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# An exploratory analysis of the relationship between electricity futures prices and guarantees of origin prices in Poland (2022–2025)

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## ABSTRACT

The 2022–2023 energy crisis fundamentally altered the functioning of the guarantees of origin (GO) market in Poland, exposing structural inefficiencies and accelerating regulatory and behavioral changes among market participants. This paper examined the GO price dynamics in Poland during the energy transition period 2022–2025, assessing the relationship between electricity prices and GO prices against the backdrop of the European energy crisis, intensifying decarbonization policies, and structural transformation of the Polish energy sector. The empirical analysis is based on monthly market data from the Polish power exchange (TGE) and related statistical sources. A quantitative framework was applied, using Pearson correlation analysis and a linear regression model linking BASE electricity futures prices with GO prices. The findings indicate that the GO market dynamics are driven not only by developments in wholesale electricity markets but also by structural and institutional factors, including ESGfocused corporate demand, renewable energy policy developments, regulatory conditions, market liquidity, and the supply of renewable energy certificates. The study further shows that, following the 2022 crisis, the GO prices adjusted more gradually than electricity prices, suggesting delayed market responses and partial market inefficiency. The Jarque–Bera normality test confirms nonnormal residual distributions, pointing to structural breaks, asymmetric adjustments, and potential nonlinearities in the GO market behavior over the analyzed period. This paper contributes to the limited empirical literature on Guarantees of Origin markets in Central and Eastern Europe and provides new evidence that GO markets follow distinct pricing mechanisms compared with conventional electricity markets, warranting more advanced modeling approaches that incorporate nonlinear and regimedependent dynamics.

**Keywords:** guarantees of origin, renewable energy, market efficiency, energy crisis, decarbonization, electricity market.

## INTRODUCTION

The transition toward low-carbon energy systems has accelerated significantly in recent years, particularly in response to the energy crisis triggered by geopolitical tensions and disruptions in fossil fuel supply in 2022 (European Commission, 2022; Goldthau & Tagliapietra, 2022; IEA, 2023). European countries, including Poland, have intensified the efforts to increase the share of renewable energy sources (RES) and improve energy security (European Commission, 2023; PSE, 2023; URE, 2024). Within this context, guarantees of origin (GO) have emerged as an important market-based instrument supporting the traceability and disclosure of renewable electricity (AIB, 2023; Ramos et al., 2020). GOs certify that a given amount of electricity has been generated from renewable sources and allow market participants to demonstrate the environmental attributes of their energy consumption. In Poland, guarantees of origin take the form of electronic certificates issued by the President of the Energy Regulatory Office (URE), confirming that electricity has been generated from renewable energy sources. This instrument enables companies to document the use of green energy, reduce their carbon footprint, and support activities aimed at strengthening their environmentally responsible corporate image. They play a key role in corporate decarbonization strategies, voluntary green energy procurement, and the development of renewable energy markets (Gillenwater, 2008; Hulshof et al., 2019). However, the functioning of GO markets depends on multiple factors, including regulatory frameworks, electricity prices, supply–demand balance, and cross-border trade (Kitzing et al., 2012; Del Río, 2012).The energy crisis of 2022 introduced significant volatility into energy markets, affecting both electricity prices and renewable energy incentives (IEA, 2023; Newbery, 2018; Flachsland et al., 2022). In Poland, the crisis coincided with ongoing structural changes in the energy sector, including increasing RES capacity, evolving regulatory policies, and growing participation in European energy markets (PSE, 2023; TGE, 2024; URE, 2024). These developments have raised important questions regarding the efficiency and maturity of the Polish GO market. Despite the growing importance of GOs, relatively little research has focused on their market behavior in Central and Eastern Europe, particularly in the post-crisis period. Most existing studies concentrate on Western European markets, where liquidity and integration are more advanced (Hulshof et al., 2019; Kitzing et al., 2012). Therefore, there is a clear research gap in understanding how emerging GO markets respond to external shocks and regulatory changes. The aim of this study was to evaluate the market prices of guarantees of origin in Poland during the period from 2022 to 2025. The study focused on identifying the key drivers of GO price dynamics, assessing the level of market efficiency, and analyzing the impact of the energy crisis on market behavior. By combining statistical analysis with a policy perspective, this research contributed to the broader discussion on the role of market-based instruments in supporting the energy transition. This study provided empirical analyses of the Polish GO market in the post-2022 crisis period. In 2023, amendments to the Renewable Energy Sources Act expanded the scope of the guarantees of origin system. From January 1st 2024, guarantees of origin may be issued not only for electricity generated from renewable energy installations, but also for biomethane, heating, cooling, renewable hydrogen, biogas, and agricultural biogas. The amendment also created a legal framework for the internationalization of GO trading by enabling the President of the Energy Regulatory Office (URE) to join the Association of Issuing Bodies (AIB) (TGE, 2022, 2023).

## RESEARCH METHODOLOGY

### Research design

This study adopted a quantitative research design based on basic econometric analysis. The objective was to examine the determinants between BASE futures contract and guarantees of origin by estimating a linear regression model.

### Model specification

The baseline simple empirical model is defined as:

$$GO_t = \alpha + \beta_1 \cdot BASE_t + \varepsilon_t \tag{1}$$

where: $GO_t$ – dependent variable representing the outcome of interest, $BASE_t$ – electricity futures price (PLN/MWh), $\alpha$ – the intercept, directional coefficient, $\beta_1$ – slope coefficients, $\varepsilon_t$ – the stochastic error term.

### Pearson correlation analysis

In the subsequent part of the study, a Pearson linear correlation analysis was conducted to examine the relationship between electricity prices (BASE futures) and prices of guarantees of origin. The dataset consists of monthly observations covering the period from January 2022 to December 2025 ($n = 48$ observations; $d_f = 46$) (Table 1). The Pearson correlation coefficient was computed using the standard formula:

$$r = \frac{\Sigma(x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\Sigma(x_i - \bar{x})^2 \cdot \Sigma(y_i - \bar{y})^2}} \tag{2}$$

where: $x_i$ – denotes electricity prices (BASE futures), $y_i$ – denotes GO prices, $x$, $Y$ – are sample means.

$$t = \frac{r \cdot \sqrt{n-2}}{\sqrt{1-r^2}} \tag{3}$$

Table 1 presents the average values of guarantees of origin for the period from 2022 to 2025,

**Table 1.** Poland BASE futures vs guarantees of origin (average monthly, PLN/MWh); own source based on TGE and kapitalpolski.pl access to the source: May 12th, 2026)

| Year | Month | BASE price (PLN/MWh) | Guarantees of origin average (PLN/MWh) |
|---|---|---|---|
| 2022 | Jan | 666.90 | 3.14 |
| | Feb | 525.89 | 3.19 |
| | Mar | 618.30 | 2.90 |
| | Apr | 789.82 | 3.30 |
| | May | 1092.67 | 4.38 |
| | Jun | 1102.40 | 4.61 |
| | Jul | 1518.97 | 4.15 |
| | Aug | 1790.07 | 3.96 |
| | Sep | 1781.79 | 5.94 |
| | Oct | 1076.58 | 5.60 |
| | Nov | 1018.55 | 7.18 |
| | Dec | 790.82 | 9.68 |
| 2023 | Jan | 870.42 | 7.36 |
| | Feb | 807.11 | 13.89 |
| | Mar | 738.65 | 11.00 |
| | Apr | 763.22 | 10.93 |
| | May | 701.17 | 20.21 |
| | Jun | 661.64 | 15.98 |
| | Jul | 655.66 | 12.45 |
| | Aug | 634.30 | 17.03 |
| | Sep | 629.20 | 16.53 |
| | Oct | 600.13 | 24.66 |
| | Nov | 546.40 | 21.93 |
| | Dec | 376.53 | 22.53 |
| 2024 | Jan | 473.16 | 14.91 |
| | Feb | 436.41 | 9.80 |
| | Mar | 443.17 | 9.88 |
| | Apr | 466.97 | 7.59 |
| | May | 479.06 | 6.21 |
| | Jun | 474.40 | 7.49 |
| | Jul | 458.25 | 9.63 |
| | Aug | 467.99 | 9.46 |
| | Sep | 441.83 | 10.15 |
| | Oct | 424.64 | 7.84 |
| | Nov | 433.88 | 7.78 |
| | Dec | 426.75 | 6.68 |
| 2025 | Jan | 458.77 | 7.38 |
| | Feb | 453.78 | 9.89 |
| | Mar | 427.32 | 5.30 |
| | Apr | 409.91 | 6.39 |
| | May | 412.75 | 3.78 |
| | Jun | 419.47 | 4.89 |
| | Jul | 414.53 | 6.78 |
| | Aug | 418.95 | 3.58 |
| | Sep | 429.18 | 4.27 |
| | Oct | 434.96 | 4.44 |
| | Nov | 448.40 | 5.12 |
| | Dec | 453.92 | 3.06 |

along with BASE values on which preliminary statistical analyses were conducted, including correlation and regression analyses.

### Data sources and sample period

The study used secondary data obtained from internationally recognized databases such as World Bank World Development Indicators, OECD Statistics, Eurostat, International Energy Agency (IEA), and TGE statistical databases. The dataset covers a time series (or panel structure, depending on specification) over the period from 2022 to 2025. Data frequency is monthly, ensuring consistency across variables.

### Hypotheses

The study tested the following hypotheses:

- **H1:** Electricity prices are significantly related to GO prices in Poland.
- **H2:** Electricity prices have limited explanatory power for GO price dynamics.
- **H3:** The GO market exhibits delayed adjustment to changes in electricity prices, indicating partial market inefficiency.

### Research limitations

Several limitations of this study should be acknowledged. First, the Polish guarantees of origin market remains relatively young and less liquid compared with more mature Western European markets, which may affect the stability and robustness of statistical relationships. Second, the analysis is based on a relatively small sample of monthly observations covering the period 2022–2025, which limits the statistical power of the econometric results. Third, the model includes only selected market variables and therefore may not fully capture all determinants influencing GO prices, such as regulatory interventions, corporate ESG demand, or developments in the EU carbon market. Finally, extraordinary geopolitical and energy-market disruptions following the 2022 energy crisis may have temporarily distorted market dynamics and reduced the predictive stability of the estimated relationships.

## RESULTS AND DISCUSSION

In the Polish academic literature, guarantees of origin for electricity have primarily been analyzed in terms of institutional design and legal frameworks (Kapalski, 2019). However, empirical research on GO price formation and market dynamics remains limited, leaving price-related mechanisms underexplored in the domestic context. A similar gap exists in the broader European literature, where studies mainly focus on the policy role and informational function of GO systems (Hamburger, 2019; Wimmer and Madlener, 2024; Ramos et al., 2020), while less attention is given to demand dynamics, market participant behavior, and price relationships between electricity and certificates. As noted by Petryk and Adamik (2023), existing research on the Polish market has largely been limited to trading volumes and simple correlation analysis, highlighting the need for more advanced empirical approaches to GO price formation and market efficiency. The functioning of the GO system in Poland is illustrated by the diagram (Fig. 1).

The need to reassess previous market regularities is further motivated by significant economic and geopolitical developments in 2022–2025. The outbreak of the war in Ukraine triggered one of the largest supply shocks in European energy markets in decades, affecting gas and coal supply chains and causing sharp increases in wholesale electricity prices. According to the International Energy Agency (IEA, 2023) and the European Commission (2023), these disruptions led to record levels of price volatility, higher production costs, shifts in demand structure, and accelerated investment in renewable energy sources. Although formally decoupled from physical energy flows, the GO market remains sensitive to changes in renewable generation costs, regulatory expectations, and corporate procurement strategies.

### Correlation and regression analysis

The empirical analysis is based on monthly data for the period 2022–2025. The relationship between BASE electricity futures prices and GO prices was examined using Pearson correlation and a simple linear regression model. The results indicate a weak negative correlation between the variables ($r = -0.163$), which was not statistically significant at the 5% significance level ($p = 0.267$). This suggests that changes in electricity prices

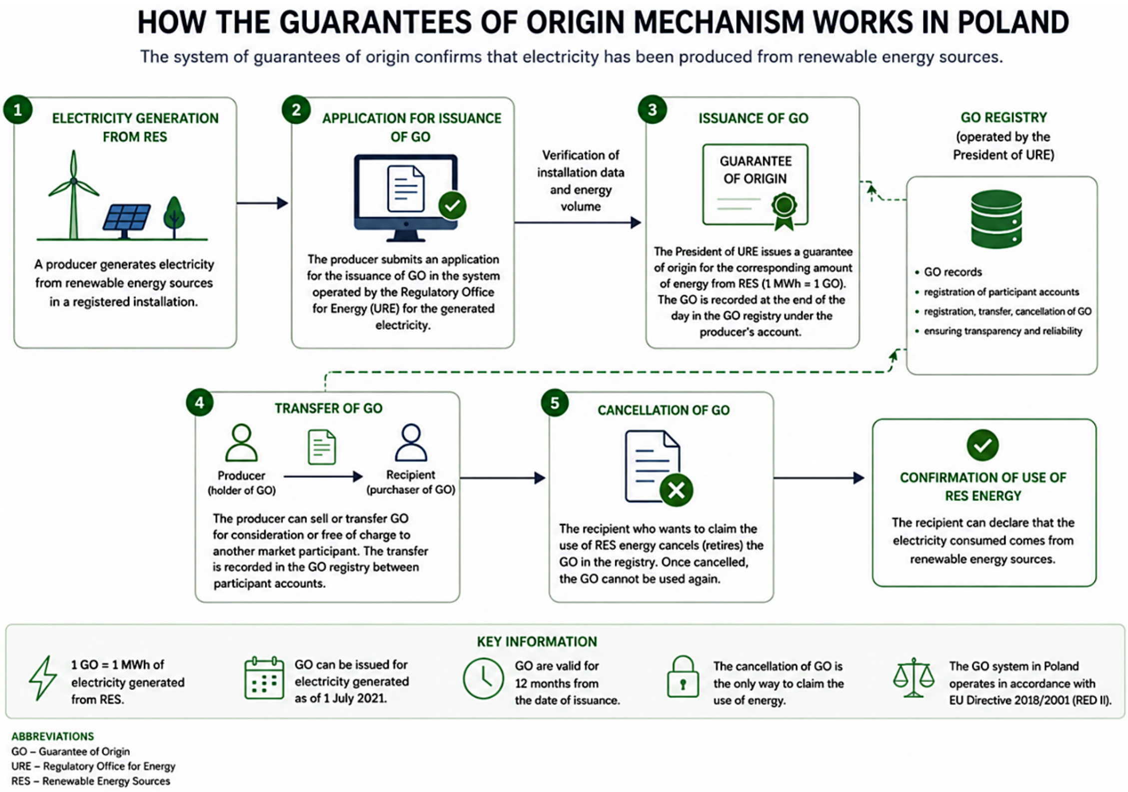


**Figure 1.** The guarantees of origin mechanism in Poland – ideological scheme

were only weakly associated with changes in GO prices during the analyzed period. The low magnitude of the correlation coefficient indicates that electricity prices alone cannot adequately explain GO price dynamics and that other structural, regulatory, and market-related factors likely played a more important role.

## Initial statistical relationship

The descriptive statistics of the analyzed variables are presented in Table 2. During the analyzed period (2022–2025), the average BASE futures price amounted to 653.45 PLN/MWh, with a median of 476.73 PLN/MWh. The relatively high standard deviation (337.19 PLN/MWh) and the wide range between the minimum (376.53 PLN/MWh) and maximum (1790.07 PLN/MWh) values indicate substantial volatility in electricity prices, particularly during the energy crisis period in 2022. The average price of GO was 8.85 PLN/MWh, with a median of 7.37 PLN/MWh and a standard deviation of 5.54 PLN/MWh. GO prices ranged from 2.90 PLN/MWh to 24.66 PLN/MWh, suggesting considerable variability over the study period, although their absolute fluctuations were markedly lower than those observed for electricity prices. Figure 2 presents the estimated linear regression model for the analyzed variables.

The following linear regression equation was obtained from the data:

$$GO_t = 10.605 - 0.0027 \cdot BASE_t \qquad (4)$$

The estimated regression model indicates a weak negative relationship between BASE futures prices and GO prices. An increase of 1 PLN/MWh in BASE futures prices is associated, on average, with a slight decrease of

**Table 2.** Descriptive statistics of the analyzed variables (2022–2025); based on TGE and kapitalpolski.pl (access: 12.05.2026)

| Variable | Mean (PLN/MWh) | Median (PLN/MWh) | Standard Deviation (PLN/MWh) | Minimum (PLN/MWh) | Maximum (PLN/MWh) |
|---|---|---|---|---|---|
| BASE futures price (PLN/MWh) | 653.45 | 476.73 | 337.19 | 376.53 | 1790.07 |
| Guarantees of origin price (PLN/MWh) | 8.85 | 7.37 | 5.54 | 2.90 | 24.66 |

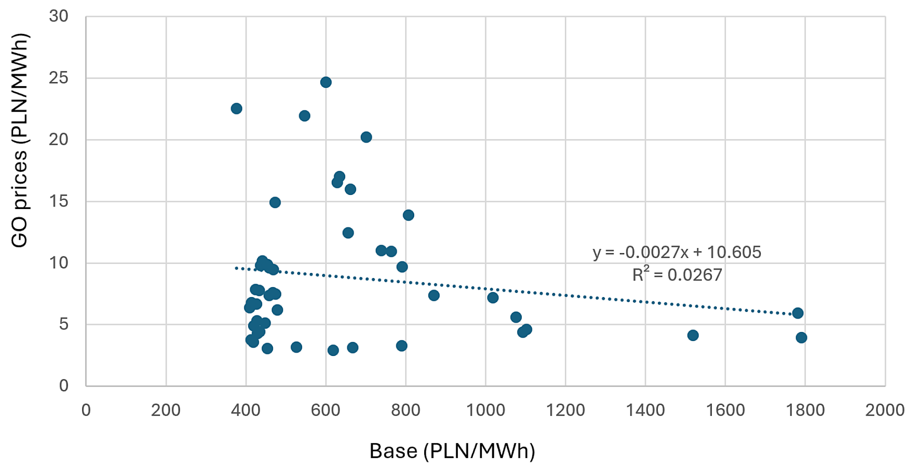


**Figure 2.** Estimated linear regression model for the analyzed variables

approximately 0.0027 PLN/MWh in GO prices. The analysis was conducted using monthly data from 2022–2025. The results do not indicate a strong linear relationship between the variables. The coefficient of determination was $R^2 = 0.0267$.

This implies that approximately 2.7% of the variation in GO prices can be explained by changes in electricity prices, indicating a very low explanatory power of the model. Therefore, electricity prices alone provide limited information about GO price dynamics. The results suggest that GO prices are driven primarily by other structural and institutional factors, including ESG-related corporate demand, renewable energy policy developments, market liquidity, regulatory conditions, and the supply of renewable energy certificates. The scatter plot additionally shows that GO prices followed a smoother and more persistent adjustment path than electricity prices. While electricity prices experienced extreme volatility during the 2022 energy crisis, the GO prices adjusted more gradually over time.

These observations suggest that GO prices followed a smoother adjustment path than electricity prices did. However, the weak correlation and low explanatory power of the regression model indicate that the relationship between electricity prices and GO prices was limited during the analyzed period. This finding suggests that the GO price dynamics were influenced by a broader set of market, regulatory, and institutional factors beyond electricity price fluctuations alone.

The Jarque–Bera normality test revealed deviations from normality in the model residuals ($p = 0.0014$). At the 5% significance level, the null hypothesis of normally distributed residuals was rejected, indicating that the residuals of the regression model significantly deviate from normality. This lack of normality may be attributed to several factors, including structural breaks associated with the 2022 energy crisis, periods of high market volatility, asymmetric market adjustments, omitted explanatory variables, and potential non-linear relationships between electricity prices and GO prices.

The results suggest that the Polish guarantees of origin market exhibited transitional dynamics and temporary distortions during the analyzed period. Consequently, the simple linear regression model should be interpreted as an exploratory approximation, rather than a comprehensive representation of the GO market behavior.

Overall, the regression results indicate that electricity prices alone explain only a small fraction of the GO price variability. Therefore, the GO price dynamics appear to be driven primarily by structural and institutional factors, including regulatory developments, market liquidity, renewable energy certificate supply, and corporate demand associated with decarbonization and ESG strategies.

## Electricity price and GO in Poland (2022–2025)

Figure 3 presents the evolution of monthly average electricity prices in Poland during the analyzed period. The empirical analysis indicates that electricity prices in Poland experienced exceptionally high volatility during the 2022 energy crisis (Borenstein and Bushnell, 2022; IES,2023). The observed spikes in BASE futures prices, exceeding 1000 PLN/MWh, are consistent with broader developments in European electricity markets documented by ACER (2023) and the International Energy Agency (2023). These institutions highlight that the crisis was driven by a combination of gas supply shocks, geopolitical tensions, and structural constraints in European energy systems. Similar conclusions were reported by Sgaravatti et al. (2022), who emphasized that policy interventions and supply-side disruptions led to unprecedented price instability across EU wholesale electricity markets.

This reflects the impact of the energy crisis and extreme market volatility (Fig. 3). In 2023, electricity prices began to decline gradually as market conditions stabilized and energy security measures were implemented, although they remained significantly above pre-crisis levels. The downward trend continued in 2024, when prices stabilized around 400–450 PLN/MWh, indicating a progressive normalization of the market. In 2025, prices fluctuated within a narrower range, suggesting reduced volatility and further consolidation of market conditions.

Overall, the period from 2023 to 2025 is characterized by a transition from crisis-driven price levels to a more stable market environment. This pattern is consistent with broader European trends (IEA, 2023), in which electricity prices peaked in 2022–2023 and subsequently declined.

Figure 4 presents the monthly evolution of guarantees of origin (GO) prices in Poland over the period 2022–2025. The data reveal three distinct phases corresponding to the energy crisis, post-crisis adjustment, and market stabilization. In 2022, GO prices increased rapidly, reaching their peak in the fourth quarter.

This upward trend coincided with the period of extreme volatility in electricity markets and reflects the increased demand for renewable energy certificates. The rise in GO prices during this period suggests that market participants intensified their use of GOs as an instrument for meeting sustainability targets and managing energy-related costs. In 2023, GO prices remained relatively high at the beginning of the year but gradually declined over subsequent months. Importantly, this adjustment occurred more slowly than the decline in electricity prices, indicating a lagged response of the GO market and supporting the hypothesis that GO prices do not immediately reflect changes in underlying energy market conditions. A further decline and stabilization can be observed in 2024, when GO prices reached lower levels and fluctuated within a narrower range. This suggests a transition towards a more balanced market environment, driven by the increasing supply of renewable energy and reduced overall volatility in the energy sector. In 2025, GO prices fluctuated moderately but did not return to the elevated levels observed during the crisis period. Compared with electricity prices, their dynamics remained

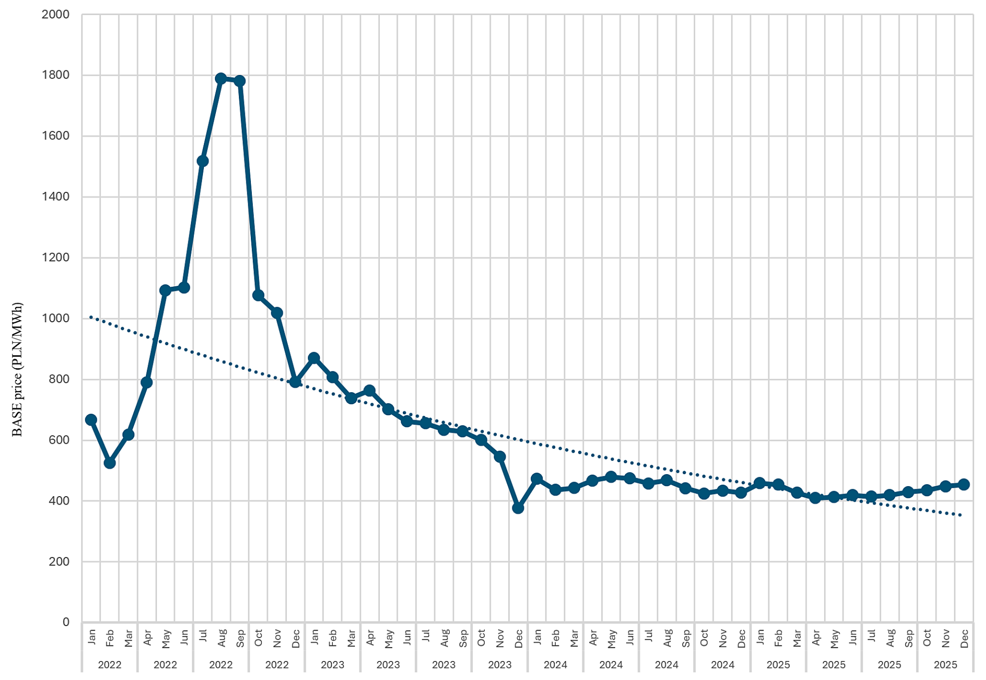


**Figure 3.** Monthly average BASE electricity prices (PLN·MWh⁻¹) in Poland in 2022–2025, based on TGE data

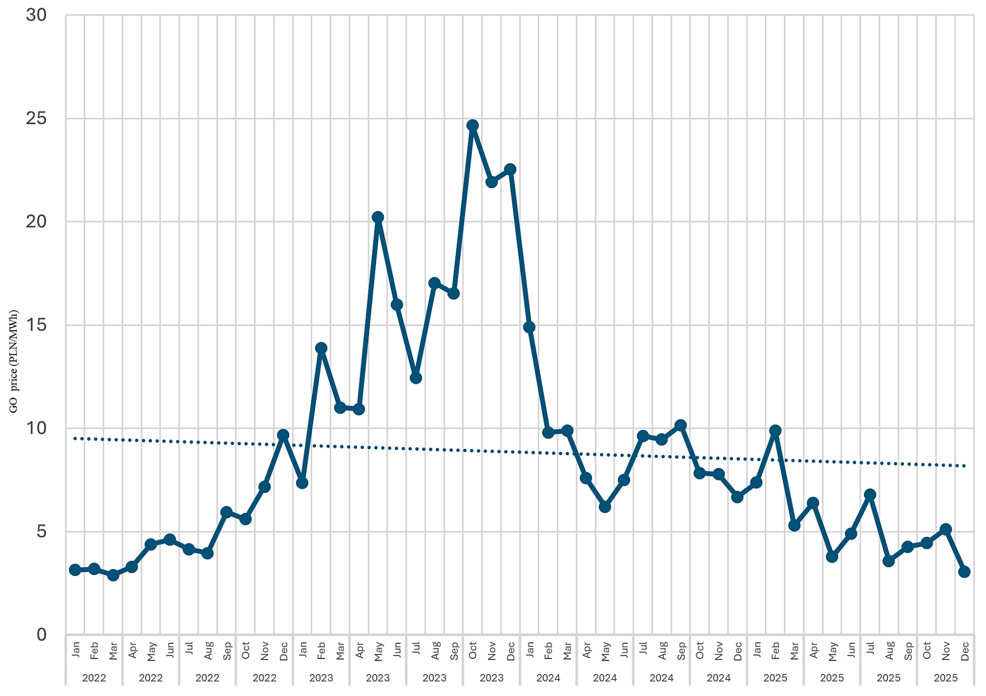


**Figure 4.** Monthly average guarantees of origin prices (PLN·MWh$^{-1}$) in Poland in 2022–2025, based on TGE data

smoother, indicating lower sensitivity to short-term market shocks and a potentially stronger influence of structural factors such as corporate demand for green energy, regulatory developments, and renewable energy certificate supply.

Overall, the results suggest that GO prices and electricity prices followed different adjustment patterns during the analyzed period. While both markets were affected by the consequences of the energy crisis, the statistical analysis indicates only a weak relationship between electricity prices and GO prices. This finding suggests that GO price dynamics were influenced by a broader range of factors than electricity market conditions alone.

In contrast, the GO market displays substantially lower volatility and a distinct price formation mechanism. The empirical results show only a weak statistical relationship between electricity prices and GO prices, as reflected in the very low coefficient of determination ($R^2 = 0.0267$). This finding suggests that electricity prices explain only a marginal share of the GO price variation and that the two markets are only loosely connected in the short run. This result is consistent with previous literature indicating that renewable energy certificate markets are primarily driven by institutional and regulatory frameworks rather than short-term electricity price fluctuations (Fripp, 2008). In this context, GO certificates function as policy-driven instruments embedded in decarbonization strategies rather than as derivatives tightly linked to wholesale electricity prices. The weak explanatory power of electricity prices is also in line with Benveniste et al. (2017), who find limited correlation between renewable certificate prices and underlying electricity market fundamentals. Their analysis suggests that GO-type instruments are mainly shaped by corporate demand for green electricity, compliance strategies related to environmental targets, and the evolving supply of renewable generation rather than spot or forward electricity prices. The observed asymmetry in adjustment dynamics further supports this interpretation. Electricity prices reacted sharply to the energy crisis, while GO prices followed a smoother and more gradual trajectory. This lagged response suggests imperfect and delayed transmission of information between the two markets. As highlighted by Held and Ragwitz (2014), certificate-based systems often exhibit slower adjustment processes due to long-term contracting behavior and the strategic nature of corporate procurement of renewable attributes. The low explanatory power of the regression model indicates that GO price formation is likely influenced by a broader set of omitted variables. These include regulatory developments at the EU level, changes in national renewable energy policies, market liquidity conditions, the supply of renewable energy certificates, and increasing corporate demand driven by ESG commitments and decarbonization strategies (Jansen, 2017). Jacobsson and Lauber (2006) emphasize that renewable energy policy instruments are deeply embedded in institutional frameworks, which can decouple their price dynamics from conventional energy market fundamentals.

Additionally, the rejection of residual normality in the Jarque–Bera test ($p = 0.0014$) suggests the presence of structural breaks or regime shifts during the sample period. This is particularly plausible given the extraordinary market conditions during the 2022–2023 energy crisis, which may have introduced non-linearities and temporary distortions in both electricity and certificate markets. Similar market disruptions have been documented by ACER (2023), which highlights transitional dynamics in European power markets during the crisis period. Overall, the findings indicate that the GO prices in Poland between 2022 and 2025 evolved largely independently from short-term electricity price movements. Instead, they appear to be driven primarily by structural, regulatory, and demand-side factors rather than direct exposure to wholesale electricity price fluctuations. Consequently, the linear regression model should be interpreted as an exploratory approximation, rather than a fully structural representation of GO price formation mechanisms.

## CONCLUSIONS

The empirical results indicate a weak relationship between electricity prices and guarantees of origin prices during the period 2022–2025. The estimated linear regression model exhibits very low explanatory power ($R^2 = 0.0267$), indicating that only a small proportion of GO price variability is explained by BASE electricity futures prices. In addition, the Jarque–Bera test ($p = 0.0014$) confirms significant deviations from normality in the residuals, suggesting that the relationship between the variables may be influenced by non-linear dynamics, structural breaks, or additional factors not captured by the model.

Time-series evidence further shows that electricity and GO prices followed different adjustment patterns during the analyzed period. While electricity prices experienced substantial volatility during the 2022 energy crisis, GO prices adjusted more gradually and exhibited smoother dynamics in subsequent years. This suggests that short-term movements in electricity prices were not closely reflected in GO prices.

The results indicate that electricity prices alone provide limited information about the GO price dynamics. The low explanatory power of the model suggests that other determinants may influence GO prices. Potential factors include regulatory developments, renewable energy policy measures, market liquidity, certificate supply, and changing corporate demand associated with decarbonization and ESG objectives. However, the influence of these factors was not directly examined in the present study and therefore requires further empirical investigation.

The findings are broadly consistent with previous studies indicating that certificate markets may be influenced by institutional and regulatory conditions in addition to energy market fundamentals. At the same time, the weak relationship identified in the Polish market suggests that GO price formation may differ from patterns observed in more mature and liquid Western European markets.

From a policy perspective, improving market transparency, trading activity, and access to information could strengthen the price discovery mechanisms and enhance the effectiveness of GOs as a market-based instrument supporting the energy transition. For market participants, the results indicate that the GO procurement decisions should not rely exclusively on current electricity market conditions, as additional factors may play an important role in determining certificate prices.

In conclusion, the results suggest that GO prices are only weakly associated with electricity prices and that a substantial share of their variability remains unexplained by the model applied in this study. Future research should incorporate additional explanatory variables and employ more advanced modeling approaches, including multivariate, non-linear, regime-switching, or dynamic specifications, to better understand the determinants of GO price formation and the evolving interactions between electricity markets and renewable energy certificate markets.

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