SCIENCE FOR POLICY BRIEF

The Merit Order and Price-Setting Dynamics in European Electricity Markets

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A 2022 and 2030 Investigation using METIS

→ Our analysis demonstrates how fossil fuel power plants, in particular gas, play an outsized role in setting EU wholesale power prices in 2022 and are projected to retain this influence in 2030

→ Gas-run power plants set the price 55% of the time in 2022 while generating 19% of total EU electricity. In 2030, the price-setting share is still close to 56%, even with generation decreasing to 11% of electricity

→ While gas retains its dominant role in the current decade, the future expanded role of power purchase agreements and contracts for difference will ensure investability in renewable and other low carbon technologies while limiting consumers exposure to high prices and volatility

→ Rising interconnection levels lead to greater prices stability and lower cross-border deltas with national prices increasingly set by foreign generation sources

→ The beneficial effect of renewables setting the price and thus driving down prices will take longer to materialise, due in part to still limited storage capacity and system flexibility

INTRODUCTION

During the last three years, European wholesale electricity markets have experienced unprecedented levels of price volatility. These veered from the record low prices observed during the pandemic in 2020 to the record high prices reached in the summer of 2022 as a consequence of Russia's aggression against Ukraine. The fluctuations in the gas price were the main driving force behind these electricity market dynamics. Natural gas-fired power plants are often the marginal technology units in the merit order, setting the price in the electricity market. For this reason, many have questioned the functioning of electricity markets and called for the decoupling of gas and electricity prices. In October 2021, the European Commission asked the European energy regulator (ACER) to study the benefits and drawbacks of the existing electricity market design[1]. In the resulting report, published in April 2022, ACER [1] argued that basing the market on the marginal price remained the most effective mechanism to promote competition and to ensure efficient allocation of generation resources, while guaranteeing an adequate return

[1] COM(2021) 660 final, Tackling rising energy prices: a toolbox for action and support

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on investment for suppliers. In a response to address the high electricity prices, temporary measures have nevertheless been introduced within the current electricity market framework. In June 2022, the Commission approved a measure for Spain and Portugal designed to reduce the electricity wholesale price in the Iberian electricity market by supporting the fuel costs of fossil based technologies[2]; this measure was prolonged in April 2023[3]. In October 2022, the European Council passed emergency legislation that temporarily limits the profit made by generators with costs well below those of marginal gas units[4]. Further instruments addressing electricity price volatility are included in the European Commission's Market Design proposal of March 2023[5]. The aim is to reduce consumers, industry and investors' exposure to volatile short-term prices, by complementing the short-term markets with a greater role for longer-term instruments, allowing consumers to benefit from more fixed-priced contracts, and facilitating investment in clean technologies.

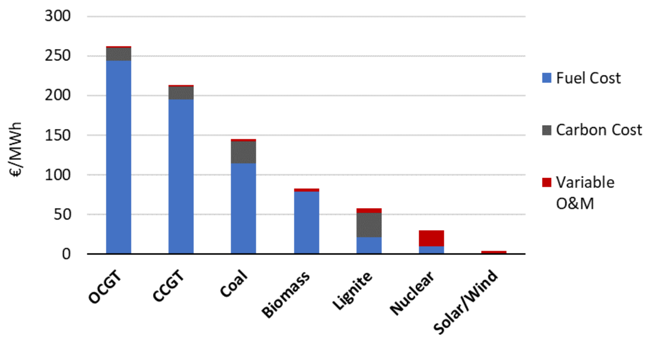
With the transition to a cleaner generation mix based on renewables, how is merit order price-setting dynamic changing in EU power system? Will the outsized role of gas decrease with a rising proportion of solar and wind in the mix? And finally, what solutions are there to deliver lower and more stable electricity prices? This Science for Policy brief aims to provide some answers by analysing the price-setting dynamics in the European power market in 2022 and 2030. The objective is to clarify how wholesale electricity prices are set and how merit order dynamics are evolving as the share of renewable energy sources increases. The results are based on an economic equilibrium model simulating the EU wholesale market hourly dispatch.

MERIT ORDER DYNAMICS

Merit order mechanism

The efficient functioning of electricity wholesale markets is crucial for the optimal allocation of resources and the reliable supply of electricity. Electricity is traded on a sequence of market sessions, ensuring the effective balance of supply and demand in real time. Day-ahead spot markets are thereby often regarded as a reference market, matching supply and demand on a hourly basis following the merit order mechanism. In this system, demand is met by ranking, in ascending order, the generator supply bids based on their marginal production cost, also known as the variable costs required to produce an additional unit of electricity. The variable generation cost typically consists of three components; fuel, carbon emissions and variable operational and management (O&M) costs – as shown in Figure 1. The fuel cost is determined by the underlying commodity price. The second element, the carbon cost, is determined in the EU by the EU ETS allowance price which follows a 'cap and trade' market-based mechanism. Each generation technology emits a different quantity of CO_2 depending on the fuel combusted and the plant efficiency, with lignite and coal power plants being the most polluting. Finally, the variable O&M covers the daily running cost of the plant, along with maintenance and labour expenditures which can vary depending on the plant production level.

Figure 1 – Generation technologies marginal production cost 2022 – simplified example



Source: EC JRC, based on external data providers (among others S&P)

Note: 1- OCGT (open combustion gas turbine) are more flexible gas plants while CCGT (combined combustion gas turbine) are generally more efficient

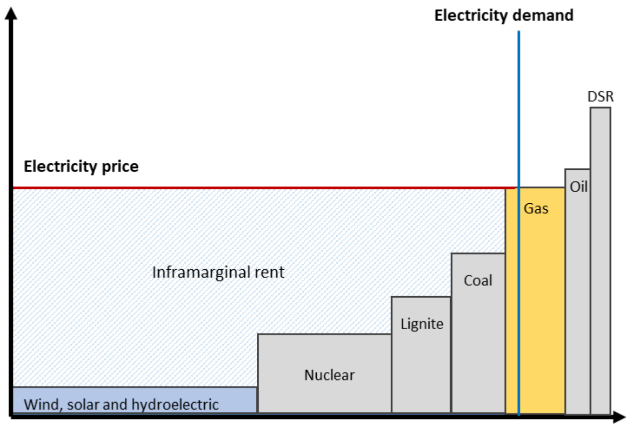
Conventional fossil fuel-based technologies such as gas, coal and lignite power plants bid at a price which is mostly driven by the underlying commodity price. For this reason, their positioning in the merit order depends to a large extent on the market prices of the underlying commodity. Nuclear is an exception as its marginal cost depends only to a degree on the market price of uranium. Costs for the processing of uranium, the fabrication of fuel elements and the safe disposal of spent fuel exceed the cost of the uranium itself, making nuclear power generation much less vulnerable to price swings in the uranium market. Finally, renewable generators such as solar, wind and hydro have close to zero variable production costs, being fuelled by zero-cost natural inputs. In the merit order mechanism, the last accepted bid, known as the marginal bid, determines the market-clearing price, which is paid to all accepted generators in the same clearing hour – as shown in Figure 2. This mechanism, also called pay-as-cleared, has several advantages: it ensures market transparency and efficiency by facilitating the usage of lower-cost technology first; it facilitates the integration of renewable sources by dispatching them first due to their lower variable cost; it allows for dynamic adjustments in response to changes in demand or the availability of generation sources. One consequence of this market process is the presence of an inframarginal rent which benefits power plants with a production cost lower than the clearing price. This allows generators to recover non-

[2] "SA.102454 (2022/N) – Spain and SA.102569 (2022/N) - Portugal – Production cost adjustment mechanism for the reduction of the electricity wholesale price in the Iberian market" of 8 June 2022
[3] C(2023) 2856 final, State Aid SA. 106095 (2023/NN) - Spain and SA.106096 (2023/NN) -Portugal – Prolongation of MIBEL fossil-fuel cost adjustment mechanism

[4] COUNCIL REGULATION (EU) 2022/1854 of 6 October 2022 on an emergency intervention to address high energy prices
[5] 2023/0077 (COD), Proposal for a regulation of the European Parliament and of the Council amending Regulations (EU) 2019/943 and (EU) 2019/942 as well as Directives (EU) 2018/2001 and (EU) 2019/944 to improve the Union's electricity market design

operational costs such as investment or fixed costs. The emergency measures from late 2022 limited these inframarginal rents if electricity prices exceeded 180 EUR/MWh, as the high prices in 2022 may have allowed inframarginal generators to make unexpectedly large financial gains without their operational costs increasing.

Figure 2 – Simplified merit order supply demand stack



Source: EC JRC

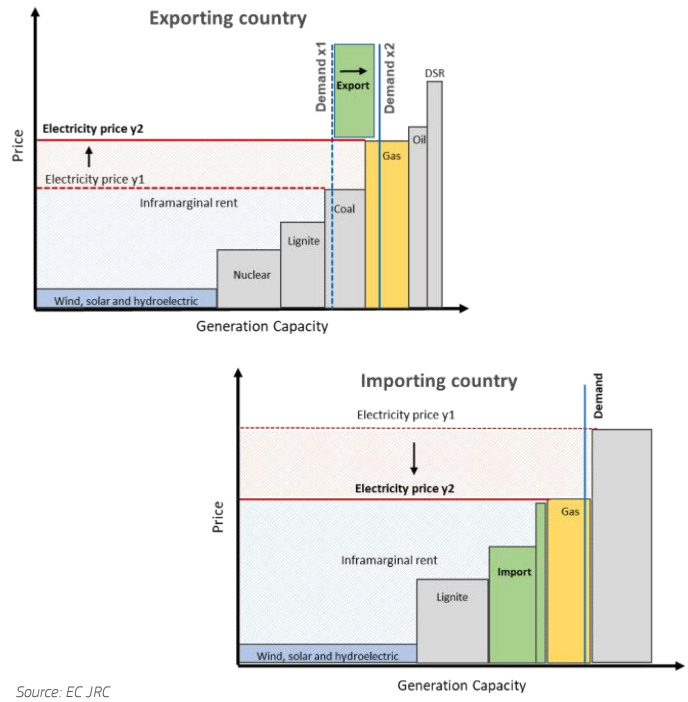
In the EU, day-ahead electricity prices are determined for each hour at zonal price levels. These are electricity market geographical areas representing, in most cases, an EU country or smaller region, as shown in Figure 3. Sub-country zones are present in Sweden (4 zones), Norway (5 zones) and Italy (7 zones) to better reflect regional differences. These zones were established to facilitate efficient electricity trading and reflect not only the different supply and demand dynamics at the regional level but also the physical constraints of the grid.

Figure 3 – EU electricity market bidding zones

Source: EC JRC

Electricity can flow across national borders and regional zones seamlessly using the many existing interconnectors and transmission lines. To promote competitiveness, efficiency and security of supply, the EU promotes a single integrated electricity market where electricity can be traded across national borders. Interconnectors expand the pool of available power generation sources by allowing electricity to be imported from neighbouring regions or countries. This increased range of supply options expands the merit order, as it introduces additional generators into the market. Consequently, for an importing area, interconnectors can lower the market-clearing price by dispatching lower-cost generators from neighbouring regions, thus benefiting electricity consumers. On the other hand, an exporting area would see an increased electricity demand, which would boost the clearing price, thus benefitting power plant generators.

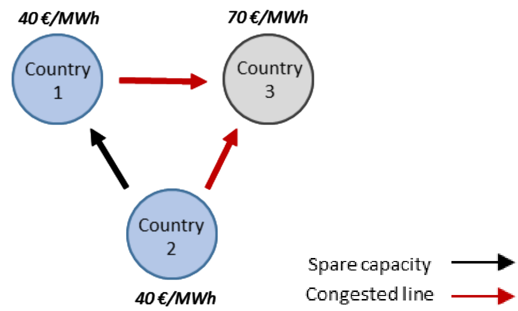
Figure 4 – Import and export merit order impact



Source: EC JRC

Import and export volumes between price zones are limited by transmission lines and interconnectors capacities. These limits affect price dynamics between market zones, with prices converging when spare capacity is available and a difference emerging when lines are congested and no additional electricity can be exchanged – as shown in Figure 5. Electricity is exported from lower price zones to higher price areas until interconnection capacities are fully booked.. Interconnectors play a crucial role in facilitating the integration of renewable energy sources, providing flexibility and risk supply diversification. For this reason, EU countries are aiming to increase the level of interconnectedness with benefits expected in terms of cost reduction and price convergence.

Figure 5 – Marginal price with cross border capacity

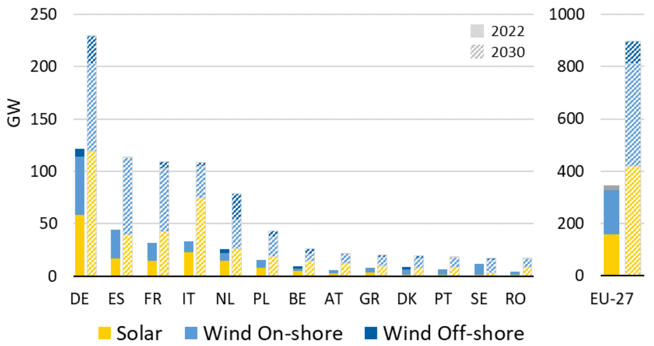


Source: EC JRC

The role of an increasing share of renewable energy

In line with the 2030 decarbonisation targets and ambitious national goals, renewable energy capacity is expected to expand rapidly by the end of the decade, more than doubling in size. Solar is projected to grow from the existing 150 GW to up to 400 GW, and total wind capacity from 170 GW to 500 GW – as shown in Figure 6. This growing share of renewable electricity with low marginal costs will exert an increasing downward pressure on wholesale electricity prices. This is because, when renewable supply is abundant, it displaces higher cost, fossil fuel-based generation in the merit order. However, rising variable renewable generation will expose market prices to intermittent production profiles and climatic volatility, which will increase market instability if not counterbalanced by adequate growth in electricity storage, system flexibility and cross-border interconnectivity.

Figure 6 – Solar and wind installed capacity in 2022 and 2030, FiT-55 EU Projections



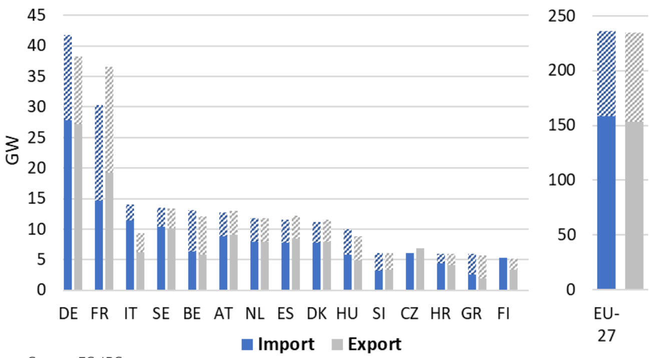
Source: EC JRC

The role of a more interconnected EU

To boost the security of supply and integrate renewable sources, the EU has ambitious targets for the expansion of cross-border interconnection capacity. The aim is for interconnection capacity to reach at least 15% of generation installed capacity in each member state by 2030 [3]. This helps to balance supply and demand, optimise renewable energy utilisation, and reduce curtailment. It further enables the transfer of electricity across borders, helping to address the variability and intermittency issues associated with renewable energy generation.

As shown in Figure 7, both import and export cross-border capacities are projected to grow by almost 50% in the EU-27, with the highest increases in central countries such as Germany, France and Belgium.

Figure 7 – Cross border transmission capacity in 2022 and 2030, FiT-55 EU Projections



Source: EC JRC

ANALYSIS APPROACH

To simulate EU power market dynamics and understand the generation technologies driving electricity prices, we use a cost-minimisation economic equilibrium model based on the METIS energy system model [4]. The model simulates the hourly dispatch of generation technologies in the wholesale electricity market for the EU and neighbouring countries, considering the supply generation mix, demand profiles, underlying commodity prices and grid system constraints. The system is represented at the national level with all generation technologies defined by their technical operating properties and availability profiles. We ran the simulation for 2022 using historical capacity and commodity prices and for 2030 using the projected assumptions of the FF55 MIX H26 scenario [2]. Renewable generation such as solar, wind and hydro are modelled using a historical climatic weather profile, based on climatic data from 1982 to 2015, with 2022 being represented by a statistically close weather year and 2030 by an average year. We note that while the simulated market model uses a robust, simplified approach to mimic wholesale electricity markets, it falls short in capturing certain dynamics such as speculative bidding behaviours, market scarcity and intra-markets rebalancing. Moreover, the resulting generation mix might present some differences compared to realised production levels, especially when comparing at national level.

To understand which generation type sets the price at a given time, we calculate the producer surplus for each generation technology, given by the difference between the market revenues and the production cost:

*Surplus = (generation * market price) – (generation * marginal cost)*

For each hour and price zone, the generation type with the lowest positive surplus is setting the price as it is running on the margin to meet total electricity demand. We exclude negative surpluses to account for must-run technologies such as cogeneration, nuclear and combined heat and power plants

[6] Coherent with the ambition considered in the Fit-for-55 policy proposals, three core policy scenarios have been developed to serve as common analytical tools for the impact assessments across the various policies within the context of the European Green Deal. This study uses the MIX-H2 scenario, which builds on top of the MIX scenario, the core policy scenario that achieves a net 55% reduction of greenhouse gases and a share of 38%-40% renewable energy sources in gross final energy consumption by 2030. The MIX-H2 scenario builds on the MIX scenario by relying on a higher uptake of hydrogen in final energy demand, which implies a considerable increase of electrolyser capacity.

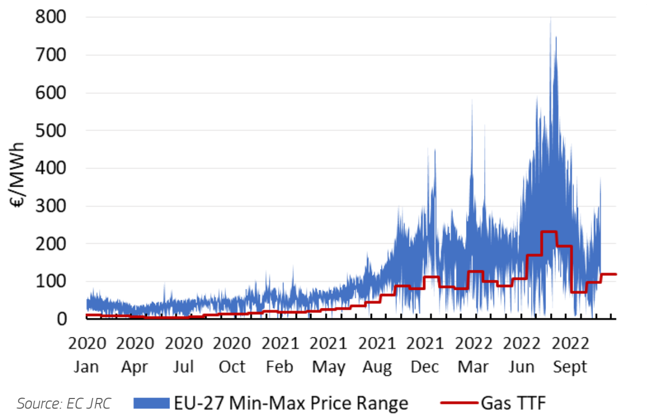
which can generate when the electricity price is lower than their break-even point. Hydro-power and battery storage were also treated separately as their marginal cost does not reflect the cost of producing a unit of power, but rather the marginal cost of an additional alternative source. These assets, in fact, generally follow a strategic bidding behaviour which aims to maximise the value of stored electricity based on the hourly supply-demand balance in the market.

2022 PRICE DYNAMICS

2022 Wholesale prices

The EU experienced a period of significant change and volatility in wholesale electricity prices during the last three years. In 2020, electricity prices were particularly low due to the economic slowdown and lower electricity demand caused by the pandemic. Afterwards, in 2021, gas prices saw a rapid rebound which coincided with reducing gas flows in Russia's pipelines and rising tensions in Ukraine. This was exacerbated during 2022 following Russia's invasion of Ukraine, when gas prices touched all-time highs. The high gas prices and volatility drove a sharp increase in wholesale electricity prices which reached record levels around Europe. These increases were not homogenous in all EU countries due to the different generation mixes and the varying reliance on gas as an electricity source. The spread between the highest priced country vs the lowest member state price level was particularly stark during August 2022, as shown in Figure 8.

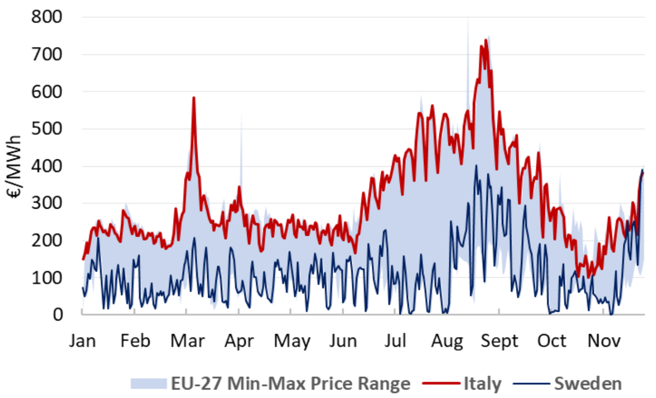
Figure 8: Historical EU daily wholesale electricity prices min-max range and monthly gas TTF evolution



Source: EC JRC

In 2022, electricity prices in EU countries reached a record high, but significant variation emerged between Member States. As shown in Figure 9, while Italy's prices were consistently amongst the highest, Sweden's were the lowest. The price range reflects the non-homogenous generation mix in the continent, with some countries relying to a greater degree on gas and coal and others on lower-cost nuclear and renewable sources. At the extremes, while Italy is highly reliant on gas, Sweden has a more diversified mix with a high share of lower cost nuclear and renewables. However, the generation mix is not the only driving force. The level of interconnection and the price dynamics of neighbouring countries also play a strong role, which in many countries can be the leading factor.

Figure 9: Historical EU 2022 daily wholesale electricity price min-max range

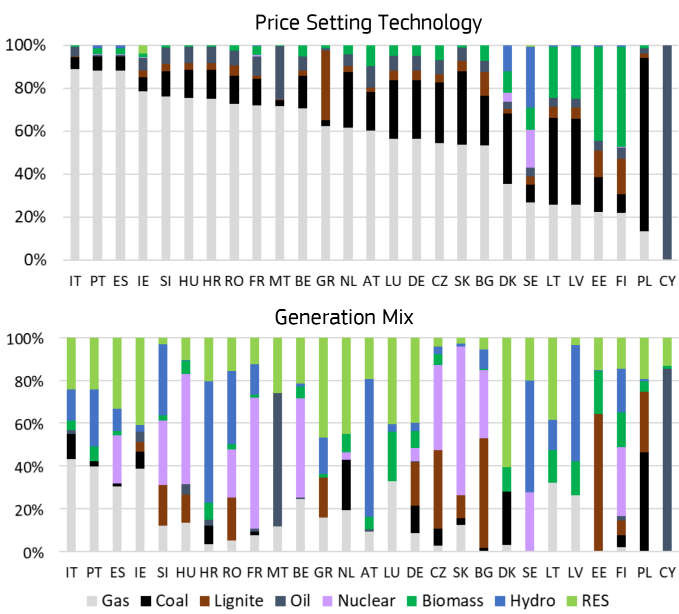


Source: EC JRC

2022 Price-setting

In 2022, gas-fuelled power plants were the most expensive generation assets, followed by coal, lignite and nuclear plants. According to the simulation results, gas was the predominant price setter in western EU countries where gas-based CCGT and OCGT played the leading setting role. Eastern EU countries were driven by coal and lignite power plants while the Nordics and Baltic states had a higher share of prices set by renewables and biomass. It is clear that the technology generation mix does not correspond directly with the share in price-setting, as seen in Figure 10. This is primarily driven by the discussed merit order effect, but also by by the interconnected nature of the EU single market, where electricity is traded across borders through transmission lines. The latter effect is relatively stark for countries such as France, Austria and Czechia. These countries are highly interconnected and price dynamics are driven by generation plants in neighbouring states.

Figure 10 – 2022 Price-setting technology per EU country vs Generation Mix (METIS Simulation results)

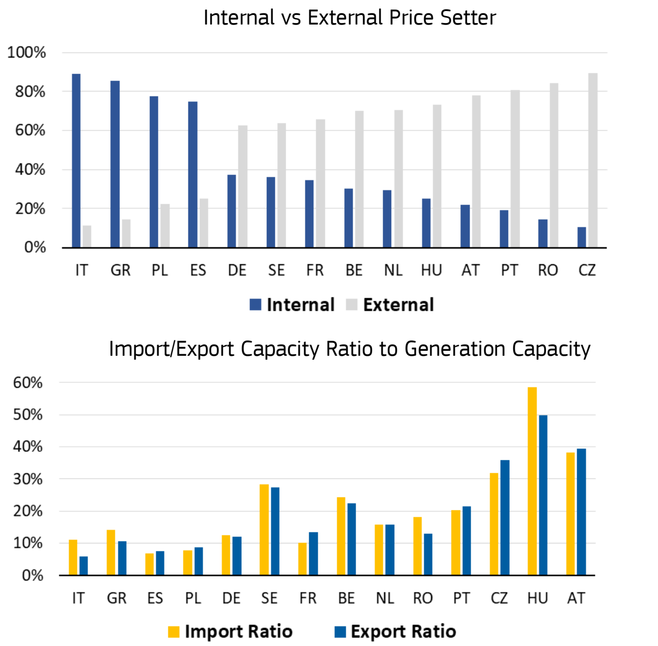


Source: EC JRC

Internal vs external setters

National wholesale prices can be determined by a power plant within the Member State or by one from a neighbouring Member State, which can be on the margin thanks to the existing cross-border interconnection capacity. Depending on the geographical location and the level of interconnection capacity, certain EU countries are more or less affected by external price dynamics (Figure 11). In 2022, our analysis shows that countries such as Italy, Greece, Spain and Poland have a high degree of nationally determined prices. This is led not only by limited interconnection capacity relative to national installed capacity but also by indigenous higher price marginal plans based on gas or coal. On the other hand, countries such as Czechia, Romania and Portugal are highly interconnected and their prices are driven significantly by the market dynamics of their neighbours.

Figure 11 – 2022 Share of price hours set by an internal vs external generator and import/export capacity ratios to generation capacity

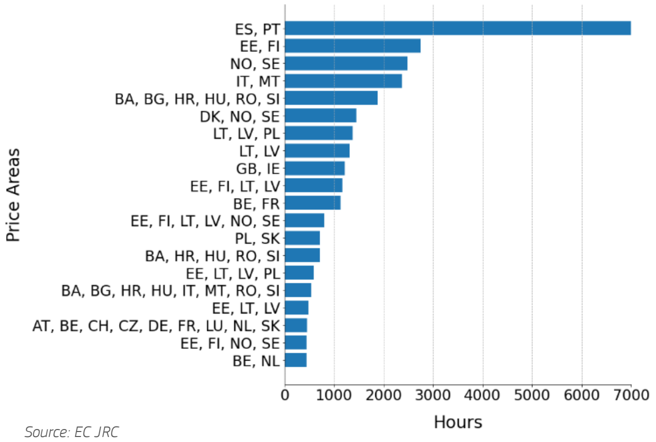


Source: EC JRC

Price-convergent areas

Cross-border interconnectors have the effect of producing bidding areas with the same price level, i.e. determined by the same marginal generator. This situation occurs wherever the lines are not fully congested and there is spare interconnection capacity available between two countries. For 2022, our analysis shows some clearly converging areas (Figure 12), such as Spain and Portugal with more than 6 000 hours, Estonia-Finland, Norway-Sweden and Italy-Malta with around 2 500 hours. Some bigger price zones are also present such as Eastern Europe (BA, BG, HR, HU, RO, SI), the Baltics (LT, LV, PL), and the Nordics (NO, SE, DK). These findings may also indicate where additional cross-border capacity is most needed, e.g. between the Iberian peninsula and the rest of the continent and between Italy and its neighbours.

Figure 12 – 2022 Most frequent price-convergent areas



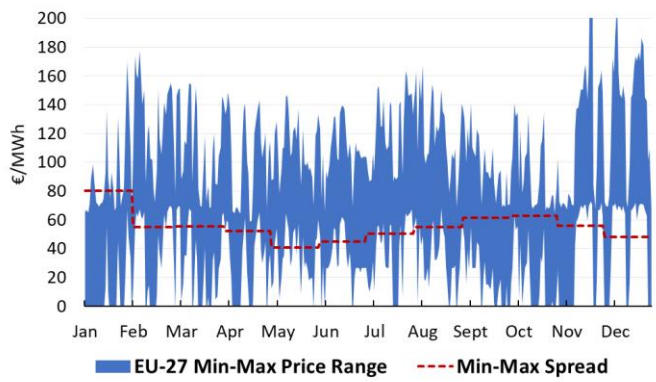
Source: EC JRC

2030 MERIT ORDER DYNAMICS

2030 Wholesale prices

2030 simulated wholesale electricity prices present, on average, lower values compared to 2022 levels due to lower expected gas prices and the rising share of renewable energy sources in the EU generation mix (Figure 13). An increase in frequency can be noted of days with a zero or close-to-zero average wholesale price driven by a higher share of low marginal cost wind and solar generation. Another interesting aspect is the increased price volatility which is mainly driven by wind conditions and a lack of sufficient storage and flexibility in the system to smooth the weather-dependent renewable sources electricity supply. At the same time, the daily spreads between the maximum and minimum prices in the EU are lower compared to 2022, driven by lower gas prices, rising renewable generation and increased cross-border interconnection.

Figure 13: Simulated 2030 EU daily wholesale electricity price min and max range and monthly spread

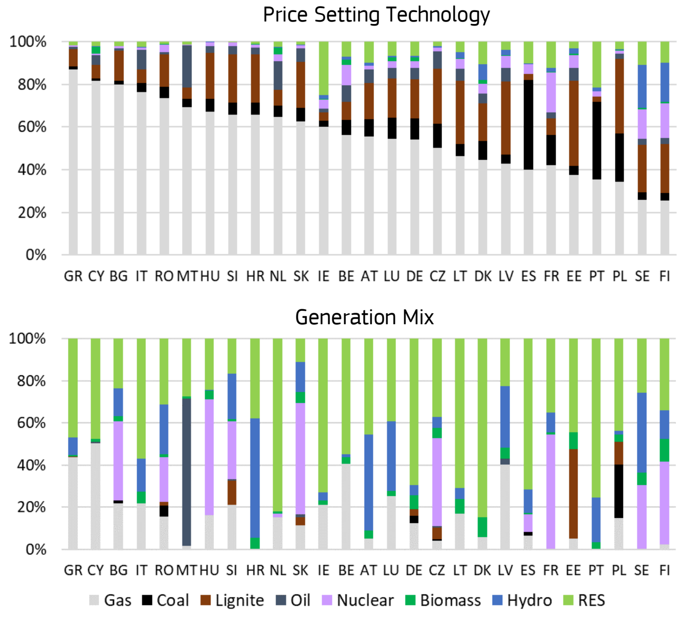


Source: EC JRC

Price-setting technologies

Electricity price-setting in 2030 is still dominated by fossil fuel-based power plants, and primarily by gas-fired power generators, as natural gas plants, in part, are expected to displace the more polluting lignite and coal power plants. Electricity generation from renewable sources greatly expands at EU level from 2022 till 2030, growing from 46% to 67%. This increase is, however, not reflected in the fossil fuel-based price-setting hours, which remain at 2022 levels. This counter-intuitive effect is due to the marginal setting role of gas and the increasing EU interconnectness. Despite the gradual phase-out of coal and lignite, renewable energy sources alone do not meet the entirety of the EU's electricity demand. Hourly residual load – demand minus renewable generation – will still be met by more expensive gas thermal power plants for most EU countries, especially during peak daytime hours.

Figure 14 – 2030 Price-setting technology per EU country vs generation mix (METIS Simulation results)

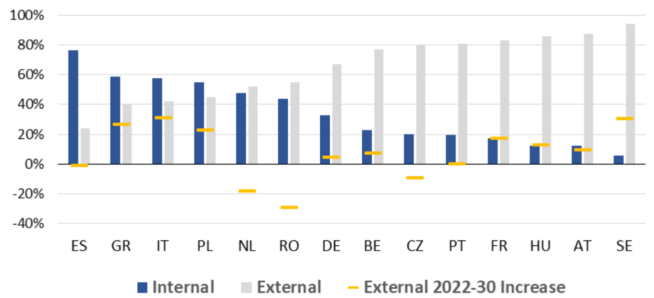


Source: EC JRC

Internal vs external setters

Increasing EU cross-border interconnecitivity will lead to lower EU wholesale price volatility and price divergence within the EU. This also means that wholesale prices will increasingly be set not at national level, but by generators across borders. As shown in Figure 15, an overall increase can be noted in the share of hours set by an external generator in 2030. This is particularly visible in Italy, Sweden, Greece, and to a lesser degree, in France and Germany.

Figure 15 – 2030 Share of price hours set by an internal vs external generator and external % increase vs 2022

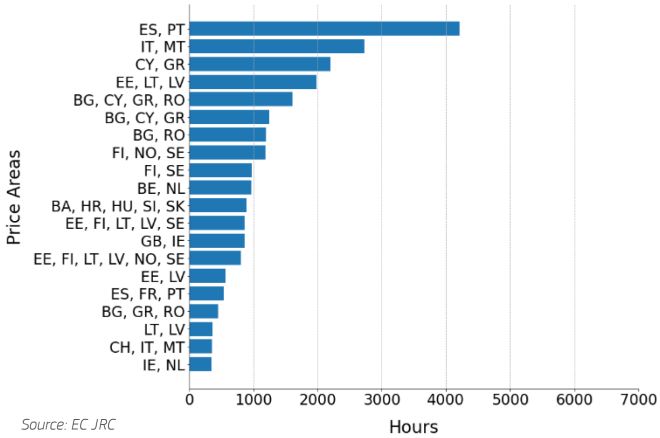


Source: EC JRC

Price-convergent areas

In 2030, the most frequently price-convergent areas present many similarities to the picture in 2022 but with some changes due to increased variable renewable sources capacity and new cross-border links. Overall, the frequency of perfect price-convergence is lower, with only four areas above 2 000 hours, namely Spain-Portugal, Malta-Italy, Estonia-Lithuania-Latvia and Greece-Cyprus. This is most likely driven by the higher share of variable renewable generation and the increased congestion in some cross-border interconnection lines. Even though convergent hours become less common, perfect convergence is not the objective of a more interconnected EU market. The aim is rather to achieve lower cross-border price deltas, which is the case in 2030 with values overall lower compared to 2022.

Figure 16 – 2030 Most frequently price-convergent areas

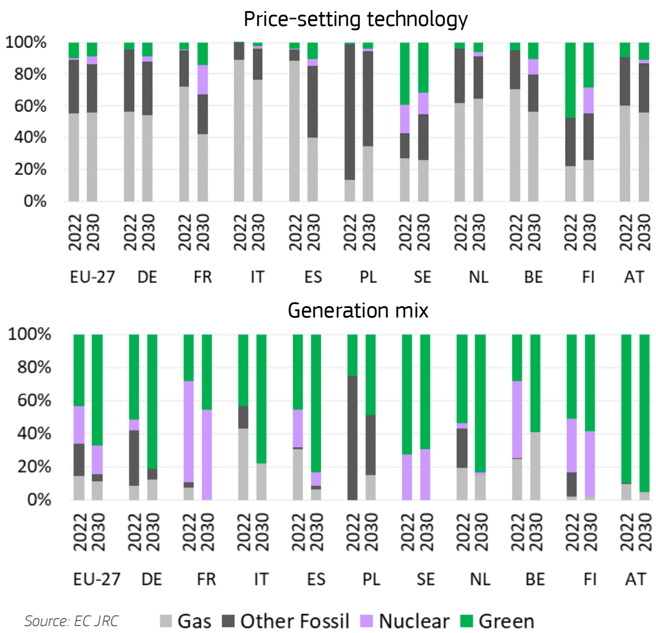


Source: EC JRC

DISCUSSION

Fossil fuels are the dominant price setters today in the EU electricity market. Especially the role of natural gas as a price setter is not going to be challenged in the next few years by rising renewables capacity. In both 2022 and 2030, at EU level fossil fuel-based plants set the price around 86% of the time, while generating 34% of electricity in 2022, and only 16% in 2030 (Figure 17). In both years, the hours natural gas is setting the price in wholesale electricity markets far exceeds its proportional generation share. While for some countries the role of gas is projected to diminish, for others, such as Poland, which are shifting away from lignite and coal, the role of gas will become even more pronounced. This dynamic should not raise alarms, as it should be taken into account that a growing share of renewable and nuclear generation would not necessarily be remunerated at market clearing prices. Rather, power purchase agreements and contracts for difference would ensure investability in these technologies while limiting consumers exposure to price volatility. Furthermore, elevated market prices and high volatility send another important signal, indicating a need for additional storage and flexibility sources which would help to reduce the role of gas in setting prices in peak daytime hours. Increasing renewable generation in the mix has a modest impact in setting power prices by 2030. This can be attributed to the fact that despite the gradual phase-out of coal and lignite, renewable energy sources alone will not suffice to meet the entirety of the EU's electricity demand. Hourly residual load (demand minus renewables generation), especially at peak daytime hours, will still be met by more expensive gas power plants on the margin. This scenario is likely to evolve in later years when renewable generation will start to exceed total EU demand for multiple hours per day, pushing average electricity prices to lower values. The combination of a higher renewable energy share paired with increasing storage and flexibility resources is expected to bring price stability and overall reductions in electricity costs in the following decade.

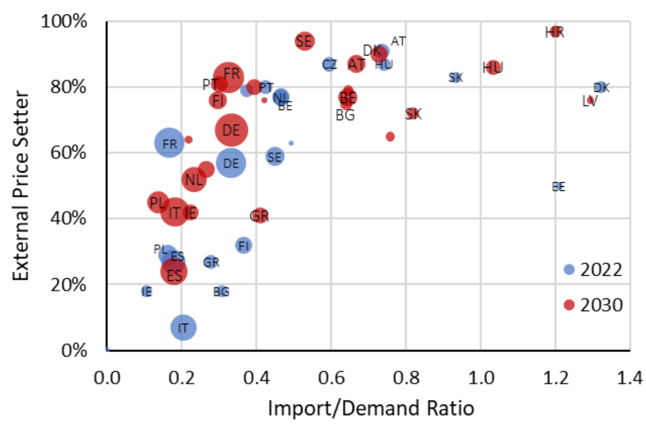
Figure 17 – 2022 vs 2030 Price-setting and generation mix



Source: EC JRC

Interconnectors are poised to play a key role in meeting the EU's decarbonisation targets. While interconnectors deliver overall annual net welfare benefits for the whole EU through increased competition, efficiency, reduced volatility and price spreads, some countries might see more benefits for consumers and others for electricity suppliers.

Figure 18 – 2022 vs 2030 External price setting and import capacity to average electricity demand ratio



Source: EC JRC

Note: 1- Bubble size represents the average country demand
2- Import/Demand ratio represents the country transmission import capacity divided by the average electricity demand

Larger countries assume a prominent role in this intricate interplay, exerting a greater influence on price formation in the surrounding Member States. As shown in Figure 18, increasing EU interconnectivivity means that national prices will be more influenced by cross-border dynamics, which can lead to higher or lower national prices depending on the national generation mix compared to the surrounding areas.

CONCLUSION

In this Science for Policy brief, we aim to investigate the merit order and price dynamics mechanism in the EU wholesale electricity market. The results of our analysis confirm that fossil-fuelled power plants, and in particular gas, play an outsized role in setting EU wholesale power prices, both in the past year and in 2030. Gas-run power plants set the price 55% of the time in 2022, while generating 19% of electricity. In 2030, the price-setting share remains at a similar level, even with a generation share decreasing to 11%. This is primarily caused by gas replacing lignite and coal running on the margin. This should not raise alarms as a growing share of renewable and nuclear generation would not necessarily be remunerated at market clearing prices. An expanded role for power purchase agreements and contracts for difference will ensure investability in these technologies while limiting consumer exposure to high market prices and volatility. Future increased interconnectivity in the EU further leads to greater price convergence with lower price differences between Member States. Converging price areas present similar patterns in 2022 and 2030 and the latter presents a rising trend of national prices determined by cross-border generation sources. While renewable generation is projected to grow from 46% to 67% during the current decade, its benefit in terms of lower wholesale prices will take longer to materialise, due in part to limited storage capacity and system flexibility. The influence of renewable sources will become more tangible in later years, when projected generation is able to meet the full EU demand, displacing fossil fuel-based power plants on the margin for a higher share of hours.

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How to cite this report: Gasparella A., Koolen D. and Zucker A., The Merit Order and Price-Setting Dynamics in European Electricity Markets, European Commission, Petten, 2023, JRC134300.

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