International Journal of
Business and **Economic Sciences Applied Research**

IJBESAR
ijbesar.ihu.gr

Analysis of the Volatility of Wind Energy Production in Romania Applying the EGARCH Model

Ioan-Cătălin Murărașu†[1]

[1] Bucharest University of Economic Studies, Faculty of International Business and Economics, Bucharest, Romania

ARTICLE INFO
Article History

Received 22 November 2023
Accepted 12 January 2024

JEL Classifications
F64; O13; P18; Q42

Keywords:
EGARCH; renewable energy; volatility; balancing costs; wind power

ABSTRACT

Purpose:
The objective of the paper is to highlight the volatility of wind energy production, the renewable source of energy whose output is the most difficult to predict due to its dependence on climatic factors. The present research helps to analyze the risks assumed both by the producers who choose to invest in wind farms and the operator who has to balance the national energy system in case of production fluctuations. Many times, these risks are taken over, without their knowledge, by the final consumers who have to pay higher prices for the energy consumed.

Design/methodology/approach:
In this study, the EGARCH model was applied with the help of EVIEWS 12 software on a data series updated at least every 10 hours (1405 entries) regarding the evolution of wind energy production from January 2021 to January 2023. As a rule, the EGARCH model is used to analyse the volatility of indices in the financial field, but the present study, as well as others before, showed that it also fits perfectly in the case of renewable energy, the statistical tests applied to the results proving this fact.

Findings:
The results of the study show a GARCH term of 0.936, which points out a volatility comparable to some of the riskiest international stock indices.

Research limitations/implications:
This volatility is reflected through increases in balancing costs, ultimately borne by the energy consumers on the national market. Against this background, it is necessary to increase the stability of the national energy system, so that the balancing process would be less expensive and less dependent on imports. The solutions are varied - from the creation of stable non-polluting production capacities, such as the nuclear ones, to the thorough analysis of the characteristics of the areas where production systems from renewable sources are installed. It must be mentioned that the main limitation of this study is the long period considered, because the accuracy of the results could be better if the model was applied several times for data from consecutive, shorter periods.

Originality/value:
This study contributes to the theoretical identification of methods to forecast the volatility of renewable energy production and to highlight the vulnerabilities of increasing the share of this energy in the European energy mix.

It tests the use of heteroscedastic models to estimate the volatility of the wind power supplied to the system, unlike most studies in the literature, which analyze the volatility of the energy market price.

In addition, it proposes some solutions that could reduce or control this instability and ensure the regional energy security.

1. Introduction

The European energy sector is going through a major change of paradigm and structure, led by the European Green Deal, whose objectives drastically limit the prospects of conventional production technologies. By 2050, at least in theory, they will be completely replaced by non-polluting and renewable sources, which may open up new environmentally friendly business opportunities, but may also open a pandora's box in terms of energy supply for European consumers, if the vulnerabilities of these technologies are ignored.

Currently, the main vulnerability of energy production from renewable sources is their dependence on climatic factors, uncontrollable by humans, which cause a high volatility of the energy introduced into the system by some categories of production technologies, especially wind and photovoltaic. The first of these is by far the most unstable source of green energy, but it also has many advantages, such as high efficiency relative to the land area occupied and low operational costs.

Although wind farms are among the most efficient electricity production capacities, they are also the most volatile, and the low production costs are counterbalanced by high balancing costs of the energy systems in which they contribute considerably. The short period of time in which the wind can change its speed and the low ability to forecast these changes makes it even more difficult to integrate wind farms into the national energy mix compared to other sources of green energy.

In the first half of 2023, according to data provided by Transelectrica (the transmission and system operator in Romania), wind energy provided, on average, 15.46% of the national electricity consumption, reaching maximum values of 2.7 MW, of twice as much as the Cernavodă nuclear power plant. However, there were also periods while the production dropped to 0. Those declines led the system operator to turn to other sources, sometimes even to imports or coal power plants, when hydro plants were already operating at full capacity.

The problem of the volatility of renewable energy sources and the need to improve its forecasting methods has not yet been sufficiently well analyzed in the specialized literature, and in practice balancing the system as a result of large fluctuations in green energy production is rather achieved through momentary improvisations (purchasing from the spot market at high prices), than through well-established methods and strategies designed to prevent increased acquisition costs of the transport operator and tense situations or interruptions in the supply of consumers.

This paper aims to test the effectiveness of the application of the EGARCH model to estimate the volatility recorded by wind energy production in Romania, between 2021 and 2023, the period that coincided with the economic recovery process after the coronavirus pandemic, the energy crisis generated by the increase in the price of natural gas and with the acceleration of the targets assumed by European Union through the Green Deal.

Later, in order to estimate the impact of the wind energy production on the energy sector in Romania, it was calculated the correlation between it and the total energy production, energy exports and imports and the energy available for balancing (formed by the sum of the production from conventional sources and imports from neighboring states). The results showed that Romania is turning to imports to compensate for the decrease in the production of wind farms, as conventional sources have already become insufficient to ensure the national needs, many being closed as a result of the anti-pollution policies agreed with the European Union.

In the first part of the paper, it can be found a brief introduction of the main specialized works that addressed the issue of the volatility of renewable energy sources, the results and the opinions of specialists regarding this challenge. There were identified some different currents of opinion regarding the impact of the volatility on the energy sector, mostly because the increase in green energy production causes prices to fall, but their instability causes the risks assumed by companies to increase. Afterwards, there is presented the research method used in the study and the stages that were followed, after which the results obtained are presented and discussed. Finally, the conclusions of the research were stated, its limitations were highlighted and it was made a brief comparison with other studies in the field.

This paper contributes to the effort of the specialized literature to identify and test methods for analyzing energy volatility and forecasting its evolution over time. The higher the percentage of renewable energy in the national energy mix, the greater its volatility and the higher the balancing costs, because the market for this activity is often speculated by producers. Thus, it is necessary to identify some solutions to reduce the impact of this characteristic of renewable energy sources on the national system. So far, in most researches where heteroskedastic models are applied for energy variables, they are used to analyze the volatility of energy prices and not the volatility of energy inputs into the system.

2. Review of Literature

The costs for renewable energy production technologies have fallen considerably in recent years, making them attractive to both investors and household consumers who choose to produce some of the energy they use themselves. In some cases, such as photovoltaic panels, prices have fallen by as much as 90% in the last 10 years. However, the increase in the percentage of the energy mix occupied by renewable sources has not increased enough to achieve the goals of the Paris Treaty, and even a faster growth is needed (Thompson, 2023).

In the context in which renewable energy must represent almost all of the energy introduced into the national systems of all European Union countries by 2050, their volatility represents a problem that must be solved urgently. In the case of wind energy, its integration into the system involves major challenges for the safety and stability of the power system, which must operate within normal technical parameters and also be economically viable. (Liu et al., 2019).

It is necessary for an energy system to be balanced by the national transmission operators, so that everything remains stable. The energy used for this activity can be acquired from internal sources or it can be imported from neighboring states, but in many states the purchases of energy for balancing are made through auctions on the free market, leaving room for speculation by producers which aim to obtain additional profits (Maekawa & Shimada, 2019;

DOI: 10.25103/ijbesar.162.03

Ehrhart & Ocker, 2021). The stability of the energy market is essential for all other economic sectors because shocks felt in it also affect other areas, such as industry and agriculture (Aiyetan et al., 2021).

A possible solution so that the percentage of the energy mix occupied by renewable sources can continue to increase until climate neutrality is reached in Europe is to increase the forecasting capacity of production. For this, Lau & McSharri (2010) were able to demonstrate that wind power production could be predicted minutes ahead using ARIMA and GARCH models.

Heteroskedastic models were also successfully used by Shen & Ritter (2015), who demonstrated the utility of the MRS-GARCH submodel in wind power volatility estimation. Their study showed that GARCH models can be useful for renewable energy investors to calculate and manage the financial risks in the energy market generated by weather conditions. The need to identify wind energy production forecasting solutions was also emphasized by Tastu et al. (2014), who were able to formulate some probabilistic forecasts for a 165 MW wind farm in Denmark.

Zhou et al. (2021) showed that due to the high contribution of energy markets to the global economy, events occurring within them have major implications on other markets. In this context, the volatility recorded in the energy markets also extends to the financial markets, which are directly influenced by the price of energy. This problem must be known and analyzed by the decision-makers of the states and the actors in the market in order to be able to prevent the risks to the financial systems.

Efimova & Serletis (2014) consider that GARCH models have become indispensable for modeling the short-term volatility of energy prices due to the efficiency shown. Therefore, they have already made their place in the analyses related to the energy market. Moreover, Ghosh & Gupta (2021) consider that correct forecasting by using heteroskedastic models can considerably improve electricity costs by planning the production surplus.

Li et al. (2023) used GARCH method to model the returns of green and conventional energy stock indices, demonstrating that climate risk factors (climate policy uncertainty, climate change news, and negative climate change news) increase the long-term volatility for brown energy, but does not affect the renewable energy. So, even if they receive negative inputs about the renewable energy sector, investors still choose to support this market.

As far as Romania is concerned, the national policies in the field of energy have fully aligned with the European ones, especially due to the available opportunities to increase the share of renewable sources in the national production. In this context, in the coming years an increase in the importance of the Black Sea offshore plateau owned by Romania is expected. It has more favorable wind for the installation of wind turbines than the onshore areas where wind farms have been built so far (Onea & Rusu, 2019).

According to studies carried out by The World Bank Group (2019), the entire coastal area of the Black Sea offers a good potential for the development of wind farms, the wind speeds being favorable, on average 7-8 m/s. In addition, the investment costs for these projects have also decreased over the last 10 years. In 2015, the levelized cost of energy in the case of offshore wind farms projects was 150 to 200 USD/MWh. In 2019 this indicator was below 50 USD/MWh, which was less than coal and nuclear projects.

In addition, Nedelcu et al. (2023) claims that although the offshore area of the Black Sea usually presents difficulties for the installation of wind farms, such as meteorological instability and large variations in wind speed, its western coast presents more favorable characteristics for the installation of turbines. The region, in which Romania is also located, has constant and moderate-strong speeds, which are good for investments in coastal wind energy production capacities.

Maniatis & Milonas (2022) show, using the GARCH-in-Mean model, that the degree of penetration of the national energy system in Greece by renewable energy has a significant impact on prices on the wholesale market, with a strong order-merit effect being found in their case. Thus, during peak hours, the wind energy contributes to price reductions. Separating the production of photovoltaic and wind power, it was found that the former tends to reduce the market price volatility, while the latter increases it because it is more unstable. The impact of the volatility of renewable energy production on market prices was also studied by Jonsson et al. (2010) on the Danish market by using a non-parametric regression. The results show that forecasts for green energy production cause price drops.

Also, Rintamaki et al. (2017) show, using a SARMA model, that in Denmark electricity price volatility on the day-ahead market is lower when wind power production is higher, while in Germany the effect is opposite. However, in both cases the price is lower when the energy production from the two renewable sources is higher, once again the order-merit effect being observed.

3. Methodology

The data used to calculate the volatility of wind energy production are taken from Transelectrica, the company that manages and operates the electricity transmission system in Romania. They are updated approximately every 10 - 12 hours and totalized 1403 values. The data used in the research are freely available and obtained from the internet page of the mentioned operator, where the electricity production is classified according to the production sources (hydropower, biomass energy, nuclear power, energy from hydrocarbons, wind power, solar energy).

In the graph in Figure 1 it can be observed the representation of these values and the considerable fluctuations of the energy production from the wind farms.

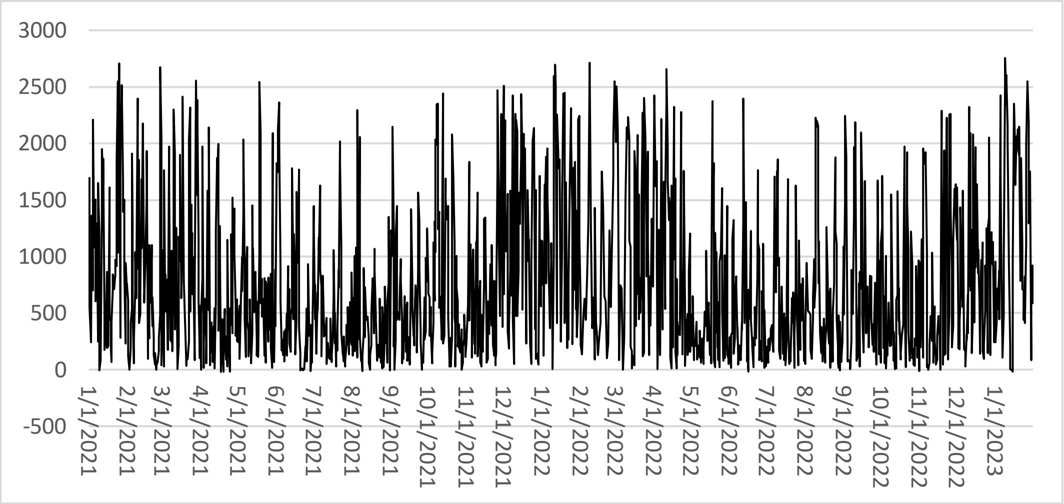

Figure 1. Wind farm energy production graphic in the analysed period.
Source: (Author's construct based on Transelectrica's data)

To avoid any trends in the analyzed time series, since it must be stationary in order to successfully apply the EGARCH model, the first difference function was used (the changing the value of the series from one point to the next point), according to the formula:

$$y = y_t - y_{t-1} \quad (1)$$

Where y_t and y_{t-1} represent the consecutive terms of the time series representing wind energy production, and y is the term of the time series resulting by applying the first difference function. Thus, the evolution of renewable energy production from Romanian wind farms is illustrated in Figure 2.

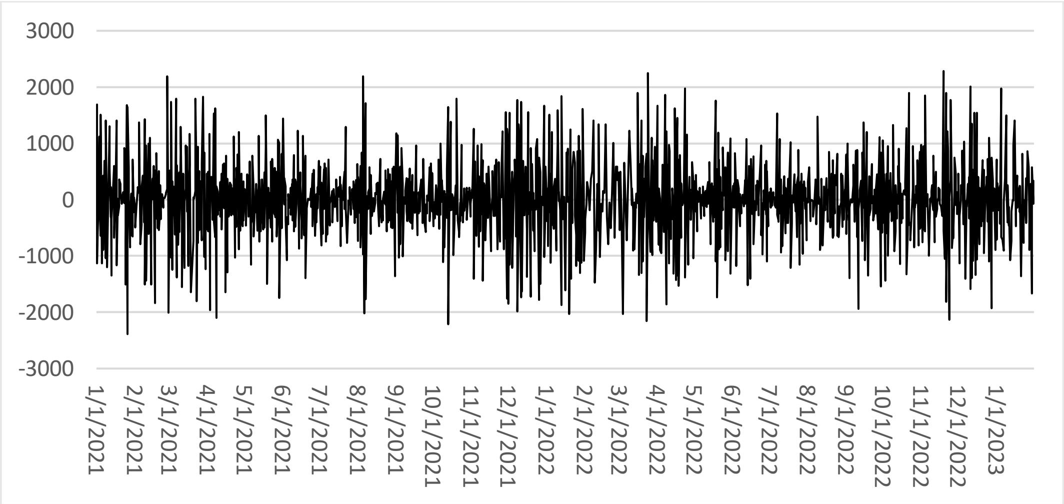

Figure 2. First difference function of wind farm energy production in the analysed period
Source: (Author's construct based on Transelectrica's data)

For the mathematical verification of the stationarity of the resulting time series, the Augmented Dickey-Fuller Test was applied, which tests the hypothesis that there is a unit root in the analyzed series. If the probability that this exists is below 0.05, it can be concluded that the time series is stationary.

Subsequently, to confirm that the time series has ARCH effects so that the heteroskedastic model could be applied, the ARCH test was used. Its null hypothesis is that the time series has no first level ARCH effects. If the probability for the null hypothesis is below 0.05, the heteroskedastic model can be applied.

The Exponential Generalized Autoregressive Conditional Heteroskedastic Model (EGARCH) was first introduced by Daniel Nelson in 1991 as an adaptation of the Generalized autoregressive conditional heteroskedasticity model (GARCH) developed by Bollerslev five years earlier. The main advantage of the model chosen for the present paper over other autoregressive models is the lack of restrictions on the parameters, since logarithmic variances are introduced in the equation instead of simple variances, which always have positive values. The formula used to express the EGARCH model is as follows:

$$\ln(\sigma_t^2) = \omega + \beta \ln(\sigma_{t-1}^2) + y \frac{u_{t-1}}{\sqrt{\sigma_{t-1}^2}} + \alpha \left[\frac{|u_{t-1}|}{\sqrt{\sigma_{t-1}^2}} - \sqrt{\frac{2}{\pi}} \right] \quad (2)$$

After applying the EGARCH model, to test the results, it was generated the correlogram (up to threshold 36) to check for possible autocorrelation and there were performed the Engle-Ng Sign-Bias Test to identify the possible presence of leverage effects in the standardized residuals and the Nyblom Parameter Stability Test to identify possible structural changes in the time series. Subsequently, ARCH LM Test was used to check whether the residues still exhibit ARCH effects.

In addition, to analyze the impact of the wind energy subsector on the entire national energy system, the correlations between wind energy production and total energy production, energy exports and imports, and energy available for balancing (conventional sources and imports) were calculated.

4. Results

The Augmented Dickey-Fuller test, applied in Table 1, shows that the time series is stationary, being suitable for the application of the EGARCH model, if it presents ARCH effects, because the absolute value of the t-Statistic (19.83216) is higher than that of the critical levels (1%, 5% and 10%).

Table 1: Augmented Dickey-Fuller Test

Test critical values	**t-Statistic**	**Probability**
Augmented Dickey-Fuller test statistic	-19.83216	0.0000
1% Level	-3.434838	
5% Level	-2.863410	
10% Level	-2.567814	

Source: (Author's construct)

The testing of ARCH effects (Table 2) shows that the F-statistic is significant, because the probability F is 0, a situation in which the conditions are met for the null hypothesis, according to which the series does not present ARCH effects, to be rejected. Thus, the heteroskedastic model can be applied.

Table 2: Heteroskedasticity Test (ARCH)

F-statistic	Prob. F	Obs. R-Squared	Prob. Chi-Square
177.7540	0.0000	157.9656	0.0000

Source: (Author's construct)

The application of the EGARCH model on the analysed time series, as shown in Table 3, indicates a high volatility of wind energy production across the country, comparable to risky financial indices such as virtual currencies, a situation that creates uncertainties in the energy market and entails negative implications such as price increases or purchase of conventional energy for balancing from non-EU countries.

Table 3. EGARCH model

Variable	Coefficient	Probability
C(1)	0.9057	0.0000
C(2)	-0.0549	0.0000
C(3)	0.4819	0.0000
C(4)	0.9362	0.0000

Source: (Author's construct)

According to the results in Table 3, the ARCH term, C(2), is significant (p-value = 0), so the size of the shock has a significant impact on the volatility of the renewable energy production. Moreover, C(2) is negative (-0.054), so the relation between the past variance and the current variance in absolute value is negative. Under these circumstances, the bigger shocks to the variance doesn't necessary determine a higher volatility.

C(3) is positive, so the series has no leverage effects. In this context, there is not a negative correlation between the past return and future volatility. Also, the bad events (so named bad news), like low winds, does not necessarily have a bigger impact on the volatility than the, so called, good events (strong wind). That happens because in the analysed period we didn't face very much frost on the airscrews (the weather was very hot in the last years). This is de difference between energy and financial series. The wind power production is objective and doesn't care about how the weather was last time when the production dropped.

Also, the C(4), which is the GARCH term, shows a very high persistence (0.9362) of past volatility. Because its p-value is also 0, it is possible and reliable to predict future volatility based on past volatility.

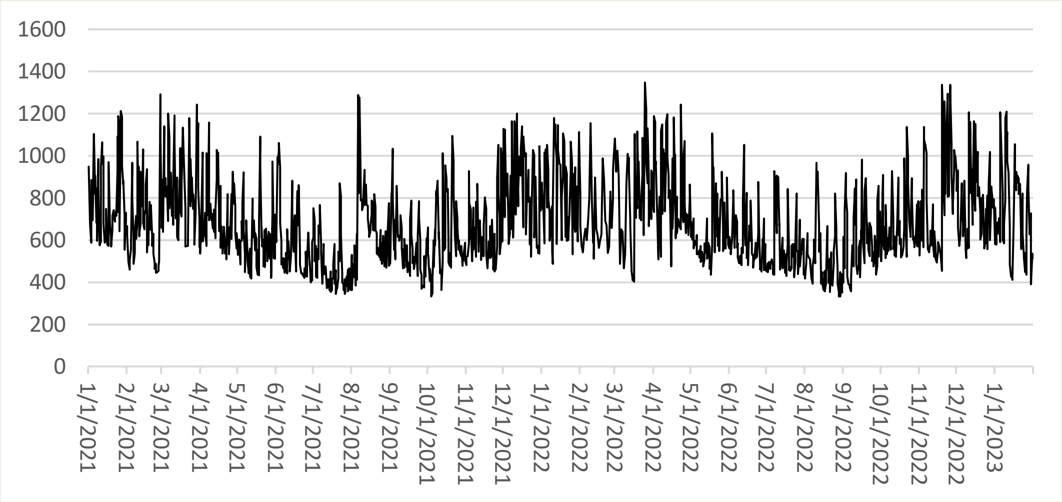

Figure 3. Conditional standard deviation
Source: (Author's construct based on Transelectrica's data)

For a better visual observation of the results, conditional standard deviation was also generated after applying the EGARCH model on the data series (Figure 3).

Table 4. Tests

Test		**Probability**
Nyblom Parameter Stability Test	1% Crit.	0.748
	2% Crit.	0.470
	3% Crit.	0.353
Engle-Ng Sign-Bias Test	Sign-Bias	0.2964
	Negative Bias	0.2794
	Positive Bias	0.9794
	Joint-Bias	0.6122
ARCH LM Test	Prob.	0.5665
Correlogram	Prob. (36 lags)	[0.544;0.973]

Source: (Author's construct)

Nyblom Parameter Stability Test shows probabilities greater than 0.05 for all three critical thresholds, indicating that the parameters are stable. Also, when applying the Engle-Ng Sign-Bias Test, all probabilities were greater than 0.05, which means that the model is well specified. The ARCH LM Test showed that the residuals no longer exhibited ARCH effects, with the F-statistic being greater than 0.05. Finally, performing the correlogram for 36 lags it resulted that there was no serial correlation.

Table 5. Correlations

	Wind power
Imports	-0.530
Exports	0.530
Production	0.703
Equilibration	-0.518

Source: (Author's construct)

Analysing the correlation between wind energy production and total energy production at national level, the value of 0.703 was found, which indicates a strong dependence of the national energy mix on wind energy. In addition, a correlation index of 0.530 was found between wind energy production and exports and an inverse correlation of -0.530 between wind energy production and imports, indicating that when wind energy is produced, Romania can export energy, while when production decreases, imports will be necessary. These values already show the high dependence on wind energy of the national energy sector, which must increasingly include this source. A similar dependence is also revealed in the case of the energy trade balance. On the other hand, wind energy producers are also dependent on exports, as they ensure the continuity of production when there is not enough demand in the domestic market.

The results of the EGARCH analysis are also doubled by the inverse correlation (-0.518) between wind energy production and energy used for balancing, meaning that when wind farm production decreases, there are not enough other renewable energy sources to compensate the shortfall, which is why conventional capacity and imports need to be used. This is the main shortcoming of renewable energy sources, because in order to be balanced, systems that include them in large proportions still depend on stable sources of energy, which are usually polluting.

Since the use of renewable energy sources takes precedence in the national energy mix, wind energy dictates the 4 correlation values with the indicators mentioned, so that we can speak, in practice, about an influence of wind energy production on them and not vice versa. So, wind power determines how much conventional energy will be needed into the system, while European countries shut down polluting generating capacity. This leads to the need to import polluting energy from third countries, which are not subject to the European Green Deal and use the EU as a destination market for the surplus energy in their system.

5. Conclusion and Recommendations

As in other cases where heteroskedastic models have been applied to estimate the volatility of renewable energy production (Lau & McSharry, 2010; Shen & Ritter, 2015), the EGARCH model also performed well, indicating high volatility in the evolution of wind energy production over the period under analysis. The statistical tests applied also confirmed the correctness and efficiency of the model and show that forecasts can be made with confidence based on it.

The present study clearly shows that renewable energy production is highly volatile. At the same time, the results of the heteroskedastic models applied by Maniatis & Milonas (2022) show that wind energy causes a reduction of energy market prices in times of scarcity but increases its volatility. On the other hand, Rintamaki et al. (2017) show that prices are less volatile in Denmark when wind power production is higher and Jonsson et al. (2010) show that renewable energy drives down energy prices in this country.

In this context, it should be noted that the impact of renewable sources on the price of energy depends on the structure of the energy mix - which is specific to each country - but its impact on the actual energy production is a constant and objective element, which is different from the impact on energy market prices.

By correlating the values recorded for wind energy production with production from other sources, whether conventional or renewable, as well as with indicators such as sources suitable for balancing market entry (due to in-band energy production), it was found that the efficiency of wind farms already has a large impact on the national energy market. To a significant extent, it dictates a significant part of the import requirements, export capacity and balancing requirements in the national energy system.

This comes with both advantages - as wind farms contribute fully to achieving the objectives of decarbonization of the economy, helping to meet the environmental standards assumed by the Romanian state in relation to European authorities - and disadvantages. The latter consist mainly of the increased instability of the national energy system, the increase in prices on the balancing market due to the even higher demand and the risk of having to resort to energy imports from neighbouring countries, often produced from conventional and polluting sources, a situation which would mean that the objectives of the Green Pact would only be achieved fictitiously, with the energy used in reality still being polluting, but produced outside the European Union.

The results of the application of the EGARCH model show its efficiency in the analysis of energy production and illustrate the high volatility of wind energy production, and the correlation between it and the other monitored indicators shows the ability of this sub-sector to influence the entire energy market.

However, a limitation of the study is that the analysis was carried out over a long time period (2021-2023). The accuracy of the results could be better if the model was applied several times for data from consecutive, shorter periods. Wind farm output fluctuates, but this fluctuation is different from period to period, depending on the different climatic conditions from season to season, which provides a minimum degree of predictability for operators.

It should be noted that the paper does not aim to highlight only the weaknesses of wind energy or to condemn the boom in the renewable energy industry, but to highlight the current shortcomings in the energy system and to contribute, as far as possible, to the identification of solutions to address them. In this way, grid integration and further development of green energy production capacities would be achieved in a healthy and efficient way and would not lead to a decrease in the quality of supply services or to higher prices for end consumers.

The results of the application of the EGARCH model on the analysed series show that the volatility of energy production from wind farms is also very high in Romania, although they are located in some of the most favourable areas of the Black Sea Region, such as the Dobrogea area or the Curvature Carpathians, with winds above 7 m/s, often exceeding 9 m/s (World Bank, 2020; Gârleanu et al., 2021, Zaides et. al, 2001).

This volatility increases prices on the balancing market and leads the system operator to resort to imports when the energy produced is not sufficient to meet the consumption level. In the case of Romania, imports mostly come from Ukraine and represent the electricity produced from conventional energy sources, as shown in Table 5. Also, as

Zhou (2021) argues, volatility propagates to other markets, such as financial markets, whose fluctuations are strongly influenced by energy market events.

In addition, the need to keep the system within normal parameters by using conventional generation capacities cannot achieve climate neutrality, as polluting sources are still indispensable for balancing in the current energy mix structure. One solution to their replacement is to increase the degree of interconnection of national energy systems, while increasing renewable energy production capacity and diversifying them, similar to reducing financial risk through portfolio diversification. So that, when climatic conditions are not favourable for energy production in one region, it can import green energy from another, and when one has a surplus of production, it can export it.

In markets where traded energy is produced in high percentages from wind farms, its volatility is also considerably reflected in the price (Maniatis & Milonas, 2022), in periods of favourable wind they are lower as the market is oversaturated and when production decreases, prices increase. A possible solution to this phenomenon is to create capacity to store the excess electricity in other forms, such as the creation of green hydrogen. This would reduce the price volatility, as in times of surplus the surplus can be converted into hydrogen that could be used in times of deficit, keeping production constant.

Another solution that needs to be encouraged is the installation of off-grid and on-grid renewable energy generation capacity directly by end-users (such as photovoltaic panels on houses and blocks or wind turbines). These can support a significant share of household consumption, reducing the demand from the centralised market, especially at peak times and thus reducing the energy prices. In addition, the installation of production capacity directly at the point of consumption also reduces the investment costs with the development of the transmission and distribution networks.

European policies aimed at achieving climate neutrality by 2050 focus heavily on financing projects of building renewable energy generation capacities, but do not focus as much on the solutions needed to integrate them into the system, leaving most of this responsibility to transmission operators. Sometimes this even prevents the development of new wind or photovoltaic plants, with investors having to abandon or postpone their projects because they cannot connect them to the power transmission system.

The development of renewable energy volatility forecasting solutions is necessary to prevent blackouts and maintain the quality of supply to end customers. The EGARCH model can be effective for this task due to the lack of restrictions on the parameters, which are always positive, since logarithmic instead of simple variances are introduced in the equation. Although heteroskedastic models can still be improved, their usefulness for modeling and predicting the volatility of renewable energy is certain, and in the future, they will play a considerable role in balancing electricity transmission systems around the world.

For future researchers it may be useful to apply heteroskedastic models over shorter time periods for data updated to the minute, so that their effectiveness for lower fluctuations can be tested. Subsequently, short-term forecasts could be made based on past volatility of output. Furthermore, the application of heteroskedastic models could also be tested separately, on all renewable sources of energy and for short periods, so that forecasts can be made and the energy mix can be modelled in advance so that balancing the system can be done more easily.

References

Aiyetan, I., Aremo, A., Olomola, P. (2021). *Assessing the Impact of Electricity Production on Industrial and Agricultural Output Growth in Nigeria.* International Journal of Business and Economic Sciences Applied Research. https://doi.org/10.25103/ijbesar.133.07.

Efimova, O., Apostolos, S. (2014). *Energy markets volatility modelling using GARCH.* Energy Economics, 43, 246-273. https://doi.org/10.1016/j.eneco.2014.02.018

Ehrhart, K. M., Ocker, F. (2021). *Design and regulation of balancing power auctions: an integrated market model approach.* Journal of Regulatory Economics. https://doi.org/10.1007/s11149-021-09430-7.

Ghosh, S., Gupta, P. K. (2021). *Forecasting of Solar Power Volatility using GJR-GARCH method.* IEEE Electrical Power and Energy Conference. 261-266. https://doi.org/10.1109/EPEC52095.2021.9621364.

Gârleanu, A., Onea F., Rusu, E. (2023). *Assessment of the Wind Energy Potential along the Romanian Coastal Zone. Inventions 2023, 8, 48. https://doi.org/10.3390/inventions6020041.*

Jonsson, T., Pinson, P., Madsen, H. (2010). *On the market impact of wind energy forecasts. Energy Economics, 32, 2, 313-320. https://doi.org/10.1016/j.eneco.2009.10.018.*

Lau, A., McSharry, P. (2010). *Approaches for multi-step density forecasts with application to aggregated wind power. Annals of Applied Statistics, 4(3), 1311-1341*

Li, H., Bouri, E., Gupta, R., Fang, L. (2023). *Return volatility, correlation, and hedging of green and brown stocks: Is there a role for climate risk factors? Department of Economics Working Paper. University of Pretoria. http://www.up.ac.za/media/shared/61/WP/wp_2023_01.zp229197.pdf.*

Liu, Y., Wang, H., Han, S., Yan, J., Li, L., Chen, Z. (2019). *Quantitative method for evaluating detailed volatility of wind power at multiple temporal-spatial scales. https://www.sciencedirect.com/science/article/pii/S2096511719300854.*

Maekawa, J., Shimada, K. A (2019). *A Speculative Trading Model for the Electricity Market: Based on Japan Electric Power Exchange.* Energies, 12. https://doi.org/10.3390/en12152946.

Maniatis G. I., Milonas, N. T. (2022). *The impact of wind and solar power generation on the level and volatility of wholesale electricity prices in Greece. Energy Policy, 170. https://doi.org/10.1016/j.enpol.2022.113243.*

Nedelcu, L. I., Tanase, V. M., Rusu, E. (2023). *An Evaluation of the Wind Energy along the Romanian Black Sea Coast. Inventions 2023, 8, 48. https://doi.org/10.3390/inventions8010048.*

Onea, F., Rusu, L. (2019). *Assessment of the Romanian onshore and offshore wind energy potential. International Conference on Renewable Energy and Environment Engineering. https://doi.org/10.1051/e3sconf/201912201003.*

Rintamaki, T., Siddiqui, A. S., Salo, A. (2017). *Does renewable energy generation decrease the volatility of electricity prices? An analysis of Denmark and Germany. Energy Economics, 62(C). https://doi.org/10.1016/j.eneco.2016.12.019.*

Shen, Z., Ritter, M. (2015). *Forecasting volatility of wind power production. Discussion Paper 2015-026. Economic Risk. Berlin.* https://dnb.info/1204920923/34.

Tastu, J., Pinson, P., Trombe, P. J., Madsen, H. (2014). *Probabilistic forecasts of wind power generation accounting for geographically dispersed information. IEEE Transactions on Smart Grid, no. 5, 480-489.*

Thompson, A. (2023). *Renewable Energy is Charging Ahead. Scientific American. https://www.scientificamerican.com/article/renewable-energy-is-charging-ahead/.*

World Bank Group. (2020). *Offshore wind technical potential in the Black Sea. https://documents1.worldbank.org/curated/en/718341586846771829/pdf/Technical-Potential-for-Offshore-Wind-in-Black-Sea-Map.pdf*

World Bank Group. (2019). *Going Global. Expanding Offshore Wind to Emerging Markets. https://documents1.worldbank.org/curated/en/716891572457609829/pdf/Going-Global-Expanding-Offshore-Wind-To-Emerging-Markets.pdf.*

Zaides E. P, Zaides I. A. (2001). *The energy conversion - technologies and resources. Bucharest: ICPE Publishing House.*

Zhou, W., Qinen, G., Chen, J. (2021). *From volatility spillover to risk spread: An empirical study focuses on renewable energy markets. Renewable Energy, Volume 180, 329-342.*