Longitudinal Study of Dispatchable Power Units Trading Strategies on Electricity Spot Markets in Italy

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2024 20th International Conference on the European Energy Market (EEM) | 979-8-3503-8174-0/24/$31.00 ©2024 IEEE | DOI: 10.1109/EEM60825.2024.10608837

***Abstract*—Over the past four years, the energy markets have experienced disruptions mainly caused by the Covid-19 pandemic and the Russo-Ukrainian conflict. In this paper, we aim to analyze the distribution of the volume traded by programmable electricity-producing units on the different electricity markets in the north power zone of Italy and its evolution over the 2017-2023 period. We investigate distinct trading profiles and their stability over time, with a focus on periods of disruption. Additionally, we evaluate whether units maintain consistent profiles or exhibit temporal variation in their trading behavior. We employ a cluster analysis approach, incorporating a temporal dimension and considering relative contributions of the different markets to units' traded volume. The study shows that units generally maintain a consistent trading strategy over time, unaffected by the pandemic and the conflict periods. We also highlight that the propensity of a unit to adopt a specific strategy is mainly driven by its technology.**

***Index Terms*—Electricity market, Power system economics, Transaction databases, Clustering methods**

I. Introduction

Over the past three years, energy markets have experienced consistent disruptions, primarily stemming from the Covid-19 pandemic that occurred between March 2020 and June 2021. As the energy sector rapidly recovered from the pandemic, a global energy crisis emerged and was intensified by a reduction in Russian gas supply due to the Russo-Ukrainian conflict. These combined factors have significantly impacted global energy dynamics.

The effects of these crisis on the energy economy have been extensively examined, with attention given to the fluctuations in wholesale prices of commodities like natural gas, crude oil [1]–[3], and electricity [4], [5] prices. Additionally, investigations have been carried out to understand the impact on the final price of the energy consumed by households and businesses, and how it affects energy demand [6]–[10]. The more specific impact on electricity systems was studied in [11]–[14]. However, limited attention has been given to studying the effects on the activity of electric power plants on electricity markets.

In this study, we propose to analyze the distribution of the volume traded by programmable electricity-producing units[1] on the different electricity markets in the north power zone of Italy and its evolution over the 2017-2023 period. The focus is put on spot markets, and the volumes traded through forward and obligations markets will be grouped as Over-The-Counter (OTC) transactions. The primary objective is to investigate the presence of distinct trading profiles and their stability over time, with a specific emphasis on periods of disruption. The second objective is to evaluate whether units predominantly adhere to a consistent profile over time or, conversely, if their trading behavior shows temporal variation.

To the best of our knowledge, this is the first work analysing global wholesale electricity trade volumes within a power system, at the level of Producing Units (PUs). While the geographical scope of our analysis is undoubtedly limited, primarily due to the scarcity of PU-specific information, the lack of consolidated market microdata across power exchanges, and the challenges related to transaction data volumetrics, we believe this initiative will stimulate the consideration of electricity transaction data in future research. Moreover we are convinced that the findings of this study hold significant value for both market participants and regulators.

In Italy, the production and commercialization of significant amounts of energy are subject to precise regulations. These regulations encompass various exchange platforms collectively known as the Italian Power Exchange (IPEX). The establishment of the Electricity Market can be traced back to the liberalization of the Italian electric sector in 1999 with the "Bersani" decree. This decree led to the establishment of Gestore dei Mercati Energetici S.p.A. (GME) [15] which is an entity entrusted with the responsibility of organizing and managing the Electricity and Natural Gas Markets. Specifically, GME

[1]Programmable units are electricity generation systems that can be dispatched on demand by market operators or at the request of network operators according to market needs, as opposed to non-dispatchable or intermittent generation systems (e.g. wind or solar generation)

oversees the comprehensive electricity trading infrastructure that supports the Forward Electricity Market (MTE), and the Spot Electricity Market (SEM) which comprises (i) the *Day-Ahead Market* (MGP), (ii) the *Intra-Day Market* (MI) and (iii) the *Ancillary Services Market* (MSD). The SEM also includes the Daily Products Market (MPEG) which concerns the trading of short-term obligations. MTE and MPEG trades are registered in the OTC category of the MGP.

In MGP, Producing Units (PUs) offer hourly volumes to retailers one day before delivery. This accounts for $\sim 85\%$ of the electricity sold over the time period considered. Two types of transactions exist:

- *Public supply offers*: These transactions correspond to accepted supply offers, valued at a zonal price, following a uniform-price double auction process. These offers account for $\sim 46\%$ of the total volume sold over the period considered.
- *OTC supply offers*: These transactions, which account for $\sim 38\%$ of the total volume sold, correspond to supply offers under forward or private bilateral contracts between producing units and retailers. These transactions are officially registered in the day-ahead market but are actually not influencing its dynamics.

In MI, both producers and retailers are able to adjust offered/purchased volumes within the day of delivery, given production and consumption forecast updates, but also to smooth the program resulting from the MGP. Currently, the MI is composed of 3 sessions and one continuous trading sub-market between European countries. The PUs can be involved in two types of transactions:

- *Supply offers* (OFF): PUs submit supply offers to sell electricity when aiming to augment their production relative to their current program. The selling price is determined following the same process as for the MGP, at a zonal level. These offers account for $\sim 10\%$ of the total volume sold during the specified period.
- *Demand bids* (BID): PUs submit demand bids to purchase back electricity when aiming to reduce their production in relation to their program on MGP or previous MI sessions. The purchasing price corresponds to the zonal selling price. These bids represent a volume equivalent to $\sim 4\%$ of the total volume sold during the specified period. Units have incentives to submit demand bids when the purchase price falls below the marginal cost of production.

In MSD, PUs submit offers to the network operator to increase or decrease their power generation, either in anticipation or in real-time. This is done to maintain a continuous balance between generation and consumption within the power grid and resolve congestion issues that arise from the results of MGP and MI. The MSD consists of two phases: the scheduling phase and the balancing (live) phase. The key distinction between MGP and MI is that the MSD operates as a "pay-as-bid" market, where each accepted offer is valued at its proposed price. Within each phase, PUs engage in two types of transactions:

- *Supply offers* (OFF): Similarly to MI, PUs submit offers to increase their production relative to their current program. The selling price corresponds to the offered price. These offers account for $\sim 6\%$ of the total sold volume during the specified period.
- *Demand bids* (BID): PUs submit demand bids when seeking to decrease their production relative to their current program. The purchase price corresponds to the bid price. These bids represent a volume equivalent to $\sim 11\%$ of the total sold volume during the specified period. As for MI BID transactions, units have incentives to submit demand bids when the purchase price falls below the marginal cost of production.

Despite the MGP accounts for the majority of transacted volumes, as will be proved in the next sections, the MI and MSD can still account for a high share of a unit's traded volume. The choice of focusing on volumes rather than revenues is due to the recent volatility of electricity prices. Nonetheless, an equivalent analysis has been performed using incomes, incorporating a proxy for units' marginal cost, enabling somehow to control the volatility effect. The volume-based approach was finally preferred given the poor reliability of the marginal cost proxy for the hydropower plants and the absence of OTC transaction prices, hence revenues.

The total traded volume of a unit is composed of the sum of the absolute values of the traded volumes on the different markets, making a distinction between OFF and BID transactions for MI and MSD. The resulting composition is the object of this analysis.

The paper structure is as follows: in Section II-A the official market dataset provided by GME is described; Section II-B deepens the methods employed for the analysis of the traded volume composition. Results and concluding remarks are addressed in Sections III and IV, respectively.

II. Methodology

A. Data

To perform our investigation, we make use of the official market data for the period 2017-2023 provided by GME, more specifically the *Public Offers* dataset. This dataset contains all supply/demand offers submitted on any of the three spot markets with information such as supplied/demanded volume, offered price, awarded price and acceptance status following the market clearing process.

As a first step, the accepted offers (hence leading to a transaction) of the 134 programmable plants in the *North* bidding zone were extracted. We then decided to enrich the unit-level information by adding the manually collected unit technology and computing the capacity (in MW) by looking, over the whole period, at the maximum value (in MWh) among every hourly final program (the volume that the unit is finally injecting on the grid). Table I presents the number of units per type and technology.

TABLE I: Units count per technology

Type	Technology	Units count
Fossil	Fossil Gas	45
Fossil	Fossil Hard coal	7
Fossil	Thermoelectric	7
Hydro	Hydro Pumped Storage	24
Hydro	Hydro Run-of-river and poundage	14
Hydro	Hydro Water Reservoir	37

The total volume resulting from the accepted offers is then aggregated at the quarter, unit, and market level. Additionally, the magnitude of exchanged volumes being naturally conditioned by the unit's capacity, we decided to work with volume per capacity, namely Equivalent Operating Hours (EOH). The list of variables composing the pre-processed dataset to be used for the analysis is reported in Table II.

TABLE II: Input dataset for the analysis

Variable	Description
`QUARTER`	Quarter in `YYYYQQ` format
`UNIT_NO`	PU ID
`OPERATOR`	Operator managing the PU
`TYPE`	PU Type
`TECHNOLOGY`	PU Technology
`mgp_off_eoh`	Volume sold on the Day-Ahead Market
`mgp_otc_eoh`	Volume sold through private contracts
`mi_off_eoh`	Volume sold on the Intra-Day Market
`mi_bid_eoh`	Volume purchased the Intra-Day Market
`msd_off_eoh`	Volume sold on the Ancillary Services Market
`msd_bid_eoh`	Volume purchased on the Ancillary Services Market

B. Analysis

First, we analyzed the temporal evolution of volume totals, globally and market-wise, as standalone indicators. We then focused on the analysis of the market contributions to the traded volumes of the units and their evolution over time.

As announced in the introduction, the first question this work aims to address is the possible existence of characteristic trading profiles and their persistence over time, especially during disrupted periods. The research of similarities in trading profiles was performed through a cluster analysis approach, leveraging the k-means clustering algorithm. For each distinct quarter, a k-means algorithm was run in order to find clusters of units sharing the same trading profile. A comparison between the clustering results of the different quarters allowed us to confirm or disprove the persistence of characteristic trading profiles over time. Once the similarity in the clustering structure between quarters was verified, the characteristic trading profiles were extracted by pooling the quarters altogether and running the k-means algorithm on all pairs of unit-quarter observations[2]. The output of this second clustering process was the attribution of a specific trading profile to each unit for each quarter.

The second investigation was to assess whether units were generally adhering to a single profile or, conversely, if their trading behavior was likely to change over time. In light of the first hypothesis, we tried to understand if some profiles were specific to particular types of units and, considering the second one, whether some profiles were more prevalent in certain periods. To answer these questions, we inspected, on the one hand, the discrete joint distributions between profiles and unit characteristics, and on the second hand, the temporal evolution of the profiles distribution.

[2]Note that a different approach could have been considered for aligning the clusters found for each quarter, for instance by considering the Voronoi partition induced by the average centroids.

III. Results

The first inspection concerned the evolution of the traded volumes over the time period. The total volume traded remained stable during the Covid-19 outbreak but experienced a drop from the second quarter of 2022, matching, amongst other, Russian gas supply cuts. As shown in Fig. 1, the sudden decrease is caused by hydropower plants, while fossil-fueled units kept the same trading activity.

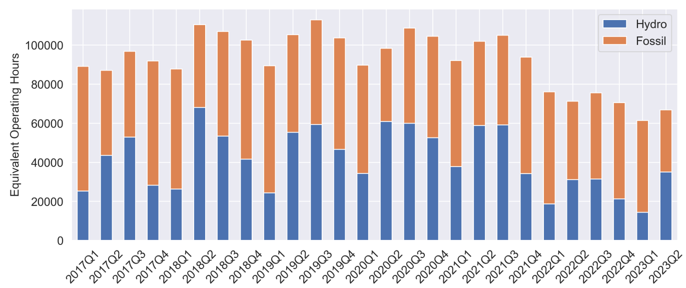


Fig. 1: Total traded volume by unit macro-technology (Operating Hours). The graphic highlights a yearly seasonality with peaks during spring and summer quarters and a significant decrease from 2021Q4

Before looking at unit-level traded volume compositions, it is useful to have in mind the composition of the global volume traded over the time period. MGP and bilateral contract supply offers account for 75% of the traded volume. The intra-day and ancillary services markets account for respectively 15% and 10% (Fig. 2). However, as will be proven thereafter, this pooled distribution is far from being representative of the unit-level distribution.

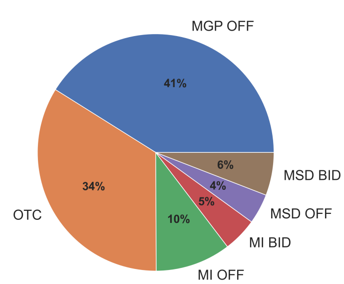


Fig. 2: Distribution of total traded volume for the 2017-2023 period

Fig. 3 illustrates the Within-Cluster Sum of Square (WCSS or Inertia) and Silhouette Scores of the k-means algorithm

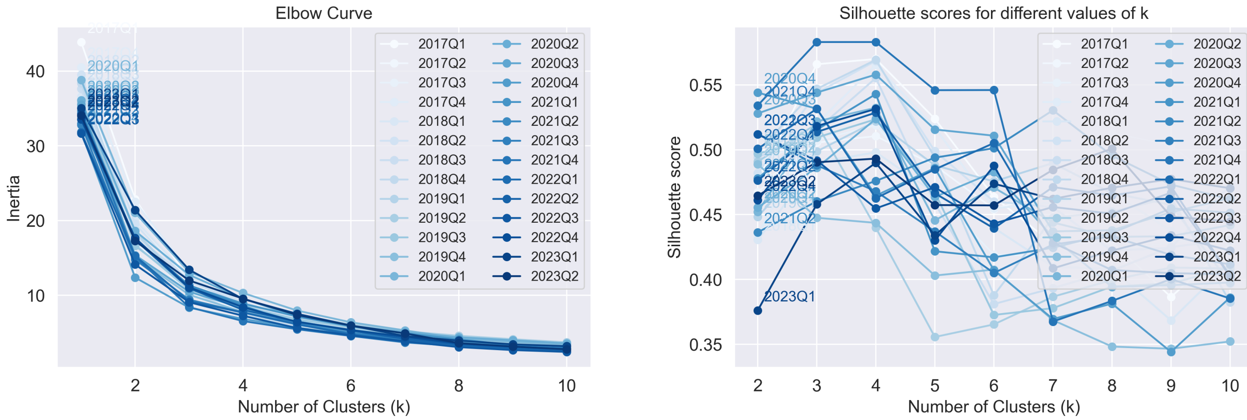


Fig. 3: Inertia and Silhouette Score for different values of k. The inertia curves show a common elbow for $k = 2$ or $k = 3$ while the silhouette score indicates a common vote for $k = 4$

ran separately on each quarter, for various values of k. The Inertia's elbow curves, depicted on the left side of the figure, indicate a consistent cluster structure across different quarters. Notably, a shared elbow point at $k = 2$ or $k = 3$ is observed. Conversely, the silhouette score indicates a consistent preference for $k = 4$ clusters, except for certain periods, particularly autumn 2020 and winter 2022. In these specific periods, the behavior of the k-means algorithm appears to deviate from that of other quarters. Regardless of the value of k, the between-quarter similarity in the inertia and silhouette curves supports the hypothesis of a stationary clustering structure. A visual inspection of the projection of the 6-dimensional points cloud for each quarter confirmed the existence of $k = 4$ distinct and persistent groups. From this point forward, we can hence accept the hypothesis that four main characteristic trading profiles exist and persist over time.

The four trading profiles that were discovered through the cluster analysis can be described as follows (Fig. 4):

- **Blue** profile (46% of the observations): This profile corresponds to an MGP-centered trading activity (around 70% of traded volume corresponding to MGP supply offers).
- **Orange** profile (34% of the observations): This profile is characterized by majority supply offers through bilateral contracts (70% of trading volume realized by OTC transactions)
- **Green** profile (13% of the observations): High share of trading activity on the intra-day market (50%) and above-average share of trading activity on the ancillary services market.
- **Red** profile (6% of the observations): Trading activity focused on MSD supply offers ($\sim$ 70% in average).

When looking at the profile distribution at the unit level, we find out that more than 90% of the units have a predominant profile, having the absolute majority over the three others. These results suggest a tendency for units to adhere to a single profile. According to Fig. 5, the (blue) MGP-centered

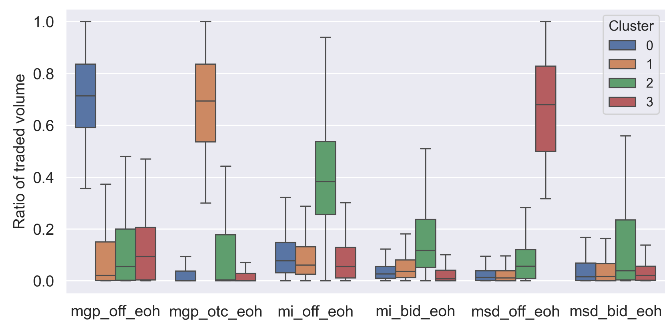


Fig. 4: Distribution of the variables in the different clusters of profit compositions

profile seems to be predominant among hydro-power units (almost 60%), while the majority trading profile among fossil-fueled plants seems to be the (orange) OTC-focused one. Furthermore, the (green) MI-centered strategy does not show up among fossil-fueled plant so it seems that the existence of this trading profile is more related to other type of technologies. A further investigation on this point shows that (almost) all hydropower units adopting the MI-centered strategy are pumped storages. This finding suggests that the storing capability inherent in these units enables them to embrace more sophisticated market strategies. Typically, these plants tend to withdraw electricity during off-peak periods when electricity prices are lower, replenishing their water reservoirs. Subsequently, they release the stored electricity during peak hours when electricity prices are higher. Consequently, these units actively engage in the intra-day or ancillary services market, leveraging price signals obtained after the closure of the day-ahead market. This distinct behavior highlights the strategic advantage afforded by the storage capacity of hydro pumped storage units, allowing them to optimize their operations and capitalize on pricing differentials across different periods. It is also worth noting that Thermoelectric and Coal plants are all associated with, respectively, the MGP-centered and the OTC-centered strategy.

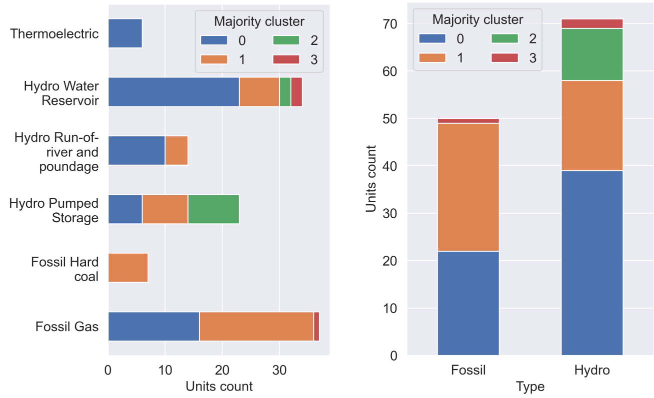


Fig. 5: Units majority cluster by unit type, technology and capacity

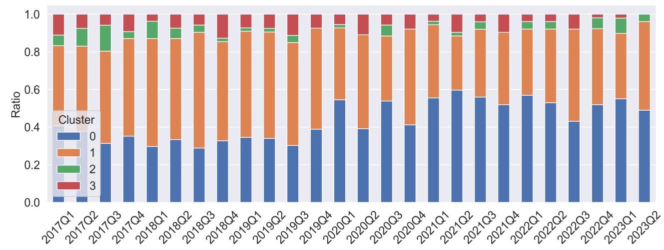
Fig. 6 shows the evolution of cluster prevalence over time (this time allowing units to have a different profile for each month) per unit type. A clear trend can be spotted for the fossil-fueled units: the share of MGP-centered (blue) strategies progressed throughout the period to the detriment of OTC-centered (orange) strategies. ∼35% of the units were adopting the MGP-centered strategy during the pre-covid period vs ∼50% of them since 2020. This trend is still observed for hydro-power units but in a less pronounced manner. A noteworthy observation concerns the downturn of red profiles during the period between spring 2019 and autumn 2021. We can also note the seasonality ruling the prevalence of MI-centered strategies (green profile), indicating the possible effect of water availability, which is partially conditioned by the gradual melting of the alpine snowpack during the spring and early summer.

IV. Concluding Remarks

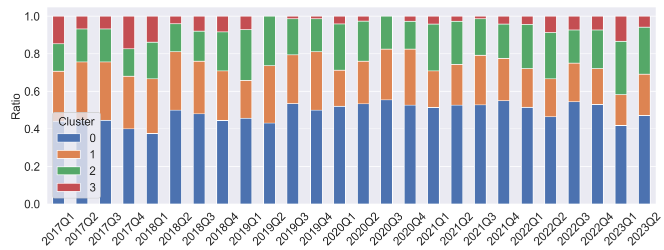
Over the past three years, electricity markets have experienced significant disruptions, including the Covid-19 pandemic and the Russo-Ukrainian conflict, resulting in a global energy crisis. In light of these disruptions, this study focused on analyzing the traded volume compositions of dispatchable electricity-producing units in the north power zone of Italy during the period from 2017 to 2023.

The analysis reveals several key findings. Firstly, though most electricity volume is traded on the day-ahead market and through forward or private bilateral contracts (75% of global traded volume), a significant number of power units, especially those leveraging hydroelectric technologies, dedicate the majority of their traded volume to the intraday and ancillary services markets.

Based on the volume compositions, four distinct market strategies have been identified. The first and most adopted strategy (46% of the observations) is characterized by dominant day-ahead market contributions (70% of the traded



(a) Fossil-fueled plants



(b) Hydropower plants

Fig. 6: Evolution of cluster distribution per unit technology

volume on average). The second strategy (34% of the observations) is based on forward contracts and obligations (70% avg. of traded volume). The third strategy (13% of the observations) is described by a high share of traded volume on the intra-day market (50% avg. of traded volume) and an above-average share of trading activity on the ancillary services market. The fourth and last strategy (6% of the observations) dedicates most volume to supply offers on the ancillary services market (50% avg. of traded volume).

Furthermore, our analysis indicates that units generally maintain a consistent trading strategy over time, unaffected by the pandemic and the energy crisis. On the one hand, fossil-fueled plants predominantly adopt the strategy based on obligations trading. Among them, all seven thermoelectric units adopt the day-ahead-market-centered strategy while all seven hard-coal-fueled plants go for the obligations-based strategy.

The intraday-market-focused profile instead is found solely among hydropower plants, and more precisely pumped storages. Finally, the fourth strategy based on the high volume share of the supply offers of the ancillary services market is principally found among water reservoirs. This suggests an implementation of arbitrage strategies by hydroelectric units, which also exploit their higher flexibility potential. Nevertheless, ancillary services provision constitutes an appreciable part also of the revenues for natural gas units.

Finally, it is worth noting that since the onset of the pandemic, there has been a shift among fossil-fueled plants from obligations-based towards day-ahead-market-based strategies. In contrast, the strategies of hydropower units appear to be relatively unaffected, except for the downturn of ancillary-services-market-supply-offer-centered profiles during the period between spring 2019 and autumn 2021.

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