Environmental and social sustainability

# Reaping the benefits of renewable energy in the Spanish economy

J. Julián Cubero, Pilar Más, Rafael Ortiz, Pep Ruíz

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## 1. Executive Summary

The price in the Spanish wholesale electricity market has experienced a significant shift, moving from consistently exceeding the European median between 2018 and 2021 to falling below it since 2022. This change coincides with a notable increase in the share of renewable energy sources, particularly solar and wind, which have grown from accounting less than 40% of the total daily wholesale electricity market to 65%, a share level about ten points higher than the European average. In this context, critical questions arise about the impact of the growing contribution of renewables on electricity prices. Two in particular stand out: (i) does the increased weight of renewables, driven by their low marginal cost, contribute to lower market prices through the "merit-order effect"? and (ii) could this same effect pose challenges to the continued penetration of renewable energy in the market? This study analyses and answers these and other questions.

## 2. Main outcomes

- **Renewables help reduce electricity prices despite their reliance on weather conditions and the current lack of energy storage.** The relationship between the penetration of renewable energy sources and wholesale electricity prices is non-linear and negative, driven by the low marginal cost of clean technologies.
- **From 2021 to 2024, the notable 20-percentage point rise in renewable energy share, driven by solar** photovoltaic **(PV) and onshore wind, reduced Spain's wholesale electricity prices by nearly 20%** (12.5% from 2021-2023 and 7.5% in 2024).
- **Lower energy prices have reduced solar and wind unit revenues, especially for solar. However, there is no clear evidence that lower energy prices are deterring renewable investment** (a phenomenon referred to as "cannibalization").
- **Looking ahead, meeting the PNIEC[1] targets could reduce prices by a further 20%.[2]** While plausible, the objectives may seem optimistic over five years. Outstanding issues—such as storage and interconnections—and the required investment, both public and private, will be decisive in determining the ultimate realization of these ambitious goals.
- **Sustaining the growth in renewables also requires essential regulatory advancements and investment to position Spain as a leader in the energy transition, ensuring a more competitive, sustainable and resilient future.**

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[1]: See National Integrated Energy and Climate Plan for Spain. Renewable target: 80% of total electricity generation by 2030.

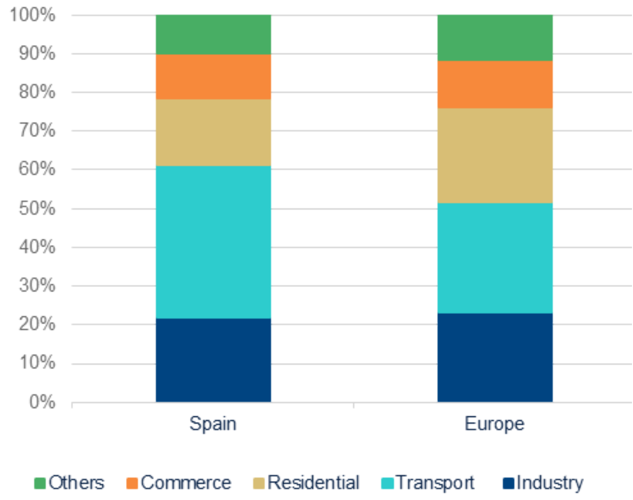
[2]: It is noteworthy that the estimate depends on the econometric model detailed in the document, and on the absence of significant changes in omitted variables, such as energy storage.

## 3. Energy consumption in Spain

**Spain's energy consumption is dominated by the transport, industry, and residential sectors.** In Spain, energy consumption in the transport, industrial and residential sectors accounted for almost 80% of the total final consumption in 2022, in line with the European structure. Total final consumption (TFC) is the energy consumed by end users such as individuals and businesses to heat and cool buildings, to run lights, devices, and appliances, and to power vehicles, machines and factories. It also includes non-energy uses of energy products, such as fossil fuels used to make chemicals. Some of the energy found in primary sources is lost when converting them to usable final products, especially electricity. As a result, the breakdown of final consumption can look very different from that of the primary energy supply although both are needed to fully understand the energy system.[3]

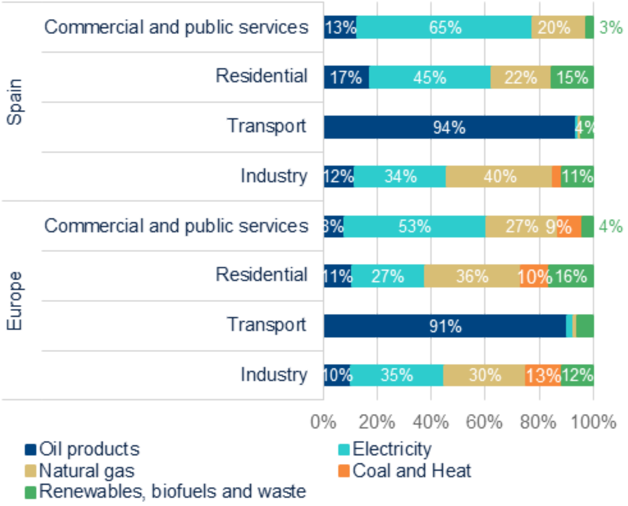
As can be seen in **Graph 1**, transport has a greater share of energy consumption in Spain than in Europe (more than 10 pp), while the residential and industrial sectors have a lower share in Spain. This difference is particularly significant as each sector relies on different energy sources. Transport largely consumes oil products, while the other sectors mainly use electricity, natural gas and coal—the latter primarily in industry and to a greater extent in Europe than in Spain (**Graph 2**).[4]

Graph 1. **TOTAL FINAL ENERGY CONSUMPTION (TFC) BY SECTOR.** 2022 (% OF TFC BY SECTOR) (*)



(*) Commerce includes commercial and public services.
Source: BBVA Research from IEA Data

Graph 2. **TOTAL FINAL ENERGY CONSUMPTION (TFC) BY SECTOR AND SOURCE.** 2022 (% OF TFC BY SECTOR) (*)



(*) Commerce includes commercial and public services.
Source: BBVA Research from IEA Data.

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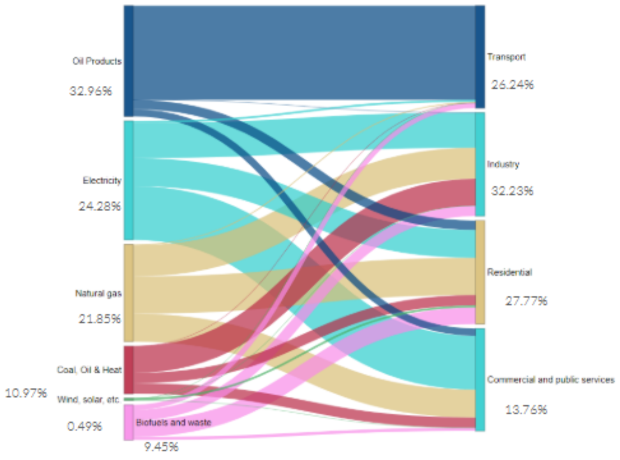
[3]: IEA.

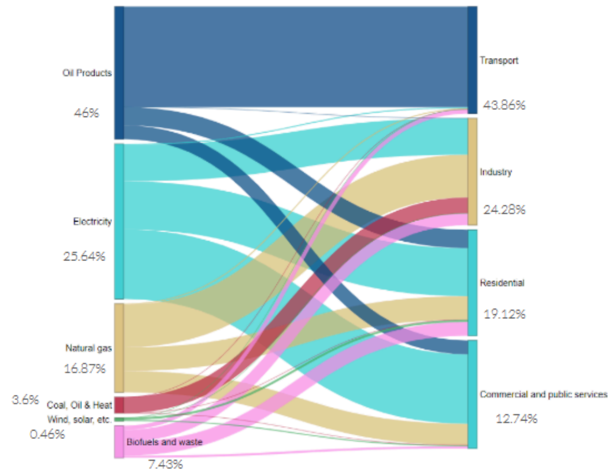
[4]: Definitions of energy sources in final consumption provided by IEA.

Graph 3. **EUROPE. TOTAL FINAL ENERGY CONSUMPTION BY SECTOR AND SOURCE.** 2022 (% OF TFC BY SECTOR) (*)



(*) Commerce includes commercial and public services.
Source: BBVA Research from IEA Data.

Graph 4. **SPAIN. TOTAL FINAL ENERGY CONSUMPTION BY SECTOR AND SOURCE.** 2022 (% OF TFC BY SECTOR) (*)



(*) Commerce includes commercial and public services.
Source: BBVA Research from IEA Data.

**Oil products[5] are prevalent in transport and electricity and natural gas in other sectors.** Oil products are the main source of energy in Spain and Europe, covering 46% and 33%, respectively, of the total final consumption in 2022.[6] This difference is mainly explained by the consumption of energy in the transport sector, highly intensive in oil products (**Graph 2**). Electricity is the second most significant energy source, covering around 25% of the total consumption in Spain and Europe, with broad applications across various sectors, ranging from residential to industry and commerce. The third energy source is natural gas, contributing around 17% in Spain and 22% in Europe and playing a pivotal role in industrial processes and electricity generation. Meanwhile, coal, crude oil[7] and heat[8] are consumed more extensively in Europe than in Spain. In contrast, wind, solar and other natural sources[9] are utilized more in Spain, particularly by the residential sector (**Graph 3 and Graph 4**).

**Spain's dependence on foreign gas is high and concentrated in a few countries.** The country's energy supply remains vulnerable due to heavy reliance on imported natural gas from a limited number of countries -Algeria, Nigeria, the United States, and Russia (**Graph 5**)- which could create difficulties in setting electricity prices, highly correlated with the gas price as it is illustrated in **Graph 6**. This relationship is largely driven by the marginalist structure of the wholesale electricity market, a common feature across most European countries. However, as shown in this study, **the growing share of renewables is helping to reduce the link between electricity and natural gas prices**.

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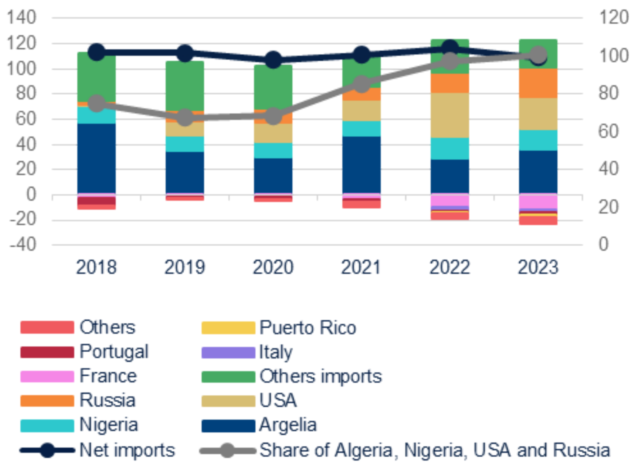
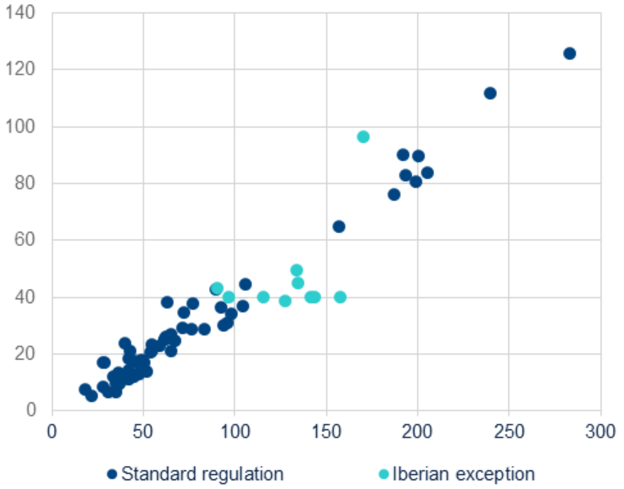
[5]: Oil products include refinery gas, ethane, LPG, aviation gasoline, motor gasoline, jet fuel, kerosene, gas/diesel oil, fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin waxes, petroleum coke and other oil products.
[6]: For these graphs and calculations it is assumed that no energy is consumed by sectors different than the one included in the graph.
[7]: Crude oil comprises crude oil, natural gas liquids, refinery feedstocks and additives as well as other hydrocarbons.
[8]: Energy consumed by end users (individuals and companies) to cook or heat buildings.
[9]: Wind, Solar, etc, are the natural sources of energy that are directly consumed as energy, such as solid biofuels (e.g. firewood, wood pellets), biogas, solar thermal energy from active systems and ambient heat captured by heat pumps. Electricity produced from renewable sources (e.g. hydro, wind, solar PV) is not included in this category, but rather in electricity.

Graph 5. **SPAIN. GAS SUPPLY FROM MAIN PARTNERS.** (UNIT OF EXPORT OR IMPORT PER UNIT OF GAS CONSUMPTION (%) (*)



(*) Gas consumption refers to gas used as raw material (non-energy use).
Source: BBVA Research from CORES data.

Graph 6. **WHOLESALE ELECTRICITY AND GAS PRICES.** (EUR/MWH. MONTHLY DATA, 2018-2023) (**)



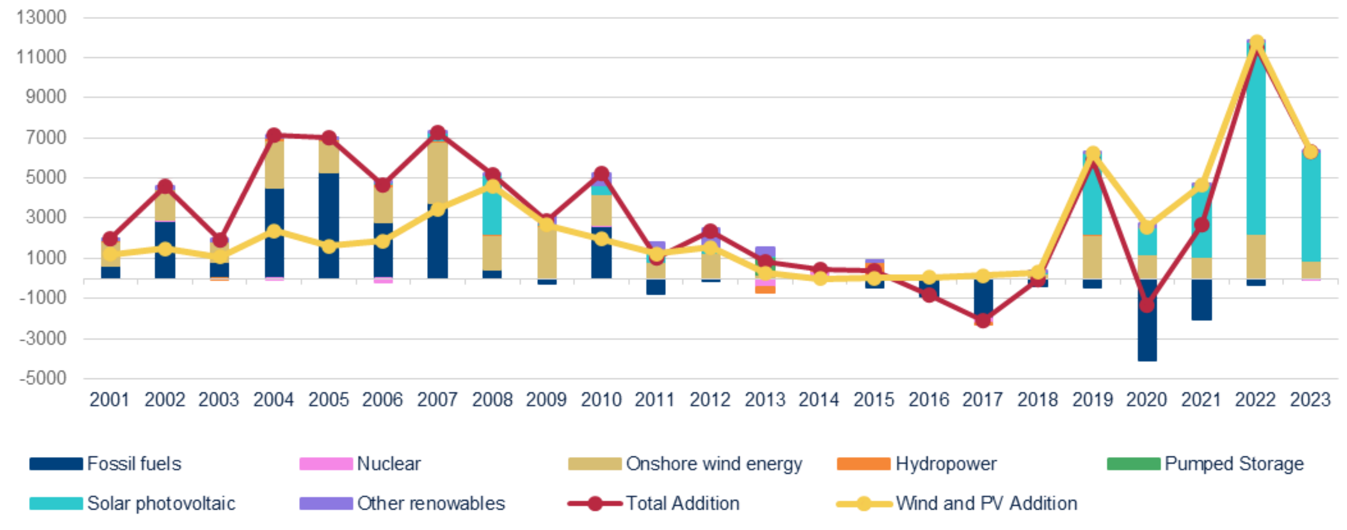
(**) For the Iberian exception, the price of gas used is the MIBGAS price if it is below the limit set by the government, and the limit if it is above.
Source: BBVA Research from OMIE and MIBGAS data.

# 4. Spain, a European leader in renewable energy sources

**Spain is advancing toward greater energy sovereignty through renewables.** Spain stands as a European and global leader in renewable energy, as evidenced by the latest published figures. In 2023, the share of renewables in total electricity generation exceeded 50% (51%, including hydropower), nearly 10 percentage points higher than the European average.

**The installed capacity of renewable energy is growing rapidly.** The installed capacity of renewables, defined as the maximum theoretical power output that a plant or energy system can produce under optimal conditions, has increased significantly in recent years, enabling a greater reliance on clean technologies for electricity generation. In 2000, Spain's installed electricity capacity was 54,000 MW, with renewable energy accounting for 38%, and by 2023 this capacity had increased to 129,000 MW, with renewables making up 65% of the total (**Graph A.1**). This rise in renewable capacity was largely driven by onshore wind power until 2018, after which solar photovoltaic (PV) became the leading contributor. Meanwhile, hydroelectric and pumped storage capacities have remained virtually unchanged. Thus, since the beginning of the century, different phases can be identified in the process of renewable energy penetration in Spain (see **Graph 7 and Box A**).

Graph 7. **GROWTH OF ENERGY INSTALLED CAPACITY IN SPAIN.** 2001-2023 (MW)



.Source: BBVA Research from CORES data.

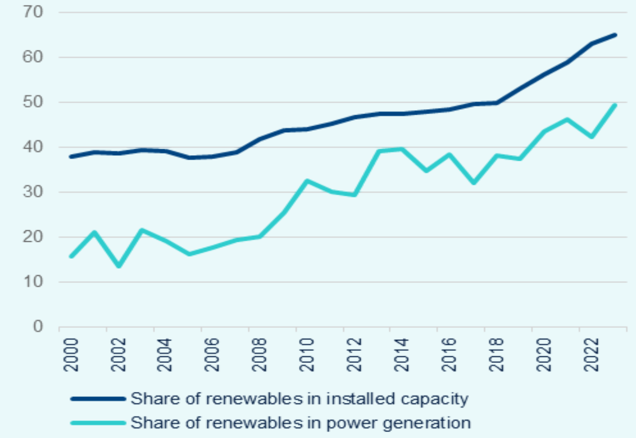
## Box A. Evolution of installed capacity of onshore wind and solar PV energy in Spain

In 2000 in Spain, less than 40% of the total installed capacity was renewable. This has changed in the last two decades with the emergence of two new technologies, which have had a huge gain in efficiency in the last two decades: **onshore wind and solar PV**.

Since the early 2000s, Spain's renewable energy development can be divided into three different phases (**Graphs 7 and A.2**). The first phase, spanning from 2000 to 2008, witnessed a significant expansion in the installed capacity of onshore wind energy. The second phase, between 2009 and 2018, was marked by minimal growth in renewable capacity, primarily due to the economic and financial crisis, as well as a temporary government-imposed moratorium on financing new renewable energy projects aimed at reducing the tariff deficit.[10] The third and final phase, covering the period 2019-2023, saw a dramatic doubling of renewable capacity, driven largely by solar PV, which experienced a fivefold increase in installed capacity. This rapid growth in solar energy can be attributed to several key factors: the allocation of 3.9 GW of new capacity in the July 2017 auction; advancements in technological competitiveness and significant reductions in production costs within the sector; the establishment of ambitious renewable energy targets by the EU; and the growing trend of self-consumption through solar panel installations.[11]

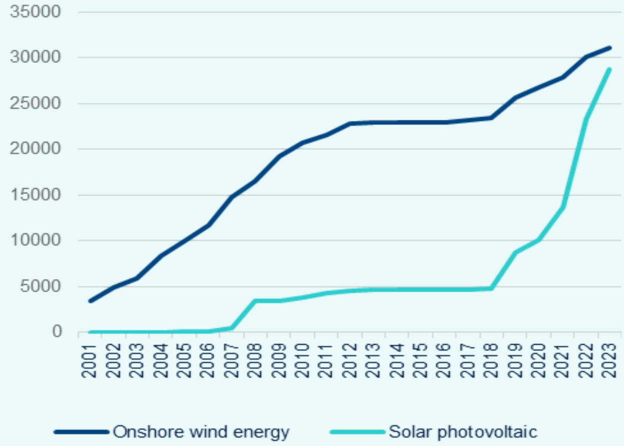
By 2023, renewables accounted for 65% of Spain's total installed electricity capacity, more than twenty percentage points higher than at the start of the century. Additionally, there has been a noticeable rebound in the share of clean technologies in total power generation (**Graph A.1**).

Graph A.1. **SPAIN. SHARE OF RENEWABLES IN TOTAL INSTALLED CAPACITY AND TOTAL POWER GENERATION** (%)



Source: BBVA Research from IRENA data.

Graph A.2. **SPAIN. INSTALLED CAPACITY OF ONSHORE WIND AND SOLAR PV** (MW)



Source: BBVA Research from IRENA data.

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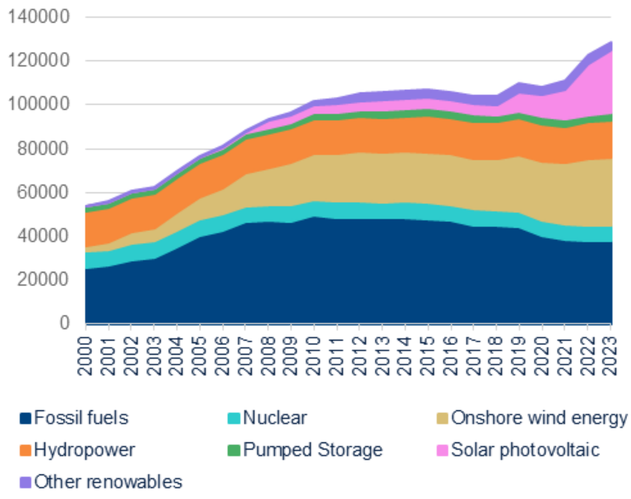
[10]: Royal Decree-Law 1/2012, January 27. This measure suspended remuneration pre-allocation procedures and economic incentives for new electricity production facilities using cogeneration, renewable energy sources, and waste.

[11] See Informe Anual Fotovoltaica 2024-UNEF.

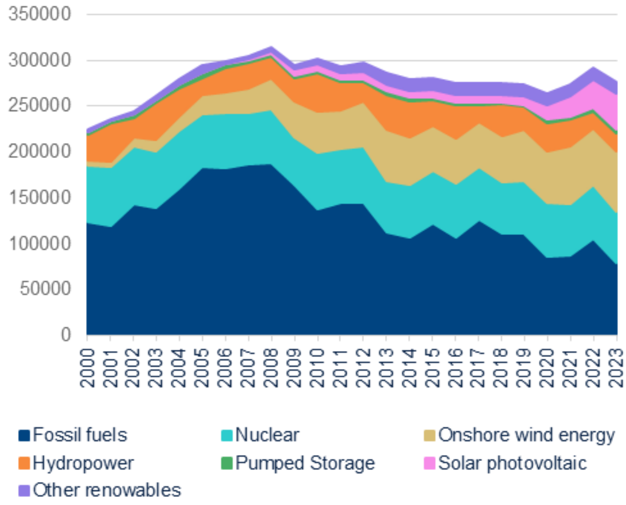
**The rapid growth in renewable capacity has significantly boosted the use of these energy sources, accounting for 51% of the total power generation in 2023.** Spain has transitioned from generating 17.2% of electricity from renewable sources in 2000 to exceeding 50% in 2023 (51.1% of the total 276,820 GWh generated). This growth has been accompanied by a notable decline in fossil fuel use, which has been reduced by half since 2008. A comparison of **Graphs 8 and 9** reveals that electricity generation from renewable sources has grown more slowly than their installed capacity, leaving a portion of the capacity underutilized. This disparity can be attributed, among other factors, to the intermittency of renewable energy sources -driven by their reliance on weather and climate conditions, such rain, wind, or sunlight- and the lack of storage infrastructures.

Graph 8. **SPAIN. ELECTRICITY CAPACITY BY SOURCE** (MW)



Source: BBVA Research with CORES data.

Graph 9. **SPAIN. ELECTRICITY MIX BY SOURCE**[12] (MW)



Source: BBVA Research from OMIE and MIBGAS data.

**The rise in renewables has been mainly driven by falling solar and wind power costs.** In the case of onshore wind energy, by 2010 the levelized cost of electricity (LCOE)[13] of new installations was $0.13/kWh in Spain, lower than in Germany and France but higher than in the U.S. and China. By 2023, this cost dropped to $0.035/kWh, below the United States. level but still higher than in China. For solar photovoltaic energy, the reduction in LCOE has been even more pronounced, decreasing from $0.36/kWh in 2010 to $0.04/kWh in 2023 in Spain. This trend is similar to that of other countries, with China and Spain recording the lowest costs among the analyzed economies. The reduction in LCOEs has been driven by technological advances, measures to promote green transition, and economies of scale for renewable technologies (**Graphs 10 and 11**). This competitiveness gain has made renewable energy more profitable, leading to an increase in their installed capacity, especially in solar PV.

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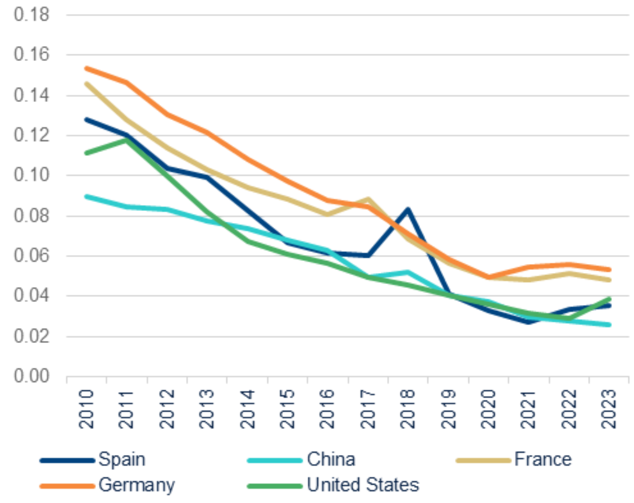
[12]: For the electricity generation in Spain in 2023 there is no available data from IRENA. Thus, we used the growth rates of Ember data.

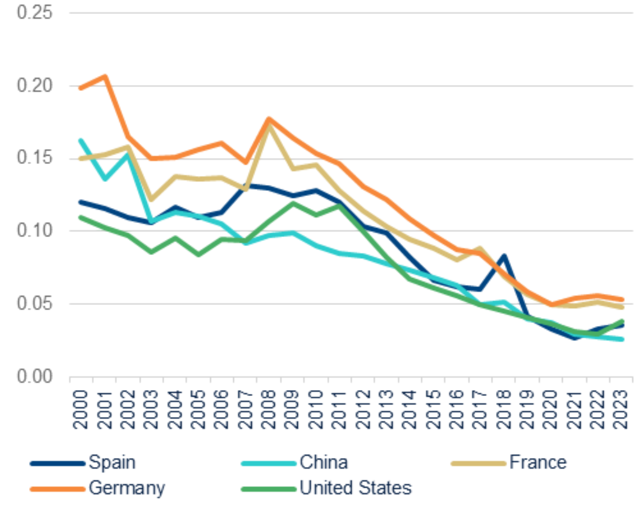
[13]: LCOE is the ratio between total costs and expected generation during the useful life of the installation, expressed in terms of present value. It represents the per-unit cost (typically expressed in currency per kilowatt-hour, such as $/kWh or €/kWh) of building and operating a generating plant over an assumed financial life and duty cycle.

Graph 10. **LEVELIZED COST OF ELECTRICITY OF NEW ONSHORE WIND** (2023 USD/KWH)



Source: BBVA Research from IRENA Renewable Power Generation Costs in 2023.

Graph 11. **LEVELIZED COST OF ELECTRICITY OF NEW SOLAR PV** (2023 USD/KWH)



Source: BBVA Research from IRENA Renewable Power Generation Costs in 2023.

## 5. The impact of renewables on wholesale electricity prices in Spain[14]

Established in 2007, the Iberian Electricity Market (MIBEL) is a joint initiative by Spain and Portugal aimed at integrating their wholesale electricity markets. It provides a unified framework to enhance efficiency, transparency, and competitiveness while facilitating the seamless cross-border flow of electricity. In Spain, MIBEL operates through two main entities: OMIE[15], the electricity market operator that manages the day-ahead and intraday electricity markets, and Red Eléctrica de España (REE)[16], the system operator that oversees electricity transmission and grid stability.

**The analysis has been focused on the Daily Market, where almost 90% of wholesale electricity prices are set.**[17] The Daily Market is the primary market where electricity transactions are scheduled for the next day. It operates as a marginalist market, where electricity prices are set based on the principle of marginal pricing. Producers, suppliers, and large consumers, submit their offers to sell or purchase electricity for the following day. These offers are ranked in ascending order of price for sellers and descending order for buyers, creating a supply and demand curve. The market clearing price, known as the marginal price, is set at the point where the supply and demand curves intersect. The marginal price is paid to all sellers and charged to all buyers for the traded electricity, regardless of their individual bids (**Box B**).

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[14] A recent IMF study (Chasing the Sun and Catching the Wind: Energy Transition and Electricity Prices in Europe. IMF, Nov-22) finds that renewable energy deployment in Europe is associated with a significant reduction in wholesale electricity prices. Specifically, for each one-percentage-point increase in the share of renewables, wholesale electricity prices drop by an average of 0.6 percent. The analysis also suggests that ramping up the renewables share in electricity generation—moving from a European average of 14 percent to 30 percent—would lower wholesale electricity prices by about 8.8 percent, and possibly by nearly 20 percent if solar and wind together reach 50 percent of the energy mix. The study notes a nonlinear effect, meaning that higher shares of renewables have an even greater price impact.

[15]: OMIE actively participates in connecting wholesale electricity markets in the EU, along with all of the NEMOs nominated in each member state.

[16]: https://www.ree.es/es.

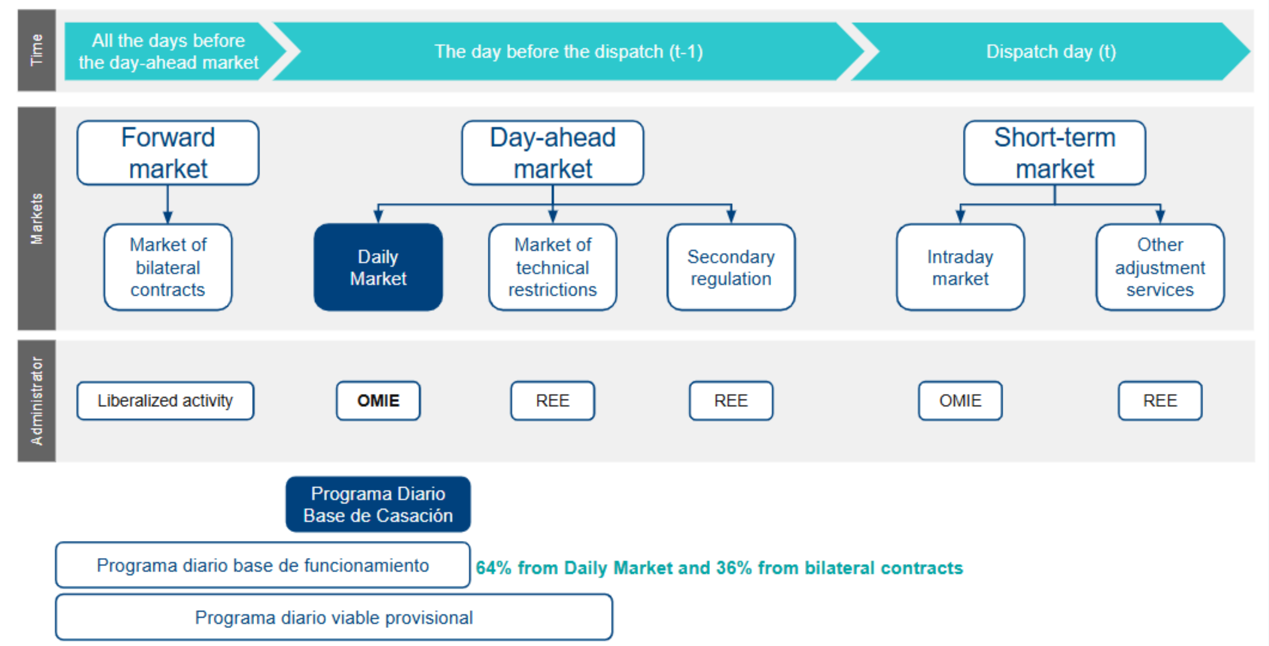
[17]: REData: Components of the final price and closure energy.

## Box B. The wholesale electricity market in Spain

The Spanish wholesale electricity market is a set of trading platforms on which electricity is contracted for delivery in different time horizons that can be forward or spot.[18] The price at which the electricity is sold to consumers depends on this transaction.

In the wholesale electricity market, prices are determined through a sequence of markets where generation and demand exchange energy and reserves for different maturities. The wholesale electricity market could be clustered in two main segments (**Graph B.1**): the forward market, a liberalized activity, and the spot market, a government-regulated activity managed by OMIE and REE, depending on the specific market. The main difference between these two markets lies in the price mechanism. In the forward market, prices are set through bilateral contracts, whereas in the spot market they are determined through a series of marginalist pricing systems designed to meet electricity demand while accounting for technical constraints. It is worth noting that between 2018 and 2023, 64% of wholesale electricity was traded through the spot market in Spain.[19]

Graph B.1. **SEQUENCE OF MARKETS IN THE IBERIAN MARKET OF ELECTRICITY** (MIBEL)



Source: BBVA Research following Energía y Sociedad.

On the Daily Market almost 90% of the wholesale electricity price is set. The results of the daily market auctions are published by OMIE in the "Programa Diario Base de Casación" (PDBC).

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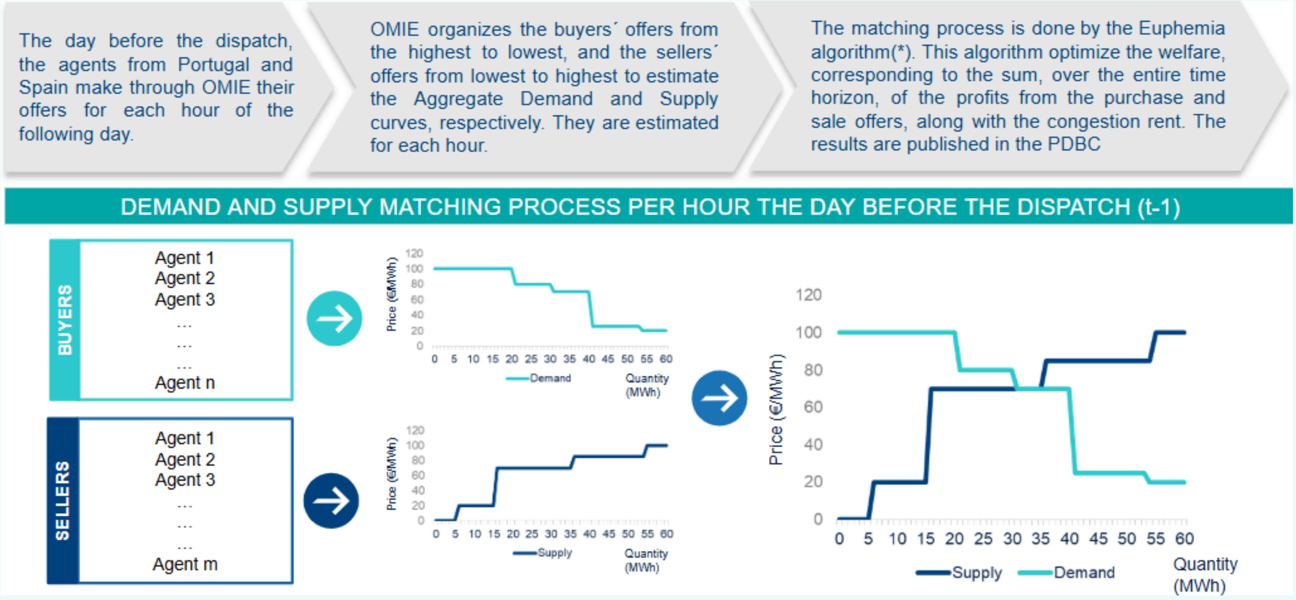
[18] : Formación de precios en el mercado mayorista diario de electricidad.

[19] : This estimation was done with the data of the "Programa Diario Base de Funcionamiento" (PDBF). In this program is included the information of all the electricity sold in the forward and the spot market for a certain hour.

Graph B.2. **THE FUNCTIONING OF THE DAILY MARKET OF OMIE IN THE IBERIAN MARKET**



The day before the dispatch, the agents from Portugal and Spain make through OMIE their offers for each hour of the following day.

OMIE organizes the buyers´ offers from the highest to lowest, and the sellers´ offers from lowest to highest to estimate the Aggregate Demand and Supply curves, respectively. They are estimated for each hour.

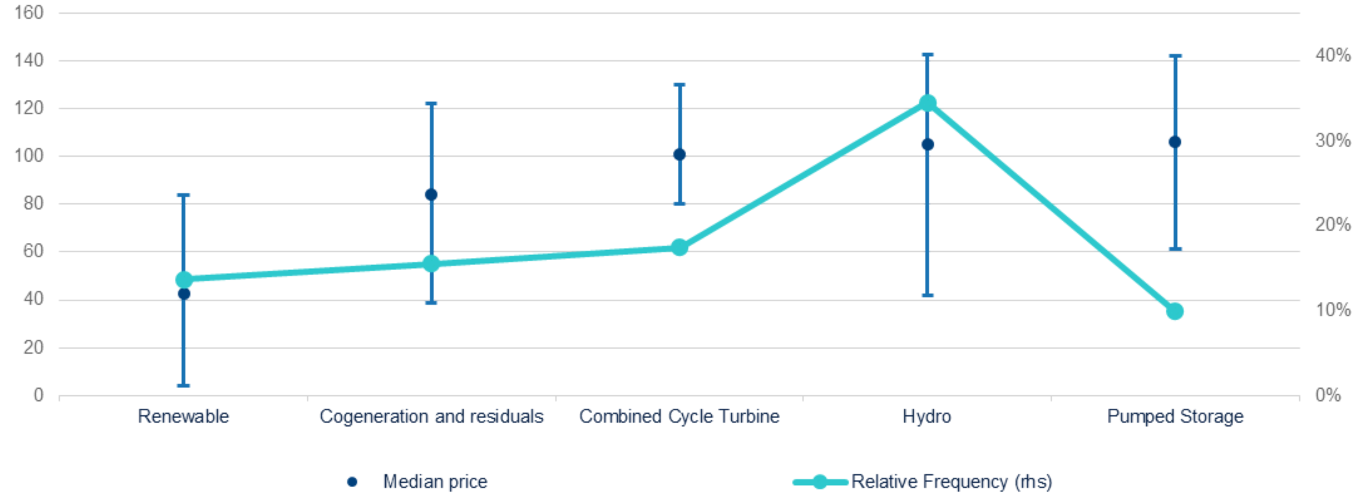
The matching process is done by the Euphemia algorithm(*). This algorithm optimize the welfare, corresponding to the sum, over the entire time horizon, of the profits from the purchase and sale offers, along with the congestion rent. The results are published in the PDBC

Source: BBVA Research following Energía y Sociedad. (*)The Euphemia algorithm is used by 23 European countries.

## What has been the impact of that share increase in the price of electricity?

**Renewables have helped to reduce electricity prices despite its weather dependence and limited storage.** The Daily Market operates on the principle of opportunity cost pricing. So, technologies capable of storing energy, such as hydro, pumped storage, or cogeneration, base their opportunity cost on the potential revenue from selling at a different time, often avoiding low-price periods. Conversely, non-storable technologies, such as renewables, rely on their marginal costs, which are typically very low or near zero. As shown in **Graph 12,** renewable energy prices ranged between €4/MWh and €84/MWh for 80% of the time in 2023, with a median price of €42/MWh —less than half the median price of storable technologies which averaged around €100/MWh. Among storables, hydro and pumped storage can sell at prices much lower than their median when surplus storage forces them to shed electricity, while combined cycle turbines (CC) act as a backup to cover unmet demand and have a narrower price range due to their reliance on natural gas, leading to a strong correlation between natural gas prices and those of wholesale electricity. **In 2023, the wholesale price of electricity was mainly set by hydro (almost 34%), followed by combined cycle (17%) and renewables, which set the price about 14% of the time**, given their dependence on weather and limited storage. However, there has been a notable increase in the share of renewables during the last years at the expense of combined cycle turbines, whose contribution has significantly been reduced.

Graph 12. **MARGINAL PRICES IN DAILY MARKET BY TECHNOLOGY.** 2023 (EUR/MWH AND %) (*)



(*) Due to data availability, to distinguish between renewable and cogeneration and residuals the following criteria has been used: "When the share of renewable is above 70% and the cogeneration and residuals below 15%, a renewable technology is considered as the marginal. In other cases, cogeneration and residuals are considered as the marginal technology". Intervals represent the 10th and 90th percentile, respectively.
Source: BBVA Research from OMIE data.

## Methodology

**A two-step approach has been used to quantify the impact of renewables on electricity prices.** As mentioned above, wholesale electricity prices are highly correlated with natural gas prices (**Graph 6**), a relationship explained by the marginalist price system of the Daily market. Technologies capable of deciding when to produce will try to sell electricity at prices close to that set by the combined cycle, so this can be used as a reference price.[20] This provides insight into how factors unrelated to the combined cycle are influencing wholesale electricity prices. To quantify the impact of renewable energy penetration on electricity prices, a two-step methodological approach has been used.

**First step: Expected electricity price based on traditional factors.** In Spain, the factors traditionally accounting for the majority of variations in wholesale electricity prices are the price of natural gas, the European Union Emissions Trading System (EU-ETS), and the Tax on the Value of Electricity Production (IVPEE[21]). These factors are directly tied to the operation of combined cycle power plants, which utilize them to generate electricity. Consequently, a regression model incorporating these variables as regressors can effectively estimate the hourly prices determined in the daily market when the combined cycle sets the marginal price. This relationship has been estimated using the following Ordinary Least Squares (OLS) regression (**Eq 1**):

$$P_{h,t,t-1} = \beta_0 + \beta_G * MIBGAS_{t,t-1} + \beta_{ETS} * ETS_{t,t-1} + \beta_{IVPEE,} * IVPEE_t + \varepsilon_{h,t,t-1} \qquad (Eq\ 1)$$

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[20]: The role of natural gas in setting electricity prices in Europe. Zakaria et al (2023). This paper shows the dependency of the wholesale electricity prices in natural gas and why it should be used as a reference point.
[21]: Impuesto sobre el valor de producción energética

Where **$P_{h,t, t-1}$** is the hourly one day-ahead wholesale electricity price; **$MIBGAS_{t, t-1}$** the one-day ahead MIBGAS price [22], **$ETS_{t,t-1}$** the one-day ahead EU-ETS price, **$IVPEE_t$** a dummy variable equal to 1 if IVPEEt= 7% and 0 if IVPEEt= 0%[23], and $\varepsilon_{h,t, t-1}$ the residuals.[24]

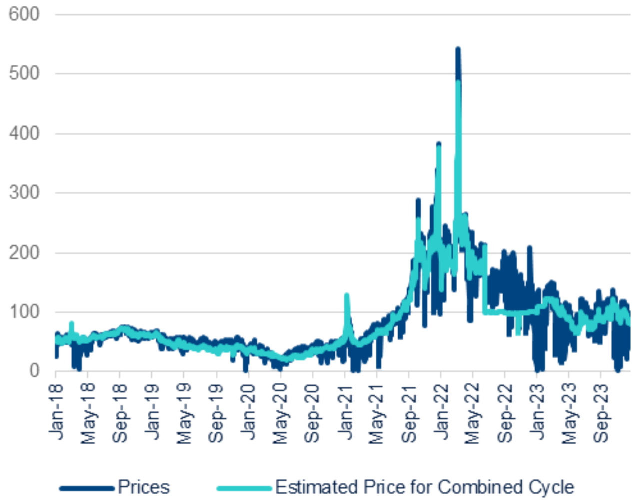
Regarding the interpretation of the regression parameters (**Table 1**), $\beta_G$ represents the amount of natural gas (in MWh) required to produce one MWh of electricity (2.104 MWh); $\beta_{ETS}$ corresponds to the CO2 emissions, measured in tons, generated to produce one MWh of electricity (0.134 tons of CO2/MWh); and $\beta_{IVPEE}$ is the marginal effect of an increase in the IVPEE tax rate, from 0% to 7% (€3.32/MWh). These three factors account for a significant part of the variation in the wholesale electricity prices set in the daily market, as illustrated in **Graph 13**. However, other factors captured in the residual term may also influence the electricity pricing mechanism. Using the light blue line as a reference, it becomes possible to determine whether these additional factors are driving electricity prices above or below the levels predicted by the traditional components.

Table 1. **ESTIMATED REGRESSION MODEL.** HOURLY DATA. 2018-2023 (*). OLS ESTIMATION

| | **One day ahead wholesale electricity** |
|---|---|
| (Intercept) | 4.75***<br>(0.44) |
| One day ahead MIBGAS | 2.104***<br>(0.0055) |
| One day ahead ETS | 0.134***<br>(0.006) |
| IVPE | 3.324***<br>(0.33) |
| **$R^2$** | **0.86** |

t statistic in parenthesis. *p<0.1, **p<0.05, ***p<0.01
(*) The period June-December 2022 was excluded due to the Iberian Exception effect together with a greater influence of coal on the marginal price.
Source: BBVA Research from IEA Data.

Graph 13. **DAILY WHOLESALE ELECTRICITY PRICES AND ESTIMATED PRICES BASED ON TRADITIONAL FACTORS.** EUR/MWH



Source: BBVA Research from IEA Data.

**Second step: A residual quantile regression was conducted to estimate the potential contribution of renewables to reducing electricity prices.** The deviations of the residuals from the initial regression, relative to the expected price based on traditional determinants, can be attributed to various factors. These include demand, the efficiency of the marginal price-setting technology, electricity market competitiveness, or changes in the technologies setting the marginal price -particularly renewable energy sources, whose penetration in the electricity mix has been steadily increasing, as highlighted earlier in this document. In this second stage, the impact of

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[22]: The one day ahead MIBGAS price is substituted by the limit set by the government during the Iberian exception when it is above that limit (June 2022 to March 2023)

[23]: Impuesto sobre el valor de producción energética (Tax over the value of the energy production).

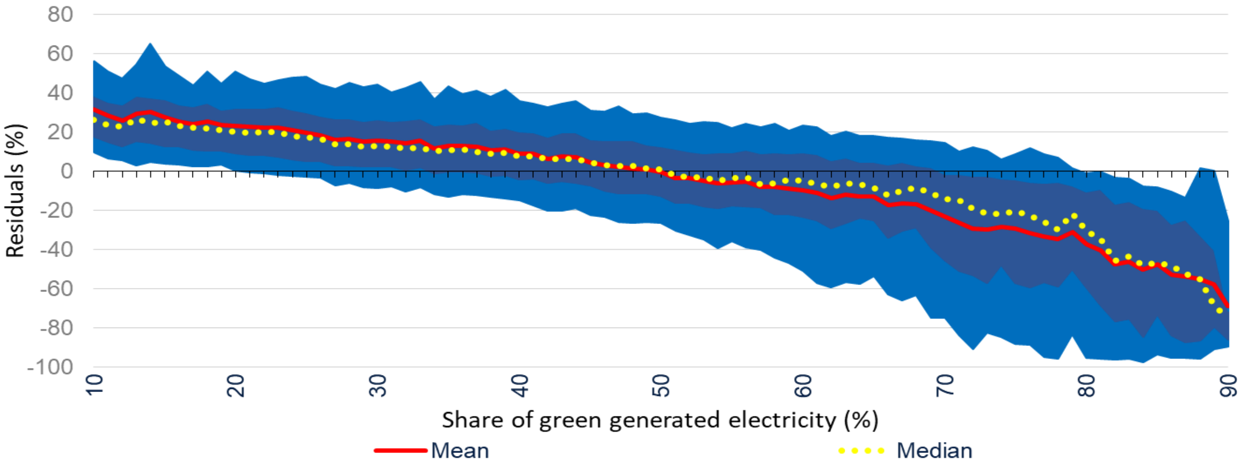
[24]: The residuals represent the part of electricity price not explained by traditional factors. This is usually due to a change in the technology that sets the marginal price, but it could also be due to a change in productivity or other factors.

renewables on the wholesale electricity price—specifically, on the residual deviations from prices determined by traditional factors—has been quantified (**Eq 2**).

**The impact of renewables on wholesale electricity prices operates through two main channels**. First, renewables increase competition among dispatchable technologies, forcing these technologies to lower their power production bids to remain competitive. Consequently, the most competitive bid sets the price, displacing less efficient technologies. Second, if renewable energy supply is sufficient to meet total demand, the supply curve shifts to the right, and the marginal price is determined by renewables, which is significantly lower than that of other technologies.

**The impact of renewables on wholesale electricity prices is non-linear**. The non-linear relationship between renewable energy share and the residuals of the first regression (% deviation) is illustrated in **Graph 14**, where residuals are grouped by renewable share. This graph displays the mean and median of each group, with blue areas representing the 10th, 25th, 75th and 90th percentiles. It is evident that the marginal effect of renewables increases as the renewable share rises. Additionally, the median and mean are similar for renewable shares up to 60%. Beyond this threshold, the mean drops significantly below the median, indicating that negative deviations (relative to the mean) are greater than positive ones. This pattern can be attributed to the dual effects of renewable energy on wholesale electricity prices. For renewables shares between 60% and 80%, the primary impact is increased competition among dispatchable technologies. However, renewable sources begin to set the marginal price, and their effect on reducing prices becomes more pronounced, particularly when gas prices or EU-ETS are exceptionally high. For shares exceeding 80%, the dominant effect is renewables setting the marginal price more frequently, which explains why the mean aligns more closely with the median at this level. However, the residual heteroscedasticity observed at high levels of renewable share indicates a statistically less significant relationship between them and electricity prices in these cases. It is noteworthy that, **during the period 2018–2023, renewables covered between 25% and 55% of electricity demand most of the time.** Therefore, up to this point, the primary effect of renewables on prices has been through the displacement effect, driven by increased competition among dispatchable technologies.

Graph 14. **RESIDUALS AND SHARE OF RENEWABLE ENERGY IN THE ELECTRICITY MIX.** (HOURLY DATA; 2018-2023)



(*) εh,t,t-1 /E[Ph,t, t-1] Blue areas represent the percentiles 10, 25, 75 and 90. (**) Green technologies refer to Wind and Solar energy. Bilateral contracts have been excluded.
Source: BBVA Research from OMIE, SENDECO and MIBGAS data.

These two distinct effects of renewables on electricity prices highlight the need for a methodology capable of capturing the non-linear impact of renewables. To address this non-linearity, a quantile regression[25] approach has been applied, using the following equation:

$$\frac{\varepsilon_{h,t,t-1}}{E[P_{h,t,t-1}]} = \gamma_{0,k} + \gamma_{1,k} * Share\ wind\ and\ solar_{h,t,t-1} + u_{h,t,t-1} \qquad (Eq\ 2)$$

Where **Share wind and solar$_{h,t,\,t-1}$** is the hourly one day-ahead percentage of electricity demand covered by wind and solar, **E[P$_{h,t,\,t-1}$]** the expected value of **P$_{h,t,\,t-1}$** and **u$_{h,t,\,t-1}$** the quantile model residuals.

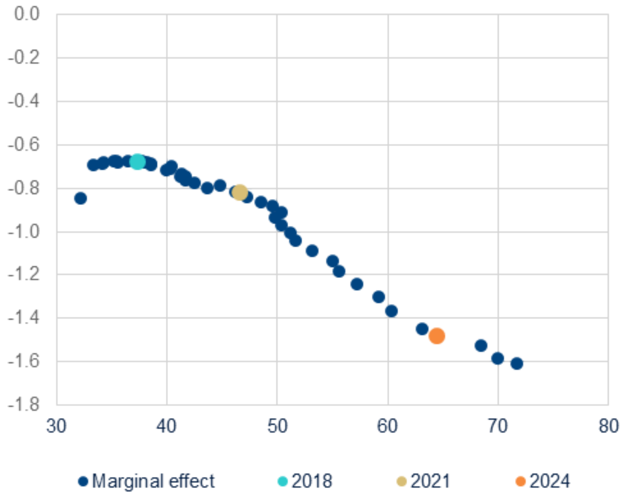
**The marginal impact of renewables in electricity prices is greater the higher the share of renewables**. The estimated quantile regression reveals that the marginal effect of renewables varies across residual quantiles. When residuals are significantly below the expected price based on traditional factors, the marginal effect of renewables is larger (in absolute terms). This is due to the dominance of the second effect, where renewables set the marginal price, particularly in quantiles with larger negative deviations. This regression shows that a 1% increase in renewable share lowers wholesale prices by 0.74% compared to combined cycle turbines, with no significant difference at the 95% level from the 90th quantile effect.. However, the effect rises in higher quantiles as renewables displace peak prices, while in the 10th quantile, the marginal effect (-1.37%) is nearly twice that of the median (**Table 2**). Grouping observations into 50 equal categories shows that renewables' marginal impact grows as their share increases (**Graph 15**). With renewables at 65% in 2024 (excluding hydro and contracts), wholesale prices may drop 1.5%, twice the 2021 reduction at 45% renewables.

Table 2. **QUANTILE REGRESSION MODEL**
HOURLY DATA. 2018-2023.

| | 10th | 50th | 90th |
|---|---|---|---|
| (Intercept) | 31.48***<br>(0.624) | 36.56***<br>(0.286) | 66.3***<br>(0.617) |
| Share renewable | -1.37***<br>(0.013) | -074***<br>(0.006) | -0.77***<br>(0.013) |
| **Pseudo-R$^2$** | **0.29** | **0.15** | **0.1** |

t statistic in parenthesis. *p<0.1, **p<0.05, ***p<0.01.
Source: BBVA Research from OMIE, MIBGAS, SENDECO data.

Graph 15. **MARGINAL EFFECT OF RENEWABLES PER SHARE OF RENEWABLES**



Source: BBVA Research from OMIE, MIBGAS, SENDECO data.

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[25]: Quantile regression (Koenker and Bassett, 1978) is an estimation method that relies on minimizing weighted absolute deviations with asymmetric weights, making it robust to extreme data points.

## Box C. Two-step approach versus One-step approach

This study employed a two-step approach, a choice based on the theoretical impact of renewables on wholesale electricity prices, which this methodology captures more accurately. For robustness, however, the analysis was also conducted using a one-step approach with the following equation:

$$\begin{aligned} P_{h,t,t-1} = \beta_{0,k} + \beta_{G,k} * MIBGAS_{t,t-1} + \beta_{ETS,k} * ETS_{t,t-1} + \beta_{IVPEE,k} * IVPEE_t \\ + \beta_{REN,k} * Share\ renewable_{\ h,t,t-1} + u_{h,t,t-1} \qquad (Eq\ C.1) \end{aligned}$$

Where **P**$_{h,t,\ t-1}$ is the hourly one day-ahead wholesale electricity price; **MIBGAS**$_{t,\ t-1}$ the one-day ahead MIBGAS price[26], **ETS**$_{t,t-1}$ the one-day ahead ETS price, **IVPEE**$_{t}$ a dummy variable equal to 1 if IVPEEt= 7% and 0 if IVPEEt= 0%[27], **Share renewable**$_{h,t,\ t-1}$ the share of renewable energy sources (without hydro) in the supply matched at the Daily market and **u**$_{h,t,\ t-1}$ the residuals.

**The effect of renewables on the wholesale electricity prices is negative in all quantiles**, although it is greater at the lowest electricity prices. These results are similar to those obtained in the two-step regression, but with a smaller marginal effect in the quantiles located at the extremes. This difference is explained by the attribution that the quantile regression gives to an increase in the efficiency of the combined cycle (a decrease in the betas of the gas price and the EU-ETS). As can be seen in **Graph C.1**, the natural gas used and the CO2 emitted by combined cycle plants decrease when the electricity price decreases. This rise in efficiency is not due to the change in prices, but by an increase in the share of renewables, which displaces other technologies such as the combined cycle. This effect is also observed in the EU-ETS.

Therefore, **in a one-step approach, the efficiency gain due to the increase in electricity demand covered by renewables is attributed to a change in the marginal effect of natural gas prices and ETS, which could be underestimating the real impact.** Furthermore, the two-step approach allows a transformation of residuals into percentage deviation from the expected price from traditional components. This definition is closer to the effect of renewables on prices, because the effect is an efficiency gain, as explained above and as shown in the charts above. This efficiency gain makes an increase in renewables have a greater effect on prices when the price of natural gas or EU-ETS is higher. Thus, assuming that IVPEE remains constant, a 10 percentage point increase in the renewables share, with natural gas and EU-ETS prices of €100 and €20/MWh, respectively, should not have the same effect when the gas price and EU-ETS double. In this case the effect should double.

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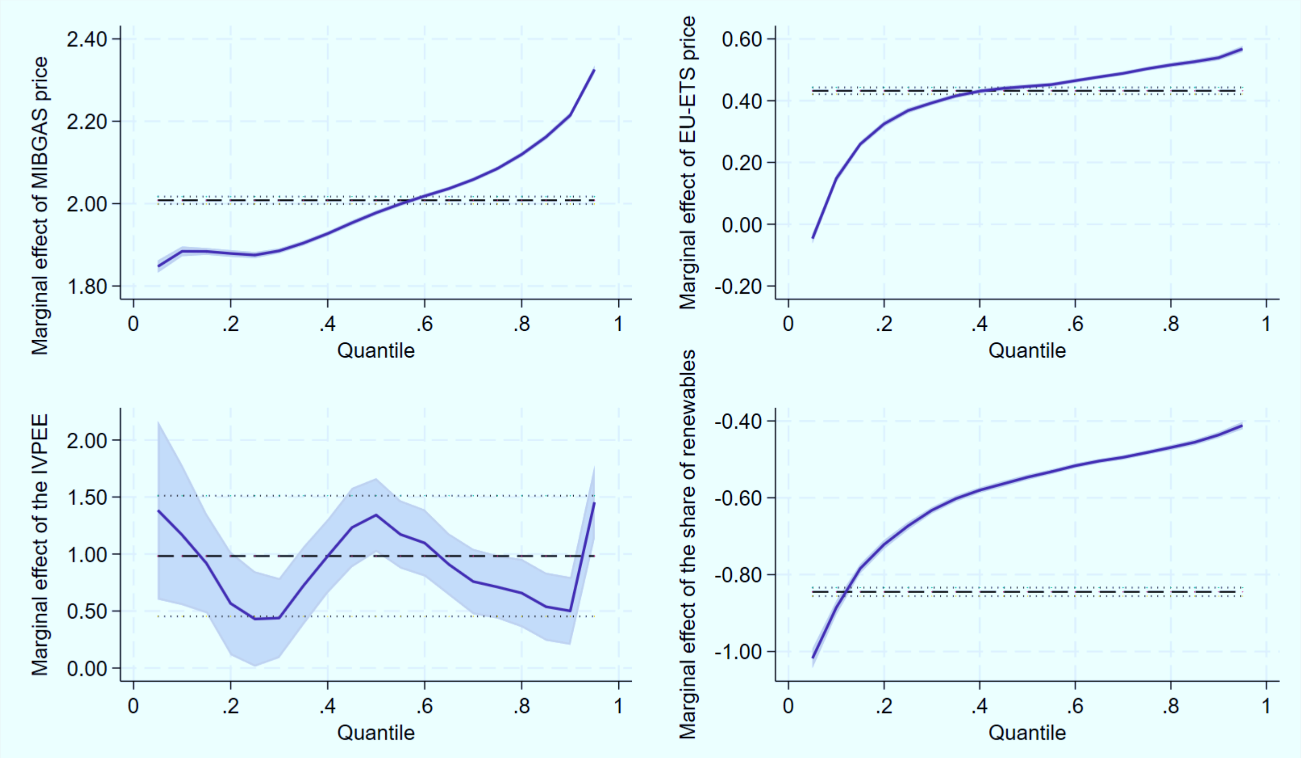
[26]: The one day ahead MIBGAS price is substituted by the limit set by the government during the Iberian exception when it is above that limit (June 2022 to March 2023)

[27]: Impuesto sobre el valor de producción energética (Tax over the value of the energy production).

Graph C.1 **ONE-STEP APPROACH RESULTS. THE ESTIMATES OF THE MARGINAL EFFECTS FOR EACH QUANTILE.** (EUR/MWh)



Source: BBVA Research from OMIE, MIBGAS, SENDECO data.

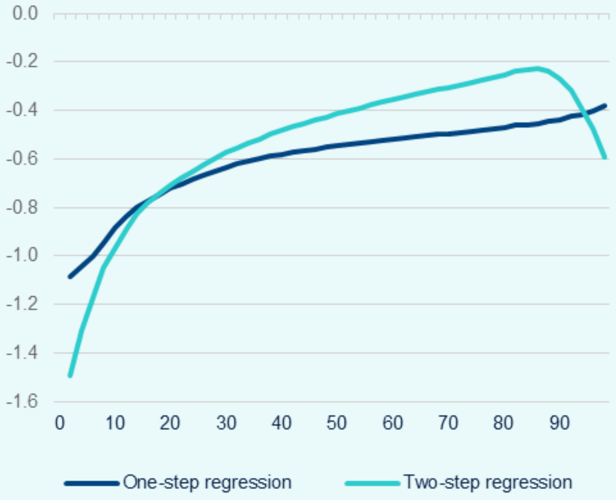
**In any case, the difference between both regressions (one and two-steps) is not significant,** apart from the effect that is not attributed to renewables in the one-step approach. This robustness check shows the increase in competitiveness among programmable technologies, and that for both analyses the marginal effect of renewables on wholesale electricity price is significantly negative across percentiles.

Table C.1. **ESTIMATED REGRESSION MODEL.** HOURLY DATA. 2018-2023 (*). QUANTILE REGRESSION

| | One-step | | | Two-step | | |
|---|---|---|---|---|---|---|
| | **10th** | **50th** | **90th** | **10th** | **50th** | **90th** |
| Intercept | 30.45***<br>(1.03) | 22.84***<br>(0.306) | 21.42***<br>(0.383) | 21.54***<br>(0.51) | 18.4***<br>(0.166) | 30.3***<br>(0.68) |
| One day ahead MIBGAS | 1.88***<br>(0.0116) | 1.98***<br>(0.0035) | 2.21***<br>(0.0045) | | | |
| One day ahead ETS | .148***<br>(0.0141) | 0.446***<br>(0.004) | 0.54***<br>(0.005) | | | |
| IVPEE | 1.17**<br>(0687) | 1.34***<br>(0.205) | 0.5**<br>(0.263) | | | |
| Share renewable | -0.886***<br>(0.014) | -0.5464***<br>(0.004) | -0.436)***<br>(0.0055) | -0.967***<br>(0.011) | -0413***<br>(0.004) | -0.267***<br>(0-0146) |
| **Pseudo -R$^2$** | **0.44** | **0.71** | **0.86** | **0.3** | **0.13** | **0.02** |

t statistic in parenthesis. *p<0.1, **p<0.05, ***p<0.01.
Source: BBVA Research from OMIE, MIBGAS, SENDECO data.

Graph C.2. **MARGINAL EFFECT OF RENEWABLES IN WHOLESALE ELECTRICITY PRICES**



Source: BBVA Research from OMIE, MIBGAS, SENDECO data.

**Increasing the share of renewables from 45% to 65% between 2021 and 2024 would have reduced wholesale electricity prices by 20%.** The penetration of renewables in the electricity mix in Spain is helping to reduce wholesale electricity prices and to decouple electricity prices from its main determinants, natural gas prices and EU-ETS. Increasing the share of renewables from 45% to 60%, as it happened between 2021 and 2023, would have reduced wholesale electricity prices by 12.5%. Moreover, in mid-2024 the share of renewables increased to 65%, reducing prices by a further 7.5% compared to 2023 (**Graph 16**).

**Given the current share of renewables in the Spanish electricity mix, reaching the target[28] set in the National Integrated Energy and Climate Plan for Spain (PNIEC 2023-2030) means increasing the share of renewables in the Daily Market -without hydro and bilateral contracts- by 15 points, an objective that, while plausible, may seem optimistic over a five-year horizon given the available evidence. Nevertheless, if this were to happen, electricity prices could be reduced by a further 20% (Graph 16), assuming everything else is constant.[29] Achieving the PNIEC goals requires a significant amount of public and, above all, private investment -85% of the total-, which depends, among other factors, on technology and financing costs.[30]**

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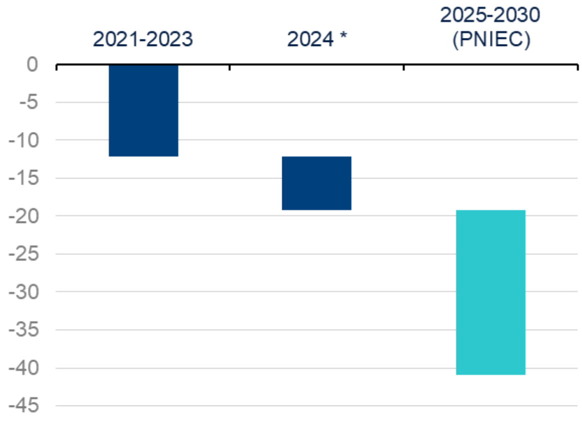
[28] 81% in the PNIEC, which is equivalent to 80% excluding hydro and bilateral contracts in the Daily Market.

[29]: Natural gas prices, ETSs and price generation process.

[30]: See Más ambición climática que concreción

Graph 16. **IMPACT OF RENEWABLES IN WHOLESALE ELECTRICITY PRICES IN SPAIN %**



Source: BBVA Research from OMIE, MIBGAS, SENDECO data and PNIEC.*The estimation is based on the available data up to June 2024.

## 6. The “Merit-order effect” and Investment in Renewables in Spain

**Greater renewable penetration lowers electricity prices through the "merit order effect".** The “merit-order effect” refers to an economic phenomenon in electricity markets where for any given demand, low marginal cost electricity technologies (such as solar and wind) entering the market shift the supply curve to the right and the marginal price declines, ultimately impacting the profitability of these technologies. The underlying reason is that variable renewable energy sources have near-zero marginal costs and produce electricity intermittently based on weather conditions. When a significant amount of variable renewable energy capacity is added to the grid, it increases supply during periods of high generation (e.g., sunny or windy days), which can lead to lower electricity prices during those periods. Furthermore, this price depression could reduce the revenues that renewable energy generators can earn, and even discourage investment in renewables, a phenomenon termed as "cannibalization effect”. Empirical studies have quantified this effect by using different methodologies[31], concluding that it poses a significant challenge to the economic viability of investment in renewables as their penetration increases. To mitigate it, strategies such as enhancing grid interconnections, implementing energy storage solutions, and designing supportive policy frameworks are essential.

Considering Lopez at al. (2020), we have analyzed the “cannibalization” effect of wind and solar in the wholesale electricity market in Spain (Daily market). After analyzing the evolution over time of the income of these technologies through the value factor (VF)[32], a quantile regression has been estimated to analyze the possible impact that renewables would be having on their sector's revenues, as well as the cross-effects between them.

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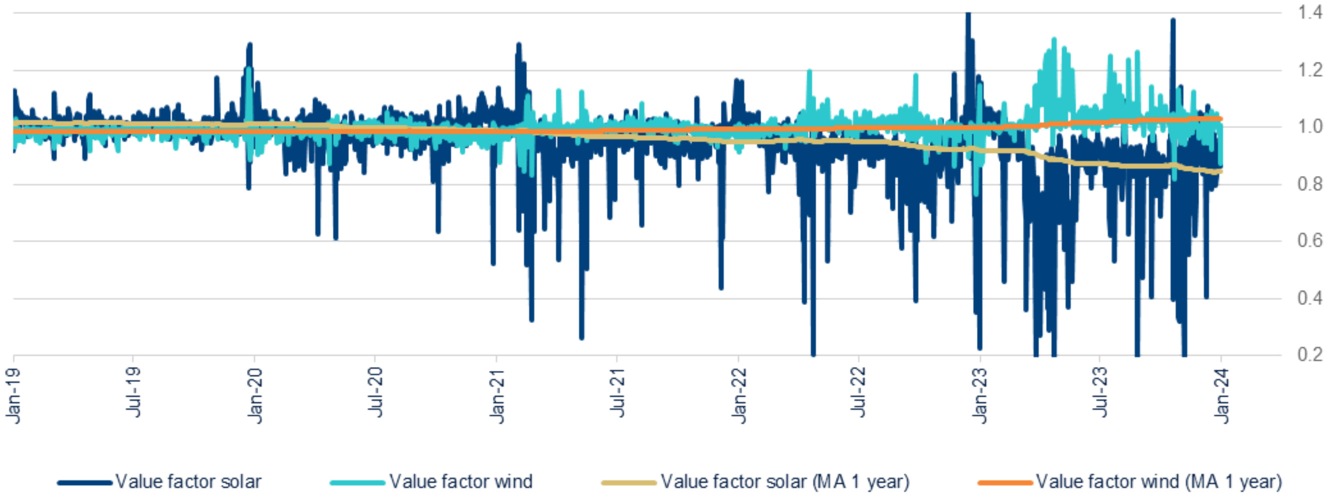
[31]: López et al. (2020), Reichenberg et al. (2021), Blume-Werry et al. (2021), Stiewe et al. (2024)
[32]: Value factor is defined as the ratio between the unit revenues (generation weighted electricity prices) and the average electricity prices.

**Solar and wind value factors were similar until mid-2021, when solar began to decline, unlike wind.** Value factors represent the average daily revenue of a technology compared to the average revenue of all technologies. Thus, a value factor below one, as it is observed for solar in **Graph 17**, suggests that the average daily selling price of the technology is below the overall market average. In 2019, the value factor (based on the moving average) for both technologies was close to one, indicating that their revenues were consistent with those of other technologies. From 2021 onwards, the revenues of solar decreased compared to other technologies, while it slightly increased for wind. The different behaviour of both technologies is explained by the natural constraint of renewables. While wind technology is able to produce electricity "randomly" during the day, solar has to concentrate its production in daylight hours. This pushes prices down and leads to lower revenues for technologies that produce electricity during these hours.

Graph 17. **ESTIMATED REGRESSION MODEL** HOURLY DATA. 2018-2023. QUANTILE REGRESSION



Source: BBVA Research from OMIE, MIBGAS and SENDECO data based on "The cannibalization effect of wind and solar in the California wholesale electricity market"

The quantile regression estimated to analyze how the supply of different technologies impacts the unit revenues of solar and wind energy is the following:

$$UR^R_{t,t-1} = \beta^R{}_{0,k} + \beta^R{}_{G,k} * MIBGAS_{t,t-1} + \beta^R{}_{ETS,k} * ETS_{t,t-1} + \beta^R{}_{IVPEE,k} * IVPEE_t$$

$$+ \beta^R{}_{SOL,k} * Solar\ supply_{\,t,t-1} + \beta^R{}_{WIND,k} * Wind\ supply_{\,t,t-1} + \beta^R{}_{CC,k} * CC\ supply_{\,t,t-1} + u^R{}_{t,t-1} \qquad (Eq\ 3)$$

Where **UR**$^R_{t,\,t-1}$ is the daily unit revenue for the technology R; **MIBGAS**$_{t,\,t-1}$ the one-day ahead MIBGAS price[33], **ETS**$_{t,t-1}$ the one-day ahead ETS price, **IVPEE**$_t$ a dummy variable taking the value 1 if IVPEEt is equal to 7% and 0 if IVPEEt is equal to 0%[34], **Solar supply**$_{t,t-1}$ the daily supply offers of solar technologies matched in the daily market, **Wind supply**$_{t,t-1}$ the daily supply offers of wind technologies matched in the daily market, **CC supply**$_{t,t-1}$ the daily supply offers of combined cycle technologies matched in the daily market and **u**$_{h,t,\,t-1}$ the residuals.

---

[33]: The one day ahead MIBGAS price is substituted by the limit set by the government during the Iberian exception when it is above that limit (June 2022 to March 2023).

[34]: Impuesto sobre el valor de producción energética (Tax over the value of the energy production).

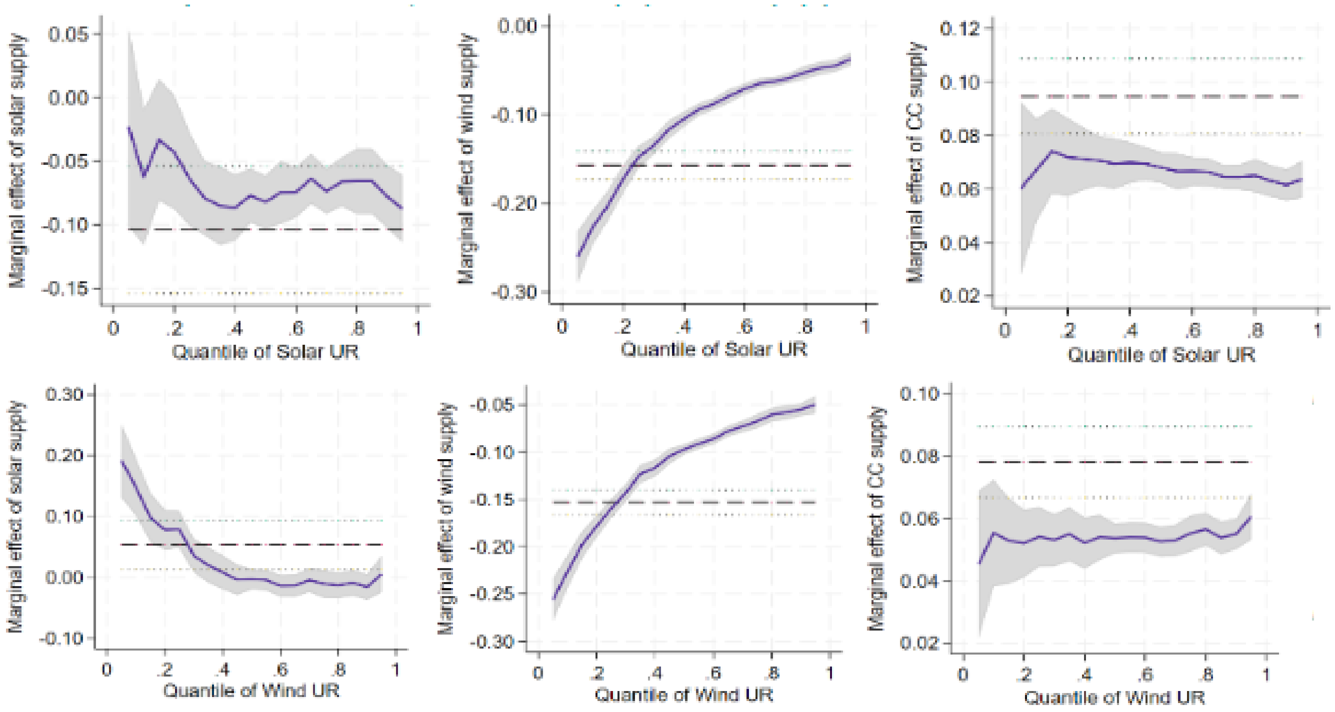
Table 3. **ESTIMATED QUANTILE REGRESSION.** DAILY DATA. 2018-2023 (*)

| | With UP | | | Solar UR | | |
|---|---|---|---|---|---|---|
| | **10th** | **50th** | **90th** | **10th** | **50th** | **90th** |
| (Intercept) | 12.86***<br>(3.51) | 7.87***<br>(1.03) | 6.31***<br>(1.12) | 21.44***<br>(3.17) | 11.5***<br>(1.24) | 9.1<br>(1.25) |
| Solar supply | 0.15***<br>(0.05) | -0.003<br>(0.015) | -0.016<br>(0.017) | -0.063<br>(0.05) | -0.082***<br>(0.02) | -0.08***<br>(0.02) |
| Wind supply | -0.23***<br>(0.016) | -0.097***<br>(0.005) | -0.055***<br>(0.005) | -0.23***<br>(0.015) | -0.09***<br>(0.006) | -0.045***<br>(0.006) |
| Non-renewable supply | 0.05***<br>(0.015) | 0.05***<br>(0.004) | 0.055**<br>(0.05) | 0.07***<br>(0.0013 | 0.07***<br>(0.005) | 0.06***<br>(0.005) |
| One day ahead MIBGAS | 2.03***<br>(0.044) | 2***<br>(0.013) | 2.11***<br>(0.014) | 2.01***<br>(0.04) | 2.01***<br>(0.015) | 2.1***<br>(0.016) |
| One day ahead ETS | -0.06<br>(0.07) | 0.32***<br>(0.02) | 0.365***<br>(0.024) | -0.21***<br>(0.066) | 0.18***<br>(0.026) | 0.3***<br>(0.026) |
| **Pseudo-$R^2$** | **0.61** | **0.8** | **0.91** | **0.52** | **0.75** | **0.89** |

t statistic in parenthesis. *p<0.1, **p<0.05, ***p<0.01.
Source: BBVA Research from OMIE, MIBGAS and SENDECO data based on "The cannibalization effect of wind and solar in the California wholesale electricity market"

**Falling electricity prices have lowered revenues for renewable generators, especially those in solar.** As shown in the top charts of **Graph 18**, in the case of solar energy, the marginal effect of its penetration on sector revenues (auto effect) is negative and consistent with OLS estimates. Additionally, wind energy supply also impacts solar generators' unit revenues (cross effect), particularly when revenues are low. In the case of wind energy (bottom charts of **Graph 18**), its effect on generator revenues is significant and non-linear, with a stronger impact when revenues are lower, but the cross effect of solar on wind is not significant for revenue quantiles above 30th. It is worth noting that the impact of solar on wind revenues in the lowest quantiles is positive, meaning that when solar sets the marginal price in the electricity market, wind unit revenues increase. This could be due to the fact that in these quantiles the price of solar energy was higher than that of wind. Finally, it should be noted that natural gas prices, the EU-ETS, and combined cycle supply have also had a positive impact on solar and wind revenues.

Graph 18. **“MERIT-ORDER EFFECT” IN SOLAR AND WIND UNIT REVENUES.** 2018-2023 (EUR/GWh) (*)



(*) The dashed line represents the OLS estimation and the 95% confidence interval, the blue line represents the quantile estimation of the parameter for each quantile and the area represents the 95% confidence interval of the quantile estimation.
Source: BBVA Research from OMIE, MIBGAS and SENDECO data based on “The cannibalization effect of wind and solar in the California wholesale electricity market”.

**There is no clear evidence of a discouragement of investment in renewables.** The answer to whether the reduction in revenues for renewable generators has discouraged investment in renewables seems to be no. There is no evidence to support this claim. As shown in the **Graphs 19 and 20**, the average annual revenues of solar and wind technologies have rebounded in recent years, primarily due to the extraordinary increase in gas prices caused by the energy crisis following the pandemic and Russia’s invasion of Ukraine. In 2018, the average MIBGAS price was €24.32/MWh, and the average revenues of solar and wind were close to their LCOE of new installations. By 2023, however, the MIBGAS price rose to €38.99/MWh and the average revenues of both technologies were well above their LCOE. Based on this analysis, one might think that the increase in solar and wind revenues is related to a lower “use ratio”[35], although no clear pattern confirms this relationship. Nevertheless, renewable energy revenues remain highly dependent on natural gas prices, which have enabled them to generate sufficient income to offset potential losses when they set the marginal price.

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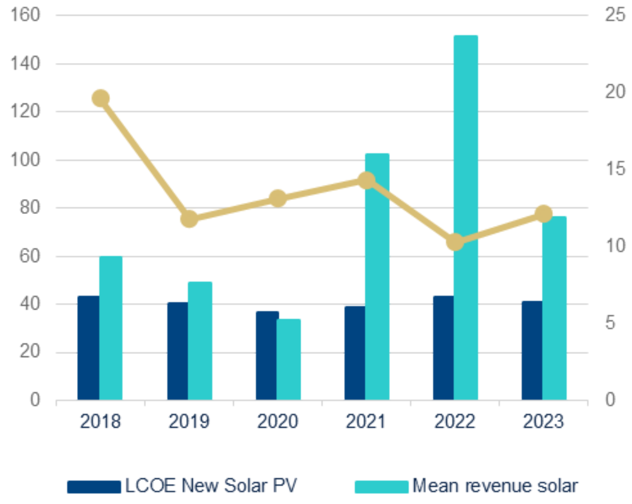
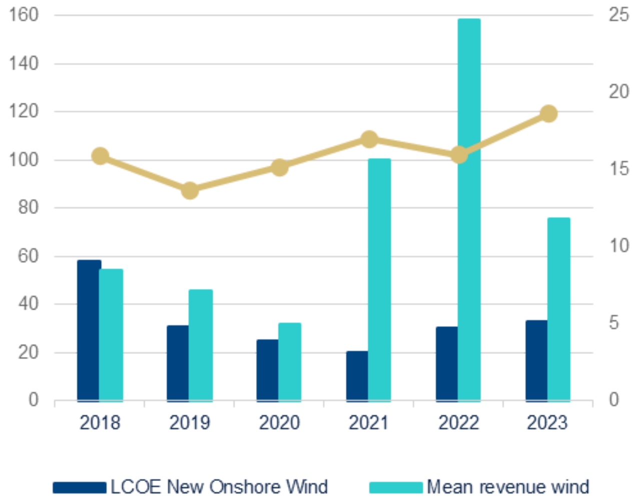
[35]: The use ratio is defined as the ratio between the electricity generation of one technology in one year and the maximum amount of electricity that could have been generated taking into account the installed capacity at the end of the year.

Graph 19. **SOLAR REVENUES, LCOE[36] AND USE RATIO.** (EUR/MWH, LEFT, % RIGHT)



Source: BBVA Research from OMIE, MIBGAS, SENDECO data.

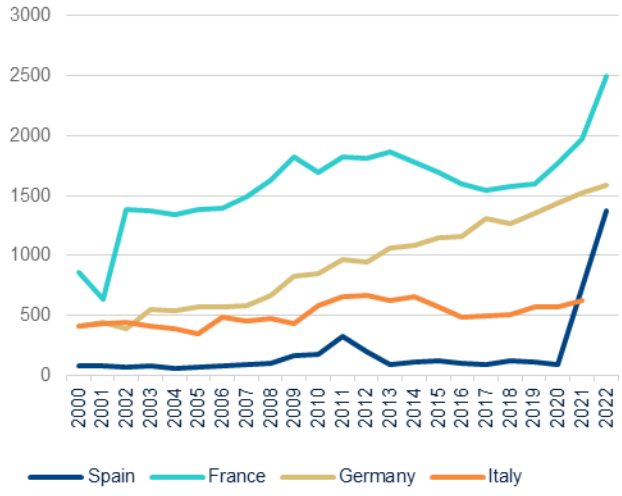
Graph 20. **WIND REVENUES, LCOE AND USE RATIO.** (EUR/MWH, LEFT, % RIGHT)



Source: BBVA Research from OMIE, MIBGAS, SENDECO data.

**Public investment in energy R&D is also increasing since 2020, mainly driven by the NGEU funds.** This trend differs from that of other European countries, such as Germany or France, where public investment has been growing more steadily since 2000. In the case of Spain, public investment has multiplied by 10 in just 2 years, driven largely by NGEU funds, which have been mainly allocated to investing in energy efficiency and renewables (**Graphs 21 and 22**).

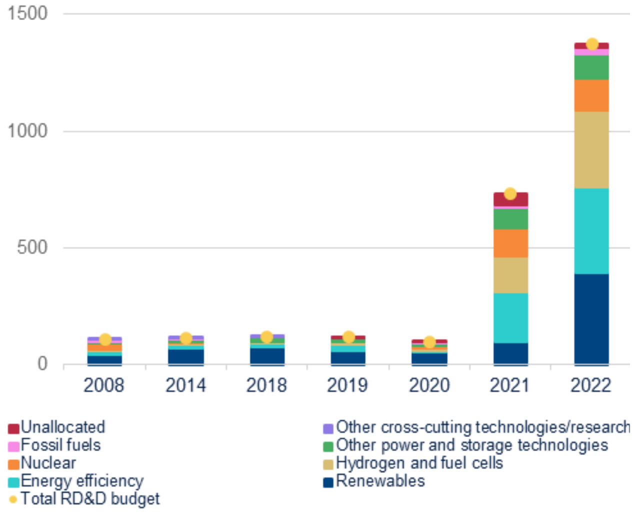
Graph 21. **PUBLIC ENERGY R&D INVESTMENT.** (CONSTANT MILL EUR 2023)



Source: BBVA Research from IEA data.

Graph 22. **SPAIN. PUBLIC ENERGY R&D INVESTMENT BY TECHNOLOGY**

(CONSTANT MILL EUR 2023)



Source: BBVA Research from IEA data.

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[36]: Due to data availability, for solar LCOE only the solar PV was taken into account.

## 7. Conclusions

The Spanish wholesale electricity market has undergone a significant transformation, with prices dropping below the European average since 2022. This shift aligns with the rapid growth of renewable energy sources, which already account for 65% of the electricity market share in Spain, surpassing the European average. Our study reveals that between 2021 and 2024, the increased penetration of renewables, particularly solar PV and onshore wind, reduced wholesale electricity prices by nearly 20%. Moreover, achieving the ambitious 81% renewable target set for 2030 in the National Energy and Climate Plan (PNIEC 2023-2030) could lead to further electricity price reductions of around 20%. An objective that, while plausible, may seem optimistic over a five-year horizon given the available evidence.

Moreover, further regulatory and investment advancements will be critical. Streamlined permitting processes, enhanced legal certainty, simplified grid access, and the repowering of renewable facilities are essential steps. Moreover, proactive policies to de-risk investments, strengthen clean-tech manufacturing, and enhance funding mechanisms will be pivotal. By fostering market integration, cross-border electricity trading, and robust Europe-wide infrastructure, Spain could position itself as a leader in the energy transition, ensuring a more competitive, sustainable, and resilient future.

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ENQUIRIES TO:
BBVA Research: Azul Street, 4. La Vela Building – 4th and 5th floor. 28050 Madrid (Spain).
Tel. +34 91 374 60 00 y +34 91 537 70 00 / Fax (+34) 91 374 25
www.bbvaresearch.com