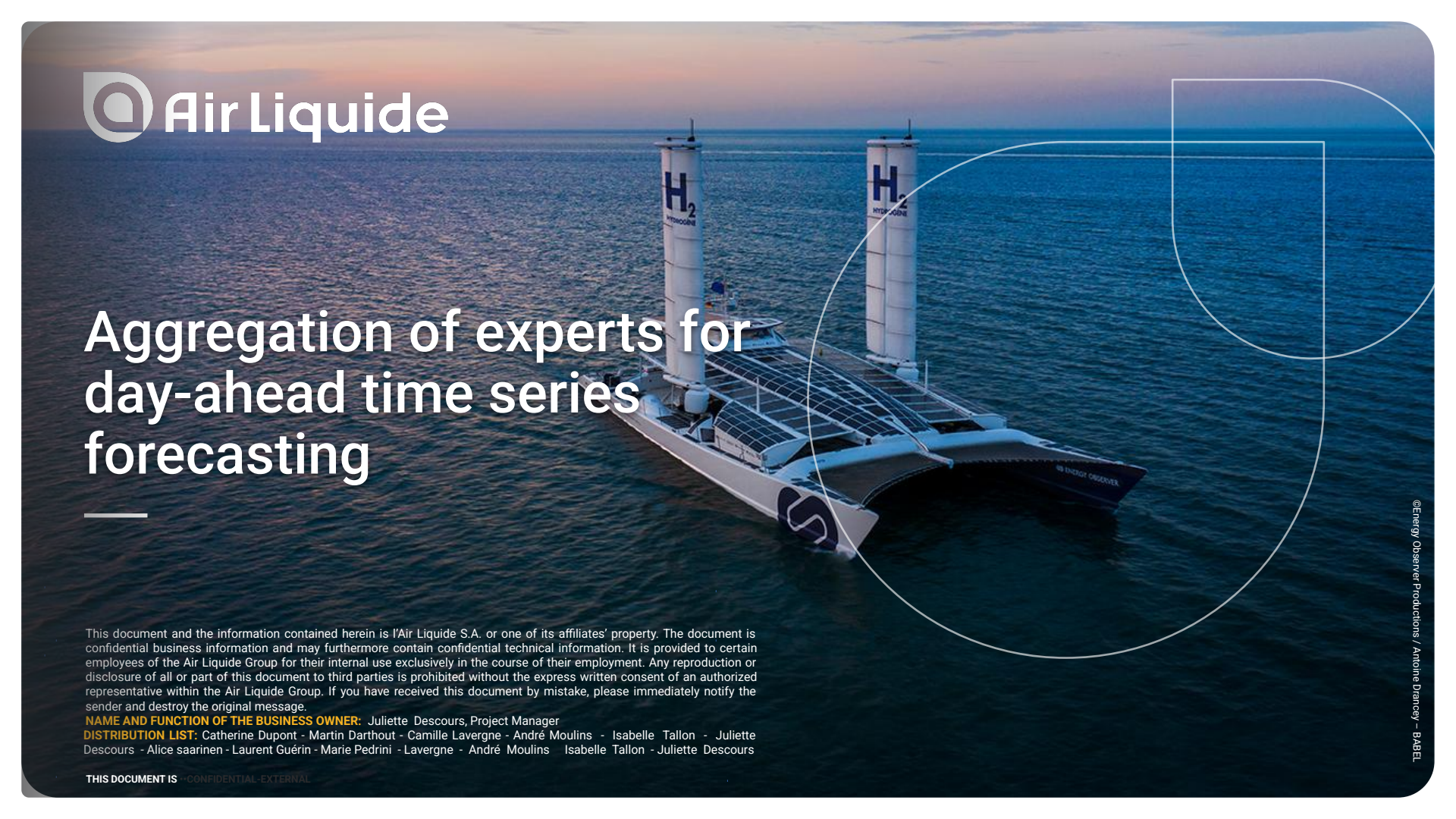
Aggregation of experts for day-ahead time series forecasting



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Air Liquide

~66,300
EMPLOYEES

PRESENT IN
60 COUNTRIES

MORE THAN
4 MILLION
CUSTOMERS &
PATIENTS

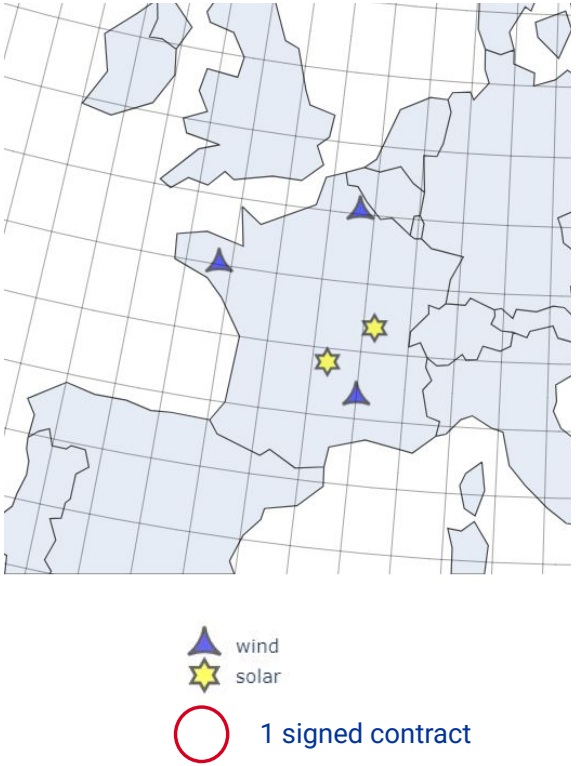
75% OF
COSTS RELATED
TO ENERGY
(LARGE INDUSTRY
BRANCH)

ELECTRICITY
INTENSIVE
42 TWh / y

CONSUME 0.15%
OF WORLDWIDE
ELECTRICITY
PRODUCTION

Context: Renewable Hydrogen production

- Normand'Hy: A 200 MW electrolyzer under construction, coming online in 2026
- Part of electricity supply from Power Purchase Agreements (PPA) to produce green hydrogen
- A **new business** for Air Liquide, with the need to adapt to new business constraints → **uncertainty of renewable availability!**



Context: Production planning

Hydrogen Production: The Economic Trade-Off Between SMR and Electrolysis

Renewables

Power production forecasts

Natural Gas

Gas price and volume

Demand

...

Core Engine

Optimization tool

Planning decisions

ELY Normand'Hy

SMR + Carbon Capture

Context: External forecast providers

Make or Buy ?

meteomatics

energy & meteo systems

ConWX

→ **Three forecast providers are evaluated since May 2025**

Given multiple expert forecasts, should we pick a single forecast or can we combine them for a better prediction?

Principles of “Mixture of experts”

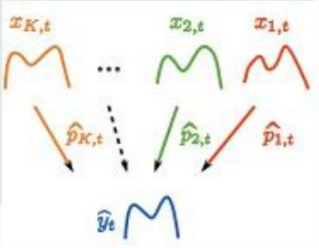
Sequential prediction of arbitrary time-series based on expert forecasts:

- a time-series $y_1, \ldots, y_n \in \mathbb{R}^d$ is to be predicted
- Expert forecasts are available: e.g., given by some stochastic or machine-learning models (for us: black boxes)

At each forecasting instance $t = 1, \ldots, n$

- forecasting black-box $k \in \{1, \ldots, K\}$ provides forecast $x_{k,t}$ of y_t
- typical solution: assign a weight $\widehat{p}_{k,t}$ to each expert and predict

$$\widehat{y}_t = \sum_{k=1}^{K} \widehat{p}_{k,t} x_{k,t}$$



- we observe y_t

(slide from Pierre Gaillard, EDF R&D, frENBIS presentation May 2023)

Principles of “Mixture of experts”

The entire field studies **online learning** methods to calculate optimal weights that can be applied to each expert, depending on their performance.

These weights are **dynamically adjusted** given the evolution of each expert’s performance.

Example on a EDF R&D Dataset:

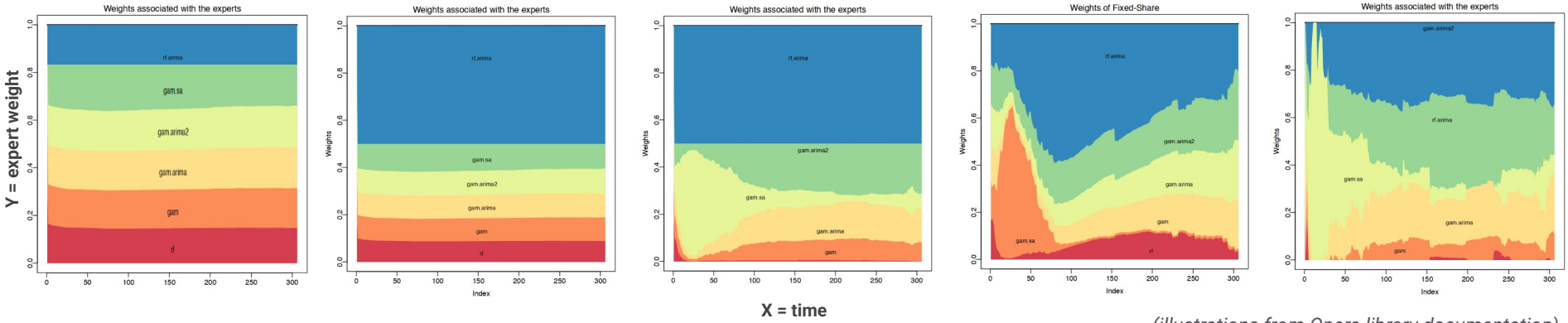
Method1
(uniform weights)

Method2
(constant weights)

Method3
(FTRL)

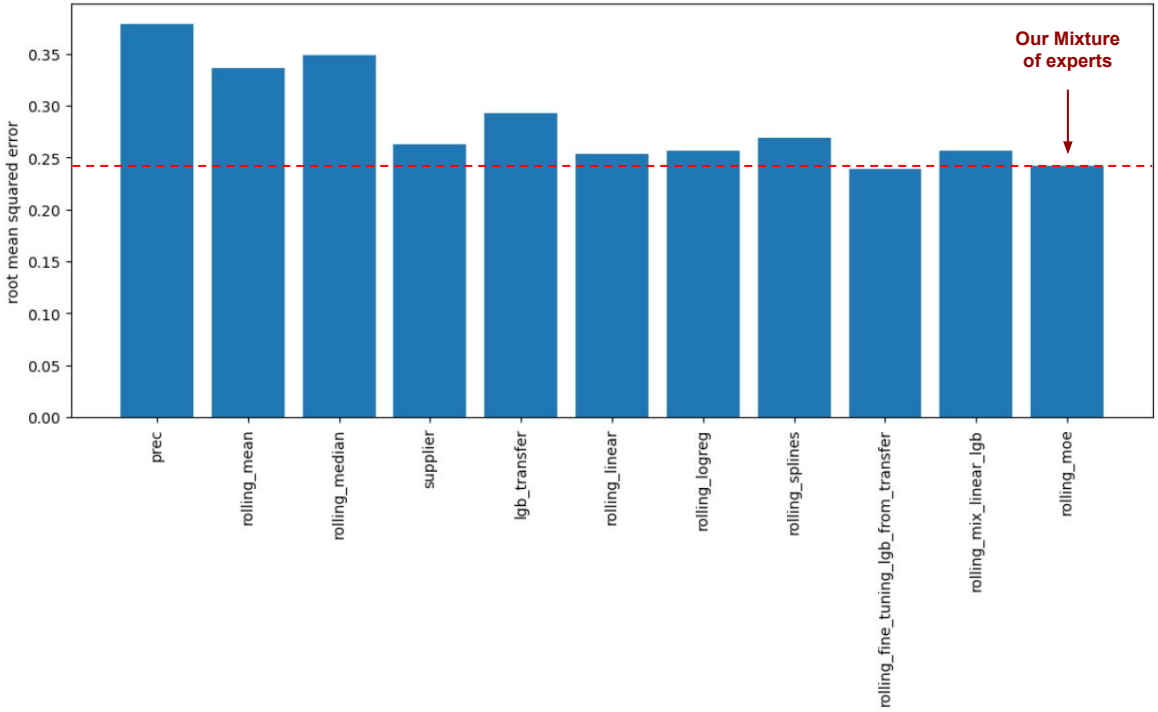
Method4

Method5



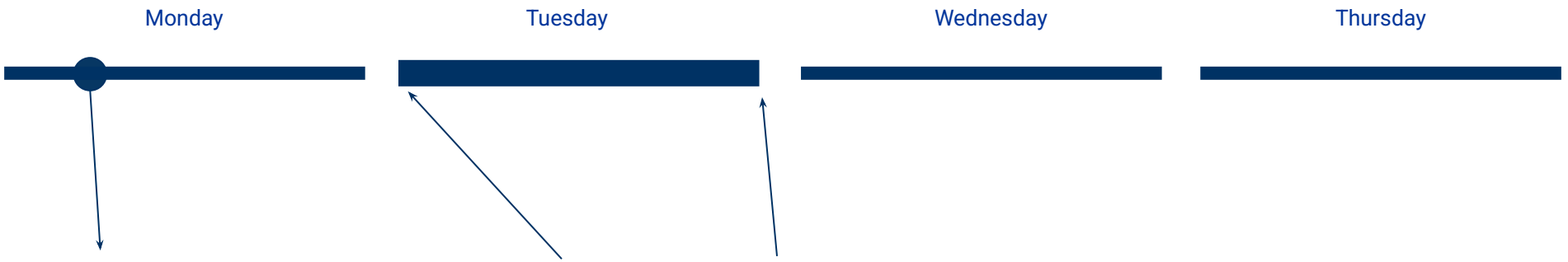
(illustrations from Opera library documentation)

Results on an Air Liquide Renewable forecasting dataset (US)



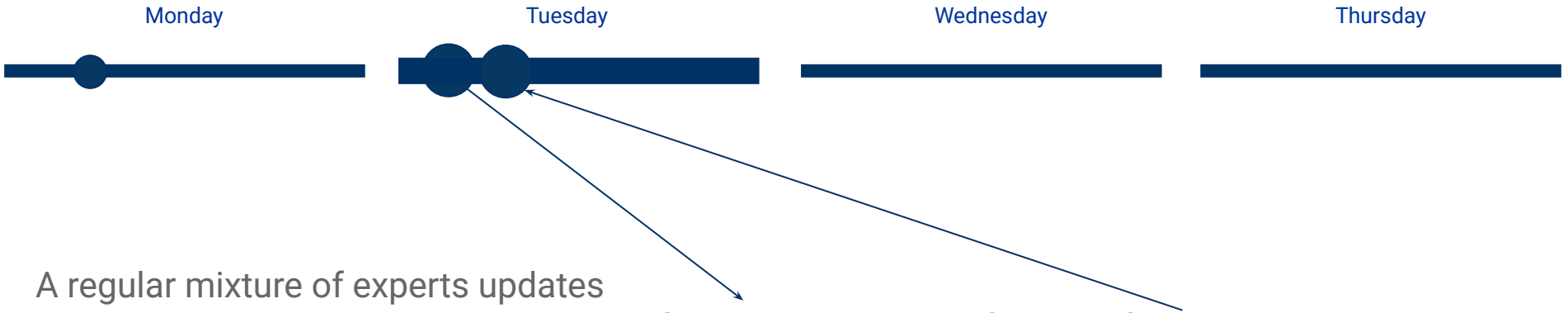
8% gain compared to supplier forecast

However...
Application in the hourly day-ahead context is not trivial



At **10am**, we must forecast from **midnight** to **midnight** on tuesday.

However...
Application in the hourly day-ahead context is not trivial



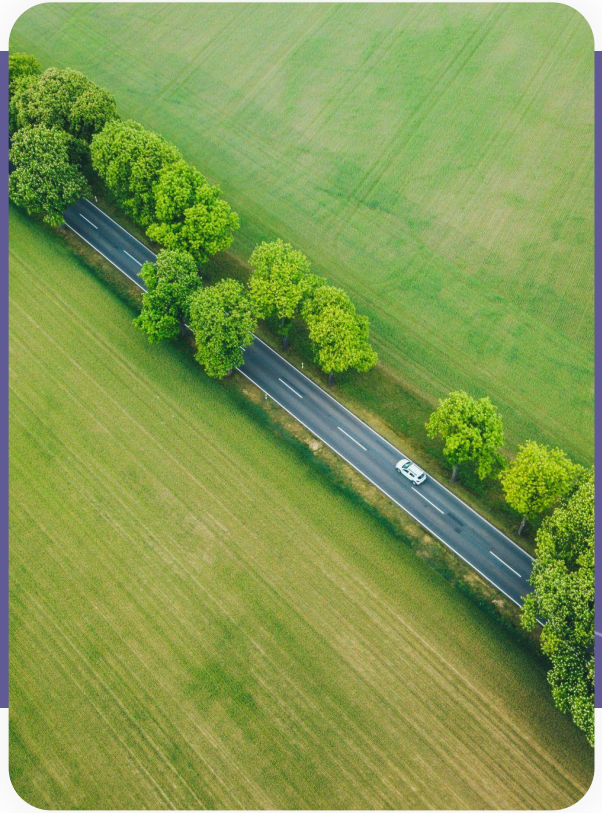
A regular mixture of experts updates its weights with observations from **2am** to make a forecast for **3am**.

But on **Monday 9am**, we don't have observations from **Tuesday 2am**. So we can't update our weights for **Tuesday 3am**!

→ Regular mixtures of experts can't be used "as-is" in a day-ahead context
→ Some development required for the day-ahead context

Our questions

- **Theory:**
  - How can the online learning setup be adapted to our day-ahead hourly situation?
  - Compare online learning algorithms with other approaches (example: sliding window linear regression)
- **Practice:**
  - What is the empirical performance of different aggregation methods on real-world datasets. Do the practical results align with theoretical expectations?



Thank you