

ANALYSIS OF MARKET PRICES OF ENERGY IN POLAND

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Abstract: *The objective of this paper is to analyze the Market Prices of Energy (RCE) in Poland in terms of opportunities for optimizing energy production and acquisition. The data used in paper contains hourly energy prices (RCE), covering the period from May 1, 2023 to March 31, 2025. The study used Exploratory Data Analysis in domain of time and frequency. In the time domain, all available data were analyzed, presenting their descriptive statistics and their visualizations in various perspectives to examine the nature of price variability. Due to the complex periodicity present in the RCE timeseries, the data were also analyzed in the frequency domain. For data from the 52-week period, the spectral analysis was performed. The analyses carried out revealed a high degree of volatility in market prices of electricity, characterized by complex periodicity, negative price values, and prices that are well above the average. The moments where negative prices and very high prices most frequently occur were identified. The conducted research has shown the need to redefine the energy price volatility measure, as due to the occurrence of negative prices, direct transfer of methods known from the financial market is impossible.*

Key words: *Market Prices of Energy, volatility, Exploratory Data Analysis, spectral analysis*

JEL codes: *Q41, C32, C81*

1. Introduction

Regional development depends on the availability of energy. A classic example is the development of Las Vegas after the construction of the Hoover Dam and the availability of cheap energy as a result. This demonstrates that the availability of cheap energy can be a driving force for regional development.

The Day Ahead Market (RDN) is a key element of the liberalized electricity market that has been operating in Poland since June 30, 2000. As a physical spot market for electricity, the RDN allows market participants to trade energy the day before its delivery. It is an important tool that facilitates the effective management of energy production and consumption, as well as price optimization. On the RDN, market participants, including energy producers, sellers, and recipients, conclude contracts for the supply of electricity based on demand forecasts. Transactions occur at specific times on the Polish Power Exchange (TGE)

Photovoltaic cells are becoming a significant source of electricity. However, with their development, the prices of energy they generate are falling. Prosumers typically settle their production at average monthly market prices (RCEm). However, these are falling drastically with the development of renewable energy sources. In February 2025, RCEm was 442.02 PLN/MWh, but in March of the same 2025 year, it dropped to 182.96 PLN/MWh ([www1](#)). Due to the need for a return on investment in photovoltaic panels – which provide cheaper electricity – this gives rise to interest in Market Energy Prices (RCE), determined on an hourly basis.

The aim of this paper is to analyze the Market Prices of Energy (RCE) in Poland in terms of opportunities for optimizing energy production and acquisition. The issue is particularly important for prosumers who generate electricity using photovoltaic panels.

The issue of electricity price modeling has been widely discussed in the literature since 2000. A detailed review of this literature can be found in (Weron, 2014). Tashpulatov (2013) presented considerations regarding the electricity market in England and Wales using both time-domain and frequency-domain analyses. Knittel & Roberts (2005) were the first to observe negative electricity prices in California, while Fanone et al. (2013) were the first to examine the impact of negative prices on electricity modeling. This work fills a research gap, as to our knowledge, RCE in the Polish electricity market has not been previously analyzed.

Following the Introduction, where we present the day-ahead market in Poland and the market price of electricity (RCE), the second part of the work presents the methodology used in this study. The third section contains the results of the analyses conducted. The paper concludes with a summary containing proposals of future work directions.

2. Methodology and Data

In the research, was analyzed data from the PSE SA (PSE) website ([www2](#)). The analyses were conducted in the R system (R Core Team, 2025), using the RStudio environment (RStudio

Team, 2025). The data is provided in two sets. Until June 13, 2023, it was recorded hourly. This historical data is available at (www3), and was downloaded, cleaned, and saved as a dataframe.

Due to changes in information requirements for the electricity market and the Polish Power System Operation starting on June 14, 2023, data is available in a new layout at (www4). Information requirements required data to be presented in quarter-hour intervals. Current data beyond the full hour is not observable, so only data from full hours were used in this study. These data were downloaded, filtered to hourly data, and saved in a format consistent with historical data. Thanks to the uniform structure, historical and current data could be combined into one dataframe, with the structure presented in Table 1.

Tab. 1 The structure of dataframe

Name	Format	Sample data	Description
Data	date format	"2023-05-01"	effective date
Year	num	2023	effective year
Month	num	5	effective month
Day	int	1	effective day
Cena	num	475	price in PLN/MWh
Godzina	num	1	time of validity

Source: own elaboration

The dataframe contains 16,823 observations of 6 variables, covering the period from May 1, 2023 to March 31, 2025. Redundant date information was retained to facilitate further visualizations. Descriptive statistics were calculated using the summary() function from the core set of R function (R Core Team, 2025). Visualizations were created with the ggplot2 package (Wickham, 2016). Certain date operations were performed using functions from the lubridate package (Grolemund & Wickham, 2011).

The data were subjected to exploratory analysis with respect to price changes in the time domain and in the frequency domain.

In the time domain, all available data were analyzed, presenting their descriptive statistics and their visualizations in various perspectives to examine the nature of price variability. Extreme phenomena were also analyzed. Negative prices and prices above 1,000 PLN/MWh were considered as such.

Due to the complex periodicity present in the RCE waveforms, the data were also analyzed in the frequency domain. For data from the 52-week period, which corresponds to a year, the Fast Furier Transform (FFT) was calculated. If the sequence $\{x_n\}$ represents a finite set of cardinality N , uniformly spaced time samples of some signal $x(t)$, where t represents time, then X_k represents a harmonic series given by Equation 1 (i - means imaginary unit).

$$X_k = \sum_{n=0}^{N-1} x_n e^{\frac{-2\pi i}{N}nk} \quad k=0, \dots, N-1. \quad (1)$$

The FFT() function from the fftw package (Mersmann, 2022) was used for these calculations. The power spectral density was also calculated using the following formula:

$$S_k = \left| \sum_{n=0}^{N-1} x_n e^{\frac{-2\pi i}{N}nk} \right|^2 \quad k=0, \dots, N-1. \quad (2)$$

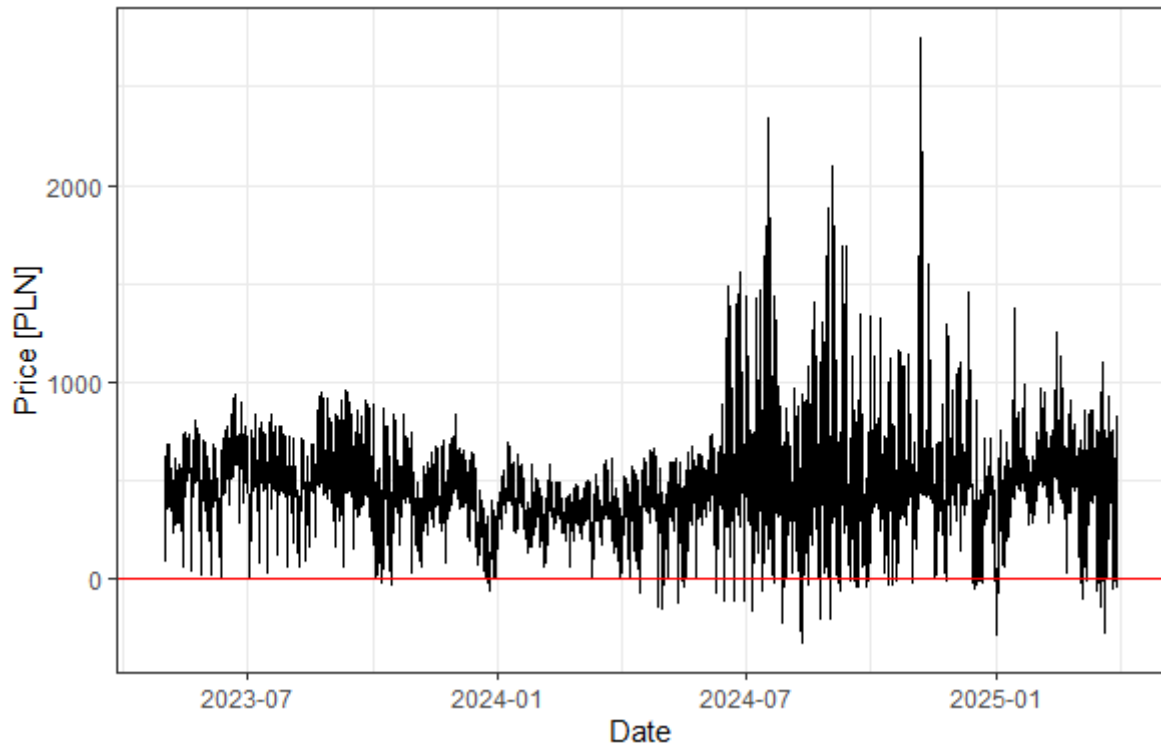
The calculation results were presented again using the ggplot2 package and the ggspectro() function from the seewave package (Sueur et al, 2008).

3. Results and Discussion

The first to be analyzed were hourly data from the entire collected period from May 1, 2023 to March 31, 2025. The data was cleaned of erroneous records. The data was then filtered to hourly data. These data are presented in Figure 1. The zero price level is also marked on this figure.

The two elements noticed in Figure 1 are the occurrence of negative prices and the occurrence of very high prices. This is confirmed by the descriptive statistics of the data presented in Table 2.

Fig. 1 Market Prices of Energy (RCE) in Poland from May 1, 2023 to March 31, 2025



Source: own elaboration in `ggplot2` package (Wickham, 2016)

At an average price of 441.5 PLN/MWh, 50% of prices are in the range [347.5, 533.6]. The minimum observed price is -318.8 PLN/MWh and the maximum is 2749.4 PLN/MWh. The weekly price fluctuations are shown in Figure 2.

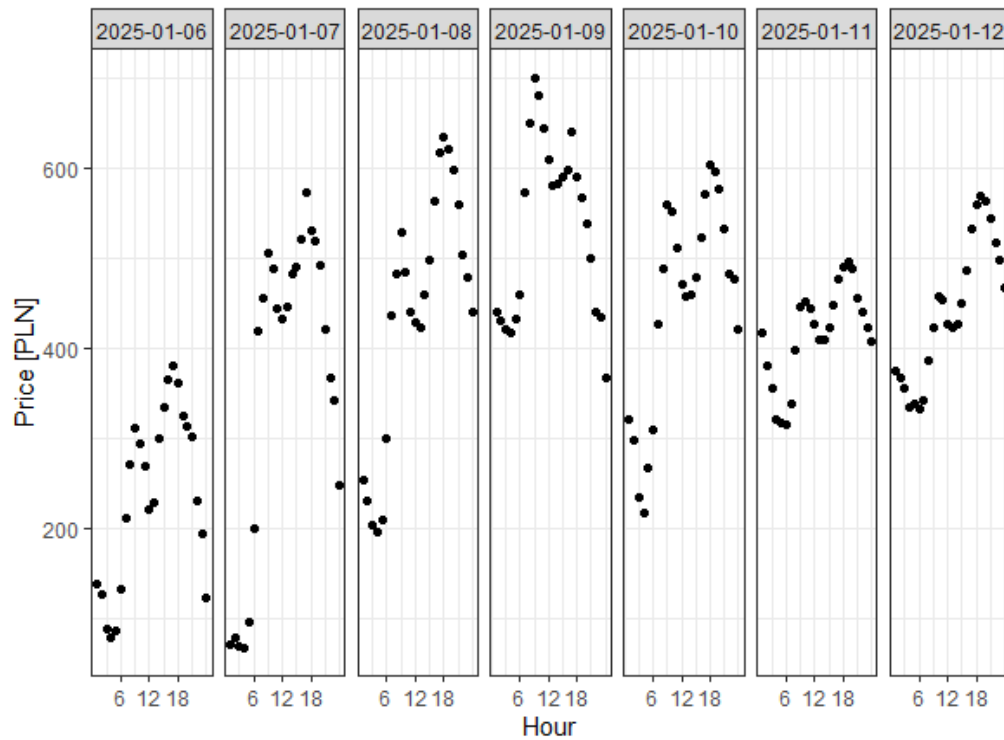
Tab. 2 Statistics of the full data

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
-318.8	347.5	435.0	441.5	533.6	2749.4

Source: own elaboration in `function summary()` (R Core Team, 2025)

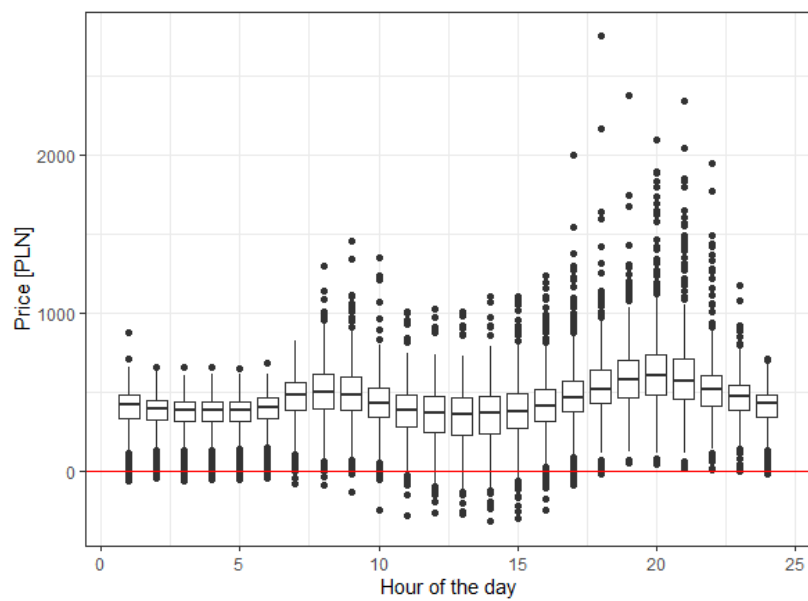
Daily price volatility is shown in Figure 2, representing a sample week from January 6, 2025 to January 12, 2025. To capture the complex periodicity of RCE energy prices, price distribution charts were created by hour of the day (Figure 3), day of the week (Figure 4), and day of the month (Figure 5).

Fig. 2 Daily price volatility January 6, 2025 to January 12, 2025



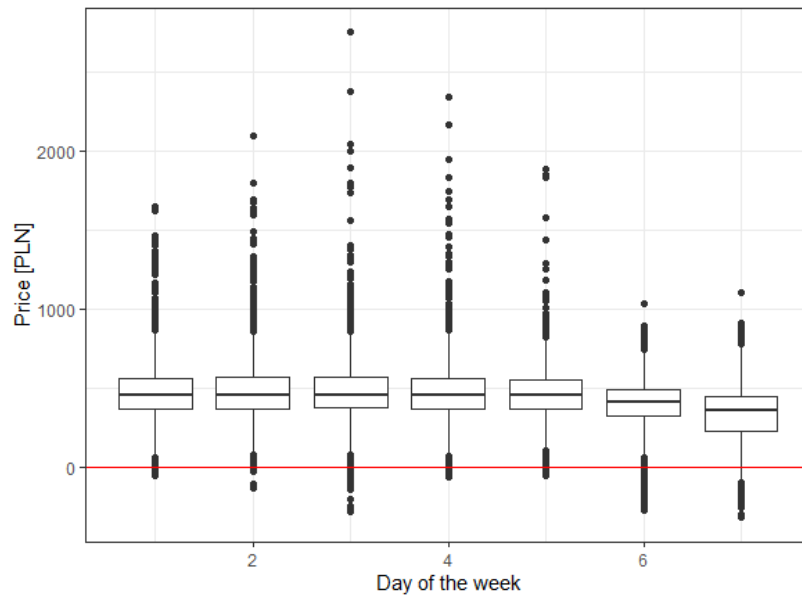
Source: own elaboration in ggplot2 package (Wickham, 2016)

Fig. 3 Price distribution by hour of the day



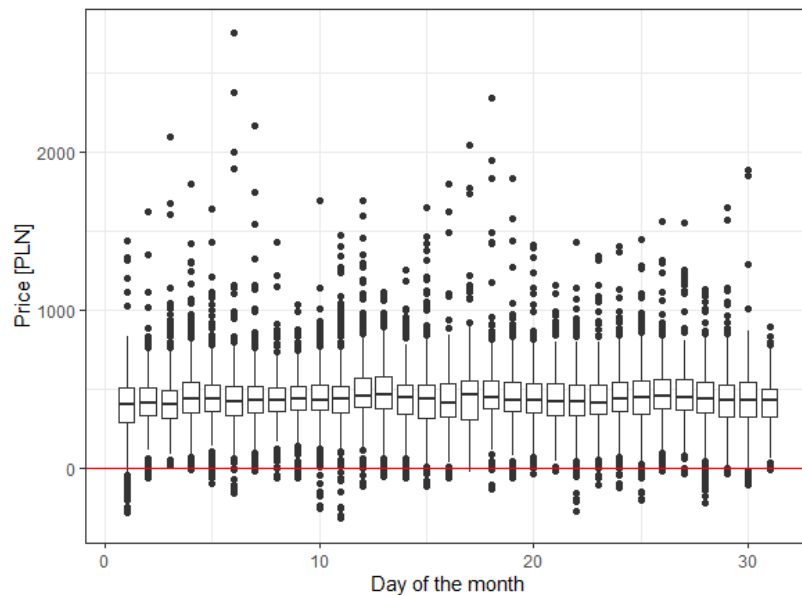
Source: own elaboration in ggplot2 package (Wickham, 2016)

Fig. 4 Price distribution by day of the week



Source: own elaboration in ggplot2 package (Wickham, 2016)

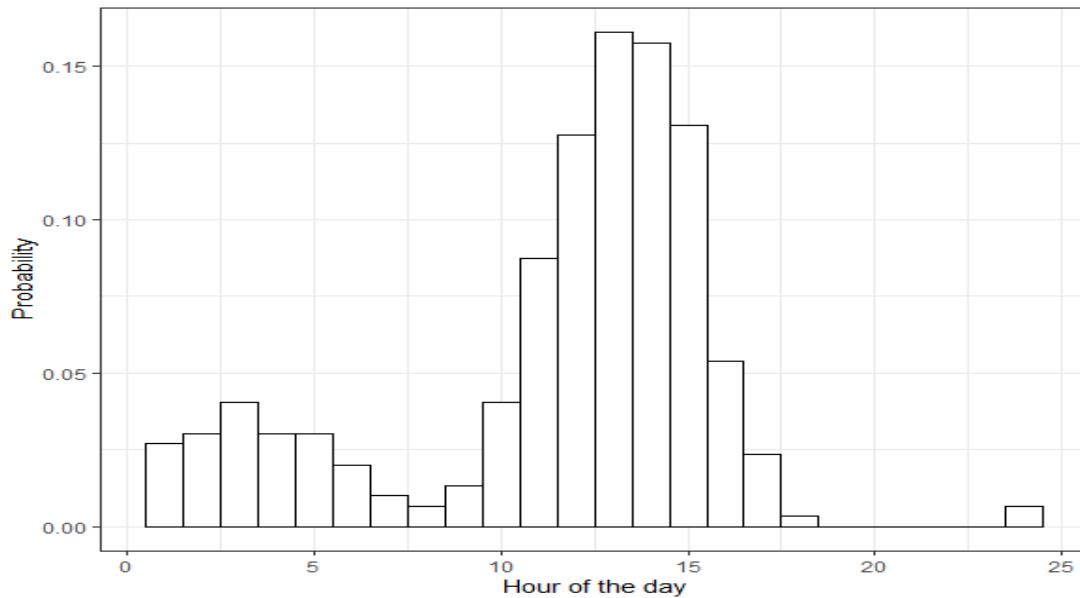
Fig. 5 Price distribution by day of the month



Source: own elaboration in ggplot2 package (Wickham, 2016)

The highest variability in average values is visible in the hourly breakdown. From a risk perspective, it is important to analyze the occurrence of outliers. These most often occur mid-week and in the afternoon.

Fig. 6 Negative prices distribution by hour of the day



Source: own elaboration in ggplot2 package (Wickham, 2016)

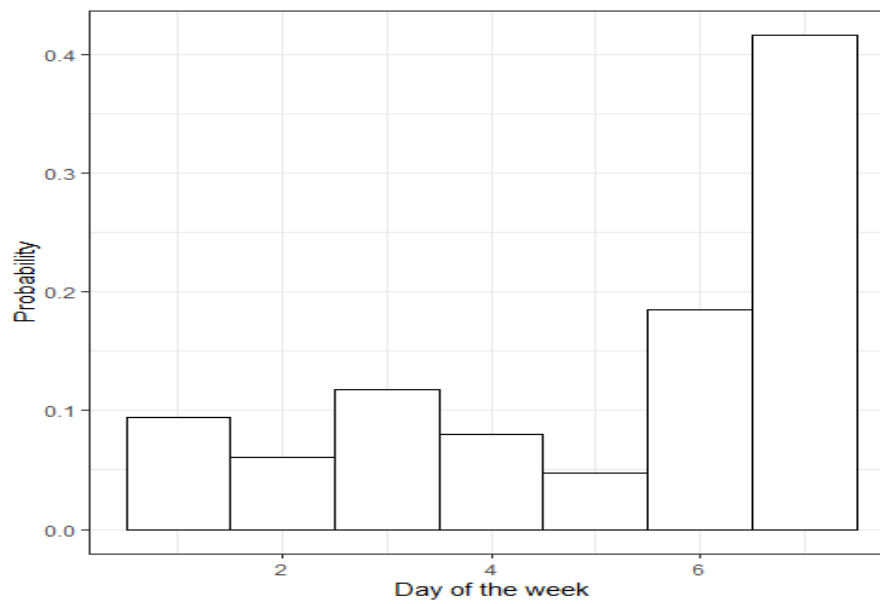
The occurrence of extreme situations was additionally analyzed for the purpose of risk assessment. Negative prices and those exceeding the limit of 1,000 PLN/MWh were thus considered. For such situations, histograms were made, divided into hours of the day and days of the week.

There were 298 occurrences of negative prices during the analyzed period. As shown in Figure 6, which presents a histogram divided into hours of the day, negative prices were observed mainly in the afternoon hours, though some were also observed at night.

When broken down by day of the week, where number 1 means Monday and number 7 means Sunday, the histogram in Figure 7 shows that negative prices most frequently occurred over the weekend. Negative prices also occurred on other days of the week.

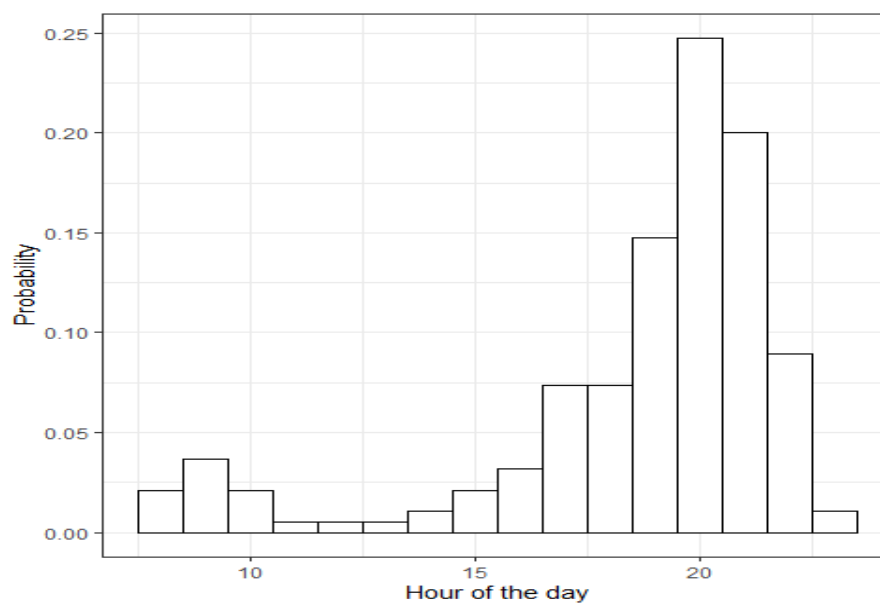
High prices were also analyzed. Prices above 1,000 PLN/MWh were considered as extreme prices. In the period under consideration, there were 190 instances of prices exceeding the 1,000 PLN/MWh limit. As shown in Figure 8, which presents a histogram divided into hours of the day, these high prices occurred mainly during peaks, with a maximum at 8 p.m. Some of them appears also in morning hours, that is, around 9 a.m.

Fig. 7 Negative prices distribution by day of the week



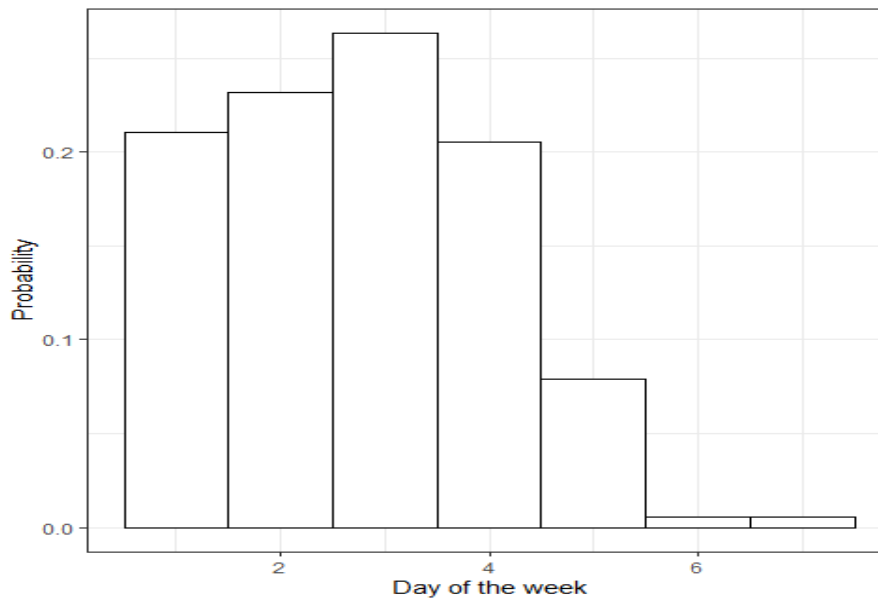
Source: own elaboration in ggplot2 package (Wickham, 2016)

Fig. 8 Extreme prices distribution by hour of the day



Source: own elaboration in ggplot2 package (Wickham, 2016)

Fig. 9 Extreme prices distribution by the day of the week



Source: own elaboration in `ggplot2` package (Wickham, 2016)

When broken down by day of the week, high energy prices were observed on weekdays as shown in Figure 9.

Due to the complex periodicity present in the RCE waveforms, the data were analyzed in the frequency domain. Table 3 presents statistics for the full 52-week period from January 1, 2024 to December 29, 2024. This period begins on Monday and ends on Sunday, comprising 8,736 hourly observations.

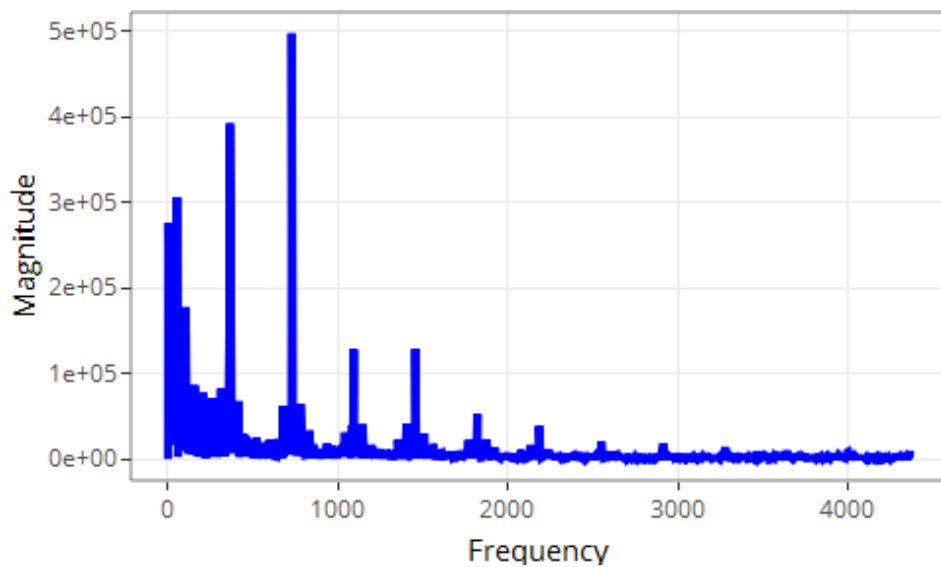
Tab. 3 Statistics of the one year data

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
-318.8	323.6	397.0	416.3	487.2	2749.4

Source: own elaboration with function `summary()` (R Core Team, 2025)

The fast Fourier transform was applied to the data. The `FFT()` function from the `fftw` package (Mersmann, 2022) was used for these calculations. The magnitude spectrum is shown in Figure 10. There are some characteristic points but the maximum value of amplitude has been occurred at $k = 728$.

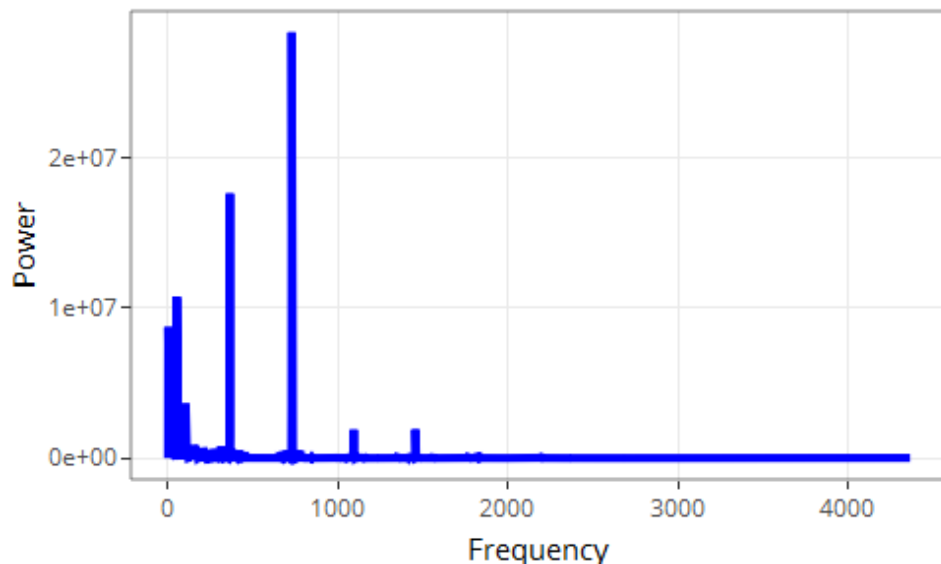
Fig. 10 The magnitude spectrum



Source: own elaboration in ggplot2 package (Wickham, 2016)

Power spectral density was also calculated according to Equation 2. The periodogram is shown in Figure 11.

Fig. 11 The Power spectral density



Source: own elaboration in ggplot2 package (Wickham, 2016)

Several characteristic frequencies are visible on both graphs. The maximum value of the power has been occurred at $k = 728$.

4. Conclusions

The analyses carried out revealed a high degree of volatility in Market prices of electricity (RCE), characterized by complex periodicity, negative price values, and prices that are well above the average. It was possible to locate moments at which negative prices and values above 1,000 PLN/MWh occur. However, this information alone is insufficient to hedge price risk. These phenomena occur randomly, which gives rise to market risk.

Since the phenomena under consideration are highly random, knowledge of RCE volatility alone may not be enough for optimal use. Understanding the degree of energy price volatility may be necessary. Such a measure of the level of stock price variability is volatility. However, due to the occurrence of negative prices, the direct application of such a concept from the stock market is not possible. Further research is needed to determine the volatility of RCE energy prices. Correctly defining such a measure will also allow for the construction of instruments to hedge against excessive price fluctuation risks.

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(www1) <https://www.pse.pl/oire/rcem-rynkowa-miesieczna-cena-energii-elektrycznej>

(www2) <https://www.pse.pl>

(www3) <https://www.pse.pl/raporty-historyczne>

(www4) <https://raporty.pse.pl>