

# From day-ahead to a 6-hour period-ahead market adapted to the stochastic behaviour of variable energy renewable sources

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**Abstract**— The existing electricity market design challenges the fair and competitive participation of variable renewable energy sources (vRES) due to their weather dependence and limited forecasting accuracy, especially for long-time horizons, as required in the day-ahead market (DAM). These challenges impact market clearing prices and create imbalances, leading to inefficiencies, such as market-splitting events. To enhance the market efficiency and fairness for vRES producers, this work proposes a period-ahead market (PAM) with a 6-hour rolling horizon instead of the traditional 24-hour DAM. A case study of the Iberian electricity market with 2030 energy mix scenarios for Portugal and Spain, demonstrates that, in PAM, vRES producers can reduce wind and solar power forecast errors by over 7% and 4%, respectively, when compared with DAM. This leads to a 2% decrease in electricity prices and an annual reduction of market-splitting events in 158 hours thus enhancing price harmonization between Portugal and Spain. Additionally, balancing prices also decreased in PAM benefiting the balance responsible parties. The findings highlight that PAM improves the market's efficiency, a key factor in the pathway for the decarbonization of power systems.

**Index Terms**-- Day-ahead market, Electricity market design, Period-ahead market, power forecast, Variable renewable energy sources.

## I. INTRODUCTION

The non-dispatchable variable renewable energy sources (vRES), especially wind and solar photovoltaic (PV), have grown significantly in power systems in the recent years, and, contrary to conventional power plants, vRES have low or residual marginal costs [1]. Additionally, vRES are typically the marginal technology, operating at optimal capacity depending on weather conditions. These factors considerably influence the market outcomes by significantly lowering clearing prices [2]. As a consequence, in recent years

researchers have focused on evaluating whether the current electricity market (EM) design remains efficient [2], especially in a context of energy transition with the increasing share of vRES that are expected to be attractive for investments without relying on support schemes.

The day-ahead market (DAM) is one of the most studied market designs in the literature due to its high participation rate and strong liquidity being normally used for the development and implementation of governmental subsidy policies [3], [4]. Research on DAM design covers various aspects [5], such as new clearing models [3], increased time granularity [6], [7] and adjustments to the gate closure time to bring it closer to real-time delivery [8], [9]. This research is important since, the current DAM design was established when dispatchable, mainly fossil fuel-based, power plants dominated the energy mix. These plants can efficiently set operational points to meet demand when scheduled several hours in advance. However, their restricted ramping rates limit their ability to adapt to periods of high demand/net load variability and are associated with increased overall system costs and significant environmental impacts. In contrast, vRES are weather-dependent, mostly constitute a non-dispatchable technology and face significant forecast errors, especially over longer periods [10].

In most electricity markets, the existing DAM requires power forecasts with at least 12 to 36 hours in advance [1]. As an example, on day “D” at 12:00 p.m. (CET), producers must submit bids based on forecasts for the entire 24-hour period of the next day (“D+1”). Despite significant advancements in forecasting systems, supported by the machine learning-based weather prediction models [11], power forecasts still exhibit substantial errors, due to the inherently chaotic nature of the atmosphere [12]. Since any discrepancies between the energy

effectively produced and the commitments made for the DAM must be resolved in the intra-day and/or balancing markets (BMs), as balance responsible parties (BRPs), vRES producers may pay significant penalties for their imbalances, reducing their market-based remuneration and jeopardizing their profitability [9]. As a result, adjusting the market's gate closure time to closer to real-time operation benefiting from, on average, improved power forecasts, may be crucial to: i) ensure

a more “fair” participation for vRES producers; and ii) increase the overall market efficiency [8].

Against this background, this work introduces the period-ahead market (PAM) as an alternative to the current day-ahead market (DAM) design. The key distinction of PAM is its shorter trading period of six hours, compared to the traditional 24-hour block in DAM.

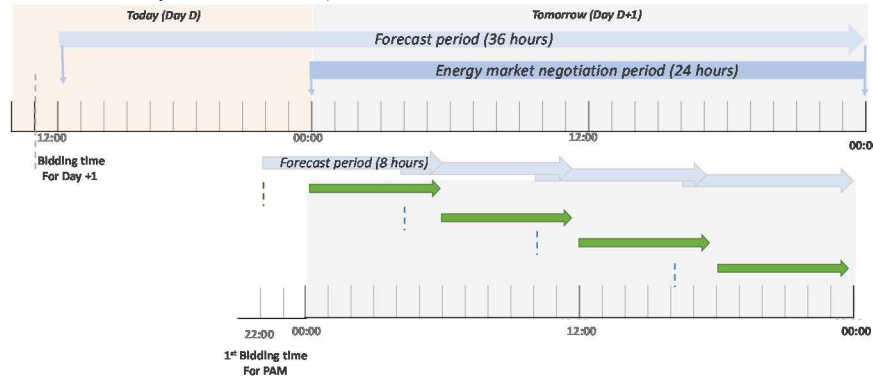


Figure 1. Schematic representation of day-ahead market (upper figure) and period-ahead market (lower figure) timeframes (adapted from [13]).

The work presents the potential benefits of PAM, strongly associated with the increase in the power forecast systems performance, using the Iberian electricity market (MIBEL) as a case study, based on 2030 energy mix scenarios derived from national energy and climate plans. A workflow integrating two complementary simulation tools was implemented: the Multi-Agent System for Competitive Electricity Markets (MASCEM) [14] and the Multi-agent Trading of Renewable Energy Sources (RES.Trade) [15]. Section II provides a description of the PAM design as an alternative to the existing DAM design. In Section III a brief description of the methodology and the bid generation process across the simulated electricity markets are presented. Section IV describes the case study and the scenario while, in Section V, the results are presented. Finally, in Section VI, some final remarks are provided.

## II. PERIOD-AHEAD MARKET (PAM) – AN ALTERNATIVE TO EXISTING DAM DESIGN

PAM design, developed within the scope of a European-funded project TradeRES, aims to align market operations with the characteristics of vRES, fostering a more responsive, adaptable, and efficient energy market. Additionally, PAM can enhance grid flexibility and encourage the development of innovative technologies and solutions that provide the necessary flexibility. A schematic representation of the timeframes associated with PAM, which involves forecasts 8 hours ahead, with four updates during the day, and the trading of 6 hours is provided in Fig. 1.

## III. METHODOLOGY

To assess the potential impact of PAM design compared with the DAM, a workflow integrating the MASCEM and RES.Trade simulation tools was implemented, Fig. 2.

MASCEM simulate the main market entities and their interactions, representing these entities as software agents, including buyer and seller agents (consumers, producers,

and/or prosumers) and market and system operators. This tool enables the simulation of three major European Electricity Markets (EM), including MIBEL (day-ahead market, the auction-based intraday market, and the continuous intraday market).

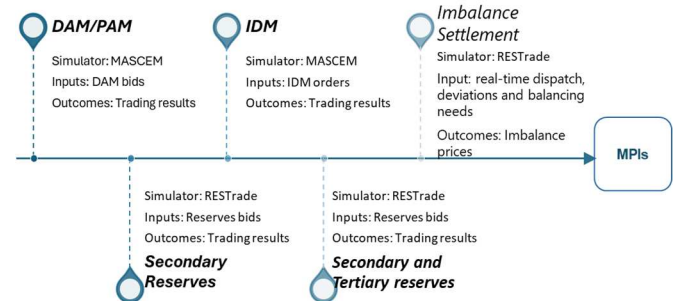


Figure 2. Identification of the market simulated with the indication of the simulators, market, and input/outcomes (adapted from [13]).

RES.Trade focuses on simulating the traditional power and energy reserve markets, and enables not only the participation of conventional dispatchable power plants, but also vRES, and demand-side players in balancing market. Moreover, it also incorporates innovative features to improve these markets and the imbalance settlement, aligning them with recent European regulations. These enhancements aim to improve market efficiency by considering: i) separate procurement, ii) marginal pricing, iii) non-discriminatory access, and iv) fair cost distribution [15], [16].

In the workflow implemented, the following markets were integrated and simulated:

- Day-ahead market (DAM): This market follows the current European single day-ahead coupling (SDAC) design [17]. It involves trading electricity for 24 hourly periods, with bids submitted the previous day at noon.

- Period-ahead market (PAM): A proposed alternative to the current DAM design [18]. PAM allows trading in six-hour periods, with four forecast updates throughout the day. Other aspects of its design are identical to DAM.
- Intraday continuous market (IDM): Based on the Single Intraday Coupling (SIDC) model, integrated in MIBEL [17]. This Pan-European continuous trading market typically has low liquidity and is not favourable for vRES, which tends to bid late to minimize forecast errors. To overcome this, a modified SIDC is considered by: i) allowing continuous bidding but deferring trading to the end of each session; and ii) giving vRES priority using the SIDC pay-as-bid scheme.
- Secondary Reserves: The current designs in both Portugal and Spain were simulated. Separate procurement of upward and downward power was modelled, allowing vRES participation. Reserve procurement followed ENTSO-E guidelines [19].
- Tertiary Reserves: vRES participation was allowed in this study. While this is not permitted in Portugal, Spain already includes both wind energy and solar PV in a pilot phase [20].
- Imbalance Settlement: The Portuguese system was applied to both countries, distributing all balancing costs equally among BRPs, regardless of the imbalance direction.

In this work, the results are assessed through (key) market performance indicators (MPIs), which comprise three main dimensions: technical, economic, and environmental.

#### A. Bid generation for the different electricity markets

In MASCEM model, the bids were created to reflect available energy per technology while ensuring prices meet or exceed marginal costs to maintain competition and realistic market behaviour. Below a brief explanation of the bid generation is provided, with more details available in [13].

1) *Bid generation for DAM/PAM*: To ensure realistic input data for DAM/PAM generation, OMIE's 2022 data [21] was used to identify existing market players, their units, and technologies. For units already present in 2022, bidding volumes in each scenario were set based on their 2022 bidding volume ratios. For newly added generating units, bidding volumes were assigned according to their capacity ratios within the same technology class. For vRES players, the bids are based on power forecasts using the methodology presented in [12]. Initially, forecast data were obtained from various wind and solar PV plants in Portugal and Spain, based on their nominal capacity in 2019 (the reference year for the TradeRES project). Then, the data were upscaled proportionally to match the installed capacity of each technology in the 2030 scenario enabling the diversification of the generated bids, aiming to mimic the bidding of vRES-based players in the EM.

Bid prices are set by multiplying a technology marginal cost [22] considered in optimisation model used to generate the

optimised scenario or water value by a random factor (+/-10%) for most technologies, while others (e.g., demand side response, solar, wind) have fixed values. This introduces price variation and competition within each technology.

2) *Bid generation for IDM*: In the case of IDM, the order generation considered the untraded supply in DAM/PAM, updated power forecasts, and units allocated to secondary reserves. vRES units adjust their bid in this market based on updated forecasts, submitting sell orders for the case of surpluses of generation when compared with the DAM/PAM program. Otherwise, these players can submit buy orders to fulfil the volume traded in DAM/PAM that may lack. Load units follow the same approach based on updated consumption forecasts.

3) *Bid generation for balancing markets*: In the case of the secondary reserve, bids are determined based on DAM/PAM dispatch schedules and the available capacity of fast-response power plants. Bid prices are derived from the bids observed in 2019 (reference year in this work) [23]. Energy bids for SecR follow the clearing bids of the secondary power market, while price bids are influenced by DAM/PAM outcomes and the marginal costs of power plants. Bids not cleared in the secondary market are carried over to the tertiary reserve (TR) market, along with bids from players limited to TR due to technical constraints. The bids in this market are fixed after IDM clearing.

#### IV. CASE STUDY: INPUT DATA AND SCENARIO DESCRIPTION

The scenario used in this work was developed within the scope of TradeRES project. All information related with the scenario is publicly available and can be consulted in [22]. The scenario was obtained using the optimization model Backbone [24] using the capacity foreseen in the 2030 national energy and climate plans from Portugal and Spain. In the scenario, a single snapshot year is simulated using hourly resolution. Fig. 3 presents the optimized installed capacities for the different technologies in Portugal and Spain, showing that the capacity mix in the Iberia peninsula is expected to be dominated by solar PV and wind (onshore) power generation.

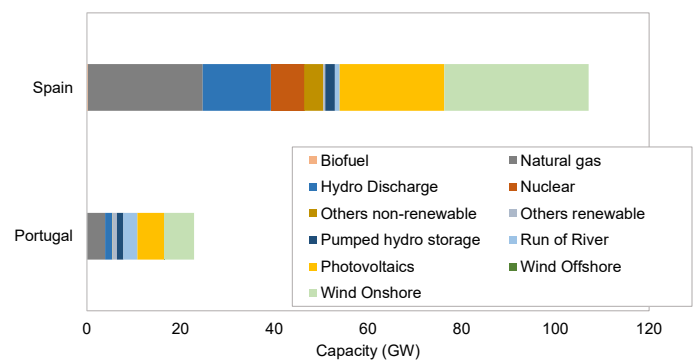


Figure 3. Identification of installed capacity for Portugal and Spain in the scenario analysed.

## V. RESULTS: ASSESSING THE IMPACT OF PAM DESIGN

This section evaluates the impact of two market designs (DAM and PAM) using relevant MPIs, for a 2030 energy mix scenario characterized by high levels of vRES.

### A. Power forecast errors for DAM and PAM timeframes

The main driver behind the expected benefits from the change from DAM to PAM is associated with the improvement of the power forecast accuracy due to the shorter forecast time horizon. Fig. 4 presents the normalized root mean square errors (NRMSE) for the national aggregated wind and solar PV technologies in Portugal (PT) and Spain (SP). The normalization is based on the average observed power production of each country.

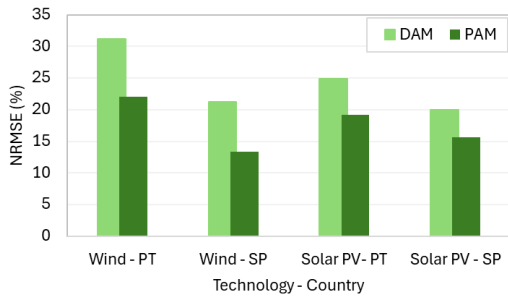


Figure 4. Normalized root mean square error for the Portuguese (PT) and Spanish (SP) national aggregated wind and solar PV technologies.

Fig. 4 shows that using PAM timeframes instead of DAM led to a reduction above 7% in NRMSE for the case of wind power. In the case of solar power, the improvement is more reduced, although still above 4% in both countries. The impact is more pronounced in Portugal, which simultaneously showed lower forecast accuracy compared to Spain. These findings are partially explained by the power smoothing effect that supports the reduction in the power forecast errors [25]. Therefore, the PAM design reduces forecast errors compared to DAM. The following sections analyse and discuss the technical, economic, and environmental impacts of this new electricity market design.

### B. Technical impacts: Renewable Energy Share, Curtailment, System Efficiency

The technical impacts of the PAM are not significant, and the main impacts are related to the increased energy procurement from the balancing markets to compensate the imbalances in relation to the programmed dispatch in DAM/PAM. In Portugal, the RES share in electricity consumption is the same in both designs, reaching 87%. In Spain, when the DAM design is used, the share of RES is 76%. With the PAM design, there is a slight decrease to 75%. This reduction is due to the improved forecast accuracy in the PAM design, which helps reduce overestimation of vRES in the market. As a result, energy procurement efficiency improves, and the need of ancillary services decreases. The annual curtailment of market-based energy is similar for both designs, with 2.8% in Portugal and 5.5% in Spain.

### C. Economic impacts: systems costs, market-based remuneration and market price convergence

Fig. 5 presents the total system costs. This MPI includes investment, operation and maintenance (O&M) and fuel costs, that were extracted from the Backbone's database [22].

Results from Fig. 5 show that system costs are lower in PAM compared to DAM due to reduced balancing needs and decreased reliance on costly dispatchable power plants. In the DAM design, costly power plants such as cycle gas turbines (CCGT) are used more in the balancing markets to compensate the imbalances observed.

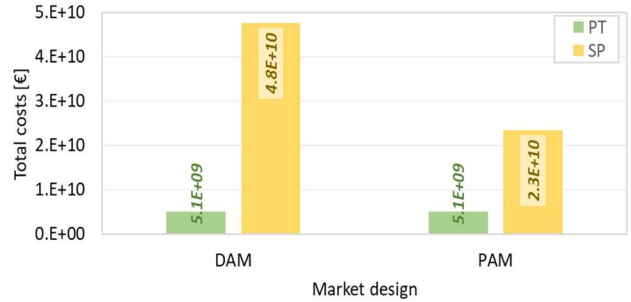


Figure 5. System total costs for dispatch for Portugal and Spain in the two market designs analysed.

This situation is particularly significant in Spain, as shown in Fig. 6. In contrast, the improved forecasting in PAM reduces the need for these expensive dispatchable plants, leading to lower overall system costs. The cost reduction trend associated with PAM design is also observed in the average day/period-ahead prices, Fig. 6. The figure also presents the cost recovery of vRES technologies. Fig. 6 highlights that PAM slightly reduces the average market price. This result is associated with a reduction in the overall total system costs. This price reduction has a minor impact on the cost recovery of vRES technologies. Therefore, there are no significant risks of reducing market-based remuneration with the new market design proposed in this work.

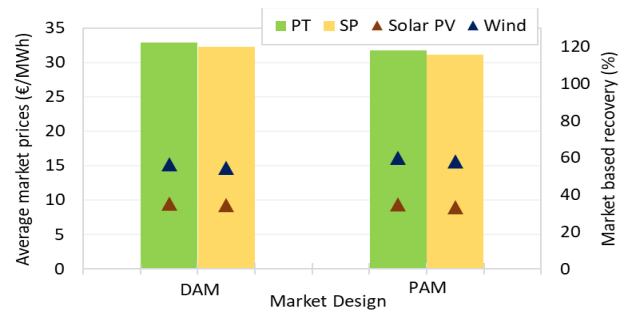


Figure 6. Average day/period-ahead prices (bars) and the percentage of market-based recovery (triangles) for wind and solar PV technologies in Portugal and Spain.

The figure also shows that solar PV experiences the lowest cost recovery values in both market designs. This result is associated with the cannibalization effect due to high market share, as presented in Fig. 3. Market price convergence among Portugal and Spain is another key economic indicator influenced by the improvements derived from the PAM design.

Fig. 7 illustrates the price difference and number of hours with market splitting hours between Portugal and Spain, i.e., the hours when cross-border transmission capacity constraints limit electricity exchanges, leading to the segmentation of the Iberian market. Results show that PAM leads to a difference, on average, of 0.02 €/MWh. This value increases to 0.10 €/MWh in the case of DAM design due to more frequent market-splitting events (additional 158 hours). DAM introduces more market distortions caused by "virtual" cross-border congestion. These distortions create price divergence between the two countries, leading to market splitting that can be mitigated in PAM design.



Figure 7. Average market difference between Portugal and Spain and number of market splitting (MS) hours.

#### D. Environmental Impact: CO<sub>2</sub> Emissions

The environmental impact of different market designs was also evaluated. The improved forecast accuracy in PAM reduces the reliance on fossil fuel-based technologies, particularly for ancillary services, supporting the energy decarbonisation of the power system with lower CO<sub>2</sub> emissions. While no significant impact was observed in Portugal, Spain experienced a reduction of 0.02 tCO<sub>2</sub>/MWh.

### VI. FINAL REMARKS

This work assesses the impact of an innovative electricity market design aiming to replace the traditional day-ahead market (DAM). The new design, designated as period-ahead market (PAM), was developed to address limitations in existing electricity market, designed in a period dominated by conventional energy technologies. The ongoing decarbonisation of power systems requires the development of new designs that can better accommodate the characteristics of dominant generation technologies, namely, the variable renewable energy sources (vRES), which are weather-dependent and have significant forecast errors, especially over long-time horizons.

The methodology implemented in this work uses two electricity market simulators in a workflow that covers all relevant markets in the Iberian electricity system: DAM/PAM, intra-day and balancing markets. The work examines an energy mix scenario based on the 2030 national energy and climate plans. Results underline the benefits of the PAM design when compared with the traditional DAM. PAM enables vRES producers to improve the accuracy of their power forecast systems reducing wind and solar power forecast errors by over 7% and 4%, respectively. This improvement increases the market efficiency by enabling better resource allocation. As

consequence the overall system costs are reduced, as well as its dependency from costly dispatchable power plants like natural gas, which is still relevant in Spain in the analysed scenario. This aspect has also a positive environmental impact with a reduction of 0.02 tCO<sub>2</sub>/MWh emissions. Another increase in efficiency can be observed in the use of cross-board capacity. PAM improves market price convergence between Portugal and Spain by reducing "virtual" congestion caused by inaccurate forecasts. This leads to a reduction of 158 hours with market splitting occurrences.

While further research is needed to, for instance, evaluate the feasibility of operationalising this new market design and the role of new flexible players, this study demonstrates that a more flexible market approach, of which PAM is an example, with shorter gate closures, enhances market efficiency, lowers overall costs, and ensures a fairer participation of vRES players. These factors are extremely relevant for future (nearly) 100% renewable power systems.

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