İSTANBUL UNIVERSITY PRESS

Istanbul Business Research,
IBR 2025, 54 (3): 332–349

https://doi.org/10.26650/ibr.2025.54.1375735

Submitted: 16.10.2023
Revision Requested: 14.09.2024
Last Revision Received: 30.06.2025
Accepted: 14.08.2025
Published Online 27.10.2025

Istanbul Business Research

Research Article

Open Access

Empirical investigation of market efficiency in the Borsa İstanbul electricity, gas, and water sector

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Abstract Exploring the efficiency of financial markets has remained a prominent area of interest for researchers and market participants. However, the debate on market efficiency continues, with studies examining different sectors and markets to assess the reliability of the efficient market hypothesis. This study investigates the weak-form efficiency of the Borsa Istanbul Electricity, Gas, and Water (EGW) sector by applying structural break unit root tests. Monthly stock price data for 19 publicly traded EGW companies and the BIST Electricity Index (XELKT), from their initial listing dates through May 2023, are analyzed using the Lee-Strazicich unit root tests with one and two structural breaks. Additionally, the Karavias and Tzavalis (2014) panel unit root test is employed to assess sector-wide price behavior while accounting for structural breaks and cross-sectional dependence. The findings reveal that most stock price series are stationary with structural breaks, indicating deviations from a random walk and thus rejecting the weak-form efficient market hypothesis for the sector. Structural breaks are primarily observed during major economic and geopolitical events, such as the coronavirus disease 2019 (COVID-19) pandemic and the Russia–Ukraine war. This study contributes to the literature by addressing a gap in market efficiency research through the application of structural break unit root tests in a sector-specific context.

Keywords Efficient market hypothesis · BIST · Energy companies · Electricity gas and water sector

Citation: Beyazgül, M., İskenderoğlu, Ö. & Karadeniz, E. (2025). Empirical investigation of market efficiency in the Borsa İstanbul electricity, gas, and water sector. *Istanbul Business Research*, 54(3), 332-349. https://doi.org/10.26650/ibr.2025.54.1375735

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1. Introduction

The efficient market hypothesis (EMH), introduced through Fama's influential 1970 work on Efficient Capital Markets, has remained a cornerstone of financial economics in explaining market behavior. Fama (1970) characterized an efficient market as one in which investors cannot reliably forecast stock returns and where prices swiftly assimilate all readily accessible market information. In line with this definition that stock prices in capital markets accurately reflect the available information, no investor can obtain abnormal returns by analyzing the information about stocks.

An efficient market ensures that the value of a company's shares reflects all information readily available to all capital market participants. Consequently, no opportune or inopportune moment exists for a firm to issue securities. In the event a company chooses to release stocks, it will obtain exactly their intrinsic value neither more nor less (Fabozzi & Peterson, 2003). Efficient market theory generally measures the efficiency of a market in three degrees: strong, semi-strong, and weakly efficient (Brigham & Gapenski, 2001, p. 249). According to the strong form of EMH, all public and private information is reflected in stock prices. This implies that the market, which encompasses all investors, has full awareness of every security, including non-public details. As a result, the strong form suggests that earning abnormal returns through trading on insider knowledge, which refers to unreleased information, is not feasible (Fabozzi & Peterson, 2003). The fact that even inside information is reflected in stock prices means that inside information cannot be used to gain an advantage over other investors.

The semi-strong market efficiency hypothesis suggests that all publicly disclosed information, such as earnings reports and news updates, is already embedded in the price of securities. When new information about the company is revealed in a market where this hypothesis is valid, the stock prices of the company will immediately and objectively change to reflect this information. As a result, trading based on public information should not enable investors to earn abnormal profits, as prices adjust rapidly to incorporate new information (Ogden, Jen, & O'Connor, 2003, p. 274). In the weak form of EMH, the current prices of securities fully incorporate all historical price data and price movements. This implies that all relevant information from previous stock prices has already been factored into today's price, rendering it impossible for investors to use past price trends to predict future prices and consistently achieve abnormal profits (Fabozzi & Peterson, 2003). What is important is that this information is easily available to everyone and can be analyzed by methods known to everyone. In markets with weak form of EMH, investors who use this information are not likely to gain more than others (Ross, Westerfield, & Jaffe, 1999, p. 337).

The weak form of EMH is assessed through examination of the random walk hypothesis, which posits that price fluctuations occur in a random and unforeseeable manner. According to the random walk hypothesis, stock price changes have no relationship with past price changes (Karan, 2018, p. 278). The random walk theory posits that time series values exhibit randomness in their movements, unpredictably changing direction at any time, and showing no reliance on past data patterns. In econometrics, the random walk theory is commonly tested with unit root tests. Unit root tests (URT), also known as stationarity tests, offer insights into the likelihood of a time series reverting to its mean values when subjected to a specific shock, a phenomenon referred to as mean reversion. In this respect, URT is frequently used, especially in the analysis of markets with weak form of EMH and in the analysis of assumptions that price movements will move like their past averages (Oğuz, 2021, p. 108). While some empirical literature on EMH includes studies showing that markets are efficient in weak form of EMH (Hudson, Dempsey & Keasey, 1996; Omran &

Farrar, 2006), some studies also prove that markets with investor behaviors such as overreaction (De Bondt & Thaler, 1985) and overconfidence (Camerer & Lovallo, 1999) cannot be efficient. On the other hand, Lo and Andrew (2004) proposed 'Adaptive Market Hypothesis' which recognizes that financial markets are not solely characterized by either complete efficiency or irrationality. The adaptive market hypothesis suggests that market efficiency is dynamic rather than static and is shaped by evolving market conditions and the adaptive nature of human decision-making. Hence, the efficiency of financial markets may exhibit periodic variations, alternating between states of efficiency and inefficiency, contingent upon the attributes and proclivities of market participants.

A structural break is a significant change in stock price behavior characterized by a sudden and significant departure from established trends or patterns (Hamilton, 2020). Structural break tests are used to examine stock price breaks to uncover the underlying causes of these breaks and to understand how these breaks affect the overall stability and efficiency of financial markets in weak form of EMH (or random-walk theory) (Timmermann, 2001). Macroeconomic events, such as financial crises, policy changes, geopolitical risks, and technological developments, can often cause sudden changes in market sentiment and investor behavior (Alam, 2013; Huang, Chan, Huang, & Chang, 2011). In addition, company-specific factors, such as mergers and acquisitions, dividend distributions, and capital structure changes, can also lead to significant changes in stock prices (Jennings & Starks, 1986; Kandir, 2008). Structural breaks in stock prices traded on stock exchanges due to short-term shocks pose a risk to investors and analysts. Therefore, considering structural breaks in understanding financial markets has recently become an important phenomenon in terms of understanding changing market conditions and taking the right investment position.

According to the Energy Market Regulatory Authority (EMRA) January 2023 report, there are 1890 licensed Electricity, Gas, and Water (EGW) companies in Türkiye (EMRA, 2023). Over the past few years, there has been a notable surge in the quantity of EGW companies listed on the Borsa Istanbul (BIST). The count of EGW companies traded on BIST, including oil, natural gas, renewable energy, and distribution, increased from 5 in 2003 to 29 in September 2023. In parallel, the BIST Electricity Index (XELKT) increased by more than 6.5 times between the end of 2019 and June 2023, after remaining at similar levels for 10 years between 2009 and 2019 (BIST, 2023). Increasing renewable energy investments and macroeconomic factors are thought to be effective in the rapid and large changes in the value of the XELKT, which consists of publicly traded companies operating in the EGW sector, in recent years. Investors may make erroneous predictions when the impact of external shocks is not considered in the evaluation of stock prices. Therefore, it is important to examine how external factors affect the stock prices of energy companies in BIST, in other words, whether the prices show breaks such as sudden falls or rises. At the same time, predicting breakout dates is useful for investors, policy makers, and the industry to make important inferences. The purpose of this research is to demonstrate the efficiency of the BIST EGW sector by analyzing the stock prices of companies with structural break URT. For this purpose, the monthly stock prices of 19 out of 29 companies in the BIST EGW sector and XELKT were calculated. The analysis spans the period from the inception of these companies' public offerings to May 2023. To assess the stationarity of these stock prices, both one- and two-structural-break URTs, as proposed by Lee-Strazicich (2013) and Lee-Strazicich (2003), are applied. In addition, the panel URT with structural breaks developed by Karavias and Tzavalis (2014) was applied to determine the degree to which the findings pertaining to company stock prices are indicative of the entire BIST EGW sector. The efficiency of the BIST EGW sector is interpreted with the findings of URT with structural breaks in companies' stock prices.

In the study, first, general information about the EGW sector is given, and the importance of the study in terms of literature is explained. In the second section, information about the studies on the subject is presented. The third section of the study provides specific information regarding the sample and the investigation methods. The study's analysis outputs are presented in the fourth section, where the study's findings are presented. Finally, the conclusion section is the fifth part of the study, which discusses the findings and makes recommendations.

2. Literature review

Structural breaks pertain to substantial alterations in a time series' underlying structure or patterns. In the context of stock prices, structural breaks can occur due to a variety of factors such as economic shocks, policy changes, financial crises, or technological developments. Detecting these structural breaks is crucial for investors, policymakers, and researchers to understand market dynamics and provide insights for risk management and forecast accuracy. This study was organized based on the sub-disciplines as they have emerged in the literature.

The development of methodologies that consider breaks in time series in financial data dates to the early 90s. Perron (1989) suggested analyzing the series by identifying and excluding structural break points. He identified the 1973 oil crisis as an exogenous break and showed that the series can be estimated as trend stationary in the economy. Zivot and Andrews (1992) argued that Perron (1989)'s assumption of exogenous events may not be appropriate and introduced a variation that predicts the break instead of correcting the break point in the Perron test (Zivot & Andrews, 1992). In the following years, studies considering more than one break have been developed to estimate structural breaks more accurately. Lee and Strazicich (2003) developed a methodology to estimate two structural breaks, while Bai and Perron (2003) addressed the issue of testing and estimating multiple structural breaks on data and errors under general conditions.

URT with structural breaks has become applicable, and these methods have been used in many fields. Many of these studies have statistically analyzed the impact of financial crises, economic policy changes, and macroeconomic factors on stocks. Timmermann (2001), to reveal the volatility and the existence of structural breaks in the stock returns of the S&P 500 in the US for the years 1871-1999, determined that the episodes characterized by heightened volatility differ from the periods marked by structural breaks in the series. In the study, the time difference between high volatility and breaks is explained by the fact that investors do not have complete information. Narayan and Smyth (2007) tested the random walk hypothesis by analyzing the stock prices of G7 countries in the 1960-2003 period with URT with structural breaks. Because of the study, the stock indices of the G7 countries do not have stationarity even if one or two structural breaks are allowed. In addition, the study concludes that the second break in stock prices has a negative impact on stock price movements in G7 countries and that the random walk hypothesis is more valid in Japan than in other countries. In a similar study by Lee, Lee, and Lee (2010) examined whether the EMH remains applicable to stock markets situated at varying stages of economic development. In the study, which covers the period from January 1999 to May 2007 and analyzes the countries with panel URT, it is found that both groups of 32 developed and 26 developing countries have stationarity with structural breaks and the EMH is not valid. Aktan, Iren, and Omay (2018) tested the weak form market efficiency of 32 European stock markets using nonlinear panel root tests. They revealed a significant link between economic development levels and market efficiency and highlighted the limitations of linear models in accurately assessing stock market efficiency. In another study Erdaş (2019) examined the weak-form market efficiency

of stock markets in 11 Central and Eastern European countries using both linear and nonlinear URT and found that all selected markets are non-stationary and support the random walk hypothesis, implying that investors cannot achieve abnormal returns by analyzing historical prices, with implications for capital allocation and stock price predictability in these markets. Gazel (2020) examined the weak form efficiency of exchange-traded funds in developed and emerging markets by comparing them with the different types of URT. The Fourier test results strongly support efficient market efficiency. This suggests that developed markets exhibit higher levels of efficiency. In addition, examining corporate stocks with structural break URT, Chipunza, Muguto, Muguto, and Muzindutsi (2020) analyzed the stock returns and firm valuation ratios of publicly traded companies in South Africa. In the study, the structural breaks of stock returns, dividends, and price/earnings ratios for the period 1996:01 - 2018:12 were determined by the Zivot and Andrews (1992) test, and it was found that the series are stationary with structural breaks, but the stationarity is at different lags. In another study Açıkalın and Sakınç (2022) analyzed the daily returns of the seven cryptocurrencies with the highest trading volume between 2018 and 2021 and revealed that the cryptocurrency market is not a weak form efficient market. The results of the normality, URT, run, and variance ratio tests demonstrated that the cryptocurrency market does not conform to the weak form efficiency model. Ighoroje and Emmanue (2022), examined the weak form efficiency of the Nigerian stock market from 1990 to 2019, finding it highly risky and inefficient for most periods except between 2016 and 2019, when it followed a random walk, and concluding that improved information security for stock valuation is essential.

Examining the existing literature on this subject in the context of Türkiye reveals the scarcity of studies using URT with structural breaks. In a pioneering study by Kıyılar (1998), examining EMH, the relationships between daily prices and some publicly disclosed information of 45 companies listed on BIST for the period January 1, 1988 - December 31, 1994, were examined using autocorrelation and run tests. In the study, it was found that the weak form of EMH is valid in BIST. However, Çevik and Erdoğan (2009) analyzed the stock market in the banking sector with structural breaks and found that all companies in the Turkish banking sector between 2003 and 2007 were stationary with structural breaks and that the banking sector was not efficient for the weak form of EMH. In another study, Aksoy and Karatepe (2014) analyzed the prices of sector indices in BIST for the period between January 1997 and July 2012 with the Zivot and Andrews (1992) test. As a result of the study, it was found that there is stationarity with structural breaks in all sectors tested. In their research, Tuna and Öztürk (2016) conducted an examination encompassing the BIST 100 Index, along with several sub-indices in BIST. The study employed the Lumsdaine-Papell (1997) URT and Carrion-i Silvestre (2009) URT to analyze the data spanning from January 2003 to September 2015 within these sectors. In the study, only the BIST Industrial Index shows stationarity with structural breaks based on the two-break LP URT, but all other indices contain URT, and the markets can be considered efficient. In another study, Alp and Seven (2019) analyzed the efficiency of the Turkish housing market using traditional URT and URT with structural break. In the study covering the 2010-2018 period of the housing price index series in Türkiye, the housing market was found to be efficient for the weak form of EMH. Similarly, Eyüboğlu and Eyüboğlu (2020) examined the weak form of EMH of 22 sub-sectors in BIST using monthly price index data and Fourier URT applied to these indices. According to the study's findings, 13 of the indices in BIST exhibit efficiency, while 9 of the indices do not exhibit efficiency. Another study assessing the weak-form efficiency of Borsa Istanbul banking sector stocks, Hailu and Vural (2020), used autocorrelation, runs test, and URT (ADF, PP, and KPSS) on weekly adjusted closing prices from 2010 to 2019, found different results across methods, with some stocks showing efficiency but overall inefficiency in the sector, indicating the potential for abnormal returns based on historical prices. Camgöz (2022) analyzed dividend-paying stocks in the BIST 100 index from

December 2011 to November 2021 and found structural break stationarity for most companies, with a few notable exceptions. In their 2023 study, Erer, Erer, and Güngör analyzed the dynamic efficiency of Türkiye's main stock market index and various sectoral indices during two major economic disruptions: the COVID-19 pandemic and the global financial crisis. Using the adaptive market hypothesis as a theoretical framework, the study highlighted a notable increase in sectoral persistence during the COVID-19 period compared to the global financial crisis. The real estate and information technology sectors consistently emerged as the least efficient sectors in both crises, further supporting the adaptive market hypothesis's assertion of fluctuating market efficiency. Finally, Sakalsız Aydıngülü and Arık (2023) assessed the price efficiency of companies included in the BIST Sustainability Index. The study scrutinized data from 32 companies that were part of the BIST Sustainability Index, spanning the years 2018 to 2020, employing a URT method with structural break analysis. As a result of the study, it was revealed that the companies in the BIST Sustainability Index are generally efficient in the weak form of EMH, but the series of AYGAZ, Turkish Airlines, and Türk Telekom are stationary with structural breaks.

Within the empirical literature, there exists a noticeable absence of studies that examine the efficiency of the market within the context of the EMH regarding the BIST EGW sector. This article serves as a significant contribution to addressing the existing void within the literature pertaining to BIST stock indices, as it assesses the efficiency of the BIST EGW sector while employing a more versatile array of statistical methodologies.

3. Data and methodology

While numerous methodologies are considered in empirical studies investigating EMH in the stock market, this study uses URT. Table 1 lists the companies analyzed in this study.

Table 1

BIST EGW Companies in the Analysis Scope

Code	Company Title	Date of First Transaction	Data Range
AKSUE	AKSU ENERJİ VE TİCARET A.Ş.	04.01.2000	2000/02, 2023/05
ZOREN	ZORLU ENERJİ ELEKTRİK ÜRETİM A.Ş.	25.05.2000	2000/06, 2023/05
AYEN	AYEN ENERJİ A.Ş.	05.07.2000	2000/08, 2023/05
AKENR	AKENERJİ ELEKTRİK ÜRETİM A.Ş.	07.07.2000	2000/08, 2023/05
AKSEN	AKSA ENERJİ ÜRETİM A.Ş.	21.05.2010	2010/06, 2023/05
ZEDUR	ZEDUR ENERJİ ELEKTRİK ÜRETİM A.Ş.	24.02.2011	2011/04, 2023/05
ODAS	ODAŞ ELEKTRİK ÜRETİM SANAYİ TİCARET A.Ş.	21.05.2013	2013/06, 2023/05
PAMEL	PAMEL YENİLENEBİLİR ELEKTRİK ÜRETİM A.Ş.	13.06.2014	2014/07, 2023/05
ENJSA	ENERJİSA ENERJİ A.Ş.	08.02.2018	2018/03, 2023/05
NATEN	NATUREL YENİLENEBİLİR ENERJİ TİCARET A.Ş.	08.08.2019	2019/09, 2023/05
ESEN	ESENBOĞA ELEKTRİK ÜRETİM A.Ş.	02.10.2020	2020/11, 2023/05
NTGAZ	NATURELGAZ SANAYİ VE TİCARET A.Ş.	28.03.2021	2021/05, 2023/05
GWIND	GALATA WIND ENERJİ A.Ş.	16.04.2021	2021/05, 2023/05
BIOEN	BİOTREND ÇEVRE VE ENERJİ YATIRIMLARI A.Ş.	28.04.2021	2021/05, 2023/05
AYDEM	AYDEM YENİLENEBİLİR ENERJİ A.Ş.	29.04.2021	2021/05, 2023/05

Code	Company Title	Date of First Transaction	Data Range
CANTE	ÇAN2 TERMİK A.Ş.	30.04.2021	2021/05, 2023/05
KARYE	KARTAL YENİLENEBİLİR ENERJİ ÜRETİM A.Ş.	09.07.2021	2021/08, 2023/05
MAGEN	MARGÜN ENERJİ ÜRETİM SANAYİ VE TİCARET A.Ş.	22.09.2021	2021/10, 2023/05
ARASE	DOĞU ARAS ENERJİ YATIRIMLARI A.Ş.	11.11.2021	2021/12, 2023/05
HUNER	HUN YENİLENEBİLİR ENERJİ ÜRETİM A.Ş.*	21.02.2022	-
SMRTG	SMART GÜNEŞ ENERJİSİ TEKNOLOJİLERİ ARAŞTIRMA GELİŞTİRME ÜRETİM SANAYİ VE TİCARET A.Ş.*	24.03.2022	-
CONSE	CONSUS ENERJİ İŞLETMECİLİĞİ VE HİZMETLERİ A.Ş.*	20.04.2022	-
ALFAS	ALFA SOLAR ENERJİ SANAYİ VE TİCARET A.Ş.*	16.11.2022	-
AHGAZ	AHLATCI DOĞAL GAZ DAĞITIM ENERJİ VE YATIRIM A.Ş.*	22.12.2022	-
AKFYE	AKFEN YENİLENEBİLİR ENERJİ A.Ş.*	16.03.2023	-
CWENE	CW ENERJİ MÜHENDİSLİK TİCARET VE SANAYİ A.Ş.*	05.05.2023	-
IZENR	İZDEMİR ENERJİ ELEKTRİK ÜRETİM A.Ş.*	16.08.2023	-
TATEN	TATLIPINAR ENERJİ ÜRETİM A.Ş.*	17.08.2023	-
ENERY	ENERYA ENERJİ A.Ş.*	23.08.2023	-
XELKT	BIST Electric (29 companies)	-	2001/01, 2023/05

*Related companies could not be included in the analysis because they have limited data regarding their BIST listing dates.

Publicly traded companies in Türkiye engaged in energy production and distribution are listed on the Public Disclosure Platform website under the sector name "Electricity, Gas, and Water" (KAP, 2023). The 29 companies in this list are also included in the XELKT. The companies' data are obtained monthly from the Finnet database (Finnet, 2023). Of the 29 publicly traded companies in the EGW sector, 19 with sufficient data for the analysis were included in the study. Of the 29 companies listed in the EGW sector, 10 were excluded due to factors such as limited trading history, low liquidity, or incomplete data availability, which could compromise the robustness and comparability of the time series analysis. In the study, the data of the XELKT for the periods 2001:01 and 2023:05 are also compiled for analysis to provide information about the general outlook of the sector.

Structural break tests are used to statistically determine whether significant changes occur in the average of a time series. In the analysis process, to reveal the stock price sustainability of the energy companies in BIST, structural break URT were applied to the stock prices of the companies in the past period. Effective and permanent changes in the trend are called structural breaks when analyzing a time series. If there is a permanent effect on the increase or decrease in the trend of the series, the presence of a structural break is examined. Depending on the duration of the analyzed process and the series, one or more structural breaks may have occurred (Güriş, Akay, & Güriş, 2017). Detecting structural breaks in companies' stock price data can provide insight into shocks or events that affect their performance (Aue, Rice, & Sönmez, 2020). In this study, publicly traded companies in the EGW sector are first analyzed separately with Lee-Strazicich (2013) URT with one structural break and Lee-Strazicich (2003) URT with two structural breaks. Then, the monthly stock prices of all companies are analyzed as a whole, and the data are reduced to a common period and panel data are created between December 2021 and May 2023. The application of the panel URT incorporating structural breaks, formulated by Karavias and Tzavalis (2014), was applied to the panel data. The time series for individual stock analyses varies due to differences in listing dates and data availability across companies

in the BIST EGW sector. To ensure statistical comparability and avoid missing data problems in the panel framework, the panel analysis was restricted to the common available period between December 2021 and May 2023.

Lee-Strazicich (2013)'s URT with structural break suggests that if the null hypothesis is rejected, the unit root need not be rejected; only the unit root without structural break should be rejected. The model with one structural break is constructed by equations (1).

$$y_t = \delta Z_t + X_t \qquad X_t = \beta X_{t-1} + \epsilon_t \tag{1}$$

In the model, Z_t denotes exogenous variables and the null hypothesis is formed as β = 1. "Model A" is defined as "Z_t = [1, t D_t]" with "D_t = 1" for "$t \geq T_B$ + 1" and "Dt = 0" for the others. The structural break period is denoted by "T_B "and "$\delta = (\delta_1, \delta_2, \delta_3)$". The test that allows a break in level and trend is "Model C". "Model C" is defined as "Z_t = [1, t D_t, DT_t]" with "$D_t = t - T_B$" for "$t \geq T_B$ + 1", and "D_t= 0" shadow variable in other cases.

The URT with structural break is estimated using the regression model (2).

$$\Delta y_t = \delta' \Delta Z_t + \phi \tilde{S}_{t-1} + u_t \tag{2}$$

In model (2) $\tilde{S}_t = y_t - \tilde{\psi} x - Z_t \delta^{(}), \ t = 2, ...T; \tilde{\delta}$ refers to the coefficients obtained from the regression of "Δy_t" on "ΔZ_t" , "$\tilde{\psi} x$" obtained by "$y_1 - Z_1 \tilde{\delta}$". The null hypothesis of the unit root is set as "$\phi = 0$". Model (3) shows the null hypothesis.

$$\tilde{r} = \text{statistic testing the null hypothesis}, \phi = 0. \tag{3}$$

The structural break date is determined by selecting the one with the smallest value of all possible breaks. Model (4) is used to estimate the break.

$$\text{price}\, \tilde{r}(\tilde{\lambda}) = \text{price}\, \tilde{r}(\lambda), \ \ where\, \lambda = TB/T \, and \, \lambda \in [0, 1]. \tag{4}$$

Lee-Strazicich (2003) employed the URT with two structural breaks. Within these models, "Model A" and "Model C" were defined, where "Model A" signifies two breaks in level, while "Model C" represents two breaks in both level and trend. "Model A" is designed to accommodate two shifts in level and can be defined as "Z_t = [1, t, D_{1t}, D_{2t}]$'$ ". Here "D_{jt}=1" when "$t \geq T_{Bj}$ +1", "j=1,2, and 0" otherwise. In this context, "T_{Bj}" represents period of time at which a break occurs. On the other hand, "Model C" involves alterations in both level and trend and can be expressed as"Z_t = [1, t, D_{1t} , D_{2t} , DT_{1t} , DT_{2t}]$'$ ", where "DT_{jt} = t-T_{Bj}" for "$t \geq T_{Bj}$+1" , "j=1,2, and 0" otherwise.

The URT statistic model with two breaks is shown below with number (5).

$$\Delta y_t = \delta' \Delta Z_t + \phi \tilde{S}_{t-1} + u_t \tag{5}$$

Within this framework, where $\tilde{S}_t = y_t - \tilde{\psi} x - Z_t \delta^{(}), \ t = 2, ...T, \text{with} \ \ \tilde{\delta}$ representing coefficients in the regression of "Δy_t" on "ΔZ_t"; and "$\tilde{\psi} x$" calculated as "$y_1 - Z_1 \tilde{\delta}$"; where "y_1" and "Z_1" correspond to the initial observations of "y_t" and "Z_t", respectively. The null hypothesis for a unit root is defined as "$\phi = 0$" and the LM URT statistic is computed as follows:

$$\tilde{p} = \text{T} \ \phi, \tag{6}$$

$$\tilde{\tau} = t - \text{statistic examine the null hypothesis} \ \phi = 0 \tag{7}$$

The test statistic provides insight into whether the null hypothesis, positing the existence of a unit root within the series along with a structural break, is confirmed or contradicted. If the test statistic exceeds the threshold values specified in the tables by Lee-Strazicich (2003), the null hypothesis is rejected.

The advantage of the Lee-Strazicich tests is their ability to incorporate structural breaks without being affected by them under the null hypothesis, unlike ADF-type endogenous break URT, which can suffer from size distortions. This robustness makes the Lee-Strazicich tests more reliable when analyzing time series data with potential structural breaks, reducing the risk of spurious rejections and leading to more accurate conclusions about whether a series is trend stationary or non-stationary. Therefore, the Lee-Strazicich tests are preferred for ensuring that structural breaks are properly accounted for in URT.

The study also applies the panel URT with structural breaks to the stock prices of BIST EGW companies. Given that the panel time series dataset encompasses a restricted timeframe and a limited pool of companies, it is more advantageous to employ the versatile URT method introduced by Karavias and Tzavalis (2014) when conducting panel URT with structural breaks. These models offer the capability to identify either one or two structural breaks while assessing the unit root. This test also able to use when the dates of these structural breaks are either known or unknown. On the other hand, the models allow for horizontal cross-sectional dependence and varying variance. These tests can be applied when the time dimension is both small and large. The bootstrap method is employed to compute the critical values and p-values for the test in instances where the dates of structural breaks are unknown. These critical values and p-values were determined through 100 iterations of the bootstrap procedure. This approach is applicable even in cases where the errors do not follow a normal distribution. Furthermore, these tests possess the capability to detect deviations from the null hypothesis, regardless of whether the underlying alternatives are characterized by uniformity or diversity in their properties (Chen, Karavias, & Tzavalis, 2022; Hao, Wang, Yan, Irfan, & Chang, 2023). Every series in the panel is assumed to have unit roots under the null hypothesis. The alternative hypothesis, however, proposes that some or all series are stationary, with structural changes in their deterministic elements, including constant and trend components. When structural shocks exist, the standard panel URT may become unreliable. Therefore, the Karavias and Tzavalis (2014) panel URT which accounts for both structural breaks and cross-sectional dependence, was preferred.

In panel data studies, various URT generations can be applied. Each URT has its own advantages and disadvantages compared to others. In this study, both the Lee-Strazicich and Karavias and Tzavalis URT were conducted to implement a comprehensive and complementary process. Apart from these methods, Zivot-Andrews, Perron, Lumsdaine-Papell, Carrion-i Silvestre, and Fourier URT methods can also be considered for examining the subject. However, this would deviate from the study's objective and lead to an undesirable situation of comparing methodologies. Therefore, the inclusiveness of the Lee-Strazicich and Karavias and Tzavalis URT has been trusted in this study.

4. Findings

This section presents descriptive statistics findings for the stock prices of companies in the BIST EGW sector and the XELKT. These findings are presented in Table 2.

Table 2
Descriptive Statistics for the Study

Companies	Mean	Median	Maximum	Minimum	Std. Dev.	Number of Observations
AKENR	0.087	0.045	0.747	−0.326	0.202	274
AKSEN	0.673	0.575	1.695	0.330	0.323	156
AKSUE	0.224	0.102	1.694	−0.495	0.513	280
ARASE	1.497	1.474	1.786	1329	0.153	18
AYDEM	1.012	0.963	1.423	0.774	0.191	25
AYEN	0.164	0.083	1.657	−0.604	0.466	274
BIOEN	0.960	0.940	1.278	0.678	0.193	25
CANTE	1.131	1.777	1.759	0.539	0.406	25
ENJSA	0.957	0.919	1.557	0.573	0.275	63
ESEN	1.572	1.525	1.920	1.228	0.164	31
GWIND	0.924	0.844	1.390	0.488	0.294	25
MAGEN	1.045	0.947	1.569	0.726	0.290	20
NTGAZ	1.071	0.874	1.654	0.743	0.314	25
NATEN	1.620	1580	2.300	0.817	0.352	45
ODAS	0.252	0.185	1.051	−0.222	0.275	120
PAMEL	0.645	0.158	2.538	−0.337	0.866	107
ZEDUR	0.609	0.514	1.819	0.013	0.478	146
ZOREN	0.080	0.085	0.897	−0.503	0.209	276
XELKT	1.520	1.442	2.671	1.051	0.288	269

Table 2 shows that NATEN has the highest average price for the years analyzed, while ESEN and ARASE also have higher averages than the others. ZOREN has the lowest average price among the EGW companies analyzed. In addition, PAMEL has reached the highest price level in the analyzed years, but the standard deviation of the same company is also high. Therefore, the stock price of PAMEL shows higher volatility than the others. In addition, the average of the XELKT values is generally higher than the average of the companies, but its standard deviation is close to that of the companies.

In accordance with the study, the stock price series of the EGW companies in the BIST are first subjected to the Lee-Strazicich (2013) URT with a single structural break. URT with a single structural break is applied with “Model A”, which considers only structural breaks in the level, and “Model C”, which considers structural breaks in both the level and trend. Table 3 presents the results of “Model A” and “Model C” in one-break URT.

Table 3
Lee-Strazicich (2013) Unit Root Test Results with One Structural Break

Code	Model A					Model C				
	Min. t-statistic	k	%1	%5	K	Min. t-statistic	k	%1	%5	K
AKENR	−2.03	0	−3.85	−3.28	2002:10	−2.87	5	−4.54	−3.99	2017:12
AKSEN	−2.10	6	−4.02	−3.42	2020:12	−4.57[b]	6	−4.69	−4.14	2020:02
AKSUE	−3.04	2	−3.85	−3.29	2006:05	−4.00[b]	2	−4.53	−3.98	2018:03

Code	Model A					Model C				
	Min. t-statistic	k	%1	%5	K	Min. t-statistic	k	%1	%5	K
ARASE	−3.49[b]	2	−4.08	−3.49	2023:02	−5.11[a]	2	−4.83	−4.27	2022:07
AYDEM	−2.72	7	−4.08	−3.49	2022:11	−5.53[a]	7	−4.91	−4.35	2022:09
AYEN	−3.66[b]	8	−3.85	−3.28	2020:05	−4.62[a]	8	−4.49	−3.95	2020:01
CANTE	−3.56[b]	8	−4.08	−3.49	2022:06	−4.94[a]	2	−4.91	−4.35	2022:06
BIOEN	−5.51[a]	8	−4.08	−3.49	2022:05	−6.62[a]	4	−4.91	−4.35	2022:09
ENJSA	−2.64	2	−4.08	−3.49	2019:02	−2.92	7	−4.90	−4.35	2020:02
ESEN	−3.18	1	−4.08	−3.49	2022:10	−4.02	7	−4.68	−4.11	2021:11
GWIND	−3.26	3	−4.08	−3.49	2022:09	−7.73 [a]	4	−4.91	−4.35	2022:10
KARYE	−3.94[b]	3	−4.08	−3.49	2022:07	−5.43[a]	3	−4.90	−4.34	2022:08
MAGEN	−3.87[b]	5	−4.08	−3.49	2022:09	−5.64[a]	3	−4.88	−4.31	2022:08
NATEN	−2.84	8	−4.08	−3.49	2020:08	−2.82	8	−4.79	−4.22	2021:02
NTGAZ	−3.65[b]	4	−4.08	−3.49	2022:12	−5.16[a]	4	−4.79	−4.22	2023:02
ODAS	−3.89[b]	7	−3.99	−3.39	2014:12	−5.30 [a]	7	−4.70	−4.16	2018:07
PAMEL	−1.40	7	−4.08	−3.49	2020:07	−4.39[b]	8	−4.91	−4.35	2020:02
ZEDUR	−2.72	6	−4.01	−3.41	2020:08	−4.64 [b]	6	−4.73	−4.18	2016:06
ZOREN	−3.18	6	−3.85	−3.28	2008:09	−5.09[a]	7	−4.61	−4.08	2011:05
XELKT	−1.82	7	−3.85	−3.28	2008:09	−4.26 [b]	7	−4.50	−3.68	2018:12

* k is the optimum lag length, and K is the break date. The longest lag length (maxlag) is set as 8. a and b denote 1% and 5% significance levels, respectively.

As revealed by the analysis of "Model A" in Table 3, the BIOEN company has stationarity with a structural break at the 1% significance level; the ARASE, AYEN, CANTE, KARYE, MAGEN, NTGAZ, and ODAS companies have stationarity with a structural break at the 5% significance level. According to the results of "Model C", ARASE, AYEN, CANTE, BIOEN, GWIND, KARYE, MAGEN, NTGAZ, ODAS, and ZOREN have stationarity with structural breaks at the 1% significance level; AKSEN, AKSUE, PAMEL, and ZEDUR have stationarity with structural breaks at the 5% significance level. In addition, BIST XELKT was found to have stationarity with structural breaks at the 5% significance level. In general, the stock prices of EGW companies in the BIST analyzed with one-break URT were found to have structural breaks in different periods except for four companies. Upon evaluating the break periods of the stock prices of BIST EGW companies, it can be said that there are usually breaks toward the middle and end of 2022, but there are also breaks in the prices of some companies in 2018 and 2020.

The structural breaks in the stock price series of the companies in the BIST EGW sector are analyzed using the URT developed by Lee-Strazicich (2003), which considers two structural breaks. URT with two structural breaks is applied with "Model A", which considers only structural breaks in the level, and "Model C", which considers structural breaks in both level and trend. Table 4 displays the URT outcomes with two structural breaks for both "Model A" and "Model C".

Table 4

Lee-Strazicich (2003) Unit Root Test Results with Two Structural Breaks

Code	Model A					Model C				
	Min. t-statistic	k	%1	%5	K_1 , K_2	Min. t-statistic	k	%1	%5	K_1 , K_2
AKENR	−2.03	0	−4.25	−3.64	2002:10, 2003:03	−4.87	2	−5.63	−5.08	2009:03, 2018:10
AKSEN	−2.15	6	−4.09	−3.58	2020:04, 2020:12	−5.53	6	−6.10	−5.61	2017:04, 2020:03
AKSUE	−3.26	2	−4.25	−3.64	2006:05, 2018:02	−4.96	2	−5.63	−5.06	2004:05, 2020:03
ARASE	-3.96_b	2	−4.07	−3.56	2022:10, 2023:02	-6.77_b	3	−6.93	−6.17	2022:06, 2022:11
AYDEM	−2.92	3	−4.07	−3.56	2022:04, 2023:03	-8.88_a	4	−7.00	−6.18	2022:03, 2022:10
AYEN	-4.11_b	8	−4.25	−3.64	2008:09, 2021:01	-5.05_b	8	−5.64	−4.87	2015:11, 2020:02
CANTE	-4.35_a	7	−4.07	−3.56	2023:01, 2023:03	-6.98_a	3	−6.93	−6.17	2021:10, 2022:07
BIOEN	-4.31_a	3	−4.07	−3.56	2021:12, 2023:02	-8.99_a	4	−7.00	−6.18	2021:12, 2022:10
ENJSA	−2.78	2	−4.07	−3.56	2019:02, 2022:02	-5.96_b	2	−6.28	−5.92	2019:03, 2022:08
ESEN	−3.27	1	−4.07	−3.56	2021:09, 2022:07	−4.04	1	−6.93	−6.17	2021:10, 2022:08
GWIND	−3.05	3	−4.07	−3.56	2022:03, 2023:03	-6.95_b	8	−7.20	−6.31	2022:03, 2022:09
KARYE	-3.64_b	3	−4.07	−3.56	2022:07, 2023:01	-7.98_a	3	−6.93	−6.17	2022:02, 2022:09
MAGEN	-4.53_a	5	−4.07	−3.56	2022:09, 2023:01	-12.52_a	3	−7.01	−6.44	2022:09, 2022:12
NATEN	−2.60	8	−4.07	−3.56	2020:08, 2022:02	−4.94	8	−6.69	−6.15	2021:03, 2022:08
NTGAZ	−3.47	6	−4.07	−3.56	2022:07, 2022:09	-8.74_a	5	−6.69	−6.15	2022:06, 2023:02
ODAS	-4.11_a	7	−4.10	−3.59	2014:12, 2018:07	-5.49_b	7	−5.85	−5.42	2016:10, 2019:01
PAMEL	−1.54	7	−4.07	−3.56	2019:07, 2020:07	−4.99	7	−6.86	−6.27	2019:01, 2020:07
ZEDUR	−2.92	6	−4.09	−3.59	2017:11, 2020:08	−5.14	6	−6.21	−5.63	2016:08, 2020:07
ZOREN	-3.90_b	7	−4.25	−3.64	2008:09, 2012:04	-5.50_b	7	−5.63	−4.98	2002:09, 2012:02
XELKT	−1.87	7	−4.25	−3.64	2008:09, 2010:04	-5.60_b	7	−5.62	−4.96	2012:09, 2020:02

Model A * k is the optimum lag length, K1 and K2 are the first and second break dates, respectively. The longest lag length (maxlag) is set as 8. a and b denote 1% and 5% significance levels, respectively.

According to “Model A” results in Table 4, CANTE, BIOEN, MAGEN, and ODAS have stationarity at the 1% significance level; ARASE, AYEN, KARYE, and ZOREN have stationarity with two structural breaks at the 5% significance level. “Model C” results in Table 4 show that AYDEM, CANTE, BIOEN, KARYE, MAGEN, and NTGAZ have stationarity at the 1% significance level; ARASE, AYEN, ENJSA, GWIND, ODAS, and ZOREN have stationarity with two structural breaks at the 5% significance level. BIST XELKT is also stationary with two structural breaks at the 5% significance level in “Model C”. When the results of Table 4 are evaluated in general, the stock prices of 12 out of 19 companies have stationarity with two-breaks in their stock prices. In other words, most of the EGW companies within the scope of the analysis have experienced at least two price breaks in different periods. Upon evaluating the periods of the breaks, the breaks generally occurred in the middle and end of 2022, as well as in the first months of 2023. It is also noteworthy that AYEN and ZOREN, whose data are more historical than the others, had breaks in 2002 and 2008, respectively.

Upon a comprehensive assessment of the findings, it can be concluded that the stock prices of BIST EGW companies were subject to significant exogenous shocks and sudden increases or decreases in the periods analyzed, resulting in a mean reversion in prices. Considering the examination and analysis, efficiency is not substantiated in the weak form of EMH within the stock market of the BIST EGW companies.

When structural breaks are evaluated in terms of their periods, evaluations can be made about what may have caused these shocks. In the findings of the structural breaks in the stocks of EGW companies in BIST, it was determined that the breaks were mostly experienced in 2022 and toward the end of this year. At the same time, the companies where these breaks were experienced generally operate in renewable energy. In 2022, this situation can plausibly be attributed to the fact that the EU sided with Ukraine due to the Russia-Ukraine War. As a result of Russia's counter-attitude, Russia cut natural gas transfers to the EU at a very high rate, and countries started to search for new energy sources, while renewable energy investments increased, which may have caused the break in the stocks of BIST EGW companies in 2022. The increase in the number of companies providing renewable energy and transportation CNG and LNG services in Türkiye since 2021 and the rapid public listing of these companies led to the growth of XELKT. However, the stock price breaks in 2020 may have been caused by the COVID-19 outbreak. In addition, the findings of the study show that price breaks were detected in some BIST EGW companies in 2018. Considering that Türkiye had the highest inflation and interest rate data in 2018 compared to the past 10 years, the shock experienced in stocks is related to economic policy. On the other hand, the price breaks in 2002 and 2008, which were observed in a few companies, may be related to the global financial crises.

In the context of this study, the application of the Karavias and Tzavalis (2014) panel URT with structural breaks was applied. This specific examination, conducted using data encompassing all firms in the sector, aimed to determine the degree to which the findings of company stock prices indicate the entire BIST EGW sector. The results of this panel URT are detailed in Table 5.

Table 5

Karavias and Tzavalis (2014) Panel Unit Root Test Results with Structural Breaks

	Constant			Constant and trend		
	Z-statistics	**Critical Values**	**Break Date**	**Z-statistics**	**Critical Values**	**Break Date**
BIST EGW Sector	−15.394***	4.007	2023:03, 2023:04	−4.689***	−0.861	2022:02, 2022:04

***, **, and * represent significance at p<=0.01, p<=0.05 and p<=0.10 levels.

Based on the findings from Table 5, derived through the panel URT with structural breaks, it is evident that the minimum Z statistic values associated with the BIST EGW sector have surpassed the critical values, demonstrating statistical significance at both the constant and level specifications. Consequently, the null hypothesis that postulates the presence of unit roots in all series across the panel is rejected. In other terms, it is established that the stock prices of companies in the BIST EGW sector exhibit stationarity, indicating that the efficiency in the weak form of EMH does not hold within the sector's stock market. Upon closer examination of the periods marked by structural breaks, a structural shift in the constant component occurred around mid-2023, while breaks in both the constant and trend components were observed in early 2022. Consequently, the outcomes derived from the URT for firms individually are in alignment with the results obtained from the panel URT, which encompassed an analysis of the firms as an aggregate entity.

The findings derived from the individual unit root tests are consistent with the outcomes of the panel-based approach, indicating sector-wide structural change patterns. Notably, the XELKT index itself was found to be stationary with structural breaks, further validating the argument that these shocks were not isolated incidents but rather reflective of systemic disruptions in the EGW sector. The convergence of findings across these analytical layers enhances the results' reliability and interpretability.

5. Conclusion

In the past, researchers have traditionally examined time series using methodologies like URT, deriving insights into the structure of the series. However, a more refined approach has emerged with the advent of URT that accounts for structural breaks. This newer approach allows testing of time series while considering the presence of these breaks, leading to more precise and insightful inferences about the underlying series. This study aims to reveal the stock market efficiency of EGW companies by analyzing the stock prices of companies in the BIST EGW sector with structural break URT. For this purpose, Lee-Strazicich (2013) and Lee-Strazicich (2003) URT with one and two structural breaks are used to analyze the stock prices of 19 companies in the BIST EGW sector and XELKT data, respectively. In addition, the entire sector was analyzed together with the Karavias and Tzavalis (2014) panel URT with structural breaks, allowing all companies to be analyzed together. In general, all EGW companies' stock prices in the BIST have been subjected to several shocks and experienced breaks over time, but then showed a rapid mean reversion movement. Stock prices of EGW companies listed on the BIST respond to external shocks and display atypical fluctuations. However, the consistent nature of their series suggests that the stock market within this sector does not align with the characteristics of a weakly efficient market. Therefore, it is possible for investors to earn abnormal gains in the BIST EGW sector. Considering structural breaks, the discovery of stationarity in the stock prices of BIST EGW companies aligns with prior research findings by Aksoy and Karatepe (2014) and Camgöz (2022). These studies observed a similar pattern of stationarity with structural breaks in the BIST 100 index. Nevertheless, the outcomes derived from this investigation diverge from those of Eyüboğlu and Eyüboğlu (2020), who affirmed the efficiency of the XELKT. It is important to point out that this study exclusively focused on testing the XELKT and did not separately analyze the data of BIST EGW companies. This isolated example may not offer a comprehensive perspective. In contrast, this study yielded distinct results for the XELKT when employing URT in "Model A" and "Model C". Nevertheless, the BIST EGW sector demonstrated stationarity in terms of individual company-based time series data and all companies in the panel.

While URT with one-structural break applied in the study detected structural break stationarity in the stock prices of 15 EGW companies, URT with two-structural breaks detected structural break stationarity in the stocks of 12 companies. In addition, according to one-break and two-break URT, they are stationary with structural breaks. According to these findings, the stocks of most of the EGW companies in Türkiye are affected by external shocks and exhibit sudden increases or decreases but then return to the average. According to the study findings, the dates of the breaks in the stocks of EGW companies generally point to 2022. Accordingly, the imposition of sanctions on Russia by the European Union (EU) due to the Russia-Ukraine war and the start of the search for new energy sources by the countries in 2022 when Russia cut natural gas imports to the EU by more than 70% (Euronews, 2022) can be considered as an event that significantly affected energy companies. With Russia's significant reduction in natural gas transfers, European countries have especially turned to transported compressed natural gas CNG and liquefied natural gas LNG services, and energy companies started to come to the forefront in 2022. The reason for the breaks in the stocks of publicly traded EGW companies in Türkiye in 2022 may be the increase in investments in renewable energy and companies providing transportation CNG and LNG services. In addition, the breaks in the structural break tests in 2018 can be explained by the fact that interest rates broke the record of the last 10 years because of the fiscal policies implemented in Türkiye in 2018, and the increase in energy prices in Türkiye was the highest among OECD countries (BBC News Türkçe, 2023; Euronews, 2018). 2020 witnessed the global ramifications of the COVID-19 pandemic, which had widespread repercussions across various markets.

This health crisis may have led to breaks in the stock performance of BIST EGW companies. Notably, the energy sector emerged as the most severely impacted industry due to Covid-19-related factors, including the closure of border crossings and disruptions in international trade (BBC News Türkçe, 2021).

The presence of structural breaks in the stock prices of BIST EGW companies during major external shocks suggests that the market does not immediately or fully incorporate new information into prices, thereby violating the weak-form efficient market hypothesis. For example, the shocks observed in 2022 coincide with the Russia–Ukraine war and realignment of the energy market, leading to persistent price shifts rather than short-lived volatility. Similarly, the COVID-19 pandemic disruptions in 2020 resulted in significant deviations from a random walk, implying delayed price adjustment. These findings imply that investors may achieve abnormal returns by reacting to such events ahead of the broader market. The observed mean reversion after shocks also indicates that price adjustments occur gradually rather than efficiently. This reinforces the conclusion that the EGW sector in Borsa Istanbul exhibits inefficiencies in absorbing and reflecting information in a timely manner.

According to the outcomes derived from this research, when assessing the price dynamics of EGW companies, investors and stakeholders must account for the existence of structural breaks. The results of the study show that the stock prices of EGW companies deviate from a random walk process. During periods of market turbulence, such as the COVID-19 pandemic or the Russia-Ukraine war, recognizing structural breaks in stock prices can help investors, CFOs, and analysts make more informed decisions. These breaks reveal market inefficiencies caused by external shocks, providing investors with opportunities to capitalize on price dislocations or mitigate risks. For CFOs, understanding these shifts can guide financial planning, risk management, and capital allocation, especially toward emerging sectors such as renewable energy or LNG services. Furthermore, the study results may serve as a warning to policymakers to develop more effective regulations and policies to ensure the stability and confidence of the energy sector. The findings of the study may also help investors identify key risks and opportunities when evaluating the EGW sector. This study covers a narrow time series and a limited number of companies. Although the panel timeframe is relatively short, it encompasses high-volatility periods such as post-COVID-19 recovery and the Russia-Ukraine war. These events allow the detection of significant structural breaks, making the period suitable for examining short-term efficiency disruptions. In future studies, more comprehensive series and methodologies can be used to statistically reveal the causes of stock price breaks. Moreover, EGW companies in different countries can be analyzed as a whole, and country-specific characteristics can be compared.

Peer Review Externally peer-reviewed.
Conflict of Interest The authors have no conflict of interest to declare.
Grant Support The authors declared that this study has received no financial support.
Author Contributions Conception/Design of study: Ö.İ., E.K.; Data Acquisition: M.B., Ö.İ.; Data Analysis/Interpretation: M.B., Ö.İ.; Drafting Manuscript: M.B.; Critical Revision of Manuscript: Ö.İ., E.K.; Final Approval and Accountability: Ö.İ., E.K.

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