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Circular behavior of oil consumption and the impact of oil prices with the Fourier approach

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ABSTRACT

In the changing world, oil continues to be important in energy production. Using monthly data from 1965 to 2022, the permanency of oil consumption fluctuations was investigated. Fourier-based Granger causality tests were used to examine cause-and-effect relationships between variables. Long-term relationships were estimated using Fourier-based Engle Granger cointegration tests. Unlike previous research, this study considers the long and short-term effects of countries that consume the most and least oil, as well as on a global scale, from different perspectives, examining oil price fluctuations together, and estimating these analyzes using the Fourier approach. Oil consumption fluctuations appear temporary in New Zealand and Luxembourg but permanent in all other countries. Oil consumption and prices share a causal relationship in the US, Japan, New Zealand, and Luxembourg, but no relationship elsewhere. A long-term relationship exists between oil consumption and prices in the US, India, Saudi Arabia, Russia, Japan, South Korea, Canada, Mexico, and Estonia. In other countries, no long-term relationship is found between these two variables. Error correction model estimation shows only the equation for Japan can be interpreted based on statistical significance. A one-unit deviation between oil consumption and prices can reach equilibrium in 20 months.

1. Introduction

Oil has always been strategically and politically important and a vital factor in terms of production among natural resources. This strategic importance stems from the widespread use of oil derivatives not only for energy but in all sectors, including industry. The world meets most of its energy needs using fossil-based energy sources, especially oil. Increasing energy demand, especially in terms of oil, and the unequal distribution and limited availability of oil reserves worldwide indicate the need to carefully consider oil consumption and policies considered. This plays an active role in strategic planning for important issues such as energy security, sustainability, and economic stability.

Although the share of renewable energy sources in the energy portfolio is constantly increasing, long-term projections indicate that fossil energy sources may continue to dominate the energy sector [1]. Considering that transition in the energy sector is a slow and complex process, more comprehensive strategies are required for sustainable energy transformation. In this context, energy policies must be shaped in the coming years with an integrated and balanced approach that aims to ensure energy security and support economic stability while minimizing harmful environmental effects.

Oil is a vital energy source for today's economies, deriving importance from its impressive share of energy consumption worldwide. Oil has many applications ranging from electricity production to transportation. The main reason for the intense use of oil is that it has a widespread consumption network. Approximately 64.5 % of the oil worldwide is used for transportation, 16.6 % for nonenergy applications, 7.8 % for industry, 5.4 % for housing, and 5.7 % for other purposes. Its various uses enable oil to function as a fundamental energy source across many sectors [2].

Each barrel of oil extracted from the ground slightly decreases the total oil reserves. This results in a decrease in underground stock resulting in a scarcity premium effect on oil prices [3]. The scarcity premium effect refers to increased demand for a good or resource due to its limited availability, thus raising prices. This occurs when the consumption demand is too high to be met because the resource is limited, or the supply is currently low. Natural resources such as oil are clear examples of the scarcity premium effect because energy demand is high whereas reserves are limited. Although oil prices are determined by supply and demand dynamics, an upward pressure on prices will continue until the increase in oil consumption slows. Even when oil demand decreases, individuals who expect oil prices to rise further likely

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will not be disappointed.

On the global energy map, oil consumption is related to not only countries' land area or population but also their economic size and development level. Countries that are part of the Organization for Economic Co-operation and Development (OECD) have a significant share in worldwide oil consumption owing to their high economic activity levels and industrial capacity. This trend is closely related to factors such as high income levels, industrialization, and energy-intensive production.

Although OECD countries consume more oil than non-OECD countries, oil consumption has decreased significantly since 2007. The combined oil consumption of the US, China, India, Saudi Arabia, and Russia constitutes almost half of the world's oil demand. Turkey ranks 21st, with a share of 1.1 %.

Although Turkey's primary energy consumption was 52,465 Mtoe in 1990, it had increased to 147.2 Mtoe by 2020. In 1990, while the share of solid fuels was 30.2 %, the shares of oil and oil products and natural gas were 46.1 % and 5.4 %, respectively. The share of renewable energy sources was 18.4 %. However, in 2020, although the share of oil and oil products decreased to 28.7 %, the share of natural gas increased to 27 %, and the share of renewable energy sources decreased to 16.7 % [4].

For Turkey, which meets approximately 40 % of its energy needs with oil, of which approximately 90 % is imported, oil makes the issue of energy supply security even more vital [4]. High foreign dependency for the national energy supply increases the risk of being affected by fluctuations in the global energy market and may affect the country's economic stability. Therefore, Turkey needs to take strategic steps with its energy policies to increase resource diversity and energy efficiency while also using local energy resources more effectively. These measures can ensure energy supply security, support economic sustainability, and reduce harmful environmental effects.

This study, in which the countries that consume the most and least oil are selected, has three main objectives. The first is to examine whether the fluctuations in oil consumption are permanent. The second aim is to examine the relationship between oil consumption and oil prices in the short and long term. Finally, the third aim is to examine whether a shock in oil prices will stabilize in the long term and, if so, when it will reach equilibrium. Oil consumption and oil prices were analyzed overall using Fourier-based tests to examine the countries that consume the most and least oil from a broad perspective in the short and long-term.

The remainder of this paper is organized as follows. Section 2 includes studies examining oil prices and oil consumption. Section 3 describes the econometric methods used to examine the relationship between oil consumption and prices. The results of the econometric analyses are presented in Section 4. Section 5 provides conclusions and recommendations based on the study's findings.

To date, no previous studies have analyzed oil consumption using time series methods and directly addressing the countries that consume the most and least oil. In addition to the traditional time series methods, Fourier-based tests have been conducted. Thus, analyzing country groups from a holistic perspective in the short and long-term, in terms of both the selected countries and the time series methods used, will make a significant contribution to the existing literature.

2. Oil consumption

The worldwide increase in oil consumption is often considered to be strongly linked to the transportation sector, especially road and air transportation. However, not only transportation but also increases in demand in the petrochemical and chemical industries have contributed to this growth. Because oil is used in a wide range of areas, from the energy sector to industrial production, this increase in demand has led to a faster depletion of scarce resources. However, due to this increase, the consumption of scarce resources has also increased exponentially.

Supposedly, a mathematician invented the game of chess to present an original gift to the Persian king. The king liked it very much and said, "Wish whatever you wish from me." The mathematician wanted exponentially increasing wheat. So, one in the first square, 2 in the second square, 4 in the third square, 8 in the fourth square, and 2 to the 64th power in the last square. Since there are 9,223,372,036,854,775,808 wheats in the last frame and the weight of 1 wheat grain is approximately 0.02 g, this number of wheat is 20,000,000,000,000,000 g, that is, 20,000,000,000 tons, or 20 billion tons. World wheat production in 2021 was 763 million tons. This anecdote is important in understanding where exponential growth will lead. How long can the exponentially increasing population sustain limited energy resources?

As long as this growth trend continues, natural resource pressure will increase, and the environmental effects will become more evident. In this context, strategic solutions must be developed to cope with population and energy demand growth. Turning to renewable energy sources, increasing energy efficiency, and sustainably managing resources are important steps in balancing this growth trend.

Although global oil consumption has decreased slightly in recent years, it has generally increased. While 2231.7 million tons of oil were consumed in 1970, 2984.4 million tons were used in 1980, followed by 3146.7 million tons in 1990, 3568.8 million tons in 2000, 3985.2 million tons in 2010, and 4017.5 million tons in 2020 [5]. During these periods, total oil consumption worldwide approximately doubled.

Global oil consumption, recorded as 97.6 million barrels/day in 2019, decreased by 9.3 %–88.5 million barrels/day in 2020. This decline, which occurred because of the impact of the COVID-19 pandemic, resulted in the lowest global oil consumption levels since 2011. In 2020, the most significant regional decreases were 13.8 % in Europe, 3.1 % in Africa, and 12.4 % in North America. On the national level, while the US and India experienced the most significant decreases in oil consumption, China increased its oil consumption by 220,000 barrels per day in 2020 [5].

Further, while crude oil and oil product trade was 70.4 million barrels/equivalent/day in 2019, it decreased by 7.6 % in 2020 to 65.1 million barrels/equivalent/day. Interregional crude oil trade figures show that China is the country that imports the most crude oil, while Saudi Arabia is the country that exports the most. These data show the decline in global oil demand and how trade is affected.

During the pandemic period, oil demand appears to have decreased significantly, especially in the US (2.3 million barrels per day), the European Union (1.5 million barrels per day) and India (480,000 barrels per day). However, China is almost the only country in which consumption is increasing; its energy needs are constantly increasing, currently reaching 220,000 barrels per day [5] Table 1).

Although OECD countries comprise a significant share of the total oil consumption, it did not increase significantly from 1970 to 2022. OECD countries consumed 34,319 thousand barrels of oil per day in 1970, and 45,108 thousand barrels of oil per day in 2022. While non-OECD countries consumed 11,069 thousand barrels of oil per day in 1970 and 52,202 thousand barrels of oil per day in 2022. Consequently, from 1970 to 2022, the oil consumption of OECD countries increased slightly; however, non-OECD countries consume approximately five times more oil than OECD countries. Furthermore, oil consumption decreased by 0.4 % in the European Union between 2012 and 2022 and by less than 0.05 % in OECD countries and 1.8 % in non-OECD countries. Globally, it increased by 0.9 % (Table 2).

Table 1
Amount of oil consumed in the world (million tons).

Year	Total Oil Consumption Worldwide
1970	2231.7
1980	2984.4
1990	3146.7
2000	3568.8
2010	3985.2
2020	4017.5

Source: BP Statistical, 2021

Table 2
Oil consumption.

Oil Consumption (Thousands of Barrels Per Day)			
Countries	**2022**	**2022 Share**	**2012–22 Growth rate per annum**
US	19140	19.7 %	0.9 %
China	14295	14.7 %	3.6 %
India	5185	5.3 %	3.5 %
Saudi Arabia	3876	4.0 %	1.1 %
Russia	3570	3.7 %	1.2 %
Japan	3337	3.4 %	−3.3 %
South Korea	2858	2.9 %	1.5 %
Brazil	2512	2.6 %	−0.3 %
Canada	2288	2.4 %	−0.6 %
Mexico	2098	2.2 %	−0.6 %
Turkey	2288	1.1 %	−0.6 %
New Zealand	148	0.2 %	−0.1 %
Luxembourg	49	0.1 %	−1.6 %
Estonia	25	Less than 0.05 %	−2.5 %
OECD	45108	46.4 %	Less than 0.05 %
Non-OECD	52202	53.6 %	1.8 %
European Union	10802	11.1 %	−0.4 %
Global Total	97309	100 %	0.9 %

Source: Statistical Review of World Energy, 2023

According to 2021 data for Turkey, the country's land area had 412 million barrels of oil reserves. Turkey's producible reserves were estimated to be approximately 70 million tons by 2022. In 2021, Turkey produced an average of 69,332 barrels/day of crude oil and consumed 96.908 million tons. These data show that Turkey meets a large portion of its energy needs from external sources and is dependent on foreign sources for energy supply security.

In 2022, despite producing 3.58 million tons of crude oil, Turkey also imported 33.49 million tons, indicating that Turkey depends on foreign imports for 90 % of its crude oil. However, increases in oil consumption and oil prices is even more vital for Turkey, which meets approximately 40 % of its energy needs through oil. Energy requirements and industrialization have led to a steady increase in oil demand worldwide. Thus, energy demand is gradually increasing, and oil is maintaining its importance in the global energy sector. In the future, it will be important to balance this growth trend with efforts to move towards sustainable energy sources and increase energy efficiency.

In 2022, the US had the highest oil consumption worldwide, followed by China, India, Saudi Arabia, Russia, Japan, and South Korea. These countries are decisive players in global energy demand, accounting for a large share of global oil consumption. This ranking is directly related to a country's economic size, industrial capacity, and activities in energy-intensive sectors. Saudi Arabia's share of oil consumption is relatively low compared to its share of oil reserves and oil production. Although the Middle East ranks first in oil production, it has a small share of oil consumption (9 %). Saudi Arabia is an important oil exporter in international markets, while its domestic consumption is relatively low.

Non-OECD Asian countries, especially those under the leadership of China, have a key role in forming world oil demand and contribute significantly to increased oil consumption [6]. Meanwhile, the Asia-Pacific region, which had a 15.2 % oil consumption share in 1970, ranked third. It increased its share to 38 % in 2020 and rose to first place. The Asia-Pacific region, which consumed 338.4 million tons of oil in 1970, consumed 1560.2 million tons in 2020, with oil consumption increasing approximately five times during this period. This situation reflects the economic growth, industrialization, and increased energy demand in the Asia-Pacific region.

3. Literature review

A review of the literature on energy consumption shows that previous studies have examined total primary energy consumption as well as energy consumption as a whole [7–10]. Some studies examined only coal consumption [11,12], whereas others examined only natural gas consumption [11,13–15]. Some studies have been conducted on oil

Table 4
F test statistic values.

Countries	F Test Statistical Value
US	0.167641
China	**11.88681**
India	0.101118
Saudi Arabia	1.520401
Russia	3.284010
Japan	0.000957
South Korea	**13.01675**
Brazil	1.271169
Canada	1.712018
Mexico	0.088523
Turkey	**23.22034**
New Zealand	**8.739441**
Luxembourg	**8.011497**
Estonia	**23.89074**
Oil Price	**7.161285**
Global Total	**8.798145**

Critical values of F (ˆk) = Max F (k) values for T = 500, respectively.
The table criterion values at the 1 %, 5 %, and 10 % significance levels are 11.52, 8.76, and 7.53 respectively.

Table 3
Frequency and optimal delay lengths of the series.

Countries	SSR	Frequency (*k*)/Lag		SSR	Frequency (*k*)/Lag
US	1728828	2 1	**Canada**	29335.40	2 12
China	233633.4	1 12	**Mexico**	30999.36	1 1
India	50324.42	1 1	**Turkey**	4846.735	3 12
Saudi Arabia	49251.23	2 1	**New Zealand**	158.3542	1 12
Russia	1986127	3 12	**Luxembourg**	32.76267	1 12
Japan	235761	2 1	**Estonia**	0.002364	2 1
South Korea	40051.48	2 12	**Oil Price**	1681.539	2 12
Brazil	21374.21	3 0	**Global Total**	17060262	1 12

SSR shows minimum sum squares residual.

consumption, which is the subject of this study [11,16]. This section includes studies that examined oil consumption using time series methods. Lean and Smyth (2009) examined the stationarity of sectorally disaggregated oil consumption in the US during 1973–2008. In this analysis, LM unit root tests revealed that oil consumption in the residential sector was stationary, whereas that in the industrial sector was not [17].

Apergis and Payne (2010) examined the stationarity characteristics of oil consumption for the 50 states in the US between 1960 and 2007 [11]. In the analysis, the stationarity tests of Narayan and Popp (2010) and Lee and Strazicich (2003) were applied to endogenously determine structural breaks. The oil consumption series for many states exhibited stationarity [18,19]. The oil consumption series for many states exhibited stationarity. Solarin and Lean (2016), conducted a stationarity analysis of oil consumption for 57 countries with data for 1965–2012, applying linear and nonlinear unit root tests. According to the results, the oil consumption series was stationary in 19 countries and a unit root was in the series in 38 countries [20].

Bozkurt and Okumus (2016) examined the stationarity of oil consumption in BRICS-T countries, conducting linear and non-linear unit root tests for data from between 1965 and 2014. The oil consumption series for India, South Africa, Russia, and Turkey followed a non-linear course [21]. Destek and Sarkodie (2020), examined the unit root properties of coal, oil, and natural gas consumption series per capita using data for 1970–2018 from 16 OECD countries. The stationarity properties of the series were analyzed using augmented Dickey Fuller (ADF) and KSS Fourier unit root tests, which showed that oil, coal, and natural gas consumption were not stationary [10]. Cağlayan-Akay, Ün, and Bülbül (2021) investigated the stationary properties of primary energy consumption in Brazil, India, Indonesia, South Africa, and Turkey (Fragile Five Countries) for 1965–2018, using linear, non-linear, and Fourier-based stationarity tests. According to their findings, the effects of shocks on oil consumption were temporary for India and Indonesia, but permanent for the other countries [22]. Ajlouni et al. (2021), conducted unit root tests in an oil consumption series in Jordan. Using annual data for 1961–2019, traditional unit root tests such as the Augmented Dickey Fuller (ADF), Phillips Perron (PP), Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) tests, and the structural break unit root test of Lee and Strazicich were applied, and the shocks to oil consumption were found to be permanent [19,23].

De Michelis et al. (2019) examined the effects of oil prices on consumption across countries and US states. Two large datasets were used, covering 55 countries between 1975 and 2018 and all US states between 1989 and 2018. Additionally, it has been stated that the harm caused by increases in oil prices outweighs the benefits provided by decreases [24]. Erdogan, Akalin, and Oypan (2020) examined the persistence of shocks in energy consumption data for 1970–2016 using the Fourier panel KPSS test. The results showed that energy consumption is not stationary at either the sectoral or general levels [25]. Bozoklu, Yilanci, and Gorus (2020) used the fractional Fourier unit root test to examine the stationarity of total energy consumption per capita for 1960–2014 in 113 countries. The study concluded that shocks only temporarily affect per capita energy consumption and will gradually disappear, owing to their long-memory feature [26].

Bağcı (2020) examined the relationship between oil prices and consumption using annual data for 1980–2015 and conducting panel data analyses with 17 OECD countries. No cointegration relationship was found between variables. A panel VAR with impulse-response functions showed that an increase in oil prices could reduce oil consumption [27]. Talha et al. (2021) investigated changes in oil prices and energy consumption in the Malaysian economy during 1986–2019. They found a significant relationship between oil prices and consumption [28]. Türköz (2022) investigated oil prices and consumption in Turkey between 1987 and 2020 using Hatemi-J's (2012) asymmetric causality analysis. The study found no causal relationship between oil prices and consumption [29]. Kızılkaya (2022) estimated the oil consumption series for 1965–2019 using panel stationarity analysis. Since the oil consumption series does not contain a unit root, the shocks to oil consumption were found to be temporary, with oil consumption returning to its previous state over time [30].

Konya (2022) used the Fourier approach to test the relationship between oil prices and consumption in Turkey between 2009 and 2021. A long-term relationship was found between sudden shocks in crude oil price and consumption in Turkey [31]. Gritli and Charfi (2023) examined the asymmetric relationship between oil price and oil consumption using the nonlinear autoregressive distributed lag (NARDL) model during 1980–2020. Asymmetric causality analysis demonstrated that positive shocks in energy consumption could affect industrialization, but not otherwise. A cointegration relationship was found between the variables [32]. Putriet et al. (2024) examined the effect of oil prices on oil consumption decision making processes. Their analysis of a dataset comprising 200 participants revealed a significant and positive relationship between oil prices and consumption [33].

4. Econometric methodology

Examining the stationarity of energy consumption, especially oil consumption, is important for achieving sustainable economic growth and development goals. Implementing policies to increase renewable energy investments is extremely important for reducing carbon emissions and dependence on fossil fuels. The success of these policies is closely related to the stationarity of fossil fuel consumption. If fossil fuel energy consumption is not stationary, shocks are expected to have a permanent effect. If it is stable, the impact of shocks will decrease rapidly [10]. Therefore, studies on the stationarity characteristics of energy consumption are also important for determining effective policies to improve environmental quality.

Whether fluctuations in oil consumption are permanent is a complex and multifaceted issue that depends on several variables. Shaping energy policies based on sustainability and stability is related to the potential to minimize the effects of these fluctuations. Temporary fluctuations can occur due to many short-term factors (e.g., economic cycles, seasonal effects, or special events), and the effects of these fluctuations can be balanced and controlled in a short time using sustainable energy policies.

If the oil consumption series is not stationary, the shocks and the effects of the implemented policies are permanent [34]. Then, the historical data will not play a significant role in predicting future demand. Future demand is impossible to predict using an oil consumption series that includes unit roots [17,35,36]. When analyzing future energy demand, the stationarity feature of energy-related series must be considered to form a more accurate prediction of future energy demand and create sustainable energy policies.

This section includes unit root and causality tests to determine cause-and-effect relationships, and integration tests to determine whether long-term relationships exist. Each test is explained using the equations in the following subsections. In addition to investigating whether fluctuations in oil consumption are permanent for the selected countries, the long and short-term relationships with oil prices, an important variable determining oil consumption, were examined First, a stationarity analysis of the countries' oil consumption and oil price series was performed before conducting further analysis. The Fourier Augment Dickey Fuller (FADF) the traditional unit root tests were conducted. Then, the cause-and-effect relationships between the variables were then examined using Granger causality and Fourier-based Granger causality. Long-term relationships were estimated using Engle–Granger and Fourier-based Engle–Granger cointegration tests.

4.1. Fourier Augmented Dickey Fuller Unit Root test

Traditional time series analyses begin with the assumption of linearity. Linear models assume that only a single structure or regime exists over a period. Events, such as oil crises and sudden price movements in energy markets, can change the linear structure of the series. When the nonlinear structure of the series is ignored, the unit-root test results are affected. This will cause the series to appear as if it is not stationary.

The FADF can be used to examine breaks and asymmetric relationships between variables in econometric analysis. The basic idea of this test is to use trigonometric terms to better capture the structural breaks and asymmetric effects in variables. Unit root tests based on the Fourier function add the sine and cosine terms to the equation as deterministic components. The greatest advantage of unit root tests based on the Fourier approach over other unit root tests is that it is not necessary to assume that the break dates, number of breaks, and break forms are known in advance [37].

This study aims to analyze the stationarity of an oil price series using the FADF unit root test od Enders and Lee. To determine the unknown number and form of breaks and deterministic components in a time series, the stationarity test is estimated as shown in equation [1] according to a structure based on the ADF test by using the Fourier function [38].

$$y_t = \alpha(t) + \rho y_{t-1} + \gamma t + \varepsilon_t \tag{1}$$

where ε_t is a stationary disturbance with variance σ_ε^2 and $\alpha(t)$ is a deterministic function of t. The null hypothesis of unit root is tested ($\rho = 1$). When the form of α (t) is unknown, any test for $\rho = 1$ is problematic if $\alpha(t)$ is misspecified. As an approximation of the unknown functional form of $\alpha(t)$, consider the Fourier expansion [2]

$$\propto(t) = \alpha_0 + \sum_{k=1}^{n} \eta_k \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \eta_k \cos\left(\frac{2\pi kt}{T}\right) \quad n \le T/2 \tag{2}$$

where n represents the number of frequencies in the approximation, k represents a particular frequency, and T represents the number of observations [38].

If $\alpha_1 = \beta_1 = \ldots\ldots\ldots\ldots\ldots\ldots\ldots = \eta_n = \beta_n = 0$, then the process is linear, and traditional unit root testing methodologies are appropriate. However, if a break or nonlinear trend is found, at least one Fourier frequency must be present in the data generating process.

$$\Delta y_t = \rho y_{t-1} + \eta_1 + \eta_2 t + \eta_3 \sin\left(\frac{2\pi kt}{T}\right) + \eta_4 \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \tag{3}$$

Equation [3] is estimated for all integer values of k such that $1 \le k \le 5$. The regression with the smallest sum of squared residuals (SSR) yields k. If the residuals are serially correlated, the lagged values of Δy_t are added as independent variables to the right side of the equation. The nonlinearities can be pretested. For this, the usual F statistic for the null hypothesis of H_0:C3=C4=0 can be performed. Fourier terms and the alternative hypothesis of H_1: C3≠C4≠0 show its significance. The distribution of the F statistic is nonstandard when a unit root null is imposed on the data generating process. The authors calculated the critical F critical values applied for the test. If the sample value of F was less than the critical value, the null hypothesis of a linear trend was not rejected. Under these conditions, the traditional ADF test is recommended.

After determining that the Fourier terms are statistically significant, the main hypothesis indicating the existence of a unit root (H_0: $\rho = 0$) is tested against the alternative hypothesis suggesting stationarity (H_1: $\rho < 0$). The test results are interpreted as in ADF type tests, and the table values are calculated by the authors as trendy τ_{DF-t} and trendless τ_{DF-t}, considering the presence of deterministic components in equation [3].

4.2. Granger fourier and granger causality test

The Granger causality estimation approach comprises of two stages. In the first stage, after determining the optimal lag length (m) with the optimal information criterion (AIC, SC, FPE) in the autoregressive regression equation [4] of the dependent variable, the optimal lag length (n) is again determined for equation [5], and the direction of causality from X to Y is determined [39].

$$Y_t = \delta + \sum_{i=1}^{m} \varphi_i Y_{t-i} + \varepsilon_t \tag{4}$$

$$Y_t = \delta + \sum_{i=1}^{m} \beta_i X_{t-i} + \sum_{i=1}^{n} \varphi_i Y_{t-i} + \varepsilon_t \tag{5}$$

H_0: $\beta_1 = \beta_2 = \ldots\ldots = \beta_i = 0$, and the F test was performed by testing the H_0 to determine causality from X to Y. If H_0 is rejected, there is one-way causality between the variables.

As Enders and Jones (2016), noted, when a structural break is sharp, it is more appropriate to use a dummy variable to estimate the exact date and magnitude of the break. Enders and Jones (2016) estimated a new causality test by adding sine (sin), and cosine (cos) terms to the traditional Granger causality equation using the flexible Fourier approach [40].

$$Y_t = \delta + \sum_{i=1}^{m} \beta_i X_{t-i} + \sum_{j=1}^{n} \varphi_j Y_{t-J} + \eta_3 \sin\left(\frac{2\pi kt}{T}\right) + \eta_4 \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \tag{6}$$

4.3. Engle Granger and residual-based Fourier Engle Granger cointegration tests

The Engle-Granger test examines whether a long-term relationship exists between series that are not stationary at the level and whether the error terms obtained from the established model result contain unit roots. If the error terms of the series obtained from the regression test do not include unit roots at their level values, the variables are cointegrated; thus, they move together in the long-term [41].

Structural changes can be observed because of factors such as economic crises, technological changes, and political regimes. Gregory and Hansen (1996) stated that if structural breaks exist, the power of cointegration tests such as. Engle and Granger (1987) that ignore these changes decreases [42,43]. The Gregory Hansen cointegration can determine whether there is a long-term relationship exist between the variables under structural breaks. Hatemi-J (2008) extended this test to allow for two structural breaks. The tests predict structural breaks by adding dummy variable(s), however, they assume the number of structural breaks in advance which creates a significant disadvantage [44].

Owing to the Fourier cointegration test, the exact location, shape, and number of breaks are not necessary to know in advance. The only value to be determined is the frequency obtained by minimizing the SSR. The main advantage of the new test, which is created by adding trigonometric terms such as sine and cosine to the Engle Granger equation, is that the locations, numbers, and forms of structural breaks do not need to be specified. To test for the existence of a cointegration relationship, the cointegration equation is estimated with unknown breaks using the Fourier approach [45]. Nevertheless, Tsong et al. (2016) and Banerjee et al. (2017) are also among those who conducted studies including Fourier series components in cointegration equations [46,47].

Yılancı (2019) proposed a residual-based cointegration method with the Fourier approach as an alternative to the traditional Engle-Granger cointegration analysis suggested by Engle and Granger (1987). Yılancı's (2019) testing procedure starts with estimating equation [7] as follows:

$$y_{1t=} d(t) + \beta' y_{2t} + \varepsilon_t \tag{7}$$

where t = 1, 2 …, T. The dependent variable y_t is a scalar, and $x_t = (x_{1t}, \ldots\ldots, x_{mt})'$ is a (mx1) vector of the independent variables. d(t) is a deterministic function of t that can be approximated using the following Fourier expansion with a single-frequency component [7]:

$$d(t)=\alpha_0+\eta_3\sin\left(\frac{2\pi kt}{T}\right)+\eta_4\cos\left(\frac{2\pi kt}{T}\right)+\beta^{'}y_{2t}+\varepsilon_t \quad (8)$$

To test the null hypothesis of no cointegration, the ADF unit root test is applied to the residuals of Model 2. Hence the following autoregression is estimated:

$$\Delta\varepsilon_t=\rho\varepsilon_{t-1}+\sum_{i=1}^{p}\gamma_i\varepsilon_{t-i}+u_t \quad (9)$$

where $u_t\sim$ i.i.d. $(0,\sigma^2)$.

The critical values for the Fourier Engle Granger (FEG) cointegration test are obtained via simulations considering different numbers of regressors (n = 1, 2, 3) and frequency values (k = 1, 2, 3, 4, 5). The table critical values are calculated considering the constant and constant and trend cases, where the sample sizes were T = 100, 500, and 1000. These values are listed at the bottom of Table 8.

5. Dataset and econometric analysis results

In this study, monthly data between 1965 and 2022 (only covering the years for the Russian Federation and Estonia between 1985 and 2022) were examined to determine whether fluctuations in oil consumption were permanent. In addition to being evaluated on a global scale, the analysis was conducted using time series data of oil prices and shows the oil consumption of the countries that consume the most (the US, China, India, Saudi Arabia, Russia, Japan, South Korea, Brazil, Canada, Mexico, and Turkey) and least (New Zealand, Luxembourg, and Estonia). The Appendix presents the oil consumption series for each country used in the analysis. Explanations of the abbreviations used in the studies are presented in Table 1 in appendix.

After determining the global oil consumption and the frequency value (k) for each country included in the study, the optimal lag length was calculated using the Akaike information criterion (AIC). These values are listed in Table 3.

After the frequency and optimal lag lengths of all series were determined, the F-statistic values of the series were calculated. The calculated F-statistic values were compared to the table critical values calculated by Enders and Lee (2012) instead of the F table values. The China, South Korea, Turkey, New Zealand, Luxembourg, Estonia, oil prices, and the global total series can be continued using the Fourier approach because the F statistic values are greater than the critical value of the table. Based on the information in this table, whether to perform both the causality analysis and the cointegration test according to traditional methods or the Fourier-based approach is decided (Table 4). For example, the F statistic value of the US series is not greater than the critical value of the table; therefore, traditional method tests are applied because it would not be appropriate to continue the analysis with Fourier-based tests. However, because the F statistic value of the Chinese series is greater than the critical value of the table, the analysis is continued with Fourier-based tests [38].

H_0 which states that the series for New Zealand and Luxembourg contain unit roots, is rejected; that is, these series do not contain unit roots and are stationary at the series level. All other series appear to be stationary at the first difference, according to the FADF test (Table 5) (Table 6).

In conventional unit root tests, stationarity analysis was performed considering the ADF and PP tests. In the case of different results for the two tests, the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test was used, and when a clear result was not obtained from that test, the Elliott-Rothenberg-Stock (ERS) test was used. The US, China, India, Saudi Arabia, Russia, Japan, South Korea, Canada, Mexico, Turkey, New Zealand, Luxembourg, Estonia, oil prices, and the global total series are stationary at the first difference. Among the countries, Brazil follows a different path. It was stationary at the second difference according to the ADF test, at the first difference according to the PP test, and at the same level according to the KPSS test. In this case, the ERS test was applied. According to this test, Brazil was stationary at first the difference. Another notable point was that, while New Zealand and Luxembourg were stationary at the level according to the FADF test, they were stationary at the first difference according to conventional tests.

Table 5
Fourier augmented dickey fuller unit root test results.

Countries	Frequency (*k*)	Level	First Dif.
China	1	−0.02	−4.46
South Korea	2	−1.19	−4.05
Turkey	3	1.68	−5.65
New Zealand	1	−3.85	–
Luxembourg	1	−4.05	–
Estonia	2	−1.70	−3.97
Oil Price	2	−1.53	−4.84
Global Total	1	−3.44	−4.10

In this table, level shows the value at the level of the Fourier Augmented Dickey Fuller Unit Root test, and the First Dif. shows the value at the first difference of the Fourier Augmented Dickey Fuller Unit Root test.
k = 1 −4.81 −4.29 −4.01 at the 1 %, 5 % 10 % significance levels respectively for T = 500 and for k = 2, it is −4.57 −3.99 −3.67.

While estimating the Granger causality test in the EViews package program, a common lag length is provided when the lagged values of the dependent variable and the optimal lag length of the equation containing the other independent variable are determined. This may have led to the misleading results. Therefore, the optimal lag length of the dependent variable was first determined using autoregressive regression equations. Then, the optimal lag length of the new equation was determined by adding the other independent variables.

H_0, which states no causality is present when the F statistic value of the final determined equation is greater than the table value, was rejected. Accordingly, a causal relationship is found between oil consumption and prices in the US, Japan (according to the Granger causality test), New Zealand, and Luxembourg (according to the Fourier Granger causality test), and oil prices affect oil consumption. In other countries, no causal relationship is found between these variables (Table 7).

To perform a cointegration test, the series must not be stationary at the same level. Because the oil consumption of New Zealand and Luxembourg is stationary at the series level, a cointegration test cannot be performed. Considering data from the US, India, Saudi Arabia, Russia, Japan, and South Korea (according to the Fourier Cointegration Test (FEG), Canada, Mexico, Estonia (FEG), and the Global Total (FEG), a long-term relationship is found between oil prices and consumption. In all other countries (China (FEG), Brazil, and Turkey (FEG)), no long-term relationship was found between these two variables (Table 8).

Another important method for examining the short and long-term dynamics of a model is the error-correction model (ECM). An ECM was developed to predict whether two or more variables act together in the long-term; that is, whether they are cointegrated. Short-term coefficients are determined by establishing an ECM with the lagged value of the error term ecm_{t-1} obtained from the equation. In the ECM, the oil consumption and oil price series of countries are stationary and cointegrated at the first difference, and ecm_{t-1} is the first lag of the error terms obtained from the cointegration equation. The variable's coefficient showing the lagged value of the error term is expected to be between −1 and 0. In this case, the system is expected to fluctuate and then balance; this fluctuation decreases each time and becomes balanced over the long-term. Consequently, to determine whether an imbalance has been eliminated in ECMs, the coefficient must be both statistically significant and negative [7]. A summary presentation of the results of the econometric analysis is shown in Fig. 2 in appendix.

A cointegration test was not performed because the oil consumption series of New Zealand and Luxembourg were stationary at this level, and the ECM could not be predicted. Therefore, these countries were not included in the ECM estimation. Thus, the imbalance between short and

Table 6
Conventional unit root test results.

Countries	ADF Test			PP Test		KPSS Test	
	Level	First Dif.	Second Dif.	Level	First Dif.	Level	First Dif.
US	−3.40	−4.02		−2.71	−5.29		
China	−1.61	−2.45	−13.79	−0.66	−4.22	0.78	0.14
India	−1.12	−4.72		−0.94	−5.23		
Saudi Arabia	−2.14	−4.09		−1.74	−4.40		
Russia	−2.47	−4.18		−1.71	−5.91		
Japan	−2.72	−3.71**		−2.71	−4.85		
South Korea	−2.17	−3.54**		−1.29	−5.83		
Brazil	−3.82	−3.17	−12.18	−1.73	−4.90	0.13***	
Canada	−2.94	−4.56		−2.19	−5.56		
Mexico	−2.60	−3.41**		−0.81	−3.87**		
Turkey	−3.29	−3.74**		−2.05	−6.24		
New Zealand	−2.25	−3.99		−1.28	−5.91		
Luxembourg	−1.78	−3.92**		−0.77	−5.53		
Estonia	−2.50	−3.81**		−1.60	−4.10		
Oil Price	−3.59	−4.85		−2.30	−5.39		
Global Total	−3.83	−4.02		−3.08	−5.65		

ADF, Augmented Dickey Fuller test; PP, Phillips Perron test; KPSS, Kwiatkowski, Phillips, Schmidt and Shin test. Level is the value of the unit root test at the first dif. The values of the unit root test at the first difference and second dif. shows the value of the second difference in the unit root test.
The critical values of the ADF and PP tests in the tables at the 1 %, 5 %, and 10 % significance levels, respectively, are −3.97, −3.41, the table critical value of −3.13, and the KPSS test results are 0.21, 0.14; 0.11.

Table 7
Fourier granger causality and granger causality test results.

Equations	F Test
DUS=DUS(-1) DUS=DUS(-1) + DOP(-1)	**F(1, 680)=4821.33*** **
DCh = DCh(-1)	F(1, 677) = 1.42
DC = DC(-1) + DDOP(-1)	
DI = DI(-1)	F(1, 680) = 0.02
DI = DI(-1) + DOP(-1)	
DSA = DSA(-1)	F(1, 679) = 0.06
DSA = DSA(-1) + DOP(-1)	
DR = DR(-1)	F(1, 679) = 0.54
DR = DR(-1) + DOP(-1)	
DJ=DJ(-1)	**F(1, 680)=4.40** **
DJ=DJ(-1) + DOP(-1)	
DSO = DSO(-1)	F(1, 678) = 0.22
DSO = DSO(-1) + DOP(-1)	
DB = DB(-1)	F(1, 680) = 0.09
DB = DB(-1) + DOP(-1)	
DC = DC(-1)	F(1, 680) = 0.40
DC = DC(-1) + DOP(-1)	
DM = DM(-1)	F(1, 680) = 0.19
DM = DM(-1) + DOP(-1)	
DT = DT(-1)	F(1, 678) = 1.12
DT = DT1(-1) + DOP(-1)	
N=N(-1)	**F(1, 678)=30.03***
N=N(-1) + DOP(-1)	
L=L(-1)	**F(1, 678)=43.66** **
L=L(-1) + DOP(-1)	
DE = DE(-1)	F(1, 438) = 1.75
DE = DE(-1) + DOP(-1)	
DTOTAL = DTOTAL(-1)	F(1, 678) = 2.04
DTOTAL = DTOTAL(-1) + DOP(-1)	

D denotes the difference operator. The values in parentheses indicate the optimal lag length and number of observations.

Table 8
Residual-based fourier cointegration and cointegration test results.

Countries	Test statistic	Frequency (*k*)
US	**−3.97** **	
China	−3.79	1
India	**−4.12** **	
Saudi Arabia	**−3.83** **	
Russia	**−4.18** **	
Japan	**−3.64***	
South Korea	**−4.04** **	**2**
Brazil	−3.12	
Canada	**−4.46*** **	
Mexico	**−3.78** **	
Turkey	**−3.90***	**1**
New Zealand		
Luxembourg		
Estonia	**−3.85** **	**3**
Global Total	**−4.22** **	**2**

Null hypothesis: Series are not cointegrated; lag specification is based on Schwarz's criterion (max lag = 19). The critical values calculated from Engle and Yoo's [48] table are −4 for the 1 %, 5 %, and 10 % significance levels, respectively: 32, −3. 67 and −3. 28. Table critical values of the FEG test are at the 1 %, 5 %, and 10 % significance levels, respectively, according to the frequency values for t = 500: k = 1 -4.756 -4.198 -3.898; k = 2 -4.517 -3.912 -3.589; k = 3 -4.333 -3.685 -3.349 [45]. n, k, and T represent the number of independent variables, number of frequencies of the Fourier function, and sample size, respectively.

long-term oil prices and oil consumption in Japan can be eliminated. In contrast, the imbalance between the short and long-term in all other countries has not been eliminated (Table 9) (OC: oil consumption, OP: oil price, ε_{t-1} one period lagged value of error terms).

$$OC = 7445.92 - 43.\underset{(3.75)}{67OP} \text{ Long} - \text{term equation for Japan} \tag{10}$$

$$OC = 0.18_{+}(0.75)\ \underset{(24.49)}{0.94OC_{t-1}} - \underset{(-0.68)}{0.02OC_{t-2}} - \underset{(-0.33)}{0.12OP_{t-1}} - \underset{(-0.18)}{0.06P_{t-2}} - \underset{(-4.16)}{0.0006\varepsilon_{t-1}} \tag{11}$$

In Japan, a 1 % increase in oil prices reduces oil consumption by 43 % over the long-term. In the short-term, an increase in oil prices does not negatively impact oil consumption. A 1 % increase in oil prices increases oil consumption by 0.94 %, albeit only slightly. The error correction (ε_{t-1}) coefficient was calculated as −0.0006 and found to be statistically significant. Accordingly, in the series, a one-unit deviation in the short-term reaches equilibrium in 1.66 periods and on an annual basis in 20 months.

Table 9
Long-term equation estimation results.

Countries	ECM_{t-1}	Long-Term
US	0.000185 (2.28)	
China	−2.57E-05 (−0.47)	
India	−4.54E-06 (−0.11)	
Saudi Arabia	−4.03E-05 (−1.03)	
Russia	−0.000223 (−1.39)	
Japan	**−0.000669 (-4.16)**	**43.67591 (3.75)**
South Korea	5.58E-05 (0.61)	
Brazil	9.01E-05 (1.28)	
Canada	0.000279 (1.42)	
Mexico	3.66E-05 (0.57)	
Turkey	−0.000102 (−0.97)	
Estonia	0.000222 (0.54)	
Global Total	0.000186 (2.11517)	

The values in parentheses show the t-statistic values of the coefficients, and the variables not in parentheses show the coefficients of the variables. According to the LR, FPE, AIC, SC, and HQ information criteria, the optimal lag length was two in all series.

6. Discussion

Constant energy sources are required for sustainable economic growth and development. Oil is considered an important energy source for national economies, and the desire to own or control it makes it an indispensable resource in the political arena. This shows that oil is a crucial factor in terms of not only energy security but also in determining political and economic strategies.

Currently, it is estimated that there is only one barrel of oil discovery capacity for every two barrels of oil consumed. The energy demand is increasing, easily accessible reserves are decreasing, and oil discovery and extraction processes are becoming increasingly complex and expensive. This indicates that the energy sector should become more sustainable and efficient energy source in the coming period.

Countries that meet most of their oil needs through imports are significantly affected by increases in international oil prices. This situation negatively affects the foreign trade balance, current account deficit, and economic stability. Therefore, focusing on diversity and energy efficiency in energy policy is essential for countries that are dependent on energy imports.

In line with the goal of reducing oil consumption, the strategy of increasing the ratio of renewable energy to energy supply is crucial. Preventing the environmental destruction caused by fossil fuels and reducing the macroeconomic vulnerabilities brought about by energy dependency require turning to alternative energy sources for high and sustainable economic growth. These strategies play critical roles in environmental sustainability, energy security, and economic independence.

Oil prices are affected by several factors created by supply and demand dynamics. Various factors play a role on the supply side, such as changes in oil production, policies of the producing countries, natural disasters, and geopolitical factors. On the demand side, effects are present such as economic growth, industrial production, vehicle use, and seasonal factors. In some economies, increases in oil prices may not immediately affect short-term consumption. Consumers and businesses cannot quickly change their oil consumption habits and business processes because they are established within a certain period. Many businesses enter long-term agreements with suppliers or sign contracts to purchase oil at fixed prices for a specified amount of time. These agreements ensure that short-term price changes are not reflected in oil consumption. In addition, many consumers and businesses base their oil consumption on a lack of alternative options. For example, no other transportation options may be available to cover certain distances or alternative energy sources may be limited. Another reason is the perception that these increases may be instantaneous and temporary, causing consumers and businesses to be maintaining their current habits and plans.

The duration of the oil price increase depends on the supply-and-demand dynamics in the oil market and the price determination process. Oil prices are determined by the balance between supply and demand in the market, which may change suddenly. Increases in oil prices usually occur because of factors such as supply shortages in the market, increased demand, or geopolitical tensions. Under such circumstances, the duration of an increase in oil prices is uncertain and may vary. Rapid and uncertain changes in oil prices may occur, especially under the influence of external factors such as geopolitical factors. In the long-term, factors such as the discovery of new production resources, increased energy efficiency, and increased use of alternative energy sources will enable the formation of a new equilibrium value for oil prices.

These short and long-term effects vary between countries that consume large amounts of oil and those that consume little oil. The economic structure of a country also determines the impact of an increase in oil price on consumption. Because developed economies generally have more diversified industry structures, the effects of an increase in oil prices may be more evenly distributed. However, in developing countries, an increase in oil prices has more significant effects on energy-intensive industries and may have a more negative impact on consumption.

The persistence of fluctuations in oil consumption reflects a complex situation resulting from various factors in global energy markets. These fluctuations occur because of several factors, such as imbalances between supply and demand, geopolitical events, technological developments, and changes in economic conditions. Therefore, the effects of oil consumption on the economy should be evaluated from a broad perspective.

Whether oil consumption fluctuations are permanent is complex, multifaceted, and depends on many variables. Shaping energy policies based on sustainability and stability is related to the potential to minimize the effects of these fluctuations. Temporary fluctuations can generally occur because of many short-term factors (e.g., economic cycles, seasonal effects, or special events). With sustainable energy policies, the effects of these fluctuations can be balanced and controlled quickly. Understanding the main factors affecting the persistence of fluctuations in oil consumption is important for determining energy policies and sustainable energy strategies.

7. Conclusions and recommendations

7.1. Analysis results

This study, in which countries that consume the most and least oil are selected, had three main objectives. Firstly, it is to be examined whether the fluctuations in oil consumption are permanent. Secondly aim, the relationship between oil consumption and oil prices is analyzed in the short and long-term. The third aim is to investigate when shocks in oil prices will reach equilibrium in the long-term. Analyzing the relationships between these variables using Fourier-based tests also offers a valuable perspective.

Many macroeconomic series are nonlinear. Events such as sudden price movements in energy markets can change the linear structure of oil-related series. The fact that the series does not contain unit roots significantly affects the consistency and effectiveness of the results of future predictions. Therefore, the Fourier unit root test was used to accurately determine whether the series of oil prices and consumption contained unit roots. It is important to accurately determine whether the effects of fluctuations in oil consumption are permanent, as well as to estimate causality and cointegration tests accurately.

Using the Fourier approach, structural changes were modeled using frequency components. This method can be used without prior knowledge of the number, location, or form of fractures, and does not impose any restrictions on the number of fractures. The Fourier function models smooth/facilitate gradual transitions in the deterministic term and enable stationarity analysis. This method can also capture the nonlinearities and structural changes in deterministic terms over time.

Fourier unit root testing uses a combination of sine and cosine waves to identify the nonlinear components and structures of a time series. This is an effective method to identify nonlinear components of the time series accurately. The Fourier unit-root test addresses the problem of the nonlinear structure of a time series using a combination of sine and cosine waves. This approach makes it possible to estimate the complex structures contained in a time series more effectively and consistently.

To achieve the first goal, unit root tests were applied to examine fluctuations in oil consumption over time. According to the Fourier ADF test, at the level of the oil consumption series of New Zealand and Luxembourg, China, South Korea, Turkey, Estonia, Total World, and Oil Price series were stationary at the first difference. According to traditional unit root tests, the US, India, Saudi Arabia, Russia, Japan, Brazil, Canada, Mexico, Turkey, New Zealand, Luxembourg, Estonia, oil prices, and the global total series are stationary at the first difference. When evaluated by considering the Fourier ADF test, fluctuations in the oil consumption series are temporary in New Zealand and Luxembourg, but appear to be permanent in China, South Korea, Turkey, and Estonia, as well as worldwide.

A causal relationship exists between oil consumption and prices in the US, Japan, New Zealand, and Luxembourg; thus, oil prices affect oil consumption in the short-term. In other countries, no relationship was observed between these variables. A long-term relationship exists between oil consumption and prices worldwide, including in the US, India, Saudi Arabia, Russia, Japan, South Korea, Canada, Mexico, and Estonia. In all the other countries (China, Brazil, and Turkey), no long-term relationship was found between these two variables.

Considering that fluctuations in oil consumption are temporary in New Zealand and Luxembourg, where oil consumption is low, short, and medium-term policies should be sufficient, without the need for long-term energy policies. However, fluctuations in oil consumption only temporarily affect a country's economy. Another important point is that future oil consumption values in New Zealand and Luxembourg are possible to accurately predict based on past values. This can help in creating effective energy policies.

Energy policies should be determined more carefully in China, South Korea, Turkey, and Estonia, where fluctuations in oil consumption are permanent. Because fluctuations and shocks cannot be balanced quickly, long-term energy policies should be planned and implemented. To reduce dependence on oil, energy resources should be used more efficiently, as well as traditional renewable energy sources (e.g., solar and wind energy). The use of zero- or low-carbon energy technologies such as hydrogen, carbon capture, utilization, and storage (CCS) technology, electrification, and bioenergy should be increased. Oil prices affect oil consumption in the short-term in the US, Japan, New Zealand, and Luxembourg. In the US, Japan, and other countries (e.g., New Zealand and Luxembourg), oil demand and prices have become more important because fluctuations in oil consumption are permanent in addition to the causality relationship.

These countries (the US, India, Saudi Arabia, Russia, Japan, South Korea, Canada, Mexico, Estonia, and worldwide), where a long-term relationship exists between oil consumption and prices, are more active in determining and implementing energy policies regarding oil demand and oil prices needs to be careful. In the ECM estimation, only the equation for Japan is statistically significant. A deviation of one unit between oil consumption and price can only be balanced within 20 months.

7.2. *Policyies implications and recommendations*

The world meets most of its energy it needs from fossil-based energy sources. Fossil fuels, particularly oil, are predicted to continue to meet a large proportion of the world's energy demand. Today, oil is in a position that closely affects and directs economic, political, social, and military developments in the international arena.

Ensuring the energy supply security of the world, whose oil consumption is rapidly increasing, energy, which is the primary input of the economy, and oil, its essential component, constitute the backbone of energy policy. As energy forms the basis of the economy, the security of energy resources, such as oil and natural gas, is of strategic importance. Countries with high energy imports should diversify their energy sources, increase energy efficiency, and reduce energy dependence by investing more in renewable energy sources. These strategies will promote a safe, sustainable, and economically effective approach for meeting energy demands. Energy policies, demographic characteristics, and economic and industrial structures are the main factors determining a country's oil demand (oil consumption). Although rapid economic growth in developing countries may increase oil demand, investments in energy efficiency and alternative energy sources may reduce it.

Incentive policies should be implemented to increase energy efficiency and investment in alternative energy sources. Such policies could increase energy independence by reducing oil demand and creating an economy that is more resilient to oil price fluctuations. Various policies can be implemented to ensure the security of the oil supply encourage the diversification of energy sources. These policies can significantly affect oil consumption long-term, to improve a country's energy security, and ensure a sustainable energy future. Additionally, the expansion and effective implementation of these policies significantly contribute to environmental sustainability as well as economic growth and development.

Short-term policies are effective in some countries while long-term policies are effective in others, and at the same time, implemented policies do not always have the same effect. Therefore, it is necessary to plan and implement energy policies to achieve the sustainable economic growth and development goals. However, it should not be forgotten that this sensitivity, should be shown for not only the economy but also the environment.

CRediT authorship contribution statement

Sabiha Oltulular: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Visualization, Investigation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendixes

Table
Explanations of Abbreviations

Abbreviations	Descriptions	Abbreviations	Descriptions
ε_t	Error term	SC	Schwartz Information Criterion
σ_ε^2	Variance	FPE	Final Prediction Error Information Criterion
$\alpha(t)$	Deterministic function of t	sin	Sine
n	Number of independent variables	cos	Cosine
k	frequency	Ch	China 's oil consumption
T	Number of observations	I	India 's oil consumption
SSR	Minimum sum squares residual.	SA	Saudi Arabia 's oil consumption
ADF	Augmented Dickey Fuller test	R	Russia 's oil consumption
PP	Phillips Perron test	J	Japan 's oil consumption
KPSS	Kwiatkowski, Phillips, Schmidt, and Shin test	SO	South Korea 's oil consumption
ERS	Elliott-Rothenberg-Stock	B	Brazil 's oil consumption
FADF	Fourier Augmented Dickey Fuller Unit Root Test	C	Canada 's oil consumption
D	Difference operator	M	Mexico 's oil consumption
First Dif.	First difference	T	Turkey 's oil consumption
ECM	Error correction model	N	New Zealand 's oil consumption
ECM_{t-1}	First lag of the error terms obtained from the cointegration equation	L	Luxembourg 's oil consumption
FEG	Fourier Engle Granger	E	Estonia 's oil consumption
AIC	Akaike Information Criterion	OP	Oil Price

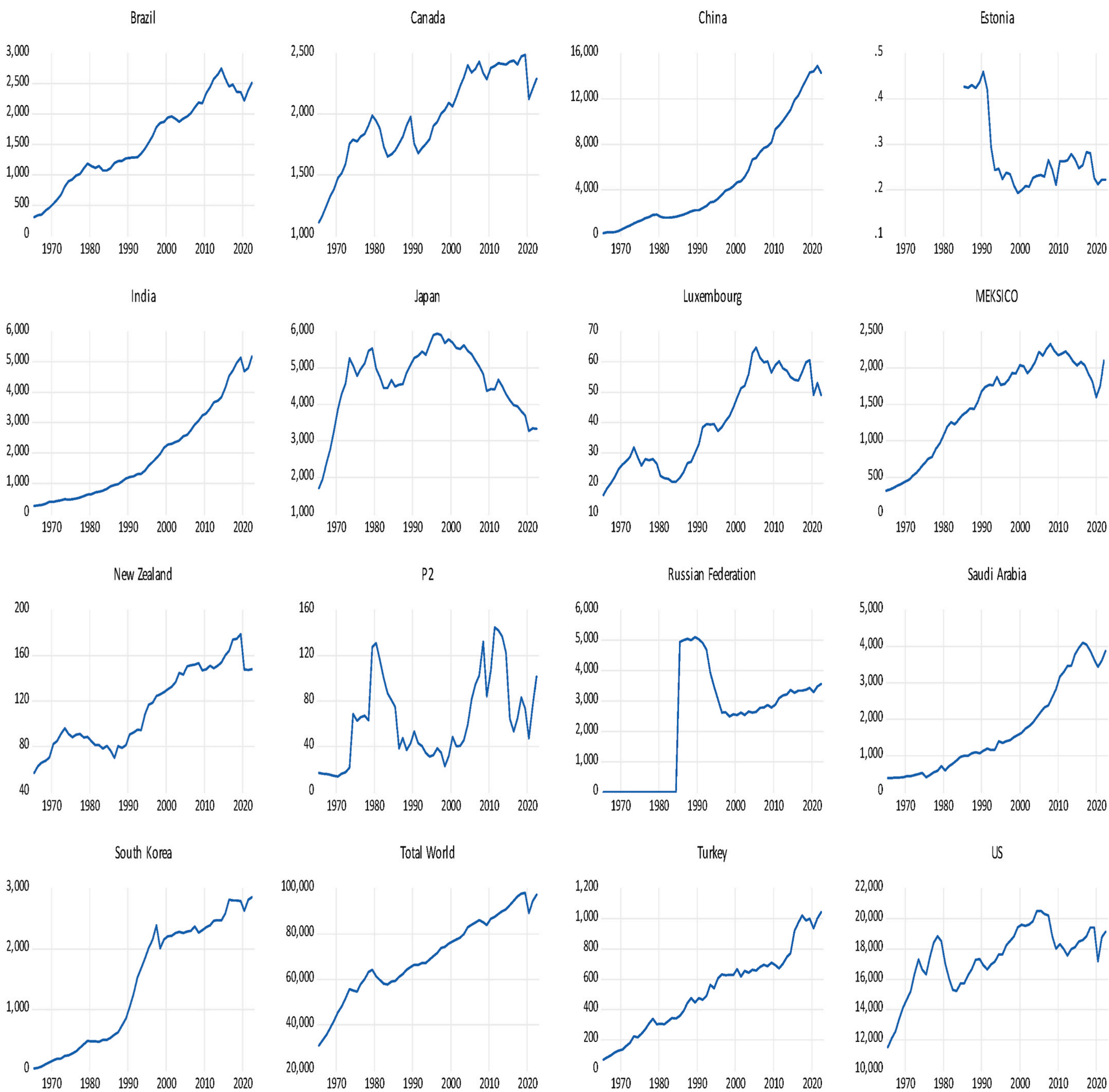

Fig. 1. Oil Consumption Series of Countries.

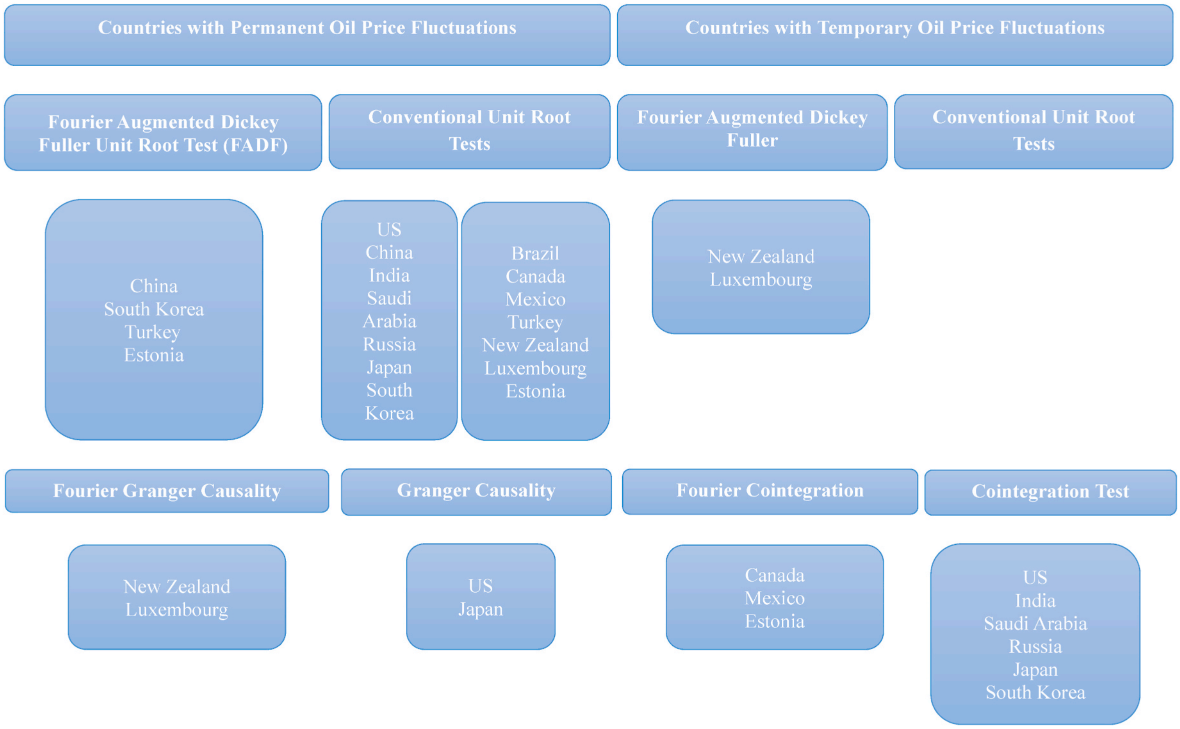

Fig. 2. Summary presentation of econometric analysis.
Source: Compiled by the author.

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