management System



## FOUR USES OF THE LIBRARIES & SEARCHING ENGINE

1. To select starting solutions for the RAS-UC
2. To identify scenarios to enforce in the first-stage
3. To identify binary variables to fix and constraints to relax
4. To avoid running the RAS-UC → Extracting Reserve Targets for CP-UC

# Learning from solutions libraries

Uncertainty  
characterization from

1

2

Energy and Reserve Availability

Risk-Adjusted Week-ahead UC  
Minimizes a function of expected cost and risk

Expected Value of Cost

Risk-Aware Reserve Targets

Risk= e.g., CVaR

1<sup>st</sup> stage: No load,  
start-up and shut-  
down costs

2<sup>nd</sup> stage: start-up of  
peakers, production costs,  
cost of load shedding

**Minimize**

$(1-\beta)\text{Expected Cost} + \beta\text{CVaR of Cost}$

**Subject to:**

**First Stage:**

Start-up/shut-down logic

Min up/down time

Pumped-hydro storage constraints

For all units  
and time  
periods

**Second Stage:**

Start-up/shut down peakers

Ramping up/down limits

Min / max generation limits

power balance constraints per area

transmission capacity limits

VRE curtailment limits

Unserved demand limits

(CVaR constraints)

For all  
scenarios  
and time  
periods

Number of  
scenarios in  
probabilistic  
forecast

Number of  
binary  
variables in  
RAS-UC

Number of  
total variables  
in RAS-UC

Number of  
constraints  
in RAS-UC

Exec.  
time  
(h)

12

92,565

868,876

2,626,473

0.18

20

146,965

1,403,428

4,252,305

0.47

25

180,965

1,737,523

5,268,450

0.92

50

350,965

3,407,998

10,349,175

2.82

Some binary variables are  
always 1 or zero

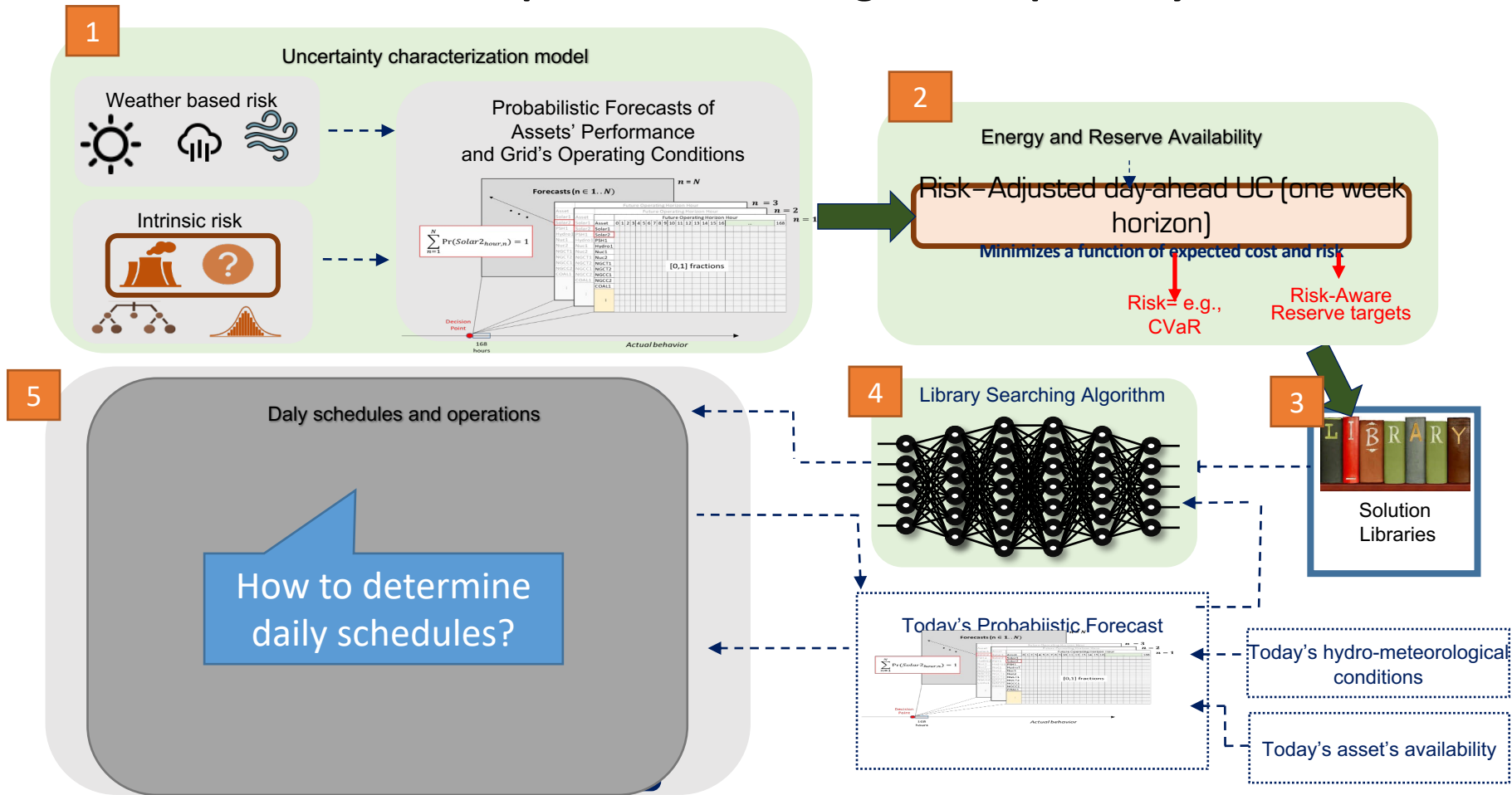
Some constraints are  
never binding

We could set the commitment  
variables of those power  
generators as inputs

Use ML to identify  
variables and  
constraints

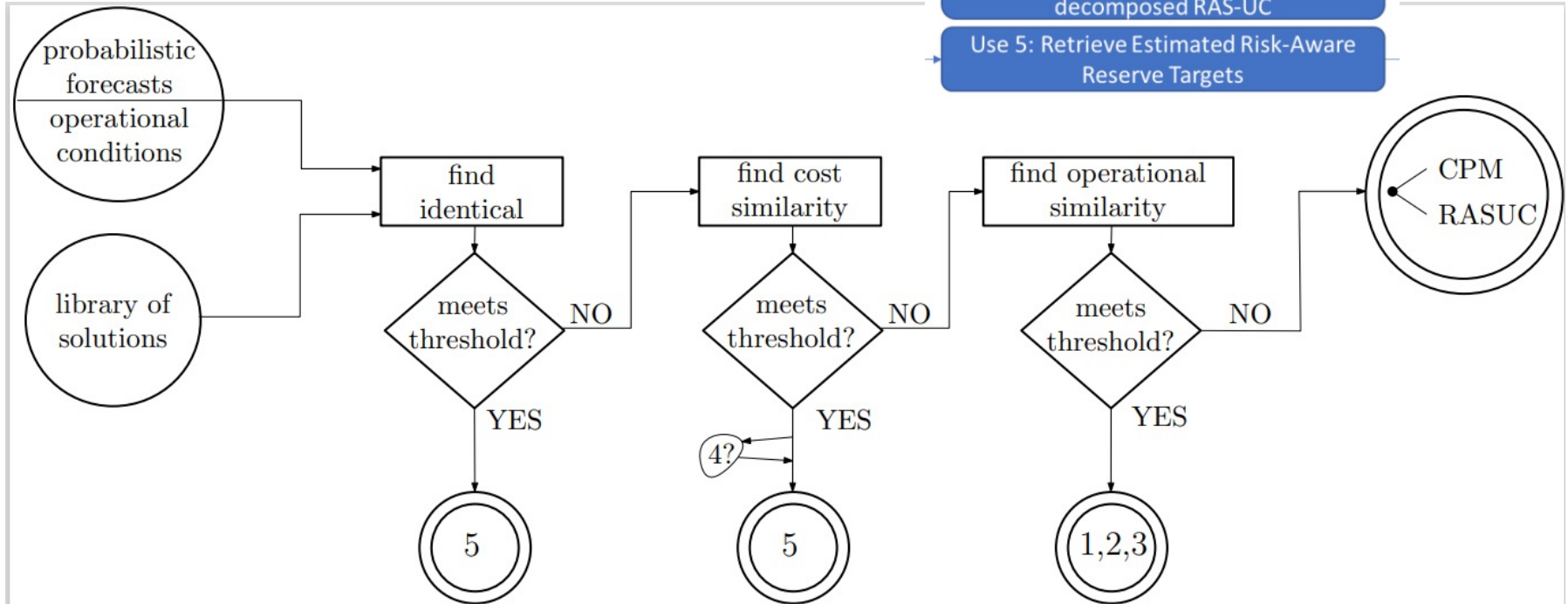
We could eliminate  
those constraints

# GRACE's Improved Scheduling and Dispatch System



# How to use the libraries?

- Use 1: Retrieve RAS-UC initial solution
- Use 2: Determine which RAS-UC binary variables can be eliminated
- Use 3: Determine which RAS-UC constraints can be eliminated
- Use 4: Determine which scenarios must be enforced in the first-stage of a decomposed RAS-UC
- Use 5: Retrieve Estimated Risk-Aware Reserve Targets



# Conclusions

- GRACE's approach is promising
  - A risk-adjusted stochastic unit commitment plus a look-ahead balancing UC reduce expected value of costs and increase reserves availability
  - We expect better results with the 2030 fleet
- The libraries search system is promising
  - More work needed to develop the four different uses of the libraries of solutions

Thank you!

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a grid that is risk aware for clean electricity

- We seek collaborators with access to
  - weather measurements & forecasts
  - power-plants operations

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