Laboratório Nacional de Energia e Geologia, I. P.

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Methodologies for optimal hybridization and complementary aggregation of vRES

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REPÚBLICA PORTUGUESA
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Goals

A) **Improving vRES spatial planning** by hybridizing vRES

- by taking into account the complementary of renewable resources and thus, reducing energy storage needs;

B) Improving vRES operation in power systems,

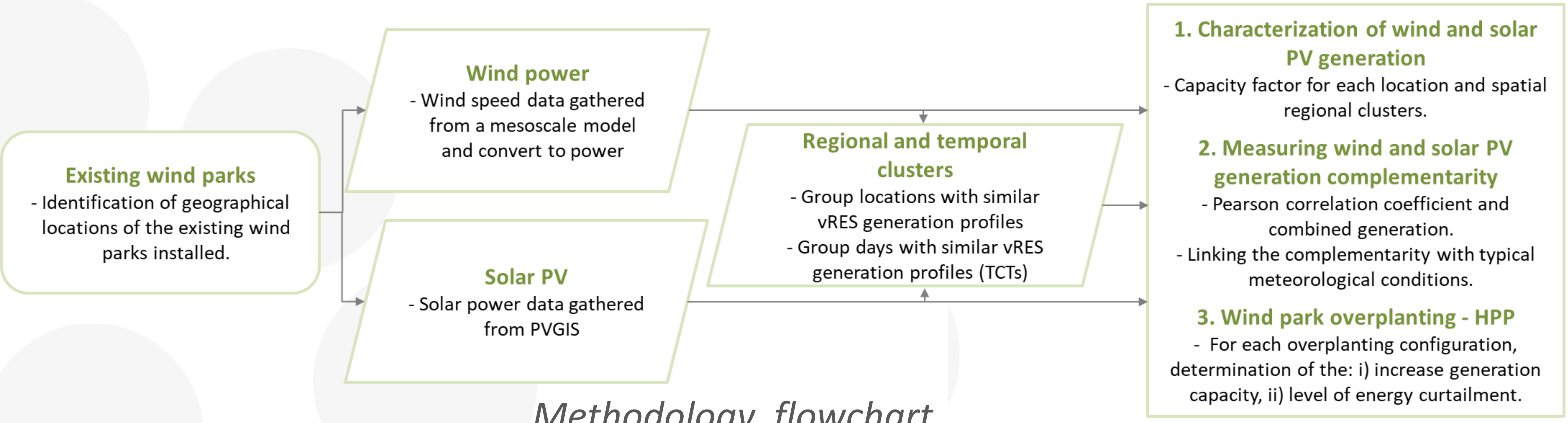
- by improving vRES forecasts in markets' timeframes, and combined wind+solar PV;

C) Increasing HPP/VRPP value in electricity markets,

- through the development of optimal bidding models enabling vRES power plants to increase their value in electricity markets.

HR EXCELLENCE IN RESEARCH

A) Hybridizing planning methodology[1]



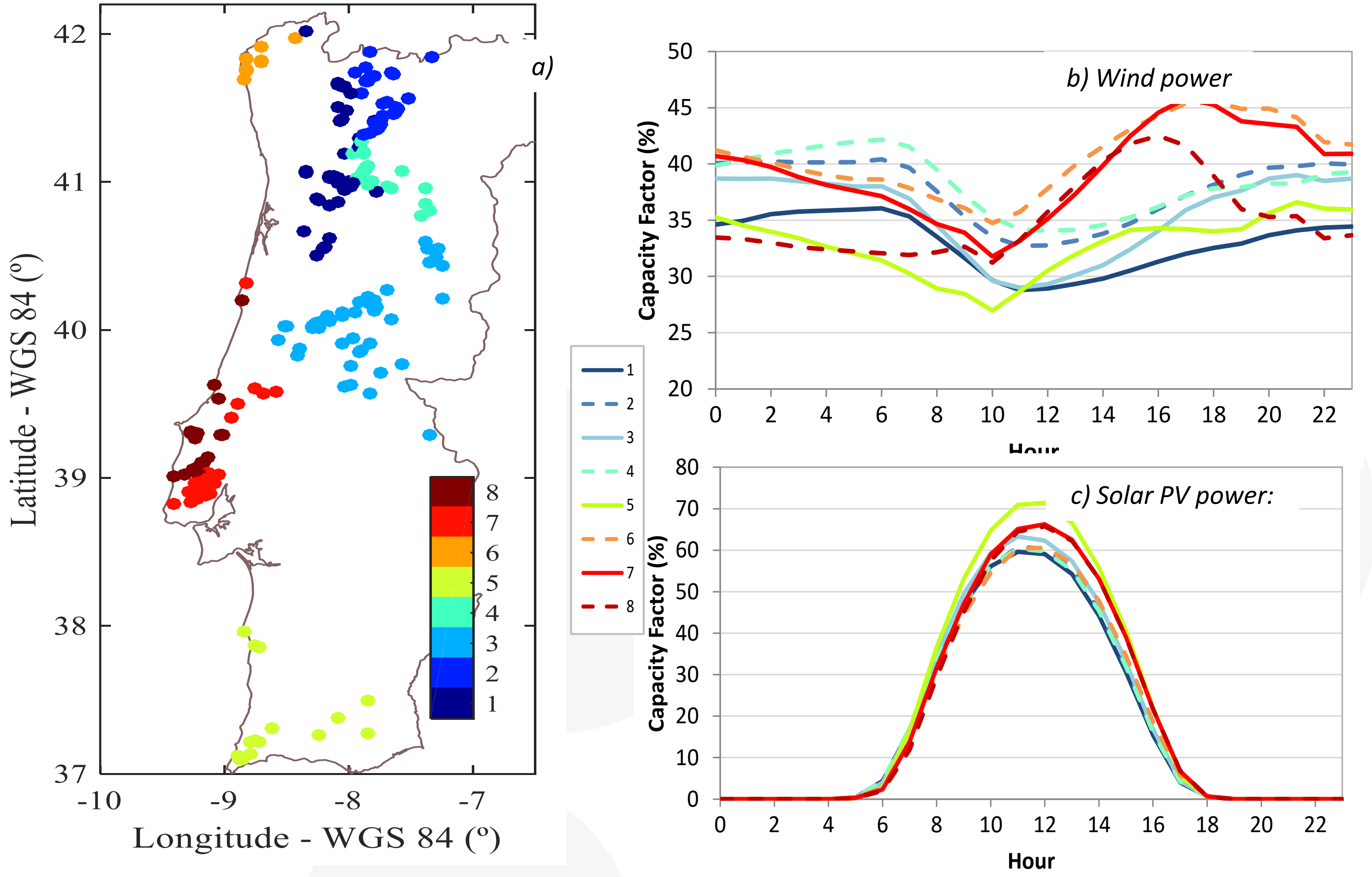
Methodology flowchart.

(1) *Couto, A. e A. Estanqueiro. (2021). "Assessment of wind and solar PV local complementarity for the hybridization of the wind power plants installed in Portugal," Journal Cleaner Production, vol. 319, no. August, p. 128728, doi: 10.1016/j.jclepro.2021.128728.*

HR EXCELLENCE IN RESEARCH

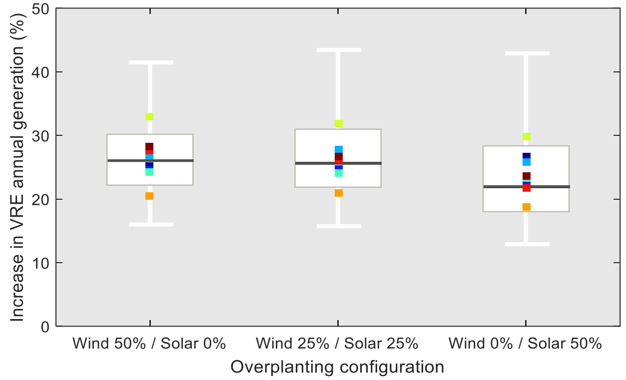
A) HPP spatial planning methodology

- vRES regionalisation and respective daily average profile for wind and solar PV technology reveals the high potential of HPPs

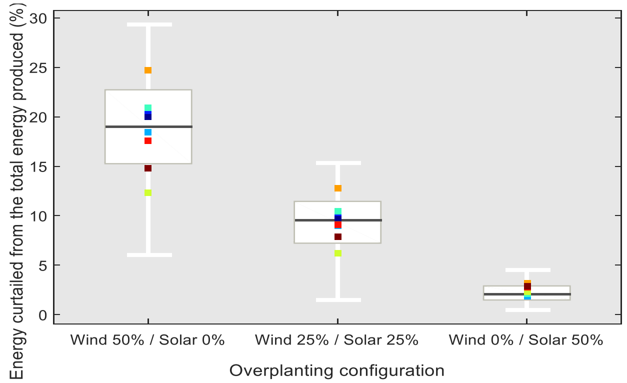


Assignment of each location to the corresponding spatial region (cluster). Daily average profile for b) wind and c) solar PV technology.

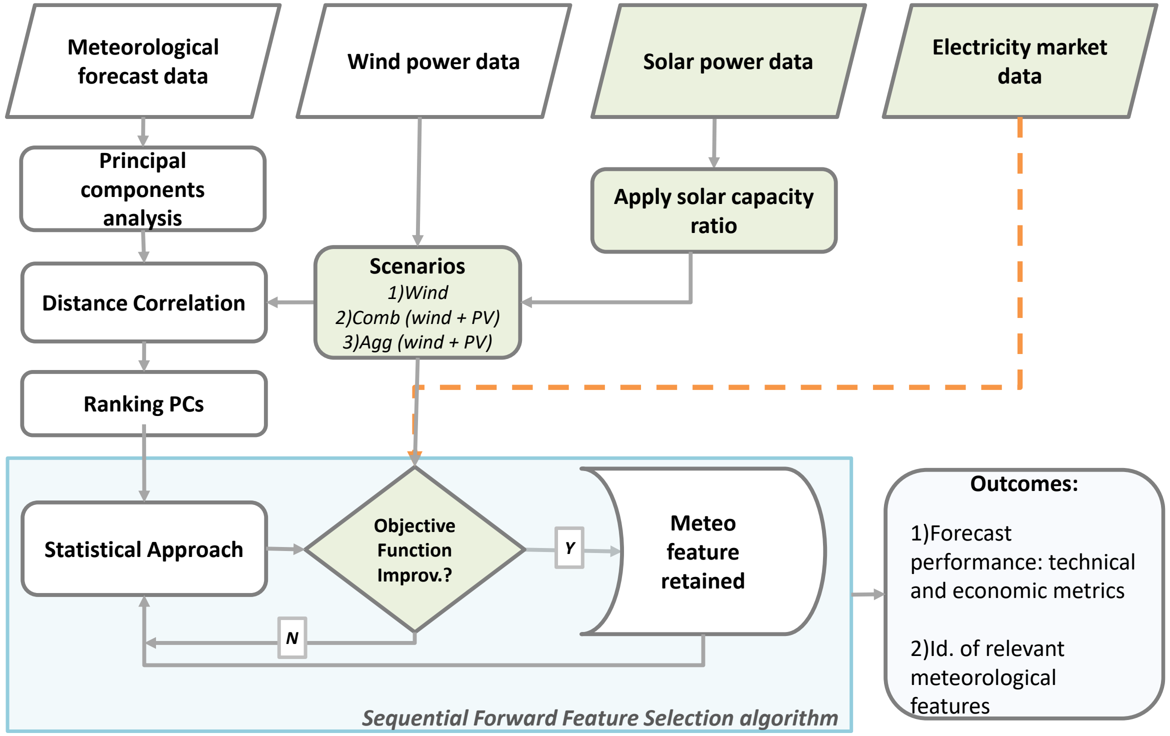
i) increase in generation



ii) Reduction in energy curtailment



B) Combined hybrid forecasting methodology[2a,b]



Methodology flowchart.

- The HPP forecasting methodology used **a sequential forward feature selection (SFFS) algorithm** presented in Couto and Estanqueiro[2] for wind power forecast using only one objective function.

- SFFS is a greedy optimization algorithm aiming to identify the most adequate input data.
  - ➢ **Artificial neural network** is used as a “statistical approach”.

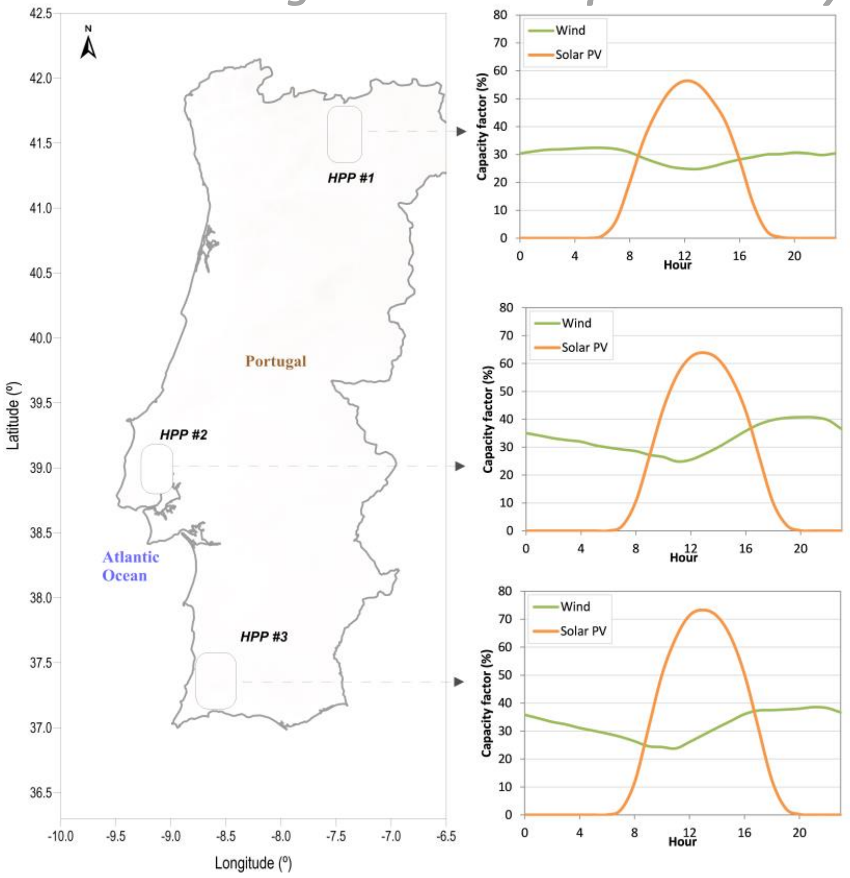
- Two objective functions (OF) were implemented:
  1. **Minimise** mean square error (**RMSE**);
  2. **Maximise** the **remuneration** in the Iberian electricity market (MIBEL): i.e., the “day-ahead (DAM) and imbalancing setlement (IS)”.

[2a]*Couto, A., & Estanqueiro, A. (2023). Wind power plants hybridised with solar power: A generation forecast perspective. Journal of Cleaner Production, 423, 138793.* https://doi.org/10.1016/j.jclepro.2023.138793

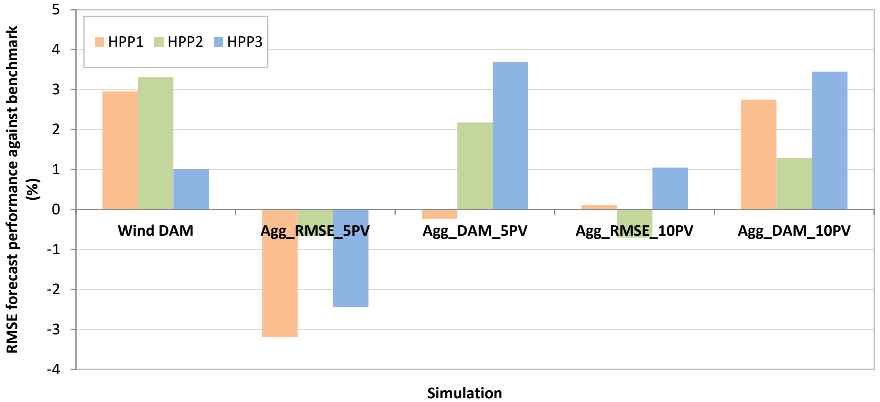
[2b]*Couto, A., & Estanqueiro, A. (2022). Enhancing wind power forecast accuracy using the weather research and forecasting numerical model-based features and artificial neuronal networks. Renewable Energy, 201, 1076-1085.*https://doi.org/10.1016/j.renene.2022.11.022

B) HPP Enhanced Operation Results

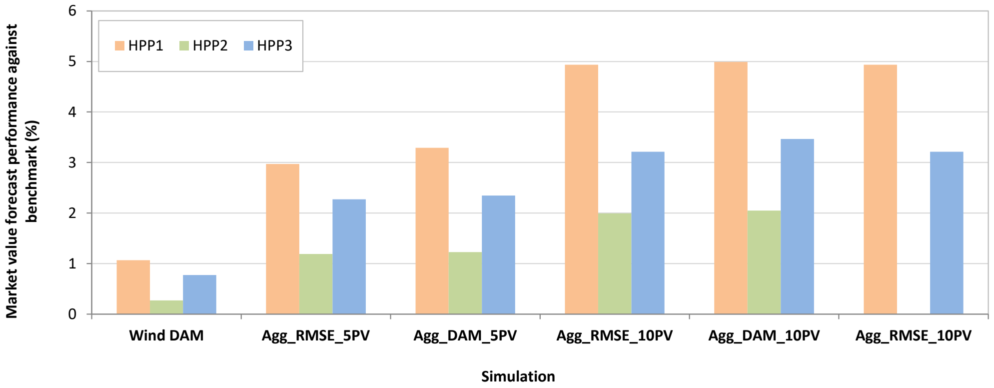
Measuring the local complementarity



Location and wind and solar PV generation profiles for the HPPs analysed.



- *RMSE performance*

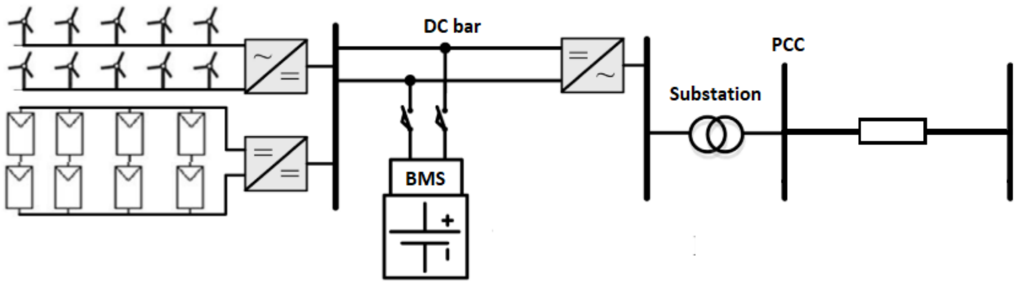


- *Market value (DAM + BS)*

- Hybridising existing wind power plants with solar PV enables to reduce the RMSE in most cases, especially for low additional levels of solar PV → a result partially explained by a reduced (combined) variability in the case of "*Agg*" scenarios.
- Hybridization of HPPs always resulted in substantial economic benefits to producers operating within an electricity market, regardless of the objective function used.

C) Improving vRES value in Electricity Markets: HPP/VPP strategic bidding[3]?

- Recently **new vRES agents – e.g. VPPs and aggregators – started to participate in electricity markets** under challenging conditions, obtaining low margins that do not support re-investment and, in some cases, require support additional to markets price (in the form of CfDs or PPAs).
- This **work aimed to assist market agents in trading vRES and enable them to increase the value of variable renewable energy assets/products**. To achieve it, a decision-aid algorithm for active market participation and optimal bidding strategy of VRPPs was developed and a **multi-stage linear stochastic model**[3] to promote the active participation of renewable energy agents in the electricity markets (day-ahead, intraday and IS/balance markets) was produced.



The VRPP: wind, solar PV and storage:

[3] *A. R. Silva, H. M. I. Pousinho, and A. Estanqueiro, "A multistage stochastic approach for the optimal bidding of variable renewable energy in the day-ahead , intraday and balancing markets", **Energy (Elsevier)**, vol. 258, p. 124856, 2022, doi: 10.1016/j.energy.2022.124856.*

The mathematical model: OptiBID

Objective Function:

$$\boldsymbol{maximize}\left(I^{DA}+\sum_{1}^{S} I^{ID^{s}}+I^{BM}\right) \tag{5.21}$$

Constraints:

$$I^{DA}=\sum_{w}^{\Omega}\pi_{w}\left(\sum_{t}^{T} P_{BID}{}^{DA}(t)\cdot\Gamma_{w}{}^{DA}(t)\right), \qquad \forall t\epsilon T, \forall w\epsilon\Omega \tag{5.1}$$

$$I^{ID^{s}}=\sum_{w}^{\Omega}\pi_{w}\left(\sum_{t}^{T} P_{BID}{}^{ID^{s}}(t)\cdot\Gamma_{w}{}^{ID^{s}}(t)\right), \qquad \forall s\epsilon S, \forall t\epsilon T, \forall w\epsilon\Omega \tag{5.2}$$

$$I^{BM}=\sum_{w}^{\Omega}\pi_{w}\left(\sum_{t}^{T} P_{BM}{}^{+}(t)\cdot\Gamma_{w}{}^{DA}(t)\cdot r_{BM,w}{}^{+}(t)\right)-\sum_{w}^{\Omega}\pi_{w}\left(\sum_{t}^{T} P_{BM}{}^{-}(t)\cdot\Gamma_{w}{}^{DA}(t)\cdot r_{BM,w}{}^{-}(t)\right) \tag{5.3}$$

$$P_{BID}{}^{DA}(t)=\hat{P}_{w}{}^{DA}(t)-P_{CURT}{}^{DA}, \qquad \forall t\epsilon T, \forall w\epsilon\Omega \tag{5.4}$$

$$0 \le P_{BID}{}^{DA}(t) \le P_{PCC}, \qquad \forall t\epsilon T, \forall w\epsilon\Omega \tag{5.5}$$

$$P_{BID}{}^{ID^{s}}(t)=\hat{P}_{w}{}^{ID^{s}}(t)-\left[P_{BID}{}^{DA}(t)+\sum_{1}^{s} P_{BID}{}^{ID^{s-1}}(t)\right], \qquad \forall s\epsilon S, \forall t\epsilon T, \forall w\epsilon\Omega \tag{5.6}$$

$$\sum_{1}^{s} P_{BID}{}^{ID^{s}}(t) \ge -P_{PCC}, \qquad \forall s\epsilon S, \forall t\epsilon T \tag{5.7}$$

$$P_{BID}{}^{DA}(t)+\sum_{1}^{s} P_{BID}{}^{ID^{s}}(t) \le P_{PCC}, \qquad \forall s\epsilon S, \forall t\epsilon T \tag{5.8}$$

$$\Delta P(t)=P^{ACT}(t)-\left[P_{BID}{}^{DA}(t)+\sum_{1}^{s} P_{BID}{}^{ID^{s}}(t)\right], \qquad \forall t\epsilon T, \forall w\epsilon\Omega \tag{5.9}$$

$$\Delta P(t)=\Delta P^{+}(t)-\Delta P^{-}(t), \qquad \forall t\epsilon T \tag{5.10}$$

$$\Delta P^{+}(t)=P_{BM}{}^{+}(t)+P_{CHA}(t)+P_{CURT}(t), \qquad \forall t\epsilon T \tag{5.11}$$

$$\Delta P^{-}(t)=P_{BM}{}^{-}(t)+P_{DIS}(t), \qquad \forall t\epsilon T \tag{5.12}$$

$$P_{BID}{}^{DA}(t)+\sum_{1}^{s} P_{BID}{}^{ID^{s}}(t)+P_{BM}{}^{+}(t) \le P_{PCC}, \qquad \forall t\epsilon T \tag{5.13}$$

$$E_{BAT}(t)=0.6\cdot E_{BAT}+\eta_{CHA}\cdot P_{CHA}(t)-\frac{1}{\eta_{DIS}}\cdot P_{DIS}(t), \qquad \forall t=1 \tag{5.14}$$

$$E_{BAT}(t)=E_{BAT}(t-1)+\eta_{CHA}\cdot P_{CHA}(t)-\frac{1}{\eta_{DIS}}\cdot P_{DIS}(t), \qquad \forall t>1 \tag{5.15}$$

$$E_{BAT}(t)=0.6\cdot E_{BAT}, \qquad \forall t=24 \tag{5.16}$$

$$E_{BAT}(t) \le E_{BAT} \tag{5.17}$$

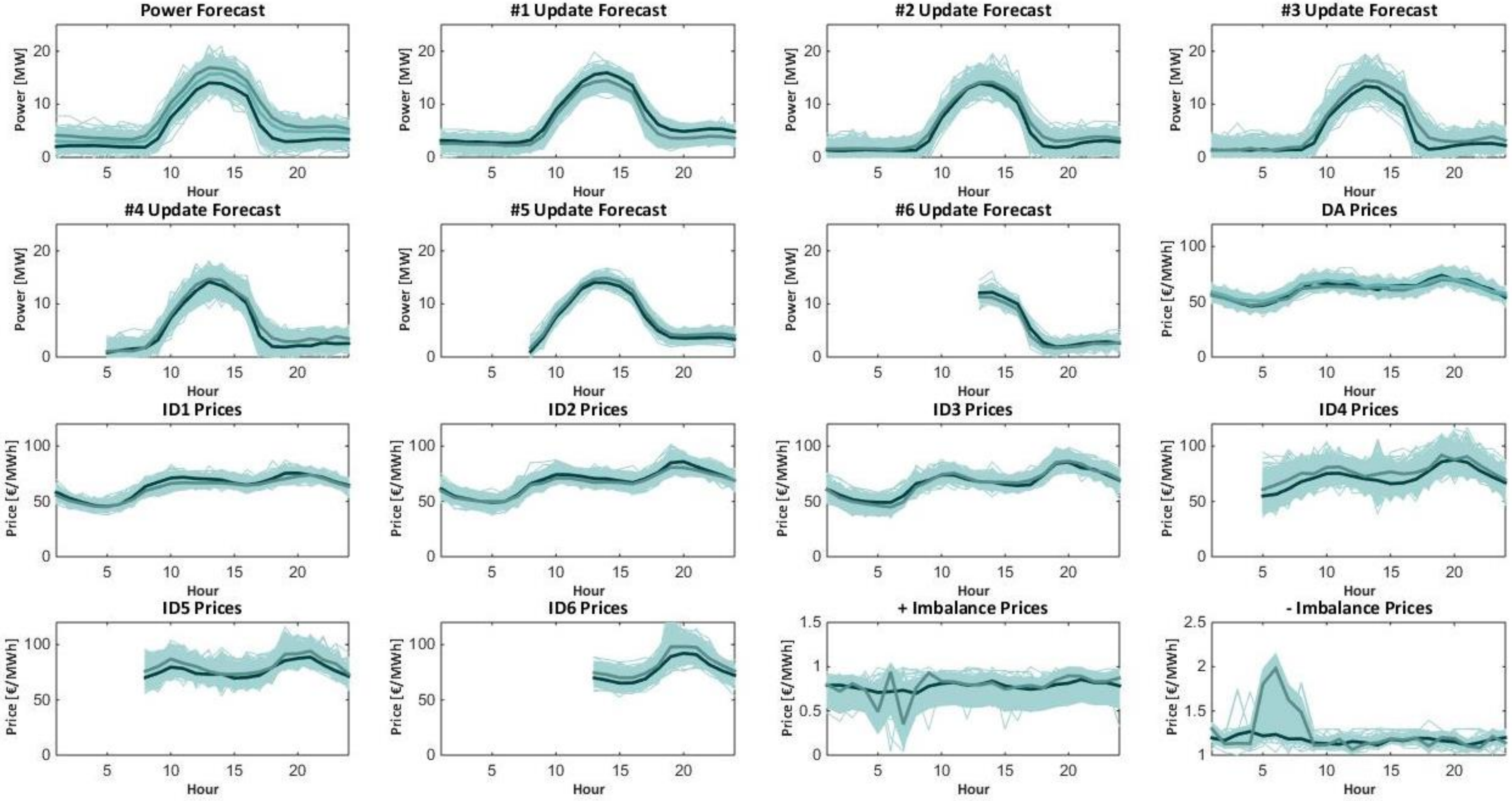
$$P_{CHA}(t) \le P_{BAT}, \qquad \forall t\epsilon T \tag{5.18}$$

$$P_{DIS}(t) \le P_{BAT}, \qquad \forall t\epsilon T \tag{5.19}$$

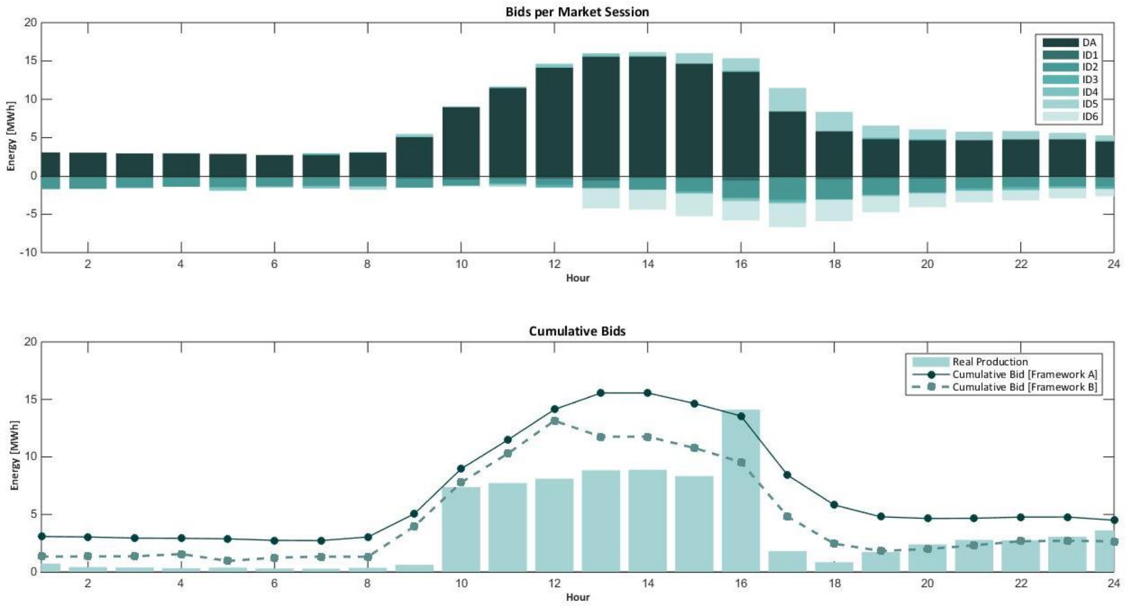
$$P_{CHA}(t) \le P^{ACT}(t), \qquad \forall t\epsilon T \tag{5.20}$$

Application of OptiBID to a Virtual Power Plant: the Scenarios

The Scenarios (16 variables)

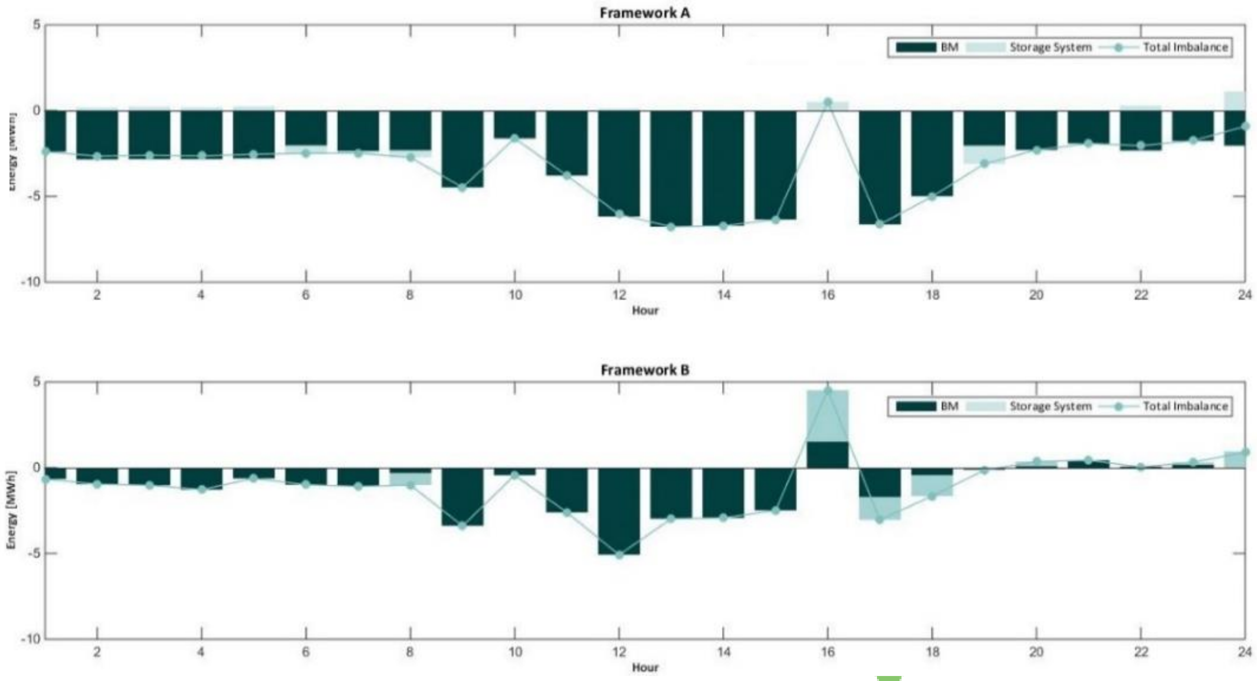


Application of the (OptiBID) to a Virtual Power Plant: the Results



Hourly bids in each session of the electricity market and representation of the cumulative bid at the end of all DA and ID sessions.

Hourly imbalances per framework studied.



+10.1% in profits

- 63.6% in imbalances penalties

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