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Renewable energy development: Current landscape, impacts, and goals

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ABSTRACT

The expansion of renewable energies, crucial for reducing emissions and transitioning to a decarbonized energy sector, has broad implications. We study how large-scale renewable energy, particularly wind and solar, impacts wholesale electricity prices, carbon emissions, and market competition. After reviewing current trends in renewable adoption, we focus on the Iberian electricity market. Using the methodology of Petersen, Reguant, and Segura (2024), we analyze impacts on prices and emissions on detailed hourly data from the wholesale electricity market for 2016 to 2022. Results show that a GWh increase in wind or solar generation reduces CO2 emissions between 200 and 300 tons, and prices by an average of 2e/MWh and 4e/MWh, respectively. By examining the evolution of traditional companies' market shares, we show that as renewable penetration increases, market concentration decreases. The study is complemented by discussing local effects of renewable developments, and challenges to increasing renewable development such as cannibalization, volatility, and intermittency.

Keywords: Renewable energy, Energy transition, Carbon emissions, Electricity prices, Market competition

1. Introduction

The current climate, geopolitical, and economic context has positioned at the center of the debate the need to transition towards a carbon-neutral economy. To achieve this goal, decarbonizing the energy sector stands as one of the main challenges. Reducing emissions in the energy sector not only involves a more efficient use of resources, it also implies transitioning to a more electrified system based on safe and clean energy production centered around renewable technologies. This decarbonization process has broad socioeconomic implications. The expansion of renewables not only contributes to sustainability, it also reshapes electricity markets, alters the energy mix, and influences local economies.

The goal of this study is to provide an overview of the current trends in renewable adoption, its contribution to energy consumption, and the impacts on the electricity market and the economy. We focus on large-scale renewable energy investments, particularly wind and solar power, and examine how increases in generation affects prices, emissions, and competition using the Iberian electricity market as a case study. To provide a complete analysis, we combine a review of existing studies with the analysis of detailed emissions and wholesale electricity market data.

The European Green deal has set the target of reducing emissions by 55% relative to 1990 levels by 2030. We start by contextualizing the role of renewable energies, especially wind and solar, in achieving this goal. In Europe, although wind and solar production represent 20% of electricity generation, fossil fuels still account for 70% of total energy consumption. Focusing on Germany, France, and Spain, the three European countries with the largest amounts of installed renewable capacity, we show that, although wind and solar energy plays an increasing role in electricity generation, substantial differences in the energy mix will require different solutions to reach netzero. These challenges have been underlined during the energy crisis, with some countries facing stricter constraints to reduce their emissions.

The expansion of renewables has been promoted by strong state support policies and substantial reductions in development costs. However, we show that countries display differences in adoption that cannot be fully explained by differential renewable potential or deployment costs, suggesting the existence of additional obstacles limiting their expansion potential. These obstacles include complex and prolonged permitting processes, grid congestion, supply chain constraints, and social opposition. Thus, the European Union is incentivizing member states to implement reforms in order to accelerate permitting, improve grid infrastructure, and modify auction designs.

The expansion of renewables, can impact electricity markets by reducing emissions and prices. As wind and solar penetrates the market with close to zero marginal costs, technologies reliant on fossil fuels, with higher marginal costs, are displaced from the electricity mix. To analyze the marginal impact of wind and solar production on carbon emissions and wholesale electricity prices in the Iberian electricity market, we adapt the methodology of Petersen et al. (2024) and use detailed hourly data for the period from 2016 to 2022.

Consistent with findings in other countries, wind and solar deployment significantly reduce carbon emissions, with wind showing a larger effect (Callaway, Fowlie, and McCormick, 2018; Cullen, 2013; Sexton, et al., 2021). We show that in the Iberian market, although the impact of emissions becomes less pronounced as fossil fuel production is displaced, each additional GWh of wind production is estimated to reduce emissions by 200 to 300 tons of CO_2. We also show that, each additional GWh of wind and solar generation reduces prices by an average of 2e/MWh and 4e/MWh, respectively, with this effect being larger as renewable production increases. The downside of such reductions for the long-term viability of renewable projects is the so-called "cannibalization effect", for which increased renewable penetration reduces revenue for renewable producers and potentially disincentivizes further investments in these technologies.

Apart from the direct effect of renewables on prices and emissions, the deployment of wind and solar energy has altered the underlying market structure, increasing competition and reducing market power of traditional generators. Using data on market participation, we compute concentration indices for the Iberian market since 2017. The evolution of those indices shows that market concentration has decreased over time as renewables entered the mix. This negative correlation between incumbent market shares and renewable generation becomes particularly evident when looking at intraday patterns. During hours of peak solar production, market share of traditional firms decreases by 20 percentage points.

Last, we provide an overview of potential socioeconomic effects on the regions where renewables are being deployed. To do so, we review existing studies analyzing the impact of renewables on local employment and finances. These studies indicate that renewable investments hold a substantial potential to promote local employment, specially in the case of solar. However, there is a mismatch between local workforce skills and the requirements of renewable projects, limiting the positive effects for the community (Fabra, et al., 2024). Regarding municipal finances, Serra-Sala (2024) shows that wind farm development has a significant and sustained positive impact in municipal revenue, with benefits persisting throughout the wind farm's operational life.

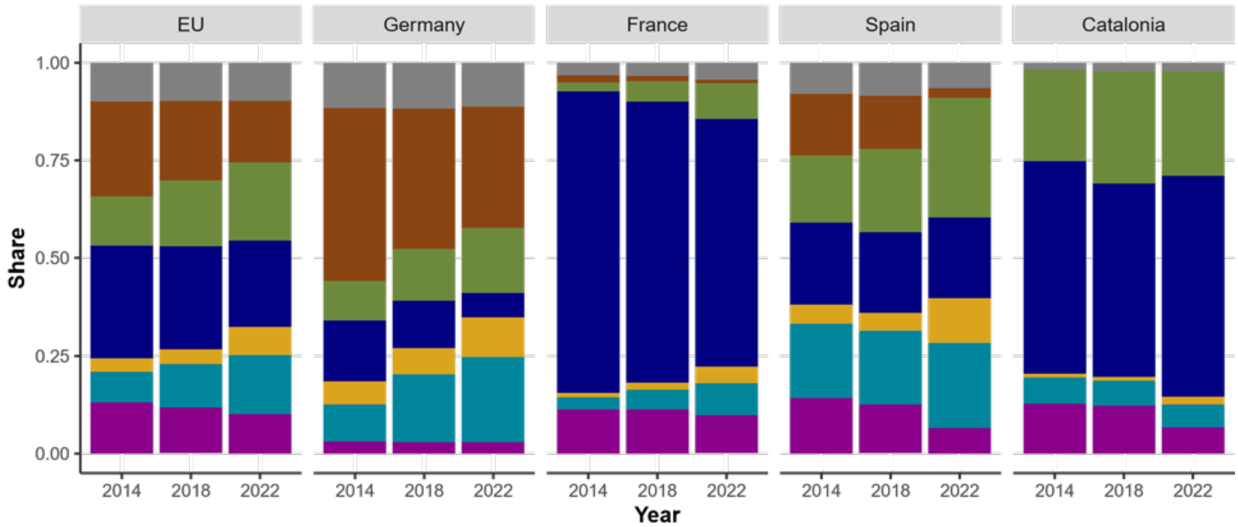
The rest of the paper is organized as follows. Section 2 contextualizes the role of renewable energies in the electricity sector. Section 3 provides an overview of current trends and targets in adoption. Section 4 analyzes the impact of wind and solar generation on carbon emissions and wholesale electricity prices. Section 5 discusses the effects on market competition. Section 6 provides an overview of potential socioeconomic impacts at the local level. Last, section 7 concludes.

2. Contribution of renewable energy to electricity production and the energy mix

To counteract climate change, the European Green Deal has set the target to reduce emissions by 55% relative to 1990 levels by 2030. Moving toward a cleaner energy system involves phasing out fossil fuels from the energy mix and increase reliance on clean energy sources. In this context, electricity production, where renewable technologies such as wind and solar hold significant weight, stands as a critical pillar to decarbonizing the energy system.

Simultaneously to increasing the share of renewables in electricity generation, promoting electrification is essential. Electricity is the energy source where renewables contribute most significantly. Thus, increasing electricity consumption at the expense of fossil fuels is a key strategy to increase the share of clean energy in the overall energy mix. This section describes the contribution of renewable energy sources, particularly wind and solar, to the electricity mix of European countries and examines their role in total energy consumption.

Figure 1: Electricity generation by energy source



Notes: Own elaboration with data from EMBER and the Spanish transmission sytem operator (REE).

Figure 1 illustrates the evolution of the electricity mix composition over the last decade for a selection of regions. At the European level, 55% of electricity generation comes from nuclear energy and renewable sources, while gas and coal remain significant contributors, accounting for 20% and 16% of the mix, respectively. Although the share of electricity produced from gas and coal has remained stable, coal use has significantly declined, offset by an increase in gas. In contrast, the weight of renewable energy sources has grown rapidly, with wind and solar energy rising from 11% of electricity production in 2014 to 22% in 2022.

While European electricity production is shifting toward a cleaner mix, it only accounts for only 23% of Europe's total energy consumption. Looking at the overall energy mix, which includes energy consumed in sectors beyond electricity generation, renewable energies[1] accounted for 18% of total energy consumption, whereas coal (13%), oil (37%), and natural gas (21%) collectively represented 70% of the energy consumed in Europe.[2]

The weight of renewable energies in the electricity mix is shifting over time and across countries (Figure 1). In Germany, the traditional European leader in renewable energy deployment, the phase-out of nuclear power has implied a strong reliance on fossil fuels, particularly coal and gas, as renewable capacity expands. With wind and solar energy accounting for 40% of electricity generation, the substantial weight of renewables in the electricity mix contrasts with the contribution of coal and gas. Although the combined share of coal and gas has declined over the past decade, it still accounts for 47% of Germany's electricity production.

In contrast, France's electricity mix is dominated by nuclear power, accounting for 63% of its electricity generation. Although the share of wind and solar has increased from 4 to 12 percent over the

1 In this case renewable energies take into account all sources that replenish themselves naturally, including biomass, biogases, renewable waste, hydropower, or wind and solar energy.

2 See https://ec.europa.eu/eurostat/web/interactive-publications/energy-2024

last decade, it remains significantly lower than the European average. France's energy strategy, dominated by strong state support for nuclear power, allows for electricity generation with minimal fossil fuel input. While over the last decade the share of gas has slightly increased, the use of coal has remained residual.

Spain's electricity mix sits between that of Germany and France. Wind and solar account for a significant share (33%), but electricity generation still depends heavily on nuclear power (20%) and fossil fuels (33%). While the participation of wind energy has steadily increased since the 2000s, rapid expansions in solar capacity over the last years have significantly increased its share in the mix. Over the last decade, coal participation has declined from 15% to 3%, replaced by a 12 percentage point increase in gas participation. Although Spain has a more diversified electricity mix, regional disparities and infrastructure limitations have created significant variations across different areas, with some of them diverging sharply from the national profile. In Catalonia, electricity production, while still dependent on gas imports, is dominated by nuclear power (56%), leaving wind and solar with an 8% contribution.

The need to accelerate the energy transition becomes more evident when examining total energy consumption across countries. Wind and solar contribution to the overall energy mix ranges from 9.7% in Spain, to 3.29% in France, while the contribution of fossil fuels (coal, oil, and gas) ranges from 45% in France, to 78% in Germany. Differences in fossil fuel reliance reflect differences in industrial needs and heating demands, as well as varying degrees of electrification across countries. On one hand, electricity consumption as a share of total energy consumption ranges from 19.6% in Germany to 25.3% in France. On the other hand, the share of nuclear power in the energy mix lays below than 1% in Germany, 13% in Spain, and 40% in France, explaining differences in fossil-fuel reliance across countries.[3]

3 See https://www.iea.org/countries/spain for Spain, https://www.iea.org/countries/france for France, and https://www.iea.org/countries/germany for Germany.

3. Trends in renewable energy adoption

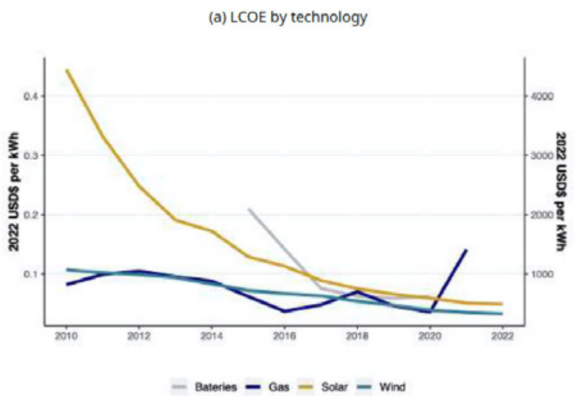
We are immersed in an energy transition that is gaining momentum. With development costs decreasing and governments positioning renewable energy as the key pillar in decarbonizing the energy sector, the global energy landscape is witnessing unprecedented expansions in renewable energy capacity. Since 2018, global solar and wind capacity has more than doubled, and 2023 has seen the largest increase in renewable electricity capacity to date. During 2023, the additions in global renewable capacity, estimated to be 507 GW, were almost 50% higher than total new capacity installed during 2022 (IEA, 2023).

Global efforts to achieve climate neutrality by 2050 are illustrated by multilevel commitments such as the 2023 COP28 target to triple the world's installed renewable energy capacity to 11,000 GW by 2030. In this context, the development of solar photovoltaic and wind energy, the leading renewable technologies, is expected to grow substantially, accounting for 92% of the total projected increase in renewable capacity by 2030. At the European level, the Green Deal aims to increase the share of energy produced from renewable sources to 42.5% by 2030. Achieving this goal translates to a total renewable capacity of 1,236 GW to be installed by 2030, more than the double the current installed capacity.

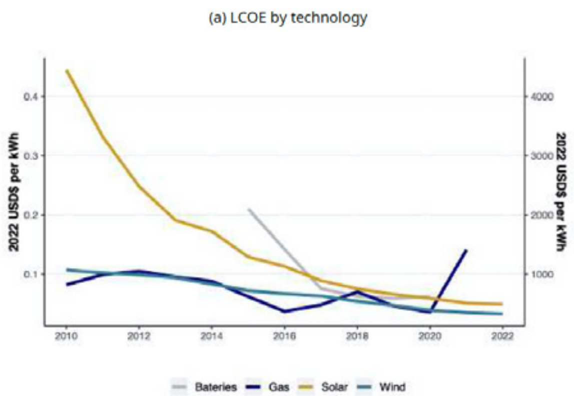
The opportunity that renewable technologies offer to produce clean energy while enhancing energy independence has made them the most viable option for decarbonizing the energy sector. Furthermore, the decrease in costs that these technologies have experienced over the last decade has boosted their competitiveness, making them an increasingly attractive option compared to fossil fuels. Figure 2a illustrates the evolution of the levelized cost of energy (LCOE) for wind and solar PV since 2010.[4] While the cost of wind energy has steadily declined, solar energy has seen a sharp improvement in competitiveness, with a 90% reduction in costs since 2010.

Figure 2: Cost and price of the main technologies

LCOE by technology



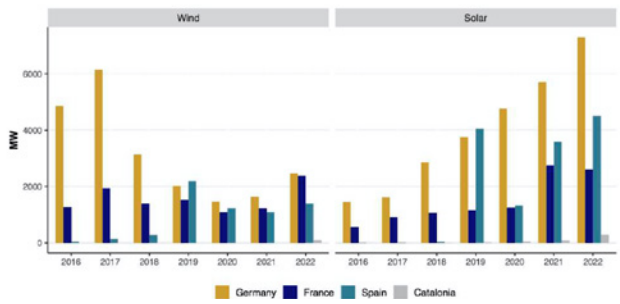
Evolution of wholesale prices



Notes: Own elaboration using data from IRENA, OMIE, and MIBGAS. In Panel A, the left vertical axis represents the cost of wind, solar, and gas. The right vertical axis represents the cost of batteries.

The unprecedented rise in gas prices in 2021 (Figure 2b) further enhanced the competitiveness of renewables relative to fossil fuels and demonstrated that these technologies not only provide a cheaper and cleaner energy source but also a more stable and reliable one. Ultimately, wind and solar energy depend only on meteorological factors, which are more predictable than the geopolitical uncertainties affecting fossil fuel prices.

Figure 3: Evolution of newly installed capacity



Notes: Own elaboration with data from IRENA and the Spanish transmission system operator (REE).

Despite the global trends in renewable deployment, growth has been uneven across regions and countries. While Europe has been one of the initial leaders in the energy transition, China accounted for 56% of the global expansion in solar PV and wind adoption in 2023 (IEA, 2023). Europe's historical progress has been driven by supportive public policies, increased concerns about energy security, and the increasing competitiveness of renewable energy compared to fossil fuels alternatives. However, supply chain limitations, delayed policy responses, and a changing macroeconomic environment marked by rising inflation and interest rates, threaten to decelerate the transition in this region. In contrast, China's renewable power expansion is being stimulated by the availability of locally manufactured equipment and low fi-

4 The levelized cost of energy (LCOE) is defined as the total cost of constructing and operating a plant, divided by the total energy generated over its lifetime.

nancing costs, positioning the country as a key player in the global acceleration of renewable energy adoption.

Focusing on the European context, the European Commission has set ambitious targets under the Green Deal: reaching 592 GW of solar PV and 510 GW of wind capacity by 2030. Meeting these goals will require substantial growth in renewable capacity across member states. As of 2023, the European Union had installed 260 GW of solar PV capacity and 240 GW of wind capacity.

While multilevel agreements set benchmarks for the energy transition, specific policies and targets are decentralized at lower regional levels, leading to significant differences in renewable energy adoption across territories. Figure 3 focuses on Germany, Spain, and France, the three European leaders in terms of installed renewable capacity. New solar installations have seen rapid growth across all three countries. As of 2022, Germany keeps leading the adoption of both wind and solar renewable deployment. In Spain, aside from a slowdown in 2020 due to the Covid-19 crisis, annual installations of large-scale solar power have averaged around 4 GW, with wind installations at a minimum of 1 GW per year.

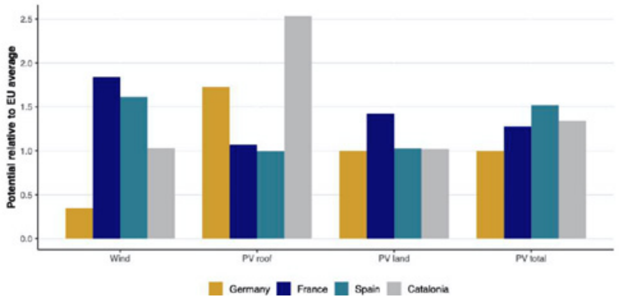
Differences in renewable development exist not only between countries but also within them. In Spain, although renewable development at the national level is progressing rapidly, there are substantial disparities across regions, with Catalonia ranking last in large-scale renewable investment. As shown in Figure 3, investment in Catalonia over the past six years has been virtually nonexistent, resulting in a lost decade for transitioning to a more sustainable and decentralized model. Importantly, the lack of new development in this region is not due to less ambitions energy policy targets or a lower potential for these technologies (Figure 4).

According to PROENCAT, the Catalan energy plan toward 2050, the goal is set at 12 GW of installed renewable capacity by 2030 (5 GW of wind and 7 GW of solar), and 62 GW by 2050. This goal contrasts with the 1,300 MW of wind and 736 MW of solar capacity installed at the end of 2022. Although the trend in new development appears to be increasing, with 300 MW of wind and 100 MW of solar energy installed in 2022, the current situation is still very far from achieving the established goals.

Differences in renewable energy deployment across European countries cannot be attributed solely to renewable energy potential. For instance, despite Germany's relatively low wind potential (Figure 4), it leads Europe in installed capacity (Figure 3). The mismatch between renewable potential and adoption indicates that, beyond meteorological and geographical factors, political, administrative, and economic factors play a significant role in shaping renewable energy adoption.

The IEA (2024) has identified several obstacles limiting renewable capacity expansion in Europe, leading the agency to estimate that total renewable energy capacity will fall 11% short of the REPowerEU targets for 2030. These obstacles include complex and prolonged permitting processes, grid congestion, supply chain constraints, and social opposition. Specially, delays in permitting and limited development areas have led to project cancellations and construction delays.

Figure 4: Renewable potential by technology



Notes: Own elaboration with data from the Energy and Industry Geography Lab.

Another relevant factor slowing down wind development is inadequate network capacity and complicated grid connection procedures due to the geographical distribution of wind potential and the inherent variability of this resource. First, wind production centers are often located far from demand centers and require of adequate transmission infrastructure to deliver energy to the grid. Second, the variability in wind production, which depends on meteorological factors, implies that as installed capacity increases, the electricity grid must implement balancing mechanisms to integrate these variable sources while ensuring network stability. Consequently, network limitations have created long queues, increasing costs for developers and delaying project timelines.

In response to these challenges, the European Commission has released targeted guidelines, and member states have implemented reforms to accelerate permitting, improve grid infrastructure, and modify auction designs. Although these measures help improve wind deployment, further efforts are needed to streamline permitting, enhance grid flexibility with storage solutions, and mobilize new investments in grid infrastructure and electrification.

4. The impact of renewable energies on prices and emissions

The expansion of renewable energies significantly impacts the structure of electricity markets on different fronts. In marginal electricity markets, where the electricity price is determined by the marginal cost of the last energy source entering the electricity mix, renewables, with marginal costs close to zero, have the potential to significantly affect electricity prices. Additionally, renewables contribute to reducing emissions derived from electricity generation by displacing fossil fuels from the electricity mix. Furthermore, renewable energies have the potential to increase welfare through improvements in consumer surplus, not only due to their direct effect on electricity prices but also by improving competition in the market.

Petersen et al. (2024) estimate the impact of wind energy on intermittency costs, prices, and emissions by focusing on the Iberian electricity market. More specifically, they exploit exogenous variation in hourly wind forecasts and assess the effect on emission by concentrating on carbon dioxide. To determine the average effect of wind generation on prices and emissions, we estimate the following specification:

$$Y_t = \beta_0 + \beta_1 W_t + \gamma X_t + \epsilon_t \quad (1)$$

where Y_t is the outcome of interest, W_t is the forecasted wind or solar energy in the market, X_t includes control variables, and ϵ_t is the error term.[5] The results reported in this section further include month-of-sample fixed effects interacted with hourly fixed effects to control

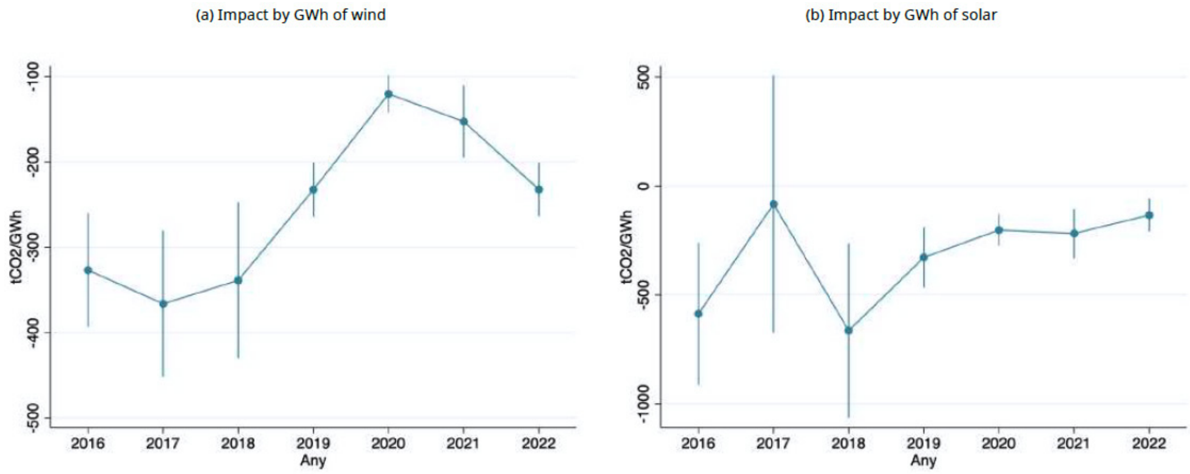
5 Following the analysis of Petersen et al. (2024), control variables include daily natural gas prices, hourly forecasted demand, temperature, temperature squared, and photovoltaic generation.

for predictable fluctuation in market condition that might not be captured by the control variables. By estimating this equation using OLS and clustering standard errors at the month of sample level, the coefficient of interest, β_1, represents the marginal effect of a one GWh increase in wind or solar generation on the outcome of interest, prices or emissions.

4.1 Impact of renewable energies on emissions offsets

As deployment of renewable energy increases, fossil fuels required to meet electricity demand are reduced. The economics literature consistently finds that renewable energy for electricity generation lowers emissions by displacing traditional fossil fuels from the electricity mix. Focusing on the USA, studies such as Callaway et al. (2018); Cullen (2013); Kaffine, McBee, and Lieskovsky (2013); Novan (2015); Siler-Evans, Azevedo, and Morgan (2012) or Sexton et al. (2021) analyze substitution patterns between renewable and conventional energy sources. The results of these studies show that increases in renewable energy lead to reductions in pollution significant enough to justify the subsidies supporting these technologies. However, reductions in emissions due to renewable energy are not homogeneous, as depend on the region, time of day, and baseline electricity mix.

Figure 5: Impact of wind and solar deployment on emissions



Notes: Adaptation of Petersen, Reguant, and Segura (2024). Own elaboration with data from transmission system operation (REE) and the Iberian market operator (OMIE)

Consistent with findings in other countries, renewable energy production in the Iberian market, particularly from wind and solar, significantly contributes to reducing CO_2 emissions. As shown in Figure 5, each additional GWh of wind energy is estimated to decrease emissions by between 200 and 300 tons of CO_2. Although this effect has become less pronounced over time due to the decarbonization of the electricity market, the temporary increase in coal usage during the gas crisis and reduced hydro resources caused the marginal impact of wind to rise again above 200 tons.

A key distinction between renewable technologies and traditional energy sources is that renewables, especially wind power, rely on meteorological conditions that vary and cannot be perfectly forecasted. Because electricity generation must always match consumption, in absence of sufficient storage options the intermittency of renewable sources has to be balanced with electricity generated from conventional sources like coal or gas. Specially in the case of wind generation, its variability affects the operation of the electricity grid and limits the potential of renewables to save emissions, especially at high levels of wind penetration Dorsey-Palmateer (2019).

How intermittency affects emissions offset varies across grids, as it depends on the generation mix and the capacity to shift to cleaner sources to compensate for wind variability. Studies such as Gutierrez-Martin, Silva-Alvarez, and Montoro-Pintadó (2013); Kaffine, McBee, and Ericson (2020), or Dorsey-Palmateer (2019) examine how sudden increases or decreases in fossil fuel generation, known as cycling, and the inconsistent ramping up and down of power plants resulting from the variability of renewable energies reduces the potential of these technologies to offset emissions. Focusing on the USA, Kaffine et al. (2020) shows that when the share of wind in the electricity mix is between 10 and 20 percent, at mean values of intra-hour wind intermittency, savings in CO_2 emissions are reduced by an average of 6.5%, and by nearly 10% at the highest levels of intermittency.

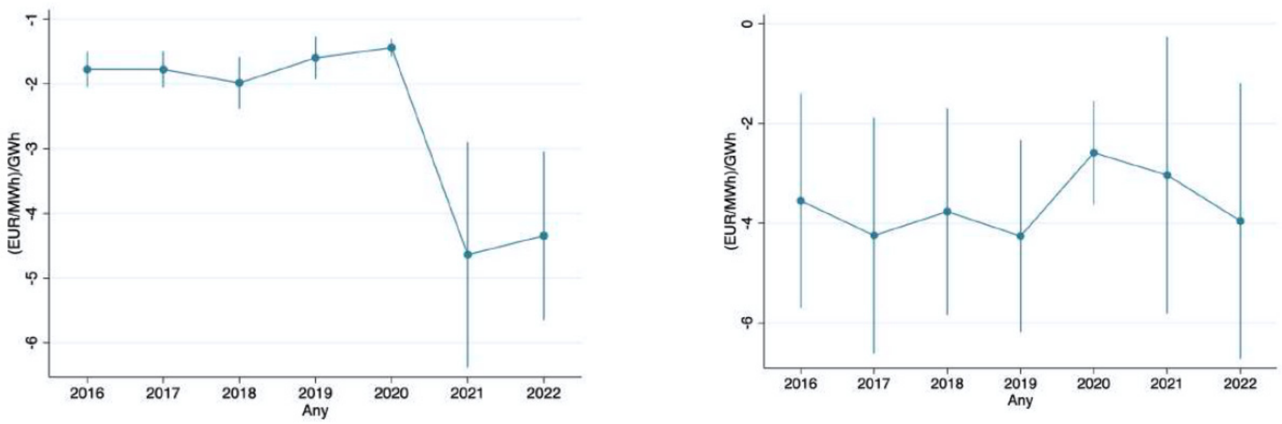
In grids with high carbon reliance, intermittency in renewable generation can lead to further emission reductions due to a shift from coal-based production to gas. Gas-fired combustion turbines and combined-cycle facilities are specifically designed to handle cycling. Thus, increases in intermittency can lead to a substitution of coal, the most polluting energy source, for gas. Consequently, emissions can be further reduced in regions with a mix of natural gas and coal, allowing to switch between those technologies to compensate for renewable intermittency (Dorsey-Palmateer, 2019).

4.2 Impact of renewable energies on prices

Studies in electricity markets of different countries have documented reductions in wholesale electricity prices due to increases in renewable energy production (Bushnell and Novan, 2021; Gelabert, Labandeira, and Linares, 2011; Ketterer, 2014; Maciejowska, 2020; Woo et al., 2011). In marginal pricing systems, power plants with different production costs offer electricity until demand is met. At the point where the market clears, the price is set by the last plant dispatching electricity and paid to all producers. As energy offers are ranked according to their offered price, the expansion of renewable energies, with marginal costs close to zero, displaces plants typically based on fossil fuels, leading to an overall reduction in electricity prices known as the merit-order effect (Sensfuß, Ragwitz, and Genoese, 2008).

In the Iberian market, the deployment of wind and solar energy has also led to substantial reductions in electricity prices. Figure 6 presents the results of estimating Equation 1 on hourly wholesale electricity prices from 2016 to 2022. These results indicate that each additional GWh of wind generation reduces wholesale electricity prices by 2e/MWh (Figure 6a). This effect, which has remained relatively stable over the last years, increased substantially during the 2021-2022 gas crisis. The rise in electricity prices, primarily driven by higher gas prices, resulted in greater reductions in wholesale electricity prices when gas-based power plants were displaced by wind power. During the crisis, each additional GWh of wind generation lowered wholesale prices by 5 to 6e/MWh.

Figure 6: Impact of wind and solar deployment on electricity prices



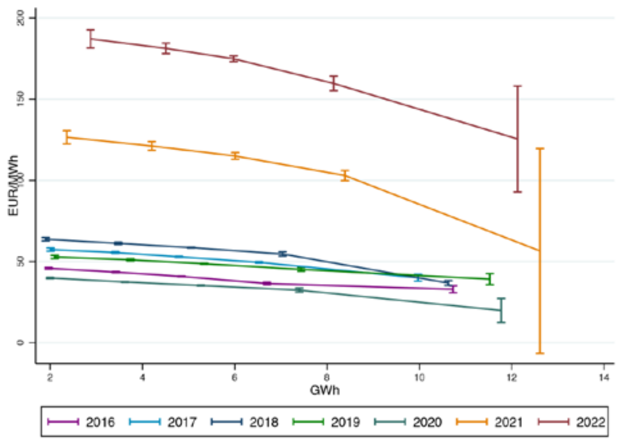
Notes: Adaptation of Petersen, Reguant, and Segura (2024). Own elaboration with data from Spanish transmission system operator (REE) and the Iberian market operator (OMIE).

Solar generation also has a significant impact on electricity prices. Figure 6b shows that each additional GWh of solar power reduces wholesale prices by 4e/MWh. This price reduction was even more pronounced before the gas crisis. Since solar energy is primarily generated during daytime hours, it typically enters the electricity mix when prices have historically been higher. As the electricity mix shifts, periods where the lowest prices occur during daytime hours have become more common, attenuating the marginal impact of solar energy on prices that are already close to minimum levels.

Other studies looking at the impact of renewable energy expansion on energy prices in markets like Spain and California have found similar effects. Bushnell and Novan (2021) shows that in the California market, growth of solar capacity leads to an overall decline in daily average prices. Although in aggregate terms, solar production has a negative influence on prices, this effect is not uniform across all hours. During daylight hours, solar expansion lowers wholesale prices due to significant reduction in output from natural gas generators and imports. However, prices rise during non-daylight hours, particularly in the early morning and evening. During those hours, ramp up and down cause a shift in the type of gas plants generating energy, from more efficient combined cycle gas turbines to more flexible but higher marginal cost ones (Bushnell and Novan, 2021).

The reduction in electricity prices resulting from increased renewable energy production leads to a "cannibalization effect" through which the growing penetration of renewable technologies diminishes their own market value. Sustained reductions in electricity prices, especially during periods of high renewable generation, translate into reduced revenue for renewable producers, undermining the profitability of these technologies (Hirth, 2013; Maciejowska, 2020; Peña, Rodriguez, and Mayoral, 2022).

Figure 7: Cannibalization in wholesale electricity prices



Notes: Adaptation from the analysis of Petersen, Reguant, and Segura (2024). Own elaboration with hourly data from Spanish transmission system operator (REE) and the Iberian market operator (OMIE).

In the Iberian market, the large presence of renewables makes cannibalization likely to occur frequently. Figure 7 illustrates average electricity prices at varying levels of wind production from 2016 to 2022. The patterns in this figure indicate that as wind production increases, prices decrease. From 2018 to 2020, coinciding with a period of large wind capacity expansion, increases in wind production were related to a decrease in prices. This trend indicates that, while electricity prices decrease with higher wind production, for a given level of wind energy generated, the reduction in price intensifies over time. This decreasing trend was interrupted during the energy crisis of 2021 and 2022, when a surge in gas prices led to an unprecedented spike in electricity prices. During this period, benefits for renewable generators were significantly larger than expected, with increases in wind production having a considerably larger effect on electricity prices than before.

Although renewable penetration in the Iberian market is substantial, hours with electricity prices close to zero are still relatively infrequent. Hourly data from the wholesale electricity market from 2016 to 2020 shows that prices below 10 e/MWh are present in around 3% of the time. Even in 2020, when the Covid-19 crisis led to high solar production and moderate electricity demand, low prices were present from 3 to 5 percent of the time and concentrated during hours of peak solar production and maximum wind generation.

Cannibalization effects can take place also in a crossed form, when increases in the penetration of a technology decreases the market value of another renewable technology. Focusing on hourly data in California from 2013 to 2017, Prol, Steininger, and Zilberman (2020) show that, while wind penetration negatively affects solar values, the effect of solar penetration on wind is positive. Since solar generation is more concentrated around midday, high solar production causes a price drop during those hours, followed by a spike in the evening when wind generation is still present and wholesale prices increase due to ramp up and down of gas turbines.

Measures improving renewable flexibility such as demand response, storage, and grid improvements can help mitigate reductions in renewable competitiveness and investment incentives due to cannibalization effects. Storage and demand management allow transferring renewable electricity between periods of low and high values, smoothing fluctuations in hourly prices. At the same time, grid improvements increasing connectivity help prevent congestion and allows connecting regions with complementary generation patterns. Thus, the stronger the cannibalization effect, the higher the value of flexibility measures.

In the absence of improved flexibility, cannibalization is often mitigated when producers have the capacity to self-regulate energy production on days with excess renewable generation. This self-regulation, known as "curtailment", takes place when a producer strategically decides not to generate renewable energy and affect wholesale prices. When curtailment takes place, participating companies are often more actively involved in both the bidding and balancing processes, in which they have been able to participate since 2016.

Market concentration, even among renewable power producers, increases the capacity of companies to regulate production. The current market structure, in which small producers receive a fixed price through power purchase agreements (PPA), and intermediary actors assume most of the risk in wholesale markets, facilitates this self-regulation. Most of the renewable production is offered at the market either through large generation companies or intermediaries in the wholesale market with substantial market shares.

4.3 Overall welfare impacts

Given the significant reduction in prices and emissions, the expansion of renewable generation has increased consumer welfare. How does this compare to its costs? Several studies have quantified the overall cost-benefit of renewable policies in a variety of contexts. Several papers in the European context accounting for reasonable costs of carbon find positive welfare effects for solar (Abrell, Kosch, and Rausch, 2019) and wind (Abrell et al., 2019; Liski and Vehviläinen, 2020) in Germany, Spain, and the Nordic electricity market.

Following the results from the same study in the Iberian Peninsula highlighted before, Petersen, Reguant, and Segura (2024) find that consumers can be better off in the presence of subsidies to large scale renewables despite its costs. As renewables expand, reductions in market prices benefit consumers, while negative impacts are being endured by traditional power producers, which see generation and prices diminished. The overall public benefits of these policies are further increased when one accounts for the environmental benefits from reduced emissions.

An additional argument for renewable subsidies often focuses on their market equilibrium effects on the supply side. Several studies have investigated how renewable subsidies enhance technological learning (Bollinger and Gillingham, 2019; Bradt, 2024; Myojo and Ohashi, 2018) and innovation (Gao and Rai, 2019; Gerarden, 2023) among solar installers and manufacturers. Covert and Sweeney (2024) and Anderson, Leslie, and Wolak (2019) study similar economic forces in the wind industry. While they do not focus on the role of renewable subsidies, Covert and Sweeney (2024) find spillovers across firms that could provide a justification for renewable subsidies.

5. The impact of renewable energies on the structure of the Iberian electricity market

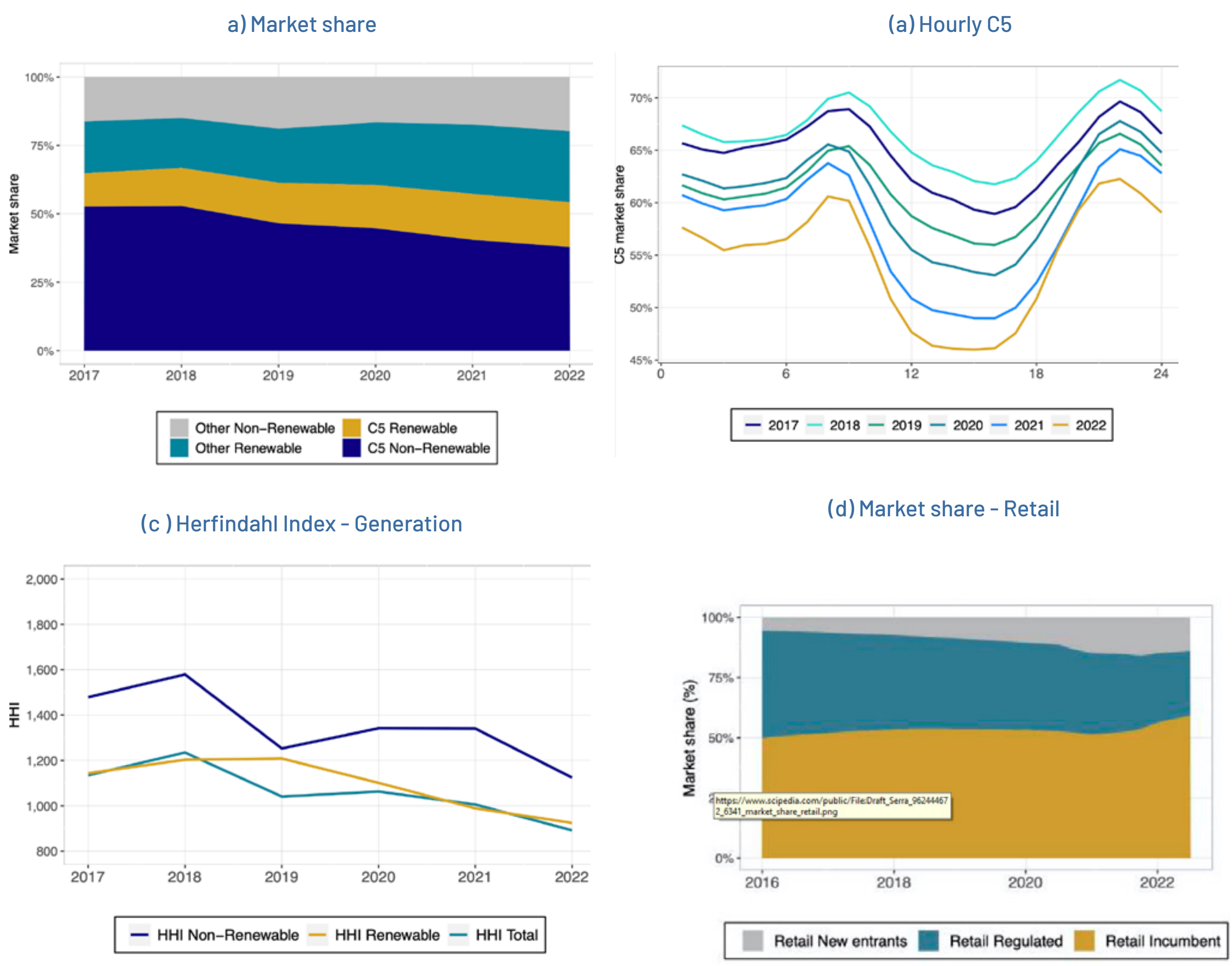
The Iberian electricity market has traditionally been dominated by vertically integrated companies, with Iberdrola and Endesa, the two largest companies, historically holding a combined market share of above 70%. Although the market keeps being relatively concentrated, its liberalization in the late 1990s and the entry of renewable energy producers has helped increase competition. Renewable energy production is typically characterized by having lower operational costs and being more distributed than traditional fossil fuel plants. These lower costs reduce entry barriers, allowing new players, including smaller firms, to enter the market and compete with incumbent companies, thus increasing overall market competition.

In the Iberian market, the growth of renewable energies continues to increase competition. Figure 8 illustrates the evolution of the C5 and Herfindahl-Hirschman (HHI) indices. These indices are computed using detailed hourly data of participation in the wholesale market from REE and OMIE, covering the period from 2017 to 2022. The C5 index reflects the combined market share of the five main incumbent companies with traditionally the largest market shares (Iberdrola, Endesa, Naturgy, EDP, and Repsol). The HHI index is calculated as the sum of the squares of each company's market share, scaled from 0 to 10,000, with 10,000 representing a monopoly with a 100% market share.[6]

Over the last decade, the market share of the five largest incumbent firms has decreased by 10 percentage points, falling from over 60 percent in 2017 to just above 50 percent in 2022 (Figure 8a). Excluding the potential impact of self-consumption, this overall decline in the C5's share masks a 15 percentage point reduction in their non-renewable share, partly offset by an increase in their renewable share from 12 to 16 percent. At the same time, the market share of the renewable energy among non-C5 companies has been increasing, shifting market concentration dynamics toward a more competitive landscape.

6 The classification of plants requires a complete mapping of companies and their subsidiaries. The results in this section provide an approximation of market concentrations and may contain minor errors if companies are not fully classified.

Figure 8: Evolution of concentration indices



Notes: Own elaboration with data from the Iberian market operator (OMIE), Spanish transmission system operator (REE) and the Spanish Competition Authority (CNMC) from 2017 to April 2022. Renewable energies include wind, solar, and small hydropower. Cogeneration and biomass, as well as other special regime categories, are included in the non-renewable category. The HHI for the wholesale generation market is computed for all firms in OMIE. The market share of the Incumbents in the retailing sector aggregates the market share of the firms that also act as a distributor and, thus, can operate in the regulated segment.

The potential of renewables to reduce market concentration is further demonstrated by fluctuations in market shares during periods of high renewable generation throughout the day. Figure 8b displays the hourly evolution of the C5 index from 2017 to 2022. Independently of the time of day, the patterns described in this figure reveal a progressive decline in the market power of incumbent companies over the years. Focusing, on hours of peak solar generation, the C5 has already reached values below 50 percent, suggesting that during these hours production of traditional companies are no longer the primary market leaders. Large renewable energy retailers now hold market shares comparable to those of some traditional producers.

As renewable generation increases, the lower concentration within this sector helps reduce total concentration in the electricity market. Figure 8c shows the evolution of the HHI index for overall electricity production, as well as a breakdown by renewable and non-renewable production. Although concentration indices in the electricity market exhibit values that are considered low from a competition perspective, total concentration has been decreasing over time. In 2017, total market concentration had an HHI index of 1,200, which has decreased to 1,000 points by 2022.

When comparing the renewable and non-renewable sectors, renewable generation shows significantly lower concentration indices than non-renewable generation. Both sectors show a substantial drop in concentration indices in 2018, coinciding with the expansion of wind and solar capacity. This expansion has reduced the HHI for non-renewable production to approximately 1,200, close to the average concentration level of the overall market at the beginning of the period. Although renewable production tends to be more decentralized, its HHI index is comparable to the market average due to the presence of large renewable operators managing substantial market shares.

Concentration in the retailing sector, although higher than in the generation sector, has also experienced a slow but progressive decrease (Figure 8d). This trend was reversed during the 2021 gas crisis, especially in the residential sector. Purchases in the wholesale market are primarily conducted by vertically integrated companies participating in both electricity production and retailing. The presence of natural monopolies in distribution, with exclusive rights to serve the residential sector until 2011, makes market concentration in this segment especially high.

Larger concentration in the retailing sector is explained by the traditional monopoly structure, with incumbent firms still having over 80% of market share in their original territories. It is also partially explained by higher risks associated to this sector, especially when companies are lacking enough diversification. A lack of diversification can expose retailers to significant financial risks during periods of price spikes, as observed by the worsening of the market shares for the new entrants during the energy crisis in 2022.

During the gas crisis, the vertical integration of large groups, along with their diversified portfolios that include technologies without competition such as large-scale hydro and nuclear power, has given them a substantial advantage. This integration allowed them to be protected from market volatility and absorb fluctuations in gas prices in the aggregate of the group. During those years, not only did vertically integrated companies with diversified portfolios secure their market positions, large renewable producers with significantly lower marginal prices were specially benefited from increases in wholesale prices.

6. Local impacts of renewable energy deployment

A characteristic differentiating large scale wind and solar production from other sources of electricity is its distributed nature. Renewable energy facilities, located in areas where renewable resources are concentrated, are likely to have socioeconomic impacts that are spread across the territory. The development of this type of infrastructure, often located in rural areas, is often presented as an opportunity for economic activity and employment creation. Beyond the potential to generate employment, renewable energy deployment can also generate additional revenue for receiving municipalities through expansions of the tax base.

This section provides an overview of studies analyzing the local impacts of renewable energy deployment, with a particular focus on employment and municipal finances. Existing studies show that, although renewable energy deployment has significant potential to generate employment at an aggregate level, the local effects tend to be smaller and vary by technology type (Fabra et al., 2024). Beyond local employment effects, these projects contribute to municipal finances by increasing revenue from property taxes and capital income, which can be reinvested into community services and infrastructure (Serra-Sala, 2024).

6.1 The impact of renewable energy deployment on the labor market

One significant dimension of the energy transition is its potential impact on the labor market. In Spain, according to Martínez, et al. (2023), employment growth in activities related to the energy transition between 2015 and 2021 (10.6%) was similar to the overall employment growth in the economy (10.9%). At the national level, the main activities related to the energy transition that contribute to job creation include energy consulting and secondary activities such as manufacturing branches supplying inputs for the activities directly related to the transition. From 2015 to 2022, secondary activities accounted for 34% of energy transition employment, while energy consulting accounted for 26%. Jobs associated with electricity, grid, and self-consumption represented only 10% (Martínez et al., 2023).

The Spanish Integrated Plan for the Energy Transition (PNIEC 2023-2030) has set the goal of reaching 50 GW of wind energy and 37 GW of solar PV by 2030.[7] As renewable capacity expands, the potential for job creation within these sectors increases. However, labor needs of wind and solar technologies differ significantly along the lifetime of the installation, both in terms of quantity and skill levels.

During the construction and installation phases, labor needs are more reliant on mid and low skilled workforce, creating opportunities for local employment. This changes once the plant becomes operational. During the operations and maintenance phase, labor needs decrease and are more concentrated among highly skilled workers. This is particularly relevant for wind energy, where approximately 66% of operations and maintenance tasks are performed by skilled workers and highly qualified engineers with specialized knowledge in wind operations

7 See https://www.miteco.gob.es/content/dam/miteco/es/energia/files-1/pniec-2023-2030/PNIEC_2024 240924.pdf

(IRENA, 2017a). In contrast, solar installations require a larger proportion of on-site tasks during the operations and maintenance phase, many of which can be performed by a less specialized workforce (IRENA, 2017b).

Although both renewable technologies have the potential to create employment opportunities, these are not necessarily at the local level. To identify whether the development of renewable infrastructure creates employment within the region, Fabra et al. (2024) exploit the geographic and temporal variation of Spanish wind and solar investments over a 13-year period. Their results point to substantial differences in the creation of local employment between wind and solar projects. While the development of a wind farm does not have a significant effect on local occupation, each MW of solar energy installed in a municipality creates 1.5 jobs per year during the construction phase and 0.7 jobs per year during the operations phase.

To evaluate whether renewable deployment impacts employment beyond the municipality level, Fabra et al. (2024) analyzes employment effects at the county level. While there are no significant effects of wind deployment, each MW of solar power creates 4.5 yearly jobs during the construction phase and 3.5 yearly jobs during the operations phase. These results indicate that solar investments create employment opportunities not only for residents in the host municipality but also for those in nearby areas who commute to work at the solar plant. In addition to analyzing broader employment effects, the study compares the effect on job creation and on unemployment reduction. They find a larger increase in employment compared to the decrease in unemployment, which they argue it may be attributed to a mismatch between the skills of residents in rural areas and those needed to work at the solar plant.

The mismatch between local labor skills and job requirements limits the potential positive impact of renewable energy investments on local employment and explain differences in employment creating depending on the technology. According to the report by IRENA and ILO (2023) and the interpretation of Fabra et al. (2024), construction, installation, and maintenance of a wind farm involve a highly skilled workforce and tasks that can be performed remotely. In contrast, solar plants require less specialized labor, which can often be sourced locally.

6.2 Financial impacts of renewable infrastructure on host municipalities

The development of renewable infrastructure can impact hosting regions by increasing financial resources of receiving municipalities. This generation of revenue is especially relevant as it can be used to compensate local negative externalities through increased public spending or reductions in the tax burden. Most of the empirical evidence on the effect of renewable energy on municipal finances focuses on the USA (Brunner, Hoen, and Hyman, 2022; Brunner and Schwegman, 2022; De Silva, McComb, and Schiller, 2016). In the European context, Costa and Veiga (2021) documents a positive impact of wind farm development on the financial resources of Portuguese municipalities, largely driven by a special tax requiring 2.5% of wind farm revenues to be paid to the municipality.

In the absence of specific taxes on renewable facilities, the primary channels through which municipalities can financially benefit from renewable deployments are existing tax instruments or capital investments in those facilities. In Spain, a large share of municipal financial resources are generated by revenue from the property tax, construction tax, and the economic activities tax. While the construction tax is an indirect tax paid during the construction phase, the property tax and the economic activities tax are paid annually, creating a potentially long-lasting and stable source of income to host municipalities.

To study the financial impact of renewable investment on host municipalities, Serra-Sala (2024) analyzes the evolution of Spanish municipal budgets from 1994 to 2022. By exploiting the temporal and geographical variation in the wind farm deployment, this study shows that wind farm development results in a substantial increase in municipal financial resources, which is mainly used to increase current expenditure and real investments. This increase in revenue, partially driven by an expansion of the tax base, is complemented by revenue generated from capital income, as well as an increase in tax rates targeted at these infrastructures.

To provide a comprehensive analysis of this impact, Serra-Sala (2024) decomposes the increase in municipal revenue by its different sources and examines its temporal dynamics. The results indicate that, in aggregate, the development of a wind farm leads to an average increase of 343 euros in revenue per capita. The magnitude of this effect, representing a 45 percent increase in revenue per capita, has to be evaluated considering that affected municipalities tend to be small and thus have very limited budgets. When examining the temporal dynamics of this effect, the study shows that the increase in revenue is driven by larger revenue from indirect taxes during the construction phase (i.e. the construction tax), and a sustained increase in capital income and direct taxes once the facility starts operating.

While empirical evidence shows that renewable energy infrastructure can generate significant revenue for host municipalities, limited competencies and resources available to effectively invest in public goods may limit the capacity to compensate for negative externalities associated with these facilities. Additionally, as the increase in revenue is concentrated in the municipality where the installation takes place, the lack of benefits extending to the broader area can limit the potential to mitigate local opposition to further renewable investments.

7. Conclusion

The deployment of renewable technologies stands as a central pillar in global efforts to reduce carbon emissions and mitigate climate change. As the integration of renewables continues to grow, electricity markets and energy mixes are reshaped. Beyond describing current trends in renewable energy deployment, we provide an overview of the impacts of large-scale wind and solar investments on market dynamics, wholesale prices, emissions, competition, and the local economies hosting these infrastructures.

One of the most direct effects of renewable energy deployment is its impact on emissions. We show that in the Iberian market, each additional GW of wind or solar generation is estimated to reduce emissions between 200 and 300 tons of CO_2. However, intermittency in renewable production, specially for wind, can mitigate their potential in reducing emissions. Existing literature documents how, in periods of wind and solar variability, fossil-fuel plants need to increase output to meet demand, partially offsetting reductions in emissions associated to renewable production.

In addition to impacting emissions, the integration of renewables significantly contributes to reduce electricity prices by displacing of energy sources with higher costs. The Iberian market is no exception. We show that each additional GWh of wind and solar generation reduces wholesale prices by 2e/MWh and 4e/MWh respectively. These price reductions, which become larger as the share of renewable production grows, can lead to the "cannibalization" of these technologies. Although in the Iberian market, hours with prices below 10e/MWh are present 3% of the time, and thus still infrequent, policies promoting an enhanced system flexibility become a cornerstone as renewables continue to expand. Measures targeting demand responses, energy storage, or grid improvements increase system flexibility and help absorb the surplus electricity generated during hours of peak renewable generation and stabilize price fluctuations, secure returns to renewable investments, and reduce dependence on fossil fuels to maintain grid stability.

Beyond looking at the impact on prices and emissions, we show that as renewables keep integrating in the Iberian market, the market share of the five largest incumbent firms in the generation sector has fallen from above 60 percent in 2017 to just above 50 percent in 2022. Lower costs associated to wind and solar installations, together with a more distributed nature of these resources, improves market competition by allowing new players to enter the market. In hours of peak solar generation, large incumbent companies, with market shares falling below 50 percent, are no longer the primary market leaders.

Although in the generation sector competition keeps increasing, in the retailing sector, concentration remains high, with a combined market share of the incumbent firms around 80%. This larger concentration is partially explained by incumbency advantages from the previously regulated sector and from higher risks associated to price volatility when lacking enough diversification, together with search frictions from households (Enrich et al., 2022). These three effects give substantial advantage to the main incumbents, as vertical integration allows them to diversify across different energy sources, spreading risk and reducing exposure to market volatility. In Spain, these companies still enjoy over 80% of the market share in their territories.

We complement our analysis by reviewing existing evidence on the local socioeconomic impacts of renewable investments in Spain. Fabra et al. (2024) study the local employment effects of wind and solar projects and show that, each MW of solar capacity installed increases employment in the region by 4.5 jobs per year during the construction phase, and 3.5 jobs per year once the plant becomes operational. In contrast, wind developments, which heavily rely on workers with specialized technical skills, are not found to have a significant effect. On the financial side, Serra-Sala (2024) shows that wind farm development leads to a substantial increase in municipal resources through expansions of the tax base complemented by increased tax pressure on renewable infrastructures, and revenue generated from capital income. These infrastructures, commonly installed in small municipalities with reduced budgets, are found to increase municipal revenue per capita in 343e, a 45% increase relative to predevelopment revenue. Yet, positive impacts of renewable development can be limited by a mismatch of skills between the local labor force and the installation needs, as well as by the concentration of municipal revenue in the localities where installation are developed.

In conclusion, we show that large-scale renewable energy deployment offers significant benefits in terms of reduced electricity prices, lower emissions, and enhanced market competition. However, renewable cannibalization, market volatility, and intermittency, present challenges requiring coordinated policies and regulatory responses to sustain the economic viability of renewable investments. Addressing these challenges is essential for sustaining the pace of renewable investments and keep advancing in the transition to a decarbonized grid. From this perspective, policies and further research into regional disparities, storage solutions, and effective market design are crucial to maximizing the socioeconomic and environmental benefits of low-carbon electricity.

References

ABRELL, J., KOSCH, M., and RAUSCH, S. (2019) "Carbon abatement with renewables: Evaluating wind and solar subsidies in Germany and Spain" Journal of Public Economics, 169, 172–202.

ANDERSON, J. W., LESLIE, G. W., and WOLAK, F. A. (2019) "Measuring the impact of own and others' experience on project costs in the U.S. wind generation industry" National Bureau of Economic Research, Working Paper No. 26114.

BOLLINGER, B., and GILLINGHAM, K. (2019) "Learning-by-doing in solar photovoltaic installations" Available at SSRN 2342406.

BRADT, J. (2024) "A policy by any other name: Unconventional industrial policy in the US residential solar industry" Working Paper.

BRUNNER, E., HOEN, B., and HYMAN, J. (2022) "School district revenue shocks, resource allocations, and student achievement: Evidence from the universe of us wind energy installations" Journal of Public Economics, 206, 104586.

BRUNNER, E. J., and SCHWEGMAN, D. J. (2022) "Windfall revenues from windfarms: How do county governments respond to increases in the local tax base induced by wind energy installations?" Public Budgeting and Finance, 42(3), 93–113.

BUSHNELL, J., and NOVAN, K. (2021) "Setting with the sun: The impacts of renewable energy on conventional generation" Journal of the Association of Environmental and Resource Economists, 8(4), 759-796.

CALLAWAY, D., FOWLIE, M., and MCCORMICK, G. (2018) "Location, location, location: The variable value of renewable energy and demand-side efficiency resources" Journal of the Association of Environmental and Resource Economists, 5(1), 39-75.

COSTA, H., and VEIGA, L. (2021) "Local labor impact of wind energy investment: An analysis of portuguese municipalities" Energy Economics, 94, 105055.

COVERT, T. R., and SWEENEY, R. L. (2024) "Winds of Change: Estimating Learning by Doing without Cost or Input Data" Workin Paper.

CULLEN, J. (2013) "Measuring the environmental benefits of wind-generated electricity" American Economic Journal: Economic Policy, 5(4), 107-33.

DE SILVA, D. G., MCCOMB, R. P., and SCHILLER, A. R. (2016). "What blows in with the wind?" Southern Economic Journal, 82(3), 826–858.

DORSEY-PALMATEER, R. (2019) "Effects of wind power intermittency on generation and emissions" The Electricity Journal, 32(3), 25-30.

ENRICH, J., LI, R., MIZRAHI, A., and REGUANT, M. (2022) "Smart Meters and Retail Competition: Trends and Challenges" AEA Papers and Proceedings, 112, 461-465.

FABRA, N., GUTIÉRREZ, E., LACUESTA, A., and RAMOS, R. (2024) "Do renewable energy investments create local jobs?" Journal of Public Economics, 239, 105212.

GAO, X., and RAI, V. (2019) "Local demand-pull policy and energy innovation: Evidence from the solar photovoltaic market in China" Energy Policy, 128, 364–376.

GELABERT, L., LABANDEIRA, X., and LINARES, P. (2011) "An ex-post analysis of the effect of renewables and cogeneration on Spanish electricity prices" Energy Economics, 33.

GERARDEN, T. D. (2023) "Demanding innovation: The impact of consumer subsidies on solar panel production costs" Management Science, 69(12), 7799–7820.

GUTIERREZ-MARTIN, F., SILVA-ALVAREZ, R. D., and MONTORO-PINTADO, P. (2013) "Effects of wind intermittency on reduction of CO2 emissions: The case of the Spanish power system" Energy, 61, 108-117.

HIRTH, L. (2013) "The market value of variable renewables: The effect of solar wind power variability on their relative price" Energy Economics, 38, 218-236.

IEA (2023) "Renewables 2023 - Analysis and forecast to 2028" International Energy Agency.

IEA (2024) "Renewables 2024 - Analysis and forecast to 2030" International Energy Agency.

IRENA (2017a) "Renewable energy benefits: Leveraging local capacity for onshore wind" International Renewable Energy Agency, Abu Dhabi.

IRENA (2017b) "Renewable energy benefits: Leveraging local capacity for solar pv" International Renewable Energy Agency, Abu Dhabi.

IRENA and ILO. (2023) "Renewable energy and jobs: Annual review 2023" International Renewable Energy Agency, Abu Dhabi and International Labour Organization, Geneva.

KAFFINE, D. T., MCBEE, B. J., and ERICSON, S. J. (2020) "Intermittency and co2 reductions from wind energy" The Energy Journal, 41(5).

KAFFINE, D. T., MCBEE, B. J., and LIESKOVSKY, J. (2013) "Emissions savings from wind power generation in Texas" Energy Journal, 34(1), 155 - 175.

KETTERER, J. C. (2014). "The impact of wind power generation on the electricity price in Germany" Energy economics, 44, 270–280.

LISKI, M., and VEHVILÄINEN, I. (2020) "Gone with the wind? An empirical analysis of the equilibrium impact of renewable energy" Journal of the Association of Environmental and Resource Economists, 7(5), 873-900.

MACIEJOWSKA, K. (2020) "Assessing the impact of renewable energy sources on the electricity price level and variability–a quantile regression approach" Energy Economics, 85, 104532.

MARTÍNEZ, M. I., ROSA, S., CASTRO, B., DE CABO, G., and RODRÍGUEZ, A. (2023) "El empleo de las mujeres en la transición energética justa en España" Fundación Naturgy e Instituto para la Transición Justa. Madrid..

MYOJO, S., and OHASHI, H. (2018) "Effects of consumer subsidies for renewable energy on industry growth and social welfare: The case of solar photovoltaic systems in Japan" Journal of the Japanese and International Economies, 48, 55–67.

NOVAN, K. (2015) "Valuing the wind: Renewable energy policies and air pollution avoided" American Economic Journal: Economic Policy, 7(3), 291-326.

PEÑA, J. I., RODRIGUEZ, R., and MAYORAL, S. (2022) "Cannibalization, depredation, and market remuneration of power plants" Energy Policy, 167, 113086.

PETERSEN, C., REGUANT, M., and SEGURA, L. (2024) "Measuring the impact of wind power and intermittency" Energy Economics, 129, 107200.

PROL, J. L., STEININGER, K. W., and ZILBERMAN, D. (2020) "The cannibalization effect of wind and solar in the California wholesale electricity market" Energy Economics, 85, 104552.

SENSFUß, F., RAGWITZ, M., and GENOESE, M. (2008) "The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany" Energy policy, 36(8), 3086–3094.

SERRA-SALA, C. (2024) "Harnessing the wind: The impact of wind farm development on municipal finances" CesIfo working series, No. 11283.

SEXTON, S., KIRKPATRICK, A. J., HARRIS, R. I., and MULLER, N. Z. (2021) "Heterogeneous solar capacity benefits, appropriability, and the costs of suboptimal siting" Journal of the Association of Environmental and Resource Economists, 8(6), 1209-1244.

SILER-EVANS, K., AZEVEDO, I. L., and MORGAN, M. G. (2012) "Marginal emissions factors for the U.S. electricity system" Environmental Science and Technology, 46(9), 4742-4748.

WOO, C., HOROWITZ, I., MOORE, J., and PACHECO, A. (2011) "The impact of wind generation on the electricity spot-market price level and variance: The Texas experience" Energy Policy, 39, 3939 - 3944.