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The impact of renewable energies on wholesale electricity prices

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Rationale

Renewable electricity generation capacity is rising significantly in Spain. Given the merit order pricing system used in the wholesale electricity market, this could have profound implications for electricity price dynamics.

Takeaways

- The share of wind and solar energy in total electricity generation increased from 26% in 2019 to over 40% in 2024 H1. In the first half of this year, wholesale electricity prices were more than 40% lower than they would have been had wind and solar generation remained at 2019 levels.
- The model estimated in this article suggests that under the renewable generation deployment scenarios envisaged in the update of the National Energy and Climate Plan, wholesale electricity prices could drop by an additional 50% by 2030.
- In any event, the future behaviour of these prices is subject to considerable uncertainty, influenced by various supply-side factors and how demand responds to the new levels of renewable generation.

Keywords

Electricity market, renewable energies, merit order pricing system.

JEL classification

E31, Q41, Q42.

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The European Union's (EU) climate targets aim to reduce greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, and achieve climate neutrality by 2050.[1] To this end, EU countries have approved a number of plans detailing the measures to be implemented and interim targets. In the case of Spain, in 2023 the Government approved the updated National Energy and Climate Plan (NECP) 2023-2030.[2] This plan includes the goal of raising the share of renewable energies in the electricity generation mix from 37% in 2019 to 81% by 2030.[3] Specifically, around 90% of this increase will come from higher wind and solar generation capacity.

Increasing the share of renewables in electricity generation could have a profound impact on price dynamics in wholesale electricity markets. In particular, under the merit order pricing system used in European markets, electricity prices are set based on the bids from the most expensive technology needed to meet demand in each time band. Thus, an increase in renewable generation (whose marginal costs are relatively low) would affect wholesale prices insofar as it displaces other, higher marginal cost technologies from the energy mix needed to meet demand in certain time bands.[4]

This mechanism is especially important in the case of wind and solar generation for two reasons. First, since wind and solar production depends on meteorological factors, its output fluctuates considerably across different time bands and periods of the year. In addition, given the current limited possibilities for storing electricity, matching solar and wind generation to demand levels in different time periods is a challenge. As a result, when these technologies supply electricity to the grid – primarily in the central hours of the day – they tend to displace a significant portion of other energy sources. Second, the cost structure of wind and solar technologies differs from that of fossil fuel-based sources.[5] Specifically, wind and solar technologies have very low marginal costs, whereas those of fossil fuel-based technologies are proportional to the price of the commodities needed to operate them. Consequently, the wholesale market price is significantly different when it reflects the marginal cost of fossil fuels compared to when renewable production is sufficient to meet demand and the price therefore reflects very low marginal costs.

However, the marginal cost of fossil fuel-based generation, especially that of combined cycle plants (primarily powered by natural gas), continues to determine wholesale prices for most hours of the day.[6] Indeed, in recent years wholesale prices have followed a similar trajectory to natural

1 Defined as reducing net greenhouse gas emissions to zero. For more details, see "Recommendation for 2040 emissions reduction target", European Commission, 6 February 2024.

2 See the draft update of the NECP 2023-2030 (in Spanish only), published by the Ministry for the Ecological Transition and the Demographic Challenge.

3 In addition to wind and solar energy, this percentage includes all other renewable sources, such as hydropower and biomass.

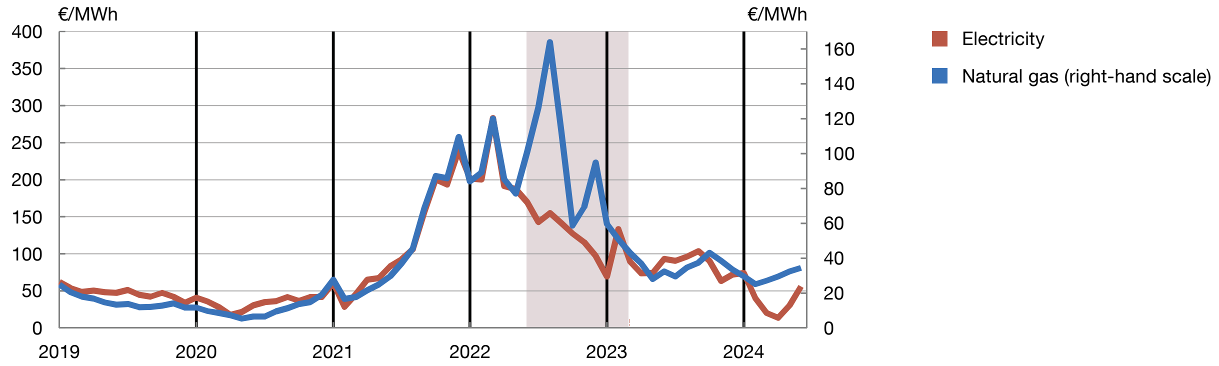
4 For more details, see Pacce, Sánchez and Suárez-Varela (2021).

5 Since wind and solar energies have low marginal costs and cannot be stored, their behaviour on the wholesale market is similar to that of nuclear energy. Other renewable energies, such as hydropower, can be stored, and therefore the timing of their generation and supply can be adjusted in response to price fluctuations.

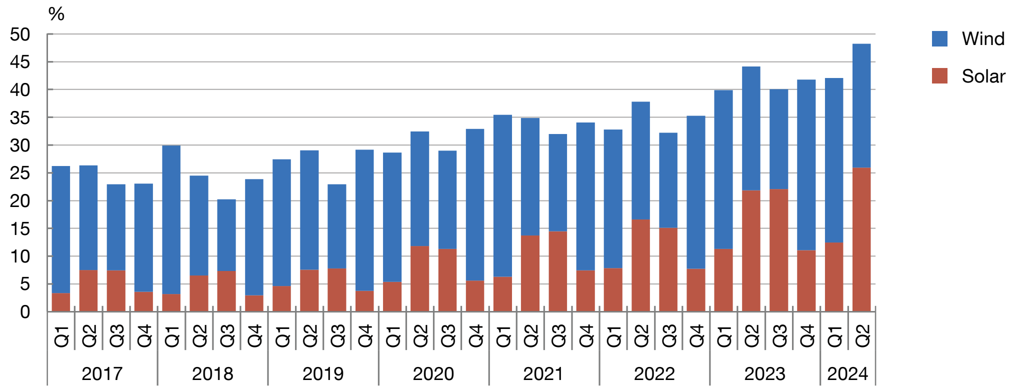
6 For hours when the price-setting technology is neither wind nor solar, wholesale prices typically reflect the cost of natural gas. For more details, see García-Martínez and Pacce (2023).

Chart 1
Relationship between electricity and natural gas prices and developments in renewable generation

1.a Electricity and natural gas prices (a)



1.b Percentage of demand covered by solar and wind energy



SOURCES: ENTSO-E and MIBGAS.

a The shaded area denotes the period when the Iberian mechanism was in effect. 2024 is shown up to 30 June.

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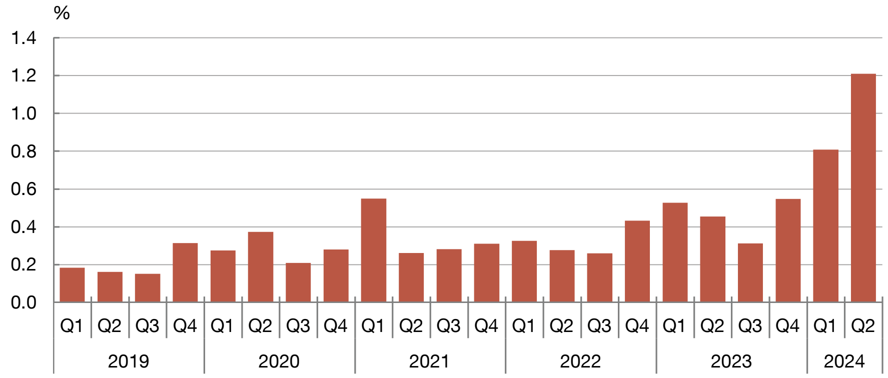
gas prices, except when the so-called Iberian mechanism was in effect (see Chart 1.a).[7] However, this relationship has begun to weaken over the past year due to the sharp increase in installed capacity of wind and solar energy, whose generation has grown from covering 26% of total electricity demand in 2019 to 44% in 2024 to date (see Chart 1.b). This has resulted in greater intraday price volatility, reflecting the growing frequency with which the marginal generation technology changes (between renewable and traditional power) within the same day (see Chart 2.a). Thus, there were no hours of zero or negative wholesale electricity prices in 2019, but in 2024 H1 prices were zero or negative for 15% of hours, when renewable generation technologies with very low marginal costs were able to meet demand (see Chart 2.b).

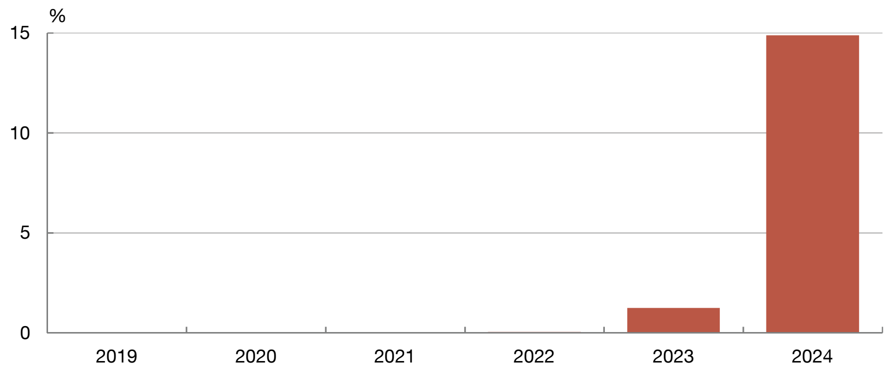
7 Under the Iberian mechanism, approved in June 2022, fossil fuel-based power plants received payments for electricity generated whenever gas prices exceeded a pre-established reference price. These power plants were required to discount those payments from their bids on the wholesale electricity market. Since February 2023 gas prices have remained below the reference price, effectively nullifying the Iberian mechanism. See García Martínez and Pacce (2023).

Chart 2
Greater intraday electricity price volatility, driven by higher installed capacity of renewable generation

2.a Coefficient of variation of intraday electricity prices (a)



2.b Percentage of hours with electricity prices equal to zero



SOURCE: ENTSO-E.

a 2024 is shown up to 30 June.

We adopt a two-step approach to quantify the impact of renewable energy penetration on electricity prices. First, we estimate an econometric model where the hourly electricity price (ph)[8] depends on traditional day-ahead market determinants, i.e. the prices of natural gas and CO_2 emission allowances.[9] Therefore, the residual of this regression (i.e. the portion of the hourly price not explained by daily changes in natural gas and emission allowance prices) captures other factors affecting hourly volatility, which, as explained, depend fundamentally on the marginal generation technology in each time band.[10]

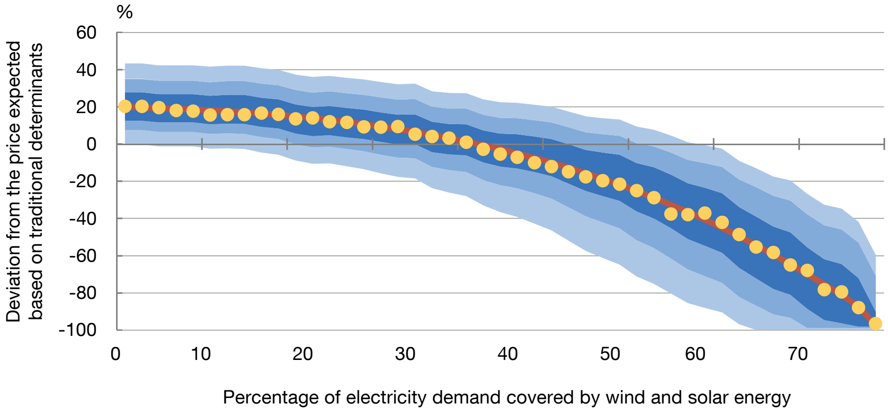
$$p_h = \alpha + \beta_1 gas_d + \beta_2 CO_{2d} + \varepsilon_h$$

8 By using hourly observations, the regression model better captures the wide variation in the percentage of demand covered by renewable sources throughout the day, and particularly time bands when this percentage is high, which would not be possible if daily or monthly averages were used. This yields a more reliable estimate, since the expected rise in the penetration of renewables implies an increase in the number of hours when a very high percentage of demand would be covered by such energies.

9 These two factors explain most of the volatility in hourly electricity prices. For more details on the importance of these determinants in price setting, see Zakeri et al. (2023).

10 The model is estimated using a sample period from 2015 to 2024, excluding June 2022 to February 2023 when the Iberian mechanism laid down in Royal Decree-Law 10/2022 was in effect. The hourly electricity price data are taken from ENTSO-E.

Chart 3
Relationship between electricity prices and renewable generation (2015-2024) (a)



SOURCES: ENTSO-E and Banco de España calculations.

a Each dot represents the mean price deviation from observed prices at each level of demand coverage by wind and solar energies. The shaded areas indicate, respectively, the 35th-65th, 20th-80th and 5th-95th percentiles of the deviation distribution for each value of demand coverage. The brown line shows the estimated relationship between the two.

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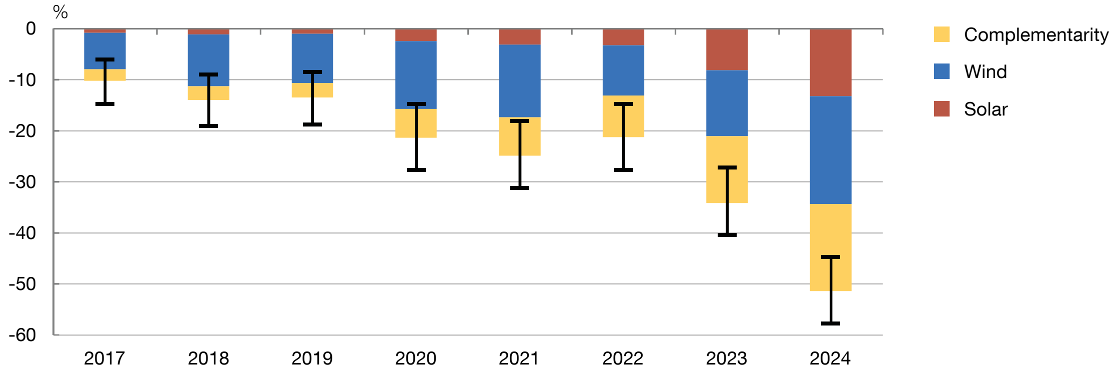
Chart 3 shows the relationship between the hourly price residual under the model described above and the percentage of demand covered by solar and wind generation.[11] As can be seen, the higher the percentage of solar and wind generation, the larger the deviation between prices on the wholesale electricity market and those predicted by natural gas and emission allowance prices. This deviation increases more rapidly as renewable generation covers a larger share of electricity demand. In other words, the greater the share of renewables in the energy mix, the greater the decoupling of wholesale electricity prices from their traditional determinants (natural gas and emission allowance prices). In any event, it is important to emphasise that these estimates are subject to uncertainty. To reflect this, the chart shows the distribution of the regression residual conditional to each level of demand covered by wind and solar.

Second, given the nature of the relationship identified in Chart 3, we consider an exponential functional form to proxy the relationship between the residuals obtained and the percentage of energy generated from solar and wind power technologies. According to the relationship estimated (see the brown line in Chart 3), an increase from 20% to 30% in the share of solar and wind power would have a relatively small impact on wholesale electricity prices. However, an increase from 50% to 60% may be expected to reduce prices by nearly 25%. In other words, there is strong non-linearity in the impact of greater renewable energy penetration on electricity prices, because the impact increases disproportionately as the share of renewables rises.

11 In Chart 3, each yellow dot denotes the average deviation of electricity prices from their determinants (i.e. the regression residuals) for each demand coverage level for wind and solar energy. As these are regression residuals, the mean of these deviations is zero, such that the distribution of the renewables share over the sample period determines the share for which these residuals take a value of zero. Consequently, at very low levels of renewable generation (relative to the set of values observed in the sample period), the regression residual yields positive values. The brown line shows the estimated relationship between the two variables. The shaded area denotes the interquartile range of the residuals.

Chart 4
Reduction in electricity prices attributable to solar and wind energy generation (a)



SOURCES: ENTSO-E and Banco de España calculations.

a Each bar depicts the difference between the observed price and a counterfactual price in the absence of renewable generation. The vertical lines show the 95% confidence intervals of the estimates. 2022 and 2023 exclude the period that the Iberian mechanism was in effect. 2024 is shown up to 30 June.

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The non-linear contribution of renewable energies to reducing electricity prices is attributable to the merit order pricing system. When renewable energy generation is at low levels, an increase in such generation has a limited effect. This is because, although renewables crowd out some of the least efficient plants operating with the most expensive technology, the replacement is partial and does not prompt a change in the price-setting marginal technology. By contrast, an equivalent increase in the share of renewables would have a significant impact if it can displace not only the least efficient plants, but also fossil fuel technologies as a whole, in which case the contribution of renewable energies would bring down wholesale electricity prices to zero.[12] It is important to note that when supply from inframarginal technologies can cover total demand and the time-band price is zero, further increases in solar or wind power generation cease to have any impact on electricity prices.

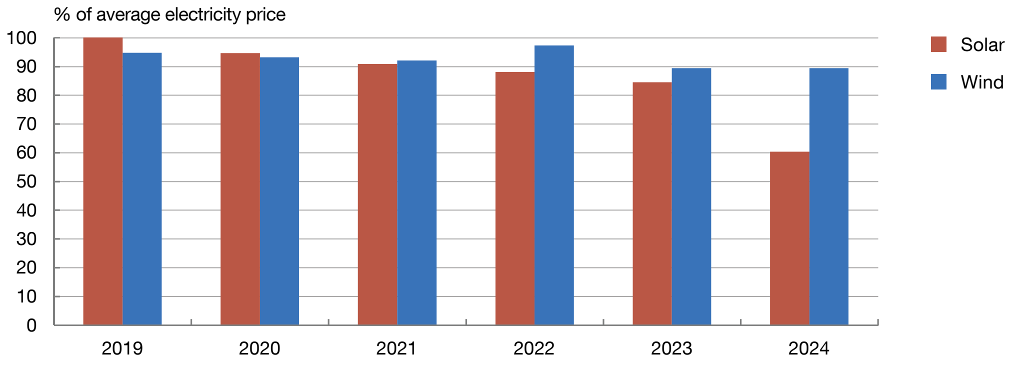
The estimated model can be used to calculate the annual average reduction in average wholesale electricity prices attributable to solar and wind energy. To this end, a counterfactual scenario is simulated in which electricity is generated without their input. According to the results obtained, average electricity prices were 10%-15% lower in 2017-2019 due to the contribution of renewable energies, and this gap has widened substantially since 2021, reaching 50% in 2024 H1, owing to the increase in their installed capacity (see Chart 4). Again, these estimates are subject to uncertainty; for example, with 95% confidence intervals, wholesale electricity prices in 2024 are between 45% and 58% lower than they would be under a counterfactual “no renewables” scenario.

If the contribution is broken down by source, we can see that most of the saving is attributable to wind power, in part owing to its greater share in total generation.[13] However, the contribution of

12 For a detailed discussion of the non-linearity of this relationship, see Quintana (2024).

13 Total share of renewable generation is not the only factor that contributes to reducing electricity prices, as the time distribution of such generation also has an effect. For example, for the same level of generation, the saving will increase if generation is highly concentrated in certain periods or occurs when electricity demand is lower.

Chart 5
Remuneration by type of generation (a)



SOURCES: ENTSO-E and Banco de España calculations.

a 2022 and 2023 exclude the period that the Iberian mechanism was in effect. 2024 is shown up to 30 June.

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solar energy has risen significantly in the past two years as a result of the increase in installed capacity. Another noteworthy aspect is the complementarity between the two technologies: given the non-linear impact of renewable generation on market prices, the concurrence of the two technologies yields savings that are larger than the sum of their individual contributions.[14] This complementarity stems from the non-linear contribution of renewable energies to the reduction in electricity prices. Thus, when wind and solar power generation coincide, they tend to fully displace marginal technologies, such that the overall impact on prices is larger than the sum of the individual effects if only one of these renewable energies had contributed to electricity generation.

An additional implication of this relationship is that the periods of greater wind and solar power generation are, to an increasing extent, time bands with lower hourly electricity prices. In consequence, the average remuneration of these technologies is substantially lower than annual average electricity prices (see Chart 5).[15]

As an alternative exercise, we can also calculate the reduction in wholesale electricity prices vis-à-vis another counterfactual scenario in which installed solar and wind capacity has not increased since 2019, such that the solar and wind generation has remained at 2019 levels. Under this counterfactual scenario, electricity prices would have been 25% higher in 2023, and slightly over 40% higher in 2024 H1.

14 To estimate the contribution of solar and wind power, we simulate scenarios using the relationship estimated in Chart 3 for hourly observations, which are then aggregated to annual frequency. The effects shown for each technology are the difference between the estimated annual price in the absence of both technologies and that obtained under a scenario that includes each technology separately. The complementarity effect is calculated as the difference between the price obtained under the "no renewables" scenario and the sum of the observed price and the two individual effects.

15 This process, known as "price cannibalisation", could jeopardise the recovery of capital costs and reduce the incentive for such investments. See, for example, López-Prol, Steininger and Zilberman (2020).

Looking ahead, a greater reduction may be expected in wholesale electricity prices attributable to an increased penetration of renewables in the energy mix under current investment plans. Using the relationship estimated above, we can simulate the impact of this increased penetration on electricity prices, taking into account possible developments in demand and price sensitivity.[16] Specifically, according to the scenarios set out in the update of the NECP 2023-2030, and assuming that natural gas prices remain at their current levels, electricity prices in 2030 would fall by up to a further 50% compared with the average observed in the past year, with a confidence interval of 45%-60%.

In sum, in addition to contributing to the green transition, renewable energies play a key role in bringing down wholesale electricity prices, and will foreseeably become even more important in this respect in the future. Nevertheless, the future behaviour of such prices is still highly uncertain and will be shaped by various factors that are themselves subject to much uncertainty and which, under general equilibrium, will also be strongly influenced by the path of electricity prices. Noteworthy examples of such factors include the feasibility and pace of execution of the ambitious investment projects to expand renewable generation capacity, how swiftly headway is made (on the demand side) in the electrification of the economy, how demand adapts to the hourly pattern of renewable generation, and the development of technologies to store surplus renewable energy generated at certain times of the day.[17]

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16 To perform the simulation, first, the level of renewable generation is projected for each hour of the year. Given that the hourly distribution of such generation over the year depends on meteorological factors, this projection can be calculated by applying the current hourly distribution to the changes in installed capacity assumed in the scenario for each type of generation. Second, to calculate the percentage of demand coverage by renewable sources, the current hourly distribution of electricity demand is multiplied by the growth assumed in the scenario. However, given that the hourly distribution could respond to new prices, simulations are performed for a range of values of electricity demand elasticity to price changes. See Fabra, Rapson, Reguant and Wang (2021) and Enrich, Li, Mizrahi and Reguant (2024).

17 For a more detailed discussion, see Quintana (2024).

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