Optimal Energy Procurement for Geo-distributed Data Centers in Multi-timescale Markets

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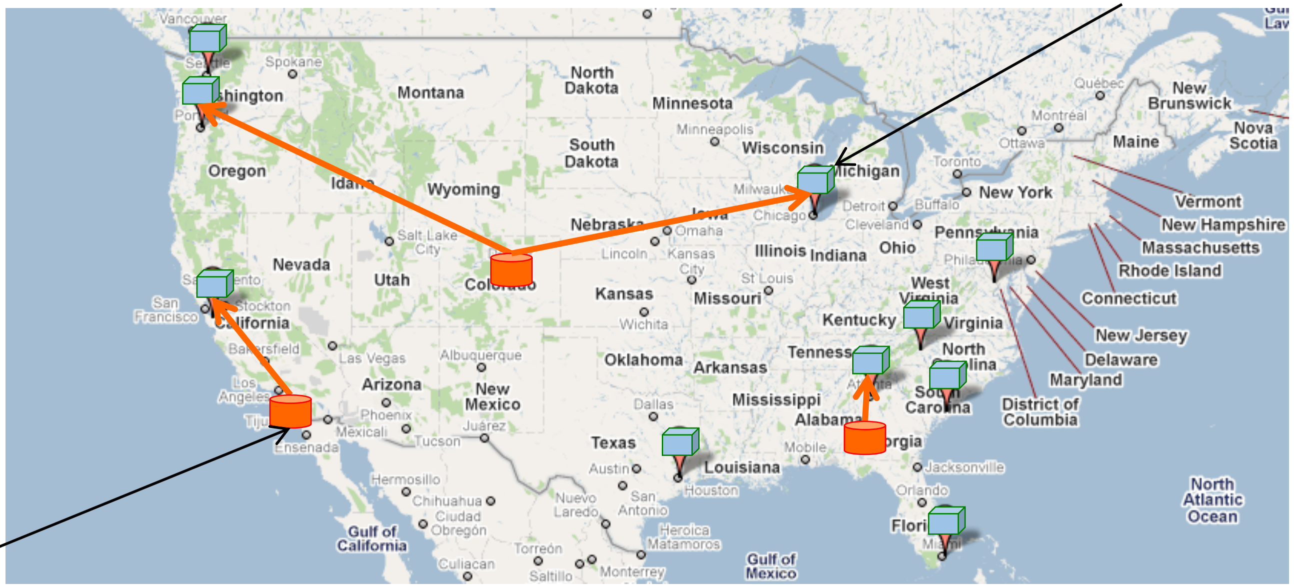
Tan N. Le, Jie Liang, Zhenhua Liu,

Ramesh K. Sitaraman, Jayakrishnan Nair, and Bong Jun Choi

tan.le@stonybrook.edu

Geographical Load Balancing (GLB)

Google data center



Data sources

+ Minimize network delay

+ Increase reliability

→Load balancing

→Network latency

→Energy

All are time varying and location dependent

Energy procurement in multi-timescale markets

<u>2 data centers in TX & NY:</u>

TX: \$0.03 kWh (*long-term*) & \$? kWh (*real-time*)

NY: \$0.05 kWh (*long-term*) & \$? kWh (*real-time*)

In real-time, renewables & electricity prices are uncertain

→ **Over or under procurement**

→ **expensive**

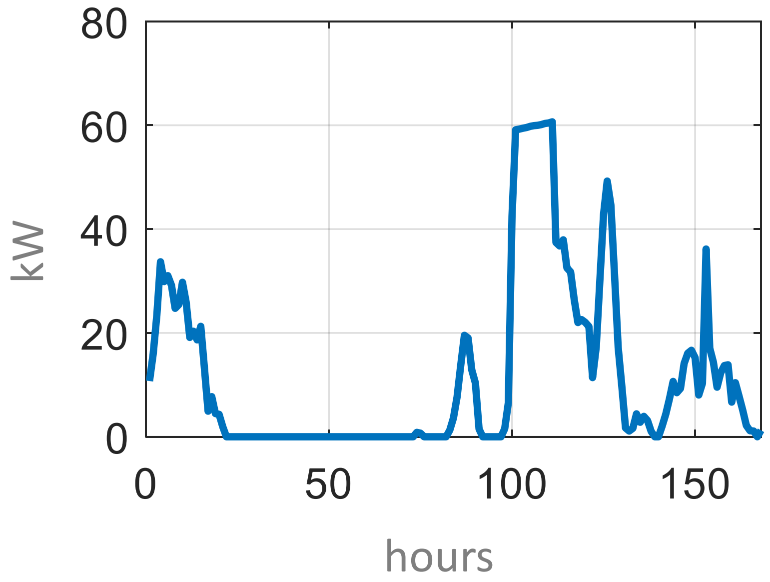
Time

Long-term

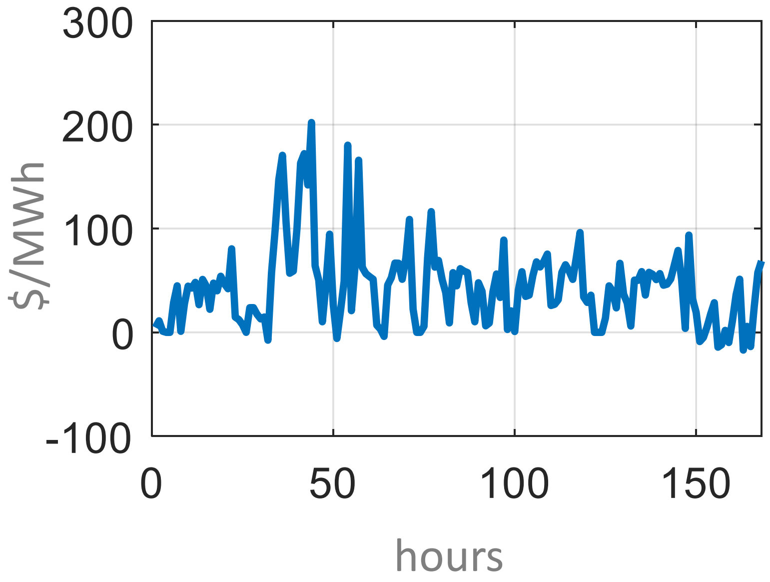
Real-time

How much electricity should we purchase in long-term for each data center?

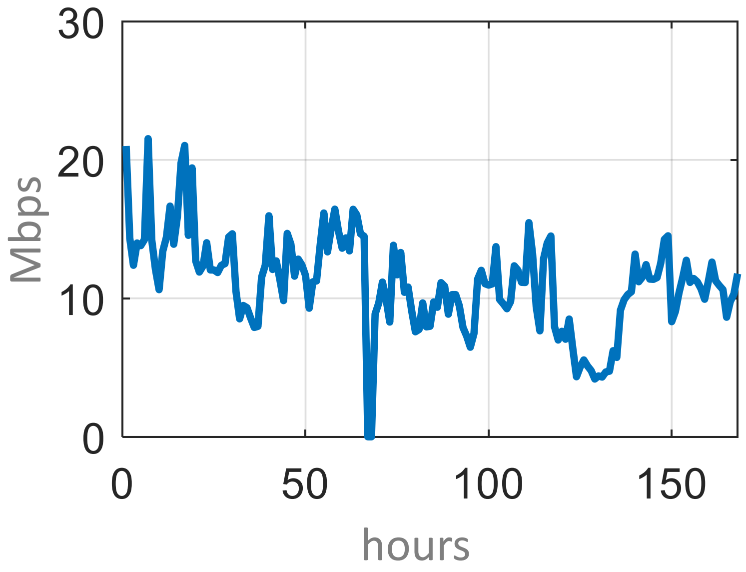
Challenges raise on the energy procurement problem



wind generation in CA
(NREL)



electricity prices
(CAISO)



workload in CA
(Akamai)

Long-term procurement and real-time GLB are coupled

✓Real-time costs depend on what happens in long-term

✓Long-term decision needs to consider how GLB works

Prior works

Real-time markets

Locational prices:

“Cutting the electric bill for internet-scale systems” SIGCOMM’09

A. Qureshi, R. Weber, H. Balakrishnan, J. Guttag, B. Maggs

“Greening geographical load balancing” SIGMETRICS’11

Z. Liu, M. Lin, A. Wierman, S. H. Low, and L. L. Andrew

Temporal prices:

“Minimizing data center SLA violations and power consumption via hybrid resource provisioning” IGCC’11

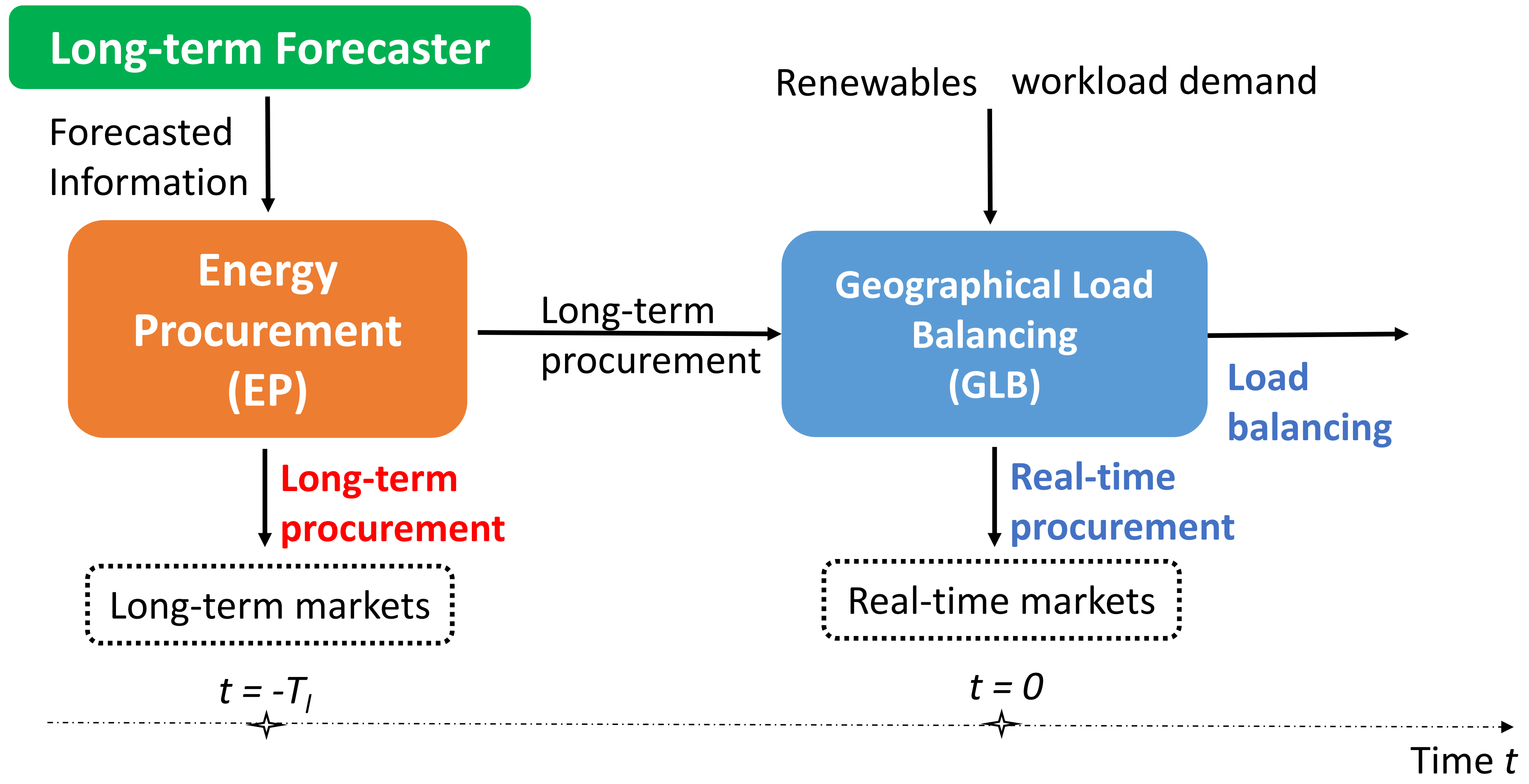
A. Gandhi, Y. Chen, D. Gmach, M. Arlitt, M. Marwah

Multi-time scale markets

“Energy portfolio optimization of data centers” Trans. Smartgrid’16

M. Ghamkhari, A. Wierman, and H. Mohsenian-Rad

Energy Procurement System



Goal: Optimize procurement in long-term markets

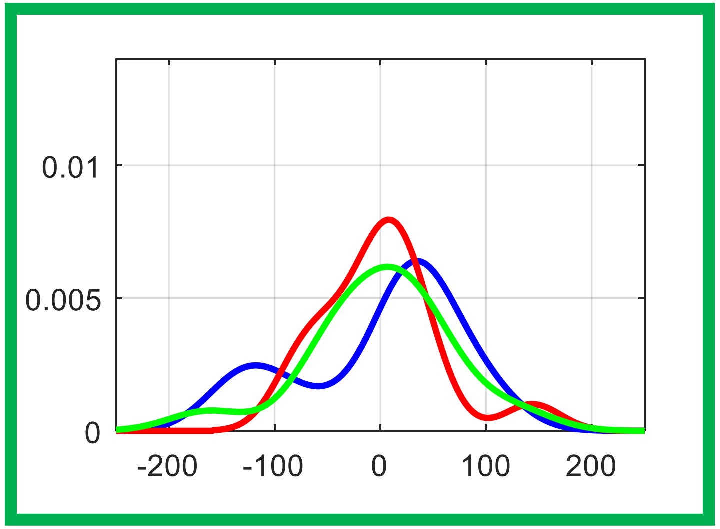
Challenges: Deal with multiple sources of uncertainty

Prediction

Modeling

Algorithms

Evaluation



Long-term forecast

✓ **AR (Autoregressive model)**
captures **daily pattern**
input: historical data

✓ **SVM (Support Vector Machine)**
captures seasonality of data
input: hour, day, month

✓ **L-AVG (Long-term Average)** as a baseline
assumes data have long-term cycles
i.e., average of 30 days at the same time of previous years

Heterogonous prediction errors based on location

AR *SVM* *L-AVG*

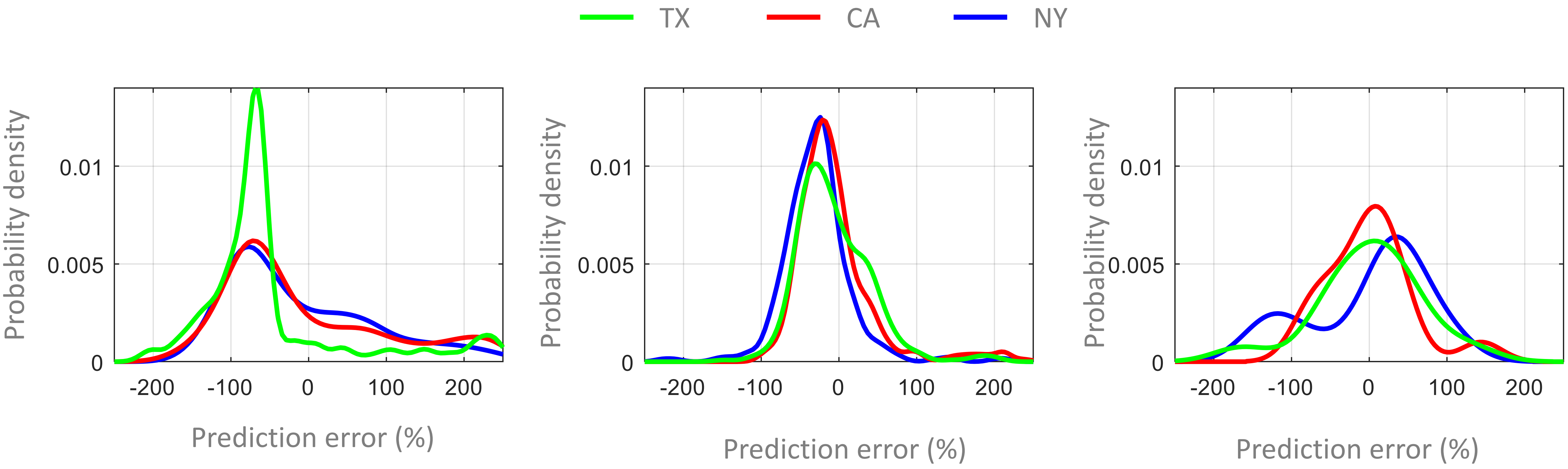
Wind generation
(30-day ahead)

Electricity prices
(30-day ahead)

workload
(1-day ahead)

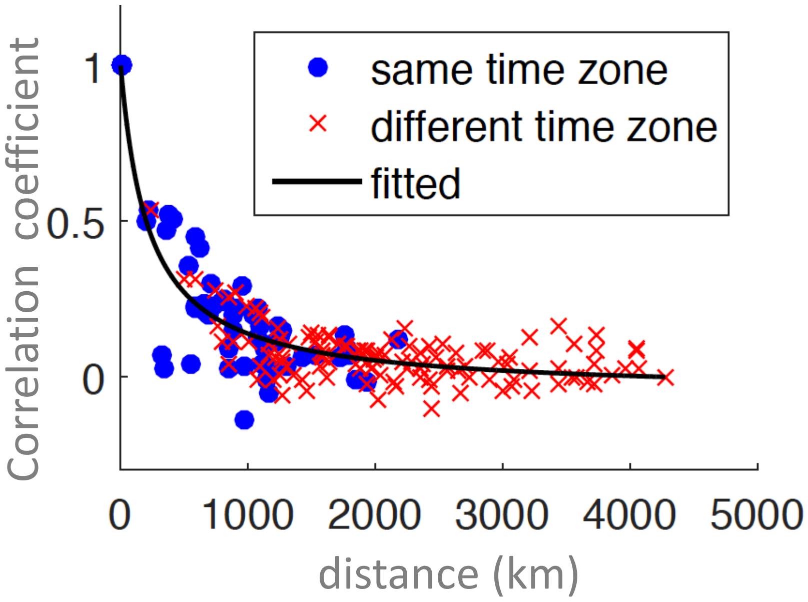
We use AR for the other results in this talk

Distributions of errors are not Normal

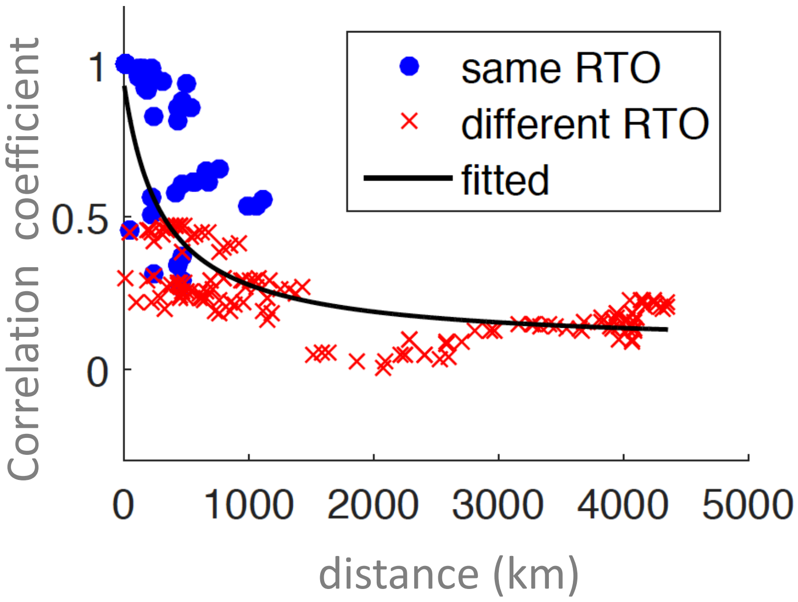


Wind generation **Electricity prices** **Workload**

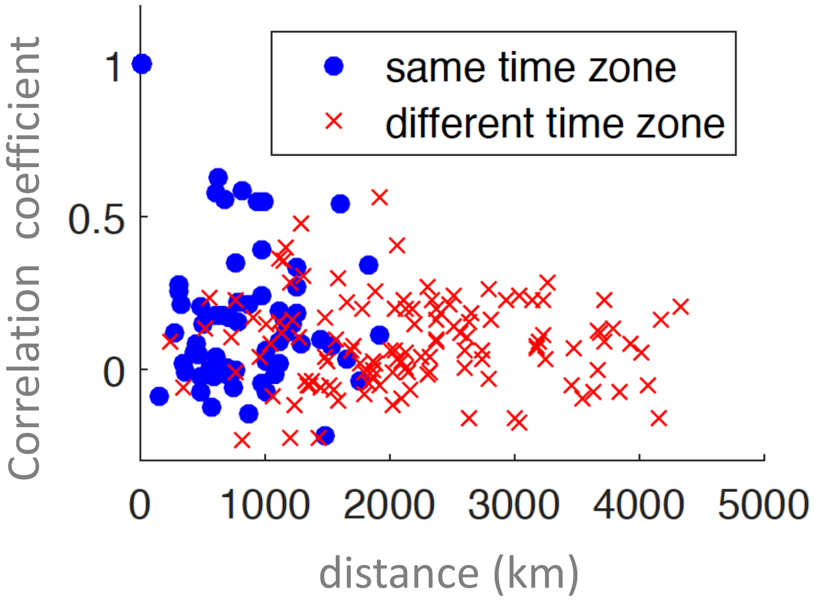
Weak correlation on long distances



Wind generation



Electricity prices



Workload

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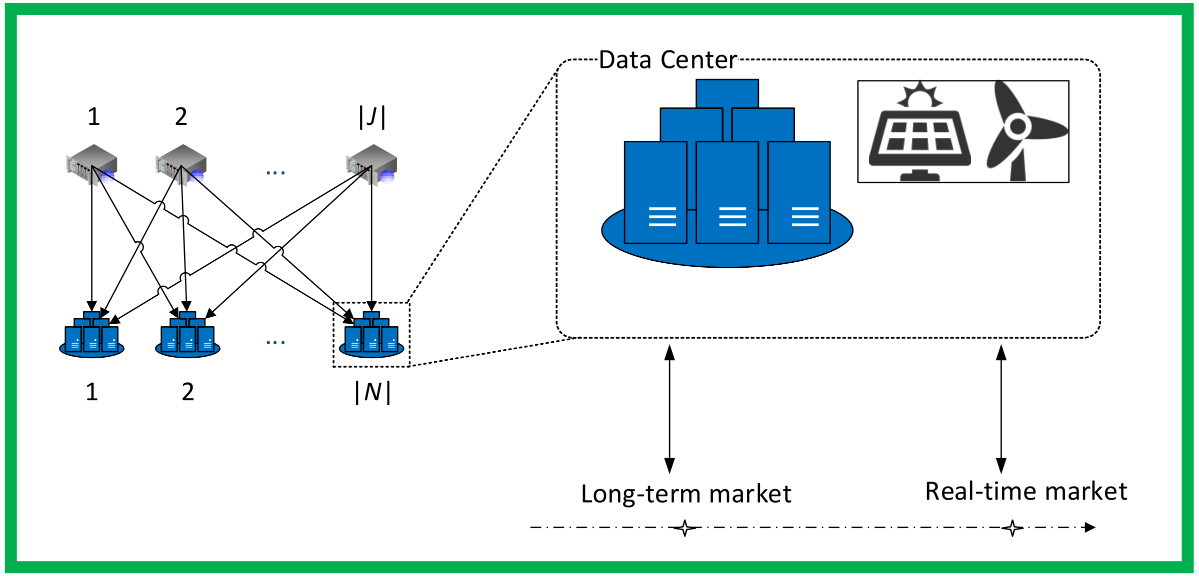
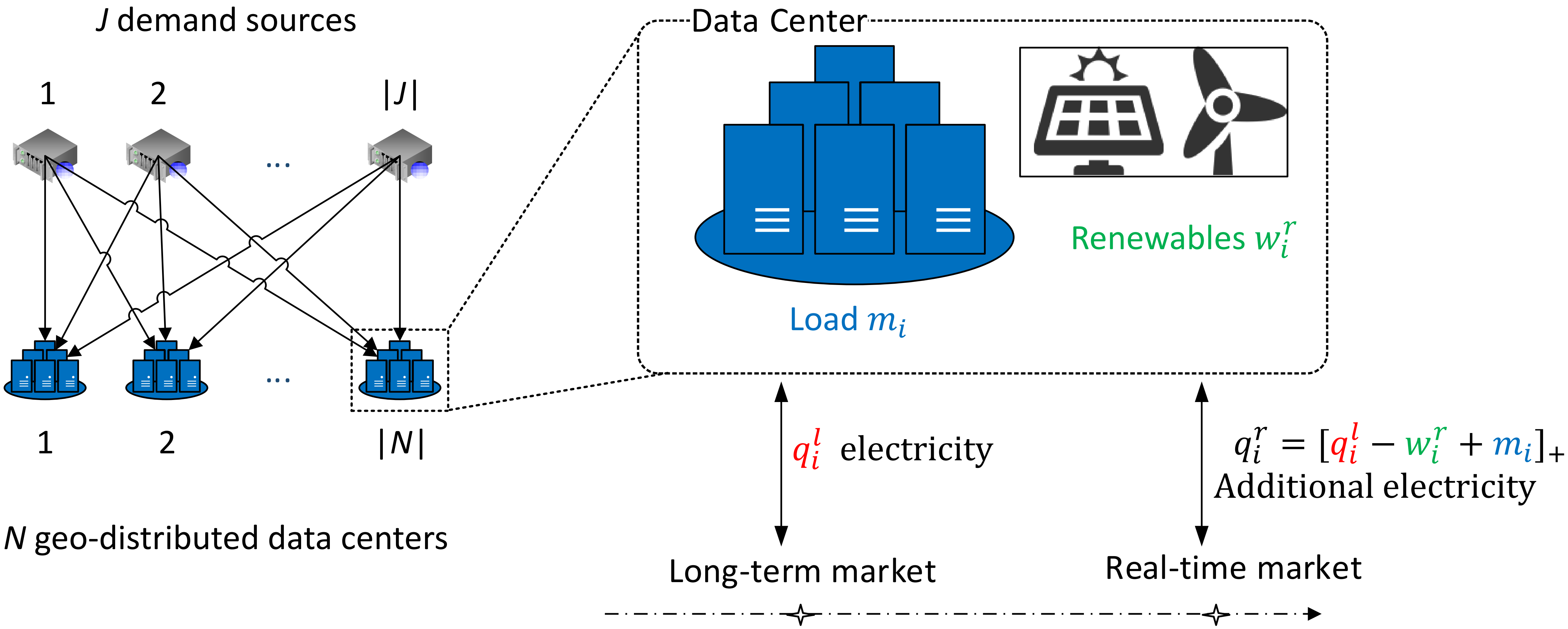


Model: GLB in Multi-timescale Markets



How to optimally purchase the electricity in long-term markets?

Real-time geographical load balancing

$F^{*r}(\boldsymbol{q}^l, \boldsymbol{w}^r, \boldsymbol{p}^r, \boldsymbol{L}^r) = \min_{\boldsymbol{q}^r, \boldsymbol{m}, \boldsymbol{\lambda}}$ **Minimize energy costs + delay costs**

input

- Long-term procurement $\boldsymbol{q}^l$
- Demand $\boldsymbol{L}$
- Electricity prices $\boldsymbol{p}^r$
- Renewable energy $\boldsymbol{w}$

output

- Load balancing $\boldsymbol{\lambda}$
- Procurement $\boldsymbol{q}^r$
- DC consumption $\boldsymbol{m}$

Long-term optimization

Minimize long-term cost
$\boldsymbol{q}^l$

+ expected optimal real-time cost

Long-term	Real-time
Energy cost $(\boldsymbol{q}^l)$	$\mathbb{E}_{\boldsymbol{q}^l, \boldsymbol{w}^r, \boldsymbol{p}^r, \boldsymbol{L}^r}$[optimal real–time cost]

$$F(\boldsymbol{q}^l) = \sum_{\{i \in N\}} R_i^l(q_i^l) + \mathbb{E}_{\boldsymbol{q}^l, \boldsymbol{w}^r, \boldsymbol{p}^r, \boldsymbol{L}^r}\left[F^{*r}(\boldsymbol{q}^l, \boldsymbol{w}^r, \boldsymbol{p}^r, \boldsymbol{L}^r)\right]$$

Properties of long-term optimal

Convexity of long-term optimal

The long-term objective $F(\boldsymbol{q}^l)$ is convex w.r.t. $\boldsymbol{q}^l$

Gradient of $F(\boldsymbol{q}^l)$

$\frac{\partial F(\boldsymbol{q}^l)}{\partial q_i^l}$ = long-term price - $\mathbb{E}_{\boldsymbol{q}^l, \boldsymbol{w}^r, \boldsymbol{p}^r, \boldsymbol{L}^r}$[**gradient of real–time cost**]

Utilization of long-term procurement

*an optimal solution always **utilizes the long-term procurement and renewables as much as possible** to reduce delay cost.*

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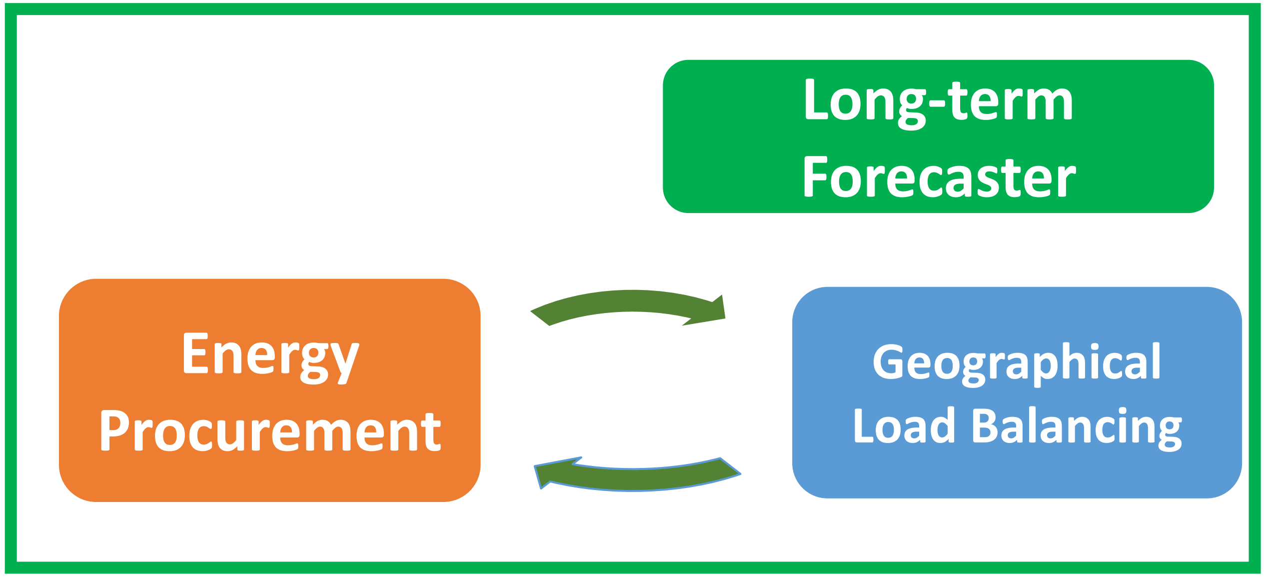


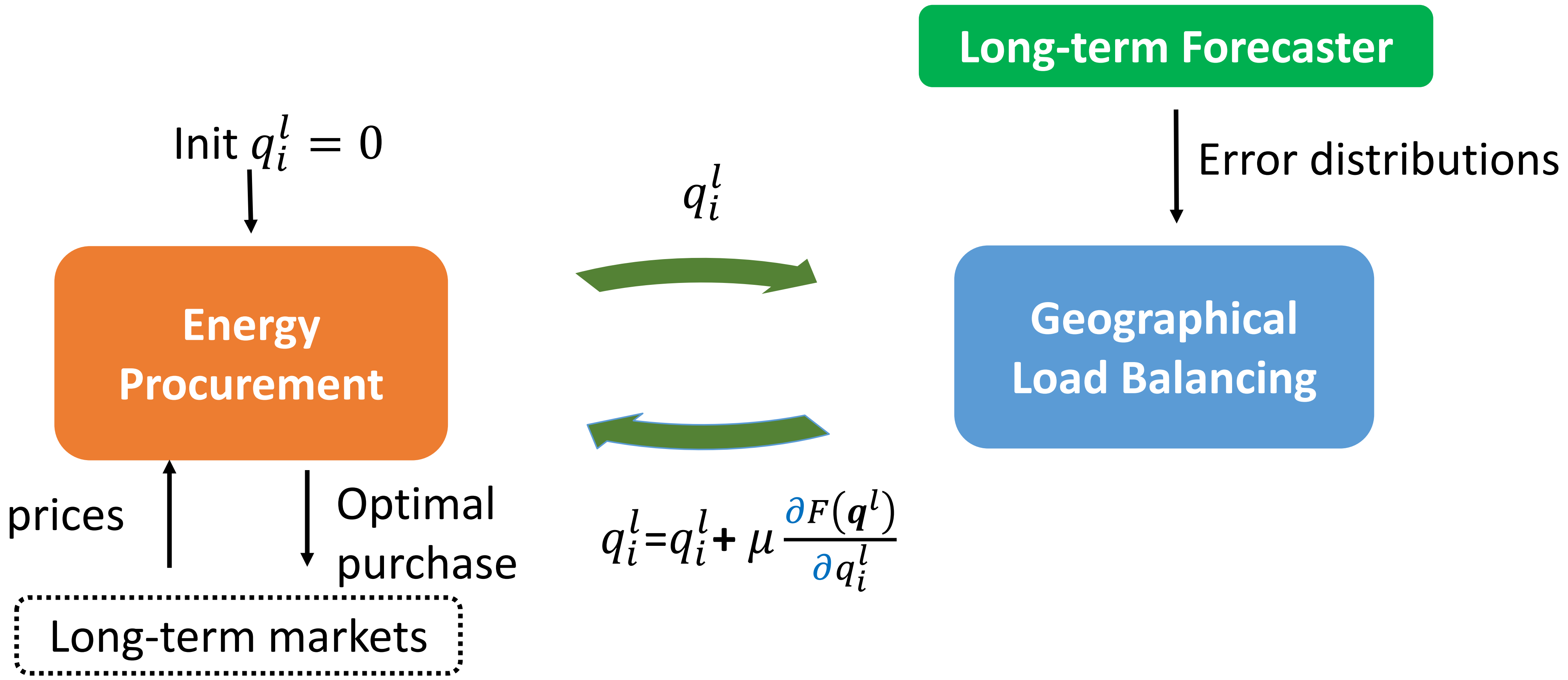
Prediction based Algorithm (PA)

Obtain the ***predicted values*** in real-time

Demand	Renewable generation	Electricity prices
$\hat{L}^r$	$\hat{w}^r$	$\hat{p}^r$

Long-term	**Real-time**
Energy cost (q^l)	$\mathbb{E}_{q^l, w^r, p^r, L^r}$ [**optimal real–time cost**]

Optimal: Stochastic Gradient based Algorithm (SGA)



Theorem. <u>The solution of SGA converges to the set of optimal solutions</u> under a right choice of step sizes.

Goal: Optimize procurement in long-term markets

Challenges: Deal with multiple sources of uncertainty

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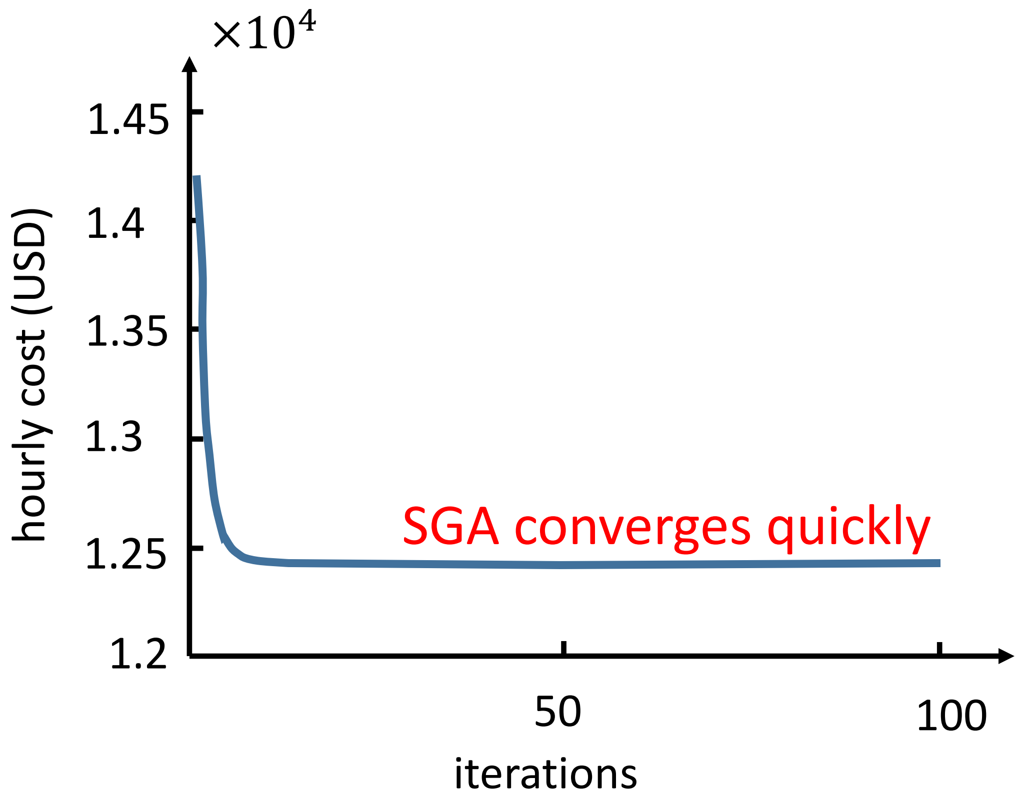
Evaluation Setup

50% wind power

50% grid power

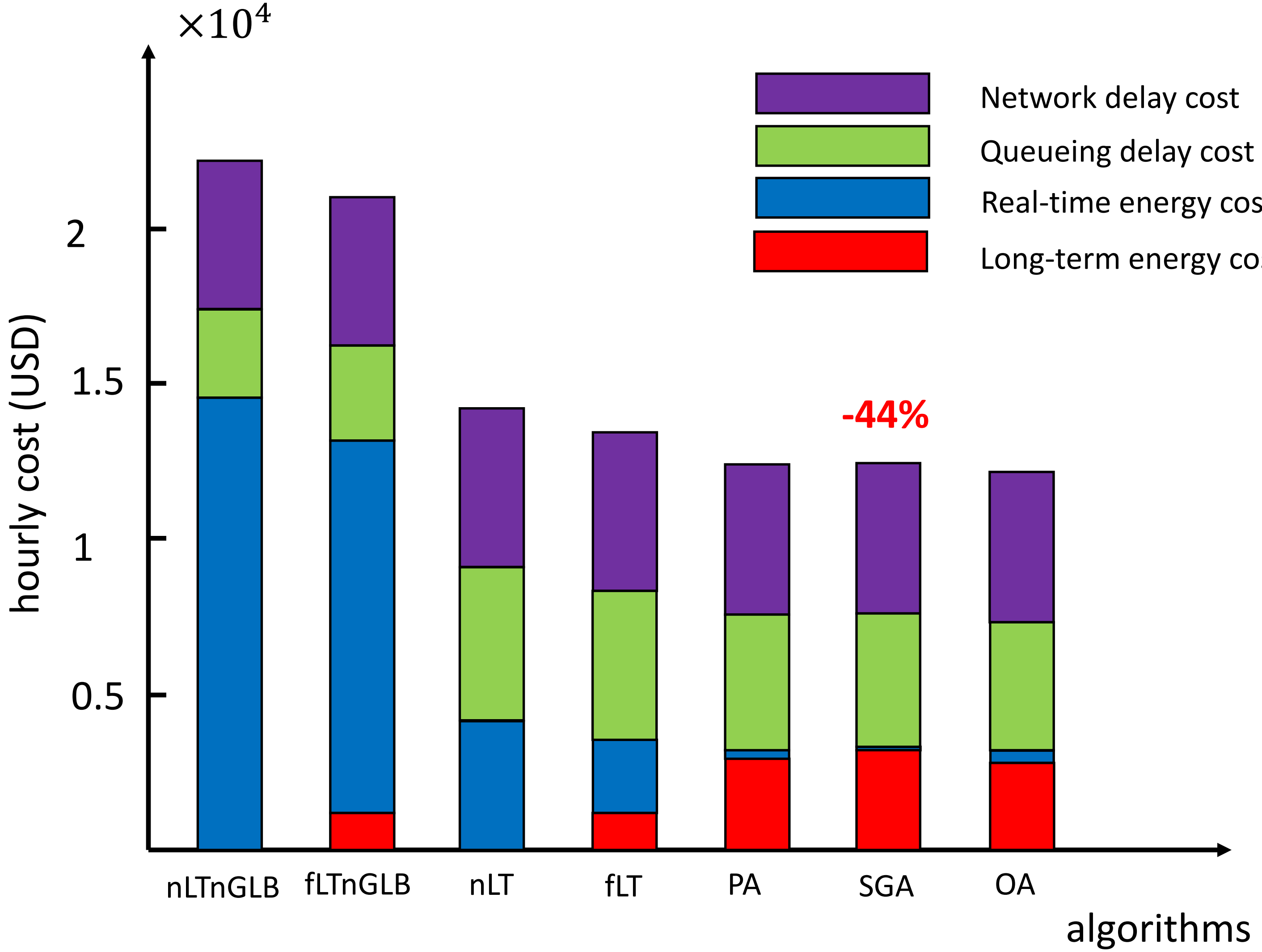
- ✓ **Workload**: Akamai data in USA
- ✓ **Electricity prices from local RTOs**
- ✓ **Prediction errors** from long-term forecaster
- ✓ **Network delay** is proportional to the distance between sources and data centers
- ✓ **Queuing delay** M/GI/1

Convergence of SGA



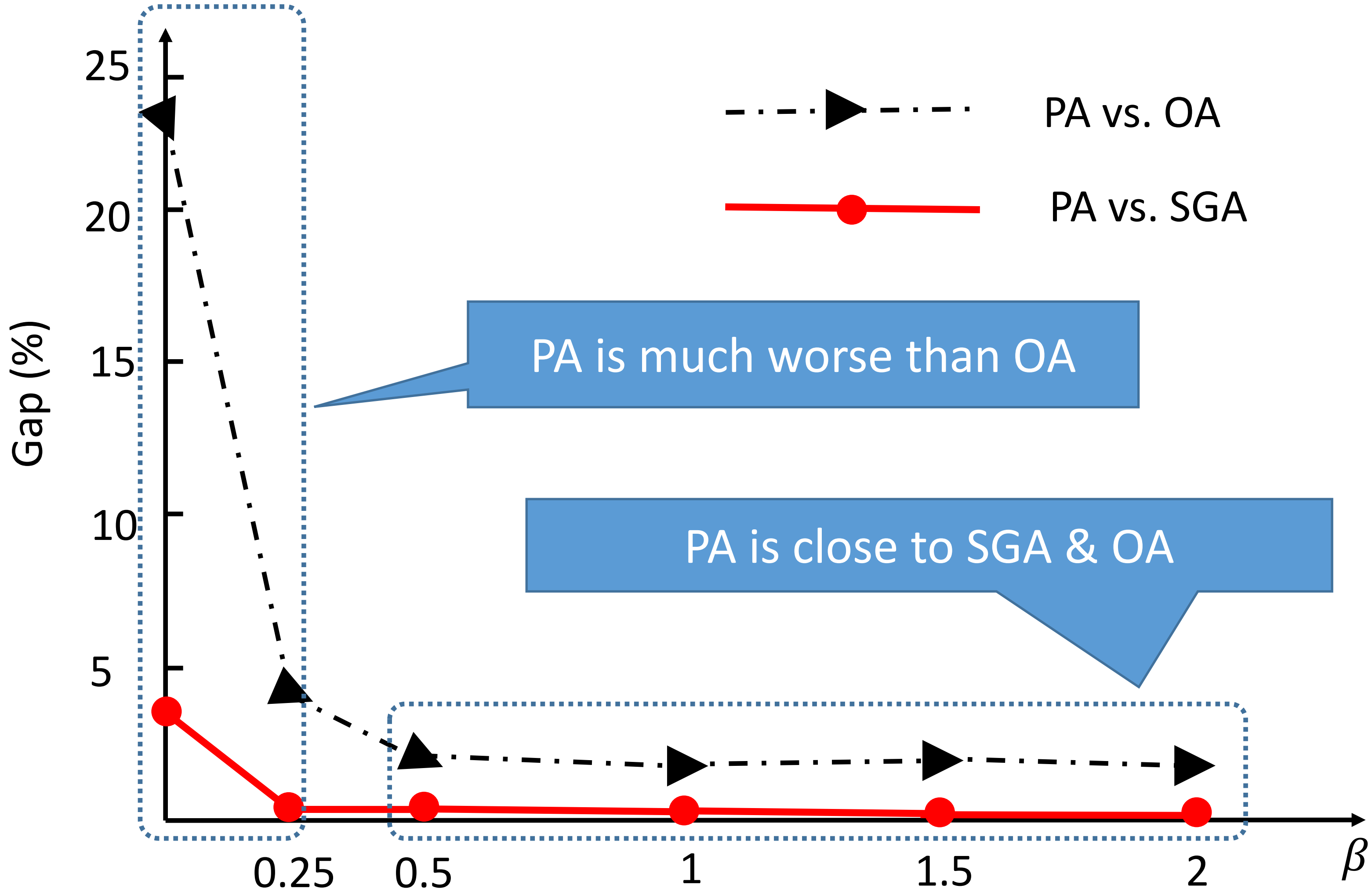
step sizes are **decreasing & dynamic**

How much do PA & SGA improve?



PA & SGA are very close to OA

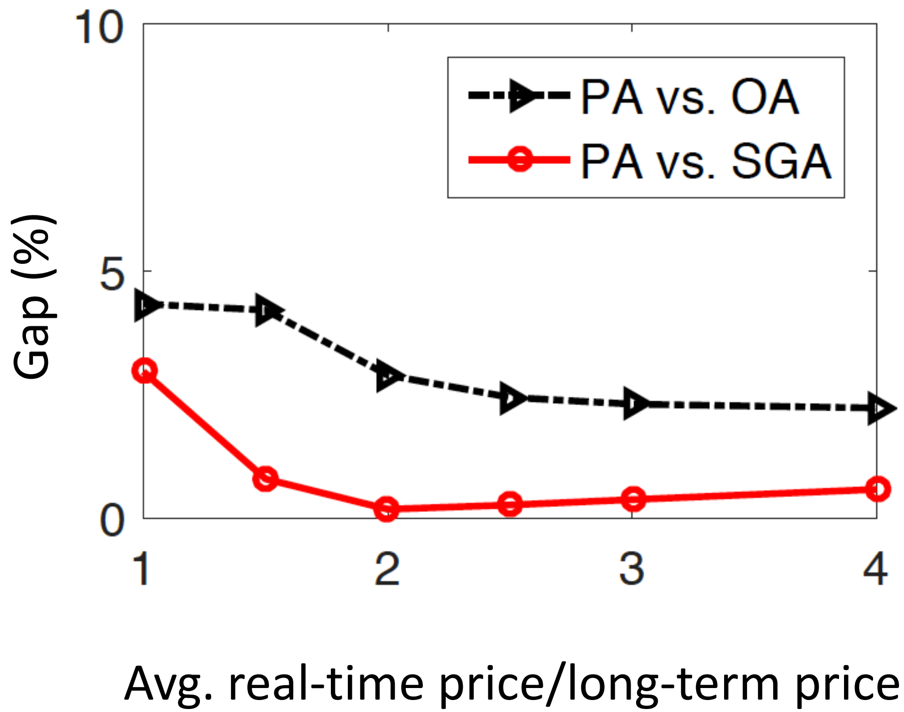
Why does PA work well?



β: scaled importance factor of delay

Trade-off between energy and delay facilitates PA

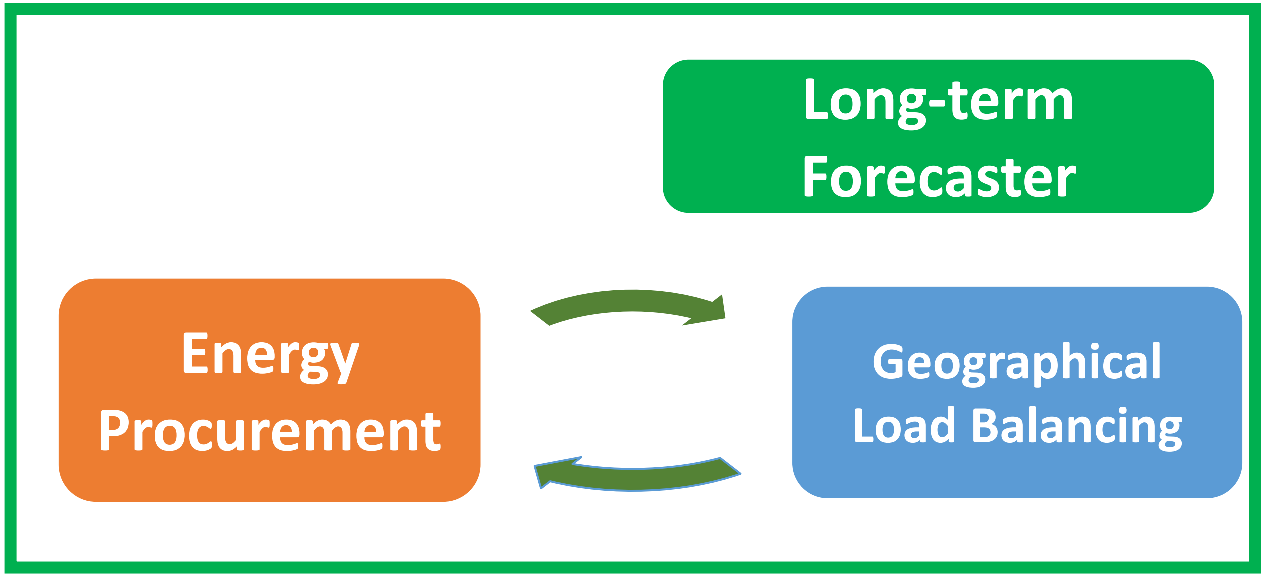
Sensitivity analysis



SGA is more preferable to PA when the long-term prices are high

Goal: Optimize procurement in long-term markets

Approach: Deal with multiple sources of uncertainty



Thank you