When Curtailment Pays: CfD Negative Price Clauses and Intraday Market Dynamics in France

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Abstract

Renewable generation and intraday market development have expanded in parallel, with the latter providing a key platform for managing forecast errors from the former. This paper broadens the role of renewables in shaping intraday market dynamics by examining how short-term production incentives created by Contracts for Difference (CfD) influence intraday trading behavior. Focusing on negative-price clauses in generation-based CfDs, we use panel econometric models to assess their effects on intraday prices and traded volumes in France. Our results show that intraday prices efficiently reflect balancing needs arising from renewable forecast errors. However, relative to CfD payments, producers adopt either selling or buying positions depending on whether day-ahead prices are zero or slightly negative, revealing the all-or-nothing incentive embedded in the CfD design. These bidding responses affect the broader intraday market through both prices and volumes, weakening the alignment between production incentives and system balancing needs. By showing how support-scheme incentives propagate beyond individual producers to affect overall market outcomes, the paper highlights the need for reconsidering CfD design and discusses potential reform options.

Keywords: Intraday market, Renewable energy, Contract for Difference, Bidding behavior, Panel data

1 Introduction

The intraday market is recognized as a key instrument for renewables integration. It provides a platform for market participants to manage forecast errors and unplanned outages, and to optimize short-term flexibility (Borggrefe and Neuhoff, 2011; Kazempour, 2025). As in other European countries, France has seen the development of intraday markets alongside the deployment of renewable capacities backed by public support schemes in recent years (Figure 1). The country is embedded in a singular balancing context with a financial incentive to manage the imbalance risk (i.e. forecast errors) known to be weaker than in other European countries (Håberg and Doorman, 2016). Moreover, the generalization of Contract-for-Difference (CfD) as the preferred support scheme tends to partially expose renewable producers to market price[1]. In particular, CfD arrangements are associated with a premium for curtailment in case of a negative day-ahead price. While this contractual incentive is of nature to distort renewables production incentives in intraday, the quantification of this effect remains empirically undocumented.

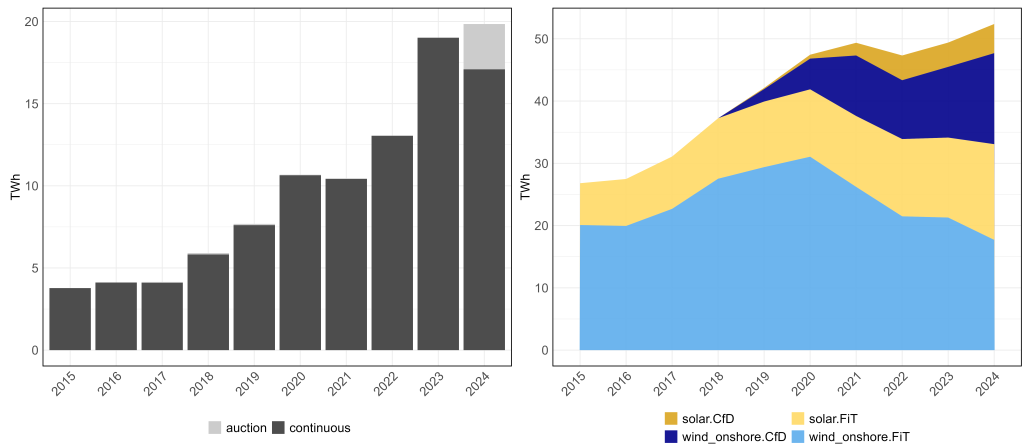


Figure 1: Yearly traded volume in the French Intraday market via Epex platform (left) and total volumes of subsidized renewable electricity generation by type of support (right)

We broaden the analysis of renewable impacts on the intraday market, which has traditionally focused on forecast errors, by examining the role of contractual incentives induced by support-scheme and their potential to distort renewable producers' behavior. This paper develops a twofold analysis. First, we assess how the imbalance risk arising from renewables forecast

[1] In 2024, 28% of onshore wind generation and 17% of solar generation originated from plants operating under this support scheme (CRE, 2024b).

errors impacts the French intraday market dynamic in terms of price and volume exchanged, that is embedded in a particular balancing context. Second, we examine the relationship between renewable distortive behavior arising from CfD contractual incentive relative to negative price, and intraday market dynamics.

This paper builds on a unique dataset from EPEX Spot, to which we were granted access. It records the full set of transactions on the continuous intraday market in 2024, covering both the buy and sell sides of French market participants affiliated with EPEX Spot. Using a panel econometric approach, this enables us to rebuild, for each trading session and hourly product, the evolution of both prices and traded volumes. Thereby, in contrast to the existing literature, which primarily focuses on intraday price drivers, our analysis jointly but distinctly examines prices and volumes, thereby shedding light on the mechanisms underlying price formation and the strategic behavior of market participants. Moreover, the ability to distinguish between buy and sell volumes allows us to link renewables balancing needs to variations in demand and supply on the French intraday market, and to infer whether the counterpart to these balancing needs is located domestically or abroad. In this respect, incorporating forecast errors from neighboring countries provides additional insights into how French market participants contribute to short-term flexibility provision abroad. Finally, we introduce a novel variable based on cross-border commercial capacity data, which enables us to robustly control for the availability of cross-border exchanges.

Our main results show the distortion effects created by CfD mechanisms in the intraday market relative to system needs. In particular, we find that the renewable producers can trade in the intraday market in an uneconomical manner relative to their marginal costs. This behavior is driven by the need to realign the actual generation level with the binary generation incentives (all or nothing) inherent in the CfD negative price clause. In these moments, the intraday market experiences distorted pricing, demonstrating how CfD desing exert negative externalities on all market participants. Importantly, our analysis underlines the ability of the French intraday market to provide a price signal that accurately reflects short-term supply and demand conditions. Therefore, despite being embedded in a singular balancing context, the French intraday market manages to fulfill its role as a price discovery mechanism. In this respect, price and volume adjustments arising from the CfD negative price clause, although not system-friendly from a balancing perspective, only mirror a distortion arising from support-scheme design but not a market failure.

This paper emphasizes the need to amend CfD design as the issue is likely to worsen with the continued expansion of renewable capacities supported by such schemes. While centered on the French case, these results are highly relevant to other European countries that employ similar pay-as-produced CfD designs. In this respect, our study advocates for substantial change in CfD design by decoupling payment from asset output (Newbery, 2022; Schlecht et al., 2024). This could have the advantage of fully aligning renewable production decisions with market price signals, thereby removing distortions that influence intraday prices and lead to unnecessary activations of flexibility.

The remainder of this paper is structured as follows. Section 2 reviews the related literature. Section 3 presents the French intraday market, followed by the empirical strategy presentation being described in Section 4. Results are then presented in Section 5, with their implications discussed in Section 6.

2 Literature review

This paper lies at the intersection of two strands of the literature, combining the standard analysis of intraday market dynamics driven by forecast errors with an examination of the effect of financial incentives created by the design of support schemes backing renewables.

2.1 Renewable imbalance risk management in the French context

Intraday market analysis has been centered around the ability of the price to reflect the uncertainty carried by weather-dependent renewables. Alongside information on supply/demand fundamentals (supply stack model), econometric studies investigated the effect of renewable forecast errors (Pape et al., 2016). It has been shown that positive forecast errors (surplus of energy on intraday) tend to lower prices, whereas negative forecast errors increase price level

(Kiesel and Paraschiv, 2017). Studying the Nordics and Baltics intraday market, Soysal et al. (2017) pointed out that intraday price adjustment is higher when overestimating production than when underestimating. Moreover on the German context, Kulakov and Ziel (2019) and Gürtler and Paulsen (2018) observed a nonlinear effect of errors on the intraday price. Renewable uncertainty effect on intraday price is also related with the composition of the electricity mix and the volumes of flexible capacities that can be enabled. Respectively studying Texas Weber and Woerman (2024) and France (Ekoue et al., 2025), the latter attributed the lower magnitude of renewable uncertainty in France due to the existence of additional flexible levies that are interconnectors and a dispatchable nuclear plant. The ability of conventional plants to deal with renewable uncertainty is also illustrated in the Danish context (Karanfil and Li, 2017). The role of renewable forecast errors relative to other market dimensions, like traded volumes and price volatility, has received much less attention from the literature. Hagemann and Weber (2013) highlighted the positive relationship between renewable errors and intraday volumes. They showed that a 1MWh solar (resp. wind) error increases intraday volumes by 0.3 MWh (resp. 0.54) in Germany. Regarding volatility, Birkeland et al. (2024) found no significant effect of renewable errors in the Dutch intraday market. Despite extensive literature linking renewable uncertainty and intraday market outputs, we identify the combination of two unaddressed gaps that may affect the estimated magnitude of this link.

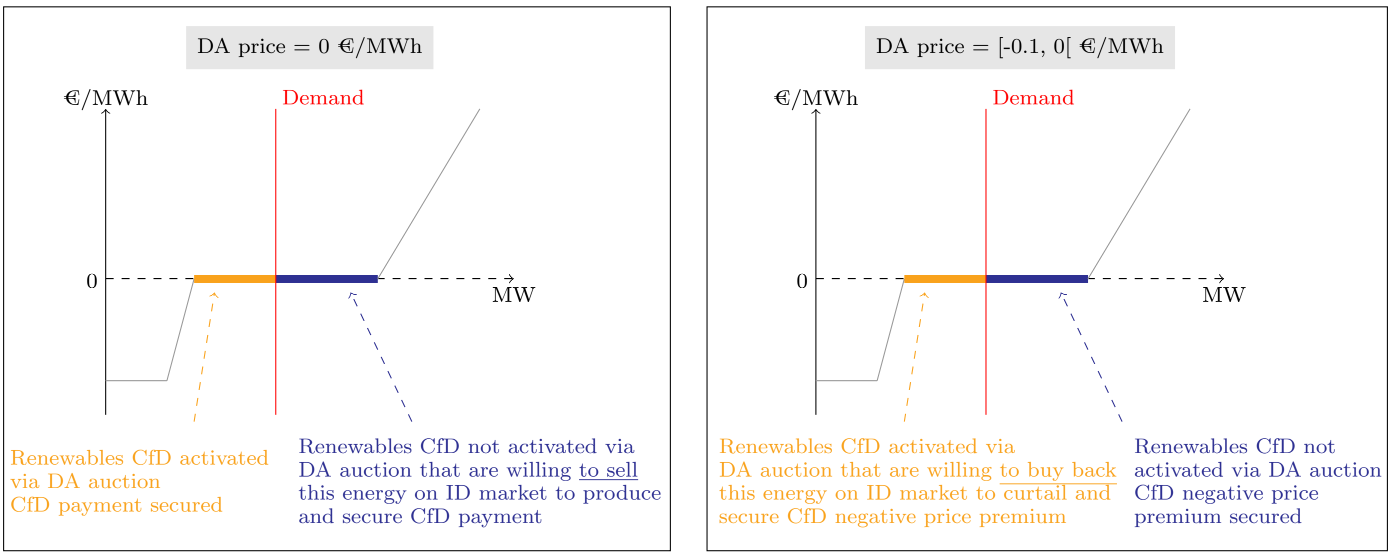
Firstly, the way forecast error is measured needs to be adapted to the current renewable context. Traditionally, it has been captured as the difference between the day-ahead renewable forecast (based on a weather model) and actual production, with both metrics provided by the TSO. However, today a significant share of renewable plants is exposed to other financial incentives, meaning that actual production is no longer driven solely by weather potential. The difference between the day-ahead forecast and actual production not only captures the actual forecasting error relative to weather uncertainty but may also capture the voluntary deviation of renewables due to cross-market price arbitrage. As we focus on forecast error arising from weather uncertainty, we rely instead on the difference between the day-ahead forecast and the most recent forecast, also based on weather potential and published close to real-time by the TSO.

Secondly, it has been shown that there is an interdependence between price dynamics across short-term markets, from the day-ahead to the imbalance market (Spodniak et al., 2021). In this respect, France operates within a distinct balancing philosophy that corresponds to the way the system manages imbalance. France relies on a proactive philosophy, which is characterized by the activation of reserve energy prior to real-time, based on forecasted imbalance. This system mainly uses tertiary reserve that tends to be cheaper than secondary reserve and in turn smooths the imbalance price (that is built on reserve energy cost). Therefore, contrary to a reactive philosophy, imbalance risk leads to lower financial penalties that may limit the incentive for market players to carry out balancing action on the intraday to limit their exposure to the imbalance risk Håberg and Doorman (2016); Deman and Boucher (2023). Our present study provides an opportunity to assess whether the balancing framework specific to the French system hampers the efficient functioning of the intraday market relative to renewable forecast errors.

2.2 Dispatch distortion of renewables plants under CfD

Most of the renewable capacities deployed in France are backed by either a feed-in tariff (FiT) or a CfD (double-sided feed-in premium). Under FiT, renewables received a fixed payment for every MWh produced. Thus, they are insensible to market prices, with no other adjustments in intraday than the ones dealing with forecast errors. Since 2018, large renewable plants have been subsidized through "Complément de Réméunération" in France, which corresponds to a CfD. It is a "pay-as-produced" CfD where producers receive or pay the difference between a strike price and a reference market price Kitzing et al. (2024). The reference price is usually the average day-ahead price calculated over a reference period (corresponding to the month in the French case). Moreover, negative price clauses are commonly associated with CfD to prevent renewable generators from producing when market prices turn negative, thereby restoring incentives consistent with marginal cost signals. In France, for each hour where the day-ahead price is negative, the CfD payment is suspended, but producers receive a negative price premium ("Prime Heures Négatives") if they effectively curtail their production. It affects the balancing process of the TSO with the on/off phenomenon (ENTSO-E, 2024). At the switch from positive to negative day-ahead prices, significant volumes of CfD-supported renewables disconnect simultaneously, requiring substantial reserve activation to manage system balance (RTE, 2025). French regulator estimates that 80% of producers under CfD in France completely stop generating electricity during negative price hours (CRE, 2025). More generally, the binary incentive prevents CfD-supported producers from participating in the intraday market when day-ahead prices are negative. By depriving the market of these production resources, this design ultimately increases overall system balancing costs(De Vos, 2015).

However, the most impacting caveat occurs when CfD producers are the marginal generators on the day-ahead market. In this particular configuration, only a fraction of CfD capacities are required to ensure system equilibrium, but due to the binary incentive, generators either produce at full capacity or not at all. This situation is of a nature to shape their behavior intraday and occurs when day-ahead prices are null or slightly negative. Due to the negative price clause, CfD producers are incentivized to bid at 0€/MWh in the day-ahead market. However, if the clearing price is null, the bids at the equilibrium price are activated on a pro rata basis (NEMO committe, 2025). CfD producers face a dilemma for the unactivated share of their bid. Because the day-ahead price is not negative, if they produce only up to the level of the activated bid, they do not receive the CfD payment for the energy corresponding to the unactivated share of their day-ahead bid. They can instead decide to produce at full capacity to maximize their CfD payment. However, in doing so, the energy produced corresponding to the volume unactivated in the day-ahead market will be valued at the imbalance price since injected into the grid without being sold beforehand. The imbalance price is unknow ex ante, and there is a risk of having a large negative imbalance price that could generate a loss more than compensating the earnings from the CfD payment. Therefore, in moments of null day-ahead price and pro rata activation, producers under CfD have an incentive to sell the unactivated day-ahead energy on the intraday market (Figure 2a). In this way, they can secure a price ex-ante, potentially leading to a loss, but that will be compensated by the level of the CfD payment. In order to avoid seeing their bid partially activated in case of null day-ahead price, generators under CfD may strategically bid at a slightly negative price in the day-ahead (Favre, 2025). This startegy ensure full activation in case on null day-ahead price, avoiding any subsequent adjustments, potentially generating a loss in the intraday market. However, this strategy exposes the generators in case of a slightly negative day-ahead price. In this configuration, they become the marginal producers and their bids are partially activated. This compels them to keep producing, whereas CfD design would dictate a halt in production to secure the CfD negative price premium. Consequently, in such a case, producers may seek to buy back the partially accepted day-ahead bid in the intraday market in order to curtail and secure the CfD negative price premium (Figure 2b). The negative price clause of the CfD creates a binary incentive when day-ahead prices fluctuate within the narrow interval of [-0.1€, 0€] (CRE, 2024a). At a zero price, generators are expected to act as sellers in the intraday market, whereas a slightly negative day-ahead price induces them to switch to a buyer position. Our analysis seeks to quantify the impact of this binary CfD incentive on intraday volumes and prices.



(a) Null day-ayhead price

(b) Near zero negative day-ahead price

Figure 2: Potential intraday adjustements of renewables under CfD follwing pro rata activation on day-ahead (adapated from Favre (2025))

3 The French intraday market

As in other European countries, the French intraday market combines a continuous market with auctions[2], with the possibility to trade hourly and half-hourly products in 2024.

[2]The design of the auction stage evolved in 2024. Prior to June 14th, 2024, there was a single intraday local auction. This auction took place on the day-ahead at 5 pm, and trading was limited to half-hourly products.

We have access to the record of trades on the French continuous market for which at least the buyer or the seller was located in France and affiliated with Epex Spot. The timing of a transaction allows us to connect trades when the buyer and seller are both French market players affiliated with Epex. When only one counterparty is located in France and affiliated with EPEX (e.g., the buyer), the dataset includes only that side of the trade. In such cases, the other counterparty is either located abroad (and may or may not be affiliated with EPEX) or located in France but affiliated with another NEMO (Figure 3).

Full continuous intraday dataset

TradeID	Side	NEMO	Country	Volume (MWh)	Price (€/MWh)
1	BUY	Epex	France	5	70
1	SELL	Epex	France	5	70
2	BUY	Epex	Belgium	3	65
2	SELL	Epex	France	3	65
3	BUY	Epex	France	4	63
3	SELL	other	France	4	63
4	BUY	other	France	5	64
4	SELL	other	France	5	64

→

Available continuous intraday dataset

TradeID	Side	NEMO	Country	Volume (MWh)	Price (€/MWh)
1	BUY	Epex	France	5	70
1	SELL	Epex	France	5	70
2	SELL	Epex	France	3	65
3	BUY	Epex	France	4	63

Figure 3: Illustration of intraday data availability depending on trade counterparties' affiliation and location

While not fully exhaustive, our dataset is representative of the French intraday market, since 5/6 of total volumes on the intraday market in 2024 were recorded on Epex spot platform. Moreover, we focus on the continuous trading of hourly products since they accounted for 90% of the total traded volumes on the French intraday market. Continuous market starts at 3 pm on the day prior to the delivery period and closes five minutes prior to the start of the delivery period, while cross border trading gate closure is set one hour ahead of real-time. While the trading window is relatively long, roughly three-quarters of trading activity takes place in the last four hours before delivery (Figure 4a). International trades are possible upon the availability of interconnection capacities. This is managed through the European Cross Border Intraday (XBID) platform that represents the shared order book that aggregates bids from players affiliated with all NEMOs while including interconnection capacity constraints.

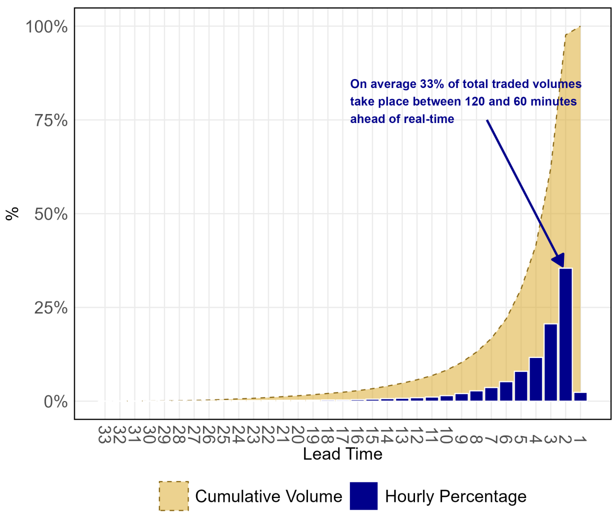
After this date, the design shifted towards three pan-European auctions (allowing for international trades). They are respectively set at 3 pm and 10 pm in the day ahead and at 10 am on the delivery day

In the following, each hourly product corresponds to a specific delivery hour, while each session is associated with a delivery day. Accordingly, the analysis is structured around product/session pairs, representing the 8784 hours of 2024. For each product/session pair, total traded volume (buy or sell) is defined as the sum of volumes across all individual trades, and the corresponding price is measured as the median trade price.

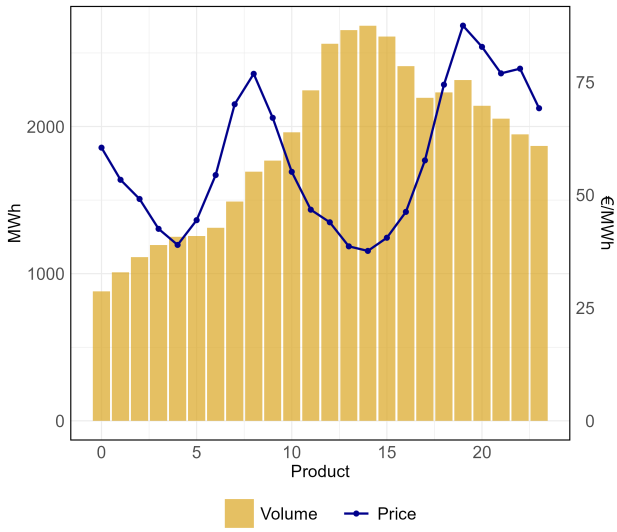
Average traded volumes by hourly product highlight the balancing role of the French intraday market. They peak during solar hours and at the end of the day, periods associated with larger forecast errors due to renewables uncertainty and longer forecasting horizons (Figure 4b).

While average intraday prices reflect the power mix similarly to day-ahead prices, price deviations (intraday minus day-ahead price) capture short-term balancing needs and are correlated with renewable forecast errors (Figure 4c). When the system is long, reflecting a renewable surplus, intraday prices tend to be lower than day-ahead prices, and conversely when the system is short. This observation, consistent with the merit order effect, suggests that intraday price signals effectively reflect balancing scarcity.

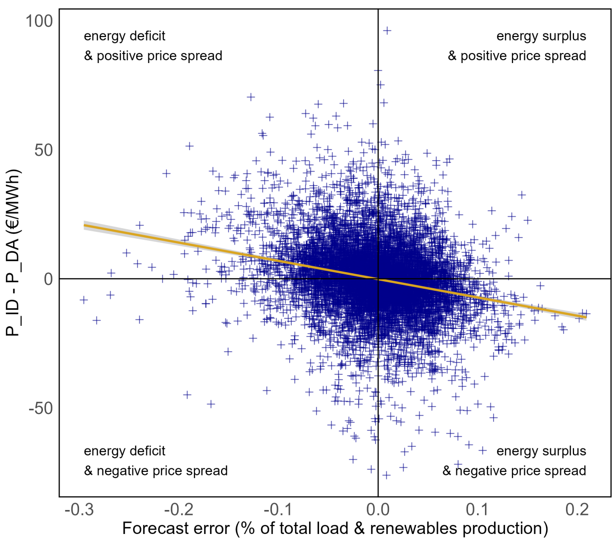
Variations in volumes and prices across day-ahead price levels suggest an effect of the CfD negative price clause. When day-ahead prices are zero, traded volumes increase in intraday, the market is long (more sellers on the French market), and intraday prices tend to drop, consistent with producers selling unactivated volumes to secure CfD payments. In contrast, when day-ahead prices are slightly negative, the market becomes short (more buyers on the French market) and intraday prices rise above day-ahead levels. This is consistent with producers buying back energy to curtail output and benefit from a negative price premium (Figure 4d).



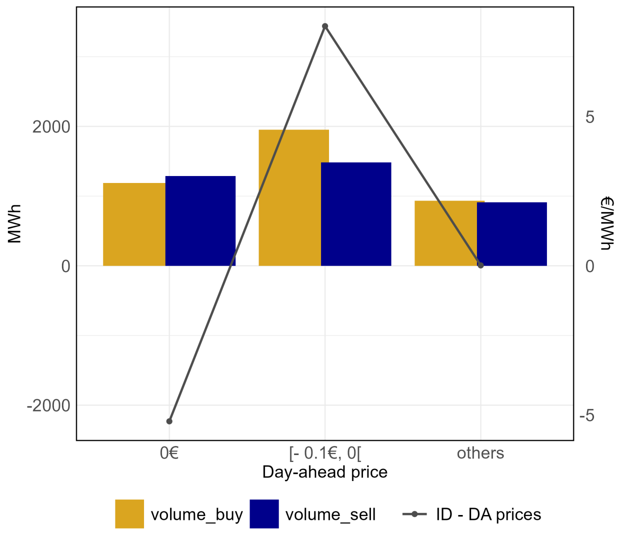
(a) Volume traded distribution by lead times



(b) Average volume traded and price by hourly product



(c) Price deviation and forecast error



(d) Average buy/sell volumes traded and price deviation by day-ahead price level

Figure 4: Observations from hourly product trading on the French continuous market in 2024

4 Empirical strategy

This paper aims to analyze the drivers of price and traded volumes on the French intraday market, with a specific focus on the role played by financial incentives faced by renewables regarding their imbalance risk and long-term contract arrangement. By separately modeling buy and sell volumes alongside prices, we disentangle two distinct mechanisms underlying intraday market dynamics: the balancing activity triggered by renewable forecast errors, and the strategic bidding distortions induced by the negative price clause embedded in CfD support schemes. This dual approach allows us to identify not only the direction and magnitude of price adjustments but also the counterparty structure of the underlying trades, in particular, whether balancing needs are absorbed domestically or through cross-border flexibility exchanges.

To this end, we run separate regressions on volume and price. We rely on panel methods to address the nature of our sample. Hourly products[3] represent individuals i (1 to 24), and the day of the year is time index t (1 to 366[4]). Moreover, we run separate regressions for daytime (products 9 to 17) and nighttime (other products) to avoid spurious effects created by solar forecast errors. We conduct a sensitivity analysis by running regressions on price and volume calculated on the full sample of trades for each session, but also for price and volume values calculated considering only trades realized at a particular timing of a session. We retained two alternatives values for each independent variable to capture different moments of the trading session. The first alternative gives the median price and total volumes only for trades occurring in the last four hours of the trading session, that encompasse, on average, around 3/4 of the total exchanged volume. The second alternative focuses on the opposite sample by considering only trades occurring before the last four hours of the session. These two alternatives sub-samples allow us to capture the temporal dimension of the intraday market and how information from different drivers is potentially impacting the market at different moments of the trading window. The set of common regressors (Equation 1) used to analyze intraday dynamics (Equations 2 & 3) is summarized in Table 1 and presented hereafter. Prior to regression analysis, conventional diagnostic tests are conducted, with details provided in Appendix B. Price variables are not always stationary in level, depending on the test specification. We display price regressions on first difference in the Appendix D, with results in line with the ones from regressions in level.

[3]product 0 corresponds to intraday electricity trading for the 0 am - 1 am delivery period, with subsequent products referring to the following hourly delivery intervals

[4]2024 being a bisextile year

$$
\begin{aligned}
\text{Z}_{i,t} = (&\text{solar\_fe\_po\_fr}_{it},\ \text{solar\_fe\_neg\_fr}_{it},\ \text{wind\_fe\_po\_fr}_{it},\ \text{wind\_fe\_neg\_fr}_{it},\\
&\text{load\_fe\_po\_fr}_{it},\ \text{load\_fe\_neg\_fr}_{it},\ \text{solar\_fe\_po\_bege}_{it},\ \text{solar\_fe\_neg\_bege}_{it},\\
&\text{wind\_fe\_po\_bege}_{it},\ \text{wind\_fe\_po\_bege}_{it},\ \text{solar\_fe\_po\_sp}_{it},\ \text{solar\_fe\_neg\_sp}_{it},\\
&\text{wind\_fe\_po\_sp}_{it},\ \text{wind\_fe\_neg\_sp}_{it},\ \text{null\_DA}_{i}t,\ \text{near\_zero\_DA}_{i}t,\\
&\text{negative\_DA}_{i}t,\ \text{interconnection}_{i}t,\ \text{outages}_{i}t, \text{alert}_{i}^{+}t,\ \text{alert}_{i}^{-}t,\\
&\text{downgraded}_{i}^{+}t,\ \text{downgraded}_{i}^{-}t,\ \text{IDA}_{i}t)'
\end{aligned} \tag{1}
$$

$$
\text{Volume}_{i,t} = \beta_0 + \beta_{1:24} Z_{i,t} + \beta_{25}\,\text{load}_{i,t} + \beta_{25}\,\text{weekend}_{i,t} + \beta_{26}\,\text{season}_{i,t} + \varepsilon_{i,t}, \tag{2}
$$

$$
\text{Price level}_{i,t} = \beta_0 + \beta_{1:24} Z_{i,t} + \beta_{25}\,\text{DA\_price}_{i,t} + \varepsilon_{i,t}, \tag{3}
$$

Table 1: Regressors notation and description

Notation	**Definition**
$\text{solar\_fe\_[po/neg]\_fr}_{i,t}$	Positive / negative solar forecast error variables in France.
$\text{wind\_fe\_[po/neg]\_fr}_{i,t}$	Positive / negative wind forecast error variables in France.
$\text{load\_fe\_[po/neg]\_fr}_{i,t}$	Positive / negative load forecast error variables in France.
$\text{solar\_fe\_[po/neg]\_bege}_{i,t}$	Positive / negative solar forecast error variables in Belgium and Germany.
$\text{wind\_fe\_[po/neg]\_bege}_{i,t}$	Positive / negative wind forecast error variables in Belgium and Germany.
$\text{solar\_fe\_[po/neg]\_sp}_{i,t}$	Positive / negative solar forecast error variables in Spain.
$\text{wind\_fe\_[po/neg]\_sp}_{i,t}$	Positive / negative wind forecast error variables in Spain.
$\text{null\_DA}_{i,t}$	Dummy variable equal to 1 if the Day-Ahead (DA) market clearing price settles at exactly 0 €/MWh.
$\text{near\_zero\_DA}_{i,t}$	Dummy variable equal to 1 if the Day-Ahead (DA) market clearing price settles in the range [-0.1, 0[€/MWh
$\text{negative\_DA}_{i,t}$	Dummy variable equal to 1 when the Day-Ahead market clearing price falls below -0.1 €/MWh.
$\text{interconnection}_{i,t}$	Available cross-border commercial interconnection capacity in MW.
$\text{outages}_{i,t}$	outage capacity in MW.
$\text{alert}^{+}_{i,t}/\text{alert}^{-}_{i,t}$	TSO alert messages flagging positive or negative balance constraints.
$\text{downgraded}^{+}_{i,t}/\text{downgraded}^{-}_{i,t}$	TSO downgraded messages flagging positive or negative balance constraints.
$\text{IDA}_{i,t}$	Dummy variable equal to 1 for periods after the introduction of Pan European intraday auctions.

The effect of renewables imbalance risk is represented by forecast errors. For French solar and wind onshore production, we calculate the forecast error as the difference between the last forecast and the day-ahead forecast. We further split between positive and negative error as in Balardy (2022). It allows for a precise analysis of how the market responds to renewable imbalances, conditional on the direction of forecast errors. In terms of price, we can track the direction of price change and a potential asymmetry in price shift between surplus and deficit (Soysal et al., 2017). Regarding volumes, the panel approach controls for the absolute rise in trades in periods of large renewable energy, such as during solar hours, through time-invariant fixed effects. The inclusion of positive and negative forecast errors, coupled with a separate analysis of Buy and Sell volumes, makes it possible to disentangle the effect of errors on total traded volumes (Figure 5). When there is a surplus of renewable generation, producers are expected to be sellers on the intraday market. The coefficient associated with the positive forecast error from regression on Sell volumes measures the intensity of producers' adjustment. Conversely, when there is a deficit, producers are on the buying side, and the intensity of adjustment is captured via the coefficient of negative forecast error from regression on Buy volumes. Consequently, when there is a surplus, the counterparties absorbing the error are buyers, whereas when there is a deficit, they are sellers. If there is no effect regarding renewable adjustment intensity (no effect of positive forecast error on sell volumes and/or no effect of negative forecast error of buy volume) but an effect on total volumes, the source of the effect can arise from a change in the nature of the counterparty because our dataset only retrieved information on the legs of a trade for which the participant is located in France. For example, if positive and negative solar forecast errors in France are adjusted with the same intensity but positive errors are systematically absorbed by a foreign counterparty, then we can expect a negative effect on total volumes from positive solar forecast errors that arises from a negative effect of positive solar errors on Buy volumes (since this leg of the trade is not recorded on our dataset if the counterparty is located abroad).

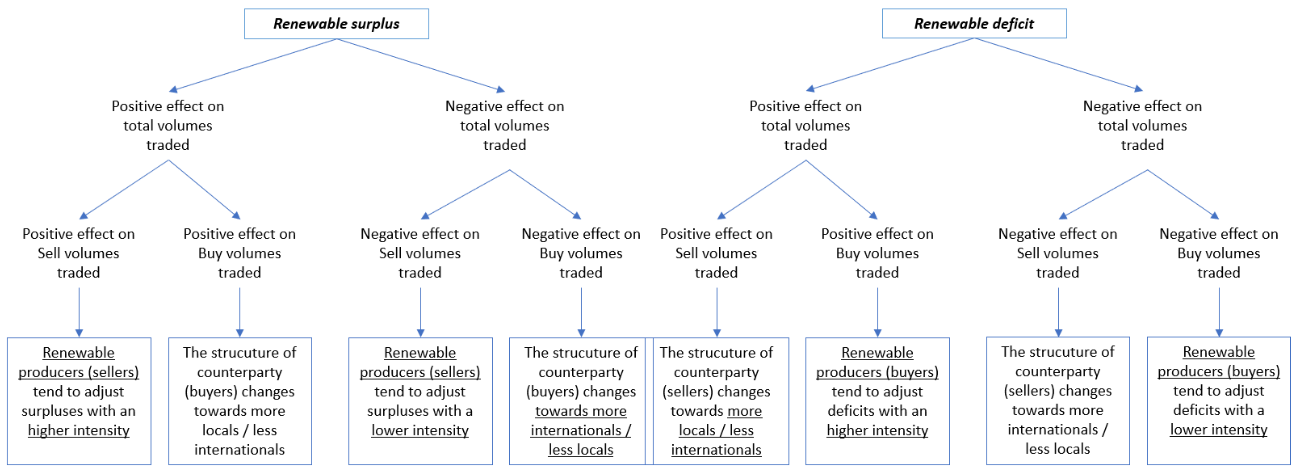


Figure 5: Interpretation of coefficients associated with renewable forecast errors for regressions on volumes

Contractual effects arising from CfD are captured via dummy variables. A first dummy maps product/session for which the corresponding day-ahead price is exactly 0€/MWh. A second dummy is defined for observations where the day-ahead price is greater than or equal to −0.1€/MWh and strictly below 0€/MWh. These dummy variables correspond to the day-ahead price range identified by the French regulator as triggering the binary production incentive switch (CRE, 2024a). A third dummy captures periods in which the day-ahead price falls below −0.1/MWh, corresponding to situations where bids from CfD generators are expected to be fully rejected in the day-ahead market, thereby preventing any subsequent adjustment in the intraday market.

Moreover, we rely on a set of control variables for which further details are available in Appendix A. We control for the level of cross-border capacities availables for commercial trade on intraday to distinguish moments where there are few opportunities for international trades from moments of relative abundance. Availability of commercial capacity between two countries is based on a netting principle and is reassessed several times during the intraday session according to the TSO recalculation. Our variable is the aggregation of available MW in import and export direction between France and the following countries[5]: Belgium, Germany and Spain. Moreover, we include renewable forecast errors from these countries in the same fashion as we do for France. We merge the solar forecast errors in Belgium and Germany, and do the same for wind errors to address potential multicollinearity issues. To further characterize the role

[5]For which information was available trough ENTSO-e platform.

of cross-border trading and how foreign forecast errors affect the French market, we conduct a sensitivity analysis based on the level of interconnector capacity available. The dataset is divided according to the level of available interconnection capacity, classified as either low or high based on the median value (see Appendix E).

Other sources of short-term uncertainty can influence market player imbalance and lead to intraday adjustment. In this regard, we include French load forecast errors and unplanned outages, both expressed in MWh. To construct this second variable, we use the public registry of plant-level unavailability to detect outages that lead to imbalances between day-ahead commitments and real-time production, and are therefore likely to be traded in the intraday market.

Beyond portfolio-level imbalance risk, market participants may react to system imbalances and adjust their intraday trading accordingly. Passive balancing refers to the strategy of intentionally remaining imbalanced in a direction that alleviates system imbalance in order to benefit from imbalance prices (Koch and Maskos, 2020). To account for such behavior likely to influence the intraday market, we introduce dummy variables capturing periods of upward and downward reserve scarcity. These are identified using RTE[6] messages indicating the direction of reserve shortages, which implicitly point to potentially high imbalance prices. There are two types of messages. "Alerts" are always published in D-1 around 7 am, whereas "Downgraded" are issued close to real time without a precise schedule. As a result, downgraded messages carry a higher risk of actual reserve shortages and exposure to high imbalance penalties.

For price and volume regressions, we also include a dummy variable controlling for the switch from local to Pan-European auctions. For volume regressions, we add seasonal and weekend dummies as the trading level may be influenced by a multi-seasonal pattern linked to the economic activity level. For price regressions, the day-ahead price is a control.

Table 2: Regression Results: Daily products [9-17] - Night products [0-8, 18-23]

	Total volumes		Buy volumes		Sell volumes		Median Price	
Variable	Day	Night	Day	Night	Day	Night	Day	Night
solar_fe_po_fr	-0.172*		-0.127**		-0.038		-0.007***	
	(0.083)		(0.047)		(0.048)		(0.001)	
solar_fe_neg_fr	-0.123		-0.038		-0.062		-0.002	
	(0.113)		(0.071)		(0.060)		(0.002)	
wind_onshore_fe_po_fr	0.051	0.094*	-0.009	0.035+	0.065	0.050+	-0.003*	-0.004**
	(0.067)	(0.042)	(0.040)	(0.021)	(0.043)	(0.026)	(0.001)	(0.001)
wind_onshore_fe_neg_fr	0.127	0.102	0.098*	0.105**	0.032	0.005	0.004**	0.002+
	(0.087)	(0.068)	(0.048)	(0.039)	(0.046)	(0.035)	(0.001)	(0.001)
solar_fe_po_bege	-0.018		0.022		-0.046*		-0.002**	
	(0.041)		(0.025)		(0.023)		(0.001)	
solar_fe_neg_bege	0.008		-0.006		0.003		0.002***	
	(0.036)		(0.019)		(0.024)		(0.001)	
wind_fe_po_bege	0.055	0.026	0.046*	0.027+	0.005	-0.006	-0.001	-0.001
	(0.036)	(0.022)	(0.020)	(0.014)	(0.019)	(0.011)	(0.001)	(0.001)
wind_fe_neg_bege	0.053+	0.059*	0.020	0.024*	0.038*	0.037**	0.002***	0.003***
	(0.028)	(0.023)	(0.018)	(0.012)	(0.017)	(0.014)	(0.001)	(0.000)
solar_fe_po_sp	-0.083		-0.038		-0.067*		0.000	
	(0.057)		(0.031)		(0.032)		(0.001)	
solar_fe_neg_sp	-0.106*		-0.053*		-0.065*		-0.000	
	(0.045)		(0.025)		(0.027)		(0.001)	
wind_onshore_fe_po_sp	0.090	0.122**	0.050	0.056**	0.028	0.072**	0.000	0.000
	(0.068)	(0.040)	(0.041)	(0.021)	(0.035)	(0.026)	(0.001)	(0.001)
wind_onshore_fe_neg_sp	0.018	0.086*	0.034	0.048+	-0.011	0.036+	0.002*	0.001+
	(0.054)	(0.043)	(0.039)	(0.025)	(0.023)	(0.021)	(0.001)	(0.001)
load_fe_po_fr	0.058	0.062*	0.011	0.009	0.036	0.043*	0.001	0.000
	(0.046)	(0.030)	(0.024)	(0.016)	(0.027)	(0.019)	(0.001)	(0.001)
load_fe_neg_fr	0.051	0.033	0.032	0.035*	0.030	-0.010	0.003***	0.002***
	(0.048)	(0.032)	(0.025)	(0.016)	(0.029)	(0.020)	(0.001)	(0.001)
message_alert_up	103.288	49.127	47.707	58.972	64.871	-1.787	8.177***	7.489***
	(178.642)	(126.105)	(82.209)	(97.425)	(108.397)	(47.389)	(2.176)	(1.642)
message_alert_down	67.149	-98.242	-48.041	-88.606+	79.431	-8.736	-1.525	-4.628+
	(91.548)	(87.073)	(57.533)	(51.078)	(60.358)	(46.327)	(2.410)	(2.576)
message_downgraded_up_	345.592**	449.158***	231.425**	260.451***	103.255	185.295**	6.788+	4.814+
	(132.343)	(132.237)	(78.218)	(73.751)	(70.882)	(65.777)	(3.515)	(2.750)
message_downgraded_down_	197.921*	-3.761	56.677	12.961	199.806**	-25.159	-11.167***	-11.933***
	(100.858)	(106.559)	(52.795)	(57.417)	(73.257)	(56.994)	(1.904)	(2.093)
null_DA	542.363***	497.787***	205.966***	292.611***	324.782***	213.496**	-4.690***	-6.524**
	(96.274)	(107.896)	(50.415)	(61.773)	(65.720)	(72.516)	(1.206)	(2.304)
near_zero_DA	1290.743***	881.829***	1006.405***	578.616***	439.663***	293.504***	5.407*	8.117**
	(156.850)	(146.635)	(141.511)	(134.536)	(99.457)	(48.369)	(2.529)	(2.924)
negative_DA	439.171**	379.470***	219.484**	230.696***	212.163**	148.390+	-0.438	5.313
	(134.156)	(89.416)	(75.673)	(64.563)	(75.737)	(88.373)	(1.903)	(3.859)
Num.Obs.	3294	5490	3294	5490	3294	5490	3294	5490
R2 Adj.	0.175	0.116	0.202	0.112	0.136	0.080	0.913	0.881

$+p < 0.10$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard errors are computed using the Driscoll–Kraay estimator to ensure robustness to heteroskedasticity, serial correlation, and cross-sectional dependence

5 Results

Main results are presented in Table ??, and discussed in the following. Most of the specifications are fixed effect models, except for regressions on median price for daily products (whatever the moment of the session sample considered) and on median price for night products in the full trading session sample. Complete results as well as sensitivity analysis results are displayed in the Appendix C.

[6] Réseau et Transport d'Electricité, the French TSO

5.1 Renewables forecast errors

5.1.1 Local errors

Our results underline the role played by both solar and wind onshore forecast error in shaping the trading dynamic in the French intraday market. Positive solar errors depress prices, whereas negative errors have no significant effect. Wind surplus decreases prices, while a deficit also affects prices but positively. The fact that only positive solar errors affect prices can be linked with the diurnal pattern of solar production. To accommodate solar production, thermal generators lower their output. It creates a situation where there is an abundance of upward flexibility but a potentially limited output of downward flexibility (Bushnell and Novan, 2018). Therefore, there are many counterparties competing to absorb deficits, thus limiting price increases, while a low competition level to absorb surpluses results in a significant price shift. The effect of competition on price variation also appears in regressions that distinguish between levels of interconnection capacity. We find that significant price effects are systematically equal to or larger during periods of low interconnection availability than during periods of high availability (see Appendix E).

In terms of volumes, a 1MWh surplus of solar decreases Total traded volumes by 0.160MWh, while there is no significant effect of solar deficit on Total volumes. In parallel, solar surplus negatively impacts Buy volumes. It indicated that while solar surpluses and deficits are adjusted with the same intensity by producers, surpluses are structurally absorbed more frequently by an international counterparty. Total traded volumes are positively affected by wind surpluses. This is associated with a rise in both Buy and Sell volumes, suggesting that producers tend to adjust surpluses more intensively at night, with counterparties more likely to be local ones.

When conducting price and volume analysis on sub-samples capturing the last four hours of the trading session, most of the results are consistent with the ones on full trading session samples. Conversely, regressions on sub-samples ignoring trades occurring on the last four hours generally lead to results with lower magnitude concerning prices and not significant for volumes. These results mirror the fact that most of the renewable errors are corrected close to real-time to benefit from higher accuracy in forecasting and a higher level of liquidity in the market.

5.1.2 International forecast errors

We find a significant effect of foreign renewable errors on the French intraday market. For daily products, positive solar errors from Belgium and Germany decrease prices, whereas negative errors increase prices. Negative wind errors from these countries, as well as from Spain, also increase prices for all products. While we cannot directly link neighbor countries' errors with the rise in local volumes traded, since those countries are also connected with other countries, we observe that Sell volumes systematically increase when there is a deficit of wind in Belgium and Germany, whereas Buy volumes rise for surpluses. It suggests that French market participants can both provide upward and downward energy to balance international forecast errors. When the interconnection level is low, the effects of foreign forecast errors on the French intraday price are, when significant, lower than or equal to the effects when prices are high. The only exception is about positive wind error from Belgium and Germany, which has a significant effect in the period of low interconnection level only. However, this significance disappears when considering only trades occurring in the last four hours. The different relationships between French market dynamics and foreign forecast errors illustrate how market coupling allows countries to share their flexibilities to deal with short-term balancing needs at the European level.

5.2 CfD effects

Results on CfD effects on the intraday market are consistent with expectations. When the day-ahead price is null, we observe a drop in the intraday price by 4.7 €/MWh for daily products and 6.5 €/MWh for night products. This is associated with the rise of Total, Sell and Buy volumes. Similarly, when day-ahead prices are slightly negatives price respectively rise by 5.4 €/MWh during the day and 8.1€/MWh at night. In particular, Buy volumes rise by 1006 MWh during the day and by 578 MWh at night in periods of near-zero but negative day-ahead prices. Importantly, our results show that when the day-ahead price is null, there is a rise in Sell volumes, and when the day-ahead price is slightly negative, there is a rise in Buy volumes.

This illustrates the strategy of renewables under CfD that adapts their bidding behavior on the intraday market in order to receive either the CfD payment or the CfD negative price premium. Renewables sell electricity as prices drop, occasionally into negative values, while opting to purchase at positive prices even though self-generation would be cheaper. Both behaviors are distortive relative to system needs. CfD generators buy energy when prices are rising, i.e., when the system is short, and their production would be valuable, and sell when prices are falling, i.e., when the system is long, even though reducing generation would be beneficial at the system level.

Moreover, we also observe a rise in Buy volumes when the day-ahead price is null, of a similar magnitude to the rise in Sell volume, indicating most of the renewables adjustments are absorbed by local counterparties. However, in the case of near-zero negative day-ahead price, the rise in Sell volumes is around two times less important than the rise in Buy volumes, showing that energy needs arising from CfD negative price clause are, in this case, partly covered by foreign counterparties.

Finally, contrary to the general liquidity trend on the intraday market, we observe that volume adjustments in these situations are realized in a balance way between the last four hours of the trading session and the rest of the trading session. It is explained by the fact that renewables under CfD know how to adjust their position as soon as the day-ahead auction clears, thus before the opening of the continuous intraday market. They face a trade-off between securing trades early with possibly higher transaction costs, or waiting to benefit from market liquidity while risking greater intraday price deviations driven by short-term balancing uncertainty.

5.3 Other drivers

Alert and downgraded messages influence prices. Messages for a lack of upward reserve raise prices, while prices drop when there is a message for a lack of downward reserve. We do not observe significant volume adjustment following alert messages. This likely reflects their lower exposure to imbalance risk and the longer anticipation horizon, which allows market participants to easily adjust their portfolios instead of relying on trades. In contrast, downgraded messages lead to noticeable changes in traded volumes that mirror the direction of imbalance risk. When they indicate insufficient upward reserve, trading volumes rise, mainly through Buy volumes (for both daily and night products), as participants hedge against the risk of being short and incurring high imbalance penalties. Conversely, when downgraded messages point to insufficient downward reserve, volumes increase through Sell volumes (only for daily products), as participants try to avoid surplus positions that could be settled at very low or even negative imbalance prices. These results underline the fact that despite weak imbalance price incentives to help the system, French market players tend to react and adapt their positions in a way that helps the system absorb imbalance.

When day-ahead prices are largely negative (variable $negative\_DA$), we observe a rise in transactions, with the buying and selling side affected. It reflects a situation of low residual load that is associated with a large renewable production (despite the fact that producers under CfD are curtailed), increasing balancing needs due to forecast errors. In terms of price, there is no significant effect. This result underlines the fact that balancing needs arise from forecast errors that are either positive or negative. Consequently, the intraday price oscillates around the day-ahead price depending on forecast error direction.

Load forecast errors follow the same logic as renewables errors. While a surplus of load does not have a significant effect on prices, a negative error is trasnlated in an increasing of intraday prices both during the day and at night.

Finally, outages on plants planned to produce have the same effect as a negative forecast error. It creates a deficit that is corrected by a rise on trdaed volumes and is systematically reflected in a rise in volumes on the buying side. This additional demand is then reflected in a rise in intraday prices.

6 Conclusion and policy implications

Our findings indicate that CfD incentives lead renewables to accept intraday losses to lock in CfD revenues and, more broadly, that the design of CfD influences the overall dynamics of the intraday market, affecting both prices and traded volumes.

A consistent price signal with short-term balancing needs

In this paper, we analyze the role of supply and demand fundamentals in shaping the French continuous intraday market dynamics, which is embedded in a unique balancing philosophy in Europe. Our findings on volumes underline the use of the intraday market by market players to adjust their physical position close to real-time. In turn, results on price highlight the ability of the intraday market to convey a price signal that accurately reflects short-term balancing needs. Moreover, we show that the intraday market provides a platform that can complement the TSO in the real-time balancing of the system. While incentives for French market participants to actively engage in the balancing phase are, in theory, weaker than in other countries due to the proactive philosophy in place (Håberg and Doorman, 2016), our results indicate that market participants nevertheless respond to TSO balancing actions. Accordingly, despite relatively low theoretical incentives compared to imbalance penalties, the French market players appear to effectively internalize system-level balancing needs, which are subsequently translated into system-friendly trades in the intraday continuous market.

A distorted price signal due to CfD design

In his role as messenger, the intraday price signals also reflect distortion arising from peculiarities in French CfD design. Importantly, price and volume variations still capture physical adjustments of supply-demand equilibrium, even if, in this case, these adjustments are not system-friendly. While the revenue losses of producers under CfD on the intraday are limited to several euros per MWh (from 5.5 to 8€/MWh), the benefits from negative price premium are much higher, estimated around 28€/MWh for solar plants and 30€/MWh for wind plants, at least[7].

As shown, this distortion affects the bidding behavior of producers under CfD and in turn impacts the intraday market as a whole. While we cannot directly estimate the deadweight loss created by CfD distortive incentives, we can calculate welfare transfer between produc-

[7]In case of negative price, the premium payment when plants stop producing is defined as follows: $LF * Pmax * Nb\,Hours * Strike\,Price$. LF is the load factor (set at 0.35 for solar and 0.5 for wind), while PMax is the installed capacity of the installation. This production potential is multiplied by the strike price set during the CfD auction and then multiplied by the number of negative hours. To estimate the negative price premium, we assume a common price strike of 80€/MWh and an actual load factor equals to 100% to have a lower-bound payment per MWh

ers and consumers. As shown, when the day-ahead price is null, renewables under CfD are selling energy on the intraday market, lowering prices. It creates a transfer from producers to consumers that benefit from lower prices. When day-ahead prices are slightly negatives, renewables under CfD want to buy energy. In this case, prices are increasing and the transfer benefits producers. While transfer levels remain limited at the market level, the implications of the distorsions spreads beyond the intraday market (Table 3). In fact, it also has implications for the activation of reserve energy due to the on / off phenomenon, leading CfD generators to switch on or off their plant at the exact same time, thus putting the system under stress when switching from null to non-null day-ahead hours (RTE, 2025). The issue is likely to worsen if the CfD design is not amended because the renewables capacity under such a support scheme will continue to rise. Moreover, while the negative price premium covers intraday adjustment losses, this premium is paid at the end of every year and not on a monthly basis as the normal CfD payment. It can create a liquidity risk for producers under CfD relative to their debt payment, especially as the amount of the negative price premium may increase with more negative hours prices in the near future.

Table 3: Intraday welfare transfers due to CfD negative prices distortion in 2024

	null Day-Ahead price	near-zero Day-Ahead price
Transfer direction	producers → consumers	consumers → producers
Transfer value (€m)	1.06	2.47

Note: $Transfer\ value = Avg\ Volume * Nb\ Hours * Coeff\ Median\ Price$

In the short term, there is a need to amend the existing CfD negative price clause design. The solution proposed by the French regulator consists of decoupling negative price premium payment from actual output when the day-ahead price is in the -0.1€ - 0€ range (CRE, 2025). By doing so, producers under CfD, even if they are partially activated on the day-ahead, receive the payment. Consequently, their behavior on the intraday price only results in the comparison of the marginal production cost and price level. This tolerance band, implemented since 2025, aims to fully realign production incentives with system needs when the day-ahead price range is within this tolerance band. In addition, a recent law "loi DDADUE" requires that the upward and downward capacity of renewable assets exceeding 10 MW be made available on the tertiary reserve capacity market (JORF, 2025). It would have the effect to enlarge the scope of flexibility available to the TSO to deal with short-term imbalance, in particular around hourly switching points, where significant variations in power arise due to the behavior of CfD-based generators (even if the effect may be mitigated due to the tolerance band). Finally, an administrative rule has also been added to smooth the power variation between negative and non-negative price periods. It consist for the TSO asking producers under CfD to connect / disconnect plants at different moments. However, this administrative rule is likely to pose further problems relative to producers' balancing obligations.

For future CfD design, we recommend modifying the reference volume on which CfD payments are realized. In the current design, the reference volume is the actual production of the asset. Moving to a reference fully decoupled from actual asset output would allow production decisions to be fully aligned with market price signals. It would remove binary production incentives, as a producer partially committed in the day-ahead market would sell remaining available output only if the intraday price exceeds marginal cost. Conversely, if intraday prices decline, the producer would have an incentive to buy back the energy sold on the day-ahead market. These mechanisms would align profit maximization with the minimization of short-term balancing costs. Renewables would thus supply low-cost energy when needed while also providing competitive downward flexibility in surplus conditions, thereby helping the system absorb imbalances rather than exacerbate them. While the flaws of pay-as-produced CfD are well-identified, alternative reference volume has been proposed, including potential-based, capacity-based (Newbery, 2022) and purely financial approaches (Schlecht et al., 2024)with distinct tradeoffs (Kitzing et al., 2024).

Concluding remarks

Overall, this work contributes to better characterizing the dynamics of the continuous intraday market by relying on a multidimensional approach. Our case study, centered on the French market, underlined the robustness of intraday market design in providing an accurate price signal dedicated to the short-term balancing of the system. While the analysis of externalities associated with CfDs has primarily focused on the day-ahead market, this study quantifies their effects on the intraday market, opening new avenues for futures research on the design of renewable support schemes.

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AI statement

ChatGPT was used to refine manuscript language and readability. The authors reviewed all suggestions and remain fully responsible for the final content.

References

Balardy, C. (2022). An Empirical Analysis of the Bid-ask Spread in the Continuous Intraday Trading of the German Power Market. *Energy Journal 43*(3), 229–255.

Birkeland, D., T. AlSkaif, S. Duivenvoorden, M. Meeng, and J. M. E. Pennings (2024, December). Quantifying and modeling price volatility in the Dutch intraday electricity market. *Energy Reports 12*, 3830–3842.

Borggrefe, F. and K. Neuhoff (2011). Balancing and Intraday Market Design: Options for Wind Integration. *SSRN Electronic Journal*.

Bushnell, J. and K. Novan (2018, August). Setting with the Sun: The Impacts of Renewable Energy on Wholesale Power Markets. Technical Report w24980, National Bureau of Economic Research, Cambridge, MA.

CRE (2024a). Analyse de la CRE sur le phénomène de prix de l'électricité négatifs et recommandations relatives aux dispositifs de soutien aux énergies renouvelables.

CRE (2024b). Délibération de la CRE du 11 juillet 2024 relative à l'évaluation des charges de service public de l'énergie pour 2025 et à la réévaluation des charges de service public de l'énergie pour 2024.

CRE (2025). Bilan de la CRE sur la mise en place du complément de rémunération en France et recommandations pour l'avenir. Technical report.

De Vos, K. (2015, May). Negative Wholesale Electricity Prices in the German, French and Belgian Day-Ahead, Intra-Day and Real-Time Markets. *The Electricity Journal 28*(4), 36–50.

Deman, L. and Q. Boucher (2023, December). Impact of renewable energy generation on power reserve energy demand. *Energy Economics 128*, 107173.

Ekoue, M. K., M. Woerman, and C. Clastres (2025, February). Intermittency and uncertainty in wind and solar energy: Impacts on the French electricity market. *Energy Economics 142*, 108176.

ENTSO-E (2024). Position Paper – Sustainable Contracts for Difference (CfDs) Design.

Favre, K. (2025, June). *Designing long-term contracts in electricity markets - Incentives, risk allocation, and challenges for power system operation.* Theses, Université Paris sciences et lettres. Issue: 2025UPSLD012.

Gürtler, M. and T. Paulsen (2018, September). The effect of wind and solar power forecasts on day-ahead and intraday electricity prices in Germany. *Energy Economics 75*, 150–162.

Hagemann, S. and C. Weber (2013, October). An Empirical Analysis of Liquidity and Its Determinants in the German Intraday Market for Electricity.

Håberg, M. and G. Doorman (2016, June). Classification of balancing markets based on different activation philosophies: Proactive and reactive designs. In *2016 13th International Conference on the European Energy Market (EEM)*, pp. 1–5.

JORF (2025). LOI n° 2025-391 du 30 avril 2025 portant diverses dispositions d'adaptation au droit de l'Union européenne en matière économique, financière, environnementale, énergétique, de transport, de santé et de circulation des personnes (1) - Légifrance.

Karanfil, F. and Y. Li (2017, March). The Role of Continuous Intraday Electricity Markets: The Integration of Large-Share Wind Power Generation in Denmark. *The Energy Journal 38*(2), 107–130.

Kazempour, J. (2025). Course Renewables in Electricity Markets: Lecture 5a: Intraday markets.

Kiesel, R. and F. Paraschiv (2017, May). Econometric analysis of 15-minute intraday electricity prices. *Energy Economics 64*, 77–90.

Kitzing, L., A. Held, M. Gephart, F. Wagner, V. Anatolitis, and C. Klessmann (2024). Contracts-for-difference to support renewable energy technologies: considerations for design and implementation.

Koch, C. and P. Maskos (2020). Passive balancing through intraday trading: Whether interactions between short-term trading and balancing stabilize Germany's electricity system. *International Journal of Energy Economics and Policy 10*(2), 101–112.

Kulakov, S. and F. Ziel (2019, November). Determining Fundamental Supply and Demand Curves in a Wholesale Electricity Market. arXiv:1903.11383 [econ].

NEMO committe (2025). euphemia-public-description. Technical report.

Newbery, D. (2022). Efficient Renewable Electricity Support: Designing an Incentive-compatible Support Scheme.

Pape, C., S. Hagemann, and C. Weber (2016, February). Are fundamentals enough? Explaining price variations in the German day-ahead and intraday power market. *Energy Economics 54*, 376–387.

RTE (2025). Bilan prévisionnel - Édition 2025 - Principaux résultat. Technical report.

Schlecht, I., C. Maurer, and L. Hirth (2024, March). Financial contracts for differences: The problems with conventional CfDs in electricity markets and how forward contracts can help solve them. *Energy Policy 186*, 113981.

Soysal, E. R., O. J. Olsen, K. Skytte, and J. K. Sekamane (2017, June). Intraday market asymmetries — A Nordic example. In *2017 14th International Conference on the European Energy Market (EEM)*, pp. 1–6.

Spodniak, P., K. Ollikka, and S. Honkapuro (2021, February). The impact of wind power and electricity demand on the relevance of different short-term electricity markets: The Nordic case. *Applied Energy 283*, 116063.

Weber, P. and M. Woerman (2024, November). Intermittency or Uncertainty? Impacts of Renewable Energy in Electricity Markets. *Journal of the Association of Environmental and Resource Economists 11*(6), 1351–1385.

APPENDICES

A Descriptive statistics

Table 4: Descriptive Statistics

	Mean	SD	Min	Max	Skewness	Kurtosis	N	Missing
volume_TOTAL_full	1868.710	910.648	243.65	5892.300	0.935	0.981	8784	0
volume_TOTAL_off240	613.300	544.431	0.00	5792.300	2.452	12.414	8784	0
volume_TOTAL_in240	1265.931	579.008	77.35	4436.900	1.096	1.580	8784	0
volume_BUY_full	952.609	492.680	97.40	4468.900	1.265	2.955	8784	0
volume_BUY_off240	300.915	275.115	0.00	3086.200	2.104	8.068	8784	0
volume_BUY_in240	651.693	315.062	36.45	3241.500	1.165	2.063	8784	0
volume_SELL_full	927.177	525.370	83.25	5621.300	2.103	11.097	8784	0
volume_SELL_off240	312.489	317.434	0.00	4830.700	4.429	41.533	8784	0
volume_SELL_in240	614.687	315.600	18.40	3460.600	1.343	3.125	8784	0
median_price_full	58.007	41.801	-50.00	296.160	0.273	0.047	8784	0
median_price_op240	58.691	41.154	-50.00	293.160	0.330	0.459	8784	0
median_price_lt240	57.856	42.125	-49.76	337.890	0.250	-0.003	8784	0
solar_fe_po_fr	90.337	218.735	0.00	1313.000	2.910	8.418	8784	0
solar_fe_neg_fr	51.711	159.601	0.00	1148.000	3.933	16.485	8784	0
wind_onshore_fe_po_fr	294.302	433.463	0.00	2315.000	1.929	3.658	8784	0
wind_onshore_fe_neg_fr	156.487	299.001	0.00	2061.000	2.713	8.689	8784	0
solar_fe_po_bege	167.856	484.230	0.00	3925.400	3.831	16.113	8784	0
solar_fe_neg_bege	235.035	595.010	0.00	4337.250	3.212	10.789	8784	0
wind_fe_po_bege	464.082	792.090	0.00	5569.000	2.329	6.148	8784	0
wind_fe_neg_bege	626.545	1012.506	0.00	6136.125	2.147	4.724	8784	0
solar_fe_po_sp	113.699	280.939	0.00	2330.275	3.609	15.029	8784	0
solar_fe_neg_sp	160.584	364.950	0.00	2437.650	3.328	11.871	8784	0
wind_onshore_fe_po_sp	302.479	457.890	0.00	2923.500	2.055	4.932	8784	0
wind_onshore_fe_neg_sp	275.054	500.205	0.00	2850.000	2.561	6.988	8784	0
load_fe_po_fr	378.396	621.125	0.00	4900.000	2.360	6.858	8784	0
load_fe_neg_fr	397.839	649.421	0.00	6013.750	2.595	9.558	8784	0
null_DA	0.022	0.148	0.00	1.000	6.450	39.602	8784	0
near_zero_DA	0.015	0.120	0.00	1.000	8.100	63.625	8784	0
negative_DA	0.026	0.158	0.00	1.000	6.019	34.232	8784	0
message_alert_down	0.044	0.205	0.00	1.000	4.443	17.739	8784	0
message_alert_up	0.013	0.113	0.00	1.000	8.644	72.730	8784	0
message_downgraded_up	0.024	0.153	0.00	1.000	6.232	36.844	8784	0
message_downgraded_down	0.032	0.176	0.00	1.000	5.308	26.175	8784	0
interconnection	8871.819	3436.996	0.00	21416.100	0.484	-0.206	8784	0
outage	379.653	598.312	0.00	4232.000	1.866	3.369	8784	0
DA_price	58.013	40.660	-87.29	284.210	0.338	0.445	8784	0

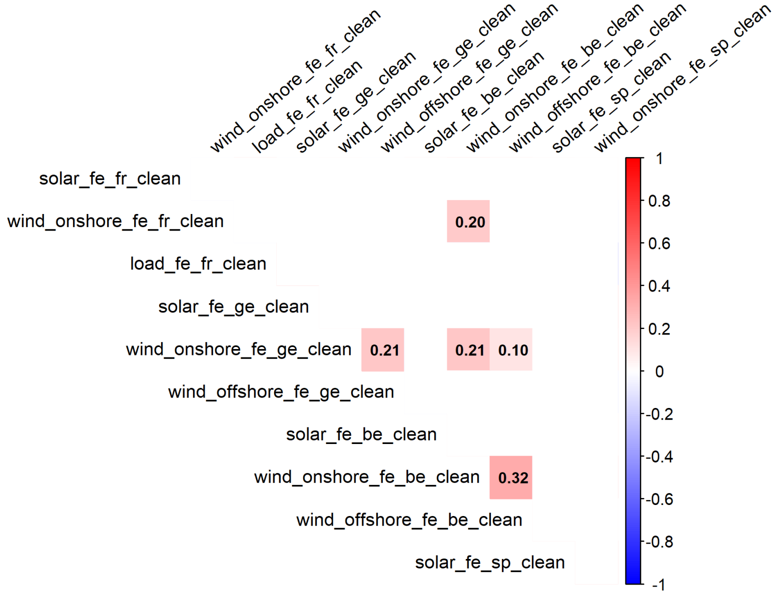

Figure 6: Forecast errors correlation heatmap

B Tests

Table 5: Test p-values summary table (1/2)

	Model								
	volume_full	volume_op240	volume_lt240	volume_op240	volume_lt240	BUY_op240	BUY_lt240	BUY_op240	BUY_lt240
honda_individual	0e+00	0	0	0	0	0	0.0e+00	0	0
pf_test	0e+00	0	0	0	0	0	0.0e+00	0	0
mundlak_test,	0e+00	0	0	0	0	0	0.0e+00	0	0
bg_cor_test	0e+00	0	0	0	0	0	0.0e+00	0	0
bp_hetero_test	1e-07	0	0	0	0	0	1.4e-06	0	0
bplm_cross_cor_test	0e+00	0	0	0	0	0	0.0e+00	0	0

Table 6: Test p-values summary table (2/2)

	Model								
	volume_full	SELL_op240	SELL_lt240	SELL_op240	SELL_lt240	median_price_op240	median_price_lt240	median_price_op240	median_price_lt240
honda_individual	0e+00	0	0	0	0	0.9190353	0.8662636	0e+00	0.0488708
pf_test	0e+00	0	0	0	0	0.9136419	0.7483678	8e-07	0.0400622
mundlak_test,	0e+00	0	0	0	0	0.9137402	0.7484445	7e-07	0.0397472
bg_cor_test	0e+00	0	0	0	0	0.0000000	0.0000000	0e+00	0.0000000
bp_hetero_test	1e-07	0	0	0	0	0.0000000	0.0000000	0e+00	0.0000000
bplm_cross_cor_test	0e+00	0	0	0	0	0.0000000	0.0000000	0e+00	0.0000000

Table 7: Levin Lin Chu stationnarity test on daily products (p-values displayed)

Variable	LLC_none	LLC_intercept	LLC_trend
volume_full	0.0235578	0.0000003	0.0000000
volume_off240	0.0001496	0.0000000	0.0000000
volume_lt240	0.0352441	0.0000004	0.0000000
BUY_full	0.0135954	0.0000000	0.0000000
BUY_off240	0.0000705	0.0000000	0.0000000
BUY_lt240	0.0207086	0.0000000	0.0000000
SELL_full	0.0060659	0.0000176	0.0000006
SELL_off240	0.0000088	0.0000000	0.0000000
SELL_lt240	0.0110966	0.0000000	0.0000000
median_price_full	0.0004984	0.9982537	0.9703186
median_price_off240	0.0009722	0.9982981	0.9823121
median_price_lt240	0.0004424	0.9991741	0.9918484
DA_price	0.0004455	0.9996448	0.9938754
d_median_price_full	0.0000000	0.0000000	0.0000000
d_median_price_off240	0.0000000	0.0000000	0.0000000
d_median_price_lt240	0.0000000	0.0000000	0.0000000
d_DA_price	0.0000000	0.0000000	0.0000000
solar_fe_po_fr	0.0000000	0.0000000	0.0000000
solar_fe_neg_fr	0.0000000	0.0000000	0.0000000
wind_onshore_fe_po_fr	0.0000000	0.0000000	0.0000000
wind_onshore_fe_neg_fr	0.0000000	0.0000000	0.0000000
solar_fe_po_bege	0.0000000	0.0000000	0.0000000
solar_fe_neg_bege	0.0000000	0.0000000	0.0000000
wind_fe_po_bege	0.0000000	0.0000000	0.0000000
wind_fe_neg_bege	0.0000000	0.0000000	0.0000000
solar_fe_po_sp	0.0000000	0.0000000	0.0000000
solar_fe_neg_sp	0.0000000	0.0000000	0.0000000
wind_onshore_fe_po_sp	0.0000000	0.0000000	0.0000000
wind_onshore_fe_neg_sp	0.0000000	0.0000725	0.0000000
load_fe_po_fr	0.0000000	0.0000000	0.0000000
load_fe_neg_fr	0.0000000	0.0000000	0.0000000
outage_down	0.0000000	0.0000000	0.0000000

C Model results

Table 8: Regression Results for Volumes Total

	Full session		Opening hours		Last 4 hours	
Variable	Day	Night	Day	Night	Day	Night
solar_fe_po_fr	-0.172*		-0.030		-0.140*	
	(0.083)		(0.045)		(0.056)	
solar_fe_neg_fr	-0.123		-0.082		-0.042	
	(0.113)		(0.052)		(0.079)	
wind_onshore_fe_po_fr	0.051	0.094*	0.011	0.009	0.048	0.077**
	(0.067)	(0.042)	(0.038)	(0.023)	(0.044)	(0.027)
wind_onshore_fe_neg_fr	0.127	0.102	0.020	-0.004	0.112+	0.113**
	(0.087)	(0.068)	(0.040)	(0.039)	(0.063)	(0.042)
solar_fe_po_bege	-0.018		-0.025		0.004	
	(0.041)		(0.017)		(0.030)	
solar_fe_neg_bege	0.008		-0.013		0.010	
	(0.036)		(0.018)		(0.025)	
wind_fe_po_bege	0.055	0.026	0.038+	-0.001	0.015	0.022+
	(0.036)	(0.022)	(0.021)	(0.013)	(0.022)	(0.013)
wind_fe_neg_bege	0.053+	0.059*	0.023	0.028*	0.035*	0.032*
	(0.028)	(0.023)	(0.016)	(0.013)	(0.017)	(0.013)
solar_fe_po_sp	-0.083		-0.050		-0.051	
	(0.057)		(0.033)		(0.041)	
solar_fe_neg_sp	-0.106*		-0.080**		-0.034	
	(0.045)		(0.027)		(0.029)	
wind_onshore_fe_po_sp	0.090	0.122**	0.021	0.091**	0.056	0.036+
	(0.068)	(0.040)	(0.030)	(0.028)	(0.050)	(0.020)
wind_onshore_fe_neg_sp	0.018	0.086*	-0.020	0.042+	0.044	0.042
	(0.054)	(0.043)	(0.020)	(0.023)	(0.040)	(0.027)
load_fe_po_fr	0.058	0.062*	0.003	0.020	0.045	0.032+
	(0.046)	(0.030)	(0.022)	(0.021)	(0.030)	(0.019)
load_fe_neg_fr	0.051	0.033	0.017	-0.008	0.046	0.033+
	(0.048)	(0.032)	(0.022)	(0.019)	(0.035)	(0.019)
outage_down	0.150**	0.109***	0.029	0.024	0.126***	0.082***
	(0.050)	(0.028)	(0.024)	(0.019)	(0.033)	(0.015)
interconnection	-0.003	-0.007	0.005	-0.000	-0.002	-0.002
	(0.010)	(0.007)	(0.006)	(0.007)	(0.007)	(0.004)
message_alert_up	103.288	49.127	-25.690	-8.460	141.369	65.375
	(178.642)	(126.105)	(59.781)	(30.932)	(126.254)	(115.319)
message_alert_down	67.149	-98.242	98.312+	9.758	-64.472	-107.253+
	(91.548)	(87.073)	(52.148)	(53.981)	(65.303)	(54.745)
message_downgraded_up	345.592**	449.158***	12.316	107.167	324.316***	338.560***
	(132.343)	(132.237)	(69.097)	(68.526)	(88.707)	(73.034)
message_downgraded_down	197.921*	-3.761	154.216*	35.235	101.333	-47.351
	(100.858)	(106.559)	(70.762)	(68.097)	(70.618)	(62.519)
null_DA	542.363***	497.787***	339.553***	258.965***	190.452**	247.175***
	(96.274)	(107.896)	(50.181)	(52.817)	(68.705)	(70.822)
near_zero_DA	1290.743***	881.829***	890.770***	394.169***	553.895***	478.204***
	(156.850)	(146.635)	(125.827)	(83.919)	(77.718)	(118.879)
negative_DA	439.171**	379.470***	165.745*	95.801	263.870**	283.453**
	(134.156)	(89.416)	(76.431)	(79.937)	(84.820)	(98.932)
Num.Obs.	3294	5490	3294	5490	3294	5490
R2 Adj.	0.175	0.116	0.180	0.041	0.135	0.127

$+p < 0.10$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard errors are computed using the Driscoll–Kraay estimator to ensure robustness to heteroskedasticity, serial correlation, and cross-sectional dependence

Table 9: Regression Results for Volumes Buy

	Full session		Opening hours		Last 4 hours	
Variable	Day	Night	Day	Night	Day	Night
solar_fe_po_fr	-0.127**		-0.052*		-0.075*	
	(0.047)		(0.022)		(0.032)	
solar_fe_neg_fr	-0.038		-0.036		-0.002	
	(0.071)		(0.032)		(0.047)	
wind_onshore_fe_po_fr	-0.009	0.035+	-0.008	0.005	-0.001	0.030*
	(0.040)	(0.021)	(0.020)	(0.011)	(0.024)	(0.014)
wind_onshore_fe_neg_fr	0.098*	0.105**	0.023	0.017	0.075*	0.088***
	(0.048)	(0.039)	(0.024)	(0.021)	(0.034)	(0.027)
solar_fe_po_bege	0.022		-0.007		0.029+	
	(0.025)		(0.010)		(0.017)	
solar_fe_neg_bege	-0.006		-0.009		0.002	
	(0.019)		(0.008)		(0.013)	
wind_fe_po_bege	0.046*	0.027+	0.027*	0.004	0.020	0.023**
	(0.020)	(0.014)	(0.011)	(0.007)	(0.014)	(0.009)
wind_fe_neg_bege	0.020	0.024*	0.015	0.017*	0.005	0.007
	(0.018)	(0.012)	(0.010)	(0.007)	(0.010)	(0.007)
solar_fe_po_sp	-0.038		-0.017		-0.021	
	(0.031)		(0.017)		(0.024)	
solar_fe_neg_sp	-0.053*		-0.033*		-0.020	
	(0.025)		(0.014)		(0.017)	
wind_onshore_fe_po_sp	0.050	0.056**	0.018	0.046***	0.032	0.010
	(0.041)	(0.021)	(0.016)	(0.014)	(0.030)	(0.011)
wind_onshore_fe_neg_sp	0.034	0.048+	0.005	0.026*	0.029	0.022
	(0.039)	(0.025)	(0.017)	(0.013)	(0.025)	(0.015)
load_fe_po_fr	0.011	0.009	0.001	0.005	0.009	0.004
	(0.024)	(0.016)	(0.012)	(0.011)	(0.015)	(0.010)
load_fe_neg_fr	0.032	0.035*	0.013	0.009	0.019	0.026**
	(0.025)	(0.016)	(0.013)	(0.011)	(0.016)	(0.009)
outage_down	0.076**	0.079***	0.010	0.020*	0.066***	0.058***
	(0.025)	(0.015)	(0.013)	(0.009)	(0.017)	(0.009)
interconnection	-0.007	-0.007+	0.000	-0.003	-0.007*	-0.004*
	(0.005)	(0.004)	(0.003)	(0.002)	(0.003)	(0.002)
message_alert_up	47.707	58.972	-24.027	-6.523	71.734	65.495
	(82.209)	(97.425)	(32.180)	(21.940)	(55.940)	(82.669)
message_alert_down	-48.041	-88.606+	-3.410	-15.442	-44.631	-73.164*
	(57.533)	(51.078)	(29.962)	(29.193)	(35.666)	(31.893)
message_downgraded_up	231.425**	260.451***	32.799	76.389+	198.626***	184.062***
	(78.218)	(73.751)	(42.934)	(41.174)	(47.621)	(42.376)
message_downgraded_down	56.677	12.961	54.604+	25.295	2.073	-12.333
	(52.795)	(57.417)	(32.298)	(33.950)	(35.103)	(33.711)
null_DA	205.966***	292.611***	106.381***	149.800***	99.585**	142.812***
	(50.415)	(61.773)	(25.945)	(32.526)	(38.170)	(42.847)
near_zero_DA	1006.405***	578.616***	658.476***	281.127***	347.929***	297.489**
	(141.511)	(134.536)	(96.419)	(65.633)	(54.574)	(106.360)
negative_DA	219.484**	230.696***	87.820*	73.104+	131.664**	157.592*
	(75.673)	(64.563)	(39.358)	(41.182)	(47.676)	(75.161)
Num.Obs.	3294	5490	3294	5490	3294	5490
R2 Adj.	0.202	0.112	0.239	0.052	0.123	0.111

$+p < 0.10$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard errors are computed using the Driscoll–Kraay estimator to ensure robustness to heteroskedasticity, serial correlation, and cross-sectional dependence

Table 10: Regression Results for Volumes Sell

	Full session		Opening hours		Last 4 hours	
Variable	Day	Night	Day	Night	Day	Night
solar_fe_po_fr	-0.038		0.023		-0.061*	
	(0.048)		(0.030)		(0.031)	
solar_fe_neg_fr	-0.062		-0.046+		-0.016	
	(0.060)		(0.028)		(0.047)	
wind_onshore_fe_po_fr	0.065	0.050+	0.019	0.003	0.046+	0.046**
	(0.043)	(0.026)	(0.022)	(0.015)	(0.026)	(0.015)
wind_onshore_fe_neg_fr	0.032	0.005	-0.003	-0.020	0.035	0.025
	(0.046)	(0.035)	(0.021)	(0.021)	(0.035)	(0.020)
solar_fe_po_bege	-0.046*		-0.018+		-0.028	
	(0.023)		(0.009)		(0.017)	
solar_fe_neg_bege	0.003		-0.004		0.007	
	(0.024)		(0.013)		(0.014)	
wind_fe_po_bege	0.005	-0.006	0.011	-0.005	-0.006	-0.000
	(0.019)	(0.011)	(0.012)	(0.007)	(0.011)	(0.006)
wind_fe_neg_bege	0.038*	0.037**	0.009	0.012	0.030**	0.025**
	(0.017)	(0.014)	(0.008)	(0.008)	(0.010)	(0.008)
solar_fe_po_sp	-0.067*		-0.033+		-0.034	
	(0.032)		(0.019)		(0.022)	
solar_fe_neg_sp	-0.065*		-0.048**		-0.017	
	(0.027)		(0.016)		(0.017)	
wind_onshore_fe_po_sp	0.028	0.072**	0.003	0.045*	0.026	0.026*
	(0.035)	(0.026)	(0.016)	(0.019)	(0.026)	(0.012)
wind_onshore_fe_neg_sp	-0.011	0.036+	-0.024*	0.016	0.014	0.020
	(0.023)	(0.021)	(0.011)	(0.012)	(0.018)	(0.013)
load_fe_po_fr	0.036	0.043*	0.001	0.015	0.035*	0.028*
	(0.027)	(0.019)	(0.012)	(0.013)	(0.018)	(0.012)
load_fe_neg_fr	0.030	-0.010	0.004	-0.018	0.026	0.007
	(0.029)	(0.020)	(0.012)	(0.011)	(0.021)	(0.013)
outage_down	0.080**	0.028	0.018	0.004	0.062***	0.024**
	(0.028)	(0.018)	(0.013)	(0.012)	(0.018)	(0.009)
interconnection	0.010	0.004	0.005	0.003	0.005	0.002
	(0.007)	(0.007)	(0.004)	(0.006)	(0.004)	(0.002)
message_alert_up	64.871	-1.787	-1.664	-1.667	66.535	-0.120
	(108.397)	(47.389)	(32.311)	(27.892)	(79.933)	(38.933)
message_alert_down	79.431	-8.736	101.722**	25.353	-22.291	-34.089
	(60.358)	(46.327)	(30.918)	(29.402)	(38.831)	(28.081)
message_downgraded_up	103.255	185.295**	-20.484	30.797	123.739*	154.498***
	(70.882)	(65.777)	(33.271)	(32.188)	(55.793)	(38.443)
message_downgraded_down	199.806**	-25.159	99.611*	9.859	100.195*	-35.018
	(73.257)	(56.994)	(45.371)	(39.343)	(43.719)	(34.680)
null_DA	324.782***	213.496**	233.172***	109.133**	91.610*	104.363**
	(65.720)	(72.516)	(34.674)	(40.985)	(43.238)	(37.821)
near_zero_DA	439.663***	293.504***	232.294***	112.790***	207.369***	180.715***
	(99.457)	(48.369)	(62.654)	(32.626)	(51.521)	(34.533)
negative_DA	212.163**	148.390+	77.925+	22.530	134.238**	125.860
	(75.737)	(88.373)	(42.198)	(46.135)	(49.640)	(87.797)
Num.Obs.	3294	5490	3294	5490	3294	5490
R2 Adj.	0.136	0.080	0.113	0.028	0.118	0.114

$+p < 0.10$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard errors are computed using the Driscoll–Kraay estimator to ensure robustness to heteroskedasticity, serial correlation, and cross-sectional dependence

Table 11: Regression Results for Median price

	Full session		Opening hours		Last 4 hours	
Variable	Day	Night	Day	Night	Day	Night
(Intercept)	1.095	1.407	0.466		0.624	
	(2.671)	(2.520)	(2.204)		(2.934)	
solar_fe_po_fr	-0.007***		-0.004***		-0.007***	
	(0.001)		(0.001)		(0.002)	
solar_fe_neg_fr	-0.002		-0.000		-0.002	
	(0.002)		(0.001)		(0.003)	
wind_onshore_fe_po_fr	-0.003*	-0.004**	-0.002	-0.003***	-0.003*	-0.004**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
wind_onshore_fe_neg_fr	0.004**	0.002+	0.002+	0.001	0.004**	0.003+
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
solar_fe_po_bege	-0.002**		-0.001		-0.002**	
	(0.001)		(0.000)		(0.001)	
solar_fe_neg_bege	0.002***		0.002***		0.003***	
	(0.001)		(0.000)		(0.001)	
wind_fe_po_bege	-0.001	-0.001	-0.001*	-0.001*	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
wind_fe_neg_bege	0.002***	0.003***	0.001***	0.002***	0.002***	0.003***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
solar_fe_po_sp	0.000		-0.000		0.000	
	(0.001)		(0.001)		(0.001)	
solar_fe_neg_sp	-0.000		-0.001		0.000	
	(0.001)		(0.001)		(0.001)	
wind_onshore_fe_po_sp	0.000	0.000	-0.000	0.000	-0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
wind_onshore_fe_neg_sp	0.002*	0.001+	0.001*	0.001+	0.002*	0.001+
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
load_fe_po_fr	0.001	0.000	0.001*	0.001	0.001	0.000
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
load_fe_neg_fr	0.003***	0.002***	0.001	0.001*	0.003***	0.003***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
outage_down	0.002*	0.002*	0.001+	0.000	0.002*	0.002*
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
interconnection	-0.000	-0.000	0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
message_alert_up	8.177***	7.489***	7.133***	6.205***	8.069***	7.813***
	(2.176)	(1.642)	(1.639)	(1.070)	(2.193)	(1.920)
message_alert_down	-1.525	-4.628+	-1.300	-3.212*	-1.677	-4.429
	(2.410)	(2.576)	(1.623)	(1.559)	(2.700)	(2.787)
message_downgraded_up	6.788+	4.814+	2.911	3.661+	7.765*	5.461+
	(3.515)	(2.750)	(2.223)	(2.195)	(3.687)	(2.944)
message_downgraded_down	-11.167***	-11.933***	-8.899***	-7.246***	-12.198***	-13.579***
	(1.904)	(2.093)	(1.735)	(1.815)	(1.981)	(2.400)
null_DA	-4.690***	-6.524**	-4.180***	-7.474***	-4.626**	-6.600*
	(1.206)	(2.304)	(1.010)	(2.263)	(1.452)	(2.625)
near_zero_DA	5.407*	8.117**	2.136	3.233	7.485**	10.565**
	(2.529)	(2.924)	(1.700)	(2.686)	(2.865)	(3.235)
negative_DA	-0.438	5.313	-1.206	-1.381	0.288	5.934
	(1.903)	(3.859)	(1.529)	(3.242)	(2.044)	(3.779)
DA_price	0.936***	0.927***	0.959***	0.944***	0.932***	0.914***
	(0.018)	(0.013)	(0.012)	(0.011)	(0.019)	(0.015)
Num.Obs.	3294	5490	3294	5490	3294	5490
R2 Adj.	0.913	0.881	0.952	0.914	0.893	0.837

$+p < 0.10$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard errors are computed using the Driscoll–Kraay estimator to ensure robustness to heteroskedasticity, serial correlation, and cross-sectional dependence

D Results for price regressions with first difference variables

Table 12: Regression Results for Median price based on lagged variables (independent and dependant variables)

	Full session		Opening hours		Last 4 hours	
Variable	Day	Night	Day	Night	Day	Night
d_solar_fe_po_fr	-0.001		0.000		-0.001	
	(0.001)		(0.001)		(0.001)	
d_solar_fe_neg_fr	-0.002		-0.000		-0.002	
	(0.001)		(0.001)		(0.001)	
d_wind_onshore_fe_po_fr	-0.000	-0.001+	-0.001	-0.001*	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
d_wind_onshore_fe_neg_fr	0.003**	0.000	0.000	0.000	0.004**	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
d_solar_fe_po_bege	-0.000		0.000		-0.000	
	(0.001)		(0.000)		(0.001)	
d_solar_fe_neg_bege	0.001**		0.000		0.002***	
	(0.000)		(0.000)		(0.001)	
d_wind_fe_po_bege	0.000	-0.001*	-0.000	-0.000	0.000	-0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
d_wind_fe_neg_bege	0.000	0.001**	0.000	0.001+	0.001	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
d_solar_fe_po_sp	0.000		-0.000		0.001	
	(0.001)		(0.001)		(0.001)	
d_solar_fe_neg_sp	0.001		0.000		0.001	
	(0.001)		(0.001)		(0.001)	
d_wind_onshore_fe_po_sp	-0.000	-0.000	0.001	-0.001+	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
d_wind_onshore_fe_neg_sp	-0.000	-0.000	0.001+	0.000	-0.000	-0.000
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
d_load_fe_po_fr	0.000	0.001	0.001	-0.000	0.000	0.001
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
d_load_fe_neg_fr	0.001+	0.001*	0.000	0.000	0.001*	0.001**
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
interconnection	0.000*	-0.000	0.000*	-0.000*	0.000*	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
message_alert_up	0.167	0.599	0.175	0.238	0.296	0.606
	(0.502)	(0.678)	(0.649)	(0.538)	(0.502)	(0.829)
message_alert_down	0.456	-0.682	0.045	0.428	0.464	-0.258
	(0.550)	(1.159)	(0.283)	(0.640)	(0.676)	(1.387)
message_downgraded_up	0.668	-0.111	0.038	-0.254	0.935+	-0.125
	(0.547)	(0.677)	(0.558)	(0.610)	(0.553)	(0.786)
message_downgraded_down	0.516	-0.713	0.426	-0.670	0.426	-0.042
	(0.510)	(0.883)	(0.404)	(0.934)	(0.639)	(0.961)
null_DA	-3.540***	-1.670	-2.354***	-1.247	-4.142***	-2.449+
	(0.830)	(1.018)	(0.658)	(1.042)	(0.894)	(1.272)
near_zero_DA	3.911***	5.664**	2.885**	5.669*	5.216***	6.804***
	(0.996)	(1.762)	(0.929)	(2.572)	(1.316)	(1.572)
negative_DA	0.552	-1.489	0.104	-3.159	0.915+	-2.333
	(0.483)	(1.586)	(0.301)	(2.563)	(0.485)	(1.675)
d_DA_price	0.653***	0.785***	0.747***	0.755***	0.618***	0.768***
	(0.032)	(0.021)	(0.022)	(0.019)	(0.035)	(0.021)
Num.Obs.	3294	5490	3294	5490	3294	5490
R2 Adj.	0.339	0.497	0.539	0.530	0.248	0.424

$+p < 0.10$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. Standard errors are computed using the Driscoll–Kraay estimator to ensure robustness to heteroskedasticity, serial correlation, and cross-sectional dependence

E Sensistivity analysis results

Table 13: Regression Results: low vs high interconnection availability

	Total volumes		Buy volumes		Sell volumes		Median Price	
Variable	Low	High	Low	High	Low	High	Low	High
solar_fe_po_fr	-0.319**	-0.178	-0.171**	-0.156**	-0.146**	-0.008	-0.008***	-0.008**
	(0.104)	(0.111)	(0.061)	(0.054)	(0.053)	(0.078)	(0.002)	(0.002)
solar_fe_neg_fr	-0.159	-0.138	-0.026	-0.080	-0.069	-0.088	-0.002	-0.003
	(0.121)	(0.151)	(0.079)	(0.090)	(0.078)	(0.072)	(0.003)	(0.003)
wind_onshore_fe_po_fr	0.090*	0.060	0.011	0.033	0.077**	0.018	-0.005***	-0.001
	(0.043)	(0.049)	(0.023)	(0.028)	(0.024)	(0.037)	(0.001)	(0.001)
wind_onshore_fe_neg_fr	0.030	0.188*	0.046	0.148**	-0.025	0.060	0.004*	0.002*
	(0.077)	(0.082)	(0.038)	(0.052)	(0.042)	(0.040)	(0.002)	(0.001)
solar_fe_po_bege	-0.059	0.014	-0.015	0.054+	-0.041	-0.051+	-0.002*	-0.003***
	(0.049)	(0.048)	(0.028)	(0.028)	(0.026)	(0.028)	(0.001)	(0.001)
solar_fe_neg_bege	-0.073+	0.097+	-0.053*	0.046+	-0.024	0.035	0.002*	0.002***
	(0.043)	(0.050)	(0.023)	(0.025)	(0.025)	(0.037)	(0.001)	(0.001)
wind_fe_po_bege	0.043+	0.036	0.031*	0.042**	0.010	-0.010	-0.001+	-0.000
	(0.026)	(0.025)	(0.014)	(0.015)	(0.014)	(0.014)	(0.001)	(0.001)
wind_fe_neg_bege	0.065*	0.051*	0.024+	0.021	0.039*	0.037**	0.002***	0.002***
	(0.028)	(0.023)	(0.013)	(0.013)	(0.018)	(0.014)	(0.001)	(0.000)
solar_fe_po_sp	-0.142*	-0.066	-0.059	-0.036	-0.088*	-0.061	-0.001	-0.001
	(0.072)	(0.058)	(0.039)	(0.033)	(0.038)	(0.043)	(0.001)	(0.001)
solar_fe_neg_sp	-0.157**	-0.120*	-0.070*	-0.067*	-0.099**	-0.036	-0.000	-0.001
	(0.054)	(0.060)	(0.031)	(0.034)	(0.031)	(0.037)	(0.001)	(0.001)
wind_onshore_fe_po_sp	0.099+	0.115*	0.060*	0.043	0.043	0.072*	0.001	-0.000
	(0.051)	(0.055)	(0.028)	(0.026)	(0.027)	(0.035)	(0.001)	(0.001)
wind_onshore_fe_neg_sp	0.148**	-0.020	0.091**	0.002	0.056*	-0.019	0.001	0.001+
	(0.049)	(0.041)	(0.030)	(0.028)	(0.025)	(0.019)	(0.001)	(0.001)
load_fe_po_fr	0.094*	0.026	0.038+	-0.014	0.056*	0.018	0.002**	-0.000
	(0.043)	(0.036)	(0.021)	(0.021)	(0.025)	(0.026)	(0.001)	(0.001)
load_fe_neg_fr	0.068	0.019	0.042+	0.024	0.026	-0.003	0.003***	0.002***
	(0.045)	(0.038)	(0.024)	(0.018)	(0.025)	(0.024)	(0.001)	(0.001)
message_alert_up	81.057	20.091	38.060	20.029	35.461	20.230	7.741***	8.628**
	(118.938)	(209.852)	(48.048)	(138.645)	(80.767)	(80.920)	(1.330)	(2.649)
message_alert_down	26.356	69.397	-32.714	-48.685	48.568	87.401	-2.260	-3.123
	(78.556)	(111.420)	(37.675)	(70.543)	(52.638)	(73.411)	(2.244)	(3.166)
message_downgraded_up_	326.551**	544.662***	203.352***	306.322***	117.152+	219.669***	9.255*	0.212
	(108.724)	(107.179)	(55.667)	(80.225)	(60.143)	(52.953)	(3.952)	(1.145)
message_downgraded_down_	153.249	226.424*	56.168	91.687	101.632+	234.583*	-12.281***	-10.804***
	(103.996)	(99.121)	(52.135)	(60.260)	(61.319)	(109.303)	(1.587)	(2.182)
Num.Obs.	4392	4392	4392	4392	4392	4392	4392	4392
R2 Adj.	0.152	0.145	0.147	0.177	0.131	0.103	0.890	0.902

$+p < 0.10$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. All products in a same regression, split only according to interconnection availability level