IA meeting 30/11/2020

Bidding Wind Energy Exploiting Wind Speed Forecasts

Giannitrapani, A., Paoletti, S., Vicino, A., & Zarrilli, D. (2015). Bidding wind energy exploiting wind speed forecasts. IEEE Transactions on Power Systems, 31(4), 2647-2656.

Bidding Wind Energy Exploiting Wind Speed Forecasts

Context

Problem:
determining the **optimal day-ahead generation** profile for a **wind** power producer by **exploiting wind speed forecasts** provided by a meteorological service.

Penalties are applied only if the delivered hourly energy **deviates** from the **schedule** more than a given relative **tolerance**.

The **optimal solution** is obtained **analytically** by formulating and solving a **stochastic optimization** problem aiming at **maximizing the expected profit**.

Contribution:
exploiting wind speed forecasts to **classify the next day** into one of several predetermined classes, and then **selecting the optimal solution** derived for each class.

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Goals & framework

GOAL = optimal day ahead bidding strategy for a Wind Power Plant (WPP)
FRAMEWORK = day ahead market

$\Delta t = 1 \ h$

$H_T = 24 \ h$

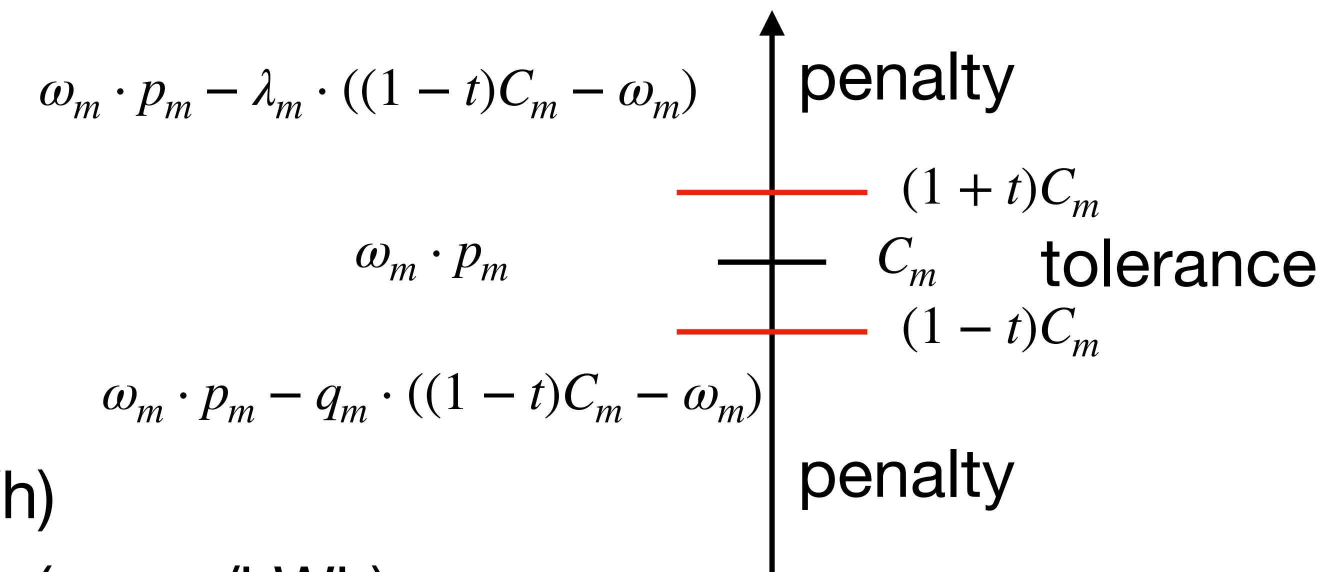
$C_m =$ bid for hour m (kWh)

$\omega_m =$ energy generated at hour m (kWh)

$p_m =$ clearing price at hour m (euros/kWh)

$q_m =$ penalty for < 0 deviation at hour m (euros/kWh)

$\lambda_m =$ penalty for > 0 deviation at hour m (euros/kWh)



Net hourly profit is

$$\boxed{\begin{aligned}\Pi(C_m, w_m) = p_m w_m &- \bar{q}_m \max\{(1-t)C_m - w_m, 0\} \\ &- \bar{\lambda}_m \max\{w_m - (1+t)C_m, 0\}.\end{aligned}}$$

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Bidding strategies compared in the paper

OB: Optimal bidding with t = 0 -> no error tolerance

OBt: Optimal bidding with t = tolerance error

WF+PC: Wind Forecast + Plant energy Curve

WF+OBt: Wind Forecast + Optimal Bidding with t

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OB & OBt = optimal bidding with/without tolerance t

Problem formulation

Stochastic quantity due to the **uncertainty** on the **generated** energy.

$$\Pi(C_m, w_m) = p_m w_m - \bar{q}_m \max\{(1-t)C_m - w_m, 0\} \\ -\bar{\lambda}_m \max\{w_m - (1+t)C_m, 0\}.$$

$$J(C_m) = \mathbf{E}[\Pi(\breve{C}_m, w_m)]$$

Expected profit with respect to the generated energy.

$$\boxed{C_m^* = \arg \max_{C_m \in [0, \bar{E}]} J(C_m)}$$

The bid that maximizes the **expected** profit.

ps: the clearing price, and penalty prices are in realty stochastic quantities that need to be predicted to be used as parameters.

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OB & OBt = optimal bidding with/without tolerance t

$$\boxed{C_m^* = \arg \max_{C_m \in [0, \bar{E}]} J\left(C_m\right)}$$

Problem to solve

The optimal bid for hour m is provided by:

$$(1-\gamma_m)(1-t)F_m((1-t)\tilde{C}_m^*) = \gamma_m(1+t)(1-F_m((1+t)\tilde{C}_m^*)) \quad (7)$$

with γ_m given by

$$\gamma_m = \frac{\bar{\lambda}_m}{\bar{q}_m + \bar{\lambda}_m}. \quad (8)$$

F = Cdf = Cumulative distribution function

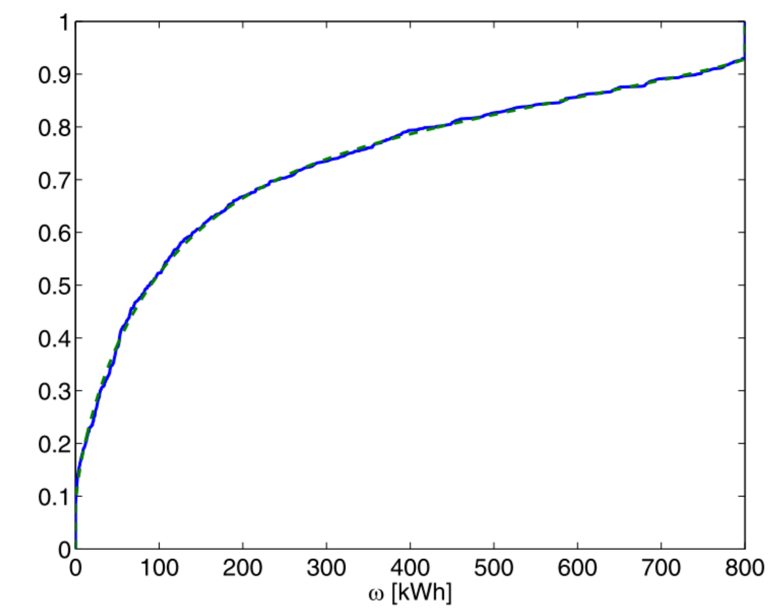

Fig. 2. Empirical *cdf* (solid) of the random variable w_{20} for a 800 kW wind turbine and corresponding BGM model (dashed) estimated from data. The two curves are in practice overlapping.

$$F_m(\omega) = cdf_m = Pr(\omega_m \leq \omega)$$

Cf appendix for the paper for the proof.

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WF+PC = Wind Forecast + Plant energy Curve

Wind power as a function of the wind speed

$$E_\sigma(v) = b + (a-b)\left(1 + e^{(v-v_0)/c}\right)^d$$

$$E(v) = \begin{cases} \min\{\max\{0, E_\sigma(v)\}, \bar{E}\} & \text{if } v \leq v_{off} \\ 0 & \text{otherwise} \end{cases}$$

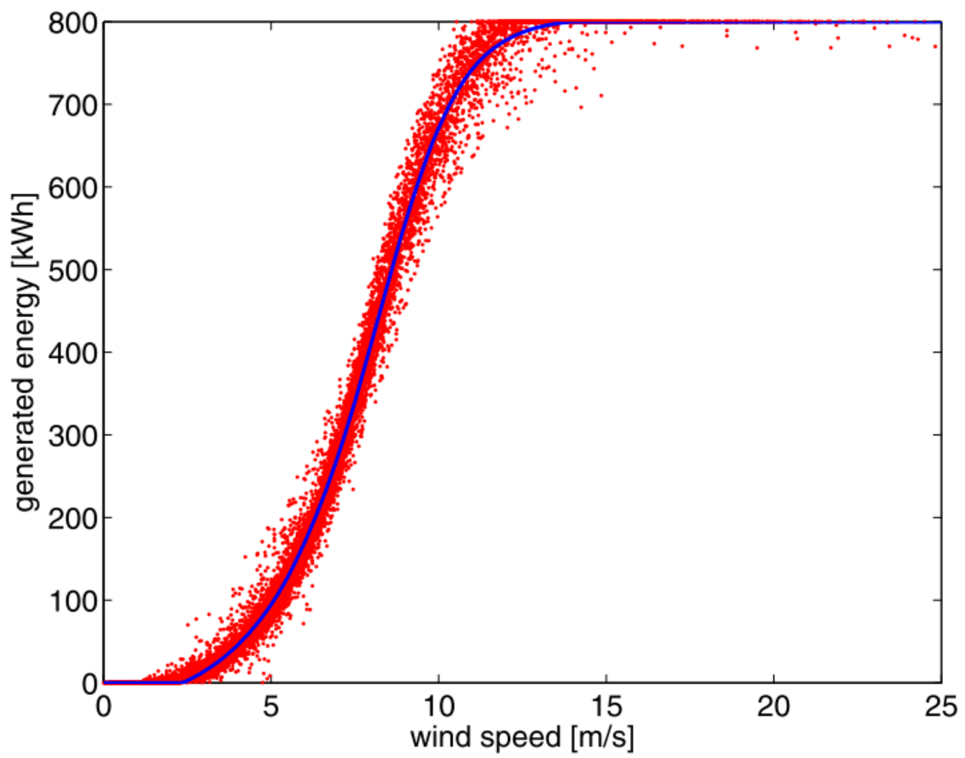

Fig. 3. Hourly generated energy vs hourly average wind speed for a 800 kW wind turbine (red points), and model (16) fitted to the data (solid blue curve).

Bidding is provided by the **wind speed forecast**

$$\boxed{C_m = E(\hat{v}_m), \quad m = 1, \ldots, 24.}$$

Pb1: inaccurate forecast -> inaccurate bid
Pb2: do not take into account the tolerance and penalty prices.

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WF+PC: Wind Forecast + Plant energy Curve

WF+OBt: Wind Forecast + Optimal Bidding with t
-> combine the pros of OBt & WF+PC with a suitable classification strategy based on wind speed forecasts
-> Multicategory Robust Linear Programming (MRLP) approach is adopted.

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WF+OBt = Wind Forecast + optimal bidding and tolerance t

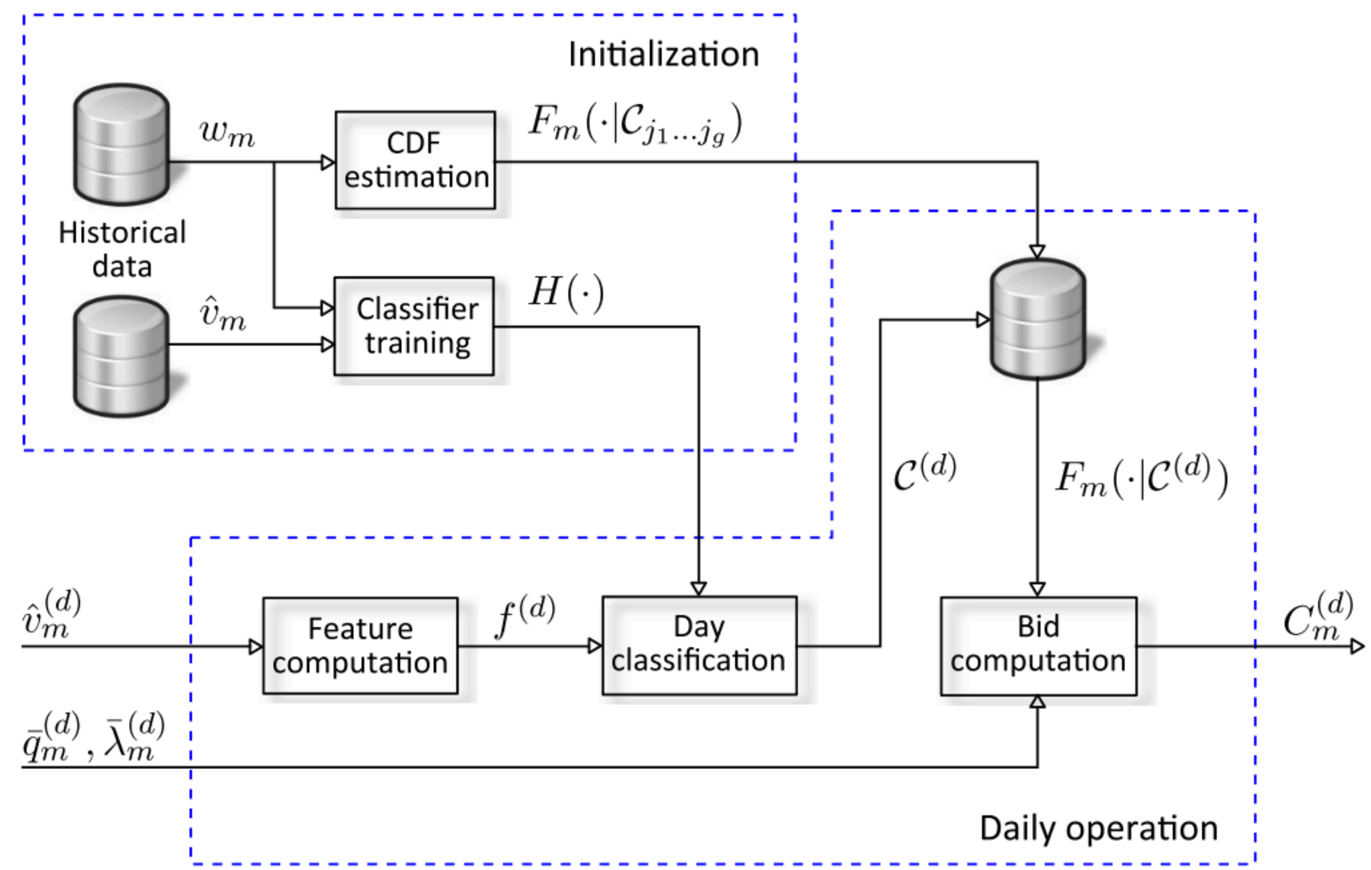
A trained a **classifier** maps a day (represented by the corresponding wind speed forecasts) to one of several classes associated to different **levels of daily generated energy**.

Then, the bids made for every hour of that day are the **optimal contracts** computed as with OBt, but using the **conditional wind energy cdf** of the **corresponding class**.

Example:
4 classes = (L,L), (L,H), (H,L), (H,H)
L = Low energy level
H = High energy level
(,) = (Morning, Evening)

$$C = C_{11}, C_{12}, C_{21}, C_{22}$$

$$F_m(\omega \,|\, C_{j1j2}) = Pr(\omega_m \leq \omega \,|\, C_{j1j2})$$



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Case study

Wind turbine of 800 kW.

Training set = from March 2010 to January 2012.

Validation set = February 2012 to April 2012.

The clearing price is issued from the day ahead Italian market.

< 0 & > 0 penalty prices are randomly sampled under 2 uniform distributions:

- Scenario I: $\bar{q}_m/p_m \sim \mathcal{U}(0.1, 0.3)$, $\bar{\lambda}_m/p_m \sim \mathcal{U}(0.4, 0.6)$
- Scenario II: $\bar{q}_m/p_m \sim \mathcal{U}(0.4, 0.6)$, $\bar{\lambda}_m/p_m \sim \mathcal{U}(0.8, 1)$

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Results

OBt > OB when t > 0

-> importance to adapt bids when t >0

WF+OBt > OBt for all t

Results with 70% of correct classification.

TABLE I
AVERAGE DAILY PROFIT (€) IN SCENARIO I WITH KNOWN PENALTIES

	$t = 0$	$t = 0.05$	$t = 0.1$	$t = 0.15$	$t = 0.2$
OB	365	372	380	387	395
OBt	365	376	389	402	415
WF+PC	375	379	384	387	391
WF+OBt	432	440	447	454	460

TABLE II
AVERAGE DAILY PROFIT (€) IN SCENARIO II WITH KNOWN PENALTIES

	$t = 0$	$t = 0.05$	$t = 0.1$	$t = 0.15$	$t = 0.2$
OB	172	183	194	204	215
OBt	172	191	211	232	254
WF+PC	239	248	256	263	269
WF+OBt	313	329	343	356	368

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Results: daily repartition

R = ideal strategy

WF+OBt is in many days close to R

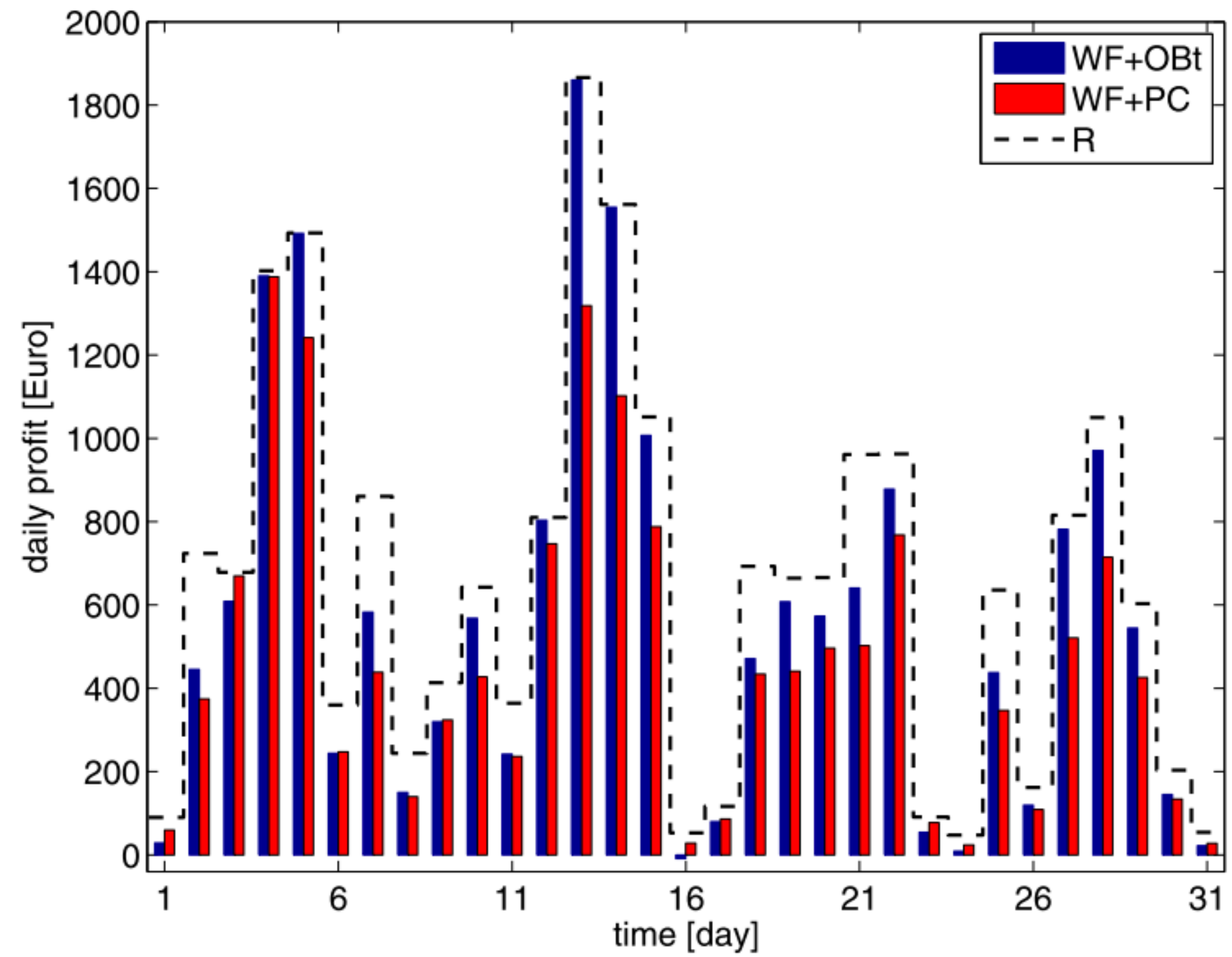

Fig. 10. Bar plots of the daily profits of the bidding strategies WF+PC and WF+OBt for Scenario I and threshold $t = 0.1$. The maximum daily profit obtained by applying the ideal bidding strategy R is also reported (dashed).

Exploiting wind speed forecasts through **classification** allows one to enhance consistently the **profit** of the WPP, with respect to:

- no classification,
- day-ahead bidding profile computed according to the wind speed forecasts & the plant energy curve.

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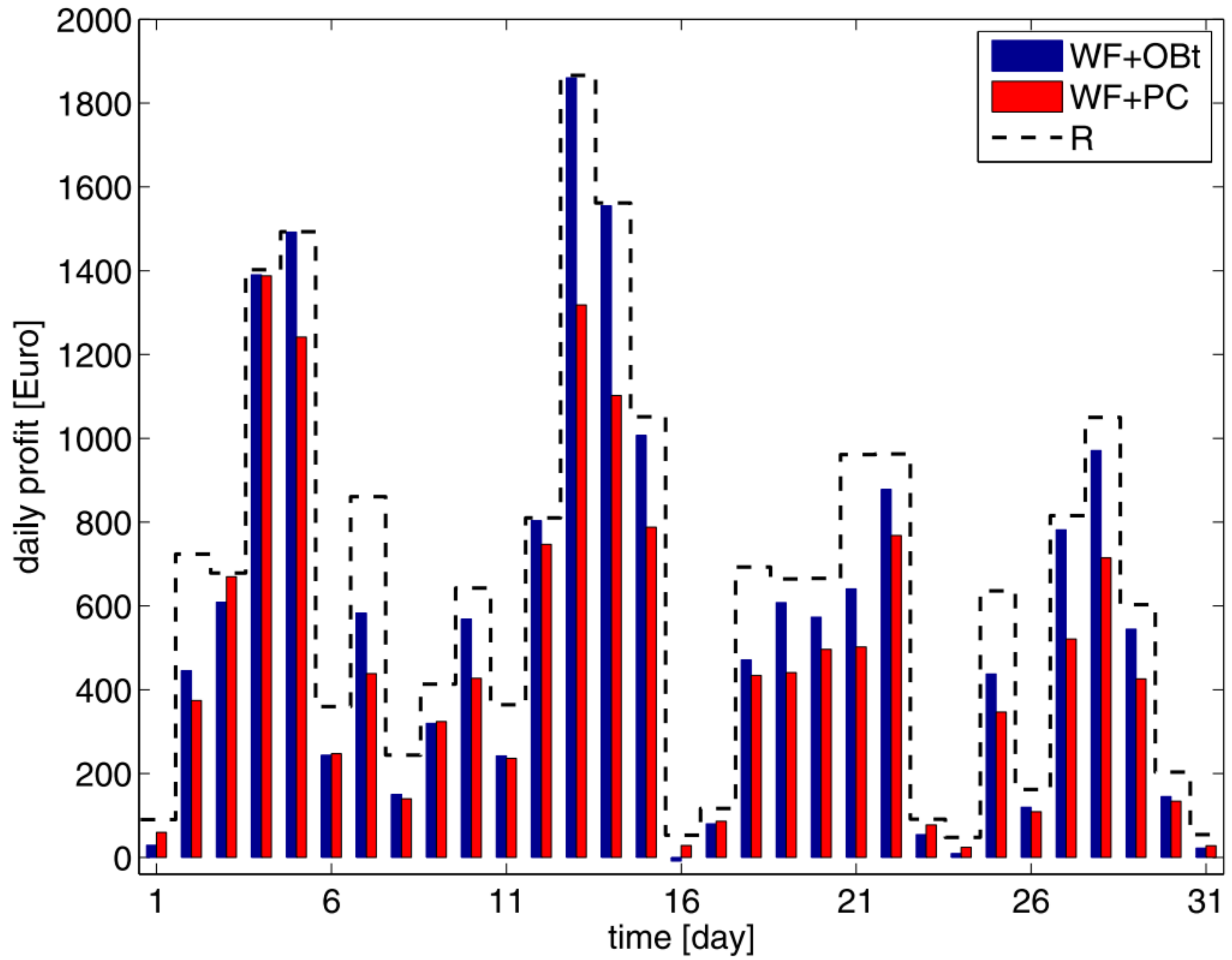
Results



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