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

Shahid Akbar[a]* Maria Idrees[b], Mubasher Ali[c]

a.b.c. Department of Economics, The University of Lahore, Lahore, Pakistan (45320)

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 sup 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 peak price volatility periods 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. Introduction

This study addresses the issue of whether bubbles are present in energy prices (EPs). Bubbles occur when the price of a good exceeds its intrinsic value (Stiglitz, 1990). Conversely, bubbles explode when buyers perceive that further price increases are unlikely, as demand declines due to lower prices (Khan et al., 2021a). Similarly, price bubbles in commodities are characterized by a sudden uptick, successive ballooning, and then a swift collapse (Lind, 2009; Brunnermeier, 2016). 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 (Khan et al., 2021c). These energy bubbles are typically characterized by a cyclical pattern of growth followed by recession (Su et al., 2017). Global energy prices tend to oscillate in a cyclical pattern due to periods of growth and decline, which have significant effects on the global economy. This was particularly evident during the 2007–2009 global recession (Khan et al., 2021b; Sharma and Escobari, 2018), and commodity price bubbles were also notable during the Great Depression of 1929 (Khan et al., 2021a). According to Khan et al. (2020), volatility in EPs remains a major challenge for both exporting and importing countries. Falling EPs tend to reduce costs, which leads to wage increases for average consumers and boosts overall spending power (Sharma and Escobari, 2018). 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 negatively. 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.

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Corresponding email: shahid.akbar@econ.uol.edu.pk (Shahid Akbar)
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 saw demand decline 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. 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. 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 (Perifanis, 2019). For example, in 2006, uncertainty about the future of oil markets and new long-term projects led to 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 COVID-19, disagreements among major oil producers in the global energy market had already influenced prices. The pandemic worsened this situation, causing a 50 percent reduction in EPs in March 2020 and plunging oil prices into a crisis zone, followed by a sharp collapse in demand. The energy market made a slight recovery after restrictions were eased and production cuts were implemented by OPEC, leading to a small 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 the 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. 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 burst in conjunction with the financial crisis of 2008 (Khan et al., 2021a). Another bubble formed around 2014–2015 due to low economic growth and a shrinking supply of oil, which reduced EPs. These results are valuable for governments, investors, regulators, and economists in understanding early warning signs. 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 provides a useful contribution, and the bubble parameters identified can be further exploited to mitigate the risk of a global energy market collapse. The results also inform pre-bubble and post-bubble strategies. The occurrence of EPs at critical moments offers an opportunity for regulators and policymakers to take preemptive measures. This paper provides a test for the presence of bubbles in Italian electricity prices, compares it with traditional ADF tests, and identifies the most appropriate method for bubble detection in Italian electricity prices.

The importance of this study lies in the improvement it brings to the understanding of the dynamics of electricity price. Using various statistical tests, it provides a more in-depth study of the patterns concerning electricity prices while indicating the presence of stationery as well as explosive phases. This information can be useful for policymakers, analysts from the energy market, and investors in determining smart decisions and strategies to curb some of the risks attributed to 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. The research has revealed the importance of demand-supply imbalances, renewable energy, and regulatory changes integration in driving explosive behavior of Italian electricity prices. The results stressed that there is a need for solid policy measures to check volatility in prices 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 pointed out that it is essential to separate price dynamics from fundamental causes and speculative bubbles for both market players and policymakers. The results provided valuable insights into the mechanisms driving price bubbles and their potential consequences on market efficiency as well as consumer welfare.
Grasso et al. (2020) introduced a non-parametric approach to explosive dynamics in Italy's electricity prices. By distributing statistical tests with distribution-free methods, the authors showed large price jumps and depicted their explosive properties. Its significant aspect is that it represents important consideration of nonlinear and nonstationary of electricity pricing dynamics due to which challenges and ways to precisely detect or control explosive behavior arise in this context. The findings supplied sufficient knowledge to stakeholders, regulatory bodies, and policymakers acting within the Italian electricity sector.

The yearly publication of the Italian Electricity Market Operator, or GME, carried in-depth analysis of the Italian electricity market, emphasizing identification and analysis of the volatile behavior of electricity prices. It was a good source that discussed trends in markets, mechanisms of pricing, and changes in regulatory issues, and thus had value to extreme price swings and what caused them; therefore, it was the very resource that researchers and policymakers sought to understand and mitigate 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 report that deals with the evaluation of the Italian electricity market, with a focus on the detection and scrutiny of erratic fluctuations in electricity pricing. The assessment scrutinized market data, pricing trends, and behavioral patterns within the market to identify and assess 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 uses three econometric techniques to achieve the objectives: the Right tail ADF test, SADF test, and GSADF test. A lot of studies have used these techniques to detect bubbles in different time series data (Obstfeld and Rogoff, 1996; Engel and West, 2005; Engel, 1999; Akbar et al., 2023; Khan et al., 2023; Waheed et al., 2023; Abid et al., 2024; Hui and Yue, 2006).

3.1 Right tail 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. 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 alternate hypothesis, the following ADF model was used to develop a right tail ADF test, which was 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 interception, p is the maximum number of lags, φi for i = 1..., p are the differenced lags coefficients, and εt is the error term. Bubble testing (i.e., explosiveness behavior) is a right tail 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 detect bubbles. Bubbles are tough to spot. Numerous assessments have been formulated in this domain, and each assessment possesses distinct limits compared to others. A test called sup ADF (SADF), proposed by Phillips et al. (2011), examines the price bubble and its timing.

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

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. The SADF test, on the other hand, has several flaws. The starting point that is common for 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 discovering many bubbles, Phillips et al. (2011) extended the SADF test to a rolling-type structure where the initial window is not defined, and it rolls across the sample, while the initial window size stays fixed. Phillips and colleagues (2015) showed that the SADF and rolling SADF tests are respectively nested within the GSADF test. It can recognize many bubbles.

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

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 (Phillips et al., 2015). 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 (Phillips et al., 2015). 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. Phillips et al. (2015) 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 intercept term outperformed the model without an intercept term. 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 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 of electricity prices is less than 0.05, this shows that electricity prices do not follow the 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 tail 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 is identified at the end of the 3rd quarter of 2021 till 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	

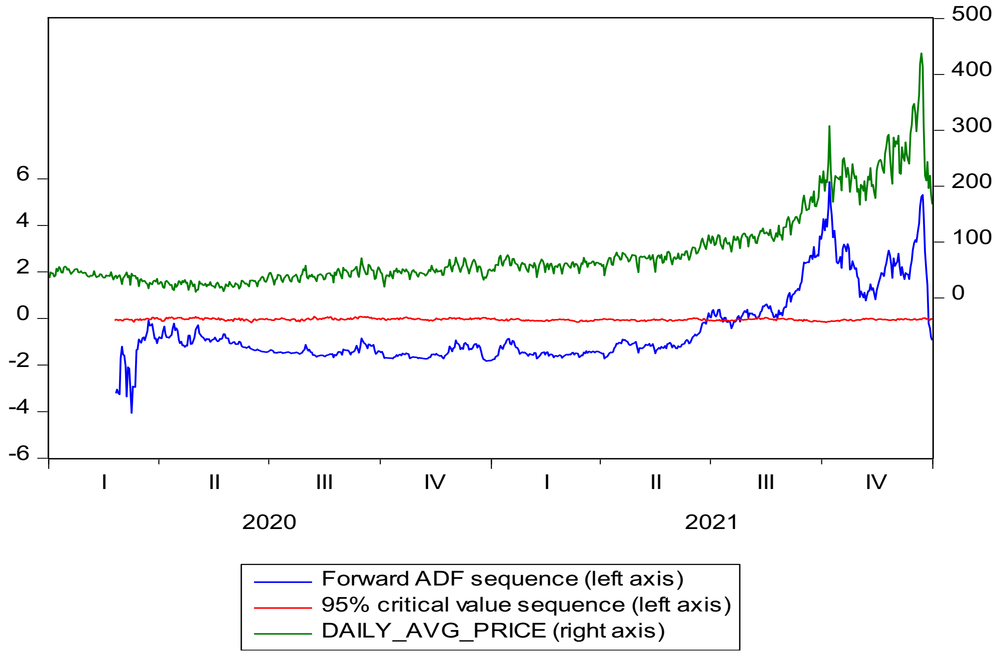

Figure 1: Bubbles Date Stamping for Italian Electricity Prices using SADF Test

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 have explosive behavior, and this explosive behavior is detected in the end of 2nd quarter of 2021 with random fluctuations till the mid of 3rd quarter of 2021, after that an explosive behavior again identified in the mid of 3rd quarter of 2021 till the end of 4th 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	
	90% level	2.082698	

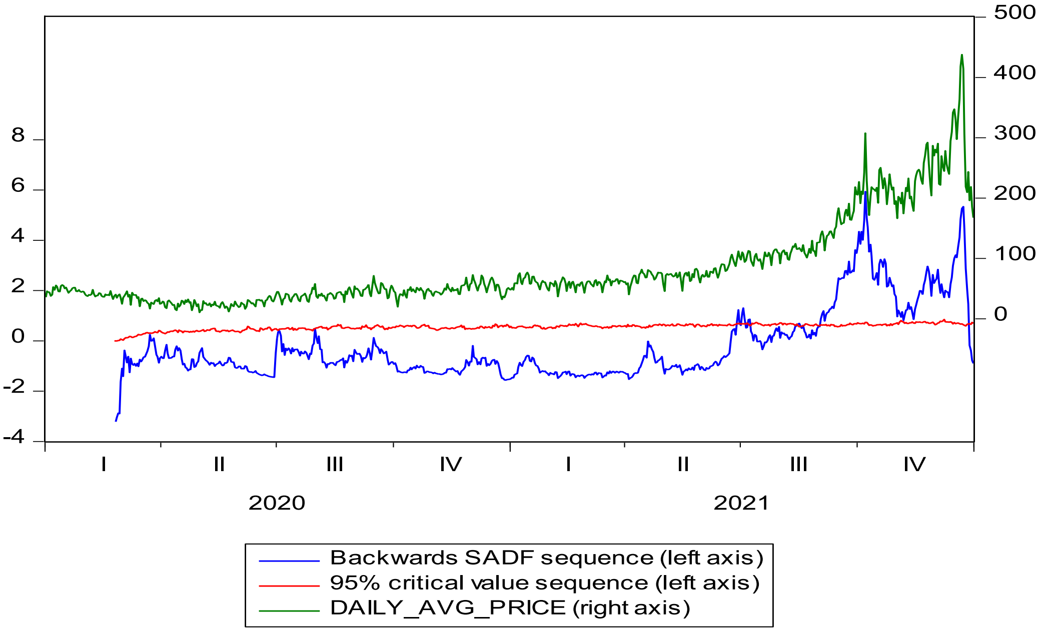

Figure 2: Bubbles Date Stamping for Italian Electricity Prices using GSADF Test

5. Conclusion and Recommendation

Based on the results, we can draw the following conclusions regarding the behavior of electricity prices dating from January 2020 to December 2021, covering the period of the epidemic: The right tail ADF test concludes that electricity prices do not have an explosive nature during the under-consideration period. 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 during 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 have no trend-reflection and thus do not display an explosive pattern, however, the tests performed by SADF and GSADF show data to consider 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 in addition to the effective behavior pattern conducive to such explosive behavior.

From the results generated by the analysis of dynamics in electricity price, a set of recommendations follows the conclusions: Considering the recognized instances of volatile behavior in electricity pricing, policymakers need to explore the introduction of mechanisms that are aimed at stabilizing prices to ameliorate 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 the policymakers must include the building and incorporation 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 the establishment of a more stable and environmentally responsible energy economy. Policies seem to put a bit less emphasis on tightening supervision and control over the electricity market to spot and curtail abusive practices likely to contribute to price volatility. This includes measures aimed at the provision of competition, the regulation of pricing with a fair degree of transparency, and the regulation of anti-competitive practices. Effective market regulation enhances competition, reduces the potential for market abuse and manipulation, and reduces the volatility of electricity prices. The other way on the electricity demand side management that can be of assistance in mitigating supply and demand mismatch outages during the high period volatilities is load shifting programs. These programs encourage consumers to modify their energy use when prices are high or other pre-specified circumstances 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 seller and buyer about their scope and duration, long-term contracts can be seen as "shielding" agreements because they provide the seller or the buyer with a better hedge against price fluctuations. This, as well as the fact that long-term contracts become limited in number as the market is liberalizing, has led to 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 means of sustaining low energy costs. There should also be enforcement of energy-saving practices through purporting energy supply tariffs that encourage a cut in electricity wastage amidst consumers. On the other hand, the promotion of energy-efficient technologies can go a long way in assuring and stabilizing energy consumption at desired levels while ensuring that the overall costs for energy consumers remain low. Most importantly, because there exist regional electricity markets, it becomes necessary for policy makers to seek collaborative effort with countries that border one's nation to handle price volatility efficiently. Furthermore, cooperating cross-border on best practices in harmony with regulation or alignment of energy policies might control prices across borders and enhance regional stability. These steps lead to the creation of a sustainable energy sector, which is in line with economic growth and environmental protection policies.

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