ICEBERG Interim Workshop
Scalable Optimization of Power Systems with Flexible Demand and Renewable Supply

June 13-14, Athens Greece

Market-Based Reserve Planning under Predominantly Uncertain Renewable Generation

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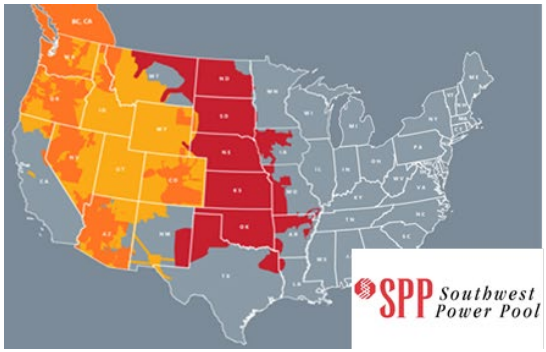
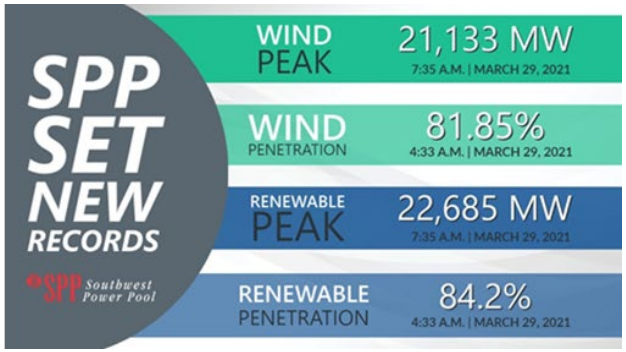
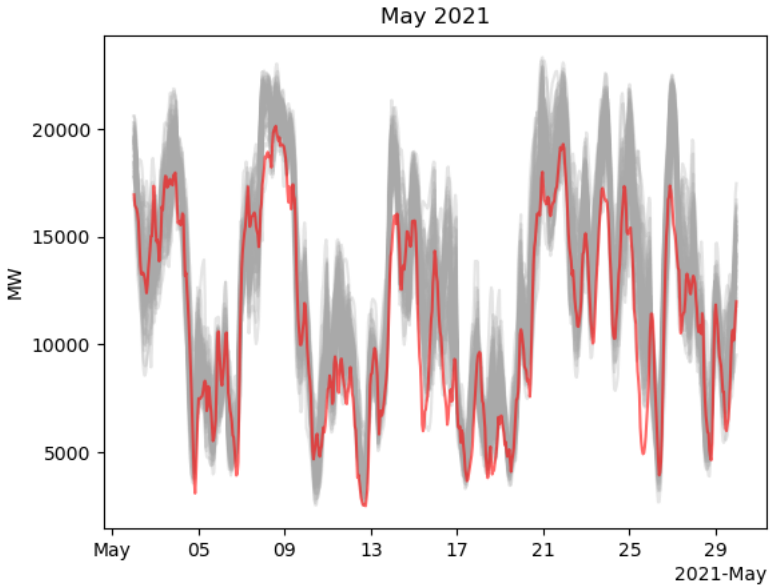
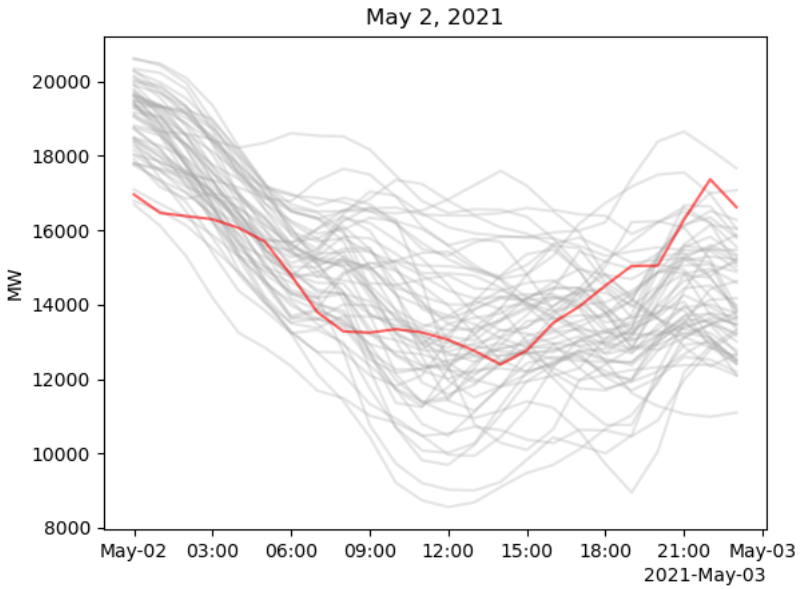
NewRAMP: A **New** **R**isk **A**ssessment and **M**anagement **P**aradigm in Electricity Markets

- SPP wind forecasts
  - received from two vendors









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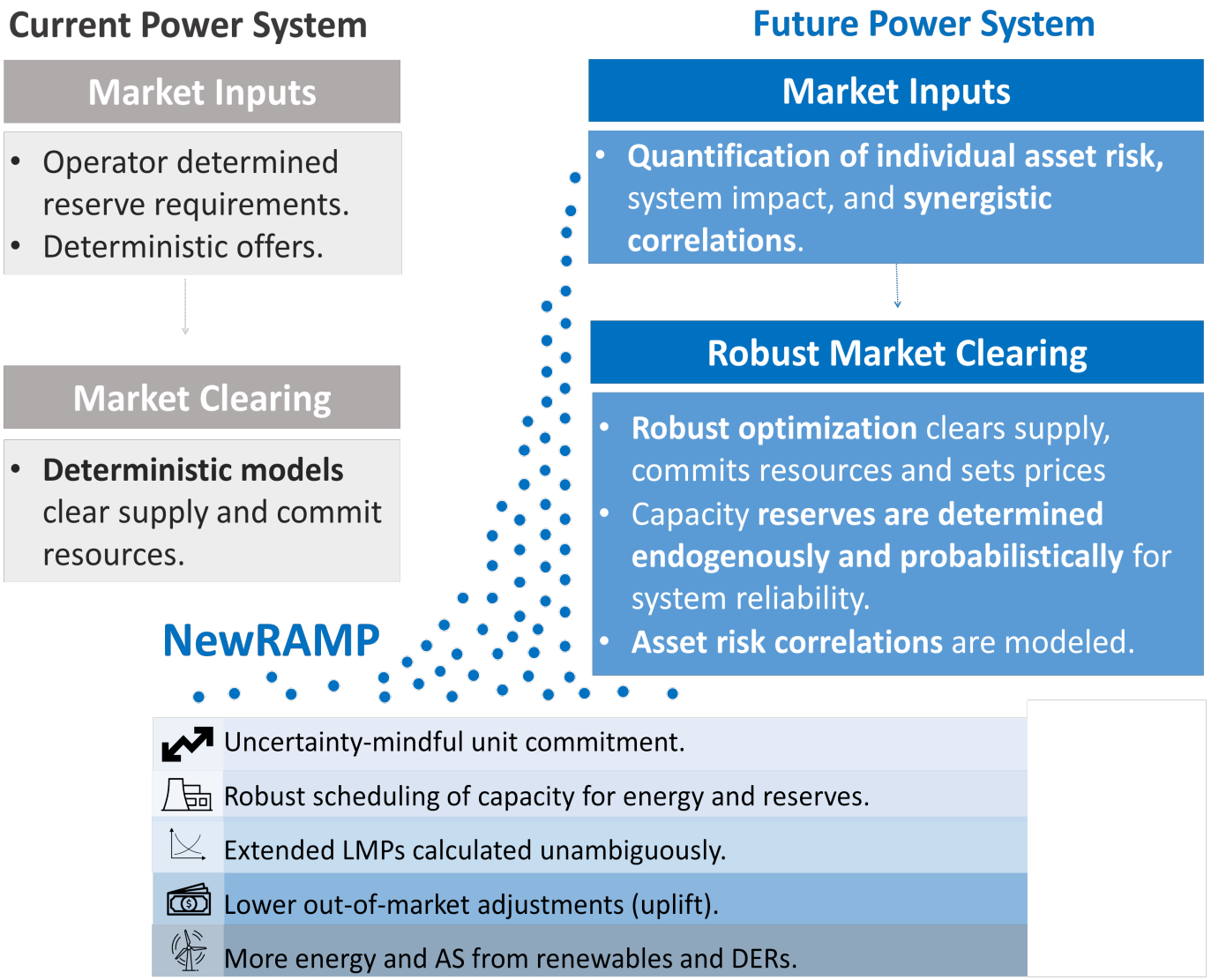
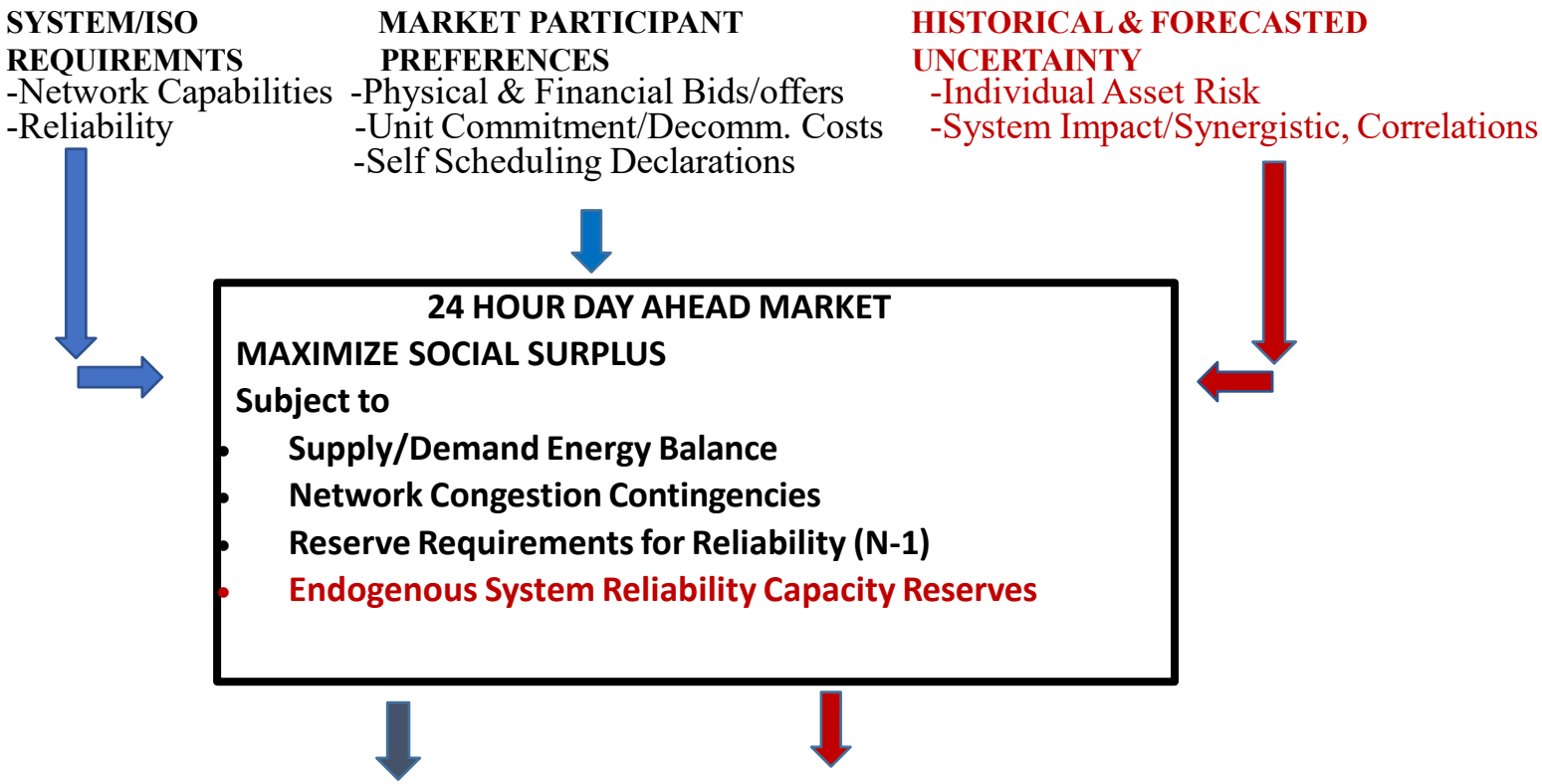
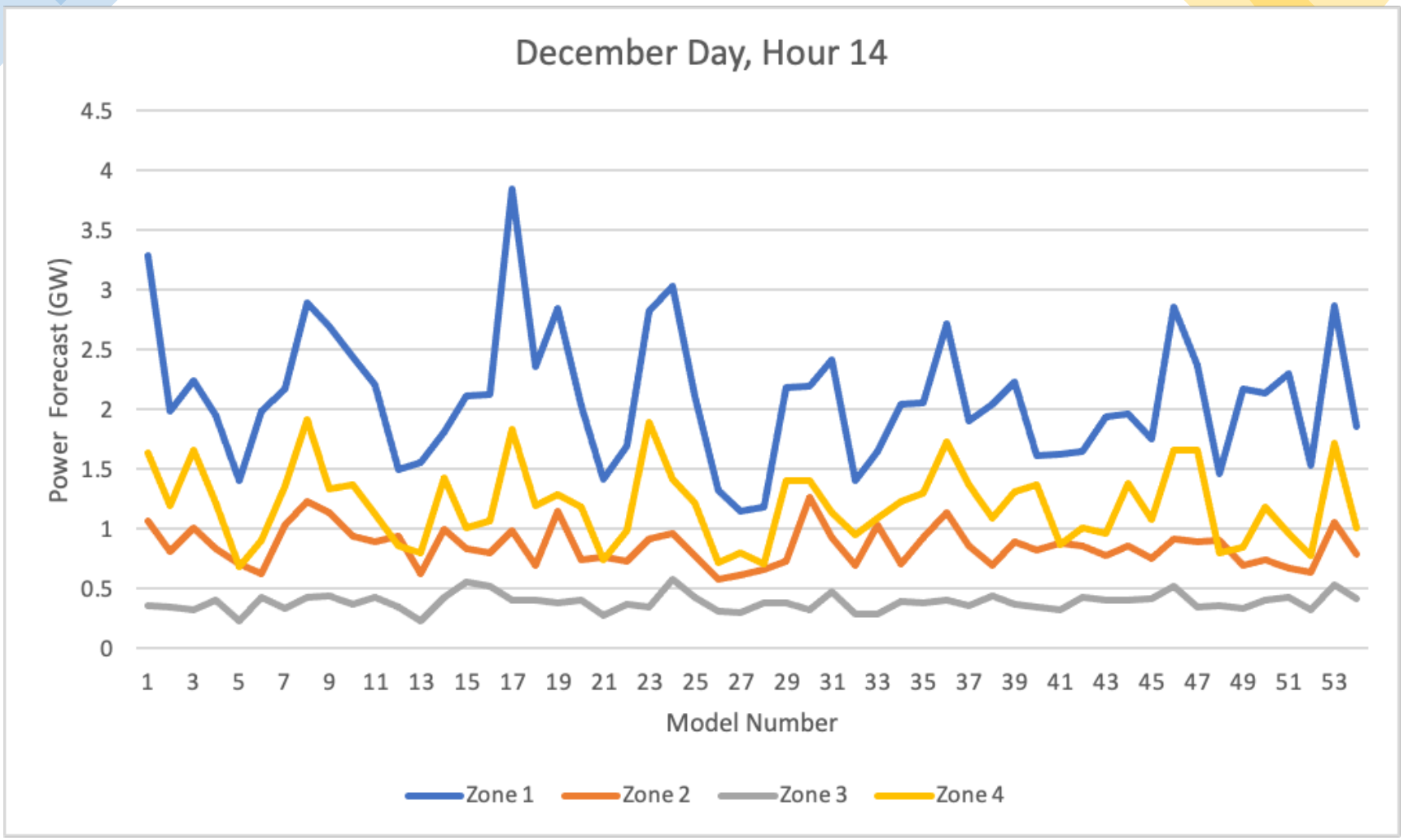
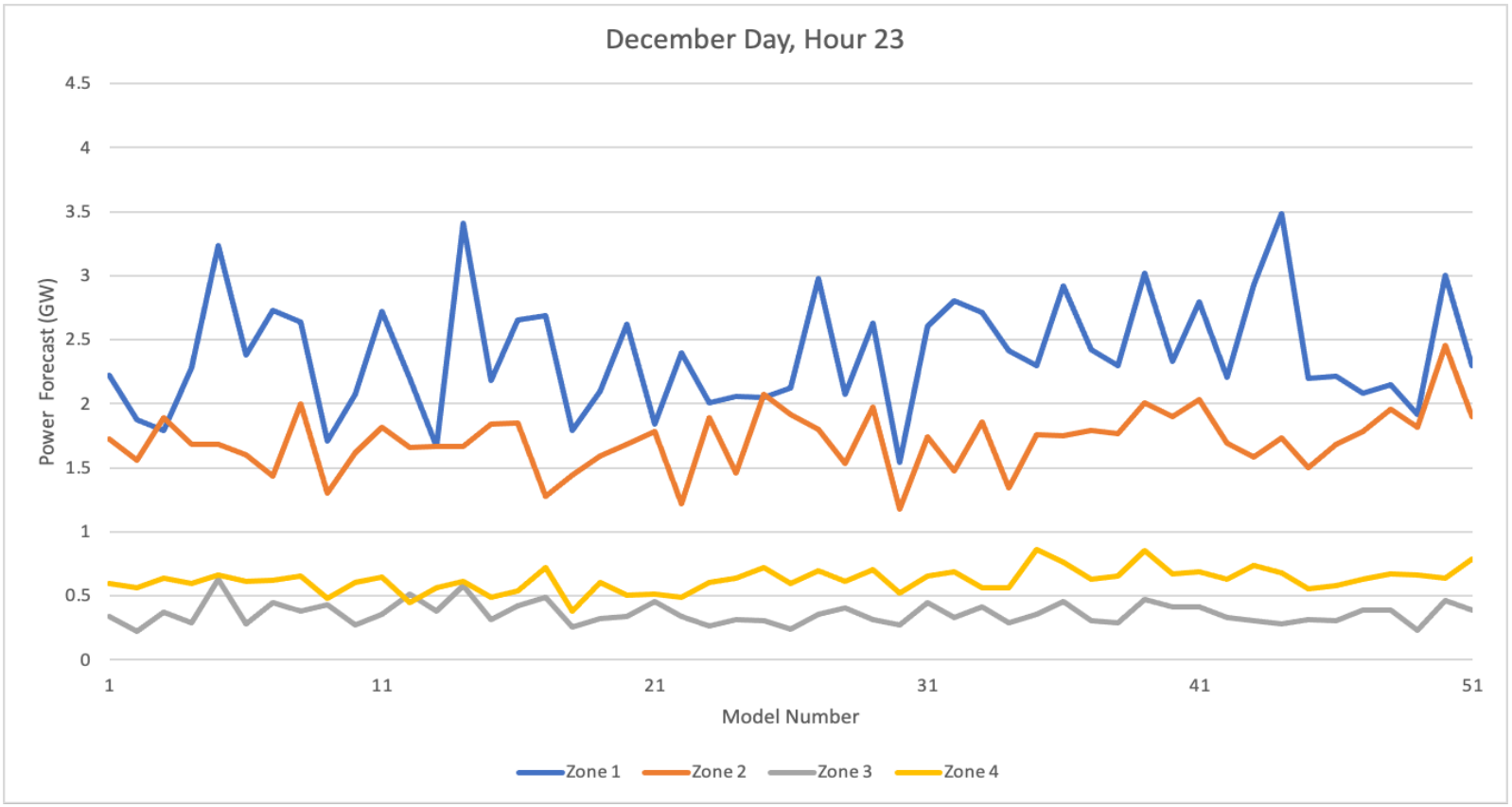


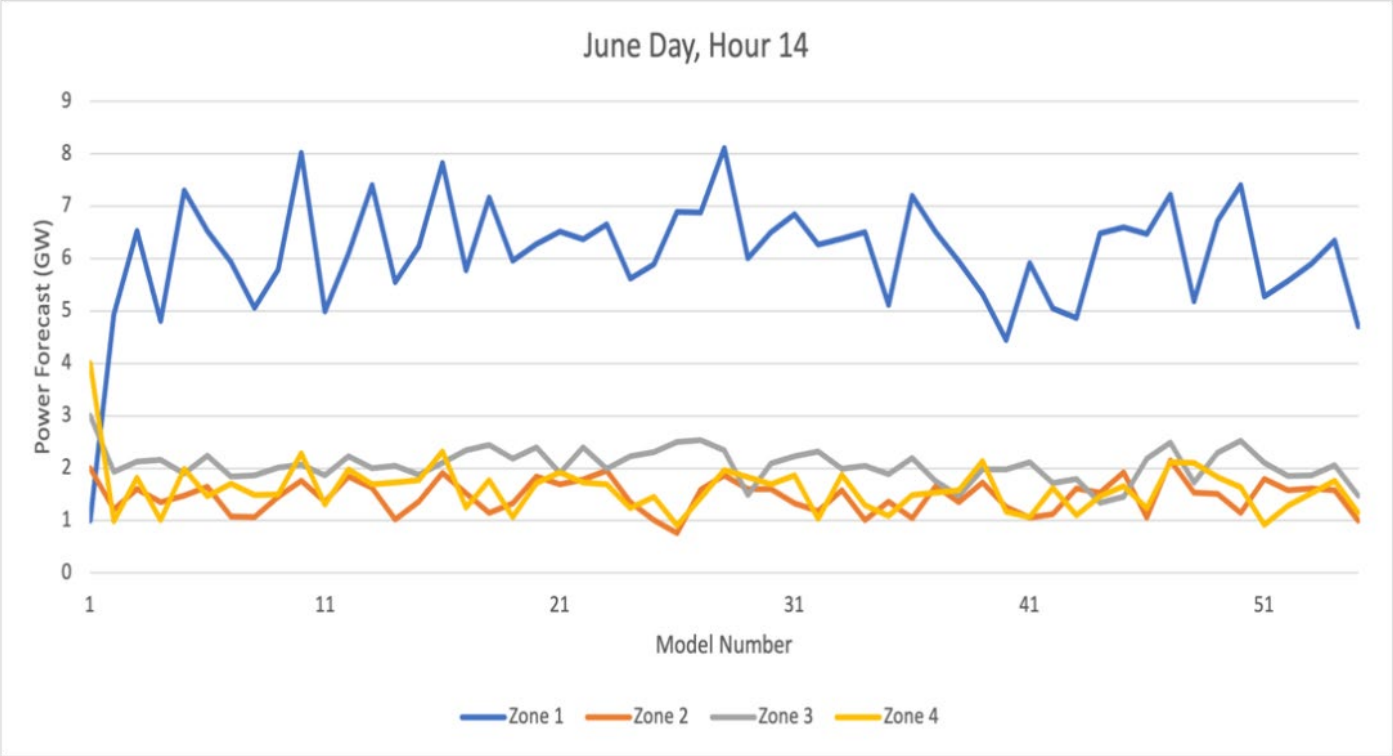

SYSTEM/ISO REQUIREMNTS
-Network Capabilities
-Reliability
MARKET PARTICIPANT PREFERENCES
-Physical & Financial Bids/offers
-Unit Commitment/Decomm. Costs
-Self Scheduling Declarations
HISTORICAL & FORECASTED UNCERTAINTY
-Individual Asset Risk
-System Impact/Synergistic, Correlations
24 HOUR DAY AHEAD MARKET
MAXIMIZE SOCIAL SURPLUS
Subject to
Supply/Demand Energy Balance
Network Congestion Contingencies
Reserve Requirements for Reliability (N-1)
Endogenous System Reliability Capacity Reserves
CURRENT PRACTICE
-Deterministic Unit commitment criteria
-Hourly Schedule of Energy Supply/Demand And of Reserve/Stand by Capacity
-Dynamic System SRMC Clearing Prices for Scheduled Energy and Reserves (LMPs)
-Out of Market Adjustments (Uplift)
UNCERTAINTY RESPONSIVE PROPOSAL
-Uncertainty Mind Full Unit Commitment
- Uncertainty Robust Scheduling of Capacity for Energy and for Reserves
-Dynamic System SRMC Clearing Prices for Scheduled Firm Capacity (LMPs), Differ/ed For Non-Firm Capacity Assets (RLMPs).
-Lower Out of Market Adjustments (Uplift)

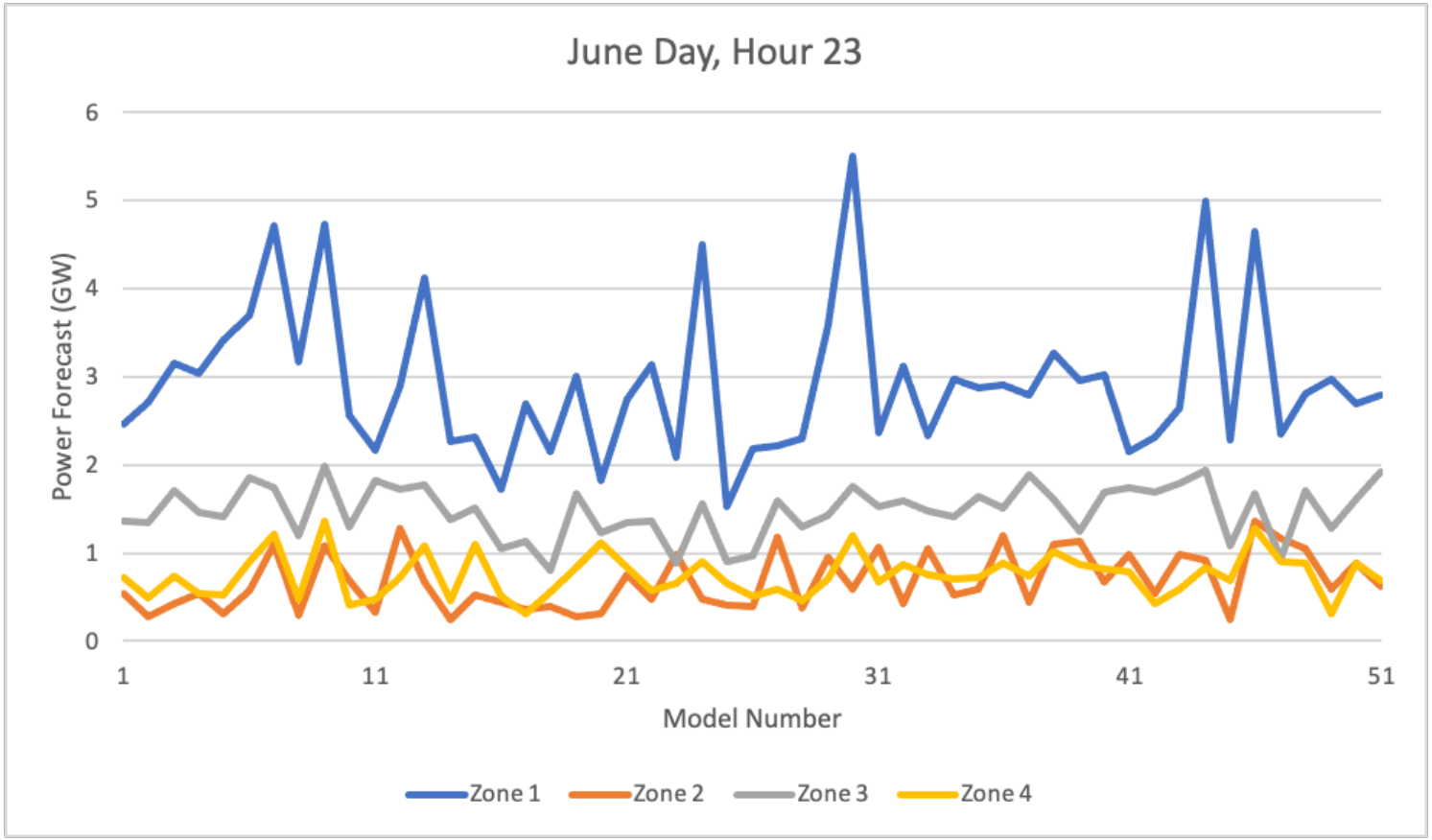
Individual Asset and System Risk

- Renewable Generation: Individual Asset Available Capacity and System Impacts through Correlation
- Conventional Generation: N-1 Contingencies
- Demand: Price Inelastic, Price Elastic Uniform Bids/Complex Bids (e.g., EV Charging HVAC)
  - Adaptive to DAM SCED/System
  - Weather Correlated/System
- Storage Adaptive to DAM SCED
- Congestion Contingency/System

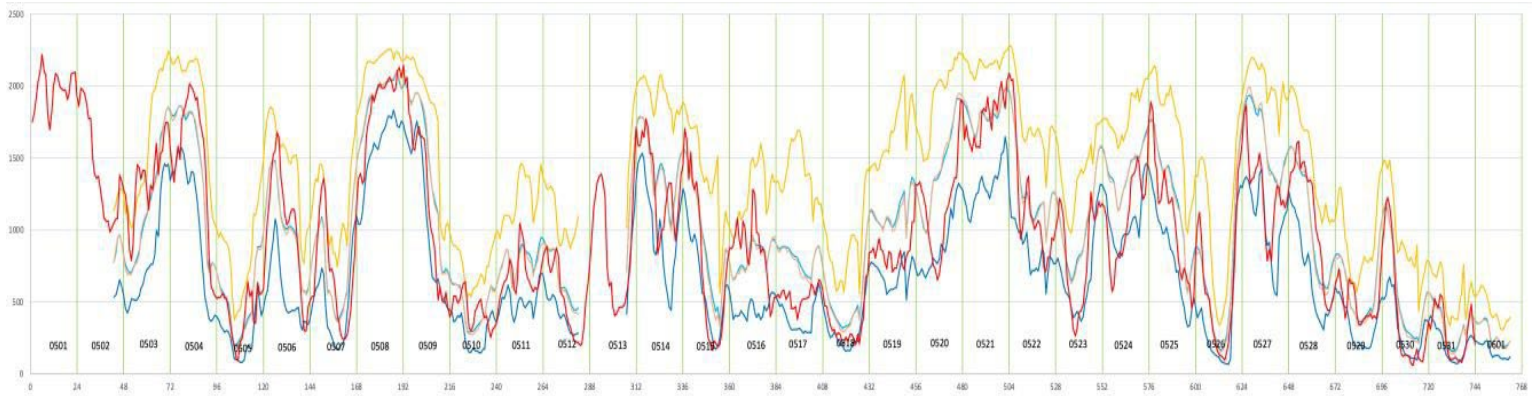

December Day, Hour 14
Power Forecast (GW)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53
Model Number
Zone 1
Zone 2
Zone 3
Zone 4


December Day, Hour 23
Power Forecast (GW)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
11
21
31
41
51
Model Number
Zone 1
Zone 2
Zone 3
Zone 4

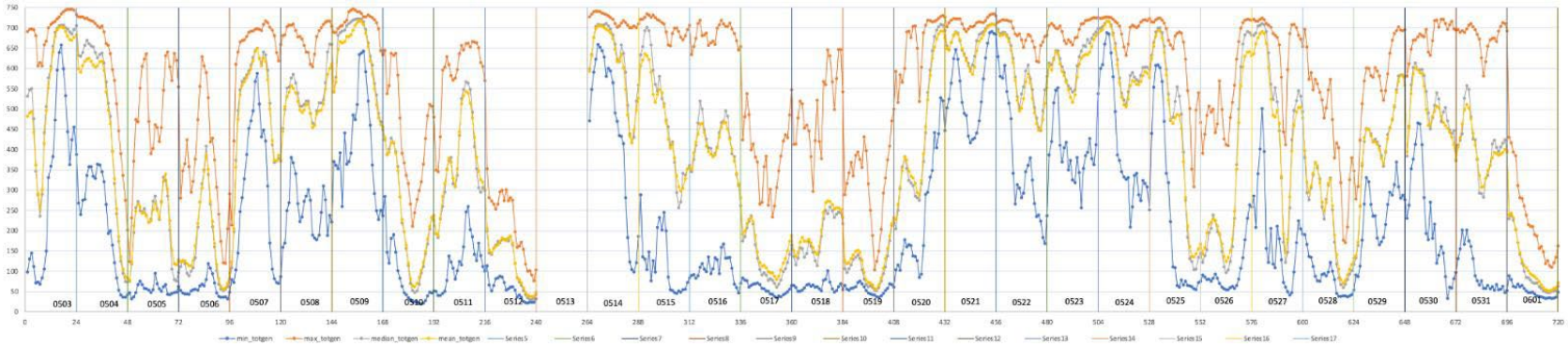

June Day, Hour 14
Power Forecast (GW)
9
8
7
6
5
4
3
2
1
0
1
11
21
31
41
51
Model Number
Zone 1
Zone 2
Zone 3
Zone 4


June Day, Hour 23
Power Forecast (GW)
0
1
2
3
4
5
6
1
11
21
31
41
51
Model Number
Zone 1
Zone 2
Zone 3
Zone 4

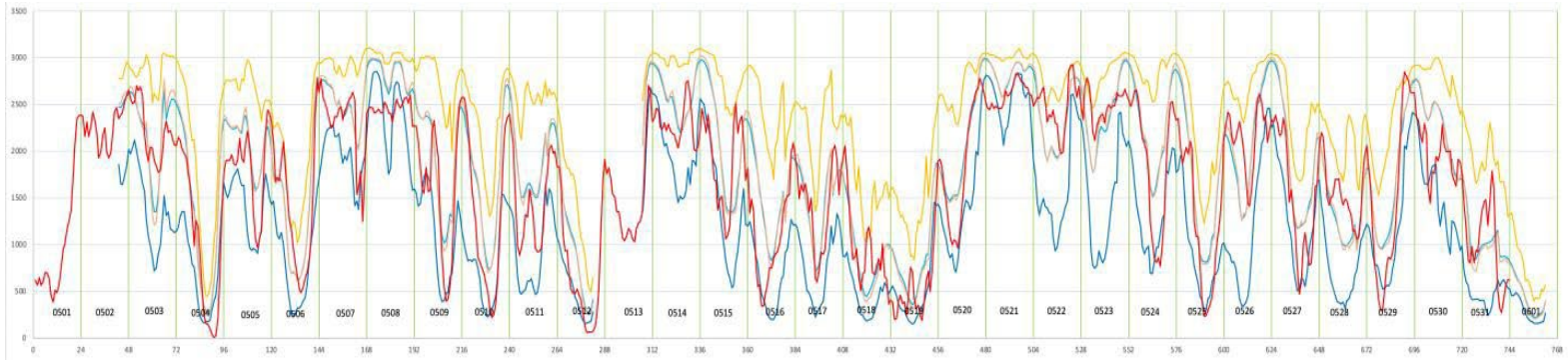
Substation xxxx windfarm output. min, max, median. Non-Firm = Max-min, May2021



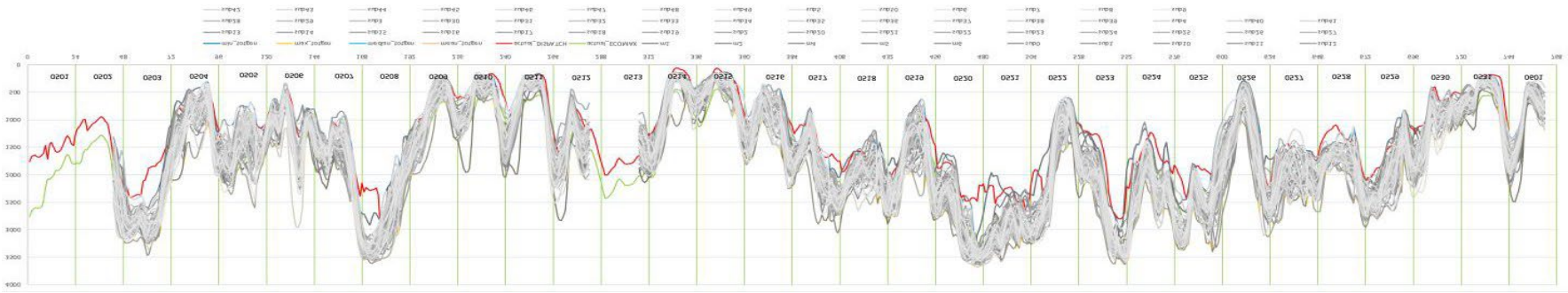
ZONE 4 (Small Capacity) Envelope and Actual (red) from RTBM



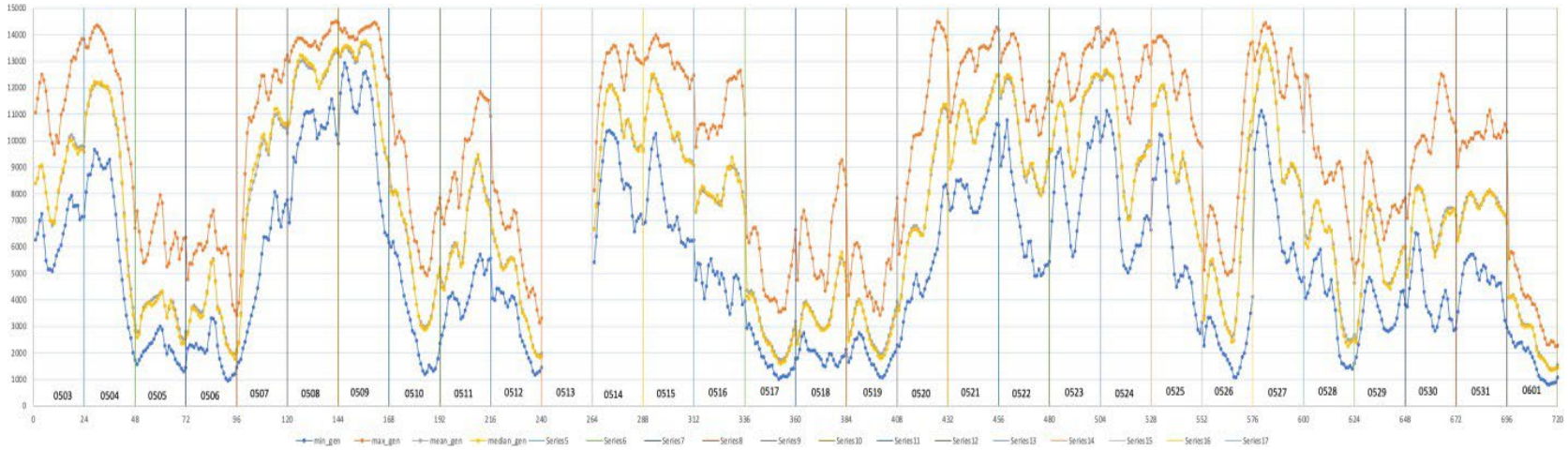
Zone 3 (Medium Capacity) Zone 3 (Medium Capacity) Wind Farms Total MW Output/available Capacity (May 2021) DA Forecast min (blue), max(orange) and median/average (green/yellow)
RTBM Actuals Wind Output(red)



ZONE 2 (small Capacity) Envelope and 56 Ensembles



Zone 1 (High Capacity) Wind Farms MW Output/available Capacity (May 2021) Forecast min (blue), max(magenda) and median/average (green/yellow)



NewRAMP: A **New** **R**isk **A**ssessment and **M**anagement **P**aradigm in Electricity Markets

- **Robust solution** that **quantifies asset risk** to better account for **forecast revealed uncertainty** in **day-ahead market** commitment decisions.
  - **Asset Risk Assessment and Management**
    - **Probabilistic forecast information**
      - **Ensemble forecasts,** numerical weather prediction models
    - **Characterize uncertainty** in **available asset capacity**
  - **System Impact of Asset Risk**
    - **Certainty** coefficients
    - Additional system **robust/reliability constraints**
    - **Worst Case/Robust Reserve Procurements that are Congestion Contingency Proof**
    - **Optimal Reliability Unit Commitment**
      - Multi-Day
      - Day-Ahead
      - Intra-Day/Short-Term

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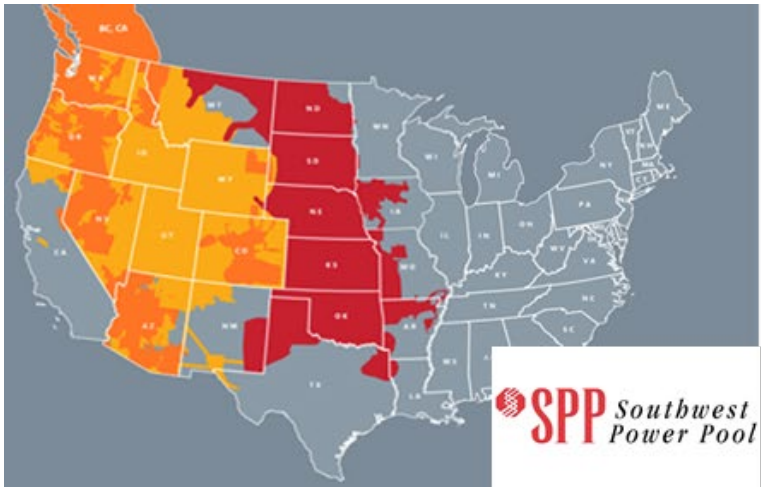
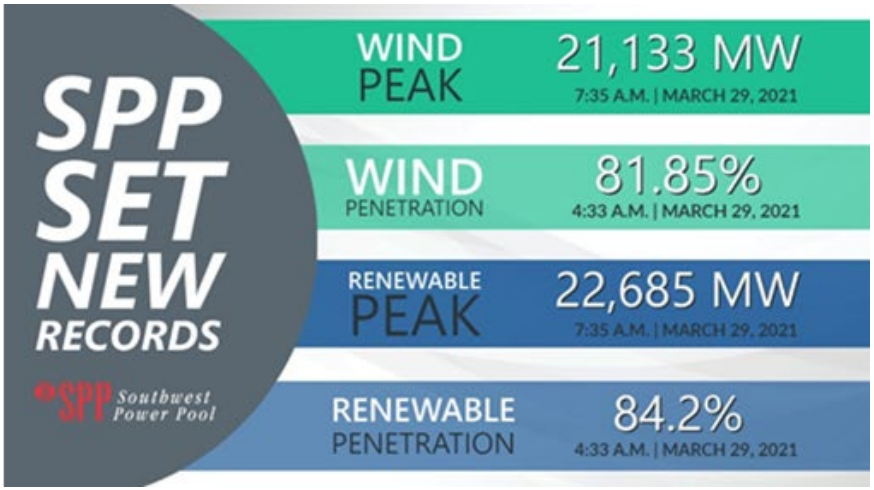




- ✓ SPP system modeled in PSO and benchmarked.
  - ✓ DAMKT costs within **0.03%** (of the SPP solution).
  - ✓ Similar prices, commitment/dispatch, flows.
- ✓ SPP wind forecasts received from Meteologica (and Energy & Meteo).
- ✓ Data obtained for “characteristic” days.

System Constraints:

$$\sum \textbf{Gen} = \text{Demand}$$

$$\sum \textbf{RegUp} \geq \text{Req}^{\text{RegUp}}$$

$$\sum \textbf{RegUp} + \textbf{Spin} \geq \text{Req}^{\text{RegSpin}}$$

$$\sum \textbf{RegUp} + \textbf{Spin} + \textbf{Supp} \geq \text{Req}^{\text{OR}}$$

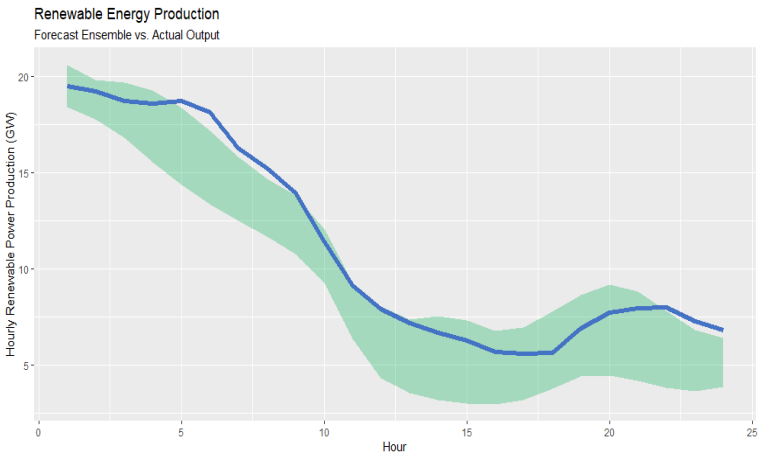
$$\sum \underbrace{\textbf{Gen} + \textbf{RegUp} + \textbf{Spin} + \textbf{Supp}}_{\text{Capacity scheduled}} \geq \text{Demand} + \text{Req}^{\text{OR}}$$

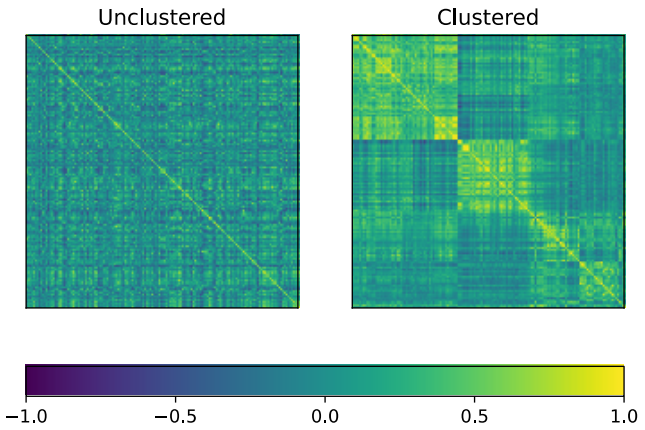
Redundant

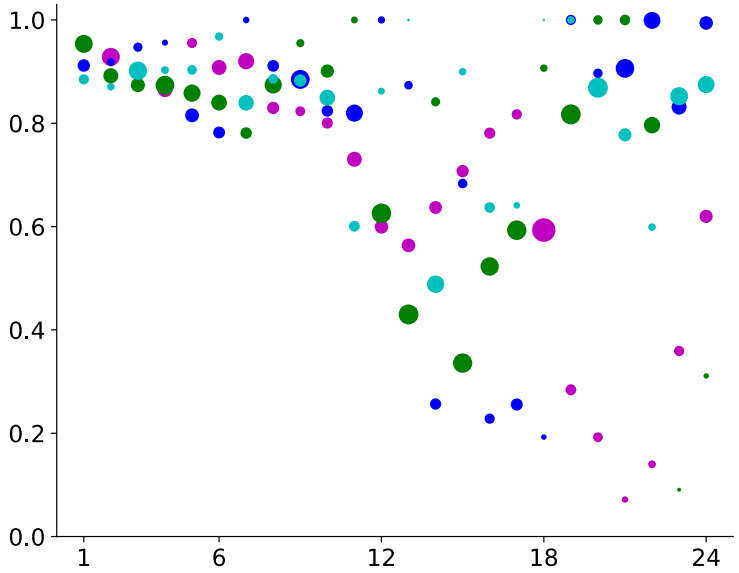
$$\sum \underbrace{\textbf{CertaintyCoefficient} \times (\underbrace{\textbf{Gen} + \textbf{RegUp} + \textbf{Spin} + \textbf{Supp}}_{\text{Capacity scheduled}})}_{\text{Available Capacity @ worst case}} \geq \text{Demand} + \text{Req}^{\text{OR}}$$

$\textbf{CertaintyCoefficient} \in [0,1]$, 1: certain

Reliability/Robust Constraint







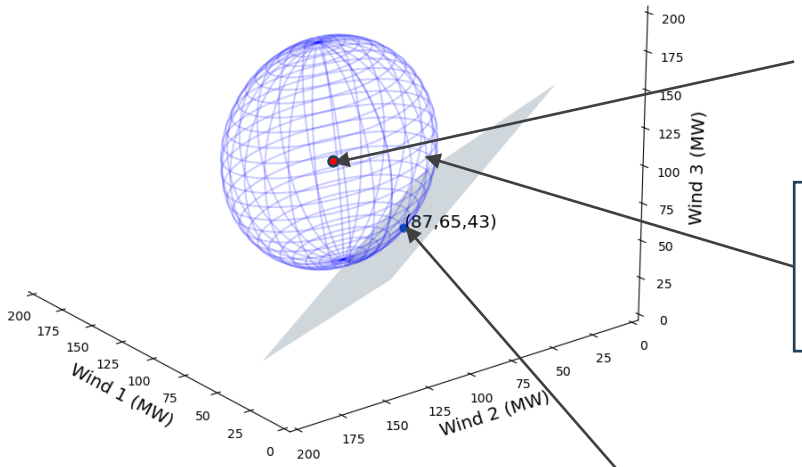
Certainty Coefficients for each of the four zone wind farm clusters

- Values between 0 and 1
- 1: certain
- The lower the value, the riskier the capacity

- Worst case and uncertainty set calculation **examples Two Cases**

Covariance	Wind 1	Wind 2	Wind 3
Wind 1	250	-50	8
Wind 2	-50	600	30
Wind 3	8	30	900

$\boldsymbol{\Sigma}$: covariance matrix (calculated from ensemble forecasts)



$\bar{\mathbf{w}}$: average forecast (100,100,100)

Uncertainty set: (ellipsoid)

$$\{\boldsymbol{w}: (\boldsymbol{w}-\bar{\mathbf{w}})\boldsymbol{\Sigma}^{-1}(\boldsymbol{w}-\bar{\boldsymbol{w}})^{\mathrm{T}} \leq \rho^2\}$$

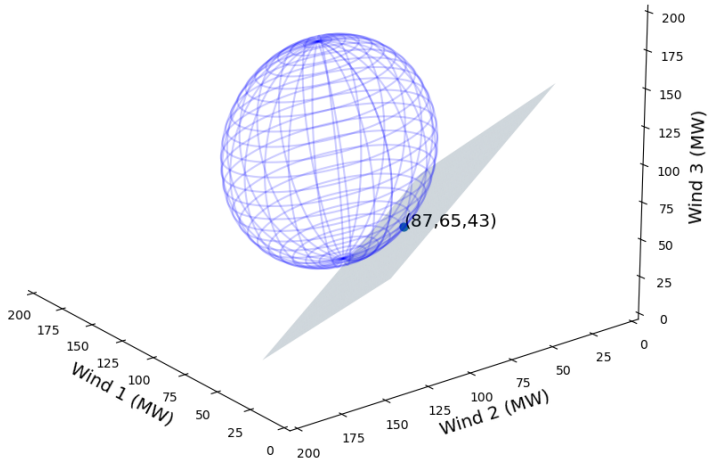
radius

	Worst Case
Wind 1	87
Wind 2	65
Wind 3	43

$$\mathbf{w}^{\text{worst case}} = \underset{(\boldsymbol{w}-\bar{\mathbf{w}})\boldsymbol{\Sigma}^{-1}(\boldsymbol{w}-\bar{\mathbf{w}})^{\mathrm{T}}\leq\rho^2}{\operatorname{argmin}} \boldsymbol{1}^{\boldsymbol{T}}\boldsymbol{w} = \bar{\mathbf{w}} - \frac{\rho\boldsymbol{\Sigma}\mathbf{1}^{\mathrm{T}}}{\sqrt{\mathbf{1}^{\mathrm{T}}\boldsymbol{\Sigma}\mathbf{1}}}$$

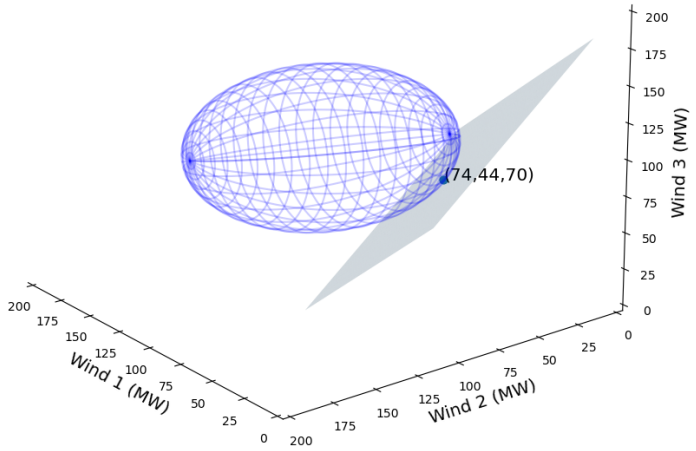
- Worst case and uncertainty set calculation **examples: Two Cases**

Covariance	Wind 1	Wind 2	Wind 3
Wind 1	250	-50	8
Wind 2	-50	600	30
Wind 3	8	30	900



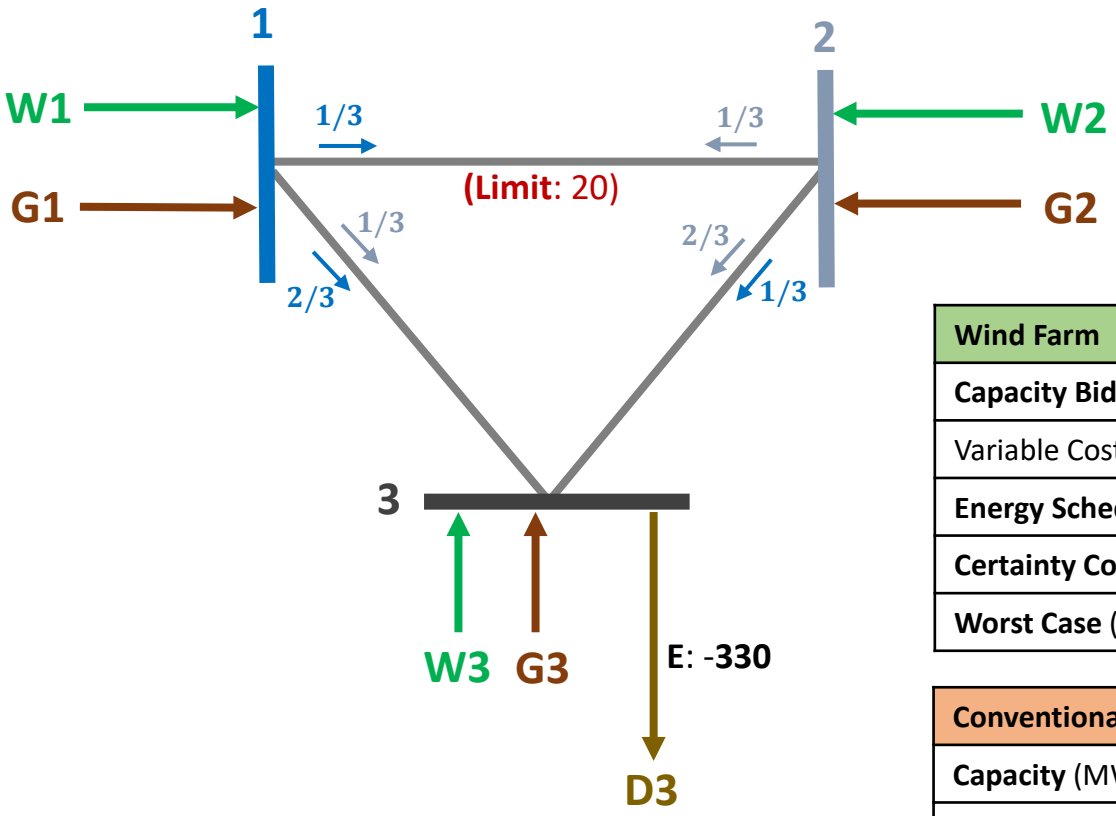
Case 1	Worst Case
Wind 1	87
Wind 2	65
Wind 3	43

Covariance	Wind 1	Wind 2	Wind 3
Wind 1	250	40	25
Wind 2	40	600	36
Wind 3	25	36	300



Case 2	Worst Case
Wind 1	74
Wind 2	44
Wind 3	70

- **Case 1 3-bus/zone example 1; demand at bus 3 no Congestion**

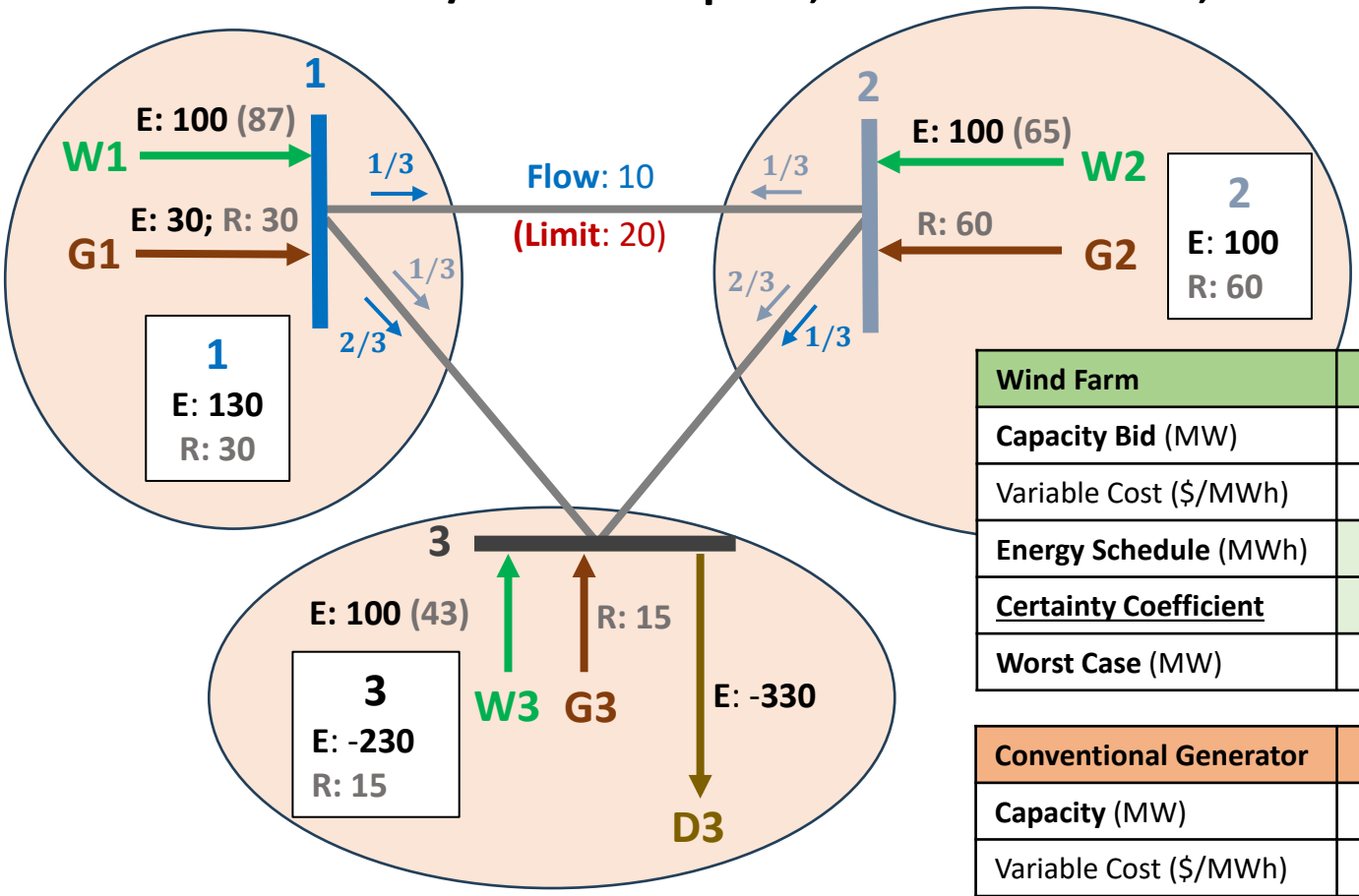


Wind Farm	W1	W2	W3	Total
Capacity Bid (MW)	100	100	100	**300**
Variable Cost ($/MWh)	0	0	0	
Energy Schedule (MWh)				
Certainty Coefficient				
Worst Case (MW)	87	65	43	195

Conventional Generator	G1	G2	G3	Total
Capacity (MW)	60	60	10	**130**
Variable Cost ($/MWh)	30	50	100	
Reserve Offer ($/MW)	20	24	29	
Energy Schedule (MWh)				
Reserve Schedule (MW)				

Demand	D3
Energy (MWh)	**330**

- **Case 1 3-bus/zone example 1; demand at bus 3; no congestion**

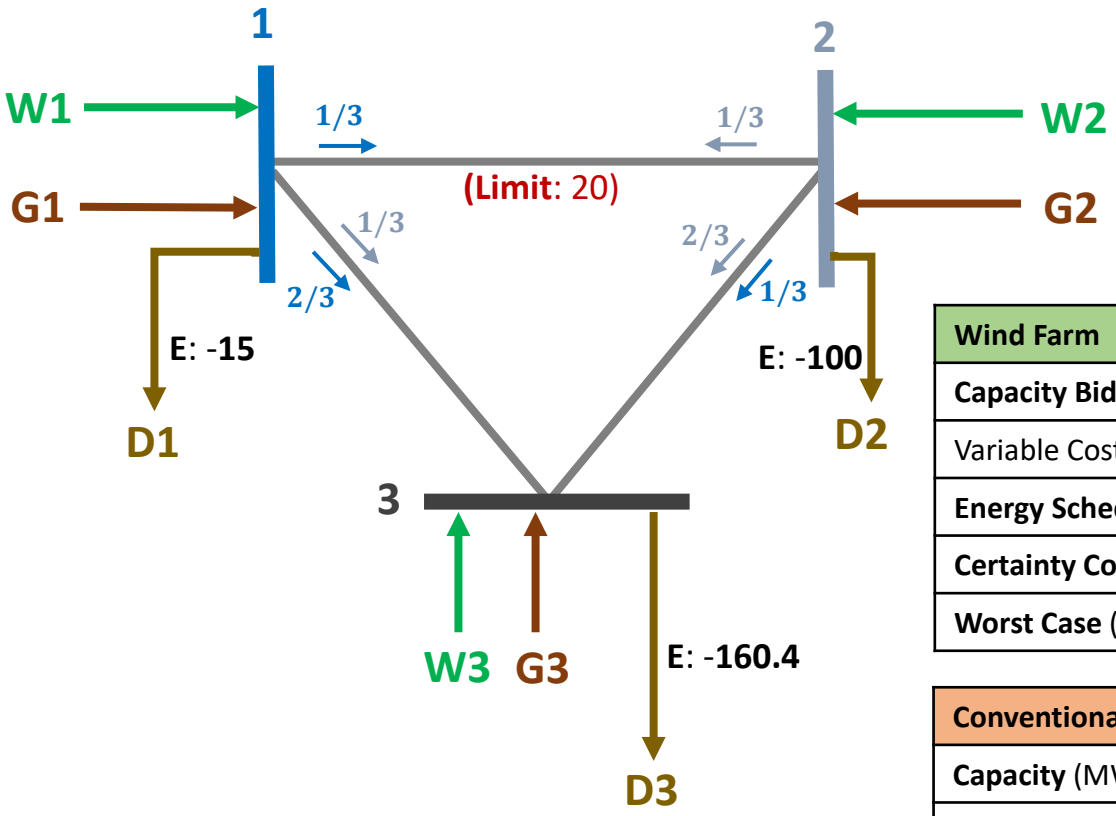


Wind Farm	W1	W2	W3	Total
Capacity Bid (MW)	100	100	100	**300**
Variable Cost ($/MWh)	0	0	0	
Energy Schedule (MWh)	**100**	**100**	**100**	**300**
Certainty Coefficient	**0.87**	**0.65**	**0.43**	
Worst Case (MW)	87	65	43	195

Conventional Generator	G1	G2	G3	Total
Capacity (MW)	60	60	10	**130**
Variable Cost ($/MWh)	30	50	100	
Reserve Offer ($/MW)	20	24	29	
Energy Schedule (MWh)	**30**	**0**	**0**	**30**
Reserve Schedule (MW)	30	60	15	105

Demand	D3
Energy (MWh)	**330**

- **Case 1 3-bus/zone example 2; demand at all busses; Congestion on Line 1-2**

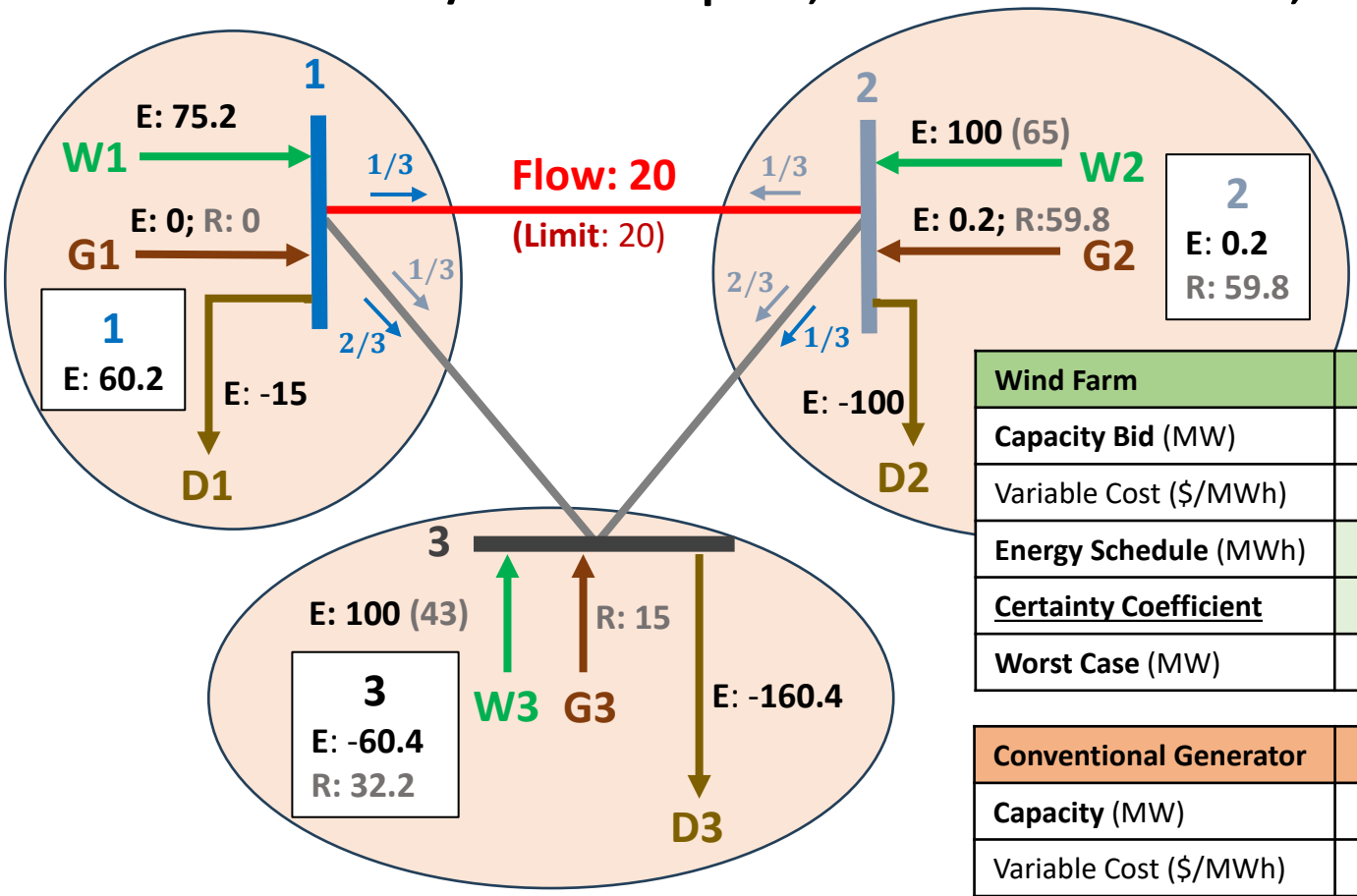


Wind Farm	W1	W2	W3	Total
Capacity Bid (MW)	100	100	100	**300**
Variable Cost ($/MWh)	0	0	0	
Energy Schedule (MWh)				
Certainty Coefficient				
Worst Case (MW)	87	65	43	195

Conventional Generator	G1	G2	G3	Total
Capacity (MW)	60	60	10	**130**
Variable Cost ($/MWh)	30	50	100	
Reserve Offer ($/MW)	20	24	29	
Energy Schedule (MWh)				
Reserve Schedule (MW)				

Demand	D1	D2	D3	Total
Energy (MWh)	15	100	160.4	**275.4**

- **Case 1 3-bus/zone example 2; demand at all busses; congestion on line 1-2**



Wind Farm	W1	W2	W3	Total
Capacity Bid (MW)	100	100	100	**300**
Variable Cost ($/MWh)	0	0	0	
Energy Schedule (MWh)	**75.2**	**100**	**100**	**300**
Certainty Coefficient	**1.0**	**0.65**	**0.43**	
Worst Case (MW)	87	65	43	195

Conventional Generator	G1	G2	G3	Total
Capacity (MW)	60	60	10	**130**
Variable Cost ($/MWh)	30	50	100	
Reserve Offer ($/MW)	20	24	29	
Energy Schedule (MWh)	**0**	**0.2**	**0**	**0.2**
Reserve Schedule (MW)	0	59.8	32.2	92

Demand	D1	D2	D3	Total
Energy (MWh)	15	100	160.4	**275.4**

Reserve Planning Issues/RUC addressed with Uncertainty Sets

- Reserves needed for each hour. Must Be Deployable (Robust Versus Transmission line congestion contingencies)
- Uncertainty of Demand Adapted on optimal SCED over and above Adaptability Can be Included in Robust Reserve Planning: Min Σw-Σd
- Ramping Needs Can Be Planned for in Robust DAM Clearing: Max $\Sigma w(t)$-$\Sigma w(t-\tau)$
- Uncertainty Set <-> Forecast likelihoods related to weather type classifications
- …..

- Discussion on future, more innovative and daring market clearing, price formation/trading, clearing Algorithms
  - **Prices that Support Market Clearing MORE IN LAST TALK by P.A. Tomorrow**
    - **Extended LMPs (?)**
    - **Market clearing prices** (if derived from the theory of convex hull pricing)
      - Support the market solution
      - Guarantee minimal uplift
      - Mitigate self-scheduling incentives
  - **Reserve cost causation?**
  - **Virtual/Financial Bids and Offers?**
  - **Purchase Reserves in DAM? (Reserve Availability Cirves in RTBM?)**
  - **Prices Conditional on Uncertainty Contingencies Rather than Robust RUC?**
  - **Other?**

Roadmap for a Pilot Phase …

- ❑ Team: BU, SPP, PSO/Enelytix, Meteologica (and/or Energy & Meteo)
- ❑ Account for uncertainty of conventional generation, load.
- ❑ Runs on-demand
- ❑ Optimize data management (runs at SPP).
- ❑ Communicate results (Tableau displays) to:
  - Uncertainty Response Team,
  - Operator trainers (to start).
- ❑ Observe/quantify benefits from:
- ❑ Feedback...

- ✓ Certainty coefficient calculation
- ✓ Multi-day unit commitment
- ✓ Reliability Unit Commitment
- ✓ DAMKT counterfactuals
- ✓ Extended LMPs
- ✓ Look-ahead RTBM (?)
- ✓ Reserve cost causation (?)

- ✓ Cost savings (commitment, dispatch)
- ✓ Endogenously determined reserves
- ✓ Lower "inefficiency costs" (out-of-market payments; RUC costs)
- ✓ Lower wind curtailment
- ✓ Lower uplifts with market solution supporting prices
- ✓ Fewer self-scheduling units (?)

Thank you

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