# Electricity Price Dynamics under Geopolitical Shocks: Assessing Resilience on the Path to Decarbonization

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# Summary

# Introduction

# Decarbonizing Europe's Energy Sector in a Shock-Prone Context

- The EU aims to **reduce greenhouse gas emissions by 55% by 2030** (vs. 1990) as a milestone toward climate neutrality in 2050.
- The energy transition requires a massive **increase in renewable energy**, with a target of at least 42.5% of final energy consumption by 2030 (up to 45%).
- However, decarbonization must remain compatible with **security of supply**, **industrial competitiveness**, and **affordable electricity prices**.
- Shocks such as the **Russia-Ukraine war** have highlighted the vulnerability of the European electricity system: soaring gas prices immediately spilled over into electricity markets.
- In response, the EU launched the **REPowerEU Plan** to reduce dependence on Russian fossil fuels and accelerate the transition.

# The European electricity market

- European electricity market has different regional groups.
- Each country has its own **electricity production mix** and **merit order curve**.
- Consequently, each country has its **own price**. Price can be zonal with sometimes different zones inside a particular country.
- Some european countries are **interconnected** to export and import electricity from other european countries.

# The electricity price

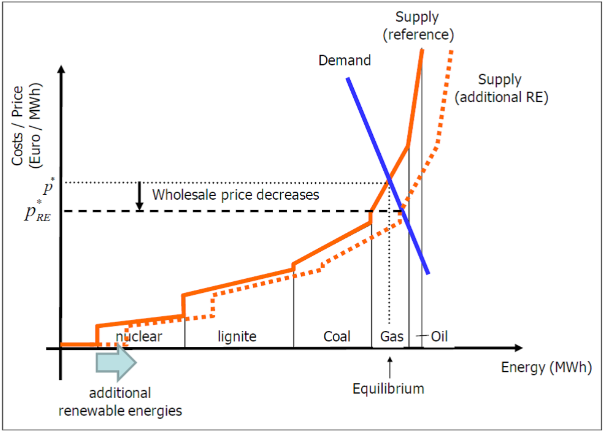



Figure: Merit Order and system marginal price

# Research question and motivations

# Research question

- Different **energy policies** have been put in place in the EU to achieve energy neutrality by 2050.
- The aim of our research is to determine the effects of a geopolitical shock on the electricity prices. More precisely, in the event of a supply disruption, how **a given electricity mix** can influence the electricity prices?
- We focus on the case of the Russia-Ukraine war.

# Key Literature Insights

**Gas disruption and price shocks**

- Russian pipeline deliveries fell by **120 bcm** between 2022–2023 (IEA).
- Gas prices surged by **+180%** within two weeks of the Ukraine invasion (ECB, 2022).
- European countries were affected **asymmetrically**, depending on their reliance on Russian gas (Martínez-García et al., 2023).

**Energy market interactions**

- **Geopolitical risks strongly shape electricity prices** (Saâdaoui et al., 2023).
- Fossil fuel and electricity prices co-move via the **merit-order mechanism** (Zakeri et al., 2023; Creti & Fontini, 2019).

**Carbon pass-through**

- Rising $CO_2$ prices increase **marginal generation costs** for fossil units (ETS).
- Several countries reopened fossil plants in 2022–2023, raising emissions and reinforcing carbon–electricity price coupling (Jouvet et al., 2013).

# Methodology

# An empirical study

- An **empirical study** is chosen to study the effects of the Ukraine-Russia War on electricity prices of Germany and France, according to their electricity mix and emissions rates.
- **Germany** and **France** have distinct approaches to energy policy, each reflecting different strategic decarbonization choices and national priorities.

# Context

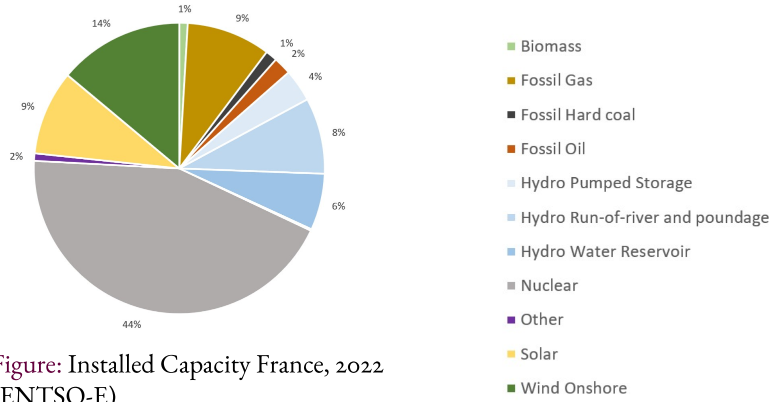



Figure: Installed Capacity France, 2022 (ENTSO-E)

# Context

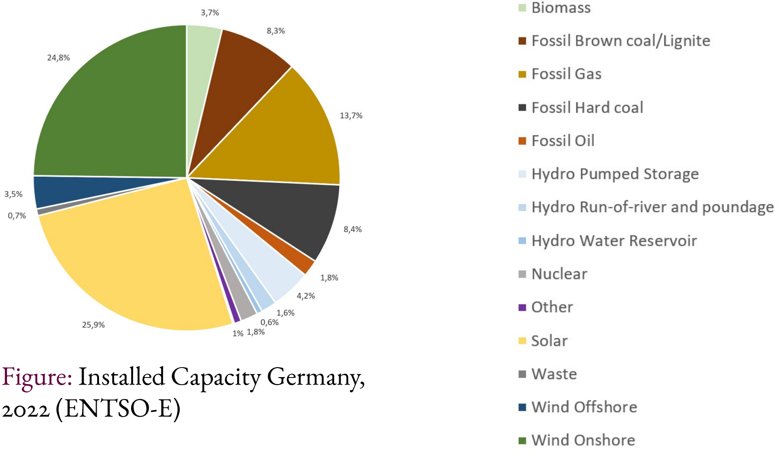



Figure: Installed Capacity Germany, 2022 (ENTSO-E)

# Variables

| Variable | Unit | Description |
|---|---|---|
| **Electricity prices (Spot)** | €/MWh | Spot day-ahead prices (France and Germany) |
| **Gas prices (TTF futures)** | €/MWh | Dutch TTF front-month futures (ICE) |
| **Coal prices (API2)** | €/t | ICE API2 Rotterdam (CIF ARA) |
| **EU ETS price (EUA)** | €/t$CO_2$ | EUA futures emissions price |
| **Electricity generation** | GWh | Converted from MW to GWh |
| **Cross-border imports (GER→FRA)** | GWh | Positive values = imports (MW→GWh) |
| **Time period** | Jan 2016 – Dec 2024 (8 years) | |
| **Frequency** | Daily (2,244 observations) | |

# I. A regression analysis

The baseline specification estimates the relationship in levels:

$$P_t^{Elec} = \beta_0 + \underbrace{\beta_1 P_t^{Coal} + \beta_2 P_t^{Gas} + \beta_3 P_t^{EUA}}_{\text{Market variables}}$$

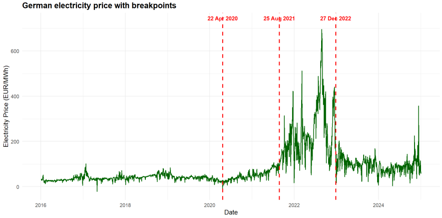
$$+ \underbrace{\beta_4 Ren_t + \beta_5 Nuc_t + \beta_6 Fos_t}_{\text{Electricity mix variables}}$$

$$+ \underbrace{\beta_7 Imp_t}_{\text{Import variable}} + \varepsilon_t$$

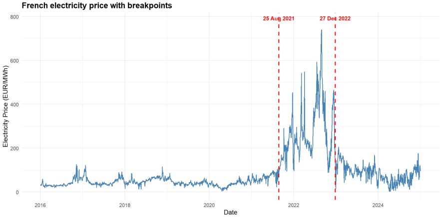
# Structural change

- Indeed, during the period observed (from January 2016 to December 2024), the energy crisis was a significant **shock on energy markets**. This type of shock generates changes in the dynamics that need to be taken into account.
- In fact, the electricity and gas prices have begun to rise months before the outbreak of the war (24th February 2022).
- Using a **breakpoint test** (Bai et al. (1998); Zeileis et al. (2003)), a **structural change** was statistically identified on **September 1, 2021.**

# Structural change




Germany (2016–2024)




France (2016–2024)

# Quantile Regressions

- **Electricity prices react asymmetrically to shocks** (geopolitical disruptions, supply stress, fuel price spikes). Mean regression (OLS) hides these heterogeneous responses across the distribution.
- **Resilience is a tail property**. Understanding how prices behave in the *upper quantiles* (extreme price events) is crucial to assess vulnerability under stress.
- **QR better identifies extremes and heterogeneity** in the pass-through of gas, coal, $CO_2$ prices and electricity generation, especially relevant during geopolitical shocks.
- We concentrate the analysis **on the 2020-2024** period to capture the effects of the Ukraine war.

# II. A Markov Switching approach

- Electricity prices exhibit **non-linear dynamics**, driven by structural changes in supply, demand, fuel prices, and extreme events.
- Standard linear time-series models fail to capture regime-dependent behavior, such as periods of high volatility or structural stress.
- A Markov Switching approach allows the system to **transition between latent regimes** (e.g., "normal" market functioning vs. "stress" or "crisis" periods).
- Regime identification improves the understanding of:
  - Price formation mechanisms under different conditions,
  - Changes in volatility and persistence across regimes,
  - Comparative dynamics between France and Germany, whose electricity mixes and shock exposures differ.

# Markov Switching Specification

**MS with exogenous regressors:**

$$P_t^{Elec} = \mu_{S_t} + \phi_{S_t} P_{t-1}^{Elec} + X_t' \beta_{S_t} + \varepsilon_{t,S_t},$$

$$\varepsilon_{t,S_t} \sim \mathcal{N}(0, \sigma_{S_t}^2), \qquad S_t \in \{1,2\}.$$

**Regime process (first-order Markov chain):**

$$\Pr(S_t = j \mid S_{t-1} = i) = p_{ij}, \qquad P = \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix}.$$

$X_t = (P_t^{Coal}, P_t^{Gas}, P_t^{EUA}, Ren_t, Nuc_t, Fos_t, Imp_t)'$

# Results

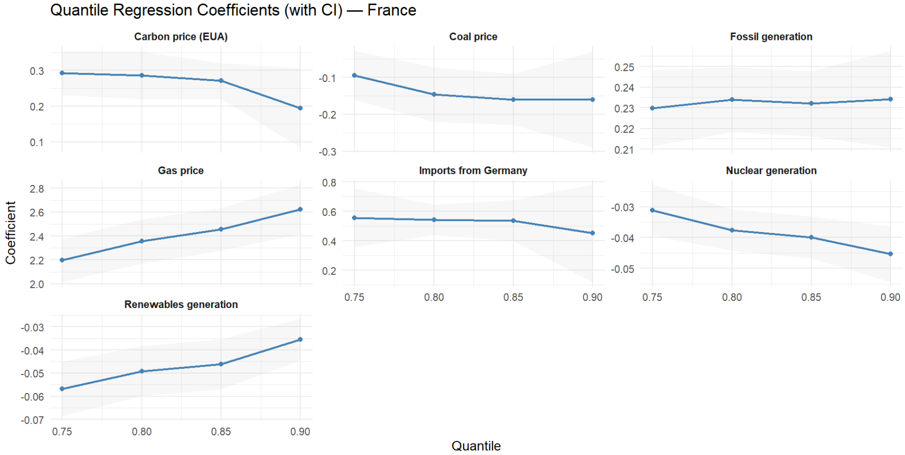
# I. 1) Linear regression results (2016–2024)

| Variable | France | Germany |
|---|---|---|
| Intercept | 9.0182. | 68.3094*** |
| | (4.7581) | (6.9659) |
| **Market variables** | | |
| Gas price | 1.9101*** | 1.8559*** |
| | (0.0370) | (0.0360) |
| Coal price | -0.0162 | -0.0950*** |
| | (0.0214) | (0.0204) |
| Carbon price | 0.3150*** | 0.3821*** |
| | (0.0290) | (0.0399) |
| **Generation mix** | | |
| Nuclear production | -0.0054 | -0.0686*** |
| | (0.0048) | (0.0128) |
| Fossil production | 0.1797*** | 0.0103* |
| | (0.0110) | (0.0041) |
| Renewables production | -0.0690*** | -0.0840*** |
| | (0.0073) | (0.0038) |
| **Interconnection** | | |
| Cross-border flows FR-DE | 0.8642*** | -0.0984** |
| | (0.0626) | (0.0309) |

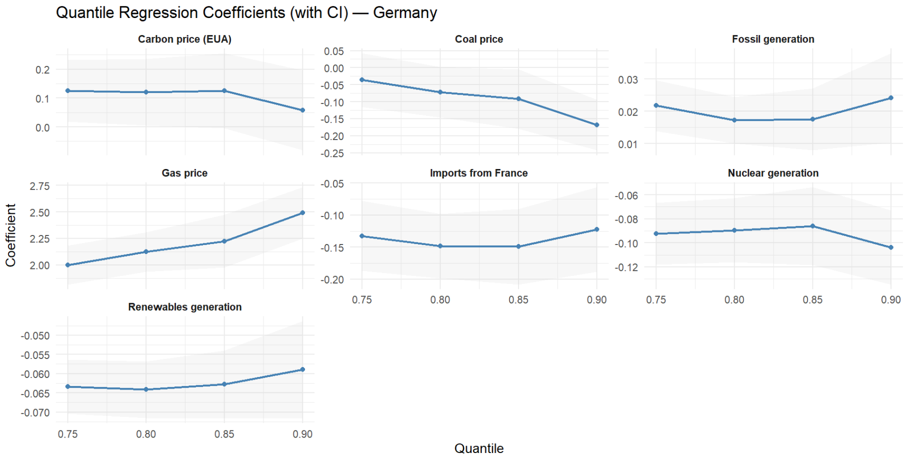
*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

- **Gas and carbon prices show the strongest correlations** with electricity prices, with similar magnitudes across markets.
- **Renewables are associated with price-depressing effects**, more markedly in Germany, consistent with higher RES penetration.
- **Interconnection effects differ**: imports from Germany **are associated with price increases in France** but with **price decreases in Germany**.
- **Linear regression appears limited in shock periods**: it does not capture correlated asymmetries and volatility clustering, motivating regime-switching or quantile methods.

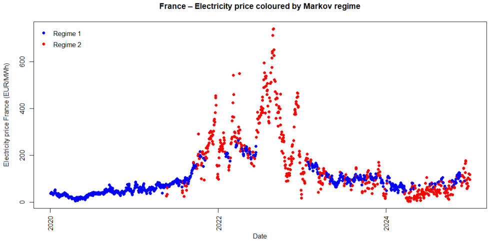
# I. 2) Quantile Regressions (France, 2020–2024)



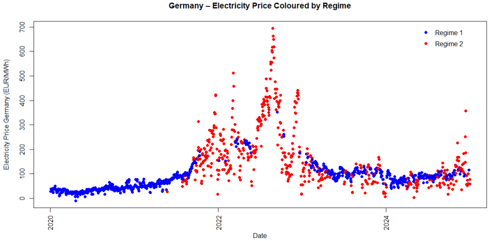
# I. 2) Quantile Regressions (Germany, 2020–2024)



# II. MS Regimes and Electricity prices




**France (2020–2024)**




**Germany (2020–2024)**

# Regime Dynamics: Transition Probabilities and Durations

**France**

*Transition matrix*

$$P^{FR} = \begin{pmatrix} 0.9573 & 0.0563 \\ 0.0427 & 0.9437 \end{pmatrix}$$

*Expected durations*

$$D_1^{FR} = 23.42, \qquad D_2^{FR} = 17.76$$

*Key points*

- Highly persistent regimes.
- Regime 1 lasts longer than Regime 2.

**Germany**

*Transition matrix*

$$P^{DE} = \begin{pmatrix} 0.9485 & 0.0515 \\ 0.0752 & 0.9248 \end{pmatrix}$$

*Expected durations*

$$D_1^{DE} = 19.41, \qquad D_2^{DE} = 13.29$$

*Key points*

- Persistent regimes but shorter than France.
- Faster cycle between stable and stress states.
- More volatile dynamics overall.

# MS Model Results – France (2020–2024)

| Variable | Regime 1 | Regime 2 |
|---|---|---|
| Intercept | 18.6661*** | -56.8704* |
| | (2.0872) | (23.3516) |
| Lagged elec. price | 0.4078*** | 0.5726*** |
| | (0.0269) | (0.0272) |
| Renewables generation | -0.0365*** | -0.0902*** |
| | (0.0035) | (0.0181) |
| Fossil generation | 0.1063*** | 0.1011*** |
| | (0.0073) | (0.0304) |
| Nuclear generation | -0.0144*** | 0.0514*** |
| | (0.0024) | (0.0155) |
| Gas price | 0.9483*** | 0.7329*** |
| | (0.0676) | (0.0738) |
| Coal price | 0.0204 | 0.0537 |
| | (0.0222) | (0.0376) |
| Imports from Germany | 0.0824** | 0.7939*** |
| | (0.0279) | (0.1318) |
| Carbon price | 0.2656*** | 0.4265* |
| | (0.0202) | (0.1763) |

**Regime-specific fit**

| | Regime 1 | Regime 2 |
|---|---|---|
| Residual standard error | 5.85 | 32.61 |
| Multiple $R^2$ | 0.986 | 0.953 |
| Expected duration | 23.42 | 17.76 |

**Main insights (France):**

- **Regime 1 = stable regime**, low volatility and strong explanatory power.
- **Regime 2 = stress regime**, with very large volatility and stronger persistence.
- **Gas and $CO_2$ dominate** price formation in both regimes.
- **Renewables associated with prices decreases**, stronger effect in Regime 2.
- **Nuclear reverses effect**: negative in Regime 1, positive in Regime 2 (scarcity context).
- **Imports from Germany** sharply raise prices in Regime 2.

# MS Model Results – Germany (2020–2024)

| Variable | Regime 1 | Regime 2 |
|---|---|---|
| Intercept | 14.8193*** | 75.5044** |
| | (3.5918) | (26.6441) |
| Lagged elec. price | 0.1947*** | 0.4342*** |
| | (0.0216) | (0.0262) |
| Renewables generation | -0.0334*** | -0.1423*** |
| | (0.0021) | (0.0120) |
| Fossil generation | 0.0152*** | 0.0191 |
| | (0.0020) | (0.0152) |
| Nuclear generation | -0.0065 | -0.1305*** |
| | (0.0075) | (0.0356) |
| Gas price | 0.7466*** | 0.9854*** |
| | (0.0607) | (0.0744) |
| Coal price | 0.2140*** | -0.0424 |
| | (0.0228) | (0.0327) |
| Imports from France | -0.0520*** | -0.1527 |
| | (0.0146) | (0.1143) |
| Carbon price | 0.4015*** | 0.6465** |
| | (0.0292) | (0.1982) |

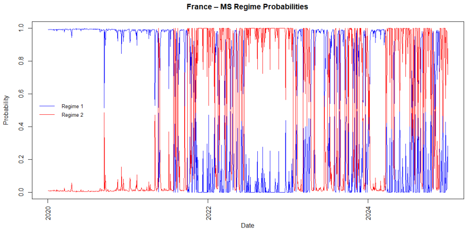
**Regime-specific fit**

| | Regime 1 | Regime 2 |
|---|---|---|
| Residual standard error | 6.0741 | 32.8748 |
| Multiple $R^2$ | 0.9814 | 0.933 |
| Expected duration | 19.41 | 13.29 |

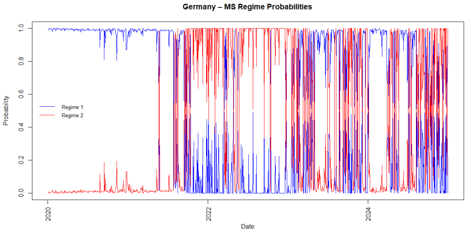
**Main insights (Germany):**

- **Regime 1 = low-volatility** with moderate persistence and tight explanatory power.
- **Regime 2 = high-volatility**, very persistent, capturing stress conditions.
- **Gas and $CO_2$** remain dominant drivers in both regimes.
- **Renewables associated with prices decreases**, especially in R2.
- **Nuclear significant only in R2**, consistent with a stabilizing role in scarcity episodes (even if phase-out).
- **Cross-border flows** associated with prices decreases in R1, but are not significant in R2.

# MS Regime Probabilities




**France (2020–2024)**




**Germany (2020–2024)**

# MS Model Comparison – France vs Germany

- Both countries exhibit two persistent regimes: a **low-volatility** regime (Regime 1) and a **high-volatility** regime (Regime 2).
- **France shows more persistent regimes**: longer expected durations in both normal and stress states.
- **Volatility in the stress regime is similar**, with very large residual errors in Regime 2 for both countries.
- **Gas and $CO_2$ prices dominate** price formation in both markets; the pass-through is slightly stronger in Germany in the stress regime.
- **Renewables associated with decreasing price in both countries**, with a stronger effect in Germany, especially in Regime 2.
- **Cross-border flows are asymmetric**: imports from Germany raise French prices (especially in Regime 2), while imports from France tend to reduce German prices mainly in Regime 1.

# Conclusion

# Conclusion

**Main findings**

- **Electricity affordability is tightly linked to fossil market dynamics**: gas is the dominant driver of price volatility, with carbon also exerting growing influence since 2021.
- **Electricity mixes matter for resilience**: renewables are associated with lower elec. prices, while nuclear acts as a stabilizing factor whose availability proved critical during the crisis.
- **European energy markets are highly interconnected**: spillovers are strong and short-lived, with gas, carbon and FR/DE electricity acting as central nodes of volatility transmission.

**Policy implications**

- **Reduce exposure to gas** by diversifying the generation mix and increasing system flexibility.
- **Accelerate renewable deployment** while supporting it with storage, demand management and robust interconnections.
- **Strengthen nuclear reliability in France** and manage German phase-out effects to limit systemic volatility.
- **Integrate demand-side strategies**: sufficiency and flexibility enhance resilience to geopolitical and climate shocks.

*Ensuring affordable and sustainable electricity requires a systemic approach combining supply diversification, European coordination, and demand management.*

# Limitations

**Scope-related limitations**

- The analysis focuses on **France and Germany**: broader EU comparisons could reveal additional heterogeneity in market resilience.

# Thank you !