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# Is it all about supply? Demand-side effects on the Spanish electricity market following Covid-19 lockdown policies

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ABSTRACT

A key characteristic of electricity prices is their sensitivity to changes in supply and demand. In this sense, the Covid-19 lockdown policies modified electricity consumption patterns at both business and household levels, affecting the shape and position of the electricity demand curve and, thus, leading to a direct effect on electricity prices. However, could this demand-side effect be greater than other supply-induced effects? Is it persistent over time? This paper uses a synthetic bidding approach and concludes that the strict lockdown phase had a strong, immediate – but not persistent – effect on the Spanish electricity price. Furthermore, a high share of renewable energy and a reduction in fossil fuel and emission prices have also proven crucial in driving prices down, though lockdown policies had more impact on prices.

## 1. Introduction

The spread of the Covid-19 virus around the globe led the World Health Organization to declare a pandemic on March 11, 2020 (WHO, 2020). Strict public-sector policies to prevent contagion, including large-scale lockdowns, were implemented worldwide. Firms and households reacted to the new measures and adapted their production and consumption patterns accordingly, which affected social, economic and health systems. Indeed, the World Bank forecasted a 5.2% fall in global GDP from 2019 to 2020 (World Bank, 2020), an uneven recovery for 2021 – depending on each country's access to vaccines (World Bank, 2021) – and a slowdown of global recovery in 2022 due to continued Covid-19 flare-ups, among other factors (World Bank, 2022).

These policies to combat Covid-19 attracted academic attention right from the pandemic's start. Some authors focused on the ability of the policies to stave off infections. In particular, Hsiang et al. (2020) analysed 1,700 non-pharmaceutical interventions from 16 January to April 6, 2020 in China, South Korea, Italy, Iran, France and the United States. They assessed the effect of these policies on the infection growth rate country by country and concluded that they prevented or delayed around 61 million confirmed cases worldwide.

Other authors have analysed the behavioural changes resulting from these anti-contagion policies. For instance, Goolsbee and Syverson (2021) compared consumer behaviour in shopping trends in the United States from March to May 2020 and considered locations coming under different policies. They concluded that individual choices (i.e., fear of the virus) influenced economic decline far more than shutdown orders per se.

Another line of research measured the economic impacts of Covid-19. Brodeur et al. (2021) reviewed articles published between March and November 2020 that documented the macroeconomic effects and labour market outcomes of the Covid-19 crisis, among other non-economic effects. They observed that stay-at-home policies were very harmful to supply chains and employment, leading to a decrease in consumption. This effect still raises many questions about the burden of the pandemic on the economy. Indeed, analysing the macroeconomic effects of Covid-19 is crucial, given the impacts produced by the resulting lockdowns, which led to a change in the social and economic behaviour of economic agents.[1]

The pandemic also changed electricity consumption. Firms and households showed a different electricity demand pattern during lockdowns, which evolved as policy measures were relaxed. Bahmanyar et al. (2020) compared the impact of different containment measures in some European countries (Spain, Italy, Belgium, the United Kingdom, the Netherlands and Sweden) on their electricity consumption profiles in April 2020. They observed that the largest drops in electricity demands were in countries with the strictest policies (Spain, Italy, Belgium and the United Kingdom). Santiago et al. (2021) quantified this drop for Spain, whose stay-at-home policies were among the most hardline, and found that demand fell by 13.49% from 14 March to April 30, 2020.

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[1] See Section 2.2 for a more detailed analysis on the macroeconomic effects of Covid-19 in Spain.

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Similarly, Benatia (2022) focused on the nationwide lockdown period in France from 16 March to May 11, 2020 and found that electricity demand was down by 12% and wholesale prices by 45%.

Outside the European Union, Yukseltan et al. (2022) analysed the decrease in electricity demand in Turkey for 2020 during the pandemic. They concluded that load scheduling should also consider the observed daily demand curve shift from daytime to nighttime to avoid supply-demand disparities. Pradhan et al. (2021) found that the power generation sector in India was severely affected by declining industrial demand for electricity during the Covid-19 pandemic and highlighted the essential role of renewable electricity in the country's future. Finally, and again related to green energy, Costa et al. (2022) focused on how public policies have influenced the dissemination of wind and solar PV sources in Brazil and analysed how they could be affected by the post-Covid-19 pandemic scenario.

The immediate negative effect of the Covid-19 pandemic on demand can thus be said to be undeniable. The question is whether this drop persisted over time, meaning that new lower consumption levels were maintained for extended periods. Indeed, according to Ma et al. (2022), electricity demand and supply shocks induced by meteorological conditions, economic or geopolitical events or changes in firm and household electricity consumption may have various degrees of persistence and even generate volatility spillovers in electricity markets. Furthermore, the impact of climate change on electricity demand has also been explored in the literature, reinforcing the role of demand-induced factors in electricity markets (e.g. Moral-Carcedo and Vicéns-Otero (2005) for Spain, Miragedis et al. (2007) for Greece, Li et al. (2018) for China or Silva et al. (2020) for Portugal). However, we cannot isolate only demand factors when analysing the electricity market and price formation but must consider them together with possible supply shocks to assess the final effect of each.

Therefore, the research question in this paper is twofold: is this Covid-19 demand-side effect greater and more persistent than other supply-induced effects? Or could it have been neutralized with an increased supply of low-cost electricity? All the analyses cited above-considered policies in the early stages of the pandemic and did not explore the final impact on electricity prices. However, like the virus, those policies have evolved, and there is scope for more research in this regard.

This paper focuses on the impact of different degrees of lockdown policies on the Spanish electricity market, which is practically an energy island and, thus, a good case study for isolating the outcome of policies affecting energy markets. First, the paper presents a qualitative analysis of how the economy and the demand for and price of electricity changed during the Covid-19 pandemic in Spain. Second, changes in the shape and position of the supply and demand curve for electricity after the pandemic are quantified. Third, the effect on electricity prices is computed, breaking the price change down into demand-induced changes (i.e., those due to Covid-19 response measures) and supply-induced changes (due to changes in electricity generation) utilizing a synthetic bidding approach (Ciarreta et al., 2017). This approach consists of computing the so-called *synthetic* electricity prices, which are prices under hypothetical conditions (i.e., scenarios), calculated by combining actual and counterfactual supply and demand curves.

In particular, the paper compares three representative periods in which the Spanish government took different measures with different outcomes for the Spanish economy as a whole and the electricity market in particular. The first phase (April 2020) looks at the electricity market in a population "*total lockdown*", when only essential workers were allowed to leave home. Phase two (June 2020) is the "*de-escalation*" phase, where the economy started gradually to open up again, but most people were still working from home, and leisure activities were limited. The last phase (October 2020) is described as "*mobility subject to restrictions*" when there was no longer a strict lockdown, but there were still restrictions on social activities and meetings. Those periods are compared to the equivalent ones in 2019, before the pandemic, to see how Covid-19 influenced the electricity market at these times.

The underlying hypothesis is that the effect of Covid-19 on electricity markets was greater than any other supply effect, such as intermittent renewable energy participation and variations in fuel or emission allowance prices.[2] However, the effect would not be persistent and diminished as lockdown measures relaxed. The paper also explores the role of other supply factors in holding prices down when facing a demand shock. These results have implications for utilities in terms of forecasting electricity price changes and their persistence in the face of future economic or policy shocks and in terms of investing in technologies that could help minimize the associated adverse effects.

This research also shows how the electricity market operates under a major shock to the economy and how the market may be affected by changes in consumer behaviour. This analysis could also be of interest beyond the Covid-19 crisis perspective since it provides insights into the evolution of future electricity markets in the face of a challenging energy transition with substantial demand-induced changes (e.g., new mobility conditions due to climate change policies or fossil fuel scarcity). Such analyses highlight the vulnerabilities of current electricity markets when faced with challenges of substantial uncertainty due to intermittent renewable energy, a decreasing share of fossil production or an international geopolitical crisis.

The rest of the paper is structured as follows. Section 2 describes the Spanish electricity market, the macroeconomic effects of the Covid-19 pandemic in Spain and the link between the electricity market and Covid-19 policies. Section 3 sets out the methodology used for the empirical analysis. Section 4 details the data used in the paper. Section 5 presents and discusses the main results. Finally, Section 6 concludes.

## 2. The electricity market and Covid-19 in Spain

This section places the electricity market within the national macroeconomic context – something that has lately become crucial in Europe, with energy costs accounting for 40% of Europe's inflation surge (Bloomberg, 2022) – and the Covid-19 pandemic. First, Section 2.1 outlines the main characteristics of the Spanish electricity market. Section 2.2 comments on the macroeconomic effects of policies to combat Covid-19 in Spain, which is necessary to understand the effect on electricity demand. Finally, Section 2.3 highlights the link between Covid-19 and the Spanish electricity market.

### *2.1. The electricity market*

Electricity markets are different from other commodity markets. Electricity is non-storable (at least on a large scale), and, therefore, an instantaneous balance between supply (i.e., generation) and demand (i.e., consumption) is necessary. Electricity markets are intended to maintain this balance and thus guarantee the safe, efficient operation of the system and reduce the cost of electricity through competition. The market environment usually includes a daily market consisting of a day-ahead market (also called the wholesale market or pool), intra-day markets and adjustment services, a floor for bilateral contracts and a forward market. This paper focuses on the day-ahead market, which clears every hour in Spain[3] and accounts for more than 85% of the total energy traded (OMIE, 2020).

Sellers (i.e., electricity producers) and buyers (i.e., retail companies and free consumers) submit bids for each hour and production unit. Each

[2] Electricity market outcomes depend on several factors, such as relative production costs, fuel prices and, overall, demand (Bushnell et al., 2008).

[3] Most electricity markets in Europe clear hourly, but some clear every 30 min (France, United Kingdom, Luxembourg, and Switzerland) or even every 15 min (Austria, Belgium, Germany, Hungary, Luxembourg, the Netherlands, Slovenia, and Switzerland) (International Renewable Energy Agency, IRENA, 2019).

production unit can be either fossil (nuclear, coal or combined cycle) or renewable (wind, solar, hydro, or biomass). Supply bids are ordered from the lowest to the highest price, and demand bids from the highest to the lowest price. Buyers and sellers in the Spanish electricity market submit their bids for each hour as a price-quantity pair, where the price is measured in EUR/MWh and electricity in MWh. In Spain, the maximum price at which the bids could be submitted in the period analysed was 180.3 EUR/MWh, and the minimum was zero.[4]

The market works as a standard symmetric uniform price auction, meaning that all producers bidding at prices lower than the marginal price get the price of the last bid accepted (i.e., the marginal price or market price). Similarly, all buyers of electricity bidding above the marginal price pay the marginal price. By contrast, at pay-as-bid auctions, producers bidding at prices lower than the marginal price get their own bid price, and all electricity buyers that bid above the marginal price also pay their bid price. Uniform price auctions are often criticized for possibly being more subject to strategic manipulation by large traders (Bergler et al., 2017). However, bid prices can be expected to be higher under pay-as-bid auctions because generators will be bidding at their expectation of the market clearing price instead of at their actual marginal generation cost (Aliabadi et al., 2017). Comparing these two systems in multi-unit markets is particularly complex, and the debate remains open.[5]

Fig. 1 presents the electricity demand (grey line) and supply (black line) curves for a representative hour and shows that demand bids are sorted from the highest price to the lowest. The horizontal part of the demand curve includes most household and small business consumption, given that these consumers have fixed contracts with their retail companies and do not compete in the market directly. The consumption behaviour pattern of households and small businesses thus determines the length of this segment. If their demand increases, the curve shifts to the right; if it decreases, the demand curve shifts horizontally leftwards. The slope of the demand curve represents the elasticity of other kinds of consumers (industrial and free riders). The greater the elasticity of demand, the smoother the demand curve is. In general, the demand curve for electricity is steep (sometimes even almost vertical), suggesting that electricity demand is very price-inelastic; i.e., consumers cannot easily substitute energy consumption from 1 h to another. However, the horizontal part of the demand curve changes significantly as demand increases (e.g., weekdays vs. weekends or peak vs. off-peak hours) or decreases (e.g., adverse economic shocks) and is 30–60% lower during low-demand periods.[6]

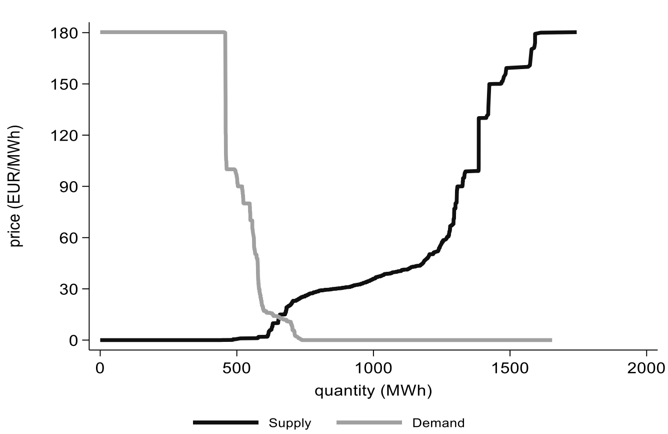


**Fig. 1.** Structure of electricity supply and demand curves
Source: Own work based on data from OMIE (2022b).

Furthermore, Fig. 1 shows the supply curve, also known as the merit order curve, which includes generator bids. The merit order curve is ordered from the cheapest technology to the most expensive in the generation mix and includes the costs and capacities of all units. Each generation plant represents a step on the curve. The cost differences are mainly due to the technology and the fuel consumed. Renewable and nuclear technologies, which have zero (or very low) marginal costs, are located on the horizontal part of the supply curve. The higher the share of renewables is, the larger this segment will be, and the supply curve will shift to the right. That share depends on weather conditions affecting wind speed, ambient temperature and incident radiation; and on the installed capacity of renewable resources. By contrast, the technologies with the highest marginal costs are coal and combined cycle (because of their fuel costs), usually marginal technologies. Large hydropower is usually a marginal technology, given the opportunity cost of using water reserves.

The intersection between demand and supply shown in Fig. 1 represents the equilibrium in the electricity market, that is, the price at which all electricity is sold/bought at that hour on that particular day. This price is known as the marginal price, the market-clearing price, the equilibrium price, or simply the electricity price.[7]

### 2.2. *The macroeconomic effects of Covid-19*

Covid-19 began in November 2019 in the Chinese province of Hubei. The World Health Organization officially declared a global pandemic on March 11, 2020 (WHO, 2020). Consequently, governments around the world reacted, and the Spanish government declared a "state of alarm" on March 14, 2020 (BOE [Spanish Official Gazette], 2020a). The main measures adopted included stopping on-site working (except for essential services) and restricting all movement (except for emergencies and to stock up on supplies). Table 1 breaks down the restrictions implemented in 2020 into three main phases: i) total lockdown, ii) de-escalation, and iii) mobility subject to restrictions.

Spain was still recovering from the Great Recession that began in 2008 when the Covid-19 pandemic hit the economy in the first and second quarters of 2020. As shown in Fig. 2, GDP (solid line, left axis) fell, and unemployment (dashed line, right axis) increased in the second quarter of 2020. The GDP drop was even greater than in the 2008 crisis, and the country's economy was effectively brought to a standstill by the lockdown legislation. Data from the Spanish National Employment Office (INE, 2022) shows a quarter-on-quarter fall of 13.2% in GDP in the second quarter of 2020, compared to average growth of 5.9% from 2002 to 2019. Comparing the second quarter of 2020 and the same quarter of 2019 shows a drop in GDP of 20.4%, compared to average growth of 3.1% for 2002–2019. Note that the biggest fall in GDP observed after the Great Recession was 4.6% between the second quarters of 2008 and 2009.

As Fig. 2 shows, the effect on unemployment (dashed line, right axis) was neither strong nor long-lasting. After lockdown legislation was passed, unemployment increased by 1.3 pp in the same period as the previous year, whereas there were increases of as much as 7.4 pp during the Great Recession. The highest unemployment rate after the Covid-19 crisis was 16.3% in the third quarter of 2020, far lower than the 26.9% recorded in the first quarter of 2013.

The effect on unemployment was not so pronounced because of the job retention measures adopted (BOE, 2020b), but the pandemic still

[4] From May 2021 onwards, the minimum bid was set at −500 EUR/MWh and the maximum at 3000 EUR/MWh, which was already the case for other European countries (BOE, 2021).

[5] See Fabra et al. (2002) for a comprehensive discussion on types of electricity auction.

[6] Own calculations based on data from OMIE (2022b).

[7] A comparison between different electricity markets worldwide can be found in Karimi et al. (2022).

**Table 1**
Main regulatory milestones related to Covid-19 in 2020.

| Phase | Period | Description |
|---|---|---|
| Total lockdown | March 14, 2020–May 1, 2020 | • “State of alarm” as of 14 March, including a stay-at-home requirement for all citizens except for emergencies and a recommendation to stock up on supplies.<br>• Temporary closure of non-essential shops and businesses, including bars, restaurants, cafes, cinemas, and commercial and retail businesses.<br>• Ban on all non-essential activity from 30 March to 9 April: total lockdown. |
| De-escalation | May 2, 2020–June 20, 2020 | • Four phases to reopen the economy (including shops, hotels, and bars with restrictions on capacity).<br>• On 21 June, the opening up all internal borders between devolved regions within Spain, the land border with France, and international flights with other European Union countries and the United Kingdom. |
| Mobility subject to restrictions | October 25, 2020 onwards | • Further “state of alarm”. National curfew and restrictions on movement between devolved regions and municipalities. |

Source: Own work based on data from the Spanish Official Gazette (BOE 2020a, c,d) and the Cabinet (2022).

affected firms greatly. Fig. 3 shows the year-on-year changes in the number of firms registered in the Social Security system in Spain from 2012 to 2021. Firms are classified as “very small” (1–9 employees, solid black line), “small” (10–49 employees, dashed black line), “mid-size” (50–249 employees, solid grey line) and “large” (250 or more employees, dashed grey line). Fig. 3 shows a drop in the number of companies registered in the Social Security system in 2020 after the enactment of the lockdown. Indeed, the year-on-year reduction recorded in 2020 was almost as great as in the period following the Great Recession, and the impact on small and medium-sized enterprises was greater, with drops of 5.9% and 5.2%, respectively. This figure represents 13% of all the firms in Spain.

### 2.3. The link between electricity and Covid-19

After exploring the negative impact of Covid-19 on GDP and the labour market in Spain, the aggregate behaviour of the economy is now related to the electricity sector. Empirical evidence suggests a positive link between electricity consumption and real GDP (Narayan and Prasad, 2008). Indeed, electricity use is considered a leading indicator of economic development (Kennedy, 2015).

Fig. 4 shows the trend in aggregate demand (dashed line, left axis) and electricity consumption in the day-ahead market (solid line, right axis) per quarter in Spain from 2016 to 2021. With the outbreak of Covid-19, the sharpest decreases of both figures in the whole time series were simultaneously in the second quarter of 2020, after stringent

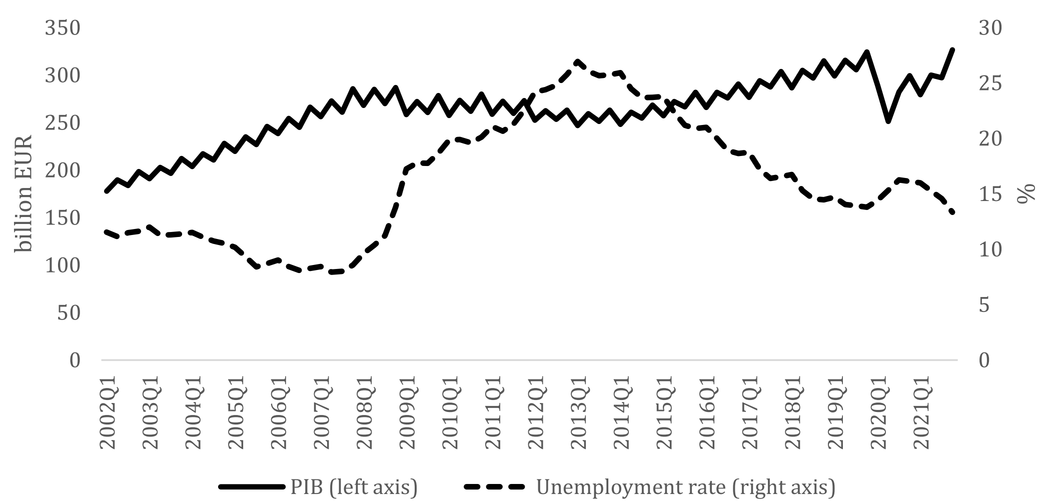


**Fig. 2.** Trends in GDP [left, billion EUR] and unemployment rate [right, %] 2002–2021.
Source: Own work based on data from INE (2022).

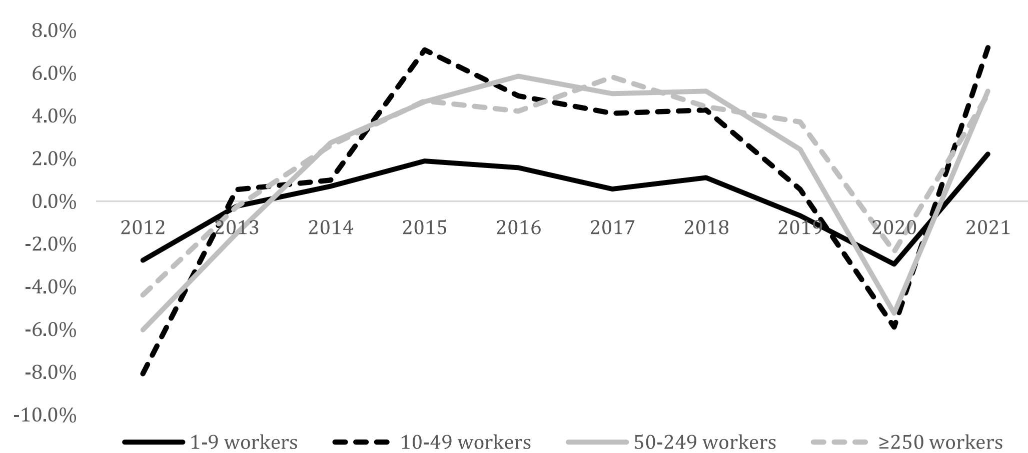


**Fig. 3.** Firms registered in the Social Security system classified by size. Year-on-year changes [%]. 2012–2021.
Source: Own work based on data from MITES (2022).

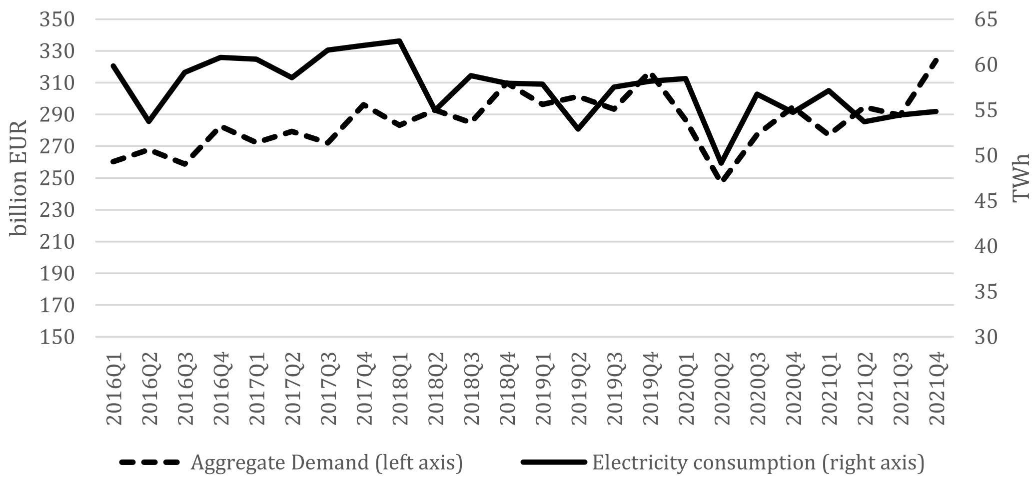


**Fig. 4.** Trend in aggregate demand [left, billion EUR] and electricity consumption [right, TWh] per quarter in Spain. 2016–2021.
Source: Own work based on data from INE (2022) for aggregate demand and Operador del Mercado Ibérico de ElectricidadOMIE (2022) for electricity consumption.

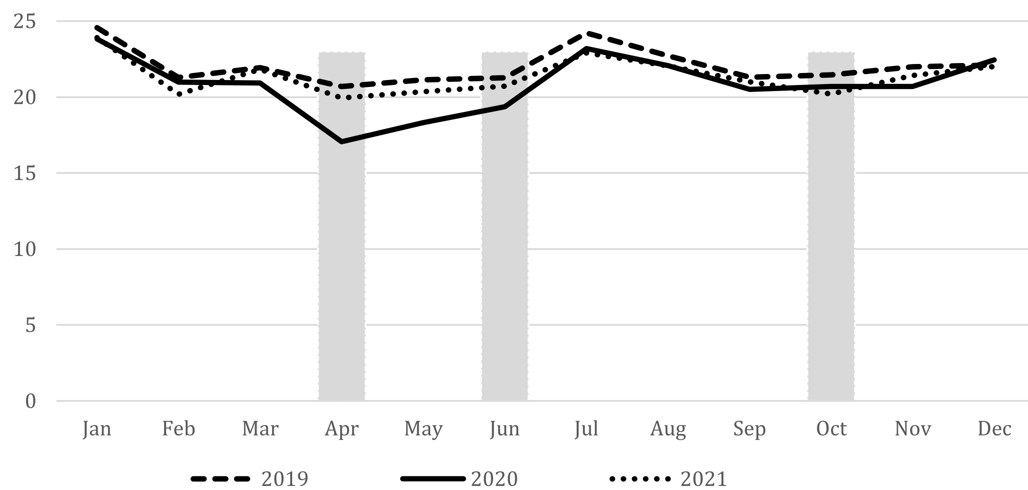


**Fig. 5.** Trend in electricity consumption [right, TWh] in Spain month by month: pre-pandemic vs. pandemic. 2019–2021.
Source: Own work based on data from REE (2022).

lockdown policies had been enacted. They began to recover when the lockdown measures were relaxed, but aggregate demand did not return to pre-pandemic levels until late 2021 and electricity consumption still had not done so by the end of 2021.

Given the seasonal behaviour of electricity consumption – affected not only by economic shocks but also by weather conditions–, Fig. 5 shows the trend in electricity demand in the day-ahead market month by month for 2019 (pre-pandemic), 2020 (first pandemic year) and 2021 (second pandemic year). Without loss of generality, demand tends to decrease in the early months of the year and increase afterwards, with a peak in summer. The demand patterns observed in Spain in 2019 (pre-pandemic) and 2021 (second pandemic year) are very similar (the correlation coefficient is 0.94), whereas differences increase when the year 2020 is involved (the correlation coefficient is 0.85). Indeed, in March 2020, demand started to decrease after the introduction of lockdown legislation (BOE, 2020a) and fell to a minimum in April 2020. Demand in the summer of 2020 seems to behave closer to the previous year's values, coinciding with a reopening of the economy and less strict anti-Covid-19 policies from June 2020 onwards; however, it always remains below. Then, electricity demand remained steady in the autumn of 2020, when there were new restrictions on mobility; but it increased in 2019 and 2021. In line with this demand picture, the focus is set on April, June, and October (highlighted in Fig. 5) as representative months for each period, seeking to determine the effects on the electricity market of different policies to combat Covid-19.

As shown in Fig. 5, the net effect on electricity demand in the months with the most restrictive anti-Covid-19 policies is negative (i.e., demand falls). However, the impact of these policies is highly dependent on the type of consumer. On the one hand, the restrictions on mobility imposed by the government during the "state of alarm" meant that citizens had to stay at home during the lockdown phase, which increased residential demand. On the other hand, the closure of many firms during the total lockdown in April 2020 meant that industrial demand fell from 2019 levels. Indeed, in 2020, the Spanish electricity system operator recorded a drop of 5.6% in electricity demand nationwide on the previous year (REE, 2020a). Thus, the fall in consumption in industry and small businesses outweighed the increase in household consumption.

Focusing on electricity prices, Fig. 6 shows the trend in average monthly electricity prices in the Spanish day-ahead market for 2019 (pre-pandemic, grey line) and 2020 (pandemic, black line) in EUR/MWh. The year 2021 is not included in the price analysis because the maximum and minimum price limits changed, and prices in 2021 were

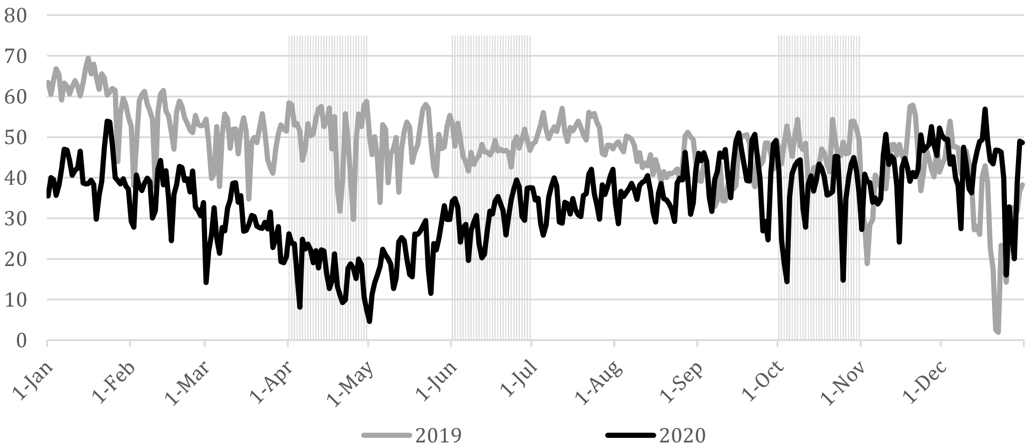


**Fig. 6.** Trend in the average daily price of electricity in Spain for 2019–2020 [EUR/MWh].
*Source: Own work based on data from* Operador del Mercado Ibérico de la ElectricidadOMIE, 2022a

abnormally high, which could disturb the analysis.[8] As can be seen, most average electricity prices for 2020 are below 2019 levels, and the gap widens from March onwards (with the total lockdown phase). Electricity prices started to recover in May 2020 and were approaching those of the previous year by September 2020. In October 2020, prices fell again due to further mobility restrictions, but they continued to fluctuate around previous-year levels until the end of the year.

Note: Daily averages.

Figs. 5 and 6 show a clear link between electricity consumption, electricity prices, and the different regulatory phases after Covid-19 hit Spain: (i) total lockdown (April 2020); (ii) de-escalation (June 2020); and (iii) mobility subject to restrictions (October 2020). In the following sections, this link is further explored using a quantitative analysis that compares periods after the onset of Covid with the equivalent periods of the previous year to avoid seasonal variations.

## 3. Methodology

This section describes the procedure followed in this paper for decomposing the price changes induced by supply and demand factors, working with monthly aggregate supply and demand curves for three representative months in the Covid-19 pandemic: April (lockdown phase), June (de-escalation phase), and October (restricted mobility phase). First, Section 3.1 explains how to compute the corresponding equilibrium price for any selected period. Second, Section 3.2 details the *synthetic approach* procedure, which consists of recombining supply and demand curves under different scenarios (i.e., pre-Covid-19 curves for 2019 and post-Covid-19-onset curves for 2020) and comparing actual and counterfactual outcomes.

### 3.1. Calculating equilibrium prices

Monthly aggregate supply and demand curves are built by aggregating all the hourly supply and demand bids in a month.[9] The algorithm proposed by Ciarreta et al. (2014) uses those inputs to compute monthly equilibrium prices. This algorithm considers stepwise supply and demand curves where the quantity traded for each price is on the short side of the market (which corresponds to the supply curve at low prices and the demand curve at high prices). It then computes the quantity traded as the maximum of the quantities obtained and finds the corresponding price.

Equations (1)–(3) summarize this procedure, where $p_i$ stands for the electricity price of the bid i, $q_{min}$ is the quantity traded at $p_i$, $q_{bid}(p_i)$ stands for the supply-side quantity bid at pi and $q_{ask}(p_i)$ stands for the supply-side quantity bid. Finally, p and q are the algorithm's output, indicating the market clearing price and quantity traded.

$$q_{min}(p_i) = \min\{q_{ask}(p_i), q_{bid}(p_i)\} \quad (1)$$

$$q = \max_{p_i}\{q_{min}(p_i)\} \quad (2)$$

$$p = \{q_{bid}^{-1}(q)\} \quad (3)$$

### 3.2. The synthetic bidding approach

The synthetic bidding approach consists of computing the so-called *synthetic electricity prices*, which are the prices that would arise under hypothetical conditions, i.e., combining actual and counterfactual supply and demand curves. *Actual equilibrium prices* are calculated using actual aggregate monthly supply and demand curves.[10] Counterfactuals are then used to infer whether the changes observed in the electricity market after the different lockdown policies during the Covid-19 pandemic are due mainly to demand (i.e., Covid-19) or supply factors (i.e., such as changes in intermittent renewable output, fuel price changes, emission allowance price changes). These changes could be due to (i) a shift to the right/left of supply or demand curves and (ii) a change in the slope of supply or demand curves.

Given the merit-order arrangement of the supply curve, where technologies are located in ascending order according to their marginal costs, a negative demand shock (Fig. 7a) such as the one caused by Covid-19 would shift the demand curve to the left, driving prices lower in electricity markets (the remainder *ceteris paribus*). Similarly, a positive supply shock that increased the amount of "cheap" electricity (i.e., from renewable resources) or reduced fuel or emission allowance prices (Fig. 7b) would also bring prices down, given the excess of low-price supply. The sign of the price change would be the same in both cases,

[8] According to Operador del Mercado Ibérico de ElectricidadOMIE (2022) data, the maximum price in 2021 was 383.67 EUR/MWh on 23 December and there were 75 days with prices over 180.3 EUR/MWh, which was the maximum price allowed in 2019 and in 2020.

[9] Simple bids are used, which only state price and energy, whereas complex bids incorporate additional technical or economic conditions, such as indivisibility, load gradient, minimum income and scheduled stoppages (OMIE, 2019).

[10] Recall that the Spanish market operator publishes supply and demand curves on an hourly basis. Since results in this paper are presented on a monthly basis, in order to avoid possible intrahour and intraday effects, it is necessary to compute monthly averages from actual values. It is called *actual*, because it comes from actual supply and demand curves (no scenarios are used).

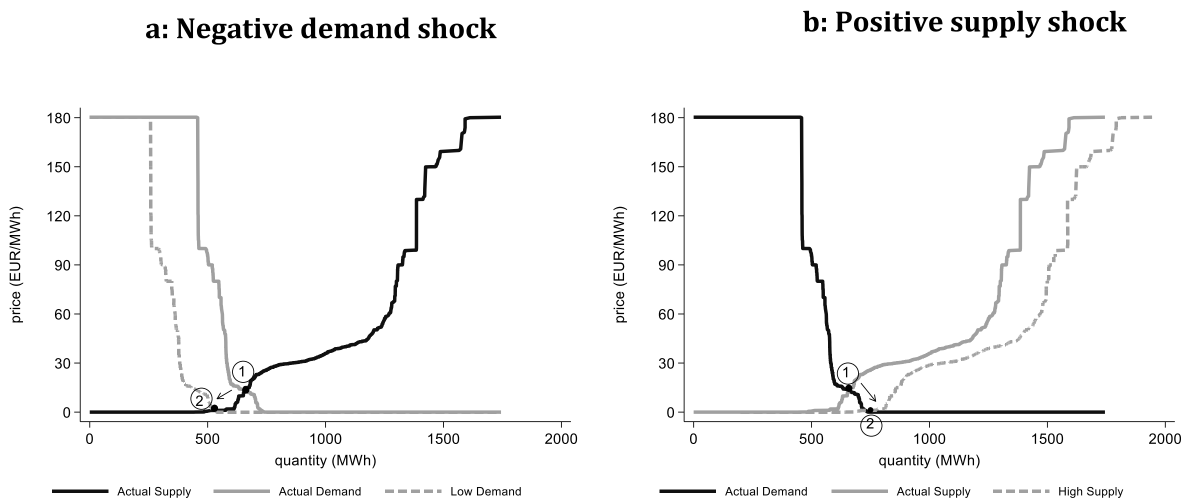


**Fig. 7.** Effect of demand and supply shocks on electricity price [prices in EUR/MWh and quantities in MWh].
Source: Own work based on data from OMIE (2022b).
Note: (1) stands for the actual equilibrium, and (2) stands for a new equilibrium holding supply and changing demand (Panel a) or holding demand and changing supply (Panel b).

but the extent could differ depending on (i) the intensity of the shock, (ii) the relative positions of supply and demand curves, and (iii) the differences in their slopes.

The question to be addressed reads as follows: what would the electricity price change in 2020 (after the onset of Covid-19) be if supply were set at 2020 levels (actual supply) and demand at 2019 levels (counterfactual demand)? Or, from the other perspective, what would the price change in 2020 (post-onset of Covid-19) be if demand were set at 2020 levels (actual demand) and supply at 2019 levels (counterfactual supply)? To that end, the price change between 2019 (pre-Covid-19) and 2020 (post-onset of Covid-19) is decomposed by comparing actual and counterfactual prices, called *synthetic prices*. The methodology alternates demand and supply changes that may occur individually or simultaneously. Both demand or supply curves could be synthetic (i.e., modified), depending on the effect to be analysed. This approach is also helpful in determining whether there has been any change in the bidding behaviour of conventional producers due either to changes down to weather conditions and the effect of the pandemic on other energy markets (i.e., non-strategic changes) or changes in the bidders' strategy.

Based on the counterfactual behaviour of one of the curves making up the equilibrium price, this synthetic bidding approach is not new in the literature. In particular, Ciarreta et al. (2017) used this methodology to identify strategy changes by conventional producers after the large-scale introduction of renewables into the Spanish electricity market. Similarly, Hirth (2018) analysed the factors behind electricity price changes in Sweden and Germany by replacing individual regression parameters with figures from another year.

Fig. 8 summarizes the background to this approach and shows demand and supply curves for two different periods, which could be the same month of two different years; for instance, a year prior to the Covid-19 crisis (2019) and a year after the onset of the pandemic (2020). Solid lines stand for supply (black) and demand (grey) curves for 2019 and dashed lines for 2020.

Focusing only on prices, Point 1 in Fig. 8 is the actual equilibrium price for 2019 ($p_1$), and Point 2 is the equilibrium price for 2020 ($p_2$). Points 3 and 4 are synthetic equilibrium points. Point 3 is the intersection between the supply of 2019 and the demand of 2020 ($p_3$). Point 4 is the intersection between the supply of 2020 and the demand of 2019 ($p_4$).

The difference between the actual prices $p_1$ and $p_2$ (i.e., $p_1 - p_2$) could be due to demand or supply factors. That difference is broken down by computing two synthetic prices ($p_3$ and $p_4$). In particular, the difference

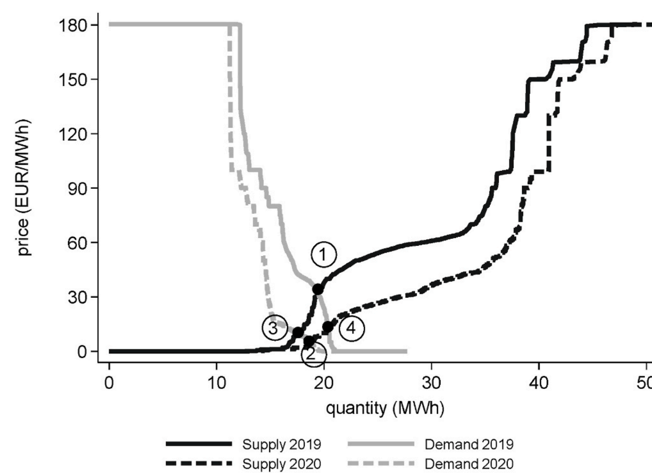


**Fig. 8.** The synthetic bidding approach
Source: Own work based on data from OMIE (2022b).
Note: (1) stands for the actual equilibrium in the year 2019 (pre-Covid-19), (2) stands for the actual equilibrium in 2020 (post Covid-19 onset), (3) stands for a synthetic equilibrium with 2019 supply and 2020 demand, and (4) stands for a synthetic equilibrium with 2020 supply and 2019 demand.

between $p_1$ and $p_3$ (i.e., $p_1 - p_3$) corresponds to the difference in demand between 2019 and 2020 since the supply curve is for 2019 in both cases. Similarly, the difference between $p_2$ and $p_3$ (i.e., $p_3 - p_2$) corresponds to the difference in supply between 2019 and 2020 since the demand curve is for 2020 in both cases. If $p_1 - p_3$ is greater than $p_3 - p_2$, the demand effect dominates. In this case, the difference in actual prices might be due to Covid-19, given that it is the biggest shock affecting demand from one of these two periods to the other. The same conclusions can be reached by breaking down the difference $p_1 - p_2$ into $p_1$ - $p_4$ (supply induced) plus $p_4$ - $p_2$ (demand induced).

Following this approach, three representative months of 2019 and 2020 under three very different Covid-19 response policies are compared here: (i) total lockdown (April 2020); (ii) de-escalation (June 2020); and (iii) mobility subject to restrictions (October 2020).

## 4. Data

The data used in the analysis came from Spanish market operator OMIE. First, the files that provide minimum, average, and maximum prices and total energy acquired daily in the Spanish day-ahead market (OMIE, 2022a) were used to analyse price and quantity trends. Second, a more detailed database, which includes all supply and demand bids from all the agents bidding in the Spanish pool at the hourly level, was used to calculate the equilibrium price and the synthetic bidding approach (OMIE 2022b). Prices were measured in EUR/MWh and quantities in MWh. For the sake of simplicity, energy was converted into TWh when monthly aggregate data was involved.

Table 2 shows the main descriptive statistics for Spanish electricity prices for 2019 and 2020. Comparing the two years shows a highly seasonal pattern in electricity prices, depending on the month and the year. In particular, prices are always higher in winter, as demand is relatively higher. Additionally, standard deviations are generally higher at the end of the year and lower in summer, which relates to the wind energy generation pattern (i.e., the more wind energy there is on the market, the more variable prices are). However, Table 2 also shows specific differences in electricity prices between these two years that could be due to the Covid-19 crisis and the associated policies. Indeed, prices are generally lower and more volatile in 2020, possibly due to the effect of the lockdown and the restrictions imposed due to Covid-19. Finally, the skewness and kurtosis coefficients show that electricity prices in Spain are not normally distributed.

An analysis of prices is a good indicator of trends in the electricity market since they always reflect the effects of supply and demand shocks. Additionally, the evolution of the electricity generated by the different sources is relevant to isolate possible supply-induced effects. In this sense, Fig. 9 shows the trend in Spanish electricity generation from the four main renewable resources, i.e., wind energy, solar photovoltaic, solar thermal and hydropower (Fig. 9a), and from the three main non-renewable resources, i.e., nuclear, coal and combined cycle (Fig. 9b). According to Fig. 9, wind power, combined cycle, and nuclear were the three biggest sources in terms of output in the Spanish renewable technology mix during 2019 and 2020, followed by hydropower, solar photovoltaic, coal and solar thermal. Furthermore, Fig. 9a shows a rise in solar and hydropower production in 2020. This increment was particularly noticeable between November 2019 and March 2020 and the last quarter of 2020. In the case of hydropower, it is due to higher rainfall during that period, as the installed capacity remained unchanged; whereas in the case of solar PV, it is due to the installation of an additional 6,947 MWh between 2019 and 2020 (REE, 2020b). Similarly, Fig. 9b shows that combined cycle production in 2020 was lower than in 2019, indicating the substitution of combined cycle technologies by hydropower, given that both technologies tend to be marginal in the electricity market and there is a substitution effect. Concerning the other non-renewable resources, nuclear production remained steady, and there was a declining trend for the generation based on coal.

Indeed, Fig. 9 visually illustrates that renewable output was higher overall in 2020 than in 2019. The quantification is presented in Fig. 10, which shows that all renewable resources but solar thermal increased their production in 2020 from the previous year (i.e., 65.39% solar photovoltaic, 23.92% hydropower and 1.22% wind power). Nevertheless, most non-renewable technologies decreased their participation in the electricity spot market (i.e., 60.38% coal and 20.31% combined cycle).

The rise in the participation of renewable electricity in the technology mix observed in this section suggests that electricity prices could have been lower in 2020 due to the presence of green sources (not even considering the possible Covid-19 effect). In this sense, the synthetic bidding approach will be useful for isolating the simultaneous effects of the different anti-Covid-19 policies and higher intermittent renewable output. Furthermore, although these policies are not directly aimed at reducing electricity (but do so given the induced decrease in demand), they could lead to substantial drops in price if renewable production levels were higher (additive effect).

## 5. Results and discussion

This section outlines and discusses the effects of different policies to combat Covid-19 on the Spanish electricity market. Subsection 5.1 analyses how the shape (i.e., position and slope) of the demand and supply curves changed before and after the onset of the pandemic. Subsection 5.2 calculates synthetic equilibrium prices for electricity and breaks price changes into demand- and supply-induced effects. The combination of these two analyses provides a comprehensive picture to understand the changes in the Spanish electricity market between 2019 and 2020.

### *5.1. Quantitative analysis of the supply and demand curves*

When analysing supply and demand curves in any electricity market, both position and shape (i.e., slope) are key elements. Concerning the position, the horizontal segments of both supply and demand curves provide insight into the effects of shocks, as shown in Table 3. In particular, the length of the horizontal part of the demand curve provides information about electricity demand from households and small businesses. The longer this segment is, the greater demand from these consumers is. In this sense, given that electricity markets are generally characterized by very inelastic demand, meaning that the demand curve is almost vertical in many cases, the horizontal segment of the demand curve is a key determinant in the final effect of any shock on the electricity market.

On the other hand, the horizontal part of the supply curve also

**Table 2**
Descriptive statistics for the electricity market in 2019 and 2020 [EUR/MWh].

| | Mean | | Median | | Min | | Max | | Std.Dev. | | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 |
| January | 62.0 | 41.1 | 62.5 | 39.5 | 44.0 | 29.8 | 69.4 | 54.0 | 4.7 | 5.2 | −1.8 | 0.7 | 8.2 | 3.6 |
| February | 54.0 | 35.9 | 55.0 | 37.8 | 37.7 | 16.6 | 61.5 | 44.3 | 5.9 | 6.2 | −1.4 | −1.2 | 5.0 | 4.4 |
| March | 48.8 | 27.7 | 50.8 | 27.7 | 34.8 | 14.2 | 55.7 | 38.8 | 5.5 | 5.7 | −1.0 | −0.1 | 3.0 | 2.9 |
| April | 50.4 | 17.7 | 52.8 | 18.2 | 29.7 | 7.5 | 58.8 | 26.2 | 7.8 | 5.4 | −1.2 | −0.4 | 3.7 | 2.0 |
| May | 48.4 | 21.3 | 49.0 | 22.2 | 33.9 | 4.6 | 58.0 | 33.1 | 5.9 | 6.7 | −0.6 | −0.4 | 3.0 | 2.6 |
| June | 47.2 | 30.6 | 46.7 | 30.9 | 41.6 | 19.6 | 53.4 | 39.4 | 2.8 | 5.4 | 0.4 | −0.4 | 3.1 | 2.4 |
| July | 51.5 | 34.6 | 51.5 | 34.9 | 45.6 | 25.9 | 57.1 | 42.1 | 3.0 | 4.3 | −0.1 | −0.1 | 2.3 | 2.2 |
| August | 45.0 | 36.2 | 44.0 | 36.6 | 38.9 | 28.6 | 51.2 | 46.3 | 3.8 | 4.0 | 0.1 | 0.0 | 1.7 | 3.0 |
| September | 42.1 | 42.0 | 42.5 | 43.7 | 32.9 | 24.7 | 50.6 | 51.1 | 5.5 | 7.0 | 0.1 | −1.0 | 1.8 | 3.2 |
| October | 47.2 | 36.6 | 47.1 | 39.3 | 38.0 | 14.4 | 54.3 | 45.2 | 4.3 | 8.5 | −0.1 | −1.4 | 2.5 | 4.2 |
| November | 42.2 | 42.0 | 42.7 | 42.5 | 18.9 | 24.1 | 57.9 | 52.6 | 8.7 | 6.9 | −0.5 | −0.7 | 3.5 | 3.3 |
| December | 33.8 | 42.0 | 38.3 | 44.3 | 1.9 | 16.0 | 54.0 | 56.9 | 13.3 | 9.3 | −0.8 | −1.2 | 3.0 | 4.1 |
| **Total** | **47.7** | **34.0** | **48.3** | **35.6** | **1.9** | **4.6** | **69.4** | **56.9** | **9.3** | **10.0** | **−1.0** | **−0.5** | **6.3** | **2.7** |

Source: Own work based on data from Operador del Mercado Ibérico de ElectricidadOMIE (2022).

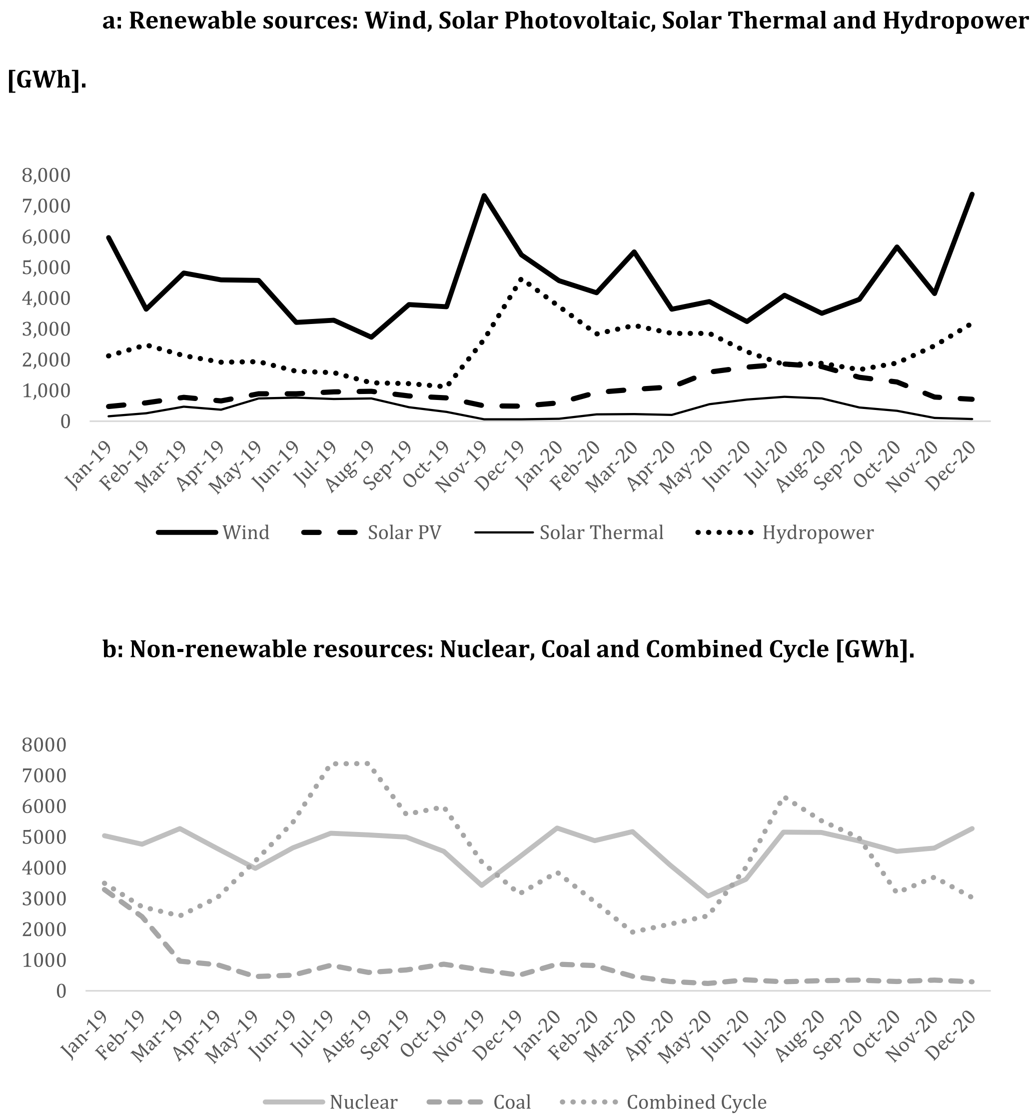


**Fig. 9.** Trend in monthly electricity generation [GWh].Source: Own work based on data fromREE (2020c). a: Renewable sources: Wind, Solar Photovoltaic, Solar Thermal and Hydropower [GWh].b: Non-renewable resources: Nuclear, Coal and Combined Cycle [GWh].

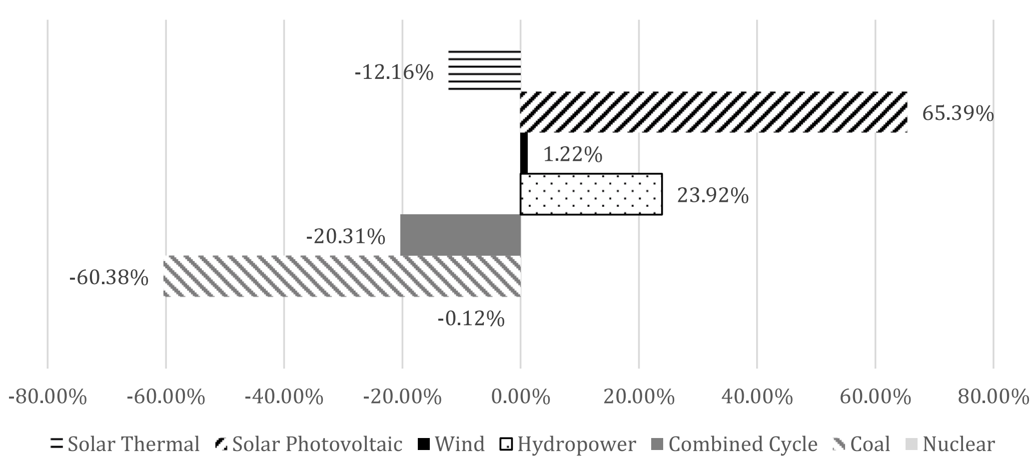


**Fig. 10.** Change in electricity production between 2019 and 2020 [%].
Source: Own work based on data from REE (2020c).

**Table 3**
Horizontal sections of the demand and supply curves [TWh].

| | Phase | 2019 | 2020 | $\Delta_{19\text{-}20}$ |
|---|---|---|---|---|
| **Demand** | Total lockdown | 11.92 | 11.07 | **−7.1%** |
| | De-escalation | 12.25 | 12.00 | −2.0% |
| | Mobility subject to restrictions | 12.79 | 12.15 | −5.0% |
| **Supply** | Total lockdown | 11.95 | 12.55 | 5.0% |
| | De-escalation | 11.22 | 11.78 | 5.0% |
| | Mobility subject to restrictions | 10.27 | 11.99 | **16.7%** |

Note: A representative month for each regulatory period is used: (i) April 2020 for the lockdown policy period; (ii) June 2020 for de-escalation; and (iii) October 2020 for mobility subject to restrictions. The pre-Covid-19 periods are the equivalent months of the year 2019.
Source: Own work based on data from OMIE (2022b).

informs about the amount of electricity produced at zero price, mainly from renewable resources. The longer this segment is, the higher the share of renewables is. Conventional technologies (i.e., coal, combined cycle and nuclear) also bid part of their energy at zero price, independently of fuel prices, as they are interested in selling a positive amount at any price. This situation is due to start-up costs since it is not profitable to stop production in one period and start up again in the next. Therefore, the amount bid at zero price is relatively stable for them, and most variations in the horizontal segment come from renewable resources, which are the technologies that bid most of their energy in that segment.

As shown in Table 3, electricity demand fell after the onset of the pandemic (2020) by between 2% (during de-escalation) and 7.1% (during lockdown). However, supply was consistently higher in 2020: 5% up in the lockdown and de-escalation phases and 16.7% up in the restricted mobility phase. This increase could be due to a 65.3% increase in solar photovoltaic generation and a 23.8% increase in hydropower, according to data provided by REE (2020b). In the case of solar photovoltaic energy, one of the possible reasons for this substantial rise could be the 33.4% increase in capacity installed in the system in the previous year (REE, 2020b), but wind speed, ambient temperature and incident radiation should also be considered.[11]

Regarding the slope, Table 4 estimates the parameters for the supply and demand curves following a cubic approach. Linear and quadratic regressions were also conducted, and the best fit was found for the cubic approach for all the analysed periods.[12]

All the parameters are statistically significant at the 1% level in the three approaches, and the adjusted $R^2$ of the cubic fit is always greater than 95%, whereas the minimum with the linear approach is around 84% and under the quadratic fit around 94%. RMSE and MAE measures have also been computed, and the lowest values are always found for the cubic approach: Between 2.90 and 5.00 for demand and in the range of 1.42–3.80 for supply for MAE; and between 4.07 and 6.64 for demand and the range of 2.67–4.63 for supply for RMSE.

The worst fit in terms of the adjusted $R^2$ is that of the demand curve for April 2020 (adjusted $R^2 = 95.29\%$), which is also the worst in the linear and quadratic approaches in terms of adjusted $R^2$, MAE and RMSE. It is apparent that the strict lockdown policies in April 2020 led to a change in the demand distribution based on the comparison to any other period in the sample. Concerning the rest of the analysed periods, the fit improves in the three approaches (i.e., linear, quadratic and cubic), even for the post-Covid-19-onset months under less strict policies (adjusted $R^2$ higher than 97% in the cubic and quadratic approaches and higher than 92% in the linear approach). In June 2020, when the economy was opening up, the fit was slightly worse than during the same month in 2019 for the three regressions. However, in October 2020, the fit is always better than in the same month before the pandemic. A look at the estimated parameters in the cubic regression for the demand curve reveals a different pattern in the shape of the demand curve before and after the pandemic, particularly in April 2020. Indeed, demand became more inelastic because of anti-Covid-19 policies (see Fig. 11b).

In this sense, it should be noted that the data presented in Table 3 indicated a decrease in the horizontal part of the demand curve of 7.1% in April 2020 relative to the previous year, the biggest decrease in the whole period analysed. Therefore, according to the findings in Tables 3 and 4, it is clear that strict lockdown policies in April 2020 induced a demand change that affected both the shape and position of the demand curve. In particular, we see the effects on industrial demand due to the slope change and residential demand due to the change in the length of the horizontal segment. This is because consumers who have the possibility to adapt their consumption to market prices (e.g., some industrial consumers) are located on the sloping side of the demand curve. Conversely, to ensure that less elastic consumers (e.g., residential and service sector) are supplied, their demand is placed on the horizontal segment (i.e., bidding at the maximum price).

Concerning supply, the cubic fit is, again, the best approach for the entire sample (adjusted $R^2$ higher than 96%, whereas for the linear and quadratic approaches, the minimum is 85%). This result is relevant given that the linear approach for supply and demand curves is still widespread in the literature, including Green (1996), Baldick et al. (2004), Acemoglu et al. (2017), and Benatia (2022). This finding thus indicates that higher degree polynomial fits should also be considered.

Additionally, Table 4 shows that the estimated parameters for the supply fit do not follow such a clear pre- and post-pandemic pattern. It is true that the shape of the supply curve also seems to change during the period analysed; however, no slope change seems to be found because of the Covid-19 pandemic since it was a demand crisis rather than a supply one. A look at the slopes for April, June and October 2020 suggests that the slope changes observed could be due to price variations in emission allowances and fossil fuels. In fact, according to SendeCO2 (2019, 2020) data, European emission allowances prices dropped by 22% in April 2020 and by 7.57% in June 2020, in the same month of the previous year. In this sense, the estimated parameters are the lowest absolute value for these two periods. Similarly, according to MIBGAS (2019, 2020), natural gas prices were 55.76% lower in April 2020 and 51.39% lower in June than in 2019. The lowest parameter change is between October 2019 and October 2020, indicating that supply curves looked similar, just when emission allowance and natural gas price changes were the lowest (1.97% increase and 3.26% increase compared to October 2019, respectively).

When a visual component is added to the previous analysis, Fig. 11 displays actual supply (solid black line) and demand (solid grey line) curves compared to their fits (dashed black line for supply and dashed grey line for demand) for April, October and June before and after the onset of Covid-19. According to the results in Table 4 and Appendix A, all the fits are cubic. Fig. 11 corroborates the findings reported in Table 4 concerning the impact of the lockdown policies and other energy markets. Indeed, the actual demand curve for April 2020 is closer to a vertical line, which indicates that the lockdown policies in force at that time eliminated much of the elasticity of demand and restricted it mostly to essential uses. However, supply curves seem to have become flatter in 2020, independently of the lockdown degree.

Thus, the policies implemented to combat the pandemic induced a demand change, but the effect on supply is not that clear. In this sense, what about equilibrium prices? Table 5 shows electricity prices calculated using the market algorithm by Ciarreta et al. (2014). In general, prices are lower in 2020, particularly during the lockdown phase (85% lower than the equivalent month of the previous year). The price decrease is stable at 44% for the de-escalation and restricted mobility phases.

Given that prior results showed that demand was strongly affected by

[11] The author thanks one anonymous referee for this clarification.
[12] Detailed results for the linear and quadratic approaches can be found in Appendix A. Fourth degree polynomial regressions were also computed, but they do not fit the data (results available upon request).

**Table 4**
Cubic fit for supply and demand curves.

| | Demand | | | | | |
|---|---|---|---|---|---|---|
| | Pre-Covid-19 | | | Post-Covid-19-onset | | |
| | April 2019 | June 2019 | October 2019 | April 2020 | June 2020 | October 2020 |
| Constant | 1351.15 | 963.84 | 1299.50 | −713.32 | 30.09 | −151.81 |
| 1st-degree parameter | −205.04 | −126.26 | −175.85 | 220.68 | 54.68 | 77.57 |
| 2nd-degree parameter | 11.22 | 6.10 | 8.52 | −18.08 | −5.55 | −6.19 |
| 3rd-degree parameter | −0.21 | −0.11 | −0.14 | 0.45 | 0.14 | 0.14 |
| RMSE | 4.07 | 5.03 | 6.64 | 5.85 | 5.66 | 4.86 |
| MAE | 2.90 | 3.42 | 5.00 | 3.80 | 3.63 | 3.34 |
| Adjusted $R^2$ | 98.50% | 97.58% | 96.98% | 95.29% | 97.28% | 97.95% |
| | **Supply** | | | | | |
| | Pre-Covid-19 | | | Post-Covid-19-onset | | |
| | April 2019 | June 2019 | October 2019 | April 2020 | June 2020 | October 2020 |
| Constant | −544.91 | −530.06 | −435.15 | −303.69 | −413.93 | −450.51 |
| 1st-degree parameter | 61.93 | 65.28 | 53.98 | 34.66 | 51.14 | 53.66 |
| 2nd-degree parameter | −2.16 | −2.49 | −2.05 | −1.26 | −2.00 | −2.04 |
| 3rd-degree parameter | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 |
| RMSE | 2.67 | 4.63 | 4.60 | 3.82 | 4.59 | 4.63 |
| MAE | 1.42 | 3.19 | 3.09 | 2.63 | 3.68 | 3.80 |
| Adjusted $R^2$ | 96.51% | 96.39% | 97.00% | 96.97% | 96.26% | 97.14% |

Note: The fitted supply and demand curves are computed as price = constant + 1st-degree parameter * quantity + 2nd-degree parameter * quantity$^2$ + 3rd-degree parameter * quantity$^3$+ error. All parameters are statistically significant at the 1% level. A representative month for each regulatory period is used: (i) April 2020 for the lockdown policy period; (ii) June 2020 for de-escalation; and (iii) October 2020 for mobility subject to restrictions. The pre-Covid-19 periods are the equivalent months of 2019.
Source: Own work based on data from OMIE (2022b).

anti-Covid-19 policies, the downward pressure on prices during the period analysed might be thought not to be due to Covid-19 alone, with supply factors also playing a role. However, it is not possible to determine which effect dominates with this analysis. Therefore, the synthetic bidding approach presented in the next section helps to analyse this hypothesis in more depth.

### *5.2. Synthetic bidding approach*

Using the synthetic bidding approach, Table 6 shows different combinations of actual and synthetic prices to isolate the demand and supply effects on the changes in electricity prices after the onset of Covid-19. In the case of actual prices (i.e., $p_1$ and $p_2$), $p_1$ stands for the electricity price at the intersection of 2019 demand and supply (i.e., the actual price for 2019, pre-Covid-19), and $p_2$ is the price at the intersection of 2020 demand and supply (i.e., the actual price for 2020, post-Covid-19-onset). As regards synthetic prices (i.e., $p_3$ and $p_4$), $p_3$ stands for the electricity price at the intersection of 2020 demand and 2019 supply and $p_4$ stands for the price at the intersection of 2019 demand and 2020 supply (recall Fig. 8). Therefore, the differences between actual electricity prices before and after the onset of the pandemic (i.e., $p_1 - p_2$) could be decomposed into differences induced by demand changes (i.e., $p_1 - p_3$) and supply changes (i.e., $p_3$ - $p_2$), thus meaning that the dominant effect can be observed. A parallel analysis could be conducted using $p_2$ and $p_4$ instead, where the supply changes are calculated as the price difference $p_1$ - $p_4$ and demand changes as $p_4$ - $p_2$.

As shown in Table 6, prices could have been 10 EUR/MWh instead of 5 EUR/MWh in April 2020, during the strictest lockdown, if supply had followed the same curve as in 2019, where there was less renewable output and fossil fuel prices, and emission allowances prices were relatively higher. Thus, the pandemic and the associated lockdown policies would not have drastically reduced electricity prices if other supply-induced factors had not been favourable. Indeed, prices could have been 12.69 EUR/MWh in April 2020 (instead of 5 EUR/MWh) without Covid-19. That is, the change in the supply curve at pre-pandemic demand levels would have reduced prices by less than Covid-19 itself did. This effect can also be seen during the de-escalation and the restricted mobility phases: Covid-19 and other supply-induced factors in 2020 brought prices down; however, the Covid-19 effect dominated. Furthermore, the Covid-19 effect was greater when lockdown policies were stricter.

By breaking the price change between 2019 and 2020 down into the sum of different price combinations, i.e., $p_1 - p_2 = (p_1 - p_3) + (p_3 - p_2)$, the demand effect $p_1 - p_3$ is found to account for 82% of the price change in the lockdown phase, 71% in the de-escalation phase and just 41% in the restricted mobility phase. The supply effect only exceeds the demand effect in the restricted mobility phase, when economic activity was returning to pre-pandemic levels, and the share of renewables was high (i.e., two simultaneous effects that drive electricity prices down). By contrast, the other possible decomposition, i.e., $p_1 - p_2 = (p_1 - p_4) + (p_4 - p_2)$, reveals that the demand effect $p_4 - p_2$ accounts for 27% of the price change in the lockdown phase, 35% in the de-escalation phase and 67% in the restricted mobility phase. In this case, the effect is the opposite: The supply effect exceeds the demand effect in the lockdown and de-escalation phases.

Therefore, the lockdown policy would have reduced electricity prices by 73% under constant demand, whereas the reduction would have been 82% under constant supply. When demand and supply change simultaneously, the two effects are not additive because an interaction effect depends on the slopes of supply and demand, which changed from 2019 to 2020. If the shift in the curves were parallel (i.e., no slope change), the interaction effect would disappear, and the result using $p_3$ and $p_4$ would be equivalent. In any case, comparing the two results shows that changing demand had more impact on prices and that this effect decreased as lockdown measures were relaxed.

## 6. Conclusion and policy implications

Electricity prices are at the heart of policy debate and the energy economics literature worldwide, as they fluctuate according to shocks, and their evolution affects all economic actors. In addition, the Covid-19 health and economic crises have also drawn the attention of governments, civil society and businesses, given the severity of the short- and long-term economic consequences. This paper analyses these two issues jointly and concludes that Covid-19 had a substantial impact on electricity consumption and, thus, on prices; but that the effect depended

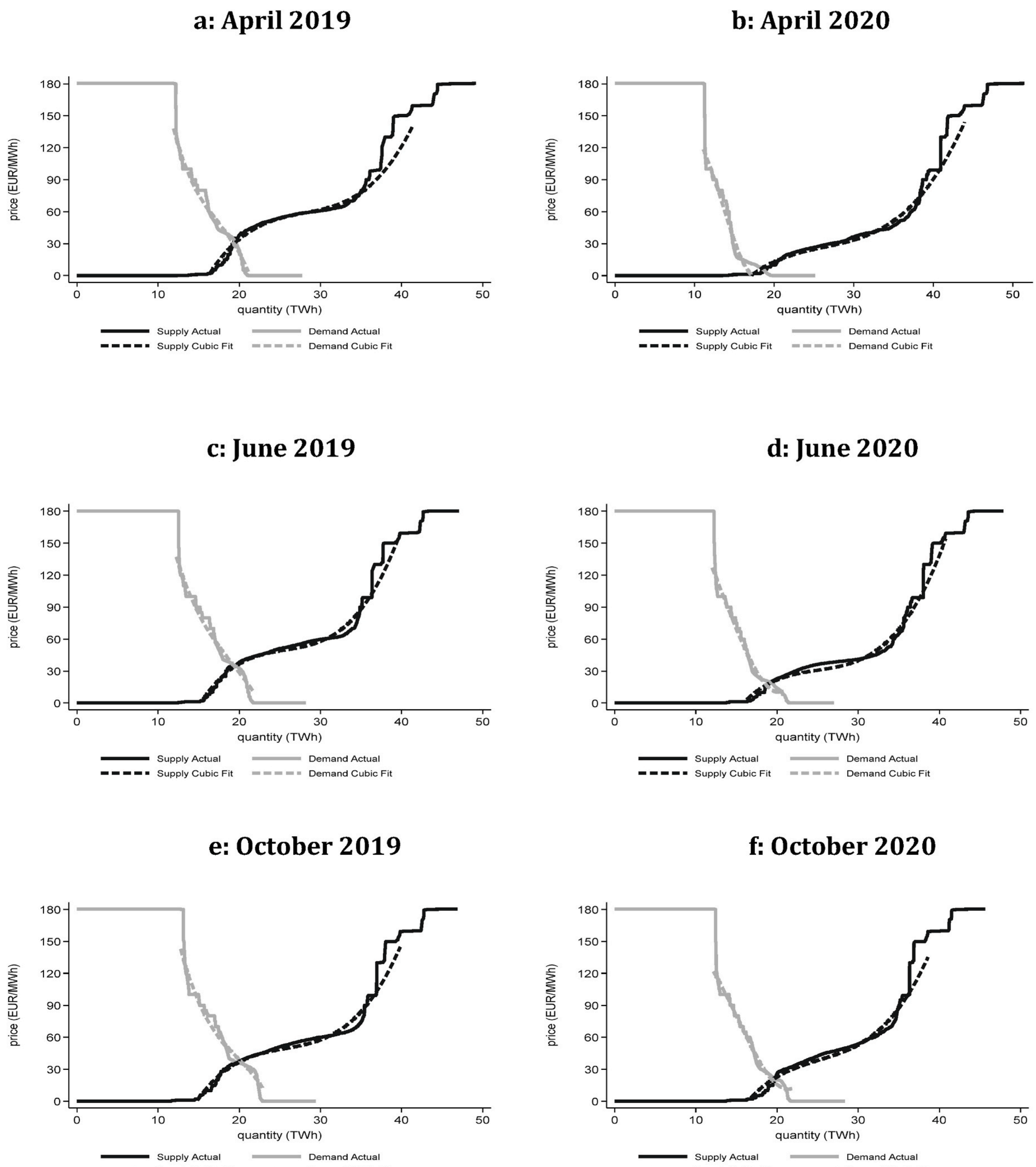


**Fig. 11.** Actual supply and demand curves vs. cubic fits [prices in EUR/MWh and quantities in TWh].
Source: Own work based on data from OMIE (2022b).
Note: April 2019 (panel a), June 2019 (panel c) and October 2019 (panel c) are pre-Covid-19 periods. April 2020 (panel b), June 2019 (panel d) and October 2019 (panel f) are post-Covid-19-onset periods.

**Table 5**
Actual price change by regulatory period [EUR/MWh].

| | Pre-Covid-19 | | | Post-Covid-19-onset | | | $\Delta_{lockdown}$ | $\Delta_{de\text{-}escalation}$ | $\Delta_{mobility\ subject\ to\ restrictions}$ |
|---|---|---|---|---|---|---|---|---|---|
| | April 2019 | June 2019 | October 2019 | April 2020 | June 2020 | October 2020 | | | |
| Actual prices | 33.30 | 35.07 | 36.59 | 5.00 | 19.50 | 20.38 | −85% | −44% | −44% |

Note: A representative month for each regulatory period is used: (i) April 2020 for the lockdown policy period; (ii) June 2020 for de-escalation; and (iii) October 2020 for mobility subject to restrictions. The pre-Covid-19 periods are the equivalent months of 2019.
Source: Own work based on data from OMIE (2022b).

**Table 6**
Actual prices versus synthetic prices [EUR/MWh].

| Policy | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_1$-$p_2$ | $p_1$-$p_3$ (%) | $p_3$-$p_2$ (%) | $p_1$-$p_4$ (%) | $p_4$-$p_2$ (%) |
|---|---|---|---|---|---|---|---|---|---|
| Lockdown | 33.30 | 5.00 | 10.00 | 12.69 | 28.30 | 82% | 18% | 73% | 27% |
| De-escalation | 35.07 | 19.50 | 24.00 | 25.00 | 15.57 | 71% | 29% | 65% | 35% |
| Mobility subject to restrictions | 36.59 | 20.38 | 29.99 | 31.30 | 16.21 | 41% | 59% | 33% | 67% |

Note: $p_1$ stands for the electricity price at the intersection of 2019 demand and supply (actual price for 2019); $p_2$ stands for that at the intersection of 2020 demand and supply (actual price for 2020); $p_3$ stands for the electricity price at the intersection of 2020 demand and 2019 supply (synthetic price); $p_4$ stands for that at the intersection of 2019 demand and 2020 supply (synthetic price). A representative month for each regulatory period is used: (i) April 2020 for the lockdown policy period; (ii) June 2020 for de-escalation; and (iii) October 2020 for mobility subject to restrictions. The pre-Covid-19 periods are the equivalent months of 2019.
Source: Own work based on data from OMIE (2022b).

mainly on the strictness of anti-Covid-19 policies and other supply factors, such as the amount of renewable electricity available, fossil fuel costs and emission allowance prices.

Actual supply and demand curves were built after the onset of the pandemic for three different anti-Covid-19 policies: i) total lockdown (April 2020); (ii) de-escalation (June 2020); and (iii) mobility subject to restrictions (October 2020). They were then compared to those for 2019, prior to the pandemic. The computation of polynomial fits for supply and demand curves probed that cubic estimates are the best proxy for analysing electricity prices in 2019 and 2020. However, the worst fit is always observed in April 2020, meaning that total lockdown policies changed the shape of the curve and reduced the price elasticity of electricity demand. Once the equilibrium prices were calculated, the conclusion is that electricity prices indeed decreased relative to the pre-pandemic period during all three phases, with the effect being strongest during the total lockdown phase and becoming stable during de-escalation and mobility subject to restrictions periods.

At this stage, it is thus clear that electricity prices decreased because of the demand-induced shock from the different policies to combat Covid-19. However, would the effect have been greater or lesser if exogenous conditions for supply had been different? A synthetic bidding approach allows synthetic equilibria to be calculated by combining supply and demand curves for different scenarios to answer this question. The main conclusion is that the total lockdown phase strongly affected electricity prices, but that effect diminished as the economy opened up again. Indeed, Covid-19 and other supply-induced effects (such as the greater presence of renewables and other changes in fossil fuel and emission prices) in 2020 both drove prices down, but the Covid-19 effect dominated. The Covid-19 effect was also stronger when lockdown policies were stricter.

All in all, the demand-side effect induced by Covid-19 was more influential than the supply-induced effects. However, as lockdown measures were relaxed and demand recovered its elasticity, supply-induced effects increased. Finally, an interaction effect is observed, given that the slopes of the supply and demand curves changed due to Covid-19 and other market conditions.

The focus of this paper is on demand; however, it has also been proven that supply also affects price formation. Its analysis is, thus, necessary to understand what supply factors could have been affecting the electricity market in 2020 that could have altered the effect caused by the change in demand due to Covid-19. The situation in 2020 was specific in Spain, with higher renewable participation and fossil fuel and emission prices reduced from the previous year. This fact is key to the results of this paper because, without these factors, the pandemic would not have caused electricity prices to drop to such an extent. Therefore, the effect of the pandemic on electricity prices could be overestimated if the supply-induced effects were not considered.

These results reflect the functioning of any electricity market under a major shock in the economy and how changes in consumer behaviour may affect it. The methodology used here could thus also be used outside the Covid-19 crisis perspective since it enables trends in future electricity markets facing a challenging energy transition with relevant demand-induced changes to be analysed (e.g., new mobility conditions due to climate change policies, high inflation or fossil fuel scarcity). Analyses such as this one also reflect the vulnerabilities of current electricity markets in the face of challenges such as increasing uncertainty due to intermittent renewable energy, decreasing share of fossil-fuel-based output and international geopolitical crises. Finally, these results also have substantial implications for utilities in terms of being able to forecast electricity price changes – and their persistence – in the face of future economic or policy shocks and investing in technologies that could help to minimize the associated adverse effects.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Cristina Pizarro-Irizar reports article publishing charges, travel, and writing assistance were provided by Basque Government. Cristina Pizarro-Irizar reports article publishing charges, travel, and writing assistance were provided by Spanish Ministry of Science Innovation and Universities. Cristina Pizarro-Irizar reports article publishing charges, travel, and writing assistance were provided by Spanish Minstry of Economy and Competitiveness.

## Data availability

Data will be made available on request.

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## Appendix A. Linear and quadratic fits for supply and demand curves

**Table A.1**
Linear fit for supply and demand curves.

| | Demand | | | | | |
|---|---|---|---|---|---|---|
| | Pre-Covid-19 | | | Post-Covid-19-onset | | |
| | April 2019 | June 2019 | October 2019 | April 2020 | June 2020 | October 2020 |
| Constant | 281.33 | 284.56 | 283.08 | 275.2 | 292.21 | 273.73 |
| Slope | −13.19 | −12.98 | −12.21 | −15.51 | −14.6 | −12.94 |
| RMSE | 5.82 | 6.66 | 9.55 | 10.22 | 8.58 | 7.04 |
| MAE | 4.48 | 4.49 | 7.40 | 7.19 | 5.91 | 4.90 |
| Adjusted $R^2$ | 96.70% | 95.60% | 93.60% | 83.90% | 92.10% | 95.30% |
| | **Supply** | | | | | |
| | Pre-Covid-19 | | | Post-Covid-19-onset | | |
| | April 2019 | June 2019 | October 2019 | April 2020 | June 2020 | October 2020 |
| Constant | −36.41 | −47.8 | −45.97 | −58.79 | −54.97 | −69.7 |
| Slope | 3.37 | 3.91 | 3.83 | 3.38 | 3.61 | 4.43 |
| RMSE | 6.75 | 9.37 | 9.04 | 7.95 | 10.31 | 8.73 |
| MAE | 4.12 | 7.03 | 6.69 | 4.87 | 7.39 | 6.73 |
| Adjusted $R^2$ | 85.20% | 89.40% | 91.20% | 88.80% | 85.70% | 92.20% |

Note: The fitted supply and demand curves are computed as price = constant + slope * quantity + error. All parameters are statistically significant at the 1% level. A representative month for each regulatory period is used: (i) April 2020 for the lockdown policy period; (ii) June 2020 for de-escalation; and (iii) October 2020 for mobility subject to restrictions. The pre-Covid-19 periods are the equivalent months of 2019.
Source: Own work based on data from OMIE (2022b).

**Table A.2**
Quadratic fit for supply and demand curves.

| | Demand | | | | | |
|---|---|---|---|---|---|---|
| | Pre-Covid-19 | | | Post-Covid-19-onset | | |
| | April 2019 | June 2019 | October 2019 | April 2020 | June 2020 | October 2020 |
| Constant | 447.3 | 476.5 | 525.07 | 751.25 | 614.32 | 471.73 |
| 1st-degree parameter | −34.2 | −36.76 | −40.68 | −79.46 | −55.47 | −37.18 |
| 2nd-degree parameter | 0.65 | 0.72 | 0.81 | 2.11 | 1.26 | 0.72 |
| RMSE | 4.47 | 5.14 | 6.91 | 7.26 | 5.96 | 5.19 |
| MAE | 3.17 | 3.34 | 4.91 | 5.02 | 4.12 | 3.84 |
| Adjusted $R^2$ | 98.19% | 97.48% | 96.73% | 93.93% | 97.08% | 97.65% |
| | **Supply** | | | | | |
| | Pre-Covid-19 | | | Post-Covid-19-onset | | |
| | April 2019 | June 2019 | October 2019 | April 2020 | June 2020 | October 2020 |
| Constant | −64.38 | 1.43 | −12.10 | 53.39 | 73.46 | 22.83 |
| 1st-degree parameter | 5.59 | −0.11 | 1.03 | −4.90 | −6.57 | −2.84 |
| 2nd-degree parameter | −0.04 | 0.07 | 0.05 | 0.14 | 0.19 | 0.13 |
| RMSE | 6.67 | 9.04 | 8.81 | 6.20 | 8.55 | 7.75 |
| MAE | 3.86 | 7.07 | 6.88 | 4.41 | 7.06 | 6.63 |
| Adjusted $R^2$ | 85.53% | 90.19% | 91.64% | 93.34% | 90.25% | 93.87% |

Note: The fitted supply and demand curves are computed as price = constant + 1st-degree parameter * quantity + 2nd-degree parameter * $quantity^2$ + error. All parameters are statistically significant at the 1% level. A representative month for each regulatory period is used: (i) April 2020 for the lockdown policy period; (ii) June 2020 for de-escalation; and (iii) October 2020 for mobility subject to restrictions. The pre-Covid-19 periods are the equivalent months of 2019.
Source: Own work based on data from OMIE (2022b).

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