ДОСТИГА ЛИ ЕЛЕКТРОЕНЕРГИЙНАТА СИСТЕМА НА ЕВРОПА СВОИТЕ ПРЕДЕЛИ?

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IS THE ELECTRICITY SYSTEM IN EUROPE REACHING ITS LIMITS?

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Докато Европа ускорява прехода си към по-зелено енергийно бъдеще, нейната електрическа система е изправена пред значителни предизвикателства. Преминаването от традиционни източници на енергия към възобновяема енергия, като слънчева и вятърна, въвежда сложен набор от проблеми, които тестват устойчивостта и адаптивността на европейската електроенергийна мрежа. Тази статия изследва дали европейската електроенергийна система достига своите експлоатационни граници чрез изследване на последните развития и възникващи проблеми в рамките на паневропейския пазар на електроенергия.

INTRODUCTION

The integration of renewable energy sources has significantly altered the dynamics of the electricity grid. Solar and wind power, though clean and sustainable, are inherently variable and unpredictable. This variability introduces new challenges in balancing supply and demand, maintaining grid stability, and ensuring reliable electricity delivery. As more renewable energy is integrated, the system's ability to manage congestion, curtailment, and frequency stability is increasingly put to the test.

Congestion management is crucial in preventing overloads and maintaining grid stability. Curtailment, or the reduction of renewable energy output to maintain grid balance, has become a pressing issue with the growing penetration of renewables. This not only leads to wasted energy but also financial losses for producers.

Interconnection, where national grids are linked to facilitate cross-border electricity flow, also presents challenges. Differences in regulatory frameworks, market designs, and technical standards between countries can hinder seamless electricity exchange. Strengthening interconnection capacity and harmonizing regulations are critical for a more integrated and resilient European electricity system.

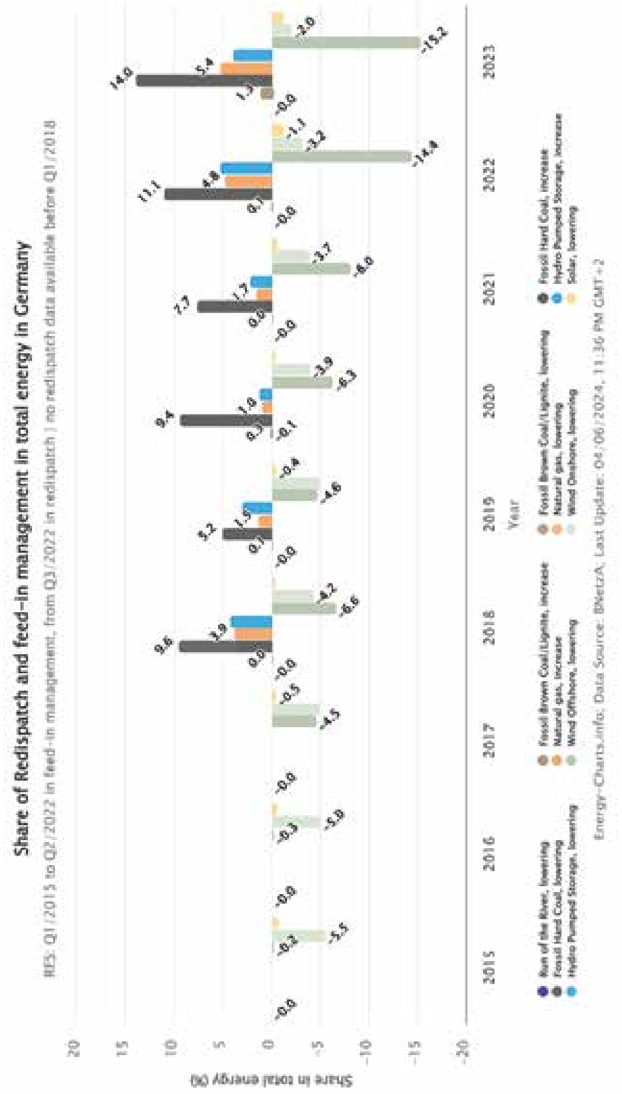
The impact of renewable energy on market dynamics, particularly in terms of pricing and flexibility, is profound. The merit order system, which prioritizes dispatch based on marginal costs, is challenged by the intermittency of renewables. Negative prices and increased price volatility highlight the need for enhanced flexibility, such as energy storage systems and flexible grid management strategies.

In addition to technical and market challenges, there are financial and regulatory hurdles. Compensation mechanisms and incentives, designed to support renewable energy adoption, sometimes create wrong signals in the market. The complexity of managing frequency stability in a renewable-heavy grid necessitates advanced technologies and coordinated efforts across European countries.

This article aims to bring attention to these pressing issues and explore potential solutions. By discussing congestion management, curtailments, interconnection and frequency issues, and balancing and flexibility, it highlights the most recent problems with the EU power grid.

CONGESTION MANAGEMENT

Congestion management in electricity markets is the process of ensuring that the flow of electricity does not exceed the physical limits of the transmission grid, thereby preventing overloads and maintaining grid stability. This involves a combination of strategies such as redispatching and countertrading. Redispatching is an intervention by system operators to modify the generation or consumption patterns within a control area or across control areas to alleviate congestion. It includes internal redispatching, where adjustments occur within the same control area, and cross-border redispatching, involving multiple control areas [1]. Countertrading, on the other hand, is a cross-zonal exchange initiated by system operators between different bidding zones specifically to relieve congestion. These measures are crucial for maintaining the reliability and efficiency of the electricity grid, especially as the integration of renewable energy sources introduces more variability and potential imbalances into the system [2].



Picture 1: Redispatch activities in Germany 2015-2023 [3]

Looking at data from the German market, in the last three years redispatch, especially offshore wind curtailments have increased [3]. According to TransnetBW in the coming years, excess energy from wind turbines in northern and eastern regions will need to be curtailed. Concurrently, backup power plants will be required in the southern and western regions to manage these imbalances, despite the overall sufficiency of electricity nationwide, due to distribution mismatches. In 2023 alone, Germany incurred approximately €3.3 billion in costs to address these imbalances. These expenses, covered by consumers through grid charges, represent the cost of redispatch [4].

The Netherlands are also facing an issue with their grid, since most of the grid is “at capacity”. This means that the system has reached its limits regarding new connections of customers. This is a problem for the expansion of renewable energy resources, but also for large consumers, who can theoretically also help the grid. One possible solution is the so-called cable pooling [5].

Countries like the Netherlands, Poland, and the Baltic states are addressing the challenges of rising renewable energy production and increasing grid connection requests through cable pooling. This strategy involves multiple renewable energy installations sharing a single grid connection point, which enhances efficiency and reduces costs. Cable pooling solves limited connection capacity issues, requires only a single set of documents and agreements, reduces costs and time for new connections, avoids delays at existing sites, mitigates congestion, and optimizes existing grid use. The connection point’s capacity sets the upper limit for power generation, and contractual freedom allows managing production limits among installations. This approach can significantly benefit asset investors and operators by enhancing optimization and forecasting automation for pooled assets [6].

Two years ago, Schiphol Trade Park's entrepreneurs and network operator Liander launched the Netherlands' first virtual network to address grid congestion, successfully enabling all companies in the Energy Collective Schiphol Trade Park to expand and electrify operations despite local grid issues. This innovative Energy Hub has allowed companies to share capacity within a virtual grid, facilitating 2,104 MWh of their consumption in 2023—34.5% of their total annual use—without needing individual energy systems like batteries and generators. Eelco Ouwerkerk of SEGRO Netherlands highlighted the importance of collaboration and innovative approaches to accelerate the energy transition, with the virtual grid ensuring operational stability during capacity shortages. The system, supported by Spectral's software, minimizes reliance on generators, leading to significant CO2 emission reductions—842 tons less in 2023 due to reduced gas usage. Further developments include optimizations for peak load balancing, zero-emission charging infrastructure for electric trucks, mutual electricity supply, and enhanced virtual network management [7].

CURTAILMENT

Curtailment occurs when excess renewable energy production cannot be absorbed by the grid, often due to congestion or lack of demand. This leads to wasted energy and financial losses for producers. The increasing penetration of renewables in Europe has made curtailment a pressing issue. Kepler has reported that the French power market recently experienced significant disruptions due to extremely low demand, resulting in historically low market prices. French nuclear power output was reduced by over 15 GW, setting a record surpassing even the reductions seen during the COVID-19 lockdown. Additionally, there were substantial curtailments in renewable energy production, with 3.5 GW of wind power and 2 GW of solar power curtailed [8].

Curtailments have been used and discussed in Western Europe for a long time [9], but the Balkan region also started experiencing this phenomenon. Bulgaria and Greece are particular examples.

On May 5, due to low electricity demand during Orthodox Easter, IPTO, the System Operator in Greece disconnected all renewable energy sources connected to the transmission lines for several hours and instructed HEDNO, the distribution operator, to disconnect an additional 1 GW of solar plants.

The high curtailment of renewable energy during the Easter period was anticipated. Pantelis Biskas from Aristotle University had warned of increased curtailment during this time and predicted that by 2030, curtailment could reach 15% of Greece's electricity generation. From March 1 to April 13, IPTO planned to curtail 220 GWh of renewable energy, about 4% of the domestic green electricity production, a significant increase compared to previous years.

Concerns were raised about the different curtailment methods used by IPTO and HEDNO. IPTO can adjust the amount of solar power injected into the grid, whereas HEDNO either connects or disconnects solar parks entirely, affecting many PV investors. A new law requires renewable energy plants over 400 kW to install equipment for HEDNO to remotely control output [10]. The DSOs in Bulgaria only curtail % of the total production for now, according to traders.

Other innovative recent updates are in the curtailment. The Netherlands is addressing grid overcapacity by introducing flexible contracts for PV owners. Pet food manufacturer E.J. Bos, operating a 5.6 MW solar plant, secured the first capacity limitation contract (CLC) in the country. This contract compensates for electricity curtailment during peak hours to manage grid congestion more effectively. Dutch transmission system operator Enexis has granted this contract, following a similar agreement in November 2022 with Eneco for a 10 MW wind farm.

Enexis explained that CLCs allow for more efficient grid use by asking renewable energy plants to reduce electricity injections during peak times in exchange for compensation. Congestion service providers (CSPs) act as intermediaries to optimize network space utilization. With the high volumes of solar capacity expected, the Netherlands is expanding grid capacity through measures like deploying transformers and managing congestion. Dutch operator Tennet plans to invest €13 billion to expand the high-voltage grid, including building 40 new onshore high-voltage stations across all provinces. This comes after warnings of limited grid capacity for solar in Groningen, Drenthe, and Overijssel in January 2019 [11].

INTERCONNECTION ISSUES

Interconnection refers to the linking of national grids across Europe to facilitate the cross-border flow of electricity. While interconnection enhances grid stability and allows for more efficient use of renewable resources, it also presents challenges. Differences in regulatory frameworks, market designs, and technical standards between countries can hinder the seamless exchange of electricity. Strengthening interconnection capacity and harmonizing regulations are crucial for a more integrated and resilient European electricity system.

More and more, there appears to be capacity reduction on certain borders. Those reductions lead to large price differences and larger spreads between the different price zones. Especially on weekends and holidays, the borders get closed.

Greece's transmission system operator, IPTO, halted electricity imports from Italy, Albania, North Macedonia, and Turkey from May 3 to May 7 to ensure grid stability. During this period, no imports were allowed, and for Bulgaria, imports were restricted from 9 a.m. to 4 p.m. with caps at other times [10].

Grid constraints in France have limited power exports, leading to lower electricity prices compared to neighboring countries like Germany and Italy. This situation has raised concerns about the transparency of the French transmission system operator, RTE. Traders and experts note that these constraints continue to pressure French prices, with the French Q3 power contract trading significantly below its German and Italian counterparts.

Data indicates that day-ahead export capacities from France to Switzerland and Italy have decreased by about 1 GW since March, attributed to both planned and unplanned outages on the French grid and high commercial exports. Particularly affected are high voltage lines in southeastern France, an area with numerous nuclear reactors and hydropower dams.

RTE has faced criticism for not meeting the EU regulation requiring a minimum of 70% of interconnector capacity to be available for cross-zonal trading. Recently, RTE has allocated only 40% of its capacity for such exchanges, prompting further scrutiny from regulatory bodies [12].

Furthermore, analysts predict that French power prices will remain significantly lower than German prices in the coming years due to France's surplus production and weak demand, coupled with insufficient interconnections. French spot and futures prices are on a steady decline, while German prices are rising. This trend is influenced by France's increasing renewable energy production, limited closures of flexible thermal plants, and continued gains in nuclear output.

The persistent price gap offers French industries a competitive advantage but negatively impacts power producers and the viability of renewable projects in France. France is expected to remain a top

European net power exporter, with the price gap with Germany likely persisting for two to three years unless there are significant shifts in demand or energy prices [13].

Interconnection capacity issues largely contribute to the price divergence. These constraints which can be monitored daily on the JAO website show the need for increased interconnection capacity to ensure a more integrated and resilient European electricity system [14].

PRICE VOLATILITY

Negative Day-ahead prices have been a major topic during the last couple of months, however price volatility in the different market segments needs to be at the forefront as well. A great analysis by Julien Jomaux emphasizes exactly those new dynamics.

Firstly, there is a notable increase in low prices on day-ahead markets, particularly in Spain and Greece, where the number of hours with prices below €5/MWh has surged in 2024 compared to previous years. For instance, on May 12th, an abundant supply of solar energy combined with low demand across Europe led to exceptionally low, even negative, prices on the day-ahead market, reaching as low as -€200/MWh in the Netherlands by 1 PM.

This oversupply of solar energy has also impacted the intraday and balancing markets. On the same day, actual solar production exceeded forecasts, leading to an oversupply and steep negative prices in intraday trades. In Germany, intraday prices hit -€539/MWh, with some trades going as low as -€2745/MWh, as market participants sought to avoid imbalance charges. This resulted in highly negative imbalance prices in Belgium and Germany.

Additionally, the value of flexible assets, such as hydro-pumped storage, has increased. These assets can store excess energy when supply is high and release it during peak demand, highlighting their importance in a solar-dominated energy mix. Data from Greece over the past 15 months shows that hydro-pumped storage has significantly higher capture rates compared to other technologies, underscoring the growing value of flexibility.

Moreover, the capacity prices for power reserves, such as aFRR (automatic Frequency Restoration Reserve), have risen notably during sunny hours. For instance, in Germany, aFRR capacity prices during sunny hours in late April were significantly higher than during winter months or nighttime blocks, indicating the increased cost of maintaining system flexibility when solar energy is abundant [15].

Other analysts also indicate those developments. The merit order system, which prioritizes the dispatch of electricity based on marginal costs, has been challenged by the intermittency of renewables. The abundance of solar and wind power is pushing conventional generation out of the merit order [16].

Data from the Entso-E 2023 Market Report shows the evolution of the balancing prices in the last years, which are progressively becoming more expensive [17].

An interesting development is also observed in Bulgaria, where the regulator recently changed the balancing mechanism, removing any price caps on the balancing market. This was done to better reflect the imbalances, their cost, but also the price volatility. On Sunday, 19th May the Day-ahead forecast was significantly higher than the actual solar production, which led to prices of more than 2000 leva/MWh [18],[19].

PICASSO PLATFORM AND ITS CHALLENGES

A particularly worrying event is the postponement of the Picasso platform.

The PICASSO platform (Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation) is an initiative designed to harmonize European energy markets by integrating automatic Frequency Restoration Reserve (aFRR) services. The platform aims to increase grid stability, enhance energy efficiency, and reduce overall costs through a common European market for balancing energy.

Despite its potential benefits, the rollout of PICASSO has faced significant challenges. Italy's experience with PICASSO is particularly illustrative. Upon joining the platform, Italy experienced severe price spikes due to differences in price methodologies and bidding behaviors with neighboring countries. This led to Italy's temporary withdrawal from PICASSO and prompted other countries to reconsider their participation.

The challenges faced by PICASSO in Italy highlight the need for comprehensive price regulation and improved clarity around the platform's algorithm. Transparency and effective risk management strategies are essential for successful integration and harmonization of energy markets across Europe. As most European countries are expected to join PICASSO by the end of 2024, lessons learned from Italy's experience will be invaluable in ensuring a smoother implementation and achieving the intended benefits of the platform [20],[21].

COMPENSATION MECHANISMS AND INCENTIVES

The problem with negative prices mainly comes from the existing support schemes around the different European countries. Whether those come in the form of feed in tariffs, net metering, or other form of compensations, they remove the natural incentive of power plant owners to reduce their production, based on market signals.

As outlined by Hans Schneider, the Netherlands is leading in the number of hours with negative electricity prices, primarily due to the net metering scheme. Under this scheme, households can sell excess solar power back to the grid during sunny hours, even when there is no demand. Energy companies are required to buy this surplus power and often incur losses, which they pass on to other customers through higher electricity prices or feed-in costs for households with solar panels.

Negative electricity prices not only impact energy companies but also other power producers, such as gas, waste, and biopower plants, as well as wind and solar farms. These producers often shut down during periods of negative prices, which can be financially damaging. Frequent shutdowns make it difficult to operate expensive generation installations, potentially leading to bankruptcies. This instability could make electricity unaffordable during high-demand periods, like winter [22].

Furthermore, the negative prices put new strains on the budgets of some countries. In Germany, the rapid expansion of photovoltaics is creating a surplus of electricity. For the first time there were negative electricity prices for eight days in a row. The consequences for the budget are immense. For the first time, from May 9th to 16th, hours with electricity prices at zero euros or below were recorded on eight consecutive days in Germany. This is proven by the current market data from the Federal Network Agency. This breaks the previous record from December 2023. At that time there were hours with negative prices on six days in a row.

This threatens to cost the federal budget new billions. The Renewable Energy Sources Act (EEG) is responsible for this. The state subsidizes the production of wind and solar power and must pay producers compensation for the negative electricity prices [23].

Bulgaria also experiences a large deficit in the Energy System Security Fund (FSES) of over BGN 1 billion [24]. Those issues have also been used to postpone the liberalization of the power-market for end customers until 2026, since the FSES is needed to compensate vulnerable consumers from the price spikes [25].

FREQUENCY PROBLEMS

Maintaining the stability of the electricity grid requires precise control of frequency. The shift towards variable renewable energy sources, which do not provide consistent power output like traditional fossil fuel plants, has led to increased frequency fluctuations. These fluctuations can cause instability and even blackouts if not properly managed. Advanced grid technologies, demand response mechanisms, and rapid-response energy storage systems are needed to maintain frequency stability in a renewable-heavy grid.

Many companies in Germany face significant issues due to short-term power outages, according to a survey by the German Chamber of Industry and Commerce (DIHK). Last year, 42 percent of companies experienced outages lasting less than three minutes, while 28 percent had longer outages. These interruptions, particularly disruptive for ongoing production processes, can lead to substantial financial consequences, including production stops and machine damage [26].

Frequency Containment Reserves (FCR) are crucial for maintaining grid frequency within acceptable limits. Different types of FCR are designed to address various frequency deviations.

The Frequency Containment Reserve for Normal Operation (FCR-N) manages minor, regular deviations from the nominal grid frequency, which is typically around 50 Hz. Its primary function is to keep the frequency within a standard range, usually between 49.9 Hz and 50.1 Hz. FCR-N is symmetrical, meaning it can both increase (up-regulation) and decrease (down-regulation) power.

In contrast, the Frequency Containment Reserve for Disturbances (FCR-D) is activated during significant frequency deviations that push the frequency outside the standard range. Its goal is to limit the frequency deviation to predefined thresholds, such as 49.5 Hz or 50.5 Hz. Unlike FCR-N, FCR-D is divided into separate upregulation (FCR-D up) and downregulation (FCR-D down) products. These products are activated rapidly, often within seconds, to counteract major frequency disturbances [27].

In the Nordics, the reliance on FCR-D up reserve is growing crucial due to the widespread use of HVDC interconnectors and offshore wind connected via DC, coupled with diminishing inertia in power systems [28].

Interestingly, Bulgaria was responsible for 50% of the continental violations in the energy system last year. The System Operator received a fine of 900 000 euro and more fines are expected. ESO recalled that on April 9 last year, Bulgaria was sanctioned due to the lack of an opportunity to balance the surplus of electricity caused by RES. The surplus reached over 1076 megawatts within 1 hour. 900 megawatts were taken out of the country unplanned, which subsequently led to frequency problems in Europe and this necessitated the activation of an emergency procedure, which cost the ESO 900,000 euros in fines. 1 million euros was the fine of the French operator, because another 1,100 megawatts were unplanned from there. [29]

FLEXIBILITY

Flexibility in the electricity system is crucial for accommodating the variable nature of renewable energy. Energy storage systems, particularly batteries, play a vital role in providing this flexibility. They can store excess energy during periods of low demand and release it when needed, thus alleviating congestion, and reducing curtailment.

Additionally, flexible grid management strategies, such as demand-side response and grid-scale storage solutions, are essential for enhancing the overall flexibility of the European electricity system.

Co-locating solar PV with BESS enhances project economics and reduces revenue risks by sharing a grid connection point. This approach optimizes grid capacity use and provides additional revenue streams through system services. Policy decisions are crucial in shaping the market. Recent policies in Bulgaria, Hungary, and Greece highlight the importance of co-location in the region's solar strategy. The combination of economic benefits, grid integration challenges, and supportive policies positions co-located solar PV and battery storage systems as a compelling solution for SEE. This trend is set to define the new standard for solar energy projects in the region [30].

NEW INVESTMENTS

The key questions arise, namely what will encourage new investments in renewable energy resources if the purely merchant model seems more and more difficult to execute. There is a need to implement better signal towards the much-needed changes, not only the presumed necessities.

To address the aforementioned challenges and ensure the sustainability of the electricity system, significant new investments are required. These investments should focus on upgrading grid infrastructure, enhancing interconnection capacity, deploying advanced grid management technologies, and expanding energy storage solutions. Additionally, policies and incentives that encourage innovation such as Demadn response and the development of new technologies will be crucial for the continued growth and stability of Europe's electricity system.

CONCLUSION

Europe's electricity system is navigating a complex landscape as it integrates more renewable energy sources and phases out traditional power plants. The challenges of congestion management, curtailments, interconnection issues, frequency stability, and the need for balancing and flexibility are becoming increasingly apparent. These issues underscore the limits of the current infrastructure and highlight the urgent need for investment and innovation.

Effective congestion management, including strategies like redispatching and countertrading, is essential to maintain grid stability. However, the rising costs associated with these measures, as seen in Germany and the Netherlands, reveal the system's strain. Curtailments are another significant issue, with countries like France and Greece experiencing substantial energy waste due to overproduction and grid constraints.

Interconnection issues further complicate the situation, as disparities in regulatory frameworks and technical standards hinder the seamless exchange of electricity across borders. This has led to price volatility and competitive imbalances between countries. Enhancing interconnection capacity and harmonizing regulations are crucial steps towards a more integrated and resilient European electricity system.

Frequency stability is another critical concern, particularly with the variable output from renewable sources. The increasing frequency fluctuations necessitate advanced grid technologies and rapid-response energy storage systems to prevent instability and potential blackouts.

Balancing and flexibility are paramount in managing the intermittency of renewable energy. Flexible assets, such as battery energy storage systems and hydro-pumped storage, play a vital role in this regard. These technologies help to store excess energy during low demand periods and release it when needed, thereby reducing curtailments and alleviating congestion.

In conclusion, while Europe's electricity system is under significant pressure, the challenges it faces also present opportunities for innovation and improvement. Investments in grid infrastructure, advanced technologies, and regulatory harmonization are essential to support the ongoing energy transition and ensure a stable and resilient electricity system for the future. By addressing these issues proactively, Europe can continue to lead the way towards a sustainable and reliable energy future.

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