Energy Intensity in CIS Economies: Insights into Convergence with OECD Benchmarks

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Summary This study evaluates energy intensity convergence in Commonwealth of Independent States (CIS) economies in comparison to the OECD average from 2000 to 2019, utilising β-convergence and σ-convergence analyses based on conventional unit root analysis alongside the KSS stationarity approach, which accounts for data nonlinearities, and the Phillips–Sul club convergence procedure. The results indicate that most CIS countries did not achieve energy intensity convergence during the period under review. Furthermore, while the Phillips–Sul test classifies all studied countries, including the OECD-20, into a single convergence club, it only presents weak evidence of significant convergence. This limited convergence is likely hindered by the continued presence of Soviet-era manufacturing infrastructure in many CIS economies. From a policy perspective, the development of comprehensive economic frameworks that incorporate legal, institutional, technical, and financial reforms, supported by targeted investments in research, cutting-edge technologies, and updated standards, is essential to significantly boost energy efficiency and effectively address challenges on both the supply and demand sides.

Keywords: Energy intensity, economic growth, unit root, nonlinear stationarity, convergence

JEL Classifications: C10, C12, Q43, Q48

Introduction

Research in energy economics expanded significantly in response to the detrimental effects of the energy crises on production during the early 1970s. As noted by Burcu Kiran (2013), the focus on energy intensity convergence intensified following the adoption of the 1997 Kyoto Protocol, which established the reduction of energy consumption and intensity as crucial strategies for mitigating emissions from industrial production.

This study employs a newly developed and comprehensive set of empirical methodologies, contributing significantly to both substantial theoretical and empirical contributions to the existing literature. We utilise advanced applied methods that accommodate asymmetric adjustments and gradual structural changes in the data generation process. This approach effectively addresses concerns raised by Reşat Ceylan, Erdinç Telatar, and Funda Telatar (2013) regarding potential nonlinearities that could result in misleading conclusions when employing linear regression analyses. Furthermore, we adopt the methodology proposed by Peter C. B. Phillips and Donggyu Sul (2007) to investigate the phenomenon of club convergence.

The remainder of this paper is organised as follows: Section 1 provides a comprehensive overview of relevant literature, highlighting key findings from previous studies in the field. In Section 2, we offer an informative examination of the energy sector within CIS, outlining its characteristics and significance. Section 3 details the econometric methodologies employed in this research. In Section 4, we present and critically analyse the results of our tests. Finally, Section 5 concludes the paper by summarising the key findings discussing their implications in the context of energy intensity convergence.

1. Energy Intensity Convergence

The convergence hypothesis, first proposed by Moses Abramovitz (1986), examines whether differences in real income per capita among countries decrease over time. Since the mid-1980s, progress in econometric techniques and access to extensive long-term macroeconomic data have significantly heightened academic interest in this area. Oded Galor (1996) identifies three main hypotheses on convergence in the literature. The absolute convergence hypothesis suggests that the per capita income levels of countries will align over time, regardless of initial conditions. In contrast, the conditional convergence hypothesis argues that such alignment occurs only among countries with similar structural characteristics, while the club convergence hypothesis adds the condition that initial circumstances must also be alike for convergence to take place.

Vinod Mishra and Russell Smyth (2014) highlight the critical importance of energy convergence due to its implications for sustainable energy consumption and the reduction of carbon dioxide emissions, particularly in understanding how energy consumption correlates with GDP growth. The occurrence of rapid energy convergence alongside moderate growth rates suggests that policies aimed at reducing energy intensity and enhancing efficiency are yielding positive results. Given the increasing share and costs of energy in economic activities, the necessity for investigation in this field has become increasingly evident.

Yannick Le Pen and Benoit Sevi (2010) state that the hypothesis of convergence between national energy intensities, despite its limited attention in the literature, holds significant importance for several reasons. First, it aids in establishing equitable environmental constraints that allow developing countries to grow while enabling developed nations to maintain their consumption levels, thus facilitating adherence to international protocols. Second, a lack of convergence can uncover patterns in the diffusion of energy-related technologies, which can inform regulatory incentives. Third, understanding trends in energy intensity is crucial for energy decision-makers responsible for managing networks and investments. Fourth, convergence has important implications for equitable climate change policies, as it addresses disparities in energy consumption. Fifth, it offers insights into the effects of energy sector liberalisation on technology diffusion and changes in energy intensity. Finally, analysing convergence contributes to the Environmental Kuznets Curve debate by raising concerns that non-convergence may result in increased pollution in developing countries as they experience economic growth.

In contrast, as A.Hakan Çermikli and Ibrahim Tokatlıoğlu (2015) indicate, technological development is regarded as the primary driver of improvements in energy efficiency. Although the relationship between technological processes and energy consumption is complex, it is clear that technological advancements contribute to energy savings. Developed countries recognised this trend and quickly adopted technological transformations following World War II. As a result, OECD countries are able to utilise energy more efficiently than the rest of the world.

In this study we specifically investigate whether the economies of the Commonwealth of Independent States (CIS) member countries are converging toward the energy intensity levels observed in OECD economies, despite the political, economic, and cultural separations since the early 1990s, which have not eliminated the significant similarities and interconnections within their economic structures. Additionally, we examine whether convergence occurs at the club level, where states with similar characteristics can be grouped into distinct clubs.

Understanding this convergence is essential for evaluating whether CIS nations can achieve their post-independence energy conservation goals, particularly by increasing the share of low-energy-intensity industries similar to those in more developed nations. The convergence of energy intensities in CIS countries to levels seen in OECD countries can be viewed as a positive development for sustainable economic growth, indicating that these nations are utilising their energy resources more efficiently. Also, this paper examines the convergence of GDP growth, as it is plausible that real incomes across these nations may align alongside energy intensity levels. By exploring these dimensions, we aim to provide valuable insights into the energy dynamics of CIS economies and their potential pathways toward sustainable development.

2. Previous Studies

A substantial body of foundational literature in this field suggests that energy intensity is declining in developed economies. Conversely, in developing countries, energy intensity often increases despite improvements in the efficiency of energy production and consumption, highlighting the ongoing industrialisation process (Lars Nielsson, 1993; Jose Goldemberg 1996; Otavio Mielnik and Jose Goldemberg, 1999). Economic theory primarily highlights that energy consumption increases as countries transition from labour-intensive agricultural production to capital- and energy-intensive industries during the economic development process. Moreover, this structural transformation in the national economy often results in the transition from industry- and energy-oriented production to an information-intensive services sector. The relationship between energy intensity and economic development is commonly described by the Kuznets Curve hypothesis in mainstream literature. This U-shaped curve illustrates that energy intensity tends to rise during the initial stages of economic development but subsequently declines as economic activities shift from industrial production to the services sector in later stages.

Several studies in the literature investigate energy intensity in transition economies. Jan Cornille and Samuel Fankhauser (2002; 2004) utilise arithmetic methods to decompose energy parameters in order to identify the primary factors influencing changes in energy intensity in transition economies from 1992 to 1998. They found that improvements in enterprise restructuring and energy prices are the key driving forces promoting efficient energy use in these economies. Furthermore, Cornille and Fankhauser (2002; 2004) indicate that, unlike other groups of transition economies, the countries that primarily compose the CIS economies did not have any incentives for either the industrial sector or the broader economy to reduce their energy intensity during the observed period. Similarly, Roberto Ezcurra (2007) investigates the spatial distribution of energy intensities across 98 countries from 1971 to 2001, employing a non-parametric approach to analyse the dynamics of the entire cross-sectional distribution. This study finds evidence of a convergence process in energy efficiency levels among the observed countries throughout the research period. Brantley Liddle (2010) enhances this research by updating the data and examining convergence among different groups of countries, in addition to global convergence. His results indicate that the group of countries, which includes former Soviet republics and several Balkan economies, is integrated into a broader European context, demonstrating a significant convergence process in energy use and development during the observed period.

Anil Markandya, Suzette Pedroso-Galinato and Dalia Streimikiene (2006) examine energy intensity convergence in several transition economies of Eastern Europe and the EU, employing an econometric model of lagged adjustment. They conclude that if energy intensity convergence in developing countries occurs rapidly enough and the economic growth rate is sufficiently high, total energy consumption in these economies may not increase. In this scenario, establishing a goal of maintaining stable energy consumption could serve as a feasible and desirable element of a sustainability strategy in developing economies.

Chepel (2017) proposes a methodological framework that employs econometric analysis of global statistical data to support the reduction of energy intensity in CIS economies. The study suggests these countries possess considerable potential for enhancing energy efficiency. To realise this potential, it is essential to strengthen governmental institutions and focus on fostering competitive markets for energy-saving technologies, econometric products, energy audits, and energy-saving standards. Additionally, measures should be implemented to reduce the shadow economy, enforce stricter fuel tariffs, and enhance the integrity of state institutions to combat corruption.

Celil Aydin and Ömer Esen (2018) analyse whether the impact of energy consumption on economic growth varies with energy intensity levels in 12 CIS countries from 1991 to 2013. Using a dynamic panel threshold regression model, the study identifies a critical energy intensity threshold of 0.44%. The findings indicate that energy consumption below this threshold positively influences economic growth, while consumption above it significantly hampers growth. The study highlights the importance of considering energy intensity when designing energy policies, as low-energy-intensity environments can yield substantial economic benefits in the examined CIS economies.

As inferred from the literature review, while energy intensity has been extensively examined in the context of CIS countries using various concepts, time periods, methodologies, and variables, the findings remain inconclusive, providing no definitive empirical evidence or consensus on effective growth or energy policies. Moreover, no existing study appears to have investigated the convergence of energy intensity between CIS and OECD countries. Although CIS countries have undertaken efforts to reduce energy intensity during their transition to market economies, their progress has been markedly uneven. Evaluating the convergence of their energy intensities with those of advanced OECD economies - which may be considered benchmarks for energy efficiency - is crucial for assessing progress toward energy-saving objectives. This study aims to address this significant gap in the literature.

3. Energy Sector in Commonwealth of Independent States

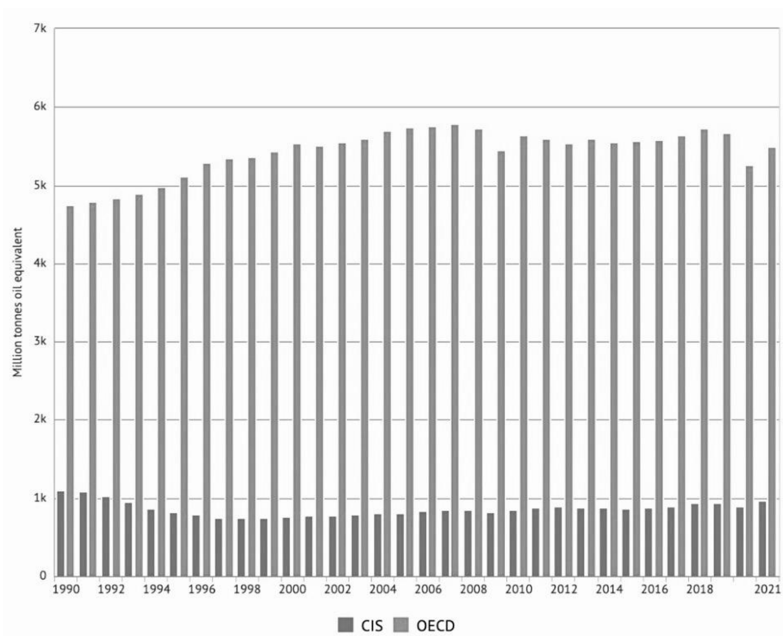
Energy is widely recognised as a vital contributor to the economic development of many CIS countries, playing a significant role in foreign investment inflows and export revenues—both essential components of national income. However, several of these nations, such as Armenia, Belarus, Georgia, Ukraine, Moldova, and Tajikistan, are classified as net energy importers, requiring substantial payments to secure energy resources from abroad. The sustainability of economic growth, in accordance with macroeconomic objectives, depends on maintaining a manageable current account deficit; therefore, energy consumption and intensity are critical factors—particularly for these energy-importing CIS economies. Policymakers should prioritise these issues to ensure long-term economic stability.

The CIS region is globally recognised as a major energy supplier, accounting for nearly 40% of the European Union's total fossil energy imports. In recent years, countries such as Belarus, Georgia, Ukraine, Azerbaijan, and Russia have emerged as critical energy transit hubs. This status not only helps attract foreign direct investment but also enables these nations to generate revenue for their public budgets through transit fees. Moreover, they have the potential to exert upward pressure on domestic energy prices, thereby influencing their economic dynamics. By capitalising on their strategic position in energy transit, these countries can enhance their economic resilience and promote greater integration into the global energy market. Since the collapse of the Soviet Union in the early 1990s, the CIS countries have sought to integrate into the global market system. Characterised by high rates of primary energy consumption, these countries are recognised as significant energy consumers, reflecting their persistent high energy intensity. The low domestic tariff policies established during the Soviet era have impeded the implementation of energy-saving measures, thereby fostering a landscape of energy inefficiency across all CIS nations.

Furthermore, the rising energy consumption within the manufacturing sector in the post-Soviet period has substantially impacted the competitiveness of CIS economies. The increased energy requirements in production processes have led to higher production costs for final goods, ultimately diminishing their competitiveness in both domestic and international markets. This situation underscores the pressing need for these countries to adopt more efficient energy practices and policies to enhance their economic performance and integrate more effectively into the global economy.

As illustrated in the figure below, the primary energy consumption of member countries in the Commonwealth of Independent States (CIS) increased from 757.33 million tonnes of oil equivalent in 2000 to 923.93 million tonnes of oil equivalent in 2019. This growth represents an average annual increase of 1.07%. This trend highlights the rising demand for energy within the region, reflecting both economic development and ongoing energy consumption patterns over the specified period.

Figure 1 Primary Energy Consumption in CIS and OECD countries 1990-2021



Source: Calculations based on BP Statistical Review of World Energy - Main Indicators[1]

The primary driver of increased energy consumption in the CIS countries can be attributed to the inefficient use of fuel and electricity within both the industrial sector and residential housing. This inefficiency is exacerbated by

[1] https://public.knoema.com/sdybxie/bp-statistical-review-of-world-energy-main-indicators?location=1000120-cis

relatively low domestic energy prices, which fail to incentivise energy conservation practices. Additionally, the energy transport infrastructure in these countries is considerably outdated, resulting in further reductions in efficiency.

Addressing the challenges associated with high energy consumption and low energy efficiency is crucial for CIS nations. By improving these aspects, they can significantly enhance the energy intensity indicators of their economies—an issue that has emerged as a critical economic concern in recent years. Furthermore, achieving greater energy efficiency will not only bolster energy security but also reduce dependence on foreign energy sources, thereby fostering greater economic stability and sustainability in the region.

In addition to the annual growth in primary energy consumption, the inadequate and often minimal utilisation of renewable energy resources in CIS economies contributes significantly to their high energy intensity relative to developed OECD countries. This disparity indicates that, for the same volume of energy resources consumed, industrialised nations are able to generate several times more value-added output compared to their CIS counterparts[2].

Among the member economies of the CIS, the highest levels of energy intensity per unit of GDP are observed in Kazakhstan, Turkmenistan, Uzbekistan, and Ukraine[3]. This trend highlights the urgent need for these countries to enhance their energy efficiency and diversify their energy portfolios by integrating more renewable sources, thereby improving their economic performance, and aligning more closely with the energy utilisation standards of developed nations. The Russian Federation plays a pivotal role in the energy sectors of the Commonwealth of Independent States (CIS) and is recognised as one of the largest suppliers of fossil energy resources in the global energy markets. Notably, prior to 2009, Russia emerged as a global leader in reducing energy intensity relative to GDP. According to research by Tatiana Mitrova and Yuriy Melnikov (2019), from 1998 to 2008, the gap in energy intensity between the Russian Federation and developed industrial countries decreased significantly, with a remarkable 40% reduction in the energy intensity of GDP during this period. However, the onset of the global economic crisis in 2009 not only halted this positive trend but also reversed it. In contrast, Azerbaijan has experienced a consistent decline in energy intensity since 1990. Between 2000 and 2010, Azerbaijan's energy intensity decreased annually by an impressive 12%, and from 2010 to 2019, this reduction continued at a rate of 2.3% per year[4]. This divergence in energy intensity trends between Russia and

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[2] Economic Aspects of the Energy Sector in CIS Countries CASE – Center for Social and Economic Research, European Communities, 2008.
https://ec.europa.eu/economy_finance/publications/pages/publication12678_en.pdf
[3] 3https://unece.org/DAM/energy/se/pdfs/eneff/publ/Incr_EE_SecureEnergySupplies_Report_e.pdf
[4]https://www.enerdata.net/estore/energymarket/azerbaijan/#:~:text=The%20energy%20intensity%20of%20GDP,level%20at%20purchasing%20power%20parity.

Azerbaijan highlights the varying dynamics and challenges faced by CIS countries in their pursuit of energy efficiency and economic development.

4. Empirical Specification

The convergence hypothesis, often specified as β-convergence and σ-convergence, fundamentally proposes the alignment of per capita output or income across economies and has been a central focus in applied economic literature, particularly since the late 1980s. Following the foundational works of Robert J. Barro and Xavier Sala-i-Martin (1995) and Sala-i-Martin (1996), absolute β-convergence occurs in capital-poor countries where there is a negative relationship between initial income levels and economic growth rates. This phenomenon is attributed to the higher marginal productivity of capital in such economies due to diminishing returns. Under β-convergence, one series tends to grow faster than another, reflecting a catch-up dynamic.

In contrast, σ-convergence pertains to the reduction in cross-sectional dispersion of the series over time. A group of series is considered to exhibit σ-convergence if the variance in their levels shows a declining trend. Naves R. Balado, Jose Banos-Pino, and Matias Mayor (2021) highlight that this conventional framework has been employed in earlier studies, such as those by Asami Miketa and Peter Mulder (2005), Markandya, Pedroso-Galinato, and Streimikiene (2006), Liddle (2010; 2012), Sebastian Voigt et al. (2014), and Zsuzsanna Csereklyei, M. d. Mar Rubio-Varas, and David I. Stern (2016). These studies investigate energy convergence across various sectors and economies, yielding mixed findings concerning conditional and absolute β- and σ-convergence.

Additionally, Andrew B. Bernard and Steven N. Durlauf (1996) propose two critical definitions of convergence grounded in neoclassical economic growth theory. The first suggests that countries are converging if the gap in per capita domestic production between two different periods shows a declining trend.

$$E\left(y_{i,t+T} - y_{j,t+T} \middle| \delta_t\right) < y_{i,t} - y_{j,t}.$$

Here, δ_t represents all information available at time *t*. Secondly, convergence can be defined in terms of long-term forecasts at a fixed point in time. Under this definition, two countries are considered to converge if their long-term forecasts for per capita domestic production are equal at the specified time:

$$\lim_{k\to\infty} E\left(y_{i,t+k} - y_{j,t+k} \middle| \delta_t\right) = 0.$$

Based on this equality, investigated series will not convergence if $(y_{i,t+k} - y_{j,t+k})$ does not converge to a limiting stochastic process. Bernard and Durlauf (1996) state that if $(y_{i,t+k} - y_{j,t+k})$ equals 1 in even periods and -1 in odd periods, countries will not converge, even if the sample mean of the differences is equal to zero. Hence, the convergence among the demeaned series as $(y_{i,t+k} - y_{j,t+k})$ with a zero mean or stochastic pattern may be disregarded (Erdinç Telatar and Nermin Yasar, 2020).

Following Clive W. J. Granger and Timo Teräsvirta (1993), it is essential to account for potential nonlinearities in economic time series, as many such series may follow nonlinear processes. Neglecting these dynamics can lead to statistically insignificant or misleading results. Additionally, George Kapetanios, Yongcheol Shin, and Andy Snell (2003) emphasise that conventional unit root tests have reduced power when the data-generating process is influenced by regime changes. If a time series is globally stationary but exhibits nonstationary behaviour within specific regimes, test procedures that disregard regime-dependent dynamics and nonlinearities may yield biased outcomes, erroneously rejecting stationarity.

a. Linear Unit Root Tests

In this study, we initially apply linear unit root tests, including those developed by David A. Dickey and Wayne A. Fuller (1981), Peter C. B. Phillips and Pierre Perron (1988), and Denis Kwiatkowski et al. (1992), to examine whether energy intensity series are stationary. As an extension of the basic Dickey-Fuller test, the Augmented Dickey-Fuller (ADF) test incorporates additional lagged values of the dependent variable to account for potential autocorrelation within the observations. The ADF test is applied to the following regression model:

$$\Delta y_t = \alpha y_{t-1} + x_t'\delta \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + e_t \quad (1)$$

Here Δ represents the difference operator, y_t is the dependent variable, x_t is a vector of optional exogenous repressors α, δ, β are parameters that should be estimated, and e_t is the error term that is assumed to be white noise.

$$t_\alpha = \frac{\widehat{\alpha}}{s_e(\hat{a})}$$

The conventional t-statistics illustrated above can be employed to test the null hypothesis of a unit root (H_0: $\alpha = 0$) against the alternative of a stationary process, $(H_1\colon \alpha < 0)$, where $\hat{\alpha}$ denotes the estimation of α and $(\hat{\alpha})$ is the coefficient of standard error.

The Phillips and Perron (1988) and Kwiatkowski et al. (1992) tests can also be applied to equation (1). However, compared to the ADF test, the Phillips and Perron (1988) test employs a non-parametric approach to stationarity testing. This method is robust to serial correlation and time-dependent heteroscedasticity in the series, as well as to regime changes during the observation period, providing statistically significant results under such conditions.

In contrast, the Kwiatkowski et al. (1992) test adopts a Lagrange Multiplier approach, testing the null hypothesis of stationarity against the alternative hypothesis of a unit root. This framework differs fundamentally from the ADF and Phillips and Perron (1988) tests, which assume a null hypothesis of a unit root.

b. Nonlinear Unit Root Procedure

The Kapetanios, Shin, and Snell (2003) (KSS) testing procedure accommodates nonlinearities in the data-generating process and is built upon the Exponential Smooth Transition Autoregressive (ESTAR) model. This model is represented as follows:

$$\Delta y_t = \gamma y_{t-1}\,[1 - exp(-\theta y_{t-1}^2)] + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \quad (2)$$

Here, θ determines the speed of transition between two regimes that correspond to extreme values of the transition function. The global stationarity of the process y_t can be established by testing the null hypothesis $H_0\colon \theta = 0$ against the alternative $H_0\colon \theta > 0$. Since the parameter γ is not identified under the null, Kapetanios, Shin and Snell (2003) substitute the transition function $F(\theta, y_{t-1}) = 1 - \exp(-\theta y_{t-1}^2)$ by its first-order Taylor approximation around $\theta = 0$, yielding the following auxiliary regression:

$$\Delta y_t = \delta y_{t-1}^3 + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + e_t \quad (3)$$

where e_t contains ε_t and the error term resulting from Taylor approximation (Ceylan, Telatar and Telatar, 2013). The test statistic for the null hypothesis of unit root $\delta = 0$, against the alternative one $\delta < 0$ can be expressed as below:

$$t_{NL} = \frac{\widehat{\delta}}{s.e.(\hat{\delta})}$$

where $\hat{\delta}$ is the OLS estimate of δ and s.e.($\hat{\delta}$) is the standard error of $\hat{\delta}$.

c. Club Convergence

Panel unit root tests are widely employed in empirical research to assess whether a variable exhibits convergence, with the presence of a unit root signifying the absence of convergence. A major limitation of these tests lies in their assumption that all countries in the sample are uniformly affected by the same external factors. As a result, when only a subset of countries within the panel is converging while the majority are not, the tests may inaccurately indicate a lack of convergence, thereby undermining the effectiveness of shared policy recommendations. Phillips and Sul (2007) introduce a convergence testing approach that tackles this challenge by employing a clustering methodology. This method groups the countries in the analysis based on similarities within the data matrix and evaluates convergence within each identified group or "club."

This methodology employs a time-varying common factor framework, outlined as follows.

$$X_{it} = \delta_i \mu_t + \varepsilon_{it} \qquad (4)$$

As noted by Phillips and Sul (2007), the parameter δ quantifies the idiosyncratic distance between a common factor μ_t and the systematic component of X_{it}, where μ_t may represent aggregate behavior or any shared variable influencing individual outcomes. The model describes the progression of X_{it} relative to μ_t by incorporating its systematic component δ_i and the associated error term $\varepsilon_{it.}$ According to Apergis Nicholas, Christou Christina and Miller Stephen (2012), all N economies will eventually reach a steady state in the future, provided that $\lim_{k\to\infty} \delta_{i,t+k} = \delta$ for every $i = 1,2,\dots,N$ regardless of whether the economies are currently close to the steady state or in a transitional phase. This is particularly significant as the trajectories toward the steady state (or states) can vary considerably across different countries. As $\delta_{i,t}$. cannot be directly estimated from Equation (1), Phillips and Sul (2007) address this by normalising the common component μ_t to the cross-sectional average:

$$h_{it} = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}} \qquad (5)$$

The relative measure h_{it} reflects the transition path relative to the panel average. Developing a formal econometric test for convergence and an empirical algorithm for identifying club convergence necessitates the following assumption regarding the semi-parametric form of the time-varying coefficients δ_{it}:

$$\delta_{it} = \delta_i + \sigma_{it}\xi_{it} \qquad (6)$$

Here, $\sigma_{it} = \sigma_i L(t) t^a$, where $\sigma_i > 0$, t ≥ 0 and ξ_{it} is weakly dependent over t but independent and identically distributed over i. The function $L(t)$ increases slowly and diverges as t approaches infinity. Under this framework, the null hypothesis assumes convergence for all (H_0: $\delta_i = \delta$, α ≥ 0), while the alternative hypothesis suggests non-convergence for some (H_1: $\delta_i \neq \delta$ or α < 0).

Phillips and Sul (2007, 2009) propose the log-t regression model described below to test this null hypothesis:

$$Log\left(\frac{H_1}{H_t}\right) - 2\log L(t) = a + b\log(t) + \varepsilon_{it} \qquad (7)$$

Here, $H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2$ is the square cross-sectional distance relative transition coefficients. As recommended by Phillips and Sul (2007), Equation (4) is estimated for $t = [\mathrm{rT}], [\mathrm{rT}] + 1, \ldots, \mathrm{T}$, where $r > 0$. rT represents the first observation in the regression. Drawing on Monte Carlo simulations, Phillips and Sul (2007) suggest setting $r = 0.3$ when T ≤ 50. The null hypothesis of convergence is rejected if $t_b < -1.65$. According to this method known as the Log(t) test, if the panel fails to exhibit convergence, the analysis proceeds to apply the clustering mechanism.

5. Data and Estimation Results

This study draws on annual data for energy intensity and GDP spanning 2000 to 2019, encompassing 20 OECD countries and 12 CIS countries. These data are sourced from the World Bank's World Development Indicators. The initial phase of the analysis concentrates on high-income OECD nations—Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. For these countries, the average energy intensity and GDP growth rates—collectively referred to as the OECD-20 average—are calculated over the sample period. Subsequently, the study employs both traditional and advanced econometric techniques to examine the stationarity properties of the energy intensity and GDP growth gap between the CIS economies and the OECD-20 average.

Given the Russian Federation's historical, political, and economic prominence within the CIS, it serves as the benchmark or leading case in this analysis. The study subsequently investigates whether energy intensity and GDP growth in other CIS countries converge toward Russian levels between 2000 and 2019.

A preliminary visual examination of the energy intensity data, depicted in Figure 2, suggests that CIS countries appear to be converging toward a shared mean over time.

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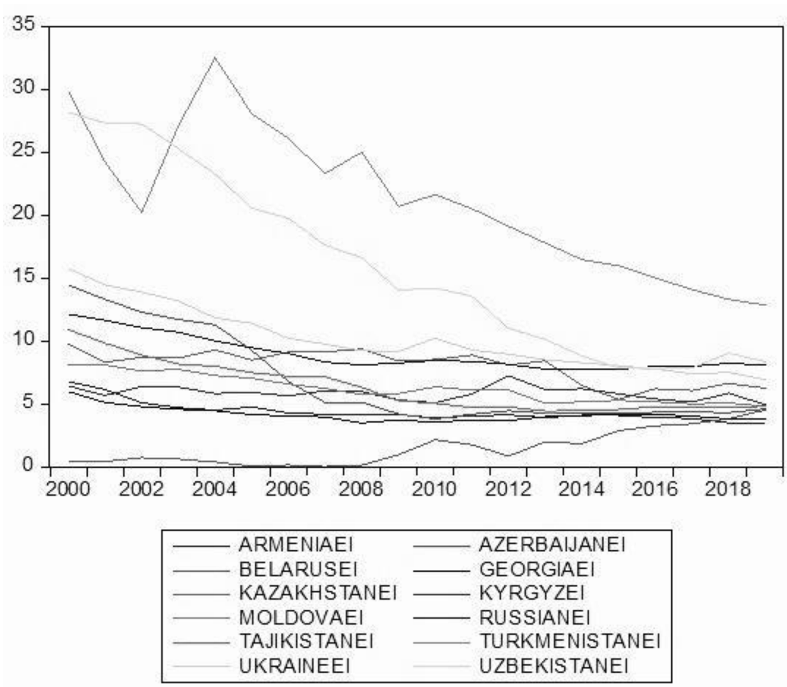
Figure 2: Energy Intensity Series of CIS Countries



Source: Calculations based on World Bank Data Bank – World Development Indicators

Although preliminary visual inspection suggests a possible convergence trend among CIS countries, it does not suffice as conclusive evidence. To address this limitation, the study assesses the stationarity of squared demeaned energy intensity and GDP series, along with the corresponding gaps relative to the Russian Federation and the OECD-20 average. By employing the conventional Augmented Dickey-Fuller (ADF) tests (results presented in Table A1 of the Appendix), the analysis aims to determine whether these series exhibit mean-reverting properties. The presence of stationarity would support a convergence hypothesis, whereas persistent unit roots would indicate otherwise. This approach thus provides a more rigorous framework than purely visual methods for evaluating long-run convergence dynamics in the energy intensity data.

According to the ADF test findings, the squared demeaned energy intensity series and their deviations from the OECD-20 average exhibit stationarity (I(0)) in Armenia, the Kyrgyz Republic, the Russian Federation, and Tajikistan, indicating potential convergence with the OECD-20 in these instances. By contrast, the remaining countries display nonstationary energy intensity and GDP growth series, suggesting no evidence of convergence. Furthermore, the lack of statistically significant stationarity in the deviations from the Russian Federation benchmark implies that no convergence occurs between the Russian Federation and the other CIS countries in terms of energy intensity and GDP growth.

Because the conventional ADF test does not accommodate potential nonlinearities in the data-generating process, its interpretations may be ambiguous. Consequently, this study applies the LM-type test proposed by Luukkonen, Saikkonen, and Teräsvirta (1988), later refined by Granger and Teräsvirta (1993), to determine whether the examined series exhibit linear or nonlinear behaviour. Specifically, the LM-type test is conducted for d=1,2, and 3 to capture any general nonlinearity over the sample period. The results, presented in Table A2, reveal that the null hypothesis of linearity is rejected in most datasets, including the energy intensity and GDP growth gap series, indicating that these series likely follow a nonlinear pattern. Building on these results, the study applies the KSS nonlinear unit root test to account for potential nonlinearities in the data-generating process.

As shown in Table A3, the KSS test predominantly rejects the null hypothesis of a unit root across most series, indicating a general lack of convergence. Nevertheless, notable exceptions arise among energy-poor countries such as Armenia, Belarus, and the Kyrgyz Republic, which appear to converge in energy intensity with both the Russian Federation and the OECD-20 average. This heterogeneity across countries implies that certain structural or policy factors may facilitate convergence in specific contexts while constraining it in others.

Conventional panel unit root tests frequently assume uniform external influences, potentially overlooking differences in convergence dynamics among various groups of countries. To address this shortcoming, Phillips and Sul (2007, 2009) propose a clustering-based “club convergence” method, which partitions economies into subgroups—or “clubs”—exhibiting similar characteristics. This approach facilitates a more nuanced analysis of convergence by recognising that not all countries follow a uniform convergence trajectory. According to the results in Table A4, the Phillips–Sul convergence test indicates that CIS countries plus the OECD-20 average form a single convergence club, with no evidence of divergent observations. The estimated speed of convergence β is negative; however, this coefficient is not statistically significant, as reflected by its standard error and low t-value. While the negative sign could suggest divergence or a very slow rate of convergence, the lack of statistical significance precludes definitive conclusions.

Moreover, the zero value of c* - a key diagnostic in the Phillips–Sul procedure - confirms that no separate convergence clubs emerge from the data. Consequently, the findings imply a single broad grouping in energy intensity without robust evidence of either pronounced convergence or distinct divergence among the sampled economies.

Concluding Remarks

This study investigates energy intensity convergence in Commonwealth of Independent States (CIS) economies relative to the OECD average between 2000 and 2019. It employs conventional unit root tests, the recently developed KSS stationarity approach, and the Phillips–Sul club convergence procedure. According to the KSS tests, which allow for nonlinearities in the data-generating process, energy intensity does not converge in most of the sampled CIS countries. However, exceptions include less energy-rich economies like Armenia, Belarus, and the Kyrgyz Republic. In contrast, the Phillips–Sul test suggests that all observed countries, alongside the OECD-20 average, fall into a single convergence club, albeit without strong evidence of rapid or robust convergence.

A plausible explanation for these results concerns the Soviet-era manufacturing systems still prevalent in many CIS economies. Outdated production technologies, combined with inefficiencies in energy generation and transportation, appear to hamper supply-side convergence, while non-competitive energy pricing disrupts demand-side adjustments. Consequently, modernising production processes and adopting more competitive pricing mechanisms emerge as critical steps for fostering convergence.

From a policy perspective, creating effective economic frameworks that include legal, institutional, technical, and financial reforms could encourage energy conservation and address both supply- and demand-side shortcomings. Drawing on the experiences of industrially advanced OECD countries, targeted investments in research and development, next-generation technologies, and updated energy- and resource-saving standards for construction, utilities, and transport are likely to significantly improve energy efficiency. Consistent with Chepel (2017), integrating energy-saving provisions into investment strategies and upgrading energy-intensive production processes offer substantial benefits. Moreover, enhancing energy efficiency can help alleviate inflationary pressures, thereby supporting higher rates of economic growth across the CIS region.

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APPENDIX

Appendix Tables

Table A1 ADF Test Results for CIS Countries

Countries	t-Statistics											
	Energy Intensity						GDP					
	De-meaned		Gap from Russian Federation		Gap from OECD-20 Average		De-meaned		Gap from Russian Federation		Gap from OECD-20 Average	
	Intercept	Intercept + Trend	Intercept	Intercept + Trend	Intercept	Intercept + Trend	Intercept	Intercept + Trend	Intercept	Intercept + Trend	Intercept	Intercept + Trend
Armenia	-10.17***	-8.96***	-1.31	-1.09	-4.76***	-4.58**	0.23	0.01	-2.07	-0.21	-2.08	-2.59
Azerbaijan	-3.03**	-2.74	-1.21	-1.50	-2.98*	-1.99	-2.78*	-2.36	-1.99	-1.93	-1.69	-1.09
Belarus	2.70	1.87	-2.07	-2.26	-0.78	-2.37	-3.15**	-2.71	-2.82	-2.82	-2.028	-1.67
Georgia	-1.69	-1.69	-1.43	-1.01	-2.23	-2.04	-0.46	2.11	-1.95	-1.09	-1.86	-3.24
Kazakhstan	-1.53	-2.67	-2.11	-1.92	-1.93	-2.61	-0.15	-3.13	-1.50	-2.39	-1.57	-1.44
Kyrgyz Republic	-4.87***	-5.08***	-2.50	-1.37	-3.59**	-3.70	-0.07	-0.01	-1.75	-1.36	-0.99	-2.18
Moldova	-2.42	-1.58	-3.04	-1.88	-1.97	-1.56	-0.04	3.29	-2.12	-0.71	-2.46	-2.46

Russian Federation	-3.99***	-3.93**	-1.72	-2.60	-2.98*	-2.08	-2.69**	-2.91	-1.80	-1.26	-1.99	-1.28
Tajikistan	-13.89***	-12.70***	-1.69	-5.09	-9.87***	-5.75***	0.60	1.30	-1.74	-1.47	-0.57	-2.20
Turkmenistan	-2.72*	-2.60	-4.06	-2.03	-1.77	-4.92***	-1.15	-0.13	-0.49	-1.48	-1.55	-3.22
Ukraine	-1.07	-4.19**	-2.80	-1.86	-5.80***	-3.44*	-3.51**	-3.23	-2.21	-1.26	-0.56	-1.66
Uzbekistan	-4.78***	-1.78	-2.31	-1.54	-2.79*	-0.40	-3.49**	-0.05	-2.10	-1.34	-1.66**	-2.21**

Notes: *** p <0.01, ** p <0.05, * p <0.1. The maximum lag length was taken as 3 and automatic lag length determined by SIC.

Table A2 LM Test Results for CIS Countries

Countries	***Energy Intensity***									***GDP***								
	Demeaned			**Gap from Russian Federation**			**Gap from OECD-20 Average**			**De-meaned**			**Gap from Russian Federation**			**Gap from OECD-20 Average**		
	d=1	d=2	d=3	d=1	d=2	d=3	d=1	d=2	d=3	d=1	d=2	d=3	d=1	d=2	d=3	d=1	d=2	d=3
Armenia	0.75	14.50***	16.94***	16.30***	9.35***	0.26	29.78***	0.34	0.23	11.61***	39.85***	104.26***	22.99***	17.08***	5.65**	0.17	14.21***	14.74***
Azerbaijan	9.17***	3.27*	0.31	10.26***	24.11***	17.70***	24.83***	7.64**	0.04	0.98	2.66	5.30**	0.23	7.72**	9.63***	0.00	24.51***	35.88
Belarus	0.35	2.53	11.89***	17.58***	12.71**	6.37**	1.40	3.05*	1.96	5.10**	10.40***	20.82***	0.18	33.61***	38.53***	0.18	33.61***	38.53***
Georgia	4.03*	1.45**	1.70	0.22	3.46*	9.90***	0.89	1.01	3.09*	8.92***	52.81***	201.66***	6.33**	9.91***	15.05***	0.84	16.04**	22.52***
Kazakhstan	12.88***	6.83**	11.05***	6.25**	3.13*	10.09***	6.70**	0.55	3.47*	25.12***	40.24***	73.28***	24.18***	8.58**	3.03	0.09	10.97***	17.79***
Kyrgyz Republic	1.18	0.38	0.45	3.21*	2.71	1.58	0.32	0.32	0.32	8.81***	18.58***	66.31	22.33***	19.52***	13.64***	0.07	11.56***	11.76***
Moldova	4.59**	4.16*	7.37**	1.51	3.13*	11.86***	1.18	0.00	0.59	3.39*	60.11***	267.05***	11.14***	28.33***	19.88***	888.83***	15.81**	13.94**

Russian Federation	6.73**	4.24*	5.32**				2.35	2.97	7.64**	5.20**	7.40**	18.26***				0.09	20.15***	34.10***
Tajikistan	12.08***	14.06***	22.41***	1.87	12.43	20.32	86.36***	58.28***	33.77***	341.69***	74.70***	341.69***	0.52	20.03***	13.18***	0.13	11.57***	11.41***
Turkmenistan	5.22**	5.86**	3.73*	23.78	20.03***	13.18***	5.87**	12.85**	5.86**	6.01**	13.08***	55.30***	4.64	10.45*	8.69***	1.63	21.17***	23.77***
Ukraine	24.46***	15.42***	29.91***	11.45**	0.68	0.23	3.64*	5.41**	3.64*	0.99	0.48	1.28	73.96***	63.16***	63.72***	0.77	16.08***	20.81***
Uzbekistan	9.68***	15.87**	64.44***	17.38***	8.37**	19.57***	28.39***	13.56***	24.64***	3.52*	21.37***	83.80***	27.36***	20.33***	11.90**	0.92	14.93**	14.22**

Note: *** p <0.01, ** p <0.05, * p < 0.1.

Table A3 KSS Test Results of CIS Countries

Countries	*Energy Intensity*			*GDP*		
	Demeaned	**Gap from Russian Federation**	**Gap from OECD-20 Average**	**Demeaned**	**Gap from Russian Federation**	**Gap from OECD-20 Average**
	t-Statistics					
Armenia	-0.16	0.01	-7.57***	1.54	0.37	0.29
Azerbaijan	-0.95	1.13	-0.28	-0.81	0.98	-0.02
Belarus	3.97	-2.55**	-0.20	-1.13	0.75	0.05
Georgia	2.86	-2.10*	3.01	1.64	0.65	0.11
Kazakhstan	4.11	-0.28	1.04	1.85	2.14	-0.76
Kyrgyz Republic	4.06	-3.43***	4.68	1.85	1.12	1.53
Moldova	1.07	0.20	-1.72	1.04	0.37	0.59
Russian Federation	-2.03		-1.64	-0.88		-0.41
Tajikistan	-1.32	0.35	-1.16	2.23	1.07	1.52
Turkmenistan	4.22	0.40	1.75	1.14	2.42	-0.05
Ukraine	1.70	-1.28	-1.27	-0.51	1.11	1.28

Uzbekistan	-0.16	-0.69	-1.04	1.39	0.90	1.11

Notes: Asymptotic critical values for the KSS test statistics at 1%, 5%, and 10% significance levels are −2.82, −2.22, and −1.92 for the test with the raw data, −3.48, −2.93, and −2.66 for the test with the demeaned data, and −3.93, −3.40, and −3.13 for the test with the demeaned and de-trended data, respectively [20]. *** p < 0.01, ** p < 0.05, * p < 0.1.

Table A4 Club Convergence Test Results for Energy Intensity

	B- coefficient	*Standard Error*	*t-value*	*c**
Club 1	-0.16	0.253	-0.633	0

Notes: If $\beta > -1.65$ the hypothesis of convergence cannot be rejected. If $\beta \leq -1.65$ the convergence is rejected.