**Are the Synergy of Stable Energy Supply, Robust Financial Service and Strong Economic Growth Achievable? Evidence from 134 Countries**

# Abstract

Stable energy supply and financial services drive economic growth, but they have also been linked to past crises. Technological progress helps prevent future energy and financial crises, potentially leading to a steady-state equilibrium in energy diversification, per-capita income, and financial development across countries. This study analyzes 134 countries from 1995 to 2019, testing convergence in these factors and exploring their interdependent relationships for the first time. While overall convergence was not found using the club convergence test, countries did converge within specific groups. Regression analysis revealed positive two-way relationships between energy diversification and per-capita income, as well as between financial development and per-capita income, with an increasing trend observed in these factors. The findings emphasize the importance of investing in human capital and technology for sustainable economic and financial development. Additionally, this study confirms the U-shape relationship between oil price and energy diversification for the first time.

Keywords: Convergence; Dynamic panel data analysis; Energy diversification; Financial development; Economic growth

JEL Classification: O47; Q01; Q42

# Introduction

Energy is a fundamental requirement for the functioning of various industries and services. The major energy sources today include crude oil, petroleum, natural gas, nuclear power, coal, and renewable energy. Among these, fossil fuels account for 80% of total energy consumption[[1]](#footnote-2). With increasing industrialization and economic modernization, global energy usage has consistently grown over the past few decades[[2]](#footnote-3) and is projected to increase by 30% by 2040[[3]](#footnote-4). However, fossil fuel energy sources are finite, harmful to the environment, and susceptible to geopolitical uncertainties (e.g., conflicts like the Russia-Ukraine war) and disruptions in the supply chain (e.g., the Covid pandemic). Reliance on a single fossil fuel energy source poses significant risks to economies[[4]](#footnote-5).

Energy diversification, which involves balancing multiple energy sources, is crucial for maintaining uninterrupted functioning of an economy. By diversifying energy sources, the risk of disruption is reduced as it is unlikely that all energy sources would simultaneously fail or become scarce. It is important to note that relying solely on renewable energy sources, which are inexhaustible and carbon-free, is insufficient to meet future energy needs[[5]](#footnote-6). Achieving sustainable energy development and a sustainable future for the planet, as outlined in the United Nations' Sustainable Development Goal 7, requires a shift towards renewable energy sources through energy diversification (De Rosa *et al.*, 2022).

However, diversifying energy sources necessitates significant investments in complex energy technologies and infrastructure. Achieving this diversification is dependent on long-term financial support and payment services provided by financial systems (Peimani, 2018, Ji and Zhang, 2019). Financial capital plays a crucial role in facilitating the transition from fossil fuels to modern renewable energy sources (Best, 2017). However, financial systems are often hesitant to finance renewable energy projects due to the high risk and low return associated with these projects (Peimani, 2018). Establishing mutually reinforced relationships between energy diversification, per-capita income, and financial development can lead to synergies, including stable energy supply, robust financial services, and strong economic growth.

Technological advancements play a crucial role in driving economic development by reducing energy insecurity and enhancing economic and financial performance. As countries progress, there is a possibility of achieving a common steady-state equilibrium in energy diversification, per-capita income, and financial development. Although technologically leading countries have witnessed slower technology innovation (Chiara *et al.*, 2016, Callaghan, 2021), there are significant opportunities for countries that have lagged behind. Copying existing technologies can be more cost-effective than developing new innovations within a certain range (Barro and Sala-i-Martin, 1997, Rubio and Folchi, 2012). The process of technological diffusion, accelerated by increasing global and regional economic and financial integration, can particularly benefit countries that are lagging behind, leading to a reduction in divergence from leading countries. Consequently, a common steady-state equilibrium in energy diversification, per-capita income, and financial development among countries may be achieved sooner. To investigate these dynamics, our study examines the convergence hypothesis by analyzing annual data on energy diversification, per-capita income, and financial development for 134 countries over the period of 1995-2019. Additionally, the study explores the relationships between these three factors to shed light on the formation of convergence groups.

Employing log t club convergence test developed by Phillips and Sul (2007) and Phillips and Sul (2009), our study indicates that although overall convergence for 134 countries from 1995 to 2019 was not observed, countries have indeed converged with their peers within the same groups. Regression analysis demonstrated positive relationships between energy diversification and per-capita income, as well as between financial development and per-capita income. Additionally, the study identified an increasing trend in energy diversification, per-capita income, and financial development. Furthermore, our study provides confirmation of a U-shaped relationship between oil price and energy diversification.

The contribution of this study can be summarized as follows. Firstly, it is the first study to examine the tri-directional relationship between energy diversification, per-capita income, and financial development. Previous studies, such as Shahbaz and Lean (2012), Destek (2018), Durusu-Ciftci *et al.* (2020), Cetin and Bakirtas (2020), Usman *et al.* (2021) and Isaeva *et al.* (2021), focused primarily on total energy consumption/production, renewable energy, and their connections to economic growth and financial development. Additionally, this study is among the few that utilize the World Bank's Herfindahl-Hirschman export market concentration index to measure energy diversification. Secondly, previous studies neglected to test the convergence hypothesis, which could have provided valuable insights for sustainable development policies. In contrast, this study addresses this gap and examines the convergence hypothesis. Thirdly, our study employs the International Monetary Fund's (IMF) financial development indices, which encompass various dimensions of financial development. Previous studies often relied on single or a few indicators, such as domestic credit to the private sector or stock market capitalization, to capture financial development, which may not present a comprehensive picture of financial development. Lastly, given the volatility of oil prices and other fossil fuel prices, this study investigates whether energy diversification declines and eventually reverses as oil prices increase. For the first time, this study explores the relationship between oil price and energy diversification under changing market conditions, including the Global Financial Crisis of 2008 and the Covid-19 pandemic, which caused significant fluctuations in fossil fuel-based energy prices, such as West Texas Intermediate (WTI) reaching a peak of US$147 per barrel in July 2008, dropping to US$34 in December 2008, and falling below US$20 in April 2020.

The structure of this paper is as follows: In Section 2, a comprehensive review of the literature is provided, and hypotheses are developed. Section 3 outlines the methodologies employed, describes the variables used, and provides an overview of the data. The empirical results are presented in Section 4. Finally, Section 5 oncludes the study with policy implications.

# Literature review

## Convergence

The convergence literature has traditionally employed two tests, namely beta and sigma convergence, introduced by Baumol (1986) and Barro and Sala-i-Martin (1992), respectively. Beta convergence refers to the phenomenon where units with a lower initial level of the variable grow at a faster rate compared to units with a higher initial level. Sigma convergence, on the other hand, denotes a decrease in cross-sectional disparities of the variable over time. However, these conventional tests assume a uniform convergence rate for all units, which may not hold due to inherent heterogeneity among individual units. The log t convergence test, developed by Phillips and Sul (2007), addresses this limitation by allowing for individual transition paths. It enables the testing of both overall convergence across all units and club convergence among specific units, categorizing them into convergence and divergence clubs. Consequently, the log t test represents the state of the art in assessing convergence in any given variable.

Our research focuses on examining the convergence of energy diversification, financial development, and real per-capita income among countries. The exploration of convergence patterns originated with Barro *et al.* (1991) who proposed that economies conform to neoclassical growth models, leading to the convergence of per-capita income across countries. Several studies have investigated per-capita income convergence, such as Cabral and Castellanos-Sosa (2019) for European countries, Michelis and Neaime (2004) for the Asia Pacific region, Zhao and Serieux (2019) for East Asian countries, Tung and Bentzen (2019) for the Indochina region, and Ghatak and De (2021) for Asian countries.

Similarly, numerous studies have explored convergence in energy-related variables, including energy consumption (Liu and Lee, 2020) across 107 countries, energy intensity (measured by energy consumption/GDP) (Markandya *et al.*, 2006) for European countries, energy and electricity consumption per capita (Mohammadi and Ram, 2012) in a global sample, and energy productivity (measured by GDP/energy consumption) (Parker and Liddle, 2017) across 33 countries. However, none of these studies have specifically examined the convergence in energy diversification.

Furthermore, there have been limited studies on the convergence of financial development-related variables. Some examples include FDI inflow to GDP (Selvarajan *et al.*, 2018) in the East Asia Pacific region and bank profitability (Olson and Zoubi, 2017) among Islamic and commercial banks in the Middle East, Africa, and Southeast Asia. These studies have employed various convergence tests, and a general consensus suggests that the gaps in per-capita income, energy-related variables, and financial development-related variables across countries have been narrowing over time (beta and sigma convergence). However, the regional or global samples indicate the formation of convergence clubs rather than a common steady-state equilibrium (no overall log t convergence).

We reason that technological progress plays a crucial role in fostering synergies among energy diversification, economic growth, and financial development. It is also expected to contribute to the enhancement of energy diversification, per-capita income, and financial development. As a result of technological progress, it is possible that a common steady-state equilibrium in these three aspects could eventually be achieved across countries. The process of economic convergence is influenced by factors such as the low cost of technology adoption for follower countries and a relatively high degree of openness (Barro and Sala-i-Martin, 1997). Globalization (Harger *et al.*, 2017), trade liberalization (Ben-David and Kimhi, 2004), foreign investment (Zhao and Serieux, 2019), and financial integration (Abiad *et al.*, 2009) have driven economies towards convergence by providing learning opportunities for agents in less advanced economies. However, the ability of laggard countries to catch up depends on the interaction between local innovation and technology diffusion (Perilla Jimenez, 2020).

Overall, log t convergence is less likely to occur when the sample includes a large number of countries (Corrado *et al.*, 2018). This can be attributed to significant disparities in country-specific factors such as technologies, preferences, government policies, and population growth across countries in such a diverse sample. The common factors generated by technological progress and diffusion, such as shared production technology, energy technology, and financial technology across all countries, may not be substantial enough to reduce disparities and bring countries to a common level of energy diversification, per-capita income, and financial development. However, this may not hold true if the data sample consists of similar economies, as the disparities could be considerably smaller. Given the rapid economic globalization, industrialization, and financial integration that have facilitated technological progress and diffusion over the past three decades, we propose the following hypothesis:

H1: There is no overall log t convergence in energy diversification, per-capita income, and financial development for the global sample, but there are groups of countries that converge to different equilibria.

## Relationships

### Energy diversification and economic development

A considerable body of literature has examined the relationship between output and energy, employing various datasets, time periods, and methodologies. Researchers have explored different aspects of energy, including total energy consumption (Wesseh and Lin, 2018, Durusu-Ciftci *et al.*, 2020), fossil fuel consumption (Cetin and Bakirtas, 2020), energy production (Kirikkaleli *et al.*, 2021), renewable energy (Abanda *et al.*, 2012), and energy security (Le and Nguyen, 2019). However, to the best of our knowledge, no studies have investigated the two-way relationship between the diversification of energy consumption sources and per-capita income. This research seeks to fill this gap in the existing literature.

The process of energy source diversification involves a shift from traditional fossil fuel-based sources to new/modern renewable energy sources. Two theoretical perspectives can explain the introduction of new energy sources into the energy portfolio. The *ladder hypothesis* suggests that as income increases, energy users have access to both traditional and modern energy sources, and they gradually switch from traditional sources to modern ones, eventually leading to the replacement of traditional sources with modern ones (Hosier and Dowd, 1987). On the other hand, the *multiple fuel use hypothesis* suggests that as income increases, energy users tend to utilize multiple energy sources, leading to a dominance of new energy sources in the energy mix, but traditional sources are not completely replaced (Masera *et al.*, 2000). Both hypotheses imply that countries tend to diversify their energy sources towards cleaner options as their wealth grows. Additionally, wealthier countries typically have greater financial, human, and technological resources, enabling them to pursue energy source diversification more effectively.

In the past three decades, global energy demand has experienced a steady increase due to factors such as population growth, industrialization, and urbanization. However, relying heavily on a single energy source that is prone to volatile fuel prices cannot sustainably meet the growing energy demand necessary for economic activities. To address this challenge, energy diversification, particularly through investments in renewable energies, becomes crucial. By diversifying energy sources, countries can enhance energy access, generate employment opportunities, stimulate business growth, and ultimately improve their economic performance. It is important to note that energy is an essential input in the production process, and a significant portion of the cost of goods sold can be attributed to energy expenses (Mickovic and Wouters, 2020). While diversification does not eliminate energy risks entirely, it does substantially reduce a country's vulnerability to disruptions in energy supply and sudden spikes in energy prices (Chuang and Ma, 2013, Bellemare, 2015). This incentivizes countries to enhance their economic output and mitigate potential setbacks related to energy-related uncertainties.

Furthermore, several studies focusing on renewable energy, such as Pata (2018), Bilan *et al.* (2019), Mahmood *et al.* (2019) and Yao *et al.* (2019), have highlighted a mutually beneficial relationship between renewable energy and economic growth. These findings suggest that there is a two-way interaction between diversifying towards renewable energy and fostering economic development. Based on this evidence, we propose the following hypothesis:

H2: There exists a bi-directional causal relationship between energy diversification and per-capita income.

### Energy diversification and financial development

While significant research has been conducted on the relationship between energy consumption and financial development, limited attention has been given to examining the connection between renewable energy consumption and financial development. Moreover, the existing studies on this topic have produced diverse findings. For instance, in Europe, a bi-directional causality was identified, whereas no causality was found in Asia and America (Khan *et al.*, 2019). In emerging countries, financial development was found to have no impact on renewable energy consumption (Saygin and Iskenderoglu, 2021), while in Southeast and East Asian countries, it had a negative impact (Nguyen, 2022). On the other hand, in the top 55 global financial countries, financial development was found to have a positive impact (Saygin and Iskenderoglu, 2021). Notably, no studies have explored the association between energy diversification and financial development.

We reason that environmental pollution stemming from fossil fuel energy is a global concern, particularly for developing nations facing financial constraints in transitioning to cleaner energy sources. Additionally, the interconnectivity of economies means that energy shortages and price fluctuations in one country can have far-reaching consequences on the global economy. Consequently, developed nations may play a role in facilitating the transfer of advanced and affordable energy technologies. Financial development, characterized by the growth of stock markets and banking activities, has been linked to increased business expansion and subsequent energy consumption (Shahbaz and Lean, 2012, Rafindadi and Ozturk, 2016). However, renewable energies still constitute a modest proportion of the overall energy portfolio. While financial institutions and private investors have facilitated the shift from fossil fuels to modern renewable energy sources (Best, 2017), there has been reluctance in financing these projects due to their long-term investment requirements, substantial capital needs for technology and infrastructure, and their high-risk, low-return nature (Peimani, 2018). The justification for such projects relies on their potential to lower costs and increase the benefits of energy usage. Considering these factors, it is plausible that financial development may promote energy diversification in the short term. However, the long-term impact on financial development may be limited, as the process of adopting and developing new energy sources to enhance energy diversification might increase the use of banking and financial services without significantly spurring overall financial development. Therefore, we hypothesize:

H3: There is no significant causal relationship between energy diversification and financial development.

### Financial development and economic development

Several studies, including Raghutla and Chittedi (2021), Durusu-Ciftci *et al.* (2020), and Cetin and Bakirtas (2020), have extensively explored the relationship between economic growth and financial development using various datasets, methodologies, and time periods. These studies have identified a bi-directional causality between the two variables. This bi-directional causality can be explained by the combination of the supply-leading and demand-following hypotheses proposed by Acaravci et al. (2009). The *supply-leading hypothesis* suggests that the causality runs from financial development to economic growth. According to this hypothesis, a well-developed financial system plays a crucial role in effectively channeling savings towards productive investments, which are essential for fostering economic growth. In other words, financial development facilitates the efficient allocation of capital, thereby promoting economic expansion. On the other hand, the *demand-following hypothesis* posits that the causality runs from economic growth to financial development. According to this hypothesis, improvements in economic performance lead to increased economic activities, which, in turn, generate a higher demand for financial services. As the economy grows, there is a greater need for financial intermediation, such as loans, investment opportunities, and other financial instruments, to support and sustain the expanding economic activities.

Since the 1990s, there has been a rapid growth of financial globalization worldwide, as noted by Jones and Knaack (2019). However, the effects of financial globalization can be both positive and negative, as highlighted by Mishkin (2009). We argue that the success of various reforms aimed at liberalization and prudential regulation and supervision in the financial sector can generally steer financial globalization towards fostering financial development. A well-functioning financial system plays a critical role in efficiently allocating funds to productive projects and facilitating the trade of goods and services, which are essential for the overall success of an economy. Furthermore, the facilitation of cross-border capital flows and the presence of cross-border banks, resulting from financial globalization, enhance the availability of funds and reduce borrowing costs. This encourages borrowing for investments that can enable a country to realize its full economic potential. Additionally, with the rapid pace of globalization, the utilization of financial services tends to increase as economic activities expand. This signifies the mutually reinforcing relationship between economic growth and financial development. Consequently, we propose the following hypothesis:

H4: There exists a bi-directional causal relationship between economic growth and financial development.

# Methodology and data

## Methodology

This study examines three key variables: energy diversification, financial development, and per-capita income. Currently, energy production relies on various sources such as fossil fuels, nuclear power, and renewable energy. Diversification, in this context, refers to the opposite of concentration. To measure energy diversification (*Energy HHI*) for country *i* in year *t*, this study adopts the Herfindahl-Hirschman export market concentration index used by the World Bank[[6]](#footnote-7):

$Energy HHI\_{i}=\frac{\sum\_{j=1}^{n\_{i}}\left(\frac{e\_{ij}}{E\_{i}}\right)^{2}-\frac{1}{n\_{i}}}{1-\frac{1}{n\_{i}}}$ (1)

Here, $E\_{i}$ represents the total primary energy consumption of country *i* measured in quadrillion British thermal units (BTUs); $e\_{ij}$ denotes the amount of energy consumption from source *j* by country *i*; $n\_{i}$ represents the number of energy sources (including renewable energy, coal, natural gas, petroleum and other liquids, and nuclear) consumed by country *i*. *Energy HHI* is in the range of 0 and 1, with a greater value reflecting greater concentration and lower diversification of energy sources.

This study adopts the approach used by the International Monetary Fund (IMF), as described by Svirydzenka (2016), to measure financial development. Financial development is assessed based on the depth, access, and efficiency of financial institutions and financial markets. The study utilizes six indices to measure financial development: i) overall index of financial development (*Financial Dev*), ii) overall index of financial institution development (*FI Dev*), iii) overall index of financial market development (*FM Dev*), and iv) three financial institution development indices in terms of depth (*FI Depth*), access (*FI Access*) and efficiency (*FI Efficiency*). Table 1 provides a brief description and construction details of these indices. The *Financial Dev* index is an aggregate of *FI Dev* and *FM Dev*, with *FI Dev* derived from combining *FI Depth*, *FI Access*, and *FI Efficiency*. These indices are constructed using multiple financial indicators, offering a comprehensive perspective on financial development and addressing the limitations of relying on single indicators as proxies. The indices range between 0 and 1, where a higher value indicates a greater level of financial development. Consistent with existing literature, this study employs per-capita gross domestic product (GDP) as a proxy for economic development, referred to as *per-capita Income*.

### Convergence

The log t convergence test, which has been demonstrated to be superior to the traditional beta and sigma convergence tests, is employed in this study to examine convergence in energy diversification, financial development, and per-capita income across 134 countries. The detailed procedures for conducting this test have been presented in previous studies by Phillips and Sul (2007) and Phillips and Sul (2009). This study provides a brief overview of the key steps involved:

The transition parameter (*hit*) is calculated to measure the transition path of country *i* relative to the panel average. It is computed as follows:

$h\_{it}=\frac{y\_{it}}{^{1}/\_{n}\sum\_{i=1}^{n}y\_{it}}=\frac{δ\_{it}}{^{1}/\_{n}\sum\_{i=1}^{n}δ\_{it}}$ (2)

where $y\_{it}$ represents one of the three variables of interest: energy diversification, financial development, or per-capita income for country *i* in year *t*; $δ\_{it}$ represents the factor specific to *i* in year *t*, which is measured by the economic distance between $y\_{it}$ and the common factor (proxied by the cross-sectional average growth rate of all countries in any given year).

The average value for *hit*is 1, so the cross-sectional difference $(H\_{t})$ between the relative transition parameters *hit* and their average in any year is defined as:

$H\_{t}=\frac{1}{n}\sum\_{i=1}^{N}\left(h\_{it}-1\right)^{2}$ (3)

To test convergence, Phillips and Sul (2007) employ a log t regression framework, which is expressed as follows::

$ln\left(\frac{H\_{1}}{H\_{t}}\right)-2 log\left(log⁡(t+1)\right)=θ+γ logt+e\_{t}$ (4)

Convergence is observed when $H\_{t}$ declines over time, leading to an increase in $ln\left(\frac{H\_{1}}{H\_{t}}\right)$. This requires a positive coefficient $γ$ on the decay function $logt$. If the *t*-statistic for the $γ$ coefficient is below -1.65, the null hypothesis of convergence ($H\_{0}: δ\_{it}=δ\_{i}$) can be rejected at the 5% significance level.

The overall log t convergence test and initial club formation are conducted using Phillips and Sul (2007) club convergence algorithm. The final convergence clubs are identified using the club merging algorithm proposed by Phillips and Sul (2009). To remove trend components from the data, the band pass filter introduced by Christiano and Fitzgerald (2003) is employed, and the first 30% of the data is discarded before running the log t regression. The choice of the band pass filter over the common filter of Hodrick and Prescott (1997) is made to avoid potential spurious dynamic associations (Hamilton, 2018).

### Interrelationships

To examine the causal relationship between energy diversification, financial development, and per-capita income, we utilize the Granger causality procedure proposed by Dumitrescu and Hurlin (2012), which involves model averaging. Before conducting the Granger causality analysis, it is necessary to check the stationarity of the variables. To do this, we employ various methods, including Levin-Lin-Chu (LLC) (Levin *et al.*, 2002), Breitung (Breitung, 2001), Im-Pesaran-Shin (IPS) (Im *et al.*, 2003), Fisher-Dickey-Fuller (Fisher-DF) (Dickey and Fuller, 1979), and Fisher-Phillips-Perron (Fisher-PP) (Phillips and Perron, 1988), both at the level and first difference forms. The Granger causality model is expressed as follows:

$y\_{i,t}=α\_{i}+\sum\_{k=1}^{K}γ\_{i}^{(k)}y\_{i,t-k}+\sum\_{k=1}^{K}β\_{i}^{(k)}x\_{i,t-k}+ϵ\_{i,t}$ (5)

where $y\_{i,t}$ refers to one of the three variables of interest (energy diversification, financial development, and per-capita income) for country *i* in year *t*; $x\_{i,t}$ refers to one of the two remaining variables for country *i* in year *t* (e.g., if $y\_{i,t}$ represents energy diversification, $x\_{i,t}$ can be either financial development or per-capita income); $ϵ\_{i,t}$is the stochastic error term; the optimal lag orders $k$ are determined using the Akaike information criterion; and $α\_{i},β\_{i}, γ\_{i}$ are parameters to be estimated.

We conclude $x$ Granger causes $y$ if past values of$x$can predict the current values of $y$. In other words, the coefficients $β\_{i}^{(k)}$ collectively demonstrate statistical significance different from zero.

Next, we proceed to examine the causal relationships while considering the controlling covariates through the following model:

$y\_{i,t}=β\_{0}+β\_{1}trend+β\_{2}x\_{i,t-1}+β\_{3}Z\_{i,t}+μ\_{i}+ε\_{i,t}$ (6)

where $y\_{i,t}$ and $x\_{i,t}$ retain their definitions from in Eq.5; $trend$ denotes the linear trend in $y\_{i,t}$ from 1995 to 2019, representing technological progress; $Z\_{i,t}$ is a set of controlling covariates; $μ\_{i}$ represents country-specific unobserved features; $ε\_{i,t}$ represents the random error component; $β$ are parameters to be estimated; all variables, excluding *trend*, are expressed in natural logarithms.

The selection of $Z\_{i,t}$ is based on existing literature and data availability. Considering that energy consumption is predominantly driven by oil (accounting for 51.23% of the share) and is a significant source of CO2 emissions, when $y\_{i,t}$ pertains to energy diversification,$Z\_{i,t}$ encompasses oil price and environmental perception, proxied by the human development index (HDI). For cases where $y\_{i,t}$ represents financial development, $Z\_{i,t}$ incorporates variables related to tourism development, international trading, and unemployment rate, as they are closely linked to the utilization of financial services. In instances where $y\_{i,t}$ serves as an indicator of economic development, $Z\_{i,t}$ includes capital stock, labor participation (proxied by the unemployment rate), and labor qualification (proxied by HDI), considering that capital and labor are major factors of production.

To obtain reliable results for Eq.6, an appropriate estimator is selected based on the outcomes of the Breusch-Pagan test (OLS versus random effects), Hausman test (fixed effects versus random effects), and F-test (fixed effects versus OLS and random effects). Additionally, the specification for the standard error is determined by considering the results of the Modified Wald test for heteroskedasticity, Pesaran test for cross-sectional dependence, and Wooldridge test for autocorrelation.

## Data

Our sample encompasses 134 countries from 1995 to 2019, representing various income groups and regions. Table 1 provides concise descriptions and key statistics for the variables utilized in this study, along with their respective data sources. The table reveals considerable variations among countries and demonstrates a distinct trend for most variables. On average, the concentration index of energy consumption sources decreases by 0.2 points per year, per-capita income exhibits an annual increase of $362 (PPP), and the financial development index improves by 0.4 points per year. The statistical significance of the "trend" variable for all three variables indicates that technological progress, represented by the linear trend, significantly and positively contributes to energy diversification, economic growth, and financial development. This finding supports the hypothesis of synergies among these three aspects and the formation of convergence clusters (Hypothesis 1).

The average annual increase in oil price is approximately US$2.583. Non-oil-based energy development necessitates substantial long-term capital investment. Consequently, when oil prices are low, non-oil energy prices tend to be less competitive. However, as oil prices rise, the demand can shift from oil to non-oil energy sources. Therefore, we anticipate a U-shaped relationship between oil price and energy diversification. A greater abundance of production factors leads to increased value in an economy's final goods and services. Hence, physical capital, human capital, and labor participation are expected to positively contribute to per-capita income. Furthermore, a more open economy, higher international tourist arrivals, and a lower unemployment rate are likely to foster increased utilization of financial services (such as foreign exchange, payment, lending, depositing, and investing). Accordingly, employment, international tourist receipts, and international trade are expected to enhance financial development.

Table 1: Summary definition, statistics, and sources of the full panel data set

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variables | Definition | Mean | SD | Min | Max | Trend |   | Data source |
| ***Energy diversification*** |  |
| *Energy HHI* | Author's calculation using Eq.1 on the data of energy consumption sources: i) renewable energy, ii) coal, iii) natural gas, iv) petroleum and other liquids, and v) nuclear. | 0.33 | 0.23 | 0.00006 | 0.99 | -0.002 | \*\*\* | <https://www.eia.gov/> |
| ***Economic development*** |
| *Per-capita Income* | Gross domestic product per person (PPP$ inflation adjusted, in $ thousands) | 19.16 | 20.66 | 0.47 | 115.00 | 0.362 | \*\*\* | <https://www.gapminder.org/data/> |
| ***Financial development*** |  |
| *FI Depth*  | A sub-index of *FI Dev* index which relies on the standard banking sector depth (bank credit to the private sector) and other financial institutions' depth (the assets of the mutual fund and pension fund industries and the size of life and non-life insurance premiums).  | 0.27 | 0.27 | 0.001 | 1.00 | 0.004 | \*\*\* | [https://data.imf.org/](https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B) |
| *FI Access* | A sub-index of *FI Dev* index which relies on the number of bank branches and ATMs per 100,000 adults. | 0.32 | 0.27 | 0.004 | 1.00 | 0.007 | \*\*\* | [https://data.imf.org/](https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B) |
| *FI Efficiency* | A sub-index of *FI Dev* index which relies on three aspects of bank efficiency: (i) efficiency in intermediating savings to investment, as measured by the net interest margin and lending-deposit spread; (ii) operational efficiency measures, such as non-interest income to total income and overhead costs to total assets; and (iii) profitability measures, such as return on assets and return on equity. | 0.59 | 0.12 | 0.07 | 0.89 | 0.003 | \*\*\* | [https://data.imf.org/](https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B) |
| *FI Dev* | The overall index of financial institution development which shows how developed financial institutions are. | 0.40 | 0.22 | 0.03 | 1.00 | 0.006 | \*\*\* | [https://data.imf.org/](https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B) |
| *FM Dev* | The overall index of financial market development which shows how developed financial markets are. | 0.24 | 0.27 | 0.00 | 1.00 | 0.003 | \*\*\* | [https://data.imf.org/](https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B) |
| *Financial Dev* | The overall index of financial development which shows how developed financial systems are. | 0.33 | 0.23 | 0.02 | 1.00 | 0.004 | \*\*\* | [https://data.imf.org/](https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B) |
| ***Control variables*** |  |
| *Oil Price* | Crude oil prices: West Texas Intermediate (WTI) ($) | 53.25 | 27.77 | 14.42 | 99.67 | 2.583 | \*\*\* | [https://alfred.stlouisfed.org](https://alfred.stlouisfed.org/) |
| *HDI* | A composite index measuring achievement in three basic dimensions of human development: a long and healthy life, knowledge, and a decent standard of living | 0.74 | 0.15 | 0.39 | 0.96 | 0.00004 |   | <http://hdr.undp.org/> |
| *Unemployment* | Unemployment, total (% of total labour force)  | 7.31 | 5.60 | 0.11 | 37.96 | -0.061 | \*\*\* | <https://databank.worldbank.org/source/world-development-indicators> |
| *Capital Stock* | Capital stock per capita at $PPPs | 18298 | 24489 | 18 | 161065 | 765 | \*\*\* | https://www.rug.nl/ggdc/productivity/pwt/ |
| *Tourism Receipt* | International tourism, receipts (% of total exports) | 11.28 | 12.40 | 0.001 | 89.12 | 0.046 |  | <https://databank.worldbank.org/source/world-development-indicators> |
| *Intl Trade* | Imports and exports of goods and services (% of GDP) | 53.43 | 89.28 | 0.000 | 1479.49 | 1.875 | \*\*\* | <https://databank.worldbank.org/source/world-development-indicators> |
| \*\*\*: 1% level of significance, respectively |  |  |  |  |  |  |  |

# Empirical results

## Convergence

Table 2 presents the findings of the log t convergence tests conducted on the global sample of 134 countries from 1995 to 2019. The t-statistics values for energy diversification, financial development, and per-capita income all fall below -1.65. These results indicate significant divergence among the entire group of 134 countries in terms of energy diversification, financial development, and per-capita income, at a significance level of 5%.

Table 2: Full Convergence Log-t Tests

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *Energy HHI* | *Per-capita income* | *FI Depth* | *FI Access* | *FI Efficiency* | *FI Dev* | *FM Dev* | *Financial Dev* |
| Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat |
| -0.35 | -6.82 | -0.24 | -13.30 | -0.74 | -38.81 | -0.81 | -22.34 | -0.46 | -8.05 | -0.84 | -27.16 | -1.52 | -28.06 | -0.74 | -14.70 |

We now proceed to examine subgroups of countries that demonstrate convergence using Phillips and Sul (2007)’s algorithm. The first column of Table 3 illustrates the classification of countries into two clubs based on energy diversification and per-capita income. In terms of energy diversification, club 1 consists of 33 countries, while club 2 comprises 101 countries. However, the speed of convergence in both clubs is slow, as indicated by the non-statistically significant log t coefficients. For per-capita income, club 1 exhibits rapid convergence, while club 2 experiences slower convergence. Club 1 consists of 68 countries, primarily non-low-income countries, while club 2 comprises 66 countries, mostly non-high-income countries. Interestingly, both clubs for energy diversification include countries from various income groups. This observation suggests that the achievement of energy diversification toward renewable sources depends on factors such as natural resources, absorptive capacity, energy infrastructure, and economic structure specific to each country. The financial development indices display substantial variations, with multiple convergence clubs identified, and there are also countries that diverge from the common trend.

Next, we investigate whether the initial convergence clubs can be merged to form larger convergence clubs, employing Phillips and Sul (2009)’s algorithm. In the middle column of Table 3, labeled "Tests of club merging," we present the results of the convergence tests between two consecutive clubs. For both energy diversification (t-value = -7.162) and economic development (t-value = -13.494), we find no evidence of convergence between clubs 1 and 2. However, regarding financial development indices, we observe the formation of larger convergence clubs by merging each club with the next one. The results of the final convergence clubs are reported in the last column of Table 3.

We note that only one large club is formed from clubs 1, 2, and 3 for *FI Depth*. Overall, countries are ultimately classified into four, three, two, seven, five, and five convergence clubs for financial institution depth, access, efficiency and overall indices, financial market overall index, and financial development index, respectively. The presence of more convergence clubs in financial development compared to energy diversification and per-capita income can be attributed to the higher level of regulation in the financial sector compared to the energy and production sectors. Consequently, the influence of technological progress and diffusion on the financial sector might be comparatively lower. Nevertheless, the extensive pursuit of financial integration in many countries could have facilitated the similarity of financial services in terms of features and costs, thus enabling catch-up in financial development between certain consecutive clubs.

Table 3: Convergence Club Classification

|  |  |  |
| --- | --- | --- |
| Initial club classification | Tests of club merging | Final club classification |
| Clubs | Members | Log t | t-stat | Clubs | Members | Log t | t-stat | Clubs | Members | Log t | t-stat |
| ***Part A: Energy HHI*** |
| Club 1 | 33 | -0.03 | -0.70 |   |  |  |  | Club 1 | 33 | -0.03 | -0.70 |
| Club 2 | 101 | 0.12 | 1.28 | Clubs 1+2 | 134 | -0.35 | -6.82 | Club 2 | 101 | 0.12 | 1.28 |
| ***Part B: Per-capita income*** |
| Club 1 | 68 | 0.19 | 14.71 |   |  |  |  | Club 1 | 68 | 0.19 | 14.71 |
| Club 2 | 66 | -0.05 | -1.27 | Clubs 1+2 | 134 | -0.24 | -13.30 | Club 2 | 66 | -0.05 | -1.27 |
| ***Part C: Financial development indices*** |
| *FI Depth* |
| Club 1 | 2 | -0.44 | -0.44 |   |  |  |  |  |  |  |  |
| Club 2 | 11 | 0.37 | 2.50 | **Clubs 1+2** | **13** | **-0.03** | **-0.36** |  |  |  |  |
| Club 3 | 16 | 0.61 | 7.27 | **Clubs 2+3** | **27** | **0.39** | **4.55** | **Clubs 1+2+3** | **29** | **0.32** | **4.08** |
| Club 4 | 35 | 0.27 | 2.86 | Clubs 3+4 | 51 | -0.13 | -4.61 | Club 4 | 35 | 0.27 | 2.86 |
| Club 5 | 60 | -0.13 | -1.47 | Clubs 4+5 | 95 | -0.52 | -8.14 | Club 5 | 60 | -0.13 | -1.47 |
| Club 6 | 6 | 0.82 | 4.67 | Clubs 5+6 | 66 | -0.33 | -5.51 | Club 6 | 6 | 0.82 | 4.67 |
| Divergence | 4 | -2.59 | -4.50 | Club 6+Divergence | 10 | -0.78 | -25.92 | Divergence | 4 | -2.59 | -4.50 |
| *FI Access* |
| Club 1 | 52 | 0.26 | 1.75 |   |  |  |  | Club 1 | 52 | 0.26 | 1.75 |
| Club 2 | 69 | -0.12 | -1.48 | Clubs 1+2 | 121 | -0.61 | -11.84 | Club 2 | 69 | -0.12 | -1.48 |
| Club 3 | 11 | 0.65 | 6.42 | Clubs 2+3 | 80 | -0.48 | -10.14 | Club 3 | 11 | 0.65 | 6.42 |
| Divergence | 2 | -1.28 | -1.97 | Club 3+Divergence | 13 | -0.42 | -6.40 | Divergence | 2 | -1.28 | -1.97 |
| *FI Efficiency* |
| Club 1 | 123 | -0.05 | -0.76 |   |  |  |  | Club 1 | 123 | -0.05 | -0.76 |
| Club 2 | 11 | -0.25 | -0.47 | Clubs 1+2 | 134 | -0.46 | -8.05 | Club 2 | 11 | -0.25 | -0.47 |
| *FI Dev* |
| Club 1 | 4 | 0.19 | 0.52 |   |  |  |  | Club 1 | 4 | 0.19 | 0.52 |
| Club 2 | 8 | -0.14 | -1.62 | Clubs 1+2 | 12 | -0.17 | -2.02 |  |  |  |  |
| Club 3 | 15 | 0.74 | 3.92 | **Clubs 2+3** | **23** | **0.47** | **3.24** | Clubs 2+3 | 23 | 0.47 | 3.24 |
| Club 4 | 76 | -0.13 | -1.56 | Clubs 3+4 | 91 | -0.31 | -4.25 | Club 4 | 76 | -0.13 | -1.56 |
| Club 5 | 17 | 0.28 | 1.74 | Clubs 4+5 | 93 | -0.42 | -5.82 |  |  |  |  |
| Club 6 | 4 | 1.22 | 2.05 | **Clubs 5+6** | **21** | **-0.04** | **-0.31** | Clubs 5+6 | 21 | -0.04 | -0.31 |
| Club 7 | 5 | 0.41 | 1.05 | **Clubs 6+7** | **9** | **0.20** | **0.58** |  |  |  |  |
| Club 8 | 2 | 1.12 | 0.43 | **Clubs 7+8** | **7** | **-0.13** | **-0.32** | Clubs 7+8 | 7 | -0.13 | -0.32 |
| Club 9 | 2 | 0.71 | 1.33 | Clubs 8+9 | 4 | -0.68 | -3.31 | Club 9 | 2 | 0.71 | 1.33 |
| Divergence | 1  |  |  | Club 9+Divergence | 3 | -0.98 | -4.97 | Divergence | 1 |  |  |
| *FM Dev* |
| Club 1 | 12 | 0.89 | 9.79 |   |  |  |  |  |  |  |  |
| Club 2 | 29 | 0.48 | 2.15 | **Clubs 1+2** | **41** | **0.29** | **1.59** | Clubs1+2 | 41 | 0.29 | 1.59 |
| Club 3 | 37 | 0.23 | 1.48 | **Clubs 2+3** | **66** | **-0.08** | **-0.64** | Club 3 | 37 | 0.23 | 1.48 |
| Club 4 | 41 | 0.08 | 0.90 | Clubs 3+4 | 78 | -0.31 | -3.96 | Club 4 | 41 | 0.08 | 0.90 |
| Club 5 | 13 | 0.05 | 0.41 | Clubs 4+5 | 54 | -0.33 | -7.91 | Club 5 | 13 | 0.05 | 0.41 |
| Club 6 | 2 | -2.05 | -0.79 | Clubs 5+6 | 15 | -3.76 | -21.30 | Club 6 | 2 | -2.05 | -0.79 |
| *Financial Dev* |
| Club 1 | 5 | 2.72 | 4.96 |   |  |  |  | Club 1 | 5 | 2.72 | 4.96 |
| Club 2 | 8 | 0.10 | 1.64 | Clubs 1+2 | 13 | -0.19 | -3.14 |  |  |  |  |
| Club 3 | 4 | 1.17 | 7.51 | **Clubs 2+3** | **12** | **0.67** | **5.35** | Clubs 2+3 | 12 | 0.67 | 5.35 |
| Club 4 | 42 | -0.10 | -0.85 | **Clubs 3+4** | **46** | **-0.11** | **-1.01** | Club 4 | 42 | -0.10 | -0.85 |
| Club 5 | 49 | -0.16 | -1.51 | Clubs 4+5 | 91 | -0.41 | -5.04 | Club 5 | 49 | -0.16 | -1.51 |
| Club 6 | 24 | 0.19 | 1.66 | Clubs 5+6 | 73 | -0.45 | -5.09 | Club 6 | 24 | 0.19 | 1.66 |
| Divergence | 2 | -0.88 | -33.47 | Club 6+Divergence | 26 | -0.50 | -9.79 | Divergence | 2 | -0.88 | -33.47 |
| Boldfacing for the “Tests of club merging” and “Final club classification” indicates that the null hypothesis of the convergence for club merge is not rejected at 5% level of significance. |

In the final stage of our analysis, we investigate convergence among countries sharing similar characteristics. Specifically, we test for convergence among low-income, lower-middle-income, upper-middle-income, and high-income countries based on the IMF's income classification in 2019. The results presented in Table 4 reveal that convergence occurs in both energy diversification and income per capita for low-income and lower-middle-income countries. It is worth noting that the convergence observed in these income groups, as opposed to upper-middle-income and high-income countries, can be attributed to the fact that low-income and lower-middle-income countries often act as technology followers, thus making it feasible for them to catch up with each other. It is important to note that the beta and sigma convergences for the global sample, as well as the subsamples, are also observed, and the detailed results can be provided upon request. Overall, the findings in this section lend support to Hypothesis 1.

Table 4: Full Convergence Tests

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *Energy HHI* | *Per-capita income* | *FI Depth* | *FI Access* | *FI Efficiency* | *FI Dev* | *FM Dev* | *Financial Dev* |
| Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat | Log t | t-stat |
| *Part A: Low-income countries (14 countries)* |
| **0.90** | **5.32** | **1.70** | **25.21** | -0.87 | -29.38 | -1.14 | -16.67 | -1.71 | -16.63 | -1.49 | -12.08 | -3.45 | -18.90 | -1.73 | -12.80 |
| *Part B: Lower middle-income countries (41 countries)* |
| **0.05** | **0.33** | **0.13** | **3.13** | -0.50 | -8.68 | -1.15 | -170.30 | -0.23 | -1.85 | -1.09 | -27.45 | -0.63 | -25.09 | -0.58 | -9.18 |
| *Part C: Upper middle -income countries (37 countries)* |
| -0.88 | -83.94 | -0.20 | -4.67 | -0.62 | -24.10 | -1.33 | -25.11 | -0.36 | -2.89 | -1.06 | -66.13 | -0.68 | -13.86 | -0.84 | -35.44 |
| *Part D: High-income countries (42 counties)* |
| -0.65 | -37.18 | -0.39 | -13.38 | -0.82 | -34.09 | -0.65 | -9.88 | -0.53 | -13.97 | -0.38 | -4.47 | -0.82 | -8.55 | -0.46 | -6.51 |
| Boldfacing indicates that the null hypothesis of convergence is not rejected at 5% level of significance. |

## Interrelationships

### Granger causality

Table 5 presents the outcomes of several unit root tests conducted using LLC, Breitung, IPS, Fisher-DF, and Fisher-PP methods. The results indicate that the null hypothesis of the presence of a unit root cannot be rejected at the level form for HHI Energy and FI Depth variables. However, when considering the first difference form, the null hypothesis is rejected for all variables. Consequently, the Granger causality analysis is performed using the first difference form to examine the causal relationships among energy diversification, economic growth, and financial development. The results of the Granger causality test are reported in Table 6, revealing a bi-directional Granger causality between these three variables.

Table 5: Unit root test analysis

|  |  |
| --- | --- |
| Variables | Unit root test methods |
| LLC | Breitung | IPS | Fisher-DF | Fisher-PP |
| ***Level*** |  |  |  |  |  |  |  |  |  |  |
| *Energy HHI*  | -7.25 | \*\*\* | 0.60 |  | -0.01 |  | 300.04 | \* | 367.49 | \*\*\* |
| *Per-capita income* | -3.12 | \*\*\* | 2.22 |  | 2.10 |  | 342.25 | \*\*\* | 219.61 |  |
| *FI Depth*  | -7.94 | \*\*\* | -1.95 | \*\* | -3.05 | \*\*\* | 426.04 | \*\*\* | 421.23 | \*\* |
| *FI Access* | -5.07 | \*\*\* | -0.10 |  | 1.49 |  | 249.89 |  | 223.97 |  |
| *FI Efficiency* | -20.91 | \*\*\* | -5.92 | \*\*\* | -9.31 | \*\*\* | 627.23 | \*\*\* | 912.85 | \*\*\* |
| *FI Dev*  | -13.18 | \*\*\* | -2.79 | \*\*\* | -5.10 | \*\*\* | 500.06 | \*\*\* | 543.32 | \*\*\* |
| *FM Dev* | -10.51 | \*\*\* | -1.27 |  | -5.58 | \*\*\* | 509.67 | \*\*\* | 510.38 | \*\*\* |
| *Financial Dev* | -15.20 | \*\*\* | -2.24 | \*\* | -7.70 | \*\*\* | 630.72 | \*\*\* | 591.26 | \*\*\* |
| ***First difference*** |  |  |  |  |  |  |  |  |  |  |
| *Energy HHI*  | -38.03 | \*\*\* | -14.32 | \*\*\* | -24.60 | \*\*\* | 1,469.82 | \*\*\* | 2,902.02 | \*\*\* |
| *Per-capita income* | -27.77 | \*\*\* | -10.30 | \*\*\* | -11.77 | \*\*\* | 787.13 | \*\*\* | 1,267.53 | \*\*\* |
| *FI Depth*  | -34.71 | \*\*\* | -17.29 | \*\*\* | -22.12 | \*\*\* | 1,301.70 | \*\*\* | 2,145.87 | \*\*\* |
| *FI Access* | -27.58 | \*\*\* | -11.23 | \*\*\* | -11.10 | \*\*\* | 720.64 | \*\*\* | 1,601.06 | \*\*\* |
| *FI Efficiency* | -47.80 | \*\*\* | -17.46 | \*\*\* | -29.83 | \*\*\* | 1,837.37 | \*\*\* | 3,956.80 | \*\*\* |
| *FI Dev*  | -40.17 | \*\*\* | -17.62 | \*\*\* | -23.26 | \*\*\* | 1,379.34 | \*\*\* | 3,190.01 | \*\*\* |
| *FM Dev* | -40.27 | \*\*\* | -13.00 | \*\*\* | -25.33 | \*\*\* | 1,526.86 | \*\*\* | 2,812.81 | \*\*\* |
| *Financial Dev* | -41.24 | \*\*\* | -16.30 | \*\*\* | -24.80 | \*\*\* | 1,489.74 | \*\*\* | 3,296.80 | \*\*\* |
| Note: The null hypothesis is that the series has a unit root; \*\*\*, \*\* and \*: 1%, 5% and 10% levels of significance, respectively |

Table 6: Dumitrescu & Hurlin (2012) Granger causality test results (at first difference)

|  |  |  |  |
| --- | --- | --- | --- |
| *Per-capita income --> Energy HHI* |   | 6.24 | \*\*\* |
| *Energy HHI --> Per-capita income* |  | 20.21 | \*\*\* |
| *Financial Development --> Energy HHI* |  |  |
|  | *FI Depth* | 15.75 | \*\*\* |
|  | *FI Access* | 12.38 | \*\*\* |
|  | *FI Efficiency* | 12.98 | \*\*\* |
|  | *FI Dev* | 12.10 | \*\*\* |
|  | *FM Dev* | 0.99 |  |
|  | *Financial Dev* | 8.21 | \*\*\* |
| *Energy HHI --> Financial Development* |  |  |
|  | *FI Depth*  | 14.80 | \*\*\* |
|  | *FI Access* | 20.91 | \*\*\* |
|  | *FI Efficiency* | 28.41 | \*\*\* |
|  | *FI Dev*  | 12.25 | \*\*\* |
|  | *FM Dev* | 14.74 | \*\*\* |
|  | *Financial Dev* | 9.84 | \*\*\* |
| *Income per capita --> Financial Development* |  |  |
|  | *FI Depth*  | 20.55 | \*\*\* |
|  | *FI Access* | 19.41 | \*\*\* |
|  | *FI Efficiency* | 6.97 | \*\*\* |
|  | *FI Dev*  | 13.65 | \*\*\* |
|  | *FM Dev* | 22.21 | \*\*\* |
|  | *Financial Dev* | 13.41 | \*\*\* |
| *Financial Development --> Per-capita income* |  |  |
|  | *FI Depth* | 37.71 | \*\*\* |
|  | *FI Access* | 20.72 | \*\*\* |
|  | *FI Efficiency* | 24.39 | \*\*\* |
|  | *FI Dev*  | 39.81 | \*\*\* |
|  | *FM Dev* | 12.40 | \*\*\* |
|   | *Financial Dev* | 26.68 | \*\*\* |
| \*\*\*: 1% level of significance, respectively |  |

### Panel regression

In order to examine the causal relationships between energy diversification, financial development, and economic growth while controlling for various factors (Eq. 6), we conducted a series of tests to determine the most appropriate estimator, and the results are presented in Table 7. The Breusch-Pagan test indicates that random effects are more suitable than pooled OLS, as it accepts the alternative hypothesis. The F-test suggests that both observed and unobserved fixed effects are non-zero, indicating that pooled OLS and random effects estimators may yield biased results. The Hausman test rejects the null hypothesis of no correlation between fixed effects and explanatory variables, suggesting that the fixed effects estimator is more preferable than the random effects estimator.

In the second part of Table 7, the significance of the tests indicates the presence of heteroskedasticity, cross-sectional dependence, and autocorrelation in the residuals of the fixed effects models. Therefore, we employ the fixed effects estimator with Driscoll and Kraay (1998)’s standard errors, which correct for heteroskedasticity, cross-sectional dependence, and serial correlations. The results of Eq. 6 are reported in Table 8.

Table 7: Diagnosis tests.

|  |  |  |  |
| --- | --- | --- | --- |
| Tests | Breusch and Pagan test for random effects | F-test for fixed effects | Hausman test for random effects versus fixed effects  |
| Models | HHI Energy | Income per capita | Financial Dev | HHI Energy | Income per capita | Financial Dev | HHI Energy | Income per capita | Financial Dev |
| *FI Depth*  | 18621 | \*\*\* | 26679 | \*\*\* | 26645 | \*\*\* | 62 | \*\*\* | 204 | \*\*\* | 181 | \*\*\* | 15 | \*\*\* | 202 | \*\*\* | 19 | \*\*\* |
| *FI Access*  | 18627 | \*\*\* | 27074 | \*\*\* | 17488 | \*\*\* | 62 | \*\*\* | 204 | \*\*\* | 79 | \*\*\* | 12 | \*\*\* | 185 | \*\*\* | 64 | \*\*\* |
| *FI Efficiency*  | 18692 | \*\*\* | 26197 | \*\*\* | 6512 | \*\*\* | 62 | \*\*\* | 188 | \*\*\* | 20 | \*\*\* | 12 | \*\*\* | 223 | \*\*\* | 9 |  |
| *FI Dev*  | 18736 | \*\*\* | 26847 | \*\*\* | 20661 | \*\*\* | 62 | \*\*\* | 194 | \*\*\* | 90 | \*\*\* | 12 | \*\*\* | 181 | \*\*\* | 20 | \*\*\* |
| *FM Dev* | 18734 | \*\*\* | 25780 | \*\*\* | 13337 | \*\*\* | 62 | \*\*\* | 185 | \*\*\* | 52 | \*\*\* | 12 | \*\*\* | 231 | \*\*\* | 53 | \*\*\* |
| *Financial Dev* | 18379 | \*\*\* | 26128 | \*\*\* | 24971 | \*\*\* | 61 | \*\*\* | 184 | \*\*\* | 178 | \*\*\* | 15 | \*\*\* | 201 | \*\*\* | 61 | \*\*\* |
| Tests | Modified Wald test for heteroskedasticity | Pesaran test for cross-sectional dependence | Wooldridge test for autocorrelation  |
| Models | HHI Energy | Income per capita | Financial Dev | HHI Energy | Income per capita | Financial Dev | HHI Energy | Income per capita | Financial Dev |
| *FI Depth*  | 190441 | \*\*\* | 2627 | \*\*\* | 7329 | \*\*\* | 9 | \*\*\* | 17 | \*\*\* | 22 | \*\*\* | 10 | \*\*\* | 653 | \*\*\* | 234 | \*\*\* |
| *FI Access*  | 195811 | \*\*\* | 3500 | \*\*\* | 8882 | \*\*\* | 10 | \*\*\* | 46 | \*\*\* | 26 | \*\*\* | 10 | \*\*\* | 626 | \*\*\* | 323 | \*\*\* |
| *FI Efficiency*  | 195125 | \*\*\* | 2535 | \*\*\* | 69781 | \*\*\* | 9 | \*\*\* | 14 | \*\*\* | 11 | \*\*\* | 10 | \*\*\* | 634 | \*\*\* | 66 | \*\*\* |
| *FI Dev*  | 191440 | \*\*\* | 2146 | \*\*\* | 5015 | \*\*\* | 9 | \*\*\* | 23 | \*\*\* | 6 | \*\*\* | 10 | \*\*\* | 627 | \*\*\* | 98 | \*\*\* |
| *FM Dev* | 195061 | \*\*\* | 2857 | \*\*\* | 2086869 | \*\*\* | 10 | \*\*\* | 16 | \*\*\* | 30 | \*\*\* | 10 | \*\*\* | 636 | \*\*\* | 6 | \*\* |
| *Financial Dev* | 192946 | \*\*\* | 2698 | \*\*\* | 3134 | \*\*\* | 9 | \*\*\* | 16 | \*\*\* | 9 | \*\*\* | 10 | \*\*\* | 617 | \*\*\* | 144 | \*\*\* |
| Note: The table presents the test statistics; \*\*\* and \*\*: 1% and 5% levels of significance, respectively |

The findings presented in Table 8 demonstrate that when the overall financial development index (last column) is used to measure financial development over the period 1995-2019, energy diversification exhibits a slight improvement, although this improvement is not statistically significant. This contrasts with the data description provided in section 3.2, which may be due to the absence of controlling covariates in the growth rate estimation in the data description. However, when financial development is captured by financial institution development in terms of depth and access, the growth trend in energy diversification becomes statistically significant.

The financial development index and per-capita income experience growth rates of 0.4% per year and 1.3% per year, respectively, aligning with the data description. The results indicate positive two-way causal relationships between energy diversification and per-capita income, as well as between financial development and per-capita income. However, the causality between energy diversification and financial development is not statistically significant, providing support for Hypotheses 2, 3, and 4.

Keeping other factors constant, based on the overall financial development index, a 1% increase in per-capita income leads to a 0.191% decrease in the concentration of energy consumption sources in the following year. Conversely, a 1% decrease in the concentration of energy consumption sources results in a 0.009% (0.009% \* 0.191 = 0.0017%) increase in per-capita income one year later. These findings suggest that the impact of per-capita income on energy diversification is stronger than the reverse.

Additionally, a 1% increase in per-capita income leads to a 0.242% increase in the financial development index in the following year. Similarly, a 1% increase in the financial development index stimulates a 0.207% (0.207% \* 0.242 = 0.05%) growth in per-capita income one year later. These results indicate that the effect of per-capita income on financial development is stronger than the reverse.

As anticipated, our analysis reveals a U-shaped relationship between energy diversification and oil price. Specifically, energy diversification initially decreases and then improves as oil price increases. The turning point for this relationship occurs at a WTI oil price of $88.33 per barrel. Additionally, the human development index exhibits a positive and statistically significant association with energy diversification, indicating that countries with higher levels of human development tend to have greater energy diversification.

In terms of financial development, we find that international tourism receipt, international trade, and employment rate are all positively and significantly linked to the development of the financial system. These factors contribute to the growth and enhancement of financial services and infrastructure. When examining economic development, we observe that all three production factors—labour participation, human development index, and capital stock—contribute positively to economic growth. Notably, the contribution of human capital is the highest, with an elasticity of 1.732. This suggests that government policies aimed at promoting factors such as life expectancy, health, knowledge, and living standards can have a significant positive impact on economic development.

These findings are largely consistent when we break down the overall financial development index into its components: the overall financial institution index (column 4) and the financial market index (column 5). Furthermore, when we further analyze the financial institution index in terms of depth, access, and efficiency, we continue to observe similar patterns and associations (columns 1-3).

Table 8: The interrelationships between energy diversification, financial development, and economic growth.

|  |  |
| --- | --- |
|   | Financial Development |
| Models | *FI Depth*  | *FI Access* | *FI Efficiency* | *FI Dev* | *FM Dev* | *Financial Dev* |
|  | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | *(6)* |
| ***Model: Energy HHI***  |
| *Trend* | -0.005\*\*\* | -0.005\* | -0.004 | -0.003 | -0.004 | -0.004 |
| L1.Log(*Financial Dev*) | 0.085 | 0.032 | 0.025 | -0.102 | -0.013 | 0.002 |
| L1.Log(*Per-capita income*) | -0.235\*\*\* | -0.217\*\*\* | -0.193\*\*\* | -0.157\* | -0.183\*\*\* | -0.191\*\*\* |
| Log(*Oil Price*) | 0.468\*\* | 0.510\*\*\* | 0.478\*\*\* | 0.434\*\*\* | 0.480\*\*\* | 0.475\*\*\* |
| Log(*Oil Price*)^2 | -0.052\*\* | -0.057\*\* | -0.053\*\* | -0.048\*\* | -0.053\*\* | -0.053\*\* |
| Log(*HDI*) | -5.532\*\*\* | -5.439\*\*\* | -5.673\*\*\* | -5.841\*\*\* | -5.664\*\*\* | -5.679\*\*\* |
| Constant | -3.452\*\*\* | -3.657\*\*\* | -3.776\*\*\* | -3.975\*\*\* | -3.853\*\*\* | -3.790\*\*\* |
| Observations | 3,192 | 3,192 | 3,192 | 3,192 | 3,192 | 3,192 |
| ***Model: Financial Development*** |
| *Trend* | 0.006\*\* | 0.013\*\*\* | 0.001 | 0.005\*\*\* | -0.012\*\* | 0.004\*\*\* |
| L1.Log(*Per-capita income*) | 0.401\*\*\* | 0.710\*\*\* | 0.083\*\*\* | 0.299\*\*\* | 0.225\*\* | 0.242\*\*\* |
| L1.Log(*Energy HHI*) | 0.007 | 0.041\*\*\* | 0.005 | -0.005 | 0.131\*\*\* | 0.007 |
| Log(*Tourism Receipt*) | 0.117\*\*\* | 0.033\* | 0.034\*\*\* | 0.034\*\*\* | 0.045 | 0.030\*\*\* |
| Log(*Intl Trade*) | 0.254\*\*\* | 0.260\*\*\* | 0.071\*\*\* | 0.131\*\*\* | 0.296\*\*\* | 0.145\*\*\* |
| Log(*Unemployment*) | -0.086\*\*\* | -0.074\*\* | -0.082\*\*\* | -0.062\*\*\* | -0.239\*\* | -0.066\*\*\* |
| Constant | -3.786\*\*\* | -4.265\*\*\* | -0.930\*\*\* | -2.240\*\*\* | -3.617\*\*\* | -2.426\*\*\* |
| Observations | 3,078 | 3,078 | 3,078 | 3,078 | 3,078 | 3,078 |
| ***Model: Per-capita Income*** |
| *Trend* | 0.012\*\*\* | 0.010\*\*\* | 0.016\*\*\* | 0.013\*\*\* | 0.016\*\*\* | 0.013\*\*\* |
| L1.Log(*Energy HHI*) | -0.014\*\* | -0.008\*\* | -0.008\* | -0.006 | -0.007 | -0.009\* |
| L1.Log(*Financial Dev*) | 0.147\*\*\* | 0.163\*\*\* | 0.052\*\*\* | 0.239\*\*\* | 0.005\*\* | 0.207\*\*\* |
| Log(*Unemployment*) | -0.043\*\*\* | -0.044\*\*\* | -0.054\*\*\* | -0.036\*\*\* | -0.058\*\*\* | -0.039\*\*\* |
| Log(*HDI*) | 1.732\*\*\* | 2.673\*\*\* | 1.656\*\*\* | 1.901\*\*\* | 1.649\*\*\* | 1.687\*\*\* |
| Log(*Capital Stock*) | 0.189\*\*\* | 0.169\*\*\* | 0.190\*\*\* | 0.173\*\*\* | 0.192\*\*\* | 0.185\*\*\* |
| Constant | 1.509\*\*\* | 2.018\*\*\* | 1.206\*\*\* | 1.666\*\*\* | 1.175\*\*\* | 1.532\*\*\* |
| Observations | 3,144 | 3,144 | 3,144 | 3,144 | 3,144 | 3,144 |
| \*\*\*, \*\* and \*: 1%, 5% and 10% levels of significance, respectively |

# Conclusions and policy implications

This study has examined the convergence patterns in energy diversification, financial development, and economic growth, as well as the interdependent relationships between these factors. The analysis utilized annual data from 134 countries spanning the period from 1995 to 2019. The findings indicate that while there was no overall convergence in these factors for the entire sample, countries did converge within their respective convergence clubs. Notably, convergence in energy diversification and per-capita income was observed among low- and lower-middle-income countries.

Both the raw data analysis and regression results affirmed the positive contribution of technological progress, represented by the linear trend, to energy diversification, financial system development, and economic growth. The Granger causality test and regression analysis revealed bi-directional positive causal relationships between energy diversification and per-capita income, as well as between financial development and per-capita income. However, there was no significant causality detected between energy diversification and financial development. Furthermore, the impacts of per-capita income on energy diversification and financial development were found to be stronger than the reverse.

Additionally, a U-shaped relationship between oil price and energy diversification was identified, with the turning point occurring at a WTI oil price of $88.33 per barrel. The human development index demonstrated a positive influence on energy diversification, while international tourism receipt, international trade, and employment rate were positively associated with financial development. Labor participation, human development index, and capital stock were found to be crucial drivers of economic growth.

The findings on convergence clubs and the positive linkages between energy diversification and per-capita income, as well as per-capita income and financial development, suggest that attaining a common steady-state equilibrium in energy diversification, economic prosperity, and financial robustness is achievable across countries through technological progress and diffusion. Thus, investments in human capital and technology to facilitate innovation and the adoption of cutting-edge technologies are vital prerequisites for sustainable economic and financial development. Forward-thinking policies, upfront investments, collaboration among stakeholders (government, financial institutions, large businesses, end-users, and development organizations), and government subsidies for innovation loans can encourage such investments in human and technological capital. Moreover, providing technical, managerial, and financial support from advanced countries or international organizations (such as the UN and the World Bank) to less developed countries can expedite their catch-up process. Particularly, given the significant rise in fossil fuel prices in 2022 due to the Russia-Ukraine war, promoting energy diversification through increased adoption of renewable energy sources can reduce the demand for fossil fuels, thereby driving down fossil fuel prices, mitigating the adverse impact of the global energy crisis on economic growth, and curbing greenhouse gas emissions. Making renewable energy technologies accessible to all countries emerges as a critical pathway to accelerate the energy diversification process. Future studies could focus on individual countries using time-series techniques or specific regional groupings, considering the global dataset utilized in this study.

**Declaration of Competing Interest**

None

**Data availability**:Data in support of findings of this study is available from the corresponding author upon reasonable request**.**

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1. 2020 data (https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html) [↑](#footnote-ref-2)
2. https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html [↑](#footnote-ref-3)
3. https://www.vox.com/ad/17587752/energy-industry-mix-green-environment-diversification [↑](#footnote-ref-4)
4. The wholesale price surge in 2022 is entirely due to soaring costs for energy. [↑](#footnote-ref-5)
5. The share of renewable energy consumption in total final energy consumption is in the range of 16.76% and 18.13% over the 1990-2018 period (https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS) [↑](#footnote-ref-6)
6. https://wits.worldbank.org/trade\_outcomes.html [↑](#footnote-ref-7)