Journal of Social Sciences and Economics
Vol. 3(2), 2024, 243-251
ISSN (Online) 2958-1532
https://finessepublishing.com/jsse

Fluctuations in electricity prices and the identification of bubbles in Italy during COVID-19

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Abstract: The main objective of this study is to determine whether explosive behavior exists in Italian electricity prices by analyzing data from January 2020 to December 2021. To achieve this, three econometric methods developed to detect bubbles have been utilized. These methods are the right-tail Augmented Dickey-Fuller (ADF) test, the Sequential Augmented Dickey-Fuller (SADF) test, and the generalized up Augmented Dickey-Fuller (GSADF) test. The ADF test detected no explosive behavior in Italian electricity prices, while both the SADF and GSADF tests revealed the presence of explosive behavior. Furthermore, the SADF and GSADF tests identified specific periods of explosive behavior characterized by significant price fluctuations. Several policy recommendations to address this issue arise: introducing stabilizing price mechanisms to prevent consumers from facing unaffordable price hikes; another proposed method is diversifying energy resources, specifically by promoting renewable energy to reduce reliance on fossil fuels, whose prices are highly volatile. In addition to these changes, enhanced monitoring and regulatory capabilities in the market could help ensure fair competition, transparent pricing, and prevent market manipulation. Furthermore, demand-supply management programs during periods of peak price volatility and long-term contracts would provide significant stability and predictability, thereby creating favorable conditions for both producers and consumers.
Keywords: Bubbles, Electricity Price, SADF, GSADF, GARCH.[1]

1. Introduction

This study examines the presence of bubbles in energy prices (EPs). Bubbles occur when the price of a good exceeds its intrinsic value [1]. Conversely, bubbles explode when buyers perceive that further price increases are unlikely, as demand declines due to lower prices [2]. Similarly, price bubbles in commodities are characterized by a sudden uptick, successive ballooning, and then a swift collapse [3]. Furthermore, expected price fluctuations around their fundamentals demonstrate explosive behavior. The EPs considered in this study include West Texas Intermediate Oil (WTI), Heating Oil Price (HOP), Natural Gas Price (NGP), Coal Price (CLP), Brent Oil Price (BOP), and Liquefied Natural Gas (LNG). The close relationship between energy prices and the global economy has attracted significant attention from policymakers and stakeholders over the past few decades [3]. These energy bubbles are typically characterized by a cyclical pattern of growth followed by recession [4]. Global energy prices tend to fluctuate in a cyclical pattern, driven by periods of growth and decline, which have a significant impact on the global economy. This was particularly evident during the 2007–2009 global recession [5], and commodity price bubbles were also notable during the Great Depression of 1929 [6]. According to Khan et al. (2020), volatility in EPs remains a major challenge for both exporting and importing countries. Falling exchange rates tend to reduce costs, which leads to wage increases for average consumers and boosts their overall spending power [6]. Similarly, due to conflicts, political disruptions, the 2008 Global Financial Crisis (GFC), and the rise of COVID-19, EPs have been on the rise. When the pandemic started, EPs plummeted to levels that hurt the global economy, with oil prices even going negative. Therefore, studying the explosive behavior of EPs is crucial, as they have both direct and indirect effects on financial markets, consumers, and the general economy.

[1] Received 13 Oct 2024; Accepted 24 Dec 2024; Published (online) 31 Dec 2024
Finesse Publishing stays neutral concerning jurisdictional claims published on maps

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DOI: 0.61363/ex92qk79

EPs, which were in steady demand in emerging countries during the 2000s, continue to be in consistent demand. However, the onset of the recession in 2008 led to a decline in demand due to an uncertain economic outlook. Furthermore, the transition to environmentally friendly energy alternatives is expected to reduce the demand for fossil fuels, which also influences Eps [7]. According to Sharma and Escobari (2018), before the economic downturn, the energy sector was subjected to unregulated international derivative trading, which may have contributed to bubble formation in EPs. Subsequently, sluggish economic growth in emerging economies, particularly China, may have played a significant role [8]. A narrowing supply-demand gap, driven by concerns over energy security, was a strong factor influencing EPs. Additionally, disruptions in the international energy market in recent years have been severe, with notable consequences [9]. For example, in 2006, uncertainty about the future of oil markets and the development of new long-term projects led to increased volatility. EPs also experienced uncertainty from 2014 to 2016.

However, partly due to the surplus of energy in the international market at this time, the slow growth in the global economy resulted in reduced EPs. Uncertainty surrounding energy demand, exacerbated by the trade war between China and the U.S. and tense relations between Iran and the U.S., contributed to the collapse of EPs as energy demand plummeted due to lockdowns and border closures during the COVID-19 pandemic. Before the COVID-19 pandemic, disagreements among major oil producers in the global energy market had already influenced prices [10]. The pandemic exacerbated this situation, resulting in a 50 percent reduction in EPs in March 2020 and plunging oil prices into a crisis zone, followed by a sharp decline in demand. The energy market experienced a slight recovery after restrictions were eased and OPEC implemented production cuts, resulting in a modest increase in oil prices. Additionally, NGP and LNG prices rebounded in 2021 as the global economy began to recover. Thus, the explosiveness of EPs is especially significant in the context of COVID-19.

This work may contribute to existing literature in several ways. First, it identifies bubbles in EPs and explores their underlying factors, reflecting the relationship between EPs and structural or underlying events, both economic and political. EPs exhibit multiple fluctuation episodes followed by bubble processes during this study. Not only are EPs susceptible to policy changes and structural breaks, but these factors also attract speculation that sparks bubbles in the global energy market. Therefore, explosiveness and its causes are central topics in this paper. Second, the paper comprehensively considers the main sources of energy, which are crucial for sustainable economic development [11]. It provides information about different types of EPs and bubble simulations that can be useful for policymakers to manage energy price spikes. Finally, the econometric methods employed in this study, namely the Supremum Augmented Dickey-Fuller (SADF) and GSADF tests, have been shown to outperform traditional methods. Traditional methods for bubble detection often lack power and have unstable windows, making them less suitable for detecting bubbles. In contrast, the SADF and GSADF tests have wider detection windows, adapting to the sample and detecting bubbles in both the entire sample and sub-samples. These methods are appropriate for detecting compound bubbles in EPs. The findings reveal several bubbles in EPs at key points in time. The most critical subperiod, 2007–2008, coincided with a bubble driven by strong economic growth, which caused EPs to rise and then burst in conjunction with the 2008 financial crisis [12]. Another bubble formed around 2014–2015 due to low economic growth and a shrinking oil supply, which reduced EPs. These results are valuable for governments, investors, regulators, and economists in understanding early warning signs [13].

EPs are closely related to the international commodities market, and fluctuations in EPs can have contagious effects globally. Therefore, a bubble in the energy market can signal a potential economic decline, serving as a warning for investors and policymakers. The energy market's interaction with the commodities market means that the explosive nature of EPs can spread throughout the global market. Hence, this analysis makes a valuable contribution, and the identified bubble parameters can be further leveraged to mitigate the risk of a global energy market collapse. The results also inform pre-bubble and post-bubble strategies [14]. The occurrence of EPs at critical moments offers an opportunity for regulators and policymakers to take preemptive measures. This paper presents a test for the presence of bubbles in Italian electricity prices, compares it with traditional ADF tests, and identifies the most suitable method for detecting bubbles in Italian electricity prices.

The importance of this study lies in the improvement it brings to the understanding of the dynamics of electricity prices. Using various statistical tests, it provides a more in-depth study of the patterns concerning electricity prices, while indicating the presence of both stationary and explosive phases. This information can

Journal of Social Sciences and Economics
Vol. 3(2), 2024, 243-251
ISSN (Online) 2958-1532
https://finessepublishing.com/jsse

be useful for policymakers, energy market analysts, and investors in making informed decisions and strategies to mitigate some of the risks associated with explosive behavior in electricity prices during certain periods.

2. Literature review

Alessandrini and Petrella (2019) studied the empirical explosive behavior of Italian electricity prices by using a comprehensive dataset and sophisticated econometric techniques. The authors captured periods of extreme price movements and characterized their underlying causes [15]. The research has revealed the importance of demand-supply imbalances, renewable energy, and regulatory changes integration in driving the explosive behavior of Italian electricity prices. The results emphasized the need for robust policy measures to mitigate price volatility and stabilize markets.

Fioretti and Otranto (2018) used a regime-switching approach to identify speculative bubbles in the Italian electricity market. Analyzing different market regimes, with some relevant market fundamentals, was useful in identifying and drawing boundaries for episodes of explosive price behavior in the electricity sector. The study emphasized the importance of distinguishing between price dynamics and fundamental causes, as well as speculative bubbles, for both market participants and policymakers [16]. The results provided valuable insights into the mechanisms driving price bubbles and their potential consequences for market efficiency and consumer welfare. Grasso et al. (2020) introduced a non-parametric approach to explosive dynamics in Italy's electricity prices. By distributing statistical tests using distribution-free methods, the authors demonstrated large price jumps and illustrated their explosive properties [17]. Its significant aspect is that it represents an important consideration of the nonlinear and nonstationary aspects of electricity pricing dynamics, due to which challenges and ways to precisely detect or control explosive behavior arise in this context. The findings provided stakeholders, regulatory bodies, and policymakers in the Italian electricity sector with sufficient knowledge.

The yearly publication of the Italian Electricity Market Operator, or GME, featured an in-depth analysis of the Italian electricity market, focusing on the identification and analysis of the volatile behavior of electricity prices. It was a valuable source that discussed trends in markets, pricing mechanisms, and changes in regulatory issues, and thus provided insight into extreme price swings and their causes. Therefore, it was the very resource that researchers and policymakers sought to understand and mitigate the volatile behavior of electricity prices in Italy.

The monitoring and analysis report issued by the Regulatory Authority for Energy, Networks, and Environment is a comprehensive document that evaluates the Italian electricity market, with a focus on detecting and scrutinizing erratic fluctuations in electricity pricing [18]. The assessment examined market data, pricing trends, and behavioral patterns to identify and evaluate instances of significant price instability. The insights and results articulated in the report constituted a valuable resource for researchers and policymakers examining the volatile dynamics within the Italian electricity market.

3. Data Description and Research Methodology

This study uses spot prices of electricity on a day-by-day basis from IPEX data, the Italian Power Exchange, for the period from January 1, 2020, to December 31, 2021, in a total of 731 days. This interval overlaps the timeframe of the pandemic outbreak caused by the novel COVID-19. It investigates the price of electricity during this time for the period in Italy.

This study employs three econometric techniques to achieve its objectives: the right-tailed ADF test, the SADF test, and the GSADF test. A lot of studies have used these techniques to detect bubbles in different time series data [19],[20].

3.1 Right-tailed Augmented Dickey-Fuller (ADF) Test

To test for unit roots, several unit root tests have been proposed in econometrics; nonetheless, the ADF unit root test is the most often employed test when compared to all other available tests. ADF tests the null hypothesis that a unit root process is present in a time series sample [21]. The alternative hypothesis differs by the version of the test used, but typically, it is stationarity or trend-stationarity. However, the alternate explosive hypothesis can also be used to identify explosive behavior in the time series under examination. Considering this alternative hypothesis, the following ADF model was used to develop a right-tailed ADF test, which has been published in the literature.

$$y_t = \mu + \delta_{yt-1} + \sum_{i=1}^{\rho} \emptyset_i \Delta_{yt-i} + \varepsilon_t, \text{ .... Equation 1}$$

Where yt is the variable under consideration (e.g., stock price), is an intercept, p is the maximum number of lags, φi for i = 1..., p are the differenced lag coefficients, and εt is the error term. Bubble testing (i.e., explosive behavior) is a right-tailed version of the classic ADF unit root test, with the null hypothesis being a unit root and the alternative hypothesis being a moderately explosive autoregressive coefficient. Formally, we examine for

$$H_0 : \delta = 1,$$

$$H_1 : \delta > 1.$$

3.2 Sequential Augmented Dickey-Fuller (SADF) test

The 2007-08 global financial crisis prompted questions about existing approaches to detecting bubbles. Bubbles are tough to spot. Numerous assessments have been developed in this domain, and each assessment has distinct limitations compared to others. A test called sup ADF (SADF), proposed by Phillips et al. (2011), examines the price bubble and its timing.

$$\text{SADF}(r_0) = \sup_{r_2 \in [r_0,1]} \{\text{ADF}_0^{r_2}\} \text{ .... Equation 2}$$

Phillips et al. (2015). Phillips et al. (2011), and Phillips and Yu (2011) pioneered new ways for identifying bubbles. They also assume that random walk activity does not equal explosive activity and that speculative bubbles arise and collapse. They created a unique recursive method for identifying bubbles that are considered explosive unit roots. The standard test is restricted to an autoregressive process (i.e., $\delta \leqslant 1$). The test we have used of Phillips and Yu (2011) would allow greater than unity, but still not far from unity. This enables the assessment of the recursively right-tailed unit root test to capture altogether probable bubbles. In terms of stationarity, this test is different from the left-tailed test. The SADF test, according to Hom and Breitung (2012), is a good tool for spotting bubbles [22]. The SADF test, on the other hand, has several flaws. The starting point common to the SADF test is the first observation of that test. However, if the results indicate the other scenario or if the second bubble exists but is weaker (SADF test will fail), then we get false at significance.

3.3 Generalized Sup Augmented Dickey Fuller (GSADF) test

To prevent the discovery of many bubbles, Phillips et al. (2011) extended the SADF test to a rolling-type structure, where the initial window is not defined and rolls across the sample, while the initial window size remains fixed. Phillips et al. (2015) demonstrated that the SADF and rolling SADF tests are, respectively, nested within the GSADF test. It can recognize many bubbles.

$$\text{GSADF}(r_0) = \sup_{r_2 \in [r_0,1],\ r_1 \in [0,\ r_2 - r_0]} \{\text{ADF}_{r_1}^{r_2}\} \text{ .... Equation 3}$$

In this case, $r2$ is the terminal point, and it ranges from $r0$ to one, with the lowest window size of r0. Likewise, $r1$ varies between $r2 - r0$ and 0. As a result, the GSADF statistics change between $r2 - r0$. The GSADF dispersion is dependent on the lowest window size r0 [11]. Prediction is impossible if r0 is too low; if it is too high, there is a chance of missing an early bubble. As a result, we use the following formula for r0, as proposed by Hu and Oxley (2017) and Phillips et al. (2015): r_0: $r_0 = 0.01 + \frac{1.8}{\sqrt{T}}$, with T showing the total number of values. This criterion provides enough window size, and an incorrectly selected lag order produces significant size distortion [12]. Consequently, zero lag length is selected in the analysis. The constrained values are obtained from 1000 replications of Monte Carlo simulations. Finally, following Phillips et al. (2015), we examined the explosive bubble using an econometric approach with an interception [23]. I tested several parameters of multiple regression models, including whether the model included an interception, whether there was a trend, etc., and found that when using actual data, the model with an interception term outperformed the model without an interception without an interception without an interception without an interception without an interception without an interception term [24]. In addition, following Hu and Oxley (2017), the use of intercept may create illusory (positive) bubbles where there was in fact, a "collapse" or "collapse and recovery period". Visual

Journal of Social Sciences and Economics
Vol. 3(2), 2024, 243-251
ISSN (Online) 2958-1532
https://finessepublishing.com/jsse

inspection can readily resolve this issue. This issue is being researched utilizing backward SADF statistics and a 95% confidence level.

4. Results and Discussion

Table 1 displays the descriptive statistics for electricity prices. The mean value of electricity prices is 82.10. The maximum and minimum values of electricity prices are 437.94 and 10.65, respectively. The average deviation of each value of electricity prices from its mean value is observed to be 70.76. The measurement of skewness shows that electricity prices are positively skewed. Since the p-value of the Jarque-Bera test for electricity prices is less than 0.05, this indicates that electricity prices do not follow a normal distribution.

Table 1: Descriptive Analysis of Italian Electricity Prices

	Daily Avg Price
Mean	82.10762
Median	55.51296
Maximum	437.9409
Minimum	10.65931
Std. Dev.	70.76842
Skewness	1.952036
Kurtosis	6.683521
Jarque-Bera	877.5077
Probability	0.000000
Observations	731

Table 2 explains the result of the right-tailed ADF test for electricity prices. We conclude that electricity prices do not exhibit explosive behavior since it has been established that prices are statistically insignificant at the 10%, 5%, and 1% levels of significance.

Table 2: ADF Right Tail Test Results for Italian Electricity Prices

		t-Statistic	**Prob.***
ADF		-0.931548	0.2160
Test critical values:**	99% level	0.732121	
	95% level	-0.071960	
	90% level	-0.443850	

Table 3 explains the result of the SADF test for electricity prices. It is noted that power prices are statistically significant (i.e., the null hypothesis of the unit root is rejected in favor of explosive behavior in the alternative hypothesis) as the SADF estimated value is higher than the critical value at the 1%, 5%, and 10% levels of significance. This suggests that the electricity price exhibits explosive behavior, which is identified at the end of the 2nd quarter of 2021, and it has remained with random fluctuations till the end of the 3rd quarter of 2021, as shown in Figure 1. Similarly, explosive behavior was identified from the end of the 3rd quarter of 2021 to the end of the 4th quarter of 2021.

Table 3: SADF Right Tail Test Results for Italian Electricity Prices

		t-Statistic	Prob.*
SADF		5.872676	0.0000
Test critical values:**	99% level	2.109459	
	95% level	1.561664	
	90% level	1.261901	

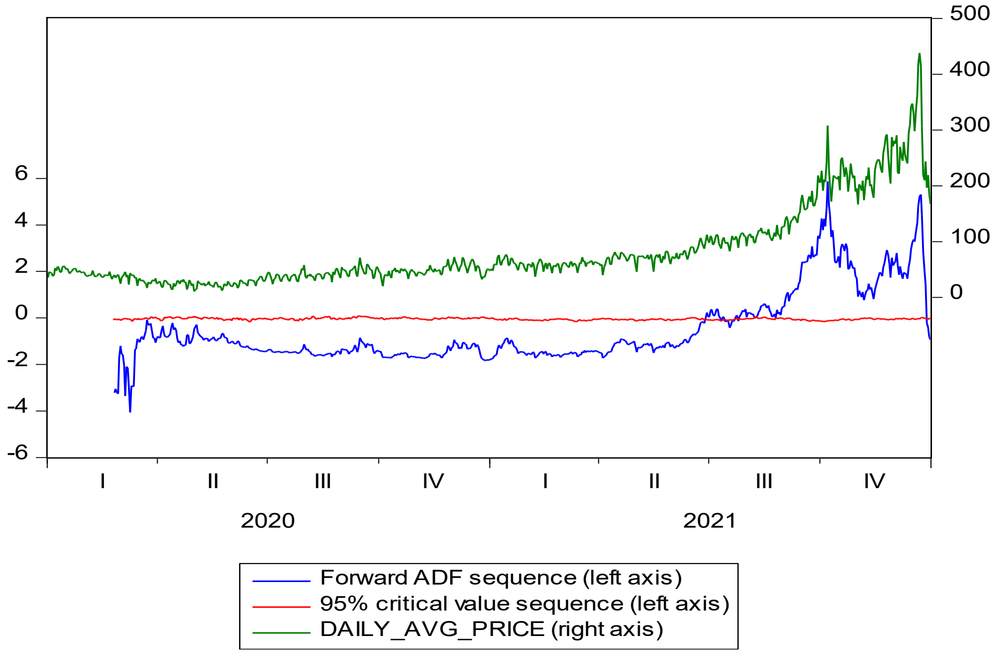

Figure 1: Bubbles Date Stamping for Italian Electricity Prices using SADF Test

Table 4 explains the results of the GSADF test for electricity prices. Electricity prices are shown to be statistically significant (i.e., the unit root null hypothesis is rejected in favor of the explosive behavior in the alternative hypothesis) since the GSADF estimated value is higher than the critical value at the 1%, 5%, and 10% level of significance. This indicates that electricity prices exhibit explosive behavior, which is detected at the end of the 2nd quarter of 2021, with random fluctuations persisting until the middle of the 3rd quarter of 2021. After that explosive behavior again occurred in the middle of the third quarter of 2021 and continued until the end of the fourth quarter of 2021, as shown in Figure 2.

Table 3: GSADF Right Tail Test Results for Italian Electricity Prices

		t-Statistic	Prob.*
GSADF		5.939799	0.0000
Test critical values:**	99% level	2.910760	
	95% level	2.296809	

Journal of Social Sciences and Economics
Vol. 3(2), 2024, 243-251
ISSN (Online) 2958-1532
https://finessepublishing.com/jsse

	90% level		2.082698	

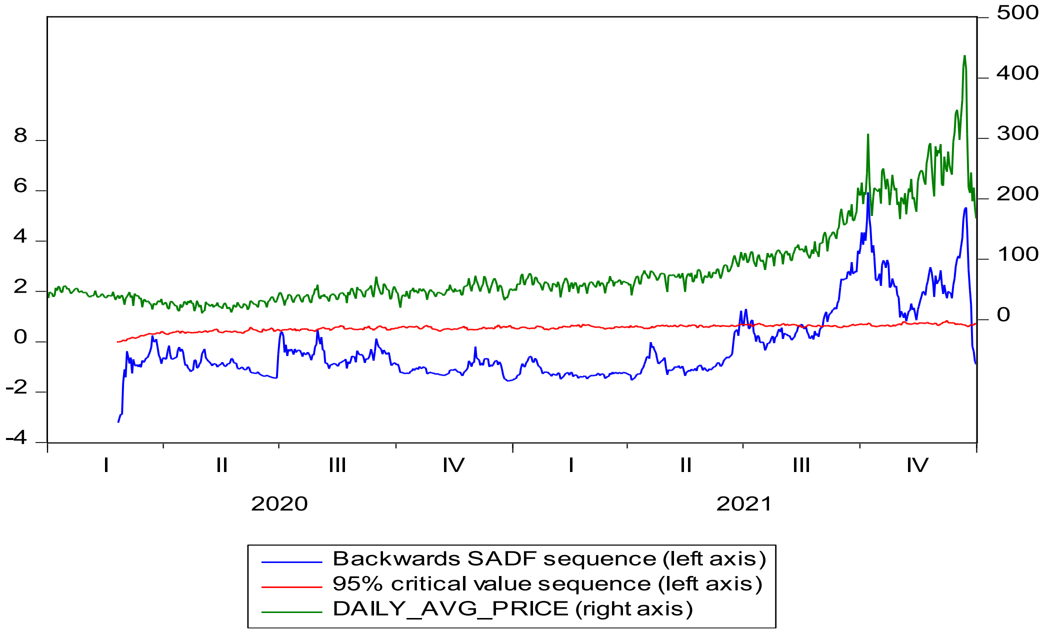

Figure 2: Bubbles Date Stamping for Italian Electricity Prices using the GSADF Test

5. Conclusion and Recommendation

Based on the results, we can draw the following conclusions regarding the behavior of electricity prices from January 2020 to December 2021, covering the period of the epidemic: The right-tail ADF test concludes that electricity prices do not exhibit an explosive nature during the period under consideration. But, as far as SADF and GSADF tests are concerned, they were consistent with explosive behavior. This explosive behavior is obtained at different intervals, for instance, from the end of the 2nd quarter of the year 2021 up to the last quarter of the 2nd quarter of the year 2021, and between the last quarter of the 3rd quarter of the year 2021 up to the end of the last quarter of the 4th quarter of the year 2021. To sum up, the ADF has the impression that electricity prices do not display a trend and thus do not exhibit an explosive pattern; however, the tests performed by SADF and GSADF reveal data that suggest periods of pronounced movements in electricity prices. These intervals are characterized by random oscillations and can be studied to determine the factors that cause explosive behavior, as well as the effective behavior pattern conducive to such behavior.

Based on the analysis of dynamics in electricity prices, a set of recommendations follows the conclusions: Considering the recognized instances of volatile behavior in electricity pricing, policymakers should explore the introduction of mechanisms aimed at stabilizing prices to mitigate the consequences for consumers. This may mean establishing price caps or ceilings during periods of significant price fluctuations, thereby ensuring that consumers are protected from jarring and prohibitive price hikes.

A mix of energy sources must be implemented to mitigate exposure to price swings. The priorities of policymakers must include the development and integration of green energy systems, such as solar, wind, and hydropower. This will help shift dependence away from fossil fuel prices, whose volatility is high, and assist in establishing a more stable and environmentally responsible energy economy. Policies appear to place less emphasis on tightening supervision and control over the electricity market to identify and curb abusive practices that are likely to contribute to price volatility. This includes measures aimed at promoting competition, regulating pricing with a fair degree of transparency, and regulating anti-competitive practices. Effective market regulation enhances competition, reduces the potential for market abuse and manipulation, and reduces the volatility of electricity prices. Another way to manage electricity demand on the supply and demand side that can assist in mitigating supply and demand mismatch outages during high volatility periods is through load shifting programs. These programs encourage consumers to adjust their energy use when prices are high or other specified conditions are met. The increased consumption tariffs encourage consumers to use electricity during off-peak periods, while the decreased unit price tariffs reduce the peak demand. Comparing contract agreements concluded by the seller and buyer regarding their scope and duration, long-term contracts can be seen as "shielding" agreements because they provide the seller or buyer with a better hedge against price fluctuations. This, along with the fact that long-term contracts become increasingly limited in number as the market liberalizes, has led to a wider use of spot market pricing. The degree to which such instruments become effectively utilized hinges on market competitiveness and effective regulation of the market itself.

Promoting the need for energy consumers to take energy-saving measures and utilize energy-efficient technologies is a sure way to sustain low energy costs. There should also be enforcement of energy-saving practices through the imposition of energy supply tariffs that encourage a reduction in electricity wastage among consumers. On the other hand, promoting energy-efficient technologies can go a long way in ensuring and stabilizing energy consumption at desired levels while keeping overall energy costs low for consumers.
Most importantly, because regional electricity markets exist, it becomes necessary for policymakers to seek collaborative efforts with countries that border their nation to efficiently handle price volatility. Furthermore, cooperating cross-border on best practices in harmony with regulations or aligning energy policies might control prices across borders and enhance regional stability. These steps lead to the creation of a sustainable energy sector, aligning with economic growth and environmental protection policies.

Funding
This research did not receive any funding.

Data availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent
Not applicable. This study uses publicly available, de-identified secondary data and does not involve human participants or personal information.

Competing interests
The authors declare no competing interests.

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