

Short-Term Probabilistic Forecasting of Individual Household Electricity Consumption

Using the Hungarian Algorithm

Graham McClone*, Chi Zhang, Lola Botman, Jan Kleissl and Adil Khurram

Department of Mechanical and Aerospace Engineering, University of California, San Diego

MOTIVATION

- Distribution line congestion causes difficulties in delivering power.
- Standard error metrics cause the double penalty effect as peak magnitudes might be correctly forecasted but may be off by a small number of time steps.
- Objective: Propose a first-ever use of the Hungarian Algorithm (HA) for probabilistic forecasting of individual household electrical consumption behavior patterns.

METHODOLOGY

- Historical electrical consumption data from 363 households in Ireland is processed to remove NaNs and separated into 7-day segments using a sliding window that advances one day at a time.
- The resulting vectors undergo min-max normalization such that all values range between 0 to 1, the timeseries for the single day following each historical week is also normalized in the same manner.
- The 7-day data for a given household is input into the proposed algorithm in which it is compared to all historical data vectors with a distance metric that uses temporal data shifting via the HA.
- The data for the single day following each of the k most similar 7-day segments to the input data is extracted to forecast the given household's next day's behavior.

Hungarian Algorithm Definition

- The HA determines the minimum linear combination of values from a matrix such that only one value is extracted from each row and each column
- This is often referred to as the assignment problem in which a set of workers must complete a set of tasks such that each task is performed once and each worker only performs one task

$$\begin{aligned} \min_P \quad & \text{Tr}(PC^{\text{HA}}) \\ \text{s.t.} \quad & \sum_{j=1}^N P_{ij} = 1, \quad \forall i \\ & \sum_{i=1}^N P_{ij} = 1, \quad \forall j \\ & P_{ij} \in \{0, 1\}, \quad \forall i, j = 1, \dots, N \\ & P_{ij} = 0, \quad \text{if } |i - j| > a \end{aligned}$$

P: Permutation Matrix C: Cost Matrix for assigning a worker to a task

N: Number of rows and columns a: Number of indices a switch is allowed to shift

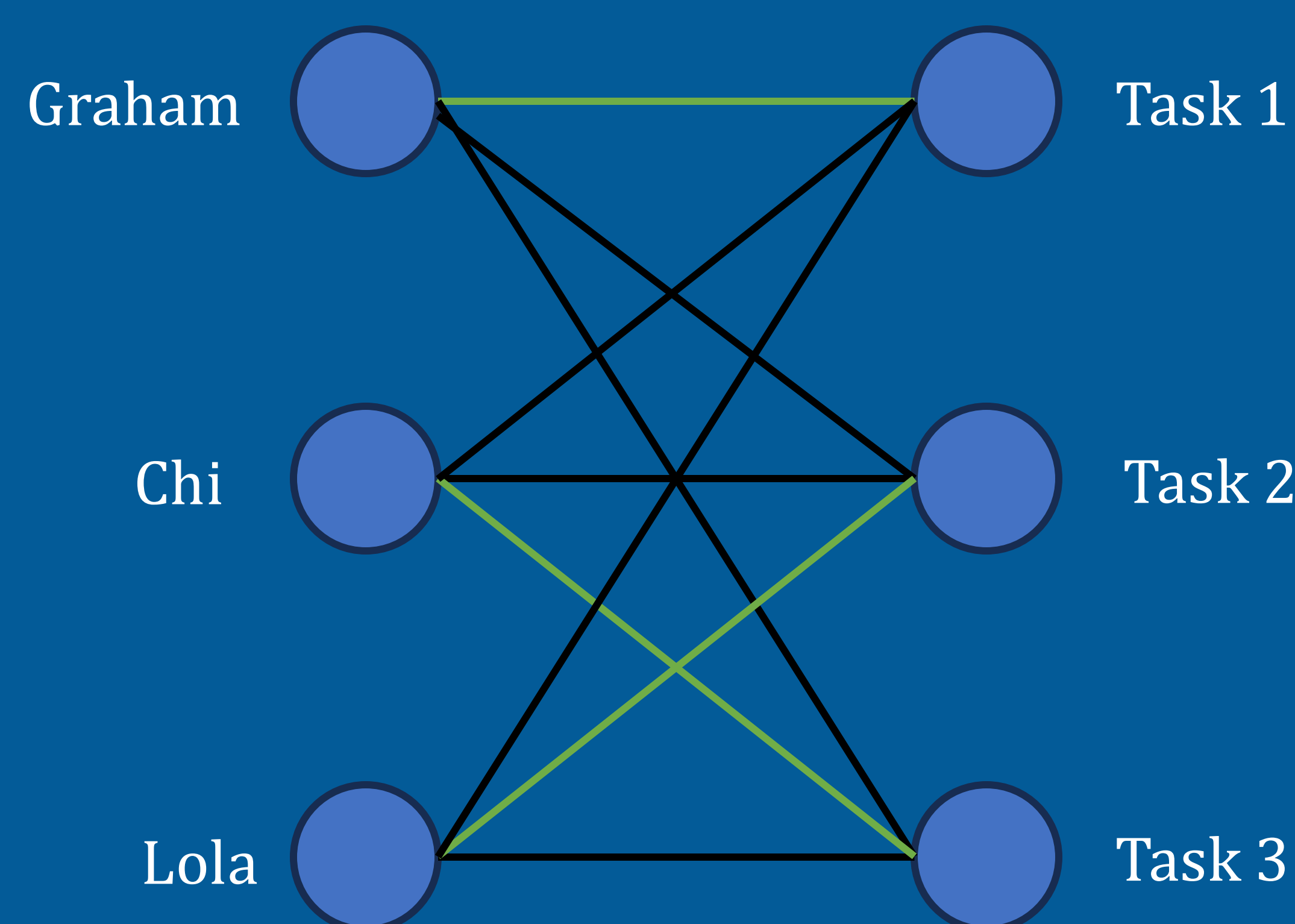
- The HA can be used to solve much larger problems, however the HA scales on $O(n^3)$
- To account for scaling, we propose the use of a novel time series clustering method
- This method maintains the HA's performance with a 94% reduction in runtime

Hungarian Algorithm Example

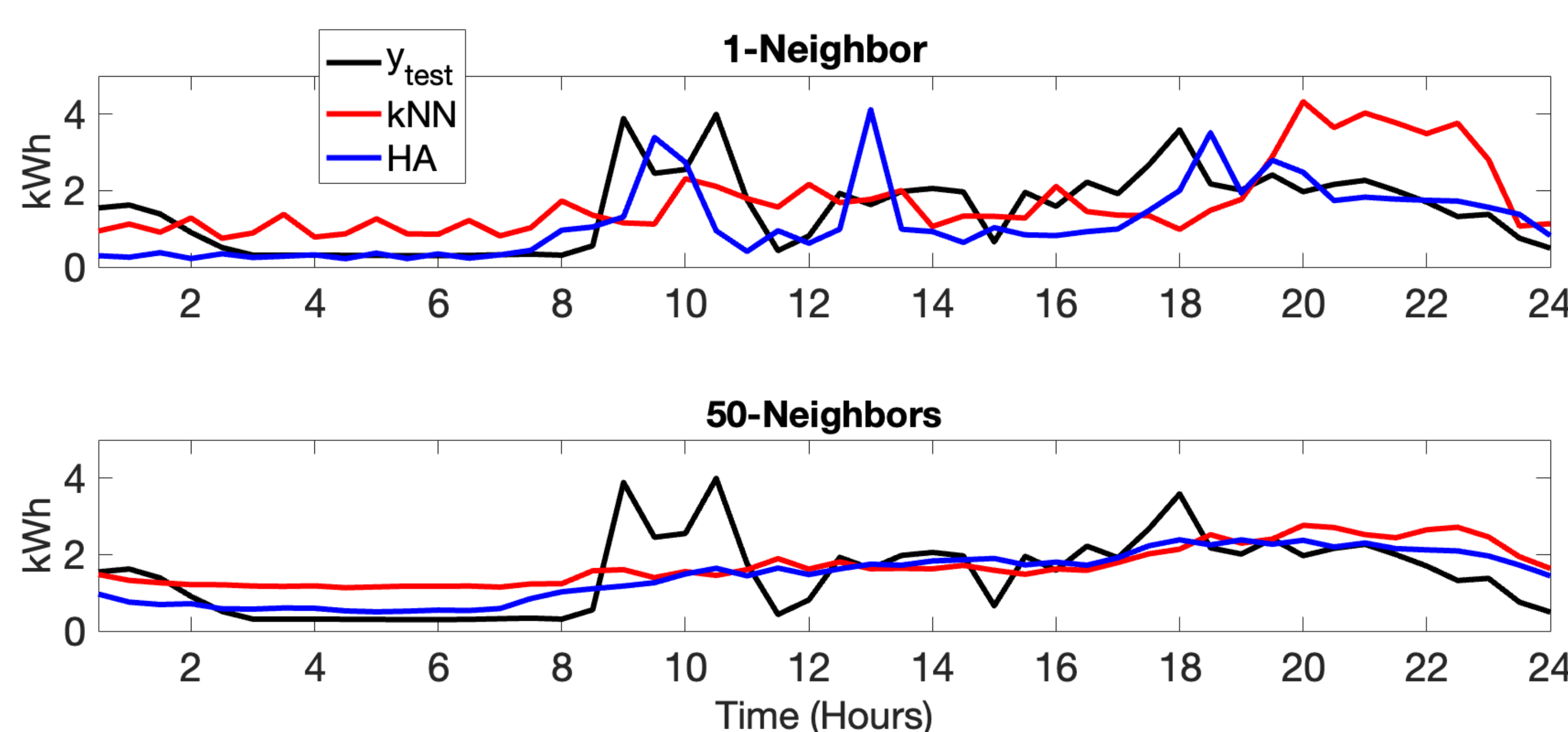
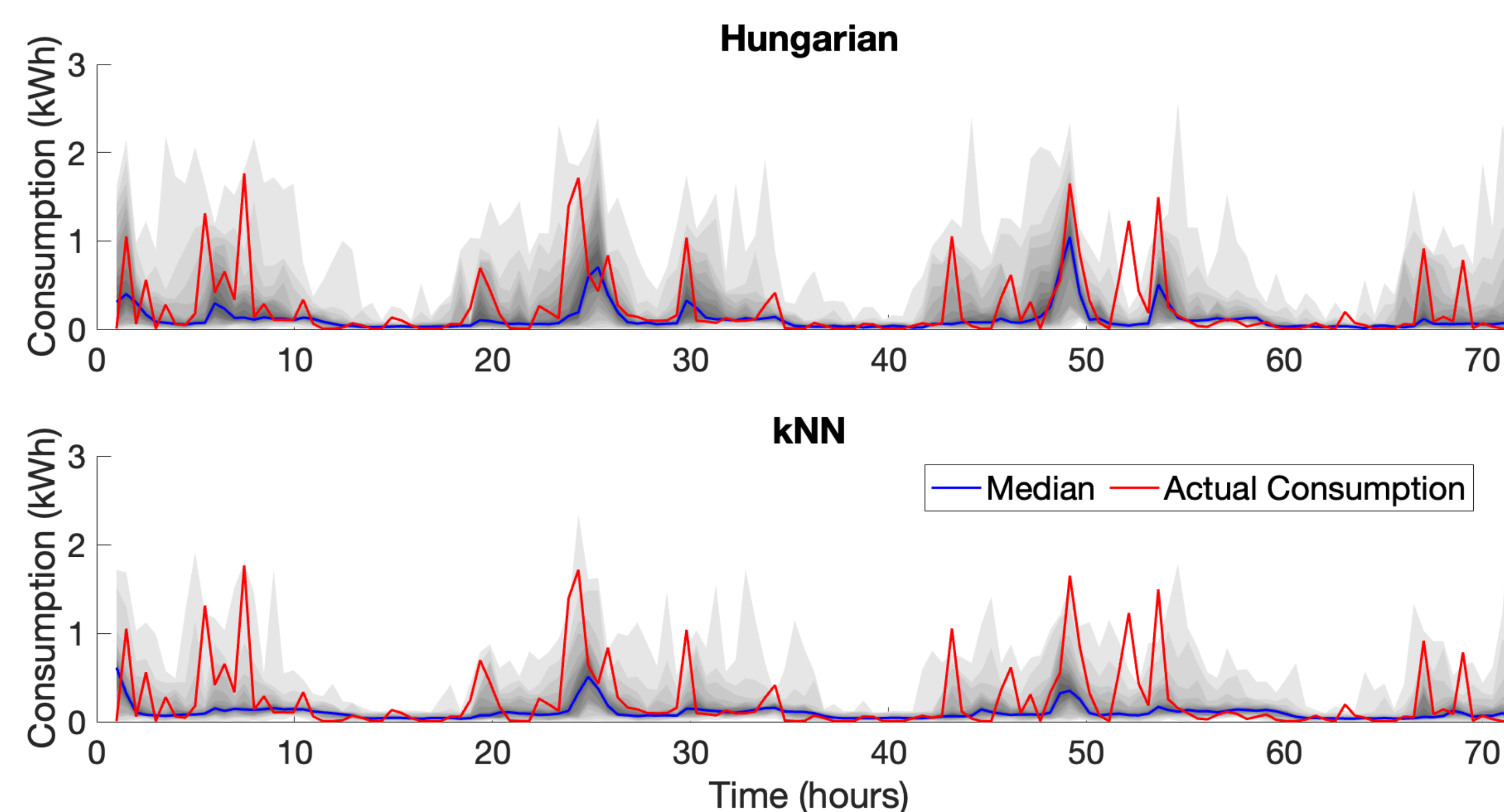
	Task 1	Task 2	Task 3	
$C^{\text{HA}} =$	\$2	\$4	\$6	2 4 6 1 0 0
Graham	\$4	\$4	\$4	$C^{\text{HA}} = 4 4 4 P^* = 0 0 1$
Chi	\$6	\$2	\$4	6 2 4 0 1 0
Lola				

- The least cost scenario for each task to be performed once and each worker to work once is provided by the C^{HA} and P^* matrices above

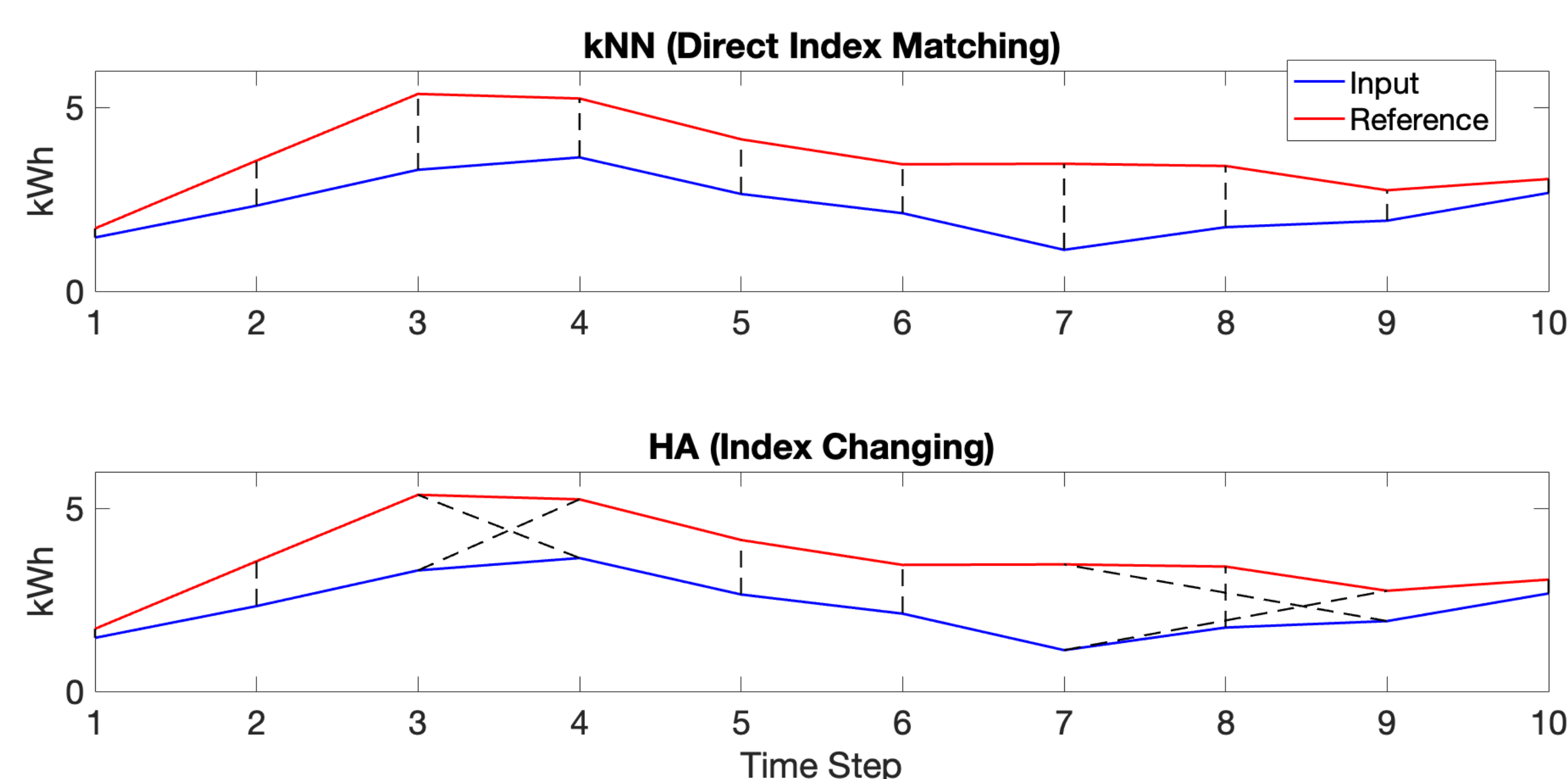
Bipartite Graph



Improve probabilistic forecasting of household electricity consumption by 2.5%-4.4%.



Full Text



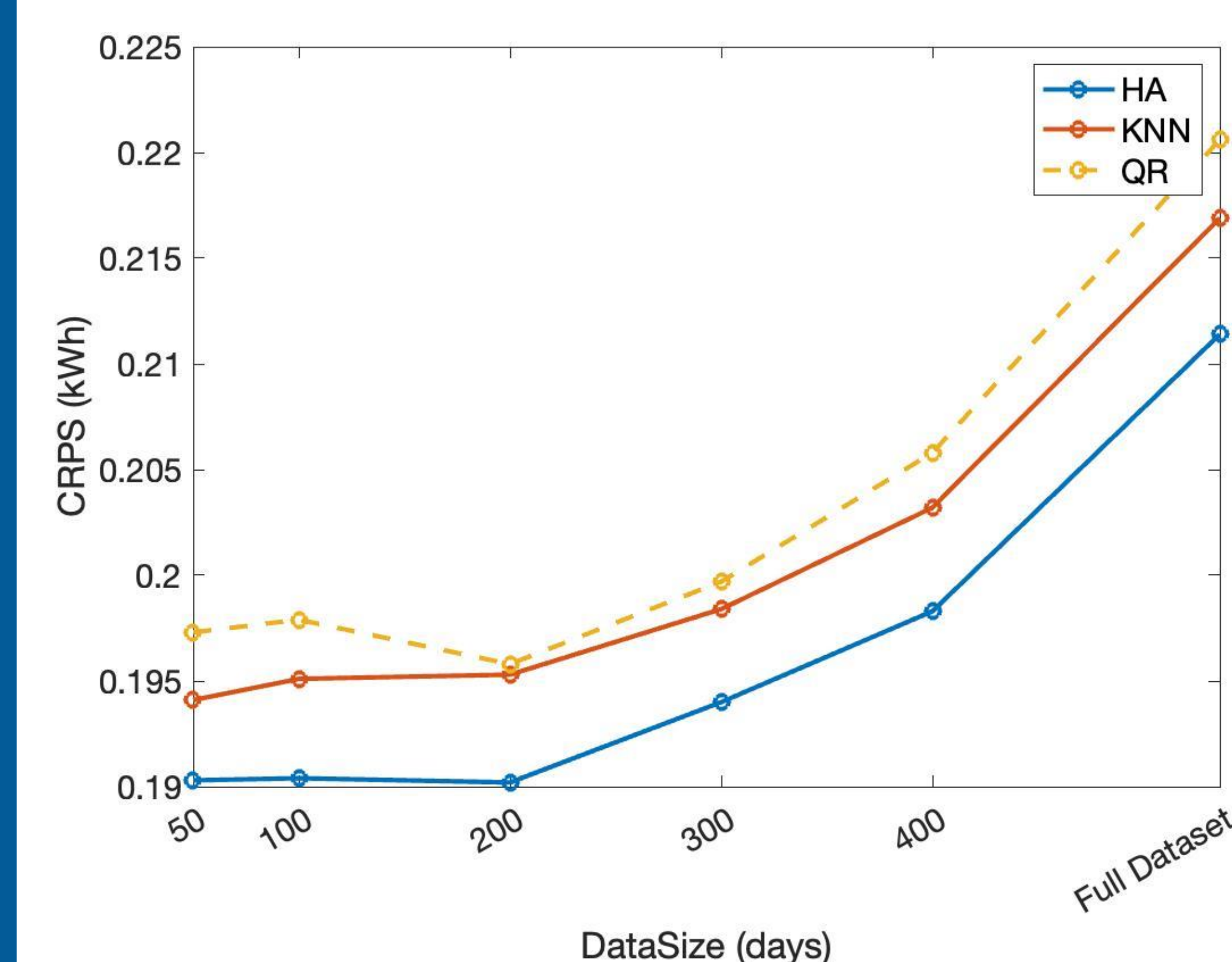
Probabilistic Forecasting

- Probabilistic forecasting generates a predicted probability distribution which informs a user of the likelihood of a given state at a given time
- Probabilistic forecasts are best evaluated using proper scoring metrics, such as the Continuous Ranked Probability Score (CRPS)
- The CRPS for discrete probability metrics (as in this case) is represented by the Pinball loss function which quantifies the accuracy of quantile forecasts by asymmetrically penalizing over- and under-predictions.

$$\text{Pinball}(\hat{Q}(q), y, q) = \begin{cases} (1-q)(\hat{Q}(q) - y), & \text{for } y < \hat{Q}(q) \\ q(y - \hat{Q}(q)), & \text{for } y \geq \hat{Q}(q) \end{cases}$$

RESULT COMPARISON

Methods	CRPS (kWh)	Approach
Hybrid HA	0.2090	Local
kNN	0.2169	Global
QR	0.2209	Local
HS	0.2212	Local
LSTM	0.2215	Local
LightGBM	0.2244	Local
XGBoost	0.2275	Local
Persistence	0.3272	Local



- The HA outperformed all other probabilistic methods by accounting for temporal shifts in peak consumption values
- A hybrid method which combines the HA with Historical Sampling demonstrated the best overall results by switching between methods

REFERENCES

S. Haben, J. Ward, D. Vukadinovic Greetham, C. Singleton, and P. Grindrod, "A new error measure for forecasts of household-level, high resolution electrical energy consumption," *International Journal of Forecasting*, vol. 30, no. 2, pp. 246-256, 2014.

L. Botman, J. Lago, T. Becker, K. Vanthournout, B. D. Moor, "A global probabilistic approach for short-term forecasting of individual households electricity consumption," *Applied Energy* 382 (2025) 125168.

* Denotes corresponding author

Email: gmclone@ucsd.edu

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