AI Institute for Advances in Optimization

Asset Bundling for Wind Power Forecasting

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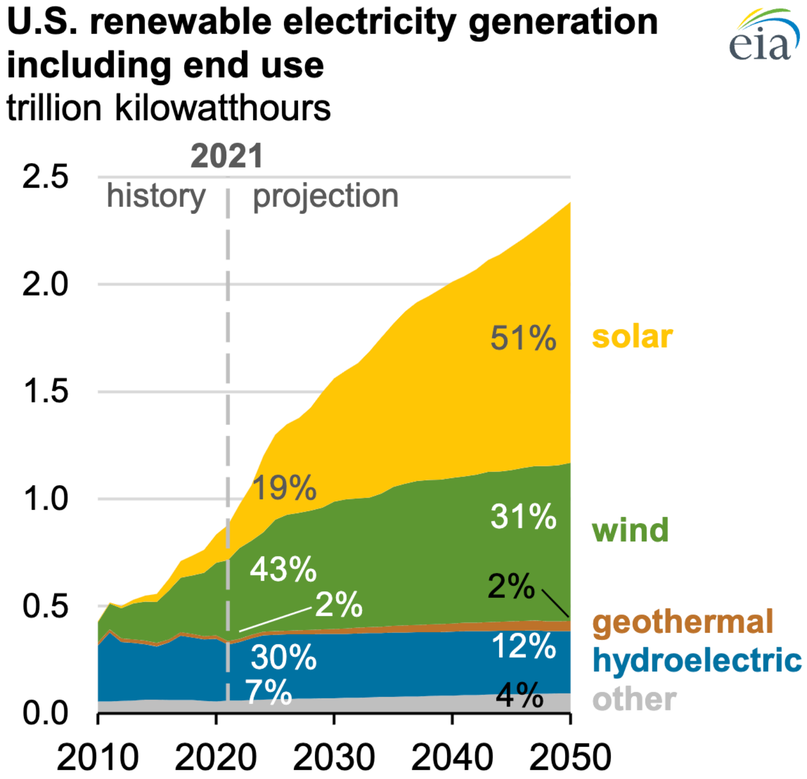
Georgia Institute of Technology

RAMC
Risk-Aware Market Clearing Project

NSF

Motivation

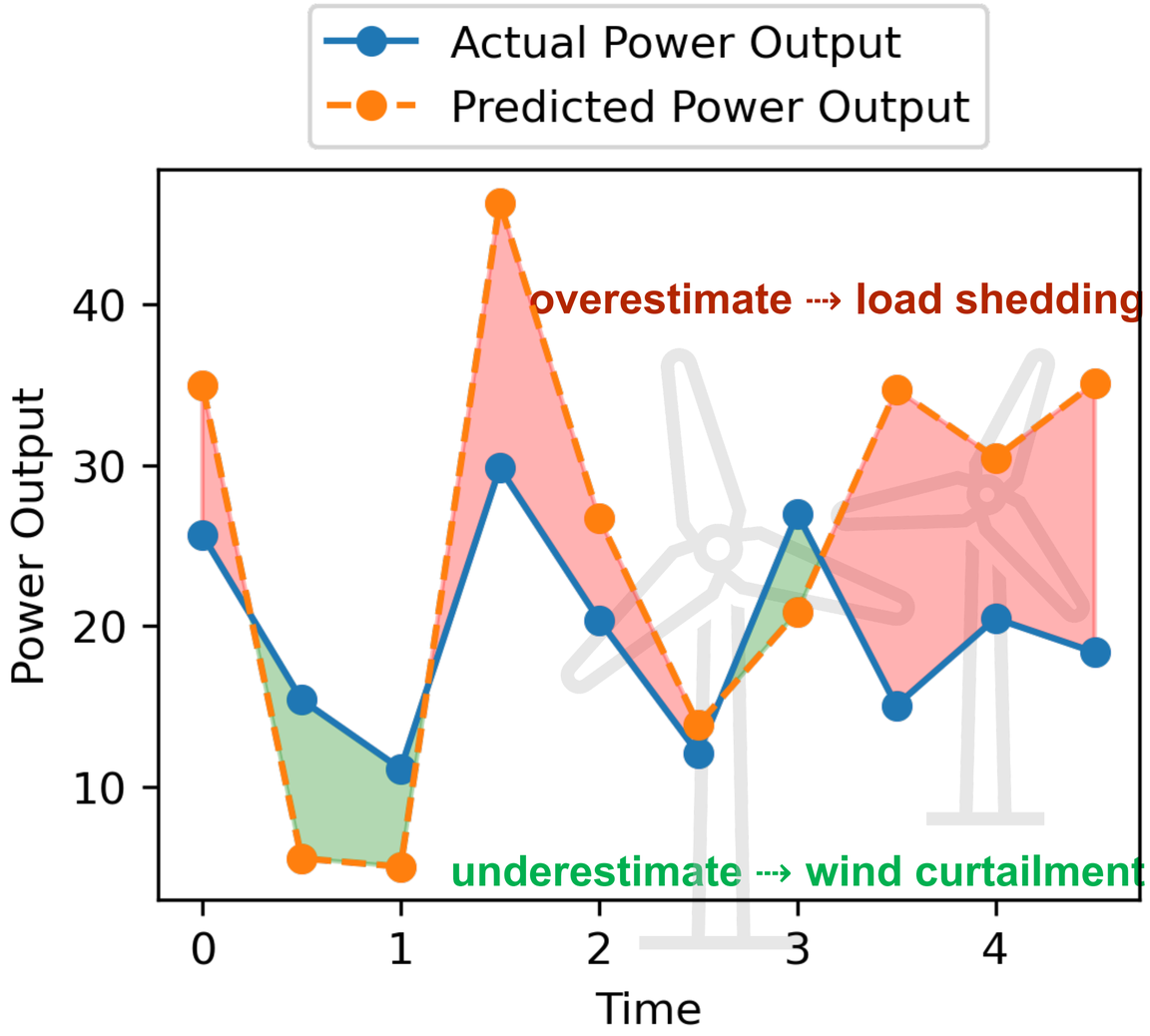
- Reaching 100% carbon pollution-free electricity by 2035
- Growing penetration of intermittent, renewable generation causes operational challenges
  - Unpredictable nature
  - Accurate forecast



The United States Government. (2023, July 20). *National Climate Task Force*. The White House. https://www.whitehouse.gov/climate/

Today in Energy. *(2022) EIA projects that renewable generation will supply 44% of U.S. electricity by 2050*. US. Energy Information Administration https://www.eia.gov/todayinenergy/detail.php?id=51698

Motivation

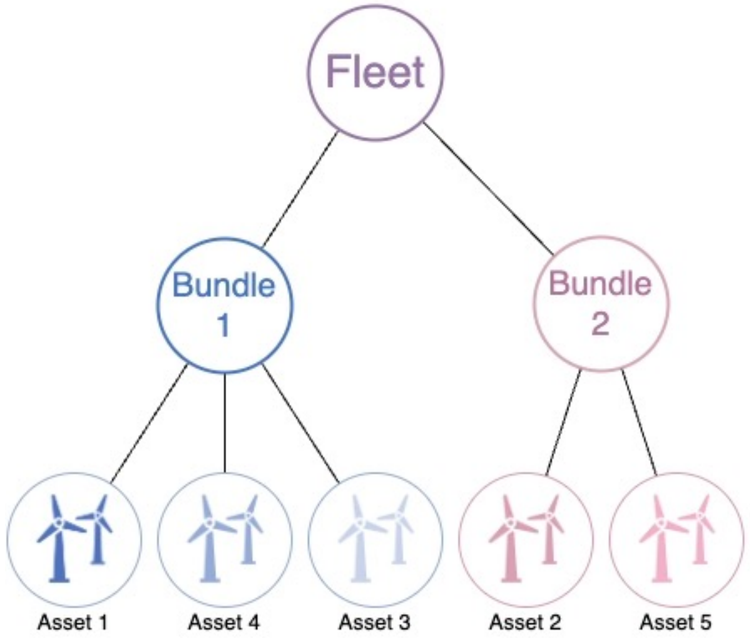

Actual Power Output
Predicted Power Output
overestimate ⇢ load shedding
underestimate ⇢ wind curtailment
Power Output
40
30
20
10
0
1
2
3
4
Time

Asset Bundling

- Bundling: Group wind farms into bundles
  - Dimension reduction
  - Easier to forecast

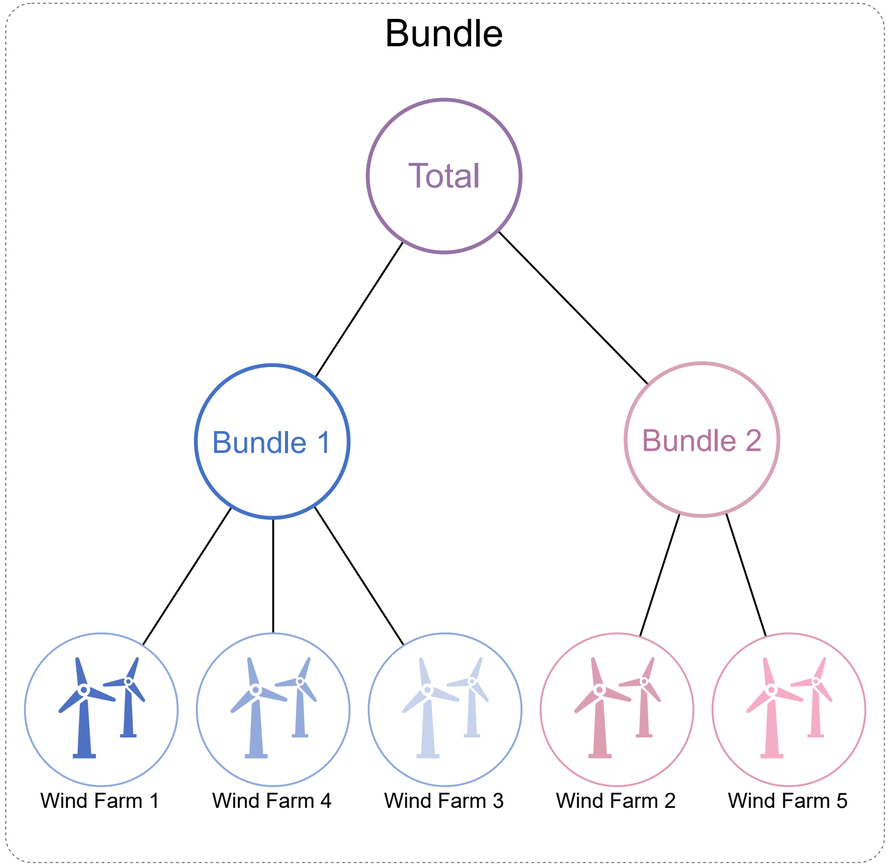
- Goal: Accurate and consistent forecast on **asset** level and **fleet** level
  - Asset level: dispatch, operation
  - Fleet level: energy market operation, system-wide reliability

- Bundle-Predict-Reconcile (**BPR**) framework, which consists of asset **b**undling, **p**rediction, and forecast **r**econciliation components



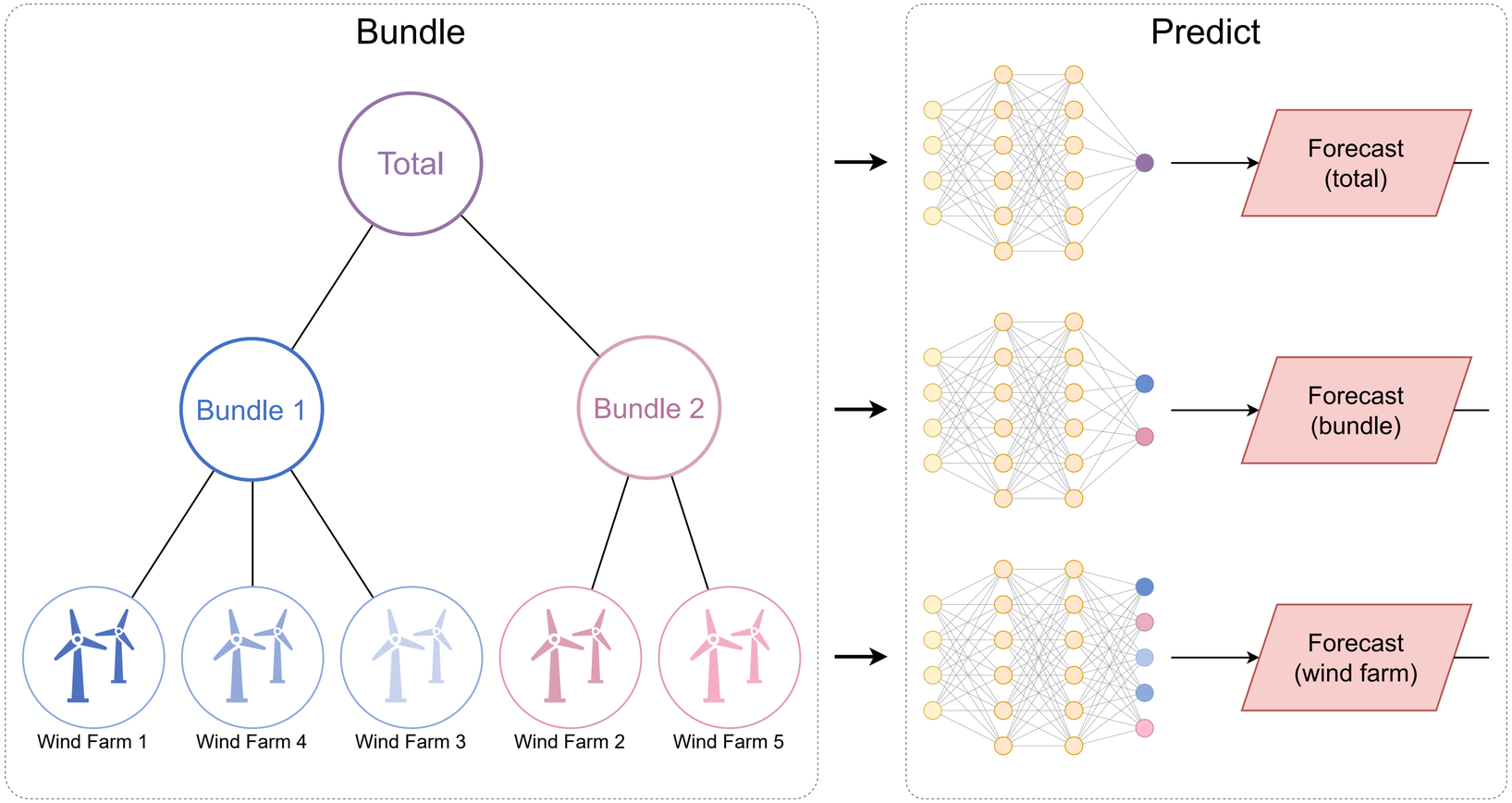
Bundle-Predict-Reconcile (BPR)

- **Asset bundling**: bundle wind farms with respect to spatio-temporal dynamics



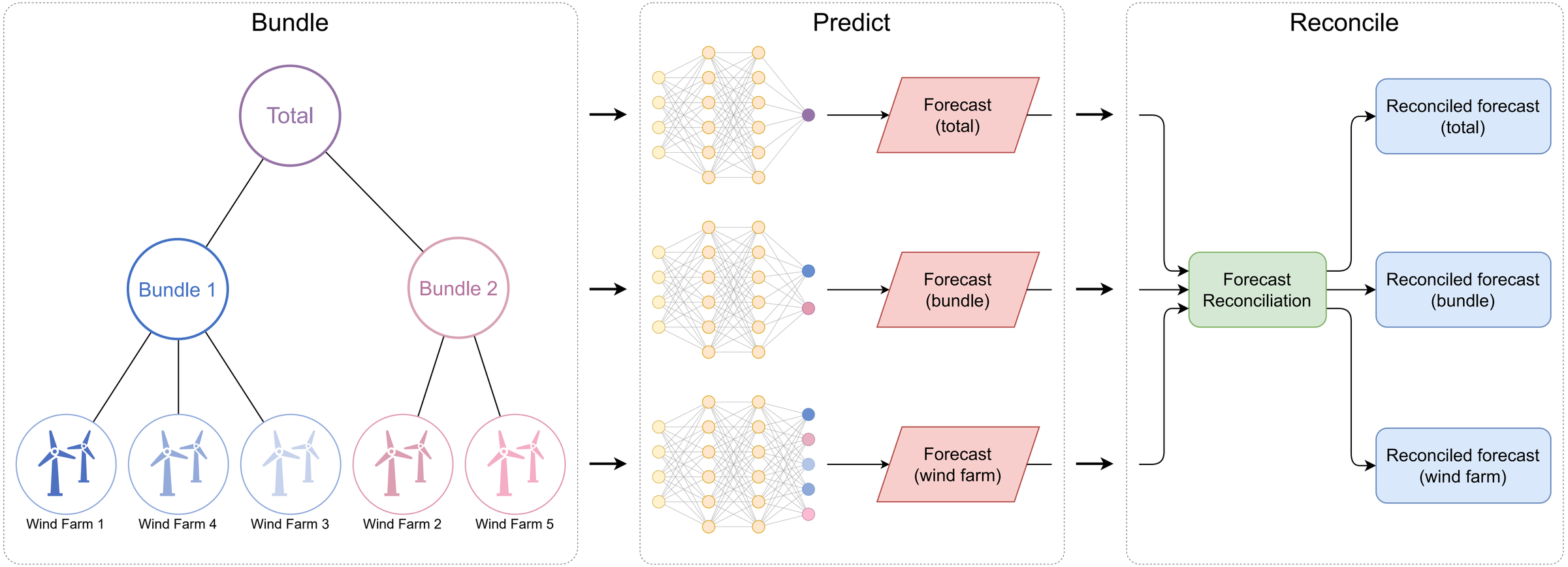
Bundle-Predict-Reconcile (BPR)

- **Predict** wind power at the asset, bundle, and fleet level



Bundle-Predict-Reconcile (BPR)

- **Reconciliation:** the sum of individual forecasts is equal to the sum of bundle forecasts and the forecast for the overall fleet, guaranteeing consistency



Bundling Criterion: SAVar

- Motivation

  Steady power output → *easier to predict*

- Method Proposed

  Minimize total variance of time series

  Formally:

$$\min_W f(W) = \sum_{i=1}^{K} Var(Z_{i,.}) = tr\,(W\,\Sigma\,W^T)\,,$$

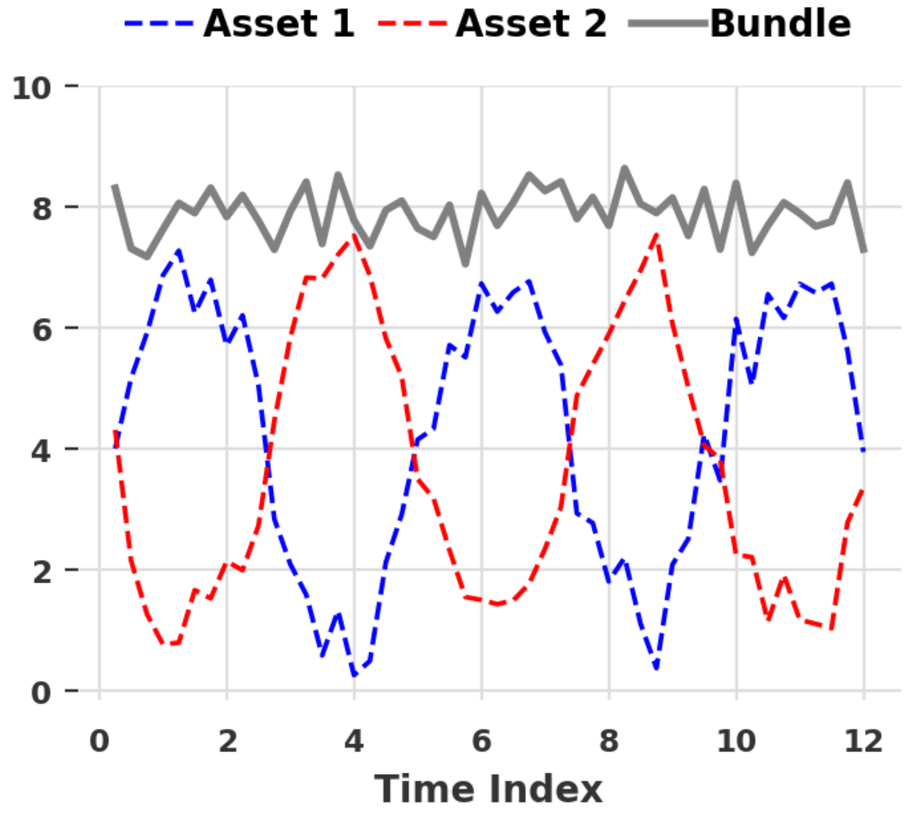
$$\text{s.t. } \textstyle\sum_i W_{i,j} = 1,\ \forall j = 1,\dots,N,$$

$$W \in \{0,1\}^{K \times N}.$$

  This requires negative correlations

$$Var(x+y) = Var\,(x) + Var(y) + 2\,Cov\,(x,y)$$

  Seasonal-Adjusted variance (SAVar) is used to create more negative correlations



Bundling Criterion: Imcy

- Motivation

  Reduce high frequency noise → *easier to predict*

- Method Proposed

  Minimize the variance of first-order-differences (intermittency index) of all bundles

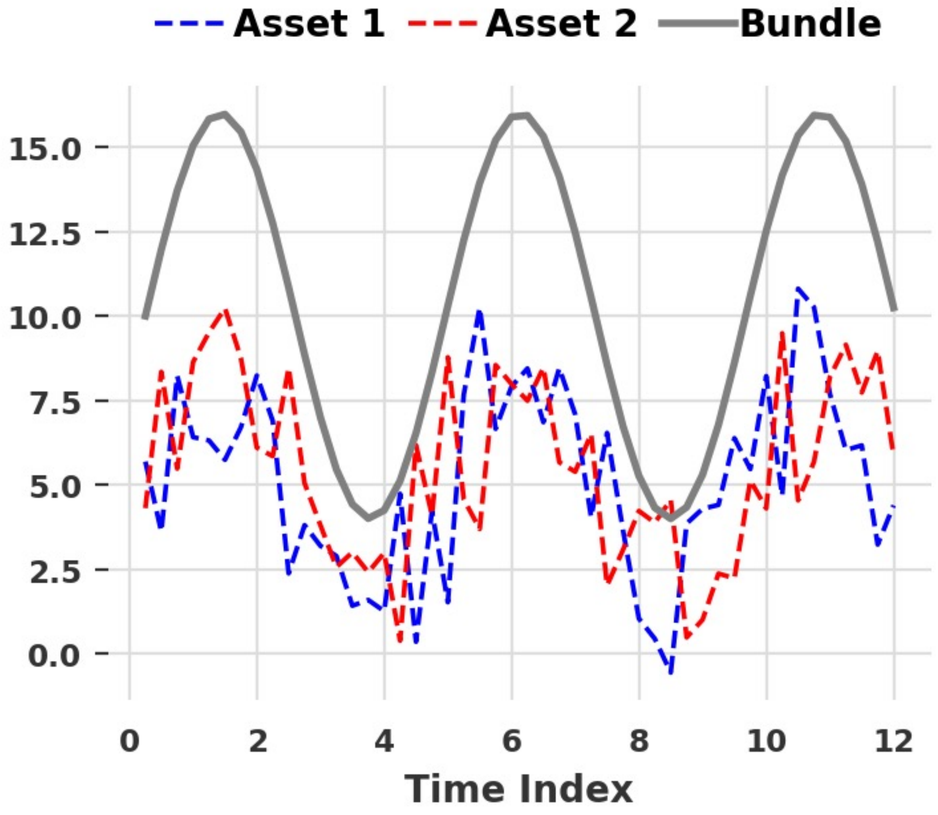
  Formally

$$\min_W f(W) = \sum_{i=1}^{K} Var\left(\dot{Z}_{i,\cdot}\right) = tr\left(W \Sigma W^T\right),$$

$$\text{s.t. } \sum_i W_{i,j} = 1, \forall j = 1, \dots, N,$$

$$W \in \{0,1\}^{K \times N}.$$

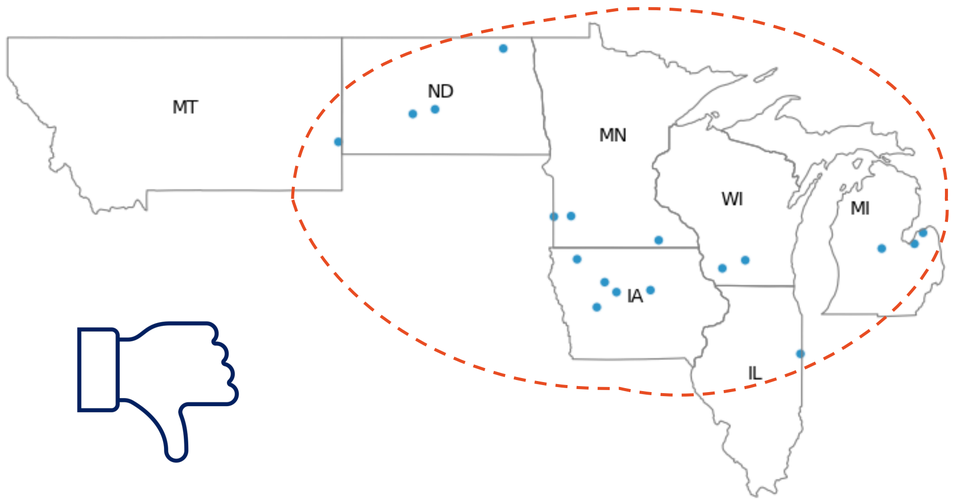
Where $\dot{Z}_{i,\cdot}$ denotes the first-order differences of the original time series of asset 1.



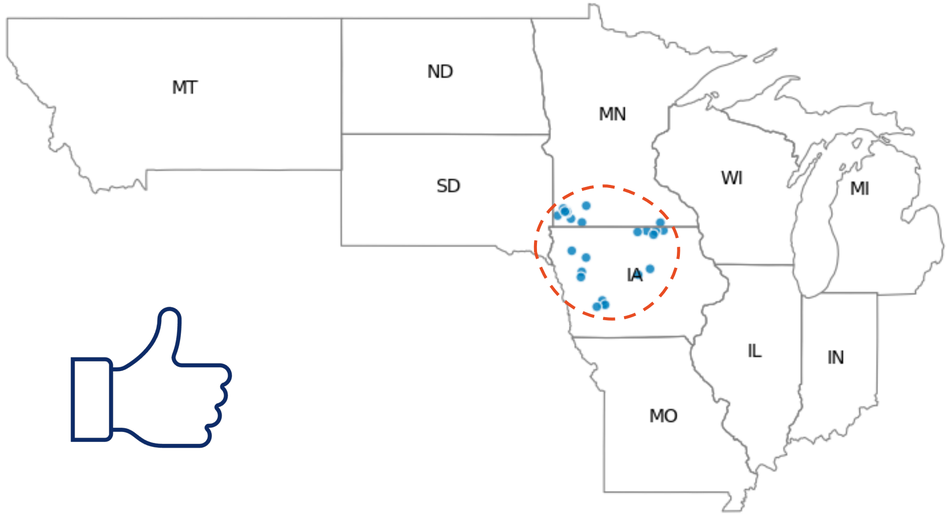
Distance Constraint

- SAVar tends to bundle all wind farms into the same bundle
- Preserve operational feasibility

  -Solve the dispatch problem at bundle-level



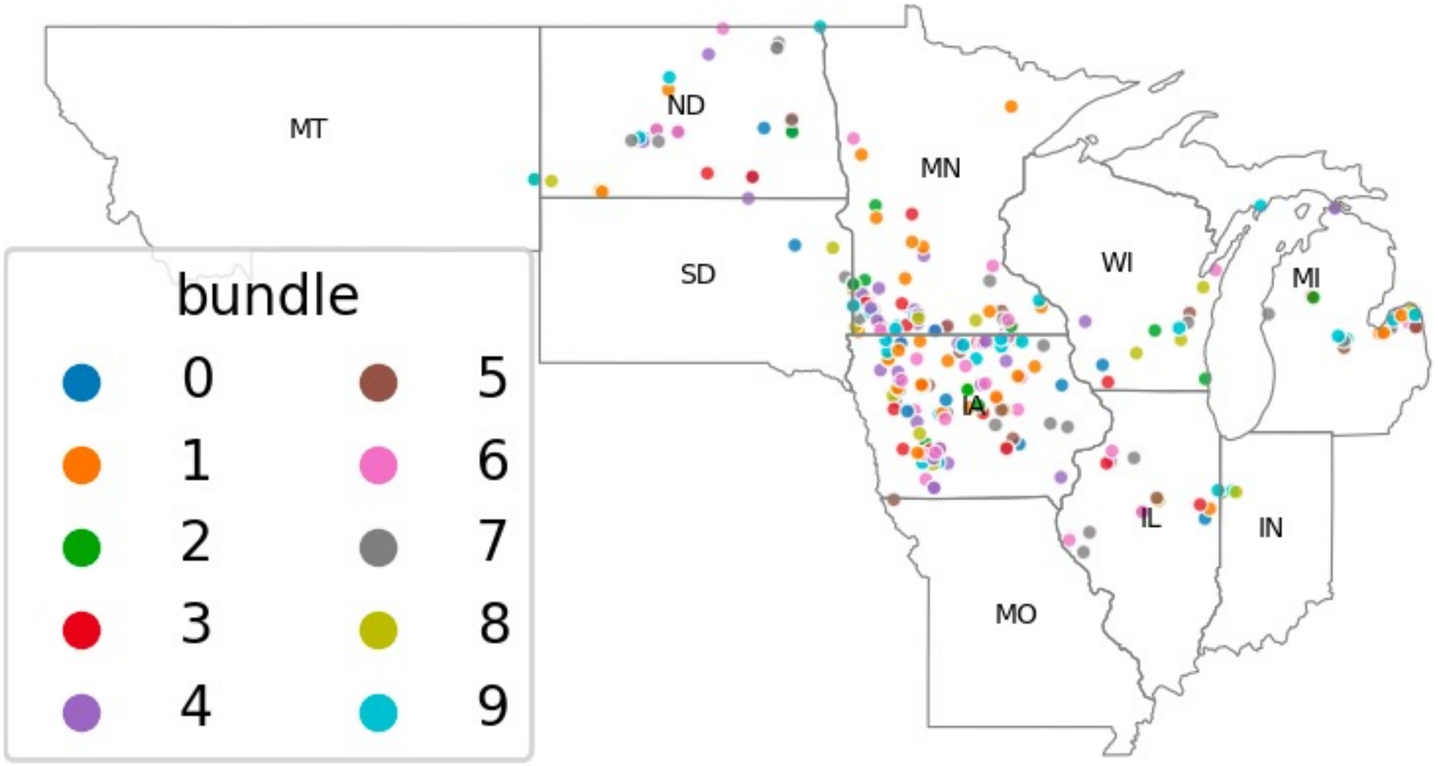
Without distance constraint

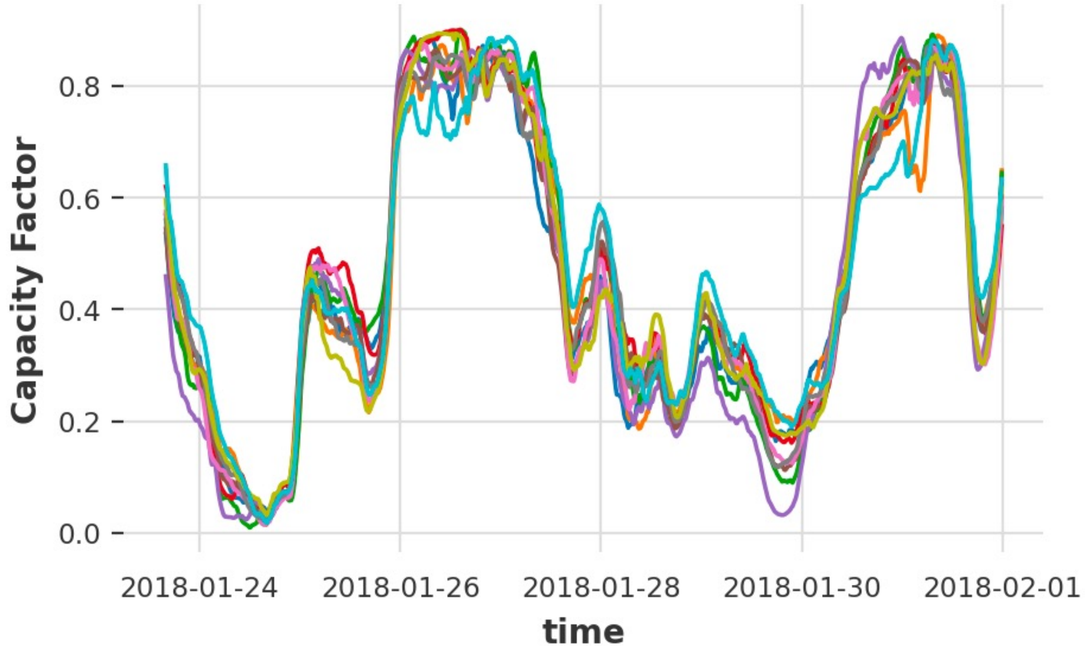


With distance constraint

Example: Bundled Time Series

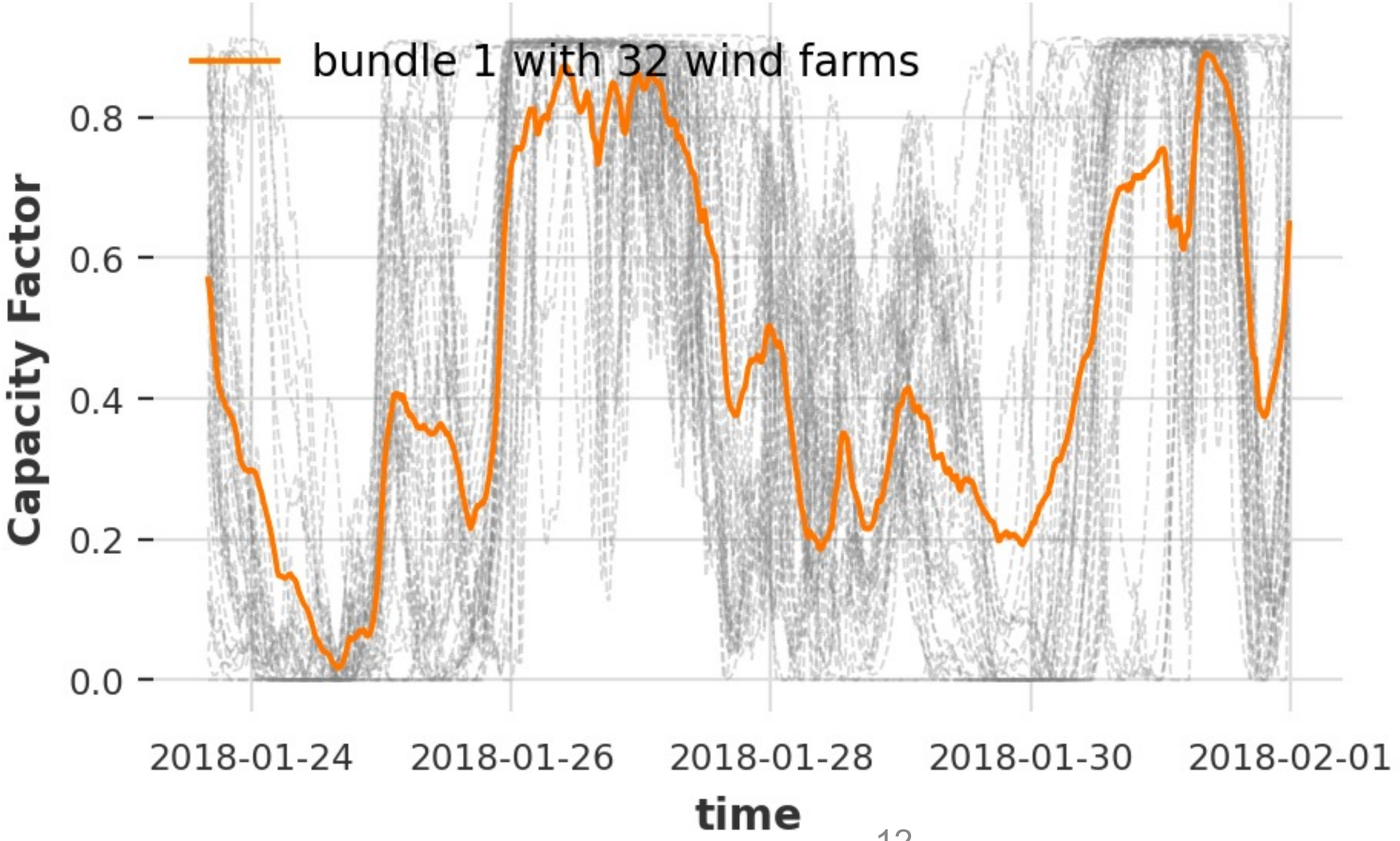
- **283** wind farms (assets) → **10** bundles via *Imcy*





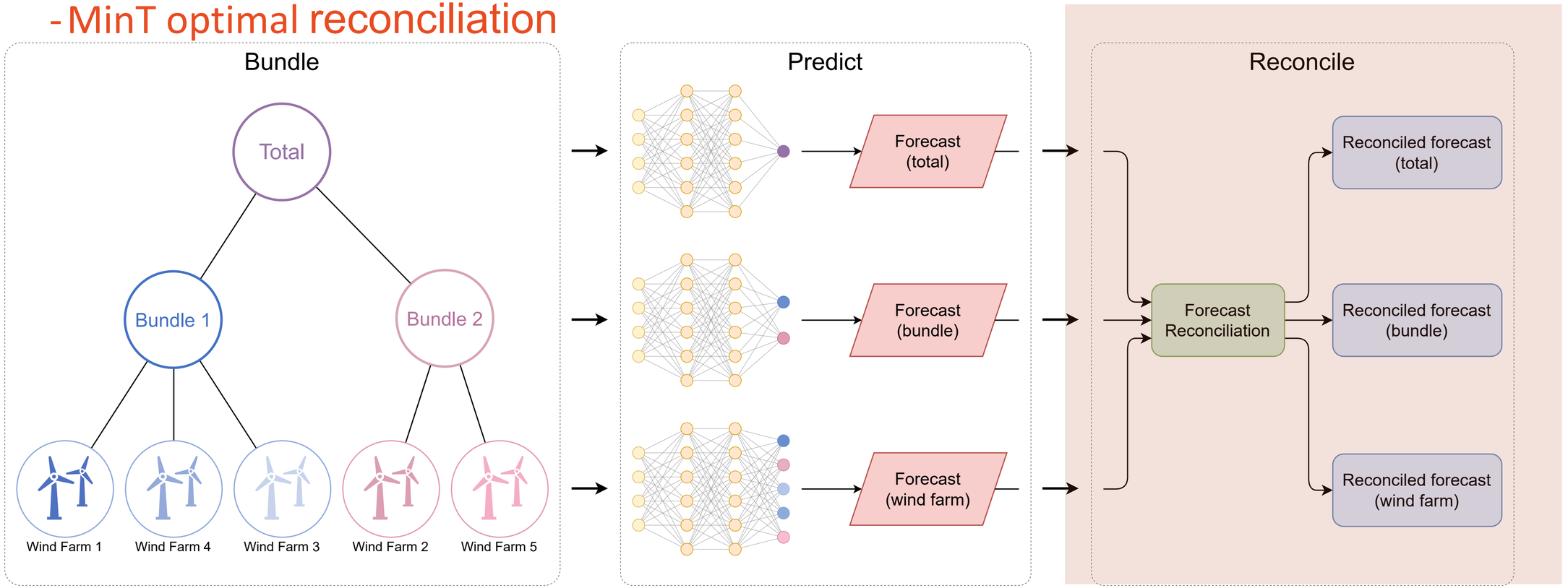
B. Sergi, C. Feng, F. Zhang, B.-M. Hodge, R. Ring-Jarvi, R. Bryce, K. Doubleday, M. Rose, G. Buster, and M. Rossol, “ARPA-E PERFORM datasets,” 08 2022.

Example: Bundled Wind Farms



Hierarchical Forecast Reconciliation

- Forecast reconciliation produces new forecasts that ensure consistency among three levels
  - MinT optimal reconciliation



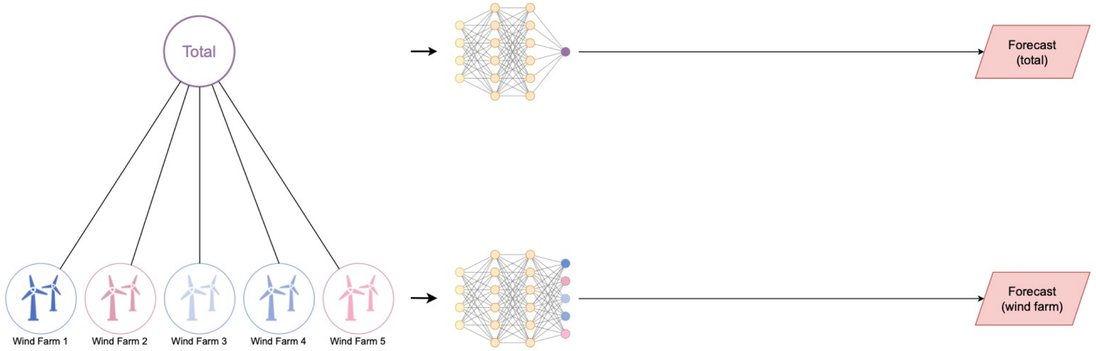
Wickramasuriya, Shanika L., George Athanasopoulos, and Rob J. Hyndman. "Optimal forecast reconciliation for hierarchical and grouped time series through trace minimization." Journal of the American Statistical Association 114.526 (2019): 804-819.

Experiments

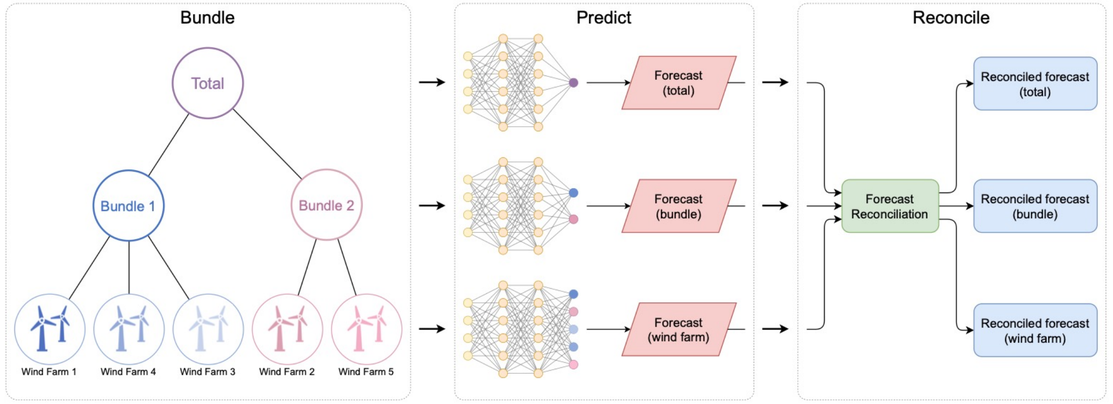
- Compare the vanilla framework (industry standard) with proposed BPR

- Compare the proposed bundling algorithm to the *kmeans* clustering baseline

- Two tasks
  -6 hours wind power prediction
  -48 hours wind power prediction



Vanilla



Proposed

Experiment Results

- Proposed BPR improves the prediction accuracy on both Fleet and Asset level

- 6 hours prediction:
  - Fleet level: BPR improves accuracy by 10% for the best model
  - Asset level: BPR improves accuracy by 2% improvement for the best model
  - Proposed *SAVar* is the strongest bundling criterion

- 48 hours prediction:
  - Fleet level: 6–8% improvement in NMAE and RMSE, 20% improvement in ED and VS
  - Asset level: 3% improvement in RMSE and ED
  - Proposed *Imcy* is the strongest bundling criterion