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RC-2025-03
Commentary

# The (Hopefully) Enlightening Blackout in Spain: Questions and Lessons for the Future

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## Executive Summary

The impact of the April 28th blackout in the Iberian Peninsula went well beyond its immediate economic effects. From the outset, different interest groups began to speculate (in their favor) not so much on the causes of the problem (not yet fully known), but on the conclusions to be drawn for the future, not only in Spain and Portugal, but globally: what should the expansion of the electricity system be like in order to make progress in the decarbonization of the economy while guaranteeing security in the short term?

Spain's electricity system is a key reference for global energy players due to several unique features: limited interconnections, ambitious decarbonization targets (80% renewables by 2030), a top-ten global ranking in non-conventional renewable penetration, government decision not to subsidize the life extension of the nuclear fleet beyond forty years, large installed capacity of combined cycle plants with utilization factors below 15%, stagnant demand growth for more than a decade.

On June 17, the Spanish government released a preliminary report on the potential causes of the blackout (Government of Spain, 2025). In short, it concludes that a chain of highly unlikely events occurred, and that Red Eléctrica (REE), energy producers (both conventional and renewable), large consumers, and distribution operators all (at least partially) failed to fully meet their responsibilities.

In a genuine exercise of Spanish political practice, the government urged the National Regulatory Authority (*Comisión Nacional de Mercados y Competencia*, CNMC) to approve a long-awaited operating procedure, discussed for years[1]

1 Following a public consultation process in 2020, REE sent a text of reform of these operating procedures to the CNMC for approval in July 2021. In 2022, the CNMC decided to test it with a regulatory sandbox. In November 2024, REE sent the final proposal to the CNMC, which was open for public consultation until December. Since then, approval of the procedure had been pending (Roca, 2025).

and whose final version had been stalled for months, pending CNMC approval. The CNMC passed it in a matter of days (CNMC, 2025b). In another demonstration of its ability to resolve in days what had been discussed for years, the Spanish government announced "Specific Actions to Increase the Resilience of the Electricity Grid," funding REE to upgrade the transmission system with synchronous compensators, FACTS technology, and substation improvements.

To complete the picture—which underscores the lack of political consensus on a matter so critical to the country's economic future—on July 23, Congress rejected a legislative proposal the government claimed was intended to strengthen the resilience of the electricity system. Although the proposal appeared to have the support of all key electricity sector stakeholders, it was nonetheless voted down.

Beyond the casuistry that triggered the collapse, we believe it is crucial to assess whether the current institutional and structural framework could be causing the electricity system to become vulnerable, and if it is the right one to minimize security costs not only now, but also in the next decades.

First, we outline the political dynamics and policy framework that shaped operational and planning decisions both before and after the incident. We then provide a brief technical diagnosis of the blackout's immediate causes, followed by an analysis and quantification of the firefighting response.

We focus on discussing the key lessons that should be learned from the blackout, particularly in relation to how to consider system security in medium- and long-term planning and the adequacy of the institutional and regulatory framework to address this challenge.

But before focusing on this dimension, it is worth reminding in brief one aspect we do not cover in this article: the blackout adds to the long list of reasons to implement locational signals—such as nodal marginal prices (Eicke & Schittekatte, 2022) and network tariffs. The most efficient way to the system expansion is to locate demand (e.g., data centers) near areas with abundant, low-cost generation—and vice versa. It not only reduces the need for investment in new network reinforcements, but also reduces the cost of adjustment services, as e.g. the resources needed for voltage control in certain locations.

The long-term lesson the blackout unveils is the need to build a solid framework to develop an efficient planning. Traditionally, planning has focused on minimizing long-term energy costs and ensuring adequacy, with little attention to technical security. Significant research and ongoing efforts are already underway to improve the balance between short-term operations and security needs with long-term system planning. This objective is a challenging task particularly in those contexts in which responsibility for generation investment was supposedly placed on private investors, relying heavily on short-term price signals.

As the Spanish case described below illustrates, the current approach to managing electricity system security relies heavily on short-term resource contracting (e.g., operating reserves). The key challenge in the planning process is to develop a strategy that balances these short-term costs with potential long-term investments—such as shunt reactors, synchronous compensators, or dedicated batteries—managed directly or indirectly by system operators. To some extent, the dilemma is not essentially different from the one related to distribution network expansion planning (the need to optimize capital expenditures, CAPEX versus operational ones, OPEX), with the difference that in this latter case, traditionally planning has been based on CAPEX, while at the wholesale level, ancillary services have in many jurisdictions relied on OPEX.

In both cases, as the diversity of potential solutions to deal with the networks security, the need for well structured institutional and governance framework is an increasingly relevant issue. In light of the lessons learnt from the blackout, we recall the suitability of a clear unbundling between the ownership of the transmission network and the system operation,[2]

2 For a discussion on the matter at the DSO side, see for example Burger et al. (2019).

achieving an optimal expansion properly dealing with adequacy and security needs requires institutional and market design reforms to enable sound decision-making, minimize conflicts of interest of regulated and market actors, and align short-term operational needs with long-term planning goals.

We argue that this is an issue in the European context, particularly in countries like Spain, where the TSO is not state-owned, unlike in France, Sweden, or Belgium. Under the TSO model, where remuneration for system operation and planning represents less than 10% of the holding company's total revenue, and companies receive a regulated rate of return on capital expenditures, there is a built-in incentive to favor CAPEX over more efficient OPEX-based alternatives (Averch and Johnson, 1962).

The current model relies on regulatory oversight of investment plans to manage this conflict of interest, sometimes supported by public consultations. However, neither ministries nor regulatory agencies are anywhere near having the technical capacity required to evaluate such a complex task. For this reason, we recommend implementing full ownership unbundling between transmission and system operation—following models like the US, or assuming that the ideal, a pan-European independent system operator is not feasible, the UK approach (DESNZ, 2025).

If this option is deemed (politically) unfeasible, an alternative would be to establish an energy planning office—ideally independent or embedded within the energy regulator—with the expertise and tools to be responsible for and carry out integrated capacity expansion planning. This model aligns with South American examples, such as Brazil's *Empresa de Pesquisa Energética* (EPE) and Colombia's *Unidad de Planeación Minero Energética* (UPME). The institution should coordinate with grid and generation stakeholders, subject its plans to public consultation, and remain free from any financial interest in the planning outcomes.

## I. INTRODUCTION

On Monday, April 28, 2025, at 12:33 p.m., an unprecedented blackout left around 50 million people across the Iberian Peninsula without electricity. Fortunately, it occurred during daylight hours on a sunny spring day, with mild temperatures around 77ºF (25ºC). The outage brought transportation infrastructure to a standstill. However, the most shocking impact for many was the collapse of telecommunications—disrupting mobile networks, internet access, electronic payment systems, and more.[3] Power was gradually restored: by 5 p.m., half of residential consumers had electricity, and the vast majority were reconnected within five hours.

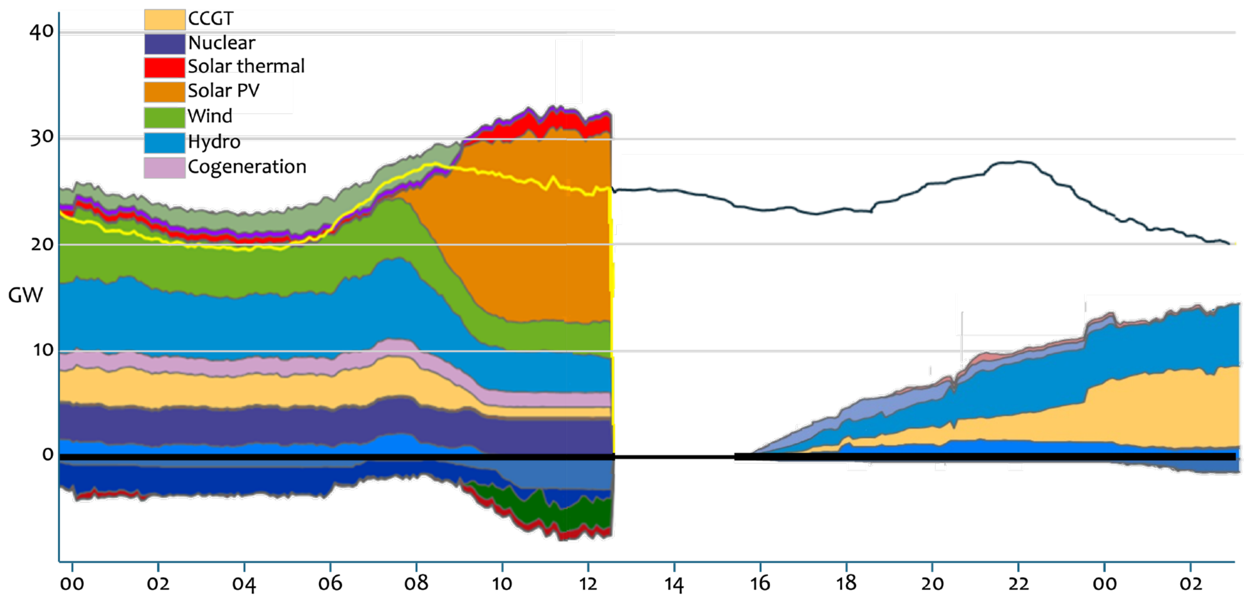


**Figure 1. April 28, 2025 blackout and gradual restoration of the service.**

Just hours later, it became clear that the blackout's implications extended far beyond its immediate economic cost. The impact was both immediate and global. With Spain and Portugal ranking among the top ten countries worldwide in non-conventional renewable energy penetration (see figure below), any disruption in their power systems draws intense scrutiny.

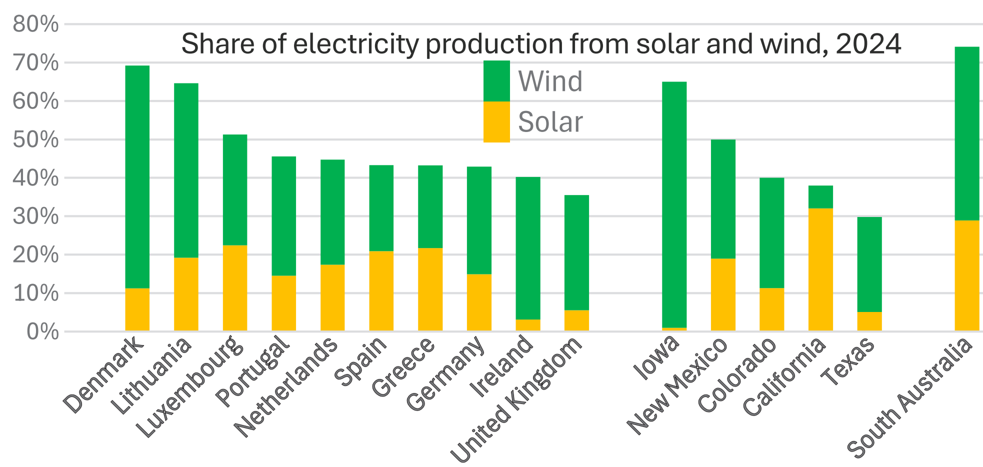


**Figure 2. Power systems with higher penetration of wind and solar generation.[4]**

3 Only those with a traditional transistor radio could stay informed. Some citizens, unable to take the subway home, didn't even know how to navigate back without access to Google Maps.

4 Own elaboration, based in data from ourworldindata.org, eia.gov and others.

Various interest groups were quick to speculate not only about the causes of the blackout but also about the lessons it offers for the future decarbonization of the economy in Spain, Portugal, and beyond. The event came at a pivotal moment in Spain, as the role of thermal generation is under debate. The system includes 26 GW of combined-cycle gas turbines (CCGTs), which in 2024 generated less than 29 TWh—an average capacity factor of under 13%. For years, plant owners have argued that energy prices do not provide sufficient revenue and have called for a capacity remuneration mechanism.[5] The government launched a public consultation on such a mechanism in 2021 and revised the proposal in 2024 (Miteco, 2024). The final design is still pending. Once completed, it will be submitted to the European Commission's Directorate-General for Competition (DG COMP) for approval. To gain approval, Spain must show that the additional compensation is needed to maintain an acceptable level of supply security.

In 2019, Spanish utilities and Enresa, the public radioactive waste management firm, and thus with the government approval (BOE, 2020) agreed on a schedule to close all of the country's nuclear power plants, between 2027 and 2035, aligning with their estimated economic and technical lifespan of around 40 years. However, the owning companies—Endesa, Iberdrola, and Naturgy—have recently indicated they intend to request extensions. The president of the Spanish Nuclear Forum has repeatedly argued for a reduction in the current tax burden on nuclear plants and stated that "their operation should be extended (...) but with guaranteed profitability" (González Navarro, 2022; Foro Nuclear, 2023).

Following the blackout, Pedro Sánchez, the current prime minister, stated that the government is open to extensions—provided that the investment risk is borne by plant owners, not taxpayers or consumers (Cué, 2025). In other words, any life extension should not rely on long-term contracts guaranteed by final consumers, which could eventually become legacy costs and distort future economic dispatch.

Associations representing energy storage and demand-side management services have also long emphasized their potential to enhance system security. They advocate for dedicated quotas in capacity mechanisms, tailored remuneration schemes, and specific auctions, arguing that market revenues alone are insufficient (Lardizabal, 2024).

In this context, to date, REE has relied on contracting operating reserves from conventional generation plants, while facing mounting pressure to reduce the associated costs. This pressure stems not only from rising expenses and repeated allegations of market dominance—prompting claims that long-term alternatives could be more cost-effective—but also from calls from the renewable lobby and the government, to minimize the cost of these services wherever possible.[6]

## The Brawl

Immediately after the blackout—and before its cause was known (speculation ranged from a cyberattack to an "induced atmospheric vibration")—political parties, industry lobbies, and their media platforms rushed to frame the event as validation of their positions on future energy planning. Headlines such as "From the nuclear lobby to the renewables bubble: the scramble to find the culprit of the blackout begins" (Cúneo, 2025) and "After today's massive blackout, can we afford to shut down the nuclear plants?" (Bermejo, 2025) captured the polarized debate. The leader of the main opposition party, Alberto Núñez Feijóo, quickly tied the incident to his energy agenda: "Feijóo considers it 'foolhardy' to give up nuclear energy after Monday's blackout" (Hurtado, 2025). And the Prime Minister fired back: "Sánchez blasts pro-nuclear 'lobbyists' and says it is 'a gigantic manipulation' to blame renewables for the blackout" (Cué, 2025). Furthermore, the governments of Spain and Portugal sent a joint letter to the European Commission, reviving a longstanding demand: the urgent need to strengthen the Iberian Peninsula's interconnection capacity with France (Alarcón, 2025).

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5 For example, Aelec (2020)—a group representing three of the largest generators (Iberdrola, Endesa, and EDP Spain)—argued that in an "energy-only" market, "some generation plants are not economically viable, even though they are essential to guarantee security of supply," and therefore called for the urgent approval of a capacity mechanism.

6 When thermal units are scheduled to provide balancing services during periods of high renewable output, part of that renewable energy must be curtailed.

To complete the picture—which underscores the lack of political consensus on a matter so critical to the country's economic future—on July 23, Congress rejected a legislative proposal the government claimed was intended to strengthen the resilience of the electricity system. Although the proposal appeared to have the support of all key electricity sector stakeholders, it was nonetheless voted down.

## II. CURRENT STATE OF THE SPANISH ELECTRIC POWER SYSTEM

Peak electricity demand in Spain reached its maximum in 2008. Since then, as the figure below shows, the installed capacity of wind and solar generation has continued to grow.

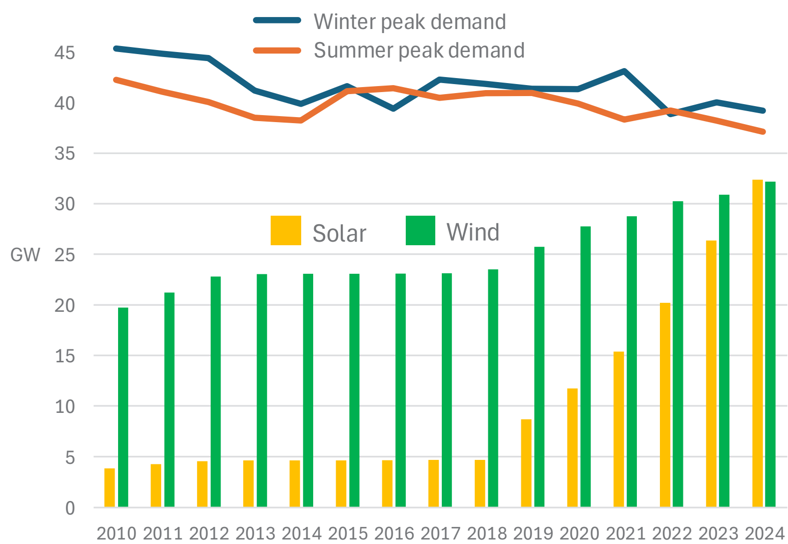


**Figure 3. Evolution of peak demand and wind and solar capacity in Spain.**[7]

The update of the National Energy and Climate Plan, submitted on 28 June 2023 to the European Commission sets a target of 76 GW of solar PV (19 GW rooftop), 62 GW of wind.

As the figures below demonstrate, these resources are distributed throughout the country.[8]

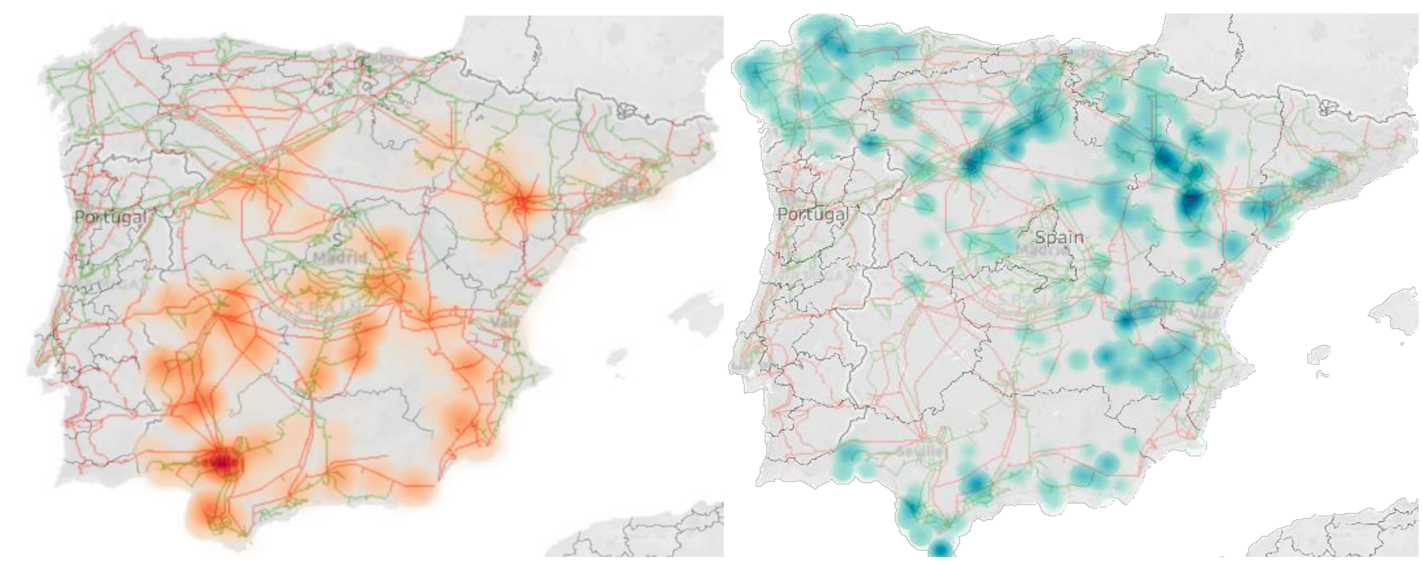


**Figure 4. Geographical dispersion of solar power plants (left) and wind power plants (right).**

7 To this capacity must be added an estimated and rapidly growing amount of just over 7 GW of rooftop solar panels.

In addition to these factors, the Iberian Peninsula has limited interconnection capacity with the rest of Europe, making it practically an electrical island. The table below shows that Spain ranks 26th out of 30 European countries, behind only Greece and three other island countries. But as shown in the table, if the Iberian Peninsula is considered in an integrated way, even Ireland is more interconnected across the border.

| | 1 | | 11 | | 14 | | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SI | … | DK | … | **PT** | … | DE | MT | NO | SE | PL | FR | FI | IT | **ES** | EL | IE | UK | CY | **IBERIA** |
| NC [MW] | 10227 | | 11143 | | **8882** | | 52628 | 381 | 13144 | 12886 | 10057 | 33906 | 4650 | 17817 | **14487** | 1762 | 500 | 4500 | 0 | **5605** |
| PL [MW] | 2322 | | 6623 | | **9359** | | 81369 | 600 | 24256 | 25165 | 25426 | 87400 | 14782 | 59282 | **61157** | 9865 | 5184 | 61365 | 988 | **70516** |
| NC/PL [%] | 440% | | 168% | | **95%** | | 65% | 64% | 54% | 51% | 40% | 39% | 31% | 30% | **24%** | 18% | 10% | 7% | 0% | **7.9%** |

NC: 2020 Nominal interconnection capacity [MW], PL: 2030 Peak load (99.9 percentile) [MW]

Table 1. Interconnection levels by Member State as measured by nominal electricity interconnection capacity to peak load in 2030 (European Commission, 2017).

## Continuity of supply

As early as 15 years ago, when installed wind and solar capacity was one-third of what it is today, many experts argued that the electricity system had reached its limit and could not be expanded. Since then, demand has not increased significantly, yet renewable penetration has tripled (solar installed capacity increased from 5 GW in 2018 to over 35 GW in 2024, including self-consumption). Nevertheless, grid operators have achieved levels of supply continuity well above their European counterparts.

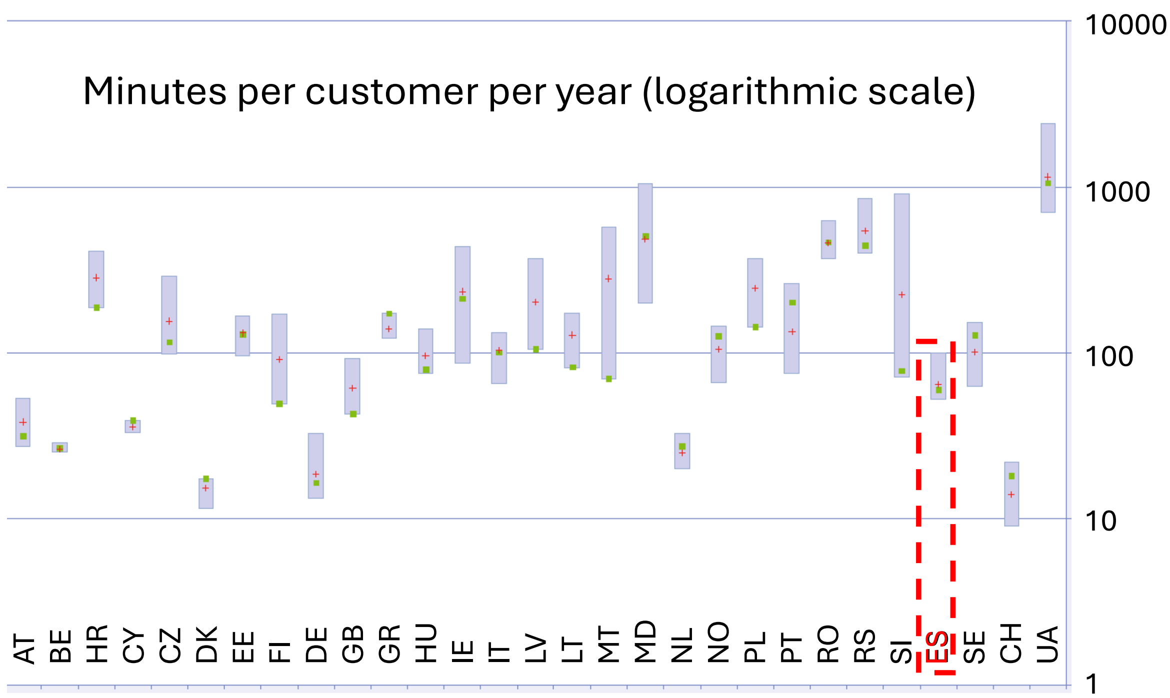


Figure 5. System Average Interruption Duration Index in the EU (CEER, 2022).

8 This poses relevant technical challenges, particularly from a voltage control point of view, given the low load on many lines, particularly at sunrise when also demand is low, which means a high level of reactive power generation that needs to be absorbed.

## III. PRESUMPTIVE ETIOLOGY OF THE BLACKOUT AND CONDITIONING CONTEXT

The process to get to a full diagnosis of the cause triggering the black out is going to take months[9] and probably years in courts. Our preliminary analysis (Batlle, 2025) led us to conclude that the trigger was a voltage control issue. This hypothesis was later confirmed by the first report published by the Government of Spain (2025a).

In this report, on the one hand, it is argued that a convergence of highly improbable events took place, and it suggests that "a series of rhythmic oscillations (...) increased the difficulty of voltage stabilization." The report identifies atypical behavior at a specific facility in the affected area[10] ("Solar Ø" on the map in Figure 6), one of the country's largest solar plants, with a capacity of 500 MW (María, 2025).

On the other hand, the report suggests that virtually no system agent fully met its expected obligations:

i. not REE, who may have contracted insufficient reserves;
ii. nor a number of the solar plants in the area;
iii. nor the generation units receiving specific compensation for voltage regulation ("may not have delivered the full contribution expected by the system operator");
iv. nor consumers connected to the transmission grid;
v. nor the distribution network operators ("a proportion of distribution networks (...) may not have responded in line with the power factor").

The report then briefly outlines the possible basis for these observations:

### *i) Redispatch due to voltage control service contracting*

The main way that REE currently has at its disposal to control reactive power is to correct the so-called economic dispatch previously determined. Generation plants with a lower production cost are replaced by other, more expensive ones, but necessary to be able to manage the reactive power balance in case of need.[11]

The analysis published by the Government of Spain (2025a) points to the system operator: "The system showed an insufficiency of dynamic voltage control capabilities to maintain stable voltage." This was particularly evident when the operator chose not to replace a plant that had initially been contracted the previous afternoon to support voltage control in the southwestern zone, but was declared unavailable the previous evening.

The map in Figure 6 shows the locations of thermal power plants (nuclear, gas-fired combined cycle, and coal) and major hydroelectric units. It highlights the three nuclear plants and the six CCGTs designated to absorb reactive power if needed. It also marks the location of the CCGT that was declared unavailable the previous evening ("CCGT X"). As shown, since voltage control requires balancing elements to be close to the source of the disturbance, the area identified

9 The Spanish Government asked REE to publish a preliminary analysis in less than three months after the incident. Following the European regulation on guidelines for the operation of the electricity transmission system, a panel of experts formed by the European Network of Transmission System Operators for Electricity (ENTSO-E) will draw up a factual report no later than 6 months after the end of the incident (ERSE, 2025).

10 "An anomalous oscillatory behavior has been identified in the active and reactive power output of the plant (...) An oscillation in these variables would, in any case, be more typical of synchronous technologies subject to setpoint voltage control, since they "see" the grid voltage and modify their power factor to keep the voltage constant. However, in a photovoltaic plant, which is subject to a fixed power factor, the output power value, especially the active power, should be constant." (Government of Spain, 2025a)

11 Once the day-ahead market closes (Batlle, 2025), power plants submit specific offers to be committed with the objective of contributing to voltage control, which include price (considering that they will be committed at minimum load, what makes the dispatch more expensive). In parallel REE considers the technical constraints of the plant (e.g., ramp rates). REE evaluates system security (voltage, frequency, congestion, etc.). Based on these offers, REE designs a zonal voltage control scheme—especially in areas with reactive power shortages or overvoltage risks due to excess renewable generation. In such cases, REE orders a reduction in renewable production in those zones, which is disconnected without any compensation. Scheduled thermal plants are paid their bid price (pay-as-bid).

by the government report as a potential origin of the oscillation ("Solar ∅," highlighted in the bottom left) was located several hundred kilometers from the generators scheduled to help rebalance voltages.

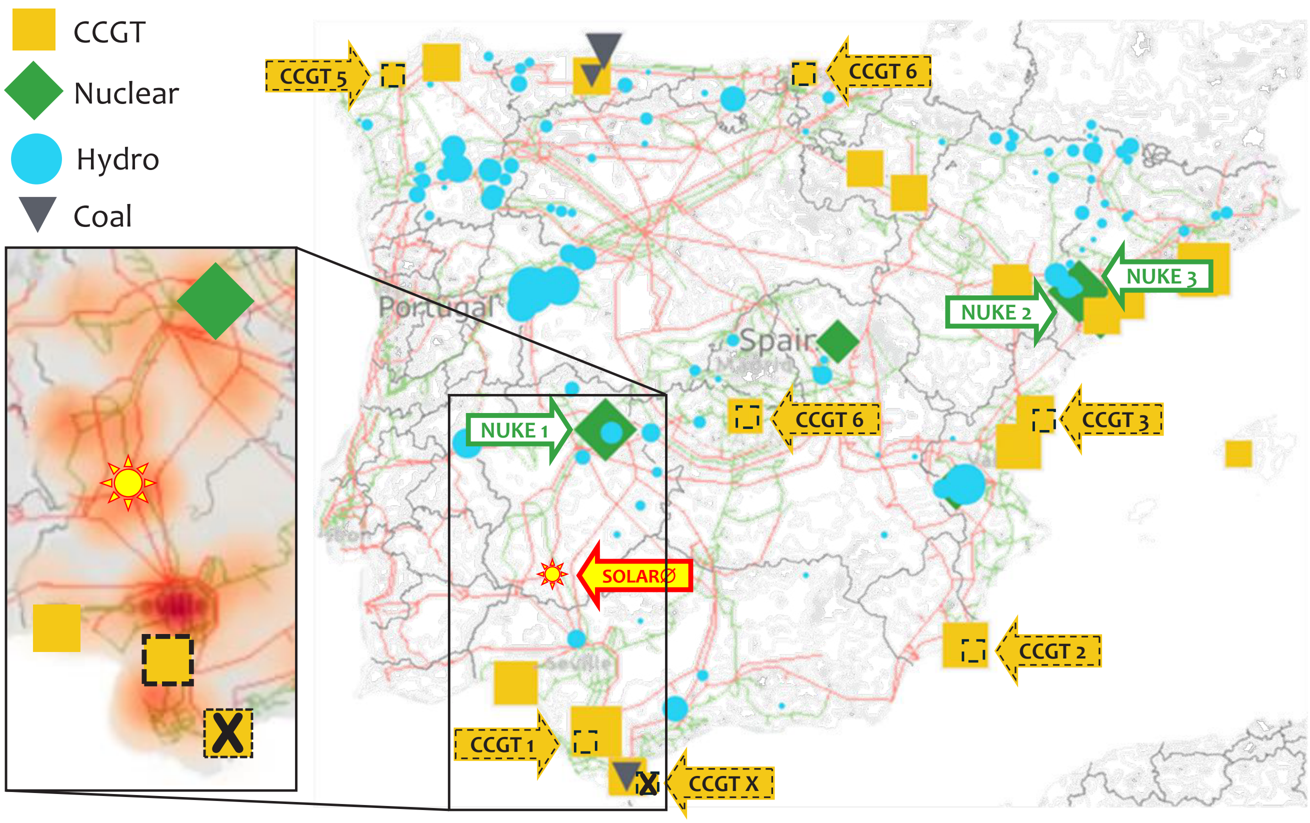


**Figure 6. Location of the conventional generation plants in Spain and units committed to support voltage control on the day of the blackout.**

One of the key questions following the incident is why, as noted in the report, REE did not schedule a replacement generator after one of the two units it had contracted in the southwestern zone was declared unavailable the previous evening.

In theory, as system operator, REE should have little incentive to take excessive risks when it comes to minimizing the cost of voltage control services. However, current regulation includes an explicit economic incentive—though, as later discussed, not particularly significant—that reflects the regulator's (i.e., the government's) interest in minimizing the volume of energy contracted for this purpose (the incentive targets the volume, not the cost). There may be several motivations behind this. On the one hand, each MWh scheduled for voltage control displaces a MWh of renewable generation, working against the policy objective of maximizing the share of renewable generation. Added to this is the longstanding controversy surrounding Spain's market-based dispatch mechanism.

From the very beginning, critics of the constraint management mechanism have argued that voltage control is inherently a local issue, addressable only by nearby generation plants—meaning that the competition levels required for an effective auction-based pricing mechanism do not exist.[12] At the same time, various stakeholders have criticized the procedure itself, claiming there are more efficient alternatives for controlling voltage. For example, a report by Aurora Energy Research (2023) suggested the need to invest in batteries, arguing that the cost of the current mechanism is disproportionate (according to their calculations, 68 € *per annum* and home), particularly considering that between 2017 and 2021,

12 As early as 2001, in a process initiated by the National Energy Commission, the Competition Defense Service argued that "only one company in each zone has the capacity to resolve technical constraints when they arise, which gives each company a dominant position in its respective area" (Plenary Session of the Competition Defense Tribunal, 2004). A similar case was opened in 2008, but once again the tribunal was unable to find conclusive evidence of illegal conduct. In 2023, however, the CNMC fined one of the main operators for manipulating the technical constraints market by submitting excessively priced offers—a decision that is currently under appeal in court.

it supplied only 3–4% of total electricity demand (half of the amount paid to 16 generating units). The cost of this mechanism has steadily increased in recent years—from €240 million in 2019 to €1.2 billion in 2024—leading to growing pressure on REE to contain it. Indeed, the Operating Procedure 3.2. approved by the CNMC on March 2024 (BOE, 2024), opens the floor to establish limits to the prices offered wherever systematic constraints and low competition level are observed.[13] The CNMC, who has the competence to fix these limits when deemed necessary has not yet resort to this alternative.

Clearly, this context did not make the system operator's job easier and may have led REE to assume a level of risk higher than what would be considered appropriate.

*ii) Power factor of renewable installations*

Operating Procedure 7.4 on voltage control, in force from 2000 (BOE, 2000) until June 2025, established that renewable installations were not required to regulate voltage but were instead obliged to operate with a constant power factor. This value was set by REE at the time of commissioning—typically between 0.98 inductive and 0.98 capacitive—depending on the technology type and point of connection. According to the Government of Spain (2025), on April 28, nearly 22% of the 850 highest-generating plants were not in compliance.

The question is whether this level of non-compliance occurred only on the day of the incident. And if, as seems plausible, it was common practice, whether it had been detected and reported to the CNMC, and whether there were any penalties for non-compliance.

In a genuine exercise of Spanish political practice, the government urged the National Regulatory Authority (*Comisión Nacional de Mercados y Competencia*, CNMC) to approve a long-awaited operating procedure, discussed for years[14] and whose final version had been stalled for months, pending CNMC approval. The CNMC passed it in a matter of days (CNMC, 2025b). Among other changes, the new version includes a provision allowing renewable installations larger than 5 MW to participate in the voltage control mechanism under the same conditions as conventional plants, and introduces specific penalties for non-compliance.

*iii) Effective contribution of conventional generation to voltage regulation*

On the other hand, both the 2000 version of P.O. 7.4[15] and the updated version approved in June 2025 require all conventional generators (thermal or hydro), once scheduled, to be capable of generating and absorbing reactive power within margins equivalent to 15% of their maximum net active power. The technical constraint management mechanism is based on this obligation, since scheduling a thermal unit is assumed to provide additional reactive power control capacity within the specified range.

The 2000 version of P.O. 7.4 also stated that generators unable to meet 100% of the required band due to technical limitations had to justify this to the Ministry. The Ministry, following a report from the regulatory authority, could authorize a reduction in the required band to match what the installation could actually deliver. At the time, many plants submitted detailed reports declaring their technical inability to fully comply (to varying degrees) with this mandatory requirement. In yet another example of institutional and administrative functioning, at the very least, in need of improvement, these

13 This approach mirrors the mitigation measures applied by U.S. Independent System Operators (ISOs) in so-called "load pockets," where local market power is addressed by replacing submitted offers with cost-based bids whenever structural constraints and lack of competition are identified (O'Sullivan & Mills, 2008), (Patton et al., 2024)

14 Following a public consultation process in 2020, REE sent a text of reform of these operating procedures to the CNMC for approval in July 2021. In 2022, the CNMC decided to test it with a regulatory sandbox. In November 2024, REE sent the final proposal to the CNMC, which was open for public consultation until December. Since then, approval of the procedure had been pending (Roca, 2025).

15 "Due to the inherently local nature of voltage control and the current impossibility of implementing a competitive market applicable to all areas, a complementary service is established to ensure system security, which requires a minimum mandatory provision." (BOE, 2000)

requests never received a response—neither approval nor rejection. While it is reasonable to assume that the system operator was well aware of what each plant could effectively provide during those 25 years, the lack of an official record does not appear to be the best way to structure the management of such a critical service.

## IV. THE COST OF FAILURES AND THE COST OF PRECAUTIONS

A thorough analysis of the causes of the blackout is undoubtedly necessary. However, our objective is to focus on what the incident can teach us about the institutional and regulatory changes that should be discussed and implemented. Following the incident, the Spanish Prime Minister stated that "it must never happen again." With the resources currently available to REE—26 GW of CCGT capacity, which in 2024 produced less than 29 TWh, implying a very low average capacity factor of under 13%—such a goal may be within reach. As will be shown later, it would "simply" require scheduling large amounts of thermal generation. But this, of course, comes at a cost.

In the short term, the key question—using financial terminology—is where the efficient frontier lies: in other words, what level of expenditure on reserves is needed to achieve an acceptable level of risk.

### *Risk (reliability standards) and costs (value of lost load)*

Electricity system expansion planning aims to minimize the expected future cost of supply, while meeting a defined reliability standard—commonly known as the Loss of Load Expectation (LOLE). In the US, the North American Electric Reliability Corporation (NERC) sets a standard of no more than 0.1 days per year (i.e., one day in ten years). In Europe, according to ENTSO-E (2025b), typical LOLE values—defined individually by each Member State—range from 2 to 5 hours per year. In Spain, until now, the only significant blackout this century occurred in 2007 and affected part of the Barcelona metropolitan area. Thus, the roughly ten hours of outage experienced for the first time in at least 25 years remain within international reliability standards.

Nevertheless, the public—and especially political—outcry was substantial. It is therefore necessary to put the magnitude of the cost into context, which is key for assessing how much weight reliability and adequacy should carry in long-term electricity system planning.

i. A study published by the European energy regulator ACER (CEPA, 2018) estimated that the Value of Lost Load (VoLL) in the electricity systems of Southern Europe ranges from a minimum of €3,000/MWh to a maximum of €11,000/MWh, with an average of €6,000/MWh. Taking the upper bound (€11,000/MWh) and assuming that the unsupplied energy corresponds to the full amount estimated the day before for the 12-hour period from noon to midnight, the total cost is estimated at just under €3.5 billion.

ii. The adequacy dimension can also be illustrated in the context of the 2021–2022 energy crisis. The gas supply shock, combined with prolonged nuclear outages in France (with up to 57% of reactors offline at certain points), caused energy prices across Europe to soar. We assessed the cost of meeting Spanish electricity demand in 2022 at those crisis-level prices and compared it to the cost that would have resulted under average-year prices. Figure 7 illustrates the resulting price differences.

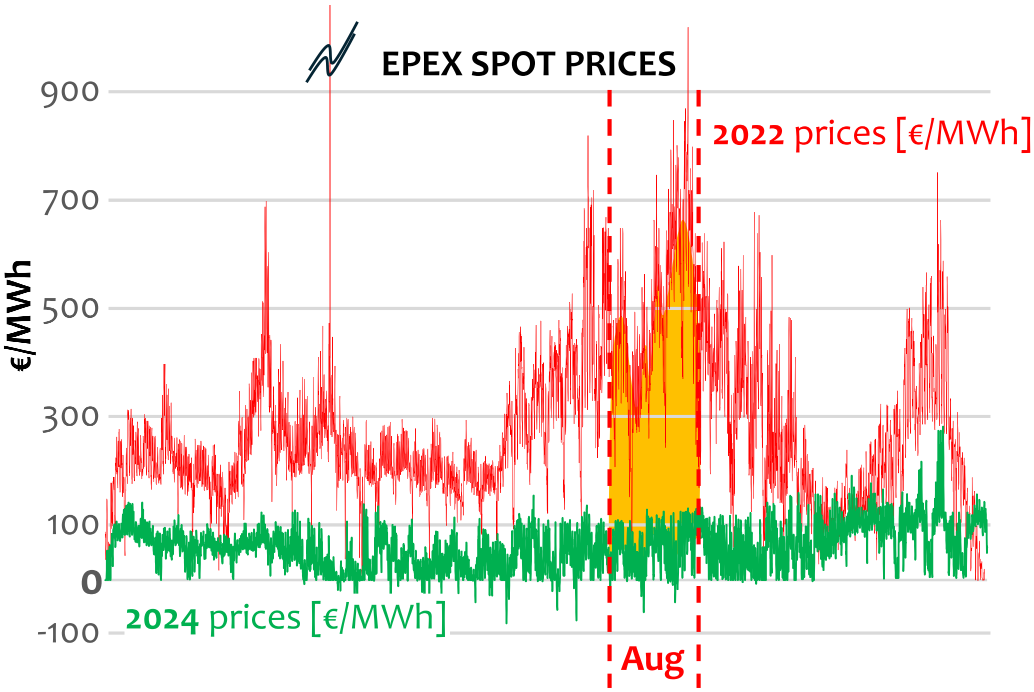


Figure 7. Evolution of peak demand and wind and solar capacity in Spain.

We found that in the month of August alone, the cost difference exceeded €8.3 billion—more than twice the estimated cost of the blackout

### *The current cost of insurance*

The Prime Minister's statements appear to have had an immediate impact on system operations. Figure 8 clearly illustrates REE's almost immediate shift in strategy following the day of the blackout, in response to the public outcry and the Prime Minister's remarks (€328 million in April, €460 million in May).

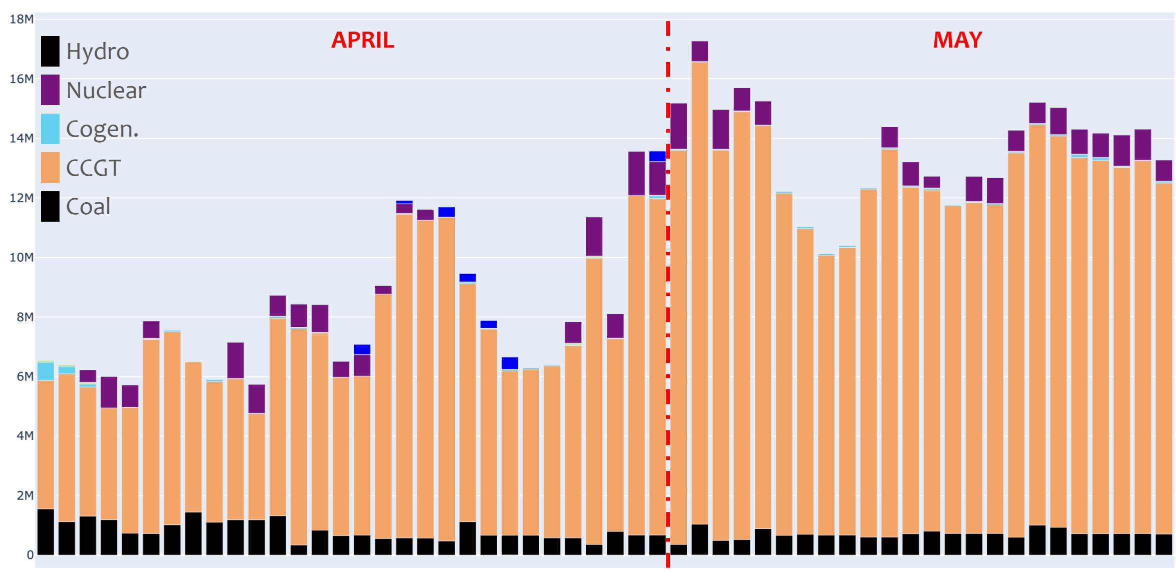


Figure 8. Cost (million euros per day) of the voltage control mechanism in April and May 2025

Figure 9 below illustrates the significant impact this contracting mechanism ultimately has on the final consumer price. In April, the average energy price paid by consumers (resulting from the day-ahead market clearing, excluding ancillary services) was €29/MWh, while the cost of the constraint management mechanism alone was around €20/MWh.

In May 2025, after the blackout, the market energy price (€18/MWh) was significantly lower than the cost of the mechanism, which on several days exceeded €30/MWh. On some days in May, this cost surpassed €18 million. This is explained by the fact that, although the mechanism only contracts a relatively small amount of energy (around 10% of total energy supplied), the price paid to combined-cycle plants—which are the main providers of this service—reaches over €175/MWh, as also shown in the figure.[16]

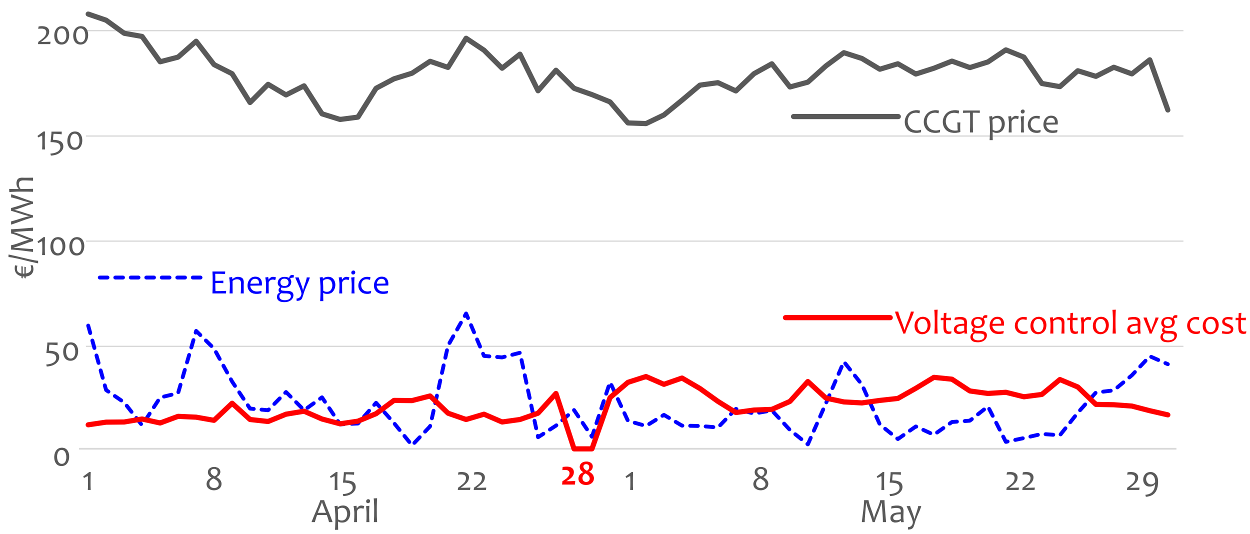


**Figure 9. Daily cost (in €/MWh) of the voltage control mechanism, average day-ahead market price, and price of CCGTs committed to support.**

The immediate consequence is that the accumulated cost of the constraint management mechanism in just the first half of 2025 exceeded the €1.2 billion incurred over the entire year of 2024. These amounts are equivalent to the total cost of the transmission activity for that same year, which was €1.25 billion (CNMC, 2025a).

### *The key challenge going forward: minimization of the ancillary services costs in the long run*

The key question that urgently needs to be addressed is not only what the optimal management cost is under current conditions with the tools currently available. The real challenge lies in evaluating how to minimize that cost over the next 10 to 20 years.

One option is to continue with a business-as-usual approach, relying on the contracting of combined-cycle gas turbines (CCGTs).[17] This strategy involves scheduling these generators, typically at their minimum production level—the so-called technical minimum or minimum load. The cost of this alternative extends beyond the immediate expense of dispatching these units to absorb reactive power; also it very likely includes structural implications. The companies that own these plants have been calling for the implementation of a Capacity Remuneration Mechanism (CRM) that guarantees fixed

16 These units must internalize their start-up costs and low efficiency during the few hours they are dispatched, as their operating regime is close to their technical minimum.

17 To provide the system with this service, combined cycle gas plants are more effective than nuclear ones. First because the overvoltage problems are more "local" and those smaller plants are more distributed throughout the grid, and second, because they have a lower technical minimum (they can be on producing at low levels). A nuclear plant can operate at 50% of its maximum capacity, while a combined cycle plant can easily operate at 30%. Hydropower plants can in principle provide this service, but they are usually located in remote places, which makes their use for this purpose infrequent.

payments over several years. However, other options can and should be considered.

One alternative is to invest in the deployment of specific voltage control equipment—such as shunt reactors or synchronous compensators.[18] To rely solely on this approach, several hundred such devices would be required. In both public and less visible forums, REE has stated that it has been trying for some time to increase the number of such devices on the grid, but has faced all kinds of obstacles.[19]

In another demonstration of its ability to resolve in days what had been discussed for years, the Spanish government announced "Specific Actions to Increase the Resilience of the Electricity Grid," funding REE adding €750 million in investments to the existing 2021–26 grid development plan, to upgrade the transmission system with the procurement of 10 new reactors, 11 synchronous compensators, FACTS technology, and substation improvements.

Another emerging alternative, not yet available in Spain, is the use of grid-scale batteries capable of providing an almost instantaneous response—injecting or absorbing both active and reactive power to stabilize frequency and maintain voltage within safe limits. The most prominent example of this solution are the battery systems deployed in South Australia since 2017 (Tulip & Hicks, 2024). Moreover, if the expected expansion of data centers materializes, their backup generators could become highly effective contributors to system support.

The core challenge of the planning exercise mentioned earlier is to develop a strategy that optimally balances short-term expenditures—such as the daily redispatch of conventional generators to manage reactive power—with long-term investments in system assets, such as synchronous compensators or dedicated batteries, managed directly or indirectly by system operators.

## V. SOUND, CONTESTABLE AND UNBIASED SYSTEM EXPANSION PLANNING

Planning the expansion of the electricity system while optimizing overall costs and ensuring both adequacy and short-term security is a highly complex task. To carry it out effectively, it is essential to rely on an institution with sufficient technical capacity, adequate financial and human resources, and the ability to use and further develop advanced modeling tools.

The Spanish case—where an unexpected blackout prompted a flurry of critical regulatory and planning changes within just a few weeks—does not appear to be the best example to promote an efficient expansion of such a vital component of the decarbonization strategy as the electric power system.

Electricity system planning should be grounded in robust analytical and modeling processes, carried out by an institution with the necessary expertise and technical capacity. The resulting proposals should also be subject to well-structured

18 An interesting alternative consists of taking advantage of the alternators of the thermal plants as they are shut down to, at low cost, convert them into synchronous compensators. The solution is to maintain the group without the capacity to produce active power, but with great capacity and flexibility to generate and absorb reactive power. Since the inertia of the generator is maintained as in the previous generation mode, its contribution to the frequency control is also maintained. This solution was considered as part of the reconversion process of the Andorra coal-fired power plant in the province of Teruel, carried out by Endesa, where the alternator of one of the 350-MW units could have been used as a synchronous compensator. For some reason, this alternative was discarded.

19 The "Report of the National Regulatory Authority on the proposed modification of certain aspects of the 2021-2026 Electric Transmission System Development Plan" (CNMC, 2024a) reads as follows:

"According to (...) the Transmission System Development Plan 2021-2026, the installation of reactances in the transmission system was the most efficient solution to this problem, requiring a very low investment cost and presenting a payback of only 8 months. It was also pointed out that if the proposed reactances had already been in operation in 2019, it would have been possible to reduce by 81% the cost overrun of technical restrictions for voltage control in that year. (...) the value of the investment of the necessary reactances in an analyzed area - area with usual voltage problems and higher costs of solving the technical restrictions in 2023 - would have been almost 8 times lower than the cost that the technical constraints for voltage control have meant, assuming the useful life of the reactance of about 40 years".

public consultations, enabling stakeholders to contribute, challenge assumptions, and offer meaningful feedback.

Governance is another key issue that requires reform. This institution must also be free from potential conflicts of interest to ensure that decisions are made in the public interest.

The current approach to managing electricity system security in Spain and in general in the EU context relies heavily on short-term resource contracting (e.g., operating reserves). The key challenge in the security planning process is to develop a strategy that balances these short-term costs with potential long-term investments—such as shunt reactors, synchronous compensators, or dedicated batteries—managed directly or indirectly by system operators. To some extent, this dilemma is not fundamentally different from that faced in distribution network expansion planning: the need to optimize between capital expenditures (CAPEX) and operational expenditures (OPEX). The difference lies in the fact that distribution planning has traditionally been CAPEX-driven, and OPEX solutions should be carefully considered, whereas at the wholesale and high-voltage level, ancillary services in many jurisdictions have primarily relied on OPEX—that is, on services provided by existing conventional plants. Analogously, in today's context, a central question is whether the optimal long-term solution may involve a greater share of new capital investments. However, the inherent conflict of interest faced by system planners in Europe makes it difficult to reach a broadly supported solution, as any proposal coming from the TSO is quickly called into question due to perceived self-interest.

In light of the lessons learned from the blackout and the subsequent discussion on the need to strengthen network planning to ensure adequate security levels, we emphasize the relevance of clearly unbundling transmission network ownership from system operation.[20]

We argue that this is an issue in the European context, particularly in countries like Spain, where the TSO is not state-owned, unlike in France, Sweden, or Belgium. Under the TSO model, where remuneration for system operation and planning represents less than 10% of the holding company's total revenue, and companies receive a regulated rate of return on capital expenditures, there is a built-in incentive to favor CAPEX over more efficient OPEX-based alternatives (Averch and Johnson, 1962). As discussed by RAP (2022), "today's system operators are subject to incentives that conflict with system efficiency because the integrated operator is subject to an incentive to favor new build as a solution (...) This incentive, however, to build violates technological neutrality and most importantly is a barrier to non-wire solutions."

The current model relies on regulatory oversight of investment plans to manage this conflict of interest, sometimes supported by public consultations. However, neither ministries nor regulatory agencies are anywhere near having the technical capacity required to evaluate such a complex task.

In Spain, REE was once a pioneer as a TSO independent from the generation companies, but today its role as the sole planner of network expansion is increasingly being called into question.[21] Every five years, REE prepares the transmission grid development plan, identifying the necessary investments. These investments must be approved by both the CNMC and the executive branch, neither of which currently has sufficient technical capacity to assess the suitability of the proposed projects. This modus operandi is increasingly criticized by various system stakeholders, who see it as "incompatible" that the entity responsible for deciding on network expansions—funded through electricity tariffs—belongs

20 For a discussion on the matter at the DSO side, see for example Burger et al. (2019).

21 Red Eléctrica de España (REE) is a rather unique transmision system operator (TSO). It is a for-profit, publicly traded corporation. Its ownership regime and the restrictions applicable to market agents are established by law (CNMC, 2024c). The Spanish State holds 20%; any individual or legal entity may not hold more than 5% of the share capital, nor exercise voting rights exceeding 3%. If the shareholder holds more than 5% in other operators within the electricity sector, their voting rights are further limited and may not exceed 1%. As reported by the company (Redeia, 2025), currently around 60% of the shares are owned by international investment funds.

This regime guarantees a reasonable level of independence in the company's decisions from market agents. However, as discussed, its private ownership and for-profit nature may entail conflicts of interest, particularly when it comes to system capacity expansion planning.

to the same corporate group that benefits from building them (Cruz & Toledo, 2025). At the same time, REE complains when the proposals are not approved, as illustrated by the text previously included in footnote 20.

As noted earlier, the System Operation division accounts for less than 7% of REE's total annual revenue, most of which is directed toward capital expenditures. This structural conflict—affecting not only transmission but also distribution system operators—was recently highlighted by the Council of European Energy Regulators (CEER, 2025): "Grid operators might choose not to utilise potential flexibility due to CAPEX biases embedded within regulatory frameworks. These biases tend to favour CAPEX-intensive solutions over potentially more cost-effective alternatives, namely more OPEX-intensive innovations. Addressing these biases is crucial for promoting efficient grid use and supporting the clean energy transition." This concern on the potential conflict of interest is not new. In 2010, the Spanish government went as far as drafting a royal decree-law (Monforte, 2025) to separate the electricity and gas system operator from their respective transmission companies and merge them into a single, independent, state-owned operator. However, the proposal was ultimately not enacted.

### *Towards a really unbundled system planning*

Our recommendation is that either an effective unbundling of ownership between transmission and system operation must be implemented, or an energy planning office must be established. This office could function as an independent body or be part of the energy regulatory authority. It must be equipped with the necessary expertise and tools to conduct integrated capacity expansion planning.
The first option aligns with the US Regional Transmission Operator (RTO) model. RTOs are independent, nonprofit entities with near-complete control over system operation and planning in their respective areas. Their mission is to operate and plan the grid to maximize net social benefit.

However, RTOs are governed by stakeholder committees that operate through sector-based voting. For example, in PJM, committees include transmission owners, generation owners, electric distributors, end-use customers, and other suppliers. While all member classes are intended to have equal input, these governance structures have come under growing criticism for being dominated by transmission and distribution companies. Incumbents outnumber and outweigh consumer advocates, reinforcing vested interests and slowing innovation (Peskoe, 2023; van de Biezenbos, 2023; Macey & van Emmerick, 2025; Vedeni Energy, 2025). Although RTOs emphasize transparency and rigor in their stakeholder engagement, doubts persist as to whether these processes truly reflect the diversity of perspectives required for efficient and balanced planning.

The optimal—or ideal—solution, as proposed for example by Heussaff & Zachmann (2025), would be the creation of a European Independent System Operator (EU ISO) to manage and plan the electricity grid at the EU level. Under this model, national companies would retain ownership of their infrastructure and continue to operate as transmission owners, but under the coordination of the EU ISO.

To avoid conflicts of interest and better align climate and energy policy goals with system expansion, the UK government transferred the electricity (and gas) system operator to public ownership (DESNZ, 2025). The National Energy System Operator (NESO) was designated by the Secretary of State as an independent body responsible for system operation and planning, while Ofgem, the National Regulatory Authority ensures that NESO can "act impartially in the public interest, free from commercial motives."

If this option is deemed (politically) unfeasible, an alternative would be to establish an energy planning office—ideally independent or embedded within the energy regulator—with the expertise and tools to be responsible for and carry out integrated capacity expansion planning. This model aligns with South American examples, such as Brazil's *Empresa de Pesquisa Energética* (EPE) and Colombia's *Unidad de Planeación Minero Energética* (UPME). The institution should coordinate with grid and generation stakeholders, subject its plans to public consultation, and remain free from any financial interest in the planning outcomes.

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