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German Data Science Days 2025

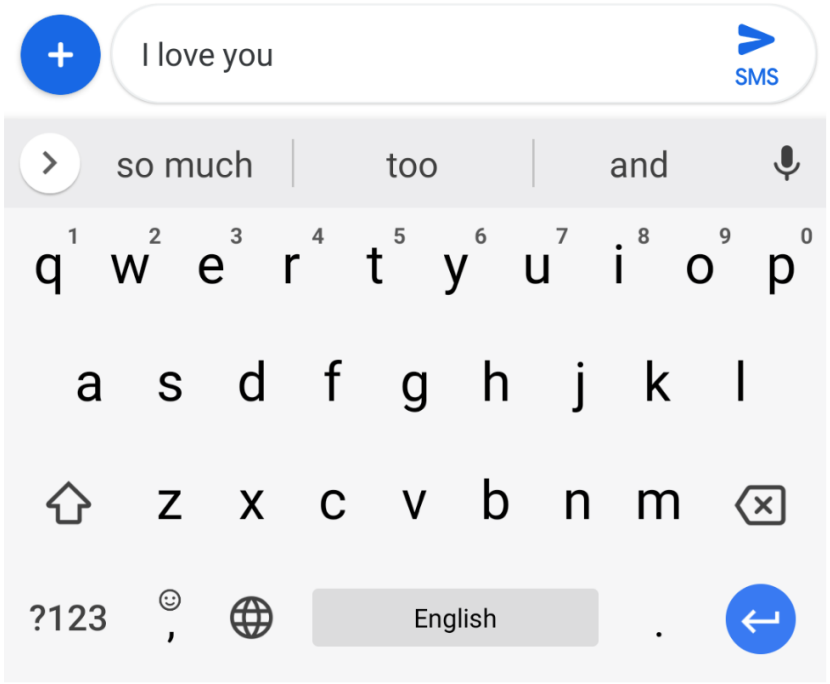
Federated Learning-based Forecasting of Renewable Energy Production

Karlsruhe University of Applied Sciences

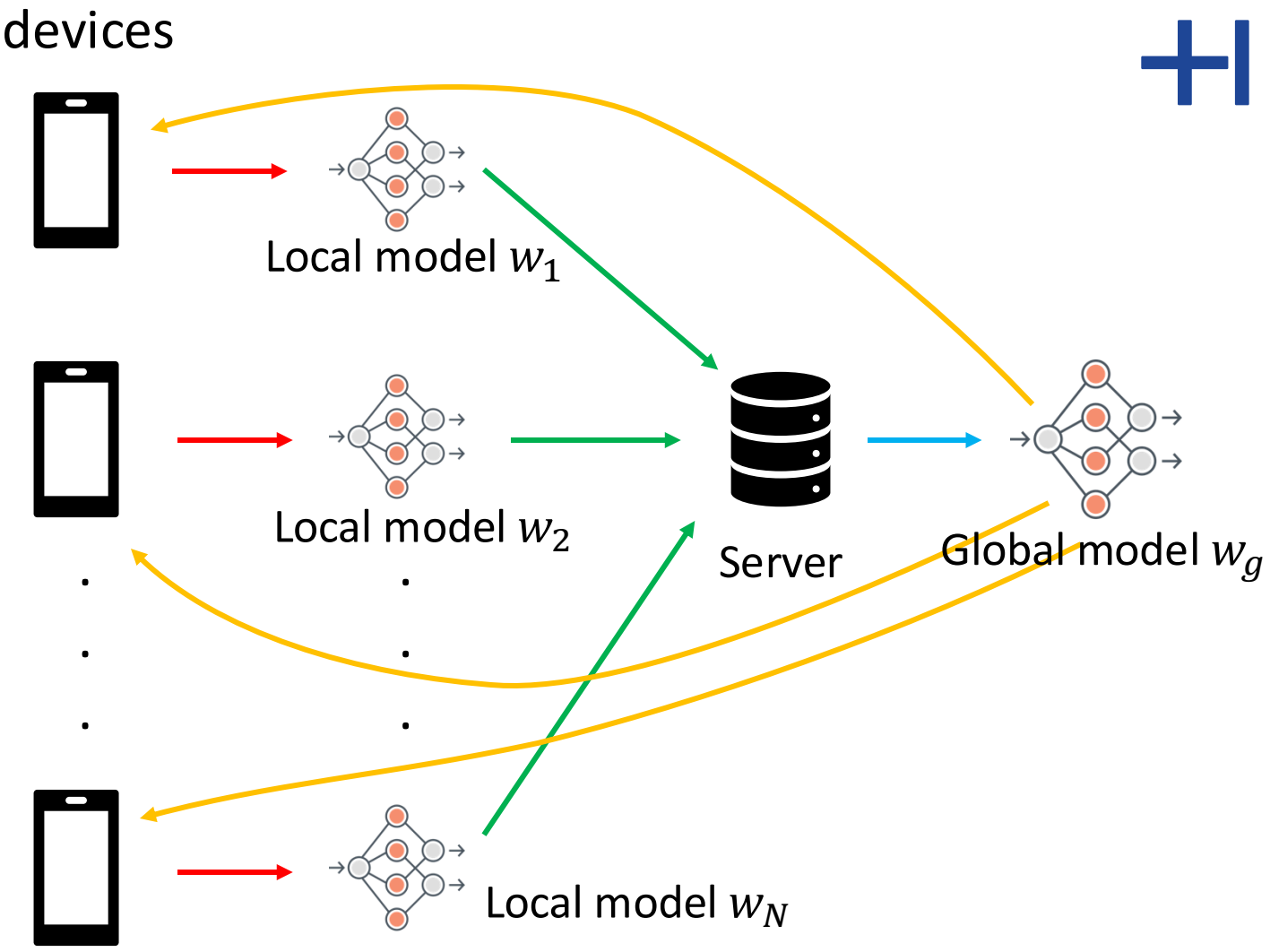
Research Project FederatedForecasts, funded by

Federal Ministry
of Education
and Research

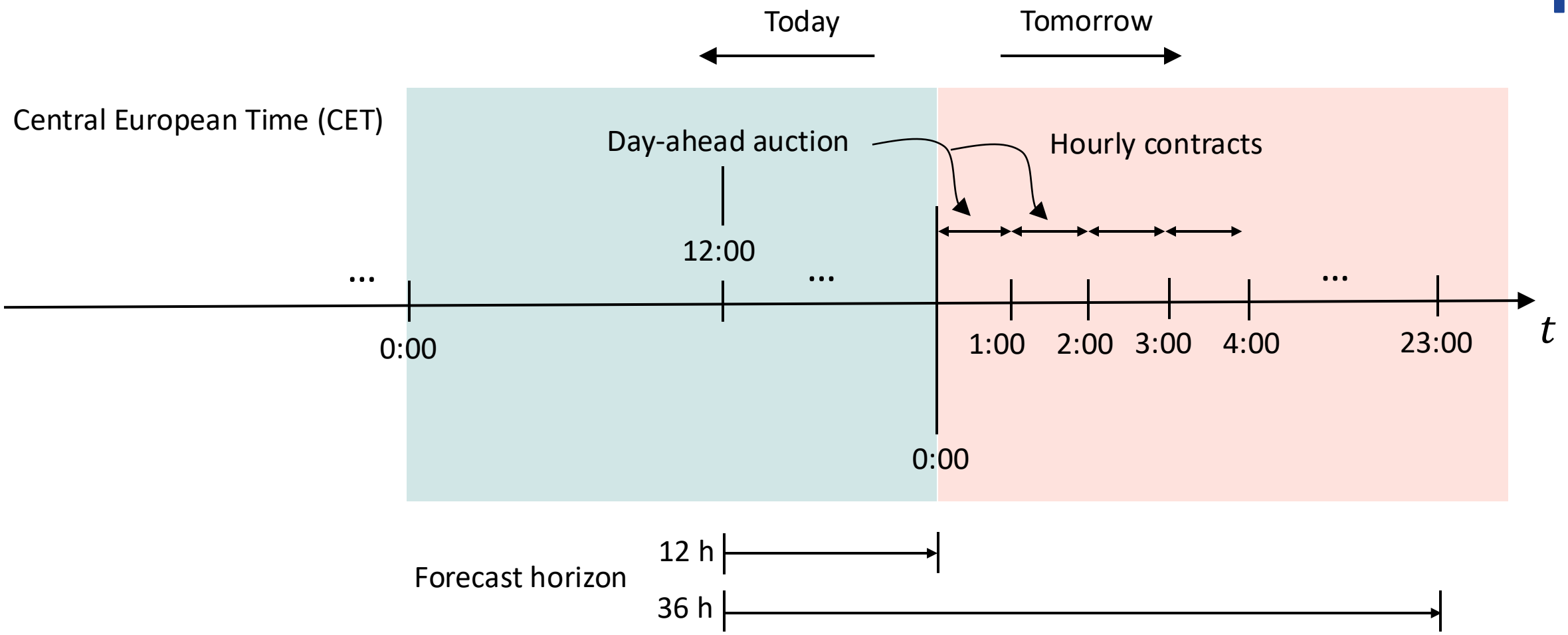
Viktor Walter



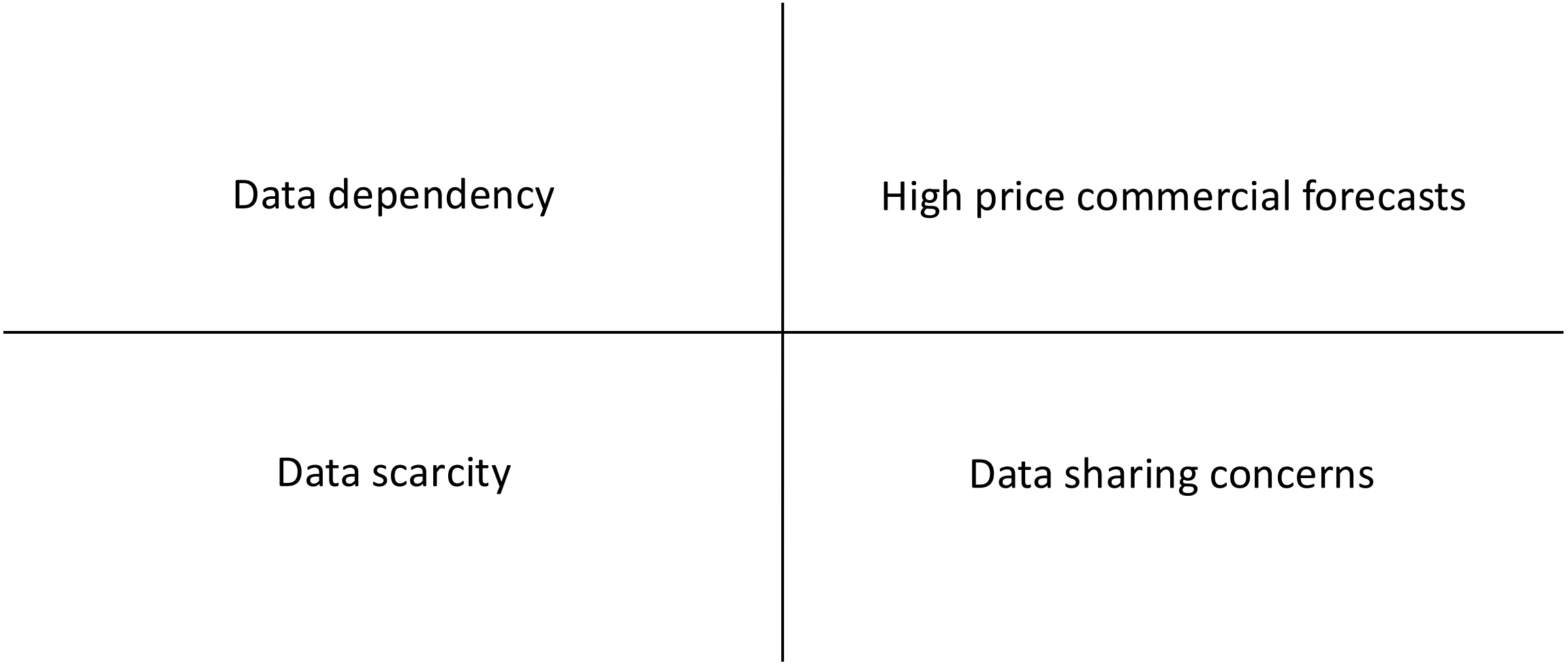
Google‘s Gboard predicts „and“, „too“ and „so much“ on the context „I love you“ (Hard et al., 2018)



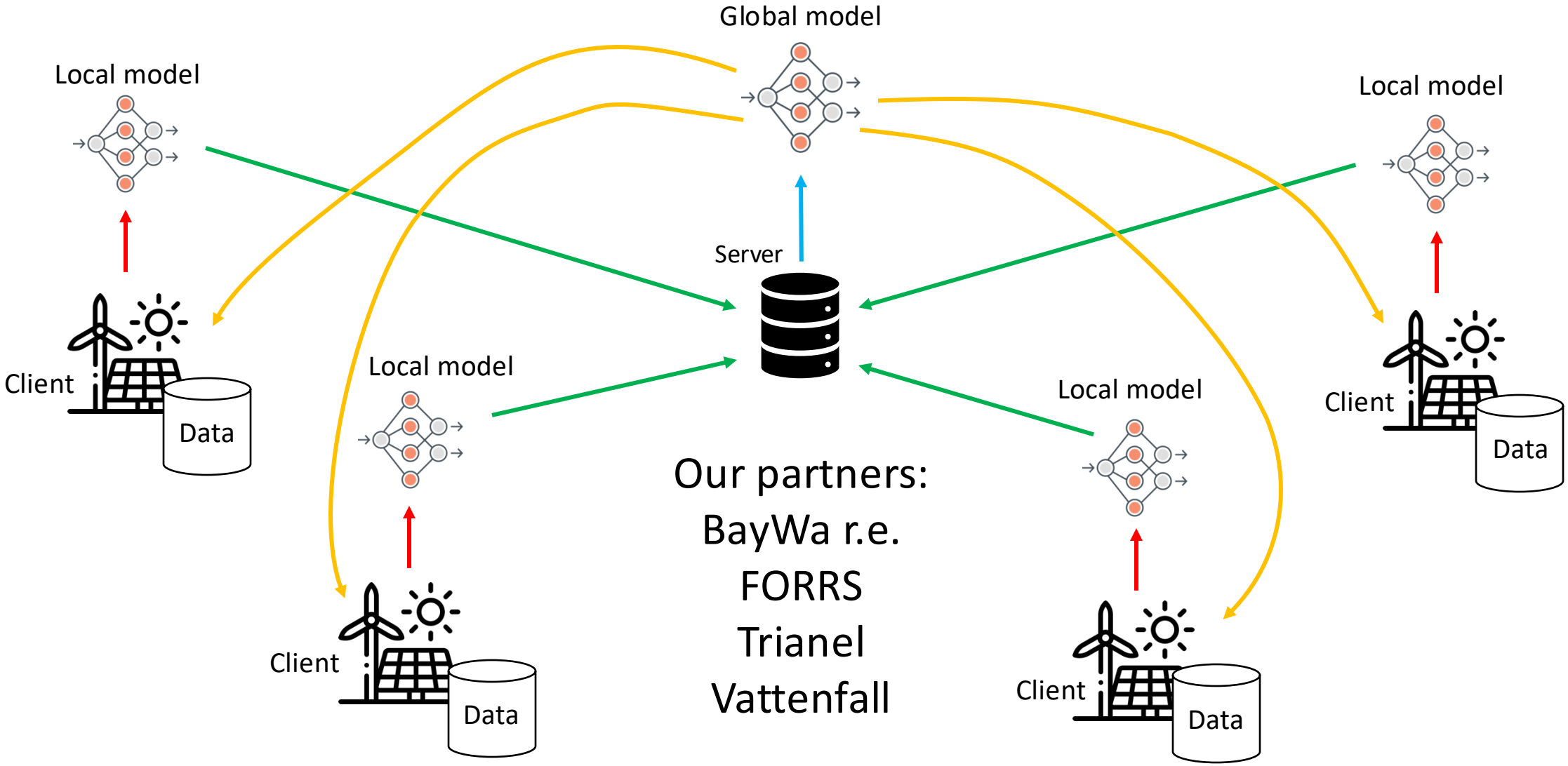
Federated Learning is about aggregating local models



Day-ahead trading with a forecast horizon of 12 to 36 hours



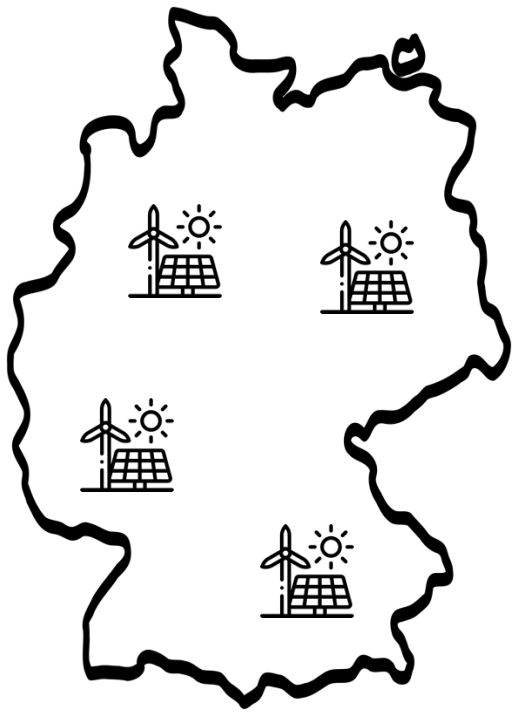
All market participants face similar problems



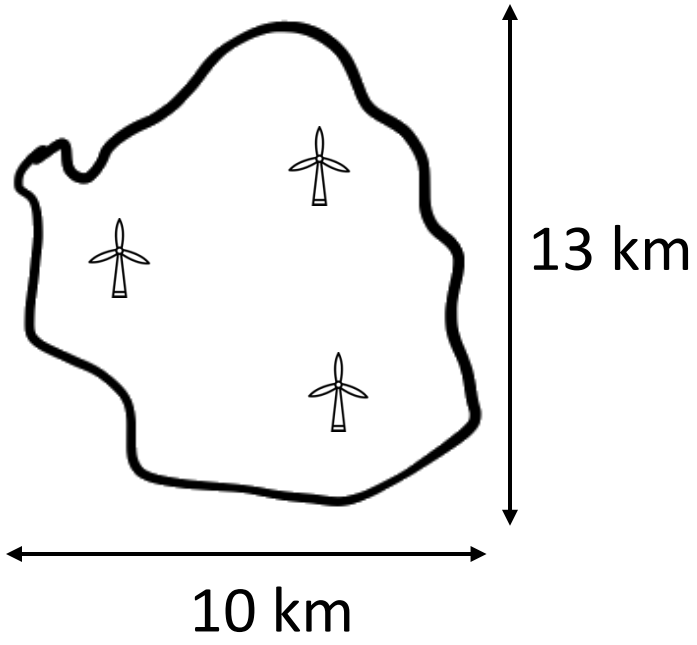
FederatedForecasts is about collaboration of competitors

Literature

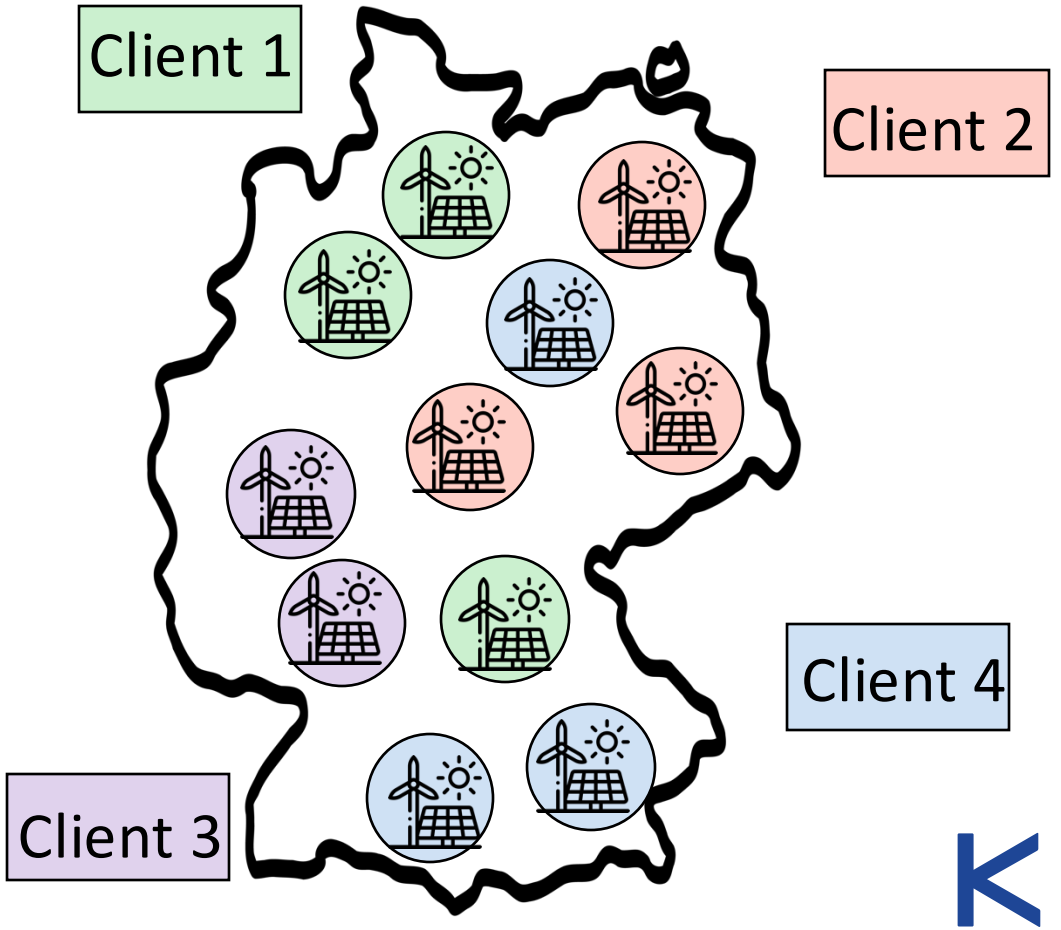
Park-level forecasts



Plant-level forecasts



FederatedForecasts



A client represents a diverse portfolio of parks

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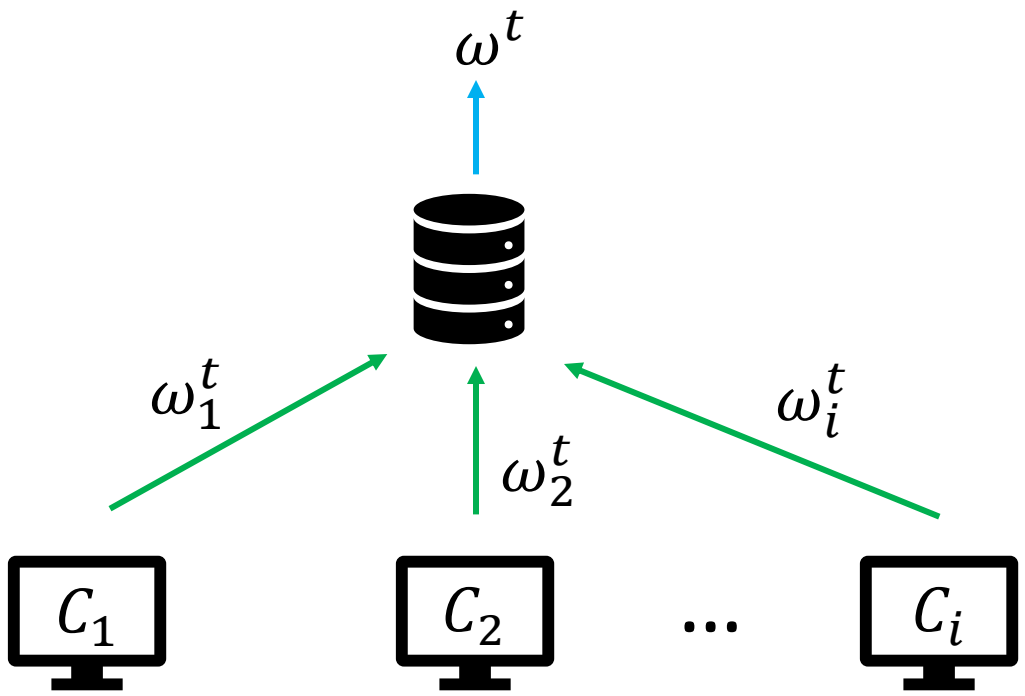
How does federated model aggregation work?

Client C_i sends local model weights ω_i^{t+1} in communication round t:



Federated Averaging (FedAvg)

$$\omega^t = \sum_{i=1}^{N} \frac{n_i}{n} \omega_i^t$$

ω^t: Global model in round t
N: Total number of clients
$n = \sum_i^N n_i$: Total number of training samples

The key operation in federated learning is weighted averaging

FedAvg with Server Momentum (FedAvgM)

Server momentum

FedAvg

$$m^{t+1} = \beta m^t + \underbrace{\left(\omega^t - \sum_{i=1}^{N} \frac{n_i}{n}\, \omega_i^{t+1}\right)}_{\Delta\omega} \qquad \omega^{t+1} = \omega^t - \eta m^{t+1}$$

„Pseudo-gradient“

Adaptive Federated Optimization (FedAdam)

$$m^{t+1} = \beta_1 m^t + (1-\beta_2)\Delta\omega$$

$$v^{t+1} = \beta_2 v_t + (1-\beta_2)(\Delta\omega)^2$$

$$\omega^{t+1} = \omega^t - \eta \frac{m^{t+1}}{\sqrt{v^{t+1}} + \tau}$$

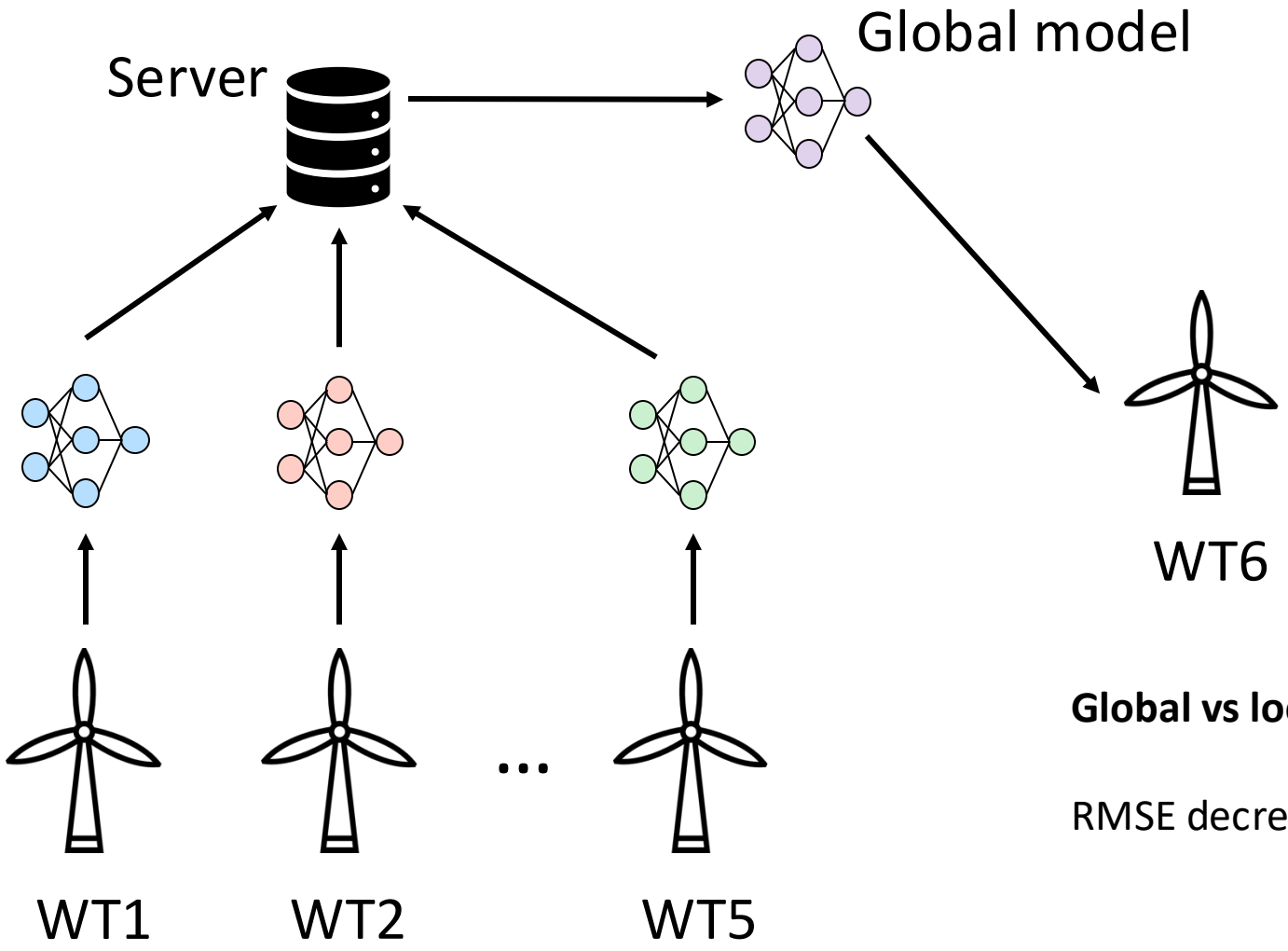
Adaptivity factor

FedAvg + proximal term (FedProx)

Regularization parameter

$$h_i(\omega_i, \omega^t) = L_i(\omega_i) + \frac{\mu}{2} \|\omega_i - \omega^t\|^2$$

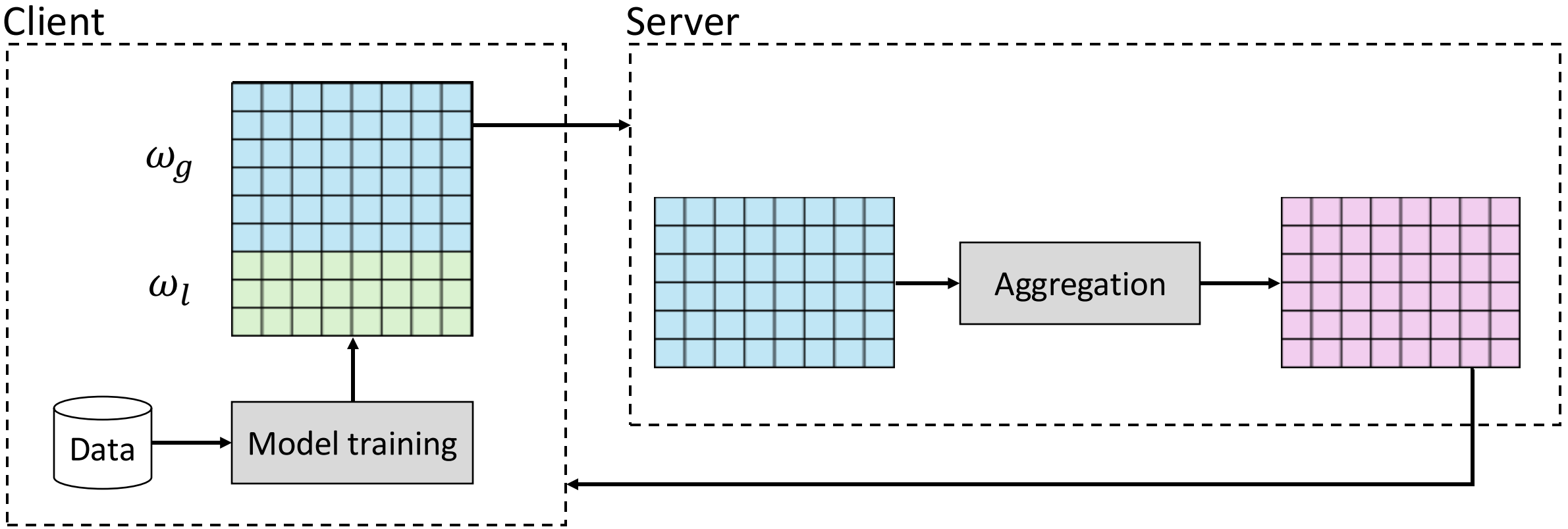
Generalization of federated averaging



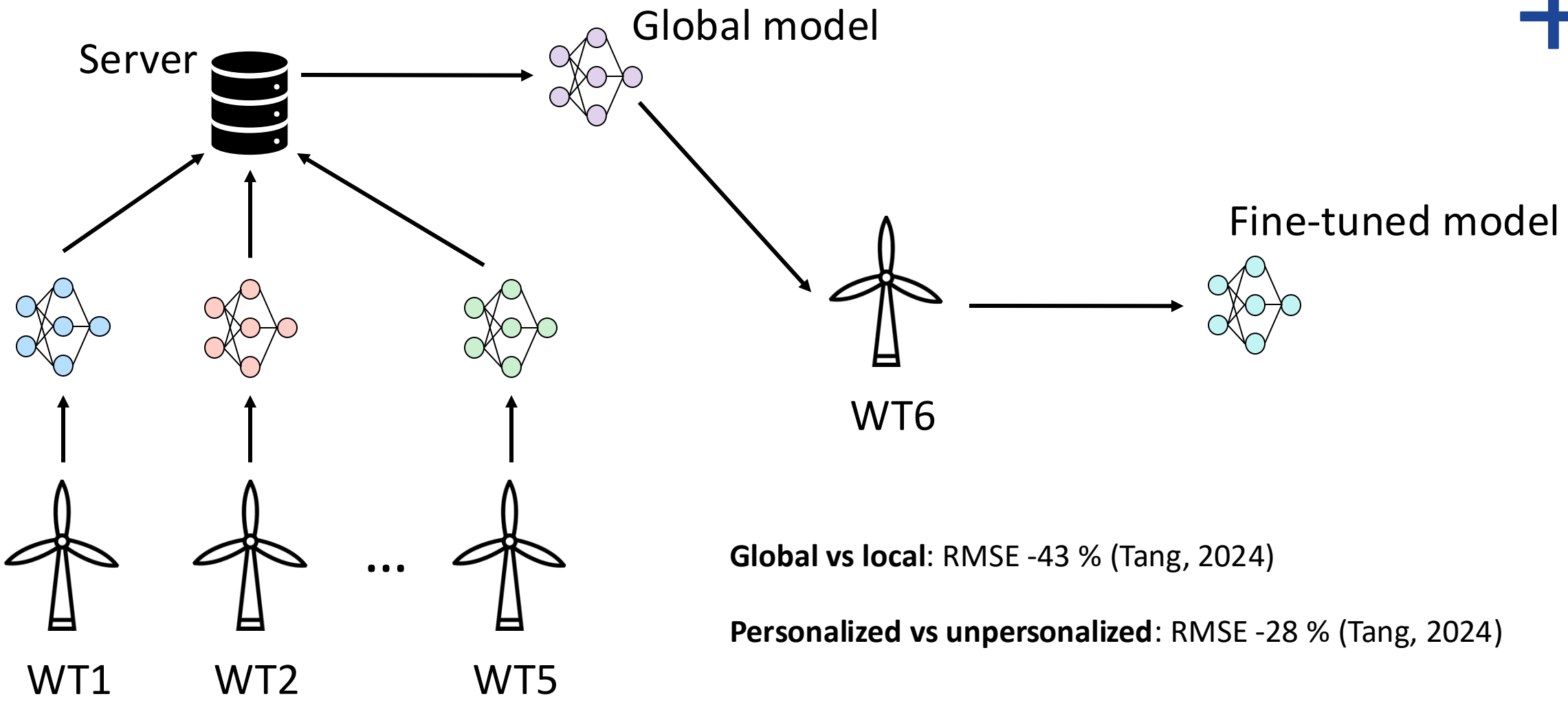
Global vs local model:

RMSE decreased by 43 % (Tang, 2024)

Federated transfer learning when data is scarce



Personalize the model by dividing it into local and global layers



Global vs local: RMSE -43 % (Tang, 2024)

Personalized vs unpersonalized: RMSE -28 % (Tang, 2024)

Personalization further improves performance

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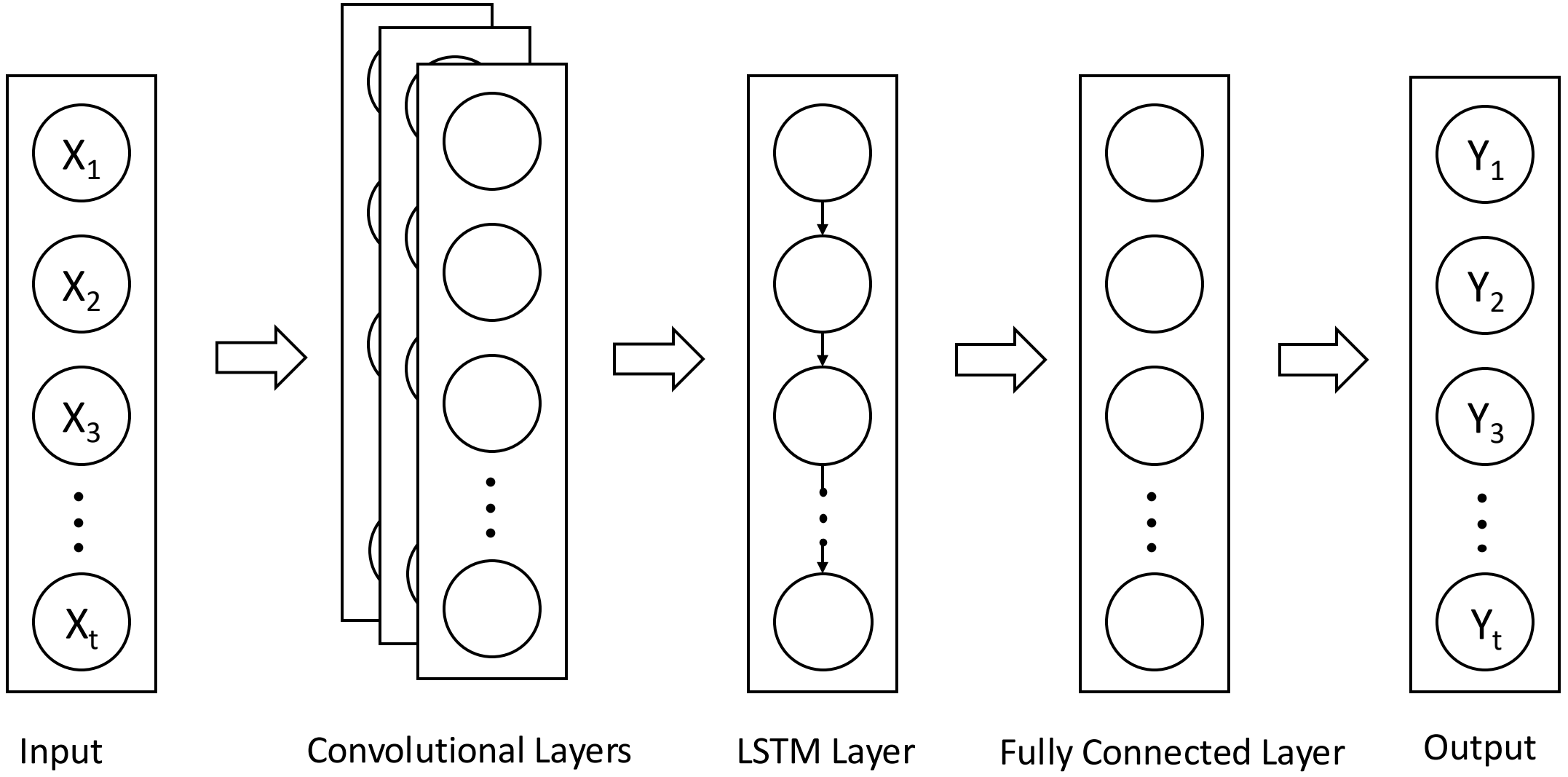
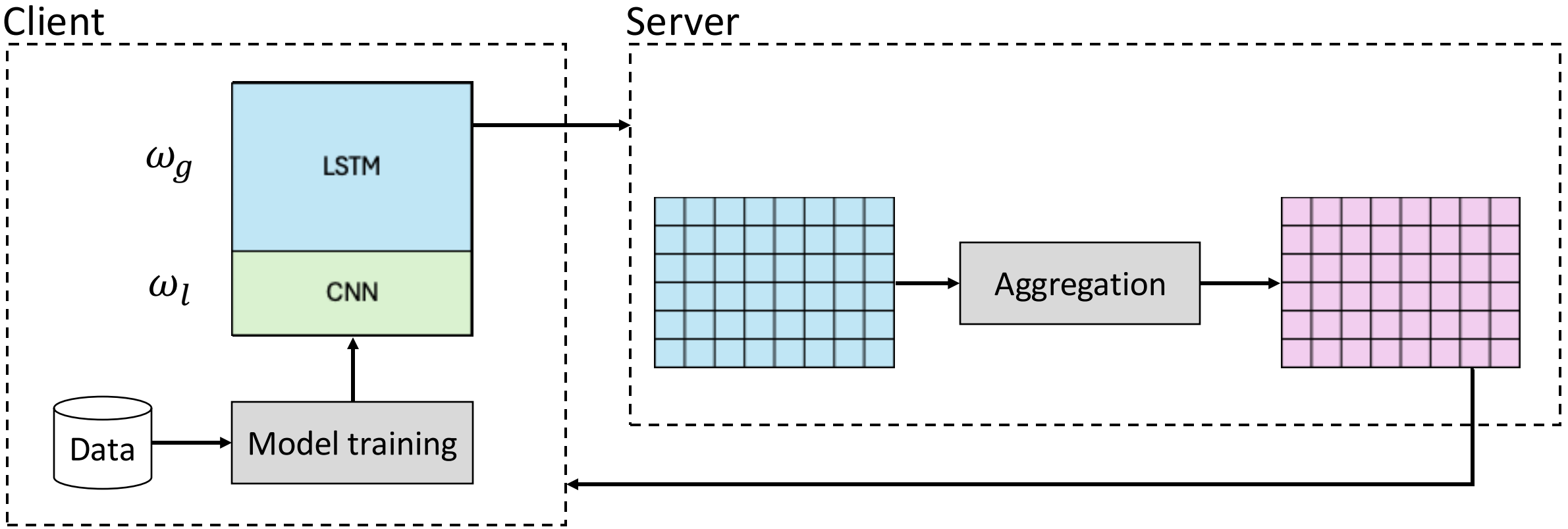
Which model to use in federated forecasting?



CNN-LSTM to predict renewable energy production



Zhang et al. (2023)

Personalize CNN in CNN-LSTM architecture

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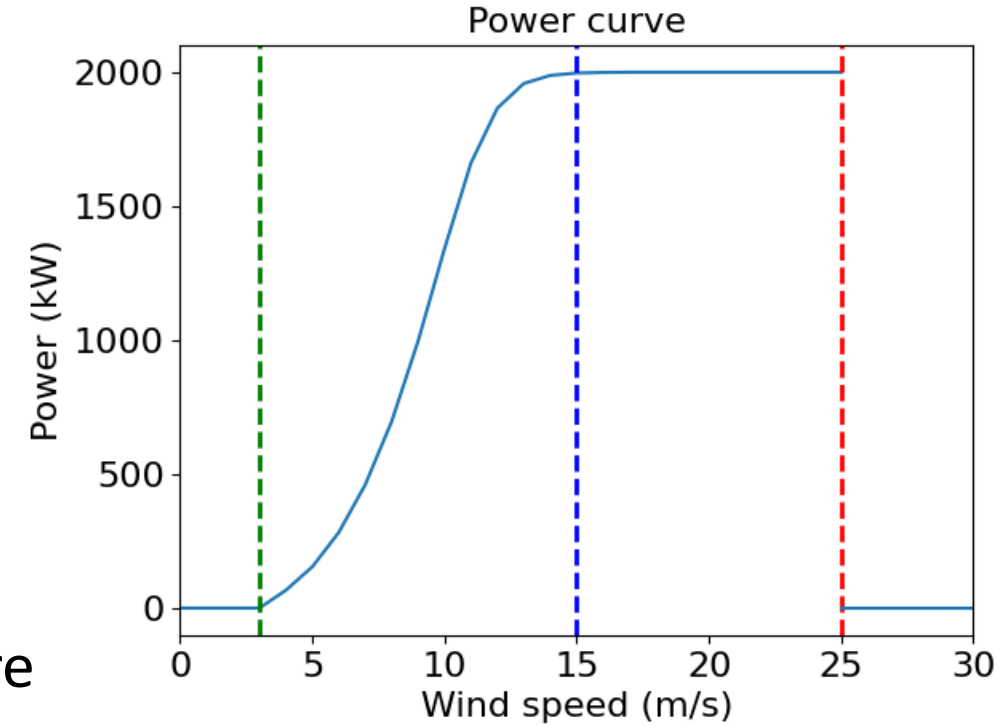
Which features to use in federated forecasting?

$$P(v) = \begin{cases} 0, & v < v_{\text{in}} \\ 0.5\rho\pi r^2 C_p v^3, & v_{\text{in}} \le v < v_n \\ P_n, & v_n \le v < v_{\text{out}} \\ 0, & v \ge v_{\text{out}} \end{cases}$$



h: Hub height

v: Wind speed

ρ: Air density

r: Rotor radius

C_p: Wind power coefficient

p: Air pressure

T: Air temperature

φ: Relative humidity

v_{in}: Cut-in wind speed

v_n: Rated wind speed

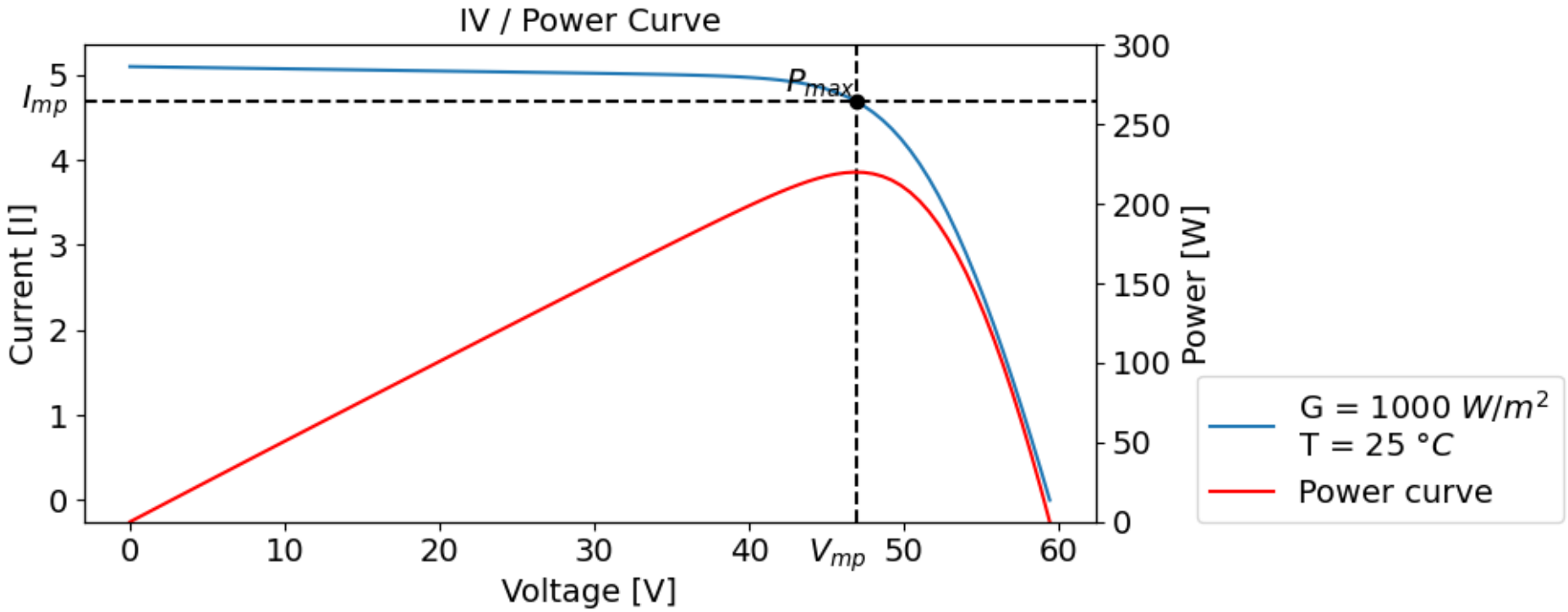
v_{out}: Cut-out wind speed

Wind power is modelled by the power curve

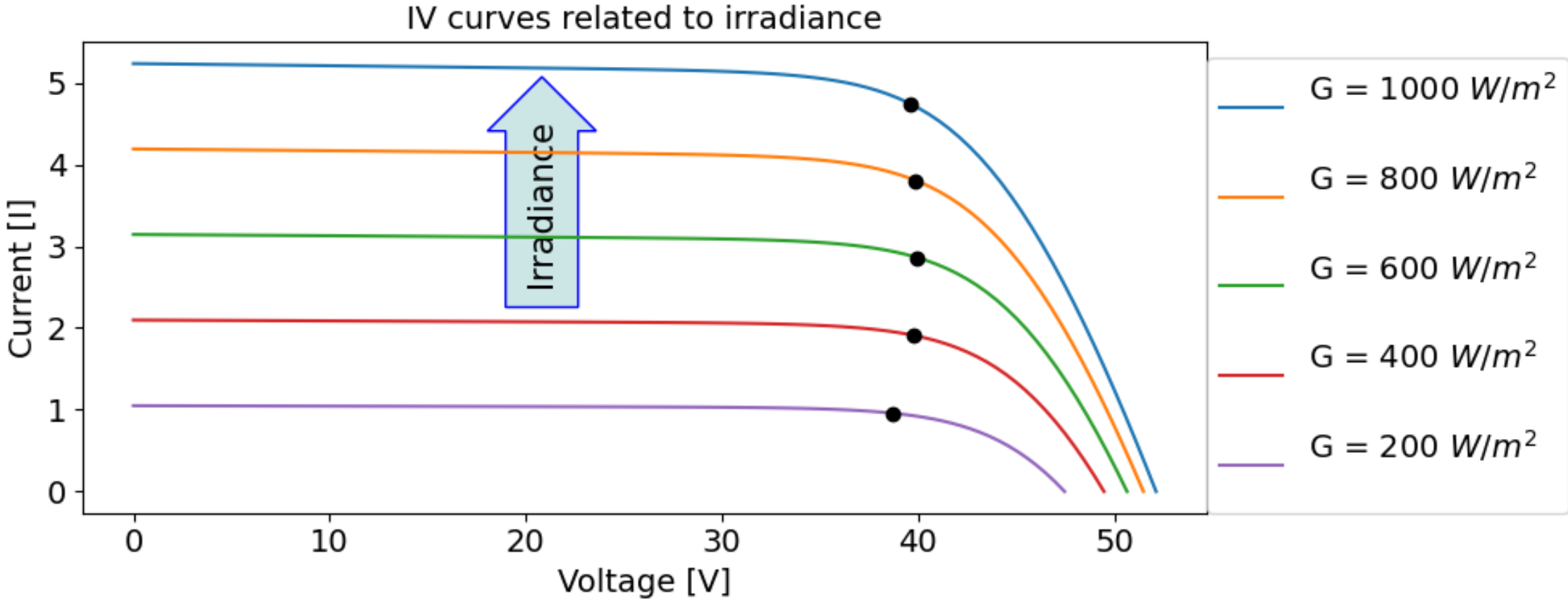
$$P = I \cdot V$$

I: Current

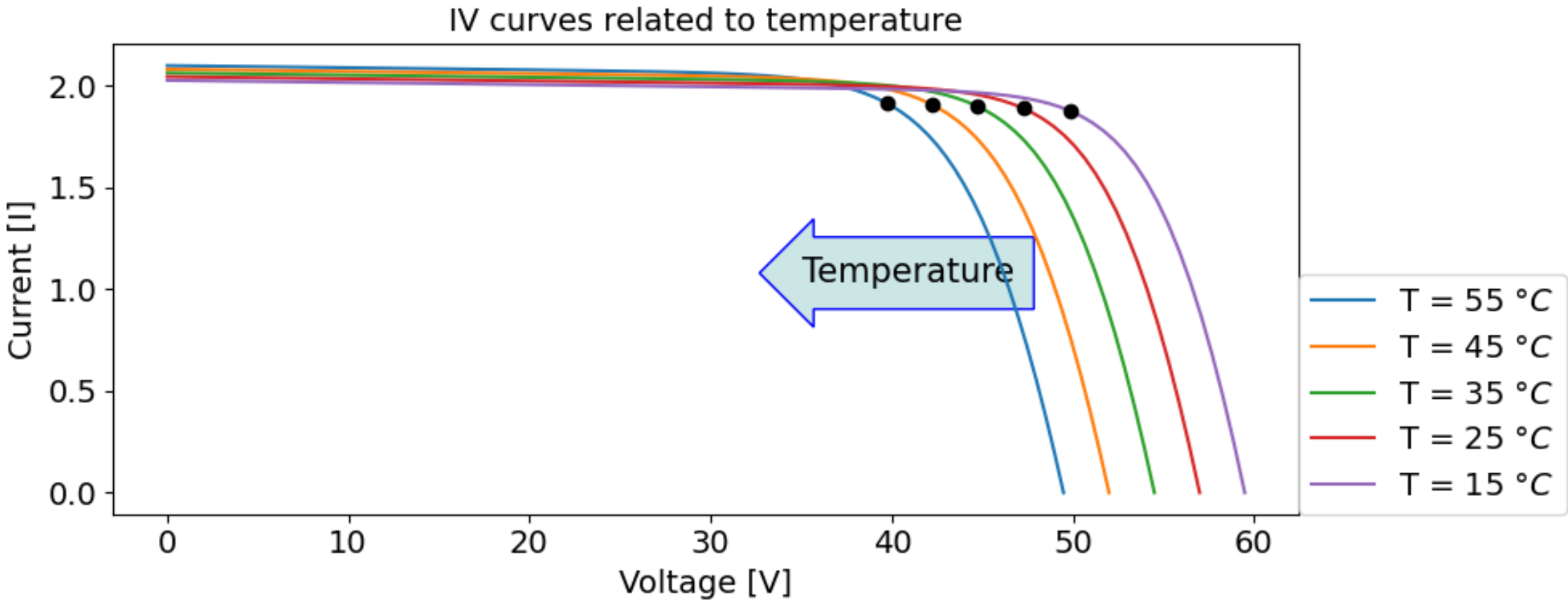
V: Voltage



PV power is the product of current and voltage



Higher irradiance results in higher power output



Higher temperature results in lower power output

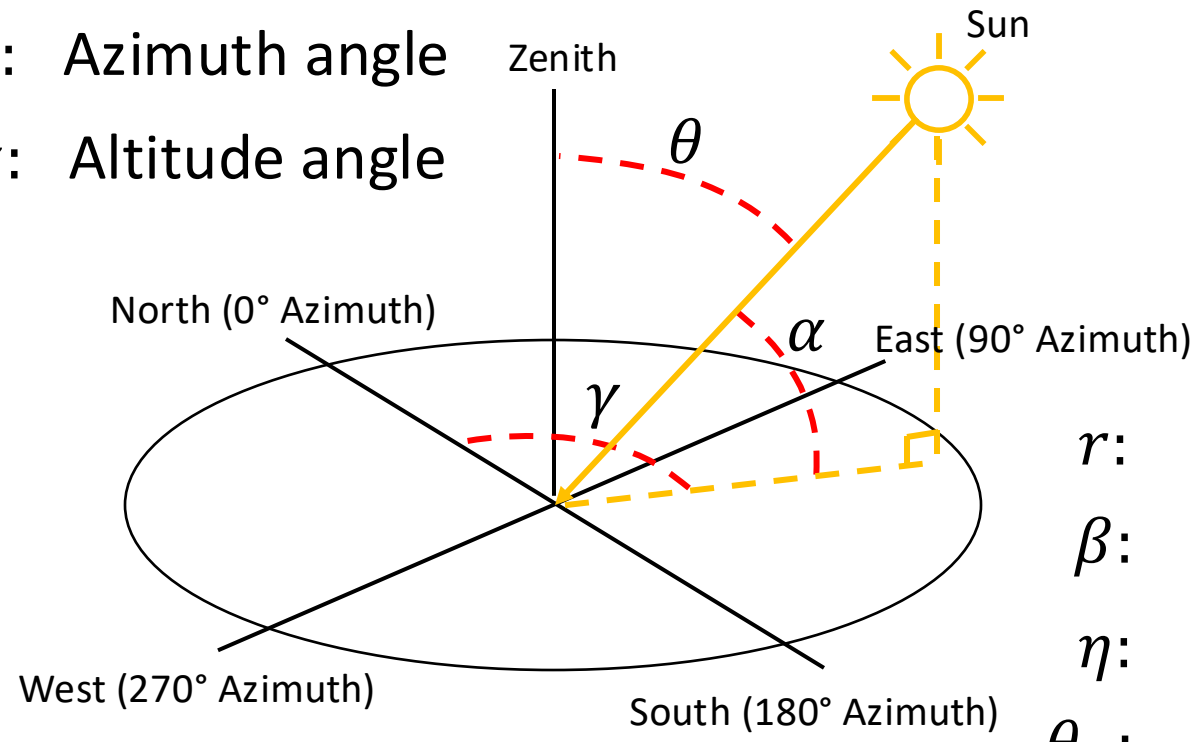
	Weather	Site-specific information
Wind	v: Wind speed p: Air pressure φ: Relative humidity T: Air temperature	h: Hub height P: Power curve
PV	DHI, DNI: Irradiance η: Albedo T: Air temperature φ: Relative humidity D: Dew point PR: Precipitation v: Wind speed PM: Particulate matter	L_{lat}: Latitude L_{lon}: Longitude β: Tilt angle r: Rotation angle

In FL, weather AND site-specific information is important

θ: Zenith angle

γ: Azimuth angle

α: Altitude angle



*Assumption of isotropy

Global tilted irradiance (GTI):

$$GTI = DHI \cdot (1 + \cos\beta)/2^{*} + DNI \cdot \cos(\theta_T) + GHI \cdot \eta \cdot (1 - \cos\beta)/2$$

r: Rotation angle from the north-south axis

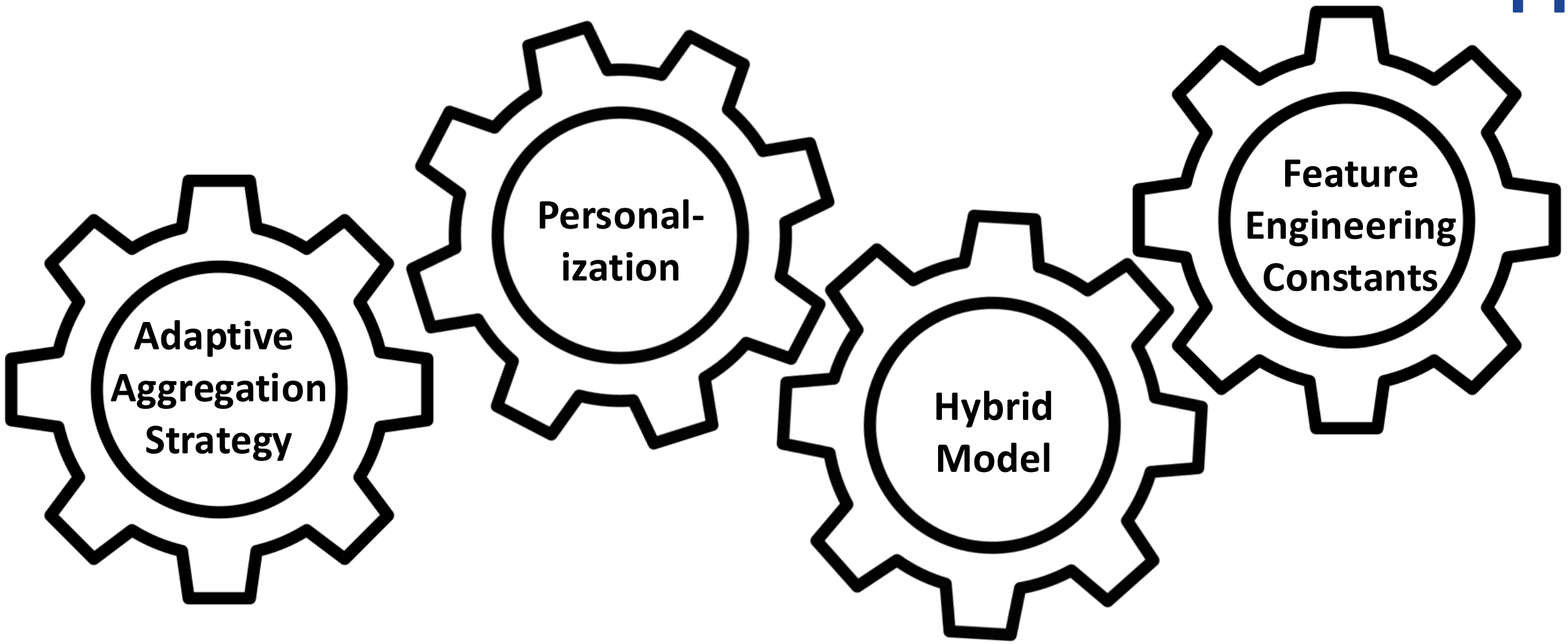
β: Tilt angle from the horizontal

η: Average albedo (ground reflectivity)

θ_T: Angle of incidence

$$\cos(\theta_T) = \cos\beta\cos\theta + \sin\beta\sin\theta\cos(\gamma - r)$$

The GTI contains site-specific features



Success factors for federated forecasting of renewable energy

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Thank You!

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