Electricity Markets Game

... forecast, experiment, succeed!!

GAMEPLAY INSTRUCTIONS

Game dynamics:

Welcome to the Electricity Markets Game (EmGA), a game designed for explaining electricity markets concepts in a more dynamic way!!

The game evolves within a number of trading days $\Omega_{\mathrm{D}} = \{1, 2, \dots, D\}$, for which, your main motivation as the Energy Portfolio administrator, is to participate in the day-ahead electricity market and maximize your revenue.

- **Portfolio selection:**

Your first task is to determine your energy portfolio. This involves the selection of the energy sources you are willing to administrate considering their main characteristics, i.e., power capacity, capacity factor, dispatchability, variability, direct emissions, indirect emissions, and construction cost. The portfolio selection page can be seen in Fig. 1. However, you need to choose wisely since **your investment cost is limited to a fixed budget**.

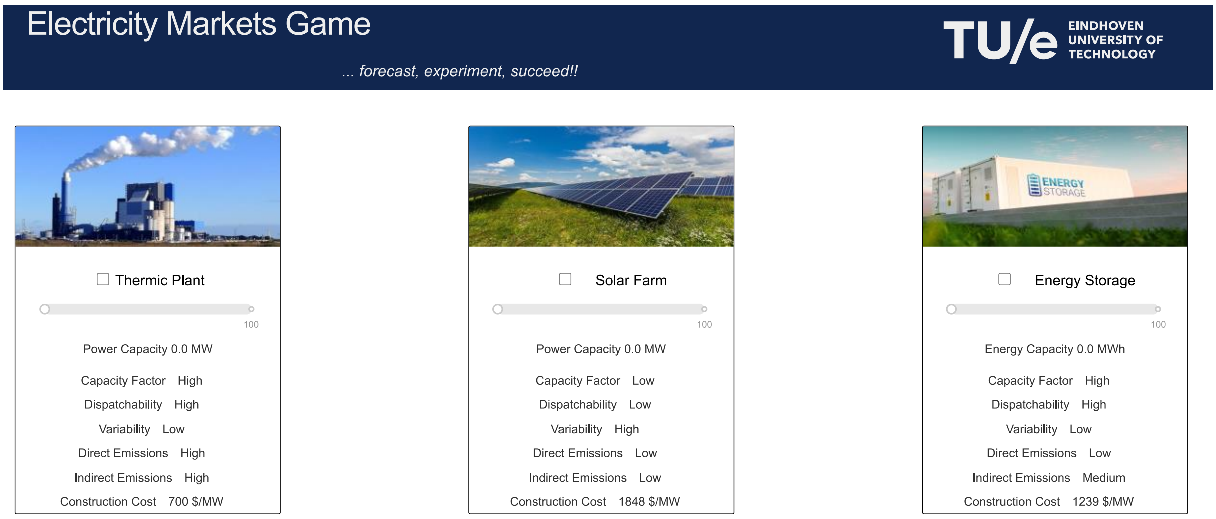

Fig. 1. Portfolio selection page.

- **Operational constraints:**

Once you have selected your portfolio, you need to be aware of the operational limitations considered in the game for each source:

- ***Thermic plants***: Ramp-up, ramp-down, min/max power constraints ($\overline{E}_{\mathrm{Th}}^{\mathrm{ramp}}, \underline{E}_{\mathrm{Th}}^{\mathrm{ramp}}, \underline{E}_{\mathrm{Th}}, \overline{E}_{\mathrm{Th}}$).
- ***Wind farms***: Maximum power ($\overline{E}_{\mathrm{Wd}}^{\mathrm{ramp}} = \infty, \underline{E}_{\mathrm{Wd}}^{\mathrm{ramp}} = -\infty, \underline{E}_{\mathrm{Wd}} = 0, \overline{E}_{\mathrm{Wd}}$).
- ***Energy storage***: ($\overline{E}_{\mathrm{St}}^{\mathrm{ramp}} = \infty, \underline{E}_{\mathrm{St}}^{\mathrm{ramp}} = -\infty, \underline{E}_{\mathrm{St}}, \overline{E}_{\mathrm{St}}, \overline{\mathrm{SOC}}_{\mathrm{St}}, \underline{\mathrm{SOC}}_{\mathrm{St}}$).

The operational limits of your portfolio are available to download as a .csv file. It is important that you consider them in your decision making algorithm since you are encouraged to submit feasible bids, i.e., bids that satisfy all operational constraints. **A pre-processing step consisting on solving an optimization problem will check the feasibility of your bids and modify all periods that are not aligned with the constraints.** This would result in loosing revenue.

- **Expected accumulated day revenue:**

Your position in the market is of a price-taker; hence, your task is to submit one-hour energy blocks, for the next trading day, namely, energy bids E_t^{bid} considering day-ahead prices DAP_t, with $t \in \Omega_{\mathrm{T}} = \{0, 2, \dots, 23\}$. You will receive a compensation accordingly (expected accumulated day revenue), which is the revenue you are willing to obtain in the next trading day, $Rev_d^{\exp}$ as:

$$Rev_d^{\exp} = \sum_{t=0}^{23} E_t^{\mathrm{bid}} \, \mathrm{DAP}_t \ [€], \qquad \forall\, d \in \Omega_{\mathrm{D}} \tag{1}$$

<u>**Note**</u>: Although bids are considered as blocks of energy, it is required that participants upload their energy bids separately for matters of reproducibility and tractability. An example of an energy bid is displayed in Fig. 2, where all bids are in MWh. Hence, $E_t^{\mathrm{bid}} = \sum_{i \in \Omega_{\mathrm{S}}} E_{i,t}^{\mathrm{bid}}$, where $E_{i,t}^{\mathrm{bid}} = \{E_{\mathrm{Th},t}^{\mathrm{bid}}, E_{\mathrm{Wd},t}^{\mathrm{bid}}, E_{\mathrm{Pv},t}^{\mathrm{bid}}, E_{\mathrm{St},t}^{\mathrm{bid}}\}$ and $i \in \Omega_{\mathrm{S}} | \Omega_{\mathrm{S}} = \{\mathrm{Th}, \ \mathrm{Wd}, \mathrm{Pv}, \mathrm{St}\}$ represent the energy sources of the portfolio.

Hour	Thermal	Wind	Solar	Storage
00:00	36	70	43	75.6
01:00	36	70	43	75.6
02:00	36	70	43	75.6
03:00	36	70	43	75.6
04:00	36	70	43	75.6
05:00	36	70	43	75.6
06:00	36	70	43	75.6
07:00	36	70	43	75.6
08:00	36	70	43	75.6
09:00	36	70	43	75.6
10:00	36	70	43	75.6
11:00	36	70	43	75.6
12:00	36	70	43	75.6
13:00	36	70	43	75.6
14:00	36	70	43	75.6
15:00	36	70	43	75.6
16:00	36	70	43	75.6
17:00	36	70	43	75.6
18:00	36	70	43	75.6
19:00	36	70	43	75.6
20:00	36	70	43	75.6
21:00	36	70	43	75.6
22:00	36	70	43	75.6
23:00	36	70	43	75.6

Fig. 2. Example of separate energy bid.

- *Pre-processing optimization step*:

A pre-processing step consisting on solving an optimization problem verifies the feasibility of your bids and modifies all periods that are not aligned with the constraints. The optimization model reads as:

$$
\begin{aligned}
&\min_{\chi} \sum_{t\in\Omega_\mathrm{T}} \sum_{i\in\Omega_\mathrm{S}} \zeta_{i,t}^{+} + \zeta_{i,t}^{-} + \varphi_{i,t}^{+} + \varphi_{i,t}^{-} + \rho_{i,t}^{+} + \rho_{i,t}^{-} \\
&E_{i,t}^{\mathrm{bid}} - \varphi_{i,t}^{+} \leq \overline{E}_i, \qquad \forall\, i \in \Omega_\mathrm{S}, t \in \Omega_\mathrm{T} \\
&\underline{E_i} \leq E_{i,t}^{\mathrm{bid}} + \varphi_{i,t}^{-}, \qquad \forall\, i \in \Omega_\mathrm{S}, t \in \Omega_\mathrm{T} \\
&E_{i,t}^{\mathrm{bid}} - E_{i,t-1}^{\mathrm{bid}} - \zeta_{i,t}^{+} \leq \overline{E}_i^{\mathrm{ramp}}, \qquad \forall\, i \in \Omega_\mathrm{S}, t \in \Omega_\mathrm{T} \\
&\underline{E}_i^{\mathrm{ramp}} \leq E_{i,t}^{\mathrm{bid}} - E_{i,t-1}^{\mathrm{bid}} + \zeta_{i,t}^{-}, \qquad \forall\, i \in \Omega_\mathrm{S}, t \in \Omega_\mathrm{T} \\
&SOC_{i,t} = SOC_{i,t-1} - \frac{\eta_i}{EC_i} E_{i,t}^{\mathrm{bid}}, \qquad \forall\, i \in \Omega_\mathrm{S}, t \in \Omega_\mathrm{T} \mid i = \mathrm{St} \\
&SOC_{i,t} - \rho_{i,t}^{+} \leq \overline{\mathrm{SOC}}_i, \qquad \forall\, i \in \Omega_\mathrm{S}, t \in \Omega_\mathrm{T} \mid i = \mathrm{St} \\
&\underline{\mathrm{SOC}}_i \leq SOC_{i,t} + \rho_{i,t}^{-}, \qquad \forall\, i \in \Omega_\mathrm{S}, t \in \Omega_\mathrm{T} \mid i = \mathrm{St} \\
&SOC_{i,t} + \rho_{i,t}^{-} \geq \overline{\mathrm{SOC}}_i^{\mathrm{ini}}, \qquad \forall\, i \in \Omega_\mathrm{S}, t \in \Omega_\mathrm{T} \mid i = \mathrm{St} \wedge t = |\Omega_\mathrm{T}| \\
&\zeta_{i,t}^{+}, \zeta_{i,t}^{-}, \varphi_{i,t}^{+}, \varphi_{i,t}^{-}, \rho_{i,t}^{+}, \rho_{i,t}^{-} \geq 0, \qquad \forall\, i \in \Omega_\mathrm{S}, t \in \Omega_\mathrm{T}
\end{aligned}
\tag{2}
$$

where $\chi = \{\zeta_{i,t}^{+}, \zeta_{i,t}^{-}, \varphi_{i,t}^{+}, \varphi_{i,t}^{-}, \rho_{i,t}^{+}, \rho_{i,t}^{-}\}$ are slack variables. Any slack variable whose value is different than 0 represents an infeasible bid; hence, a violation of the operational constraints. The bids with violation will be modified to the closest feasible operational limit and the values of the slack variables will be considered with imbalance market prices, resulting in revenue inefficiency.

- **Variability of energy sources:**

Depending on the characteristics of your portfolio, your actual energy production might not be as expected, e.g., windpower may differ from what you forecasted during the day as in Fig. 3.

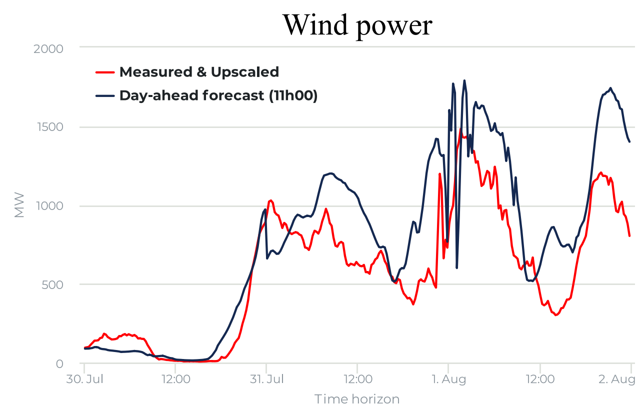

Fig.3 Measured and forecasted power generation from renewable sources – Source Elia Group
https://www.elia.be/en/grid-data/power-generation/wind-power-generation

As a consequence, the energy your portfolio is effectively injecting to the system is affected by the variability of the energy sources. In the EmGA platform, the main sources of variability are considered to be the renewable energy sources (wind farms). It has been assumed that the operation of controllable sources (thermal plants and energy storage) is perfectly deterministic.

- **Market rules:**

The market rules implemented in the EmGA platform are simple and depend on the day ahead prices and the energy mismatch between your energy bid and your actual energy injection. Consider the energy imbalance as in (3), and the imbalance cost as in (4):

$$\Delta E_t = E_t^{\text{act}} - E_t^{\text{bid}}, \forall\, t \in \Omega_{\text{T}} \tag{3}$$

$$imb_t = \lambda_t\, \Delta E_t, \qquad \text{where} \begin{cases} \lambda_t = \lambda_t^{+}\, \text{DAP}_t, & \text{if} \quad \Delta E_t > 0 \\ \lambda_t = \lambda_t^{-}\, \text{DAP}_t, & \text{if} \quad \Delta E_t < 0 \\ \lambda_t = \text{DAP}_t, & \text{if} \quad \Delta E_t = 0 \end{cases} \tag{4}$$

Notice that ΔE_t is the energy mismatch and it is positive if your portfolio is producing more energy than what has been submitted in your bid (surplus) or vice versa (deficit). The values for $\lambda_t^{+}, \lambda_t^{-} \geq 0$ are proportional to the day-ahead price, always respecting that $\lambda_t^{-} \geq 1$ and $\lambda_t^{+} \leq 1$.

Notice that the imbalance cost might be decreased by considering the flexibility of the controllable sources.

- **Flexibility:**

Thermal plants are assumed to be flexible, i.e., they are able to inject a different amount of energy than they were initially dispatched in the energy bid within a predefined range. This amount of used flexibility is represented by F_t, and it is limited by a symmetric parameter proportional to the energy bid, i.e., $\text{F}_t = \alpha E_{\text{Th},t}^{\text{bid}}$.

However, using this flexibility represents an operational cost to the portfolio since the units must deviate from their optimal operation to compensate the imbalance. In some occasions, paying the imbalance costs might be a better option than paying the flexibility costs or vice versa. Hence, the EmGA platform solves internally an optimization problem for you at each time period, always selecting the option that suits you the most depending on the sign of ΔE_t:

If $\Delta E_t > 0$:

$$\begin{aligned} & \min_{F_t} \{c_t + \lambda_t(\Delta E_t - F_t)\} \\ \text{s.t:} \quad & \\ & c_t = a(F_t)^2 + b(F_t) + c \\ & E_{\text{Th},t}^{\text{bid}} + F_t \leq \overline{E}_{\text{Th}}, \quad \forall\, t \in \Omega_{\text{T}} \\ & E_{\text{Th},t}^{\text{bid}} + F_t \leq \overline{E}_{\text{Th}}^{\text{ramp}}, \qquad \forall\, t \in \Omega_{\text{T}} \end{aligned} \tag{5a}$$

$$\Delta E_t^f = \Delta E_t + F_t, \quad t \in \Omega_\mathrm{T}$$

If $\Delta E_t < 0$:

$$\min_{F_t} \{c_t + \lambda_t(-\Delta E_t + F_t)\}$$

s.t:

$$c_t = a(F_t)^2 + b(F_t) + c$$

$$E_{\mathrm{Th},t}^{\mathrm{bid}} - F_t \geq \underline{E}_{\mathrm{Th},}, \qquad \forall\, t \in \Omega_\mathrm{T} \tag{5b}$$

$$E_{\mathrm{Th},,t}^{\mathrm{bid}} - F_t \leq \overline{E}_{\mathrm{Th},}^{\mathrm{ramp}}, \qquad \forall\ t \in \Omega_\mathrm{T}$$

$$\Delta E_t^f = \Delta E_t - F_t, \quad t \in \Omega_\mathrm{T}$$

Hence, the actual imbalance becomes ΔE_t^f. While the imbalance cost becomes $imb_t = \lambda_t \Delta E_t^f$ and the operational cost for flexibility is denoted by c_t. Finally, the infeasibility penalty is computed as the total of the constraint violations times the imbalance price, i.e., $pen_t = \lambda_\mathrm{t}\chi_t$, where $\chi_t = \sum_{i\in\Omega_\mathrm{S}} \zeta_{i,t}^+ + \zeta_{i,t}^- + \varphi_{i,t}^+ + \varphi_{i,t}^- + \rho_{i,t}^+ EC_i + \rho_{i,t}^- EC_i\,, \forall\, t \in \Omega_\mathrm{T}$.

- **Actual accumulated day revenue:**

The actual accumulated day revenue is expressed as:

$$Rev_d^{\mathrm{act}} = Rev_d^{\mathrm{exp}} + \sum_{t=0}^{23} (imb_t - pen_t - c_t)\ [€], \qquad \forall\, d \in \Omega_\mathrm{D} \tag{6}$$

Notice that these market rules encourage the players to be as accurate as possible with their forecasts, i.e., $\Delta E_t \approx 0$ and to respect the operational limits of their portfolio. Hence, it is evident that $Rev_d^{\mathrm{act}} \leq \sum E_t^{\mathrm{act}}\,\mathrm{DAP}_t$ encouraging perfect forecast ($E_t^{\mathrm{bid}} = E_t^{\mathrm{act}}$). However, it leaves room for strategy playing considering the imbalance prices and the flexibility costs.

- **Leaderboard:**

There are three main components of the game every player must be aware of: Accumulated revenue or just **Revenue**, the number of played days or **Days**, and the **Rate**.

The **Revenue** is the sum of the accumulated day revenue during the days you have played so far, $\sum_{d\in\Omega_\mathrm{D}} Rev_d^{\mathrm{act}}$. The **Days** represent the number of trading days a player has bided. While the **Rate** is a measure of the performance of each player representing the quotient between the **Revenue** and the number of bade **Days**, as:

$$Rate = \frac{\mathrm{Revenue}}{\mathrm{Days}}\ [€/\mathrm{day}] \tag{7}$$

You can monitor your general performance and compare it with the rest of your competitors by clicking on the “**Leaderboard**” button. The Leaderboard contains the position of each player, obtained accordingly to its **Rate** value. The **Rate** is then the most important parameter of the game, **so you may want to have it as high as possible!!**

The game finishes for a player when there are no more available trading days. When all players have finished the game, the **WINNER** would be the player that appears in the first position of the Leaderboard.

The general flowchart of a player on the EmGA platform is shown in Fig. 4.

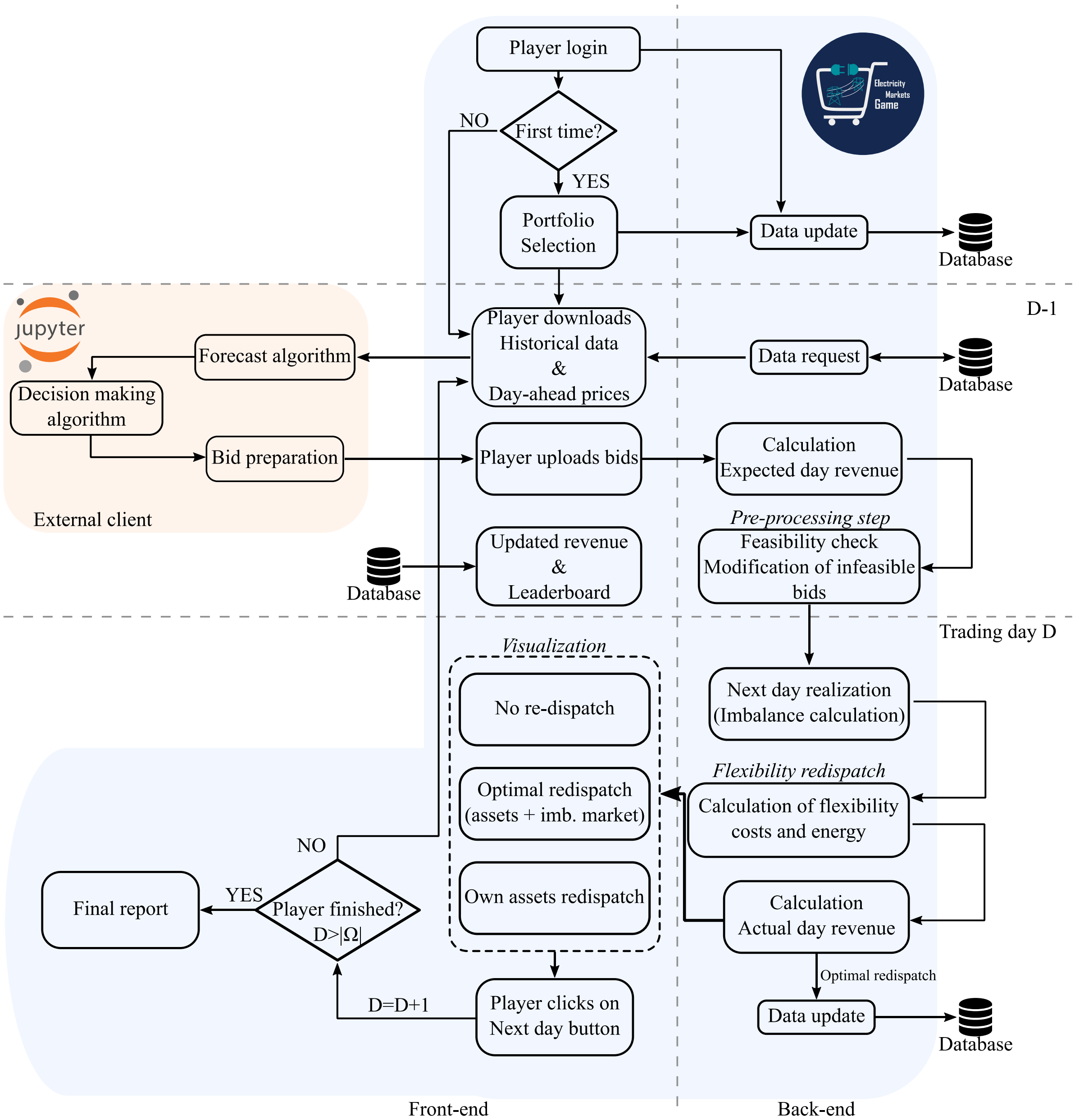

Fig. 4. Flowchart of one player in the EmGA platform.

Game instructions:

1. (EMGA) Register in the platform and access using your username and password.
    a. If it is your first time playing, you will be redirected to select your energy portfolio. After you have selected your portfolio, you will be redirected to step 2.
    b. If it is not your first time, you will be immediately redirected to step 2.

2. (EMGA) In the main page, you will be able to download the updated historical wind data and the day-ahead prices (updated for each trading day). Also, you will be able to download the operational limits of your portfolio.

3. (Jupyter notebook) Use a forecasting technique to estimate the expected hourly wind speeds for the next trading day.

4. (Jupyter notebook) Use a decision making technique to obtain the hourly energy bids for your portfolio.

5. (EMGA) Upload and submit your bid file, containing the expected hourly energy bids obtained in step 4 separated by energy source. Your file must have extensions .csv or .xls and should contain 25 rows and 5 columns in total. You can drag the file or select it from your computer.

6. (EMGA) Click on the “**SUBMIT**” button to submit your energy bids and continue with the game.

7. (EMGA) You will be redirected to the performance page, where you can review your day performance by comparing your actual revenue and the maximum revenue (perfect forecast).

8. (EMGA) Once you click on the “**Go to Next Day's Bid**” button, you will be redirected back to the main page. To continue with the game, repeat this guide from step 2.

9. The game finishes when there are no more available trading days. You will be immediately redirected to the summary page where you can see your final stats. When all players have finished the game, the **WINNER** will be the player that appears in the first position of the Leaderboard.