Investigating the CO_2 Emissions Convergence and its Nexus with Growth, Renewable Energy, and Energy Intensity in OIC Countries

Mansur Muhammad [a], Bello Audu [b], Sadiq Ibrahim Ahmed [c].

[a] *Faculty of Economics and Business, Universitas Islam Internasional Indonesia, Depok, Indonesia and Usmanu Danfodiyo University, Sokoto, Nigeria.*
[b] *Institute of Industrial Management, Economics and Trade (IIMET), Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russian Federation*
[c] *Department of Economics, Yusuf Maitama Sule University, Kano State, Nigeria*

Keywords
CO_2 emissions, energy consumption, Growth, convergence, system GMM

Abstract
Carbon dioxide (CO_2) emissions pose a significant climate threat, impacting all aspects of human activity and necessitating global collaboration to protect both human and nonhuman species. Transitioning from fossil fuels to renewable energy and enhancing energy efficiency are widely regarded as the most effective strategies for reducing emissions and mitigating global warming. Against this backdrop, we examine CO_2 emissions convergence among 50 Organization of Islamic Countries (OIC) member states, considering the role of economic growth, renewable energy use, and energy intensity. Our analysis employs stochastic, club, and beta convergence methods, alongside system generalized method of moments (GMM) estimation. Four key findings emerge from this analysis. First, accounting for country heterogeneity and cross-sectional dependence, we confirm stochastic convergence in CO_2 emissions among OIC members. Second, there is evidence of club convergence, where emissions cluster into distinct groups. Third, while renewable energy consumption negatively affects emissions pathway, energy intensity positively and directly affects CO_2 emissions' growth. However, fourth, economic growth increases carbon emissions. These findings have significant policy implications. If emissions do not converge, allocating emission rights through carbon trading could lead to substantial international wealth transfers, influencing global carbon policy. Additionally, countries with similar convergence patterns could adopt common climate policies. At the same time, all nations should prioritize increasing the share of renewable energy in their energy mix to achieve sustainable emission reductions.

Citation (APA)
Muhammad, M., Audu, B., Ahmed, S. I.(2025). Investigating the CO2 Emissions Convergence and its Nexus with Growth, Renewable Energy, and Energy Intensity in OIC Countries. *Muslim Business and Economics Review, 4*(1), 1-31
https://doi.org/10.56529/mber.v4i1.384

Submitted : 18 April 2025
1st Revision : 9 June 2025
2nd Revision : 17 June 2025
3rd Revision : 22 June 2025
Accepted : 24 June 2025-
Published - : 30 June 2025
Corresponding Author : mansur.muhammed@uiii.ac.id

1. Introduction

Among greenhouse gas emissions, carbon dioxide (CO_2) has received the most attention in efforts to curb global warming emanating from the combustion of energy and non-energy materials. It constitutes over 70 percent of the greenhouse gas emissions concentrated in the atmosphere, and its further growth constitutes a serious threat to maintaining the global temperature at 1.50 Celsius (Akyüz, 2025; Churchill *et al*., 2020). For decades now, human activities related to energy and non-energy have led to over 30 billion tons of CO_2 emissions annually (Iwata & Okada, 2014). Although CO_2 emission growth over time has been attributed to the combustion of fossil fuels, many factors have been recently identified as key to the growth of CO_2 at the regional and international levels. This has led many researchers to embark on the journey of identifying the key factors and mitigation strategies. In addition, governments at national, regional, and international levels are actively working to improve environmental quality. International initiatives such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, the Paris Agreement, and the Conference of the Parties aim to curb the growth of emissions by establishing globally accepted standards and setting emissions targets for industrialized countries, considering their historical contributions to emissions and their levels of economic development (Aldy, 2006).

Interestingly, the shared responsibility and access to climate finance have been based on the regional and global distribution of carbon emissions. Negotiations over climate change agreements have had two notable effects on the political economy of countries. First, countries with higher emissions, particularly industrialized nations in Europe and North America, are expected to take more active mitigation measures compared to low-emission countries, such as those in Africa, Asia, and Latin America. Second, in line with the periodic review of agreements, especially during the annual Conference of the Parties, there may be proposed rules and explicit guidelines aimed at integrating developing countries into the shared responsibility of emissions management (UNFCCC, 2024). For instance, Soz (1997), as cited in (Aldy & Armitage, 2022), emphasized that the aggregate quantity of emissions should be determined and allocated among participating members of the Kyoto Protocol agreement based on their population.

Economic growth has been identified as a major driver of CO_2 emissions, particularly in advanced industrialized economies, as highlighted by the Environmental Kuznets Curve (EKC) hypothesis (Ahmed & Long, 2013; Barak *et al*., 2024; Bibi & Jamil, 2021; Caporin *et al*., 2024). While this relationship is often considered indirect, the direct link lies in the extensive use of fossil fuels in industrial processes to support overall output growth. This reliance on fossil fuels significantly contributes to emissions, explaining the varying levels of growth and environmental impact observed across many countries. Energy use is not the only factor explaining the growth of carbon emissions; many studies relate it to the growth of the population (Casey & Galor, 2016), foreign direct investment (Ashraf *et al*., 2022), environmental stringency (Demiral *et al*., 2021), trade openness (Q. Wang *et al*., 2024), information and communication technology (Berkhout & Hertin, 2001) and development of automobile and aviation industries (Cui *et al*., 2022).

Multiple studies have examined CO_2 convergence across countries, regions, and globally, demonstrating the effectiveness of various statistical and mathematical methods. However, historically, the convergence hypothesis originated from the neoclassical growth model, which focuses on per capita income growth and the factors influencing growth pathways. Islam, (2003) provided a comprehensive survey of the growth convergence literature, highlighting its theoretical and empirical foundations. This hypothesis was later borrowed and applied to energy and environmental economics, particularly in studies of carbon emissions. The pioneering study in this area was conducted by (Strazicich & List, 2003). Since then, CO_2 convergence research has gained significant attention due to its implications for climate policy and access to mitigation funding.

This study investigates the stochastic, beta and club convergences in the context of member countries of the Organization of Islamic Countries (OIC), Second, we study the relationship between the CO_2 growth pathway, renewable energy consumption, economic growth and energy intensity. This becomes necessary considering the role of the OIC in global energy supply and the spread of its membership across Asia, Africa and Eurasia. The economic performance of OIC countries reached approximately USD 8.9 trillion in 2023, reflecting a 1.4 percent increase compared to 2022. This substantial figure indicates that OIC countries contribute around 8.5 percent of the global economy (OIC, 2024). The growth potential is expected to rise over time as stability and peace are gradually restored across significant parts of the region comprising the member countries. A significant number of OIC states are also members of Organization of the Petroleum Exporting Countries (OPEC), highlighting their extensive involvement in oil-related activities such as exploration, refining, and trade. These activities represent a major source of carbon emissions resulting from fossil fuel operations. In addition, renewable energy usage and adoption is a road map to the energy transition and net-zero emissions. Those countries with a high proportion of renewable energy in their energy use composition are likely to emit less compared to their counterpart (Huang *et al*., 2021).

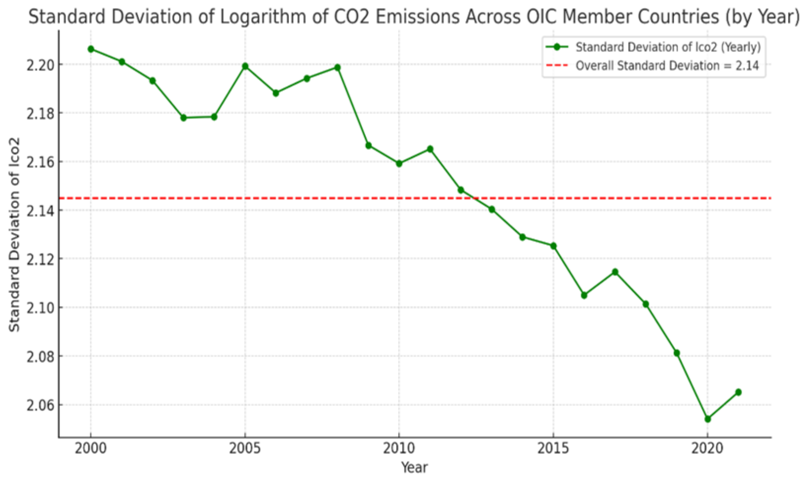

Figure 1. Dispersion in CO_2 Emissions Across OIC Member Countries (2000-2021)[1]
Source: World Bank, 2025

This study contributes to the extant literature on the debate of carbon emissions for climate change action in three ways: first, although several studies test the CO_2 convergence hypothesis, to the best of our knowledge, this is the first study investigating CO_2 emissions convergence in the context of OIC member countries. Second, the current study integrates stochastic, beta, and club convergence approaches to provide a comprehensive assessment of carbon emissions across OIC countries. By combining time series and panel approaches, this study offers a more robust framework for examining convergence patterns. Unlike many previous studies which relied on a single type of convergence analysis, this integrated approach allows for a deeper understanding of whether countries are converging globally, within specific groups, or randomly over time. Third, the use of the two-step system generalized method of moments (GMM) estimator to simultaneously examine beta convergence and the impacts of economic growth, renewable energy, and energy intensity on carbon emissions growth pathways in OIC countries is a novel contribution to the literature. By addressing endogeneity

[1] The data is the standard deviation of the natural logarithm of Carbon emissions. The graph displays the annual standard deviation of lco2 emissions among OIC member countries, with a red dashed line representing the overall standard deviation of approximately 2.14

and unobserved heterogeneity, this approach enhances the reliability of the findings. Lastly, this study offers evidence-based insights for designing region-specific carbon reduction strategies by comparing convergence patterns and their determinants, thereby guiding the balance between economic growth and environmental sustainability in OIC countries.

The structure of the study is organized as follows: Section two reviews the relevant literature and underlying theories, while section three outlines the methods and materials used. Section four presents the results and discusses the findings in detail. Finally, section five concludes the study and offers policy implications.

2. Literature Review

2.1 Sustainable Environment and Islamic Principles

Considering that Islam emphasizes sanity at the individual, community, and national level, Islamic principles sourced from the Qur'an and sunnah are increasingly recognized for their relevance in promoting environmental sustainability particularly in Islamic countries and muslim-majority countries (Bsoul, 2022). Central to Islamic environmental ethics is the concept of khalifah (stewardship), which positions humans as stewards of the Earth, tasked with maintaining the natural balance (*Mīzān*) ordained by Allah. The Qur'an and the Prophet Muhammad's teachings emphasize moderation, conservation, and the responsible use of land and water resources. These values lay the foundation for what is now referred to as eco-Islam, a movement that frames environmental protection as a religious duty among muslims (Koehrsen 2021; Kula 2001).

Islamic environmentalism has gained momentum in multiple Islamic and Muslim-majority countries, including Indonesia, Malaysia, Saudi Arabia, and Thailand, in these and other countries, , faith-based initiatives are being integrated into national climate strategies aligned with international commitments such as the Paris Agreement. Religious leaders and organizations are also integrated into efforts for orientation, advocacy, and waste reduction as expressions of Islamic morality (Avis, 2021).

The tradition of hima (protected conservation areas) reflects early Islamic approaches to sustainable land management. Despite growing interest, challenges such as financial limitations and socio-cultural resistance hinder broader implementation. Nevertheless, Islamic teachings offer practical and ethical guidance for reducing carbon emissions, managing natural resources, and promoting sustainability as a shared religious and environmental responsibility (Bin Salman & Asmanto 2024). Individual behavior oriented toward moderation and the reduction of carbon emissions is a fundamental aspect of one's responsibility as a khalifah of God on Earth. Collectively, nations within OIC contribute to the global effort to curb the growth of emissions over time. These member states are increasingly committed to adopting technologies and practices that support environmental sustainability and align with their shared ethical and religious values (Butt, 2020).

2.2. Convergence Hypothesis

The convergence hypothesis was first tested in the context of explaining the disparity in income growth among countries by neo-classical growth theorists. The hypothesis suggests that developed economies with higher initial income levels tend to experience slower growth compared to developing economies. However, as economies grow, their income levels gradually converge over time (Gálvez-Rodríguez *et al*., 2025; Sala-i-Martin, 1996). The carbon emissions convergence hypothesis is grounded in neoclassical growth theory, proposing that as economies advance, per capita carbon emissions should eventually stabilize and converge across nations. This notion aligns with the EKC framework, which suggests that countries undergoing economic growth and structural transformation are likely to transition towards cleaner energy sources and adopt more efficient production technologies. Consequently, this shift is expected to diminish emissions disparities between countries (Bai *et al*., 2019).

Furthermore, like other developing countries, OIC nations initially had lower carbon emissions due to limited industrialization, outdated technology, low economic growth, and minimal energy consumption. However, as OIC members pursued growth-oriented policies leading to industrialization and technological advancements, their emissions rose more rapidly than those of developed economies. A key factor driving this increase is their reliance on fossil fuels for electricity generation essential for industrial growth (Runar *et al*., 2017). Their rapid economic growth in these economies over the decades has come at the cost of increased emissions, sparking debates about effective climate policies to address the environmental impact of their prosperity.

2.2.1 Stochastic Convergence

The notion of stochastic convergence was developed independently as a critique and improvement of the cross-sectional approach to the convergence hypothesis in the early- and mid-1990s. See (Bernard & Durlauf, 1995, 1995; Carlino & Mills, 1996; Evans *et al*., 1992). The central argument extended in the literature on the superiority of stochastic convergence lies in its ability to account for randomness and variability in data, providing more robust and reliable estimates. It captures dynamic relationships, accommodates heterogeneity across units, and allows for hypothesis testing on convergence (Acaravci & Erdogan, 2016; Churchill *et al*., 2020).

Growing interest in testing carbon emissions convergence has led to the widespread use of stochastic approaches across various studies. Guilló and Magalhães (2023) investigated global carbon emissions convergence from 2000 to 2015, providing evidence supporting convergence and suggesting progress in global emission reduction efforts. Similarly, Topall (2021) examined low-income countries from 1960 to 2016 using structural breaks and nonlinear unit root tests, finding mixed results that highlight the influence of methodologies and structural characteristics on convergence outcomes.

Research on Organization for Economic Co-operation and Development (OECD) member countries has produced varying findings. Kizilkaya and Dağ (2021) applied the Fourier ADF test for the period 1960–2018, demonstrating that the approach effectively captures structural breaks and nonlinearities, thus supporting convergence. Presno *et al*. (2018) and Ozcan & Gultekin (2016) also confirmed convergence in OECD countries using nonlinear stationarity tests and tests accounting for structural breaks. However, Barassi *et al*. (2008) could not validate convergence in 21 OECD countries between 1950 and 2002 using Hadri and IPS panel unit root tests. Meanwhile, Romero-Avila (2008) and Carmarero *et al*. (2008) validated convergence using the panel KPSS stationarity test with structural breaks and the SURADF unit root test, respectively. Finally, Westerlund & Basher (2008) confirmed convergence for 12 developing countries and 16 developed countries.

Studies on the Middle East and North Africa (MENA) region also yield mixed results. Yildiz & Boz (2020) tested per capita emissions convergence across 17 MENA countries from 1965 to 2014 using the Cross-sectionally Augmented Dickey-Fuller (CADF) panel stationarity test, finding evidence of convergence. Magazzino & Cerulli (2019) applied the CADF test, revealing both convergence and divergence among MENA countries.

Further research includes Churchill *et al*. (2020), who applied LM and RALS-LM unit root tests to emerging economies from 1921 to 2014, finding evidence of convergence in 11 countries. In Sub-Saharan Africa, Tiwari *et al*., (2016) used the

Fourier KPSS unit root test and SPSM panel unit root, confirming convergence for 27 countries while 15 countries demonstrated convergence in the SPSM test. Solarin (2014) established convergence for 23 countries using the stochastic convergence hypothesis, while Strazicich & List validated convergence for 21 industrial countries through the IPS panel unit root test.

On the other hand, Lanne & Liski (2004) found no evidence of convergence among 16 developed countries from 1870 to 1998. Aldy (2006), examining 88 countries and 23 OECD countries using DF-GLS unit root tests, found convergence only in the OECD countries. Aslan (2009) and Ulucak & Erdem (2012) provided evidence of convergence in Türkiye, while Christidou *et al*. (2013) confirmed convergence across 36 countries using nonlinear panel unit root tests. Additionally, Yavuz & Yilanci (2013) reported convergence in the first regime and divergence in the second.

In summary, studies on CO_2 stochastic convergence produce mixed results depending on context, data, and estimation techniques. Notably, no study has specifically addressed carbon emissions convergence in OIC countries, a gap this research aims to partially fill. Based on this observation, we hypothesize:

H1: CO_2 exhibits convergence in OIC countries

2.2.2. Beta Convergence

Strazicich and List (2003) investigated CO_2 convergence in 21 industrial countries from 1960 to 1997, finding evidence of convergence through cross-sectional regression and panel unit root tests. Karakaya *et al*. (2019) extended this analysis for the same countries from 1960 to 2013, reaffirming convergence using similar methods.

Li and Lin (2013) analyzed emissions convergence in 110 countries categorized into four income groups (1971–2008) and found convergence by income groups using system GMM. Brännlund *et al*. (2017) focused on 124 countries across income groups, applying conditional β-convergence with control variables such as gross domestic product (GDP), investments, foreign trade, institutional quality, and government consumption. Their findings supported convergence by income groups. For developing countries, Solarin (2014) explored 39 African countries from 1960–2010, finding mixed results with absolute β-convergence and stochastic convergence in 31 countries using OLS and unit root tests. Also, on the data of 27 OECD countries Solarin (2019) tests beta convergence on per capita carbon footprint using a robust method that identifies the actual countries that contribute to the conditional convergence. The findings thereof indicate that 12 of 27 countries exhibit conditional beta convergence in carbon emissions, while, 15 countries indicate convergence for carbon footprint and 13 revealed evidence of convergence in per capita footprint.

A broader study by Zang *et al*. (2018), covering 201 countries across income groups and seven geographic regions (2003–2015), employed absolute beta, -convergence, and club convergence approaches, showing convergence by income groups. However, studies on OECD countries include Presno *et al*. (2018), who analyzed 28 OECD countries and distinguished between developing and developed countries over the long period of 1901–2009. They found convergence across all countries but not within developed countries alone, using univariate and panel unit root tests. On a global sample, using all the convergence classes, Li *et al*., (2020) found evidence of carbon emissions convergence on both consumption and production-based emissions, with the speed of convergence on production-based found to be higher.

Collectively, these studies highlight that beta convergence exists but is conditional to the economic structure, institutional, and regional characteristics with heterogeneity across the countries and time. However, in the context of OIC countries, the following assumptions guide this section:

H2: there is β *– convergence in carbon emissions across countries in OIC.*

2.2.3. Club Convergence

Club convergence is one of the classes of the convergence hypothesis that stipulates that countries or regions with similar characteristics such as income levels, institutions, industries and emissions level tend to converge toward similar steady state outcomes, while others form separate clubs that converge to different equilibria. Club convergence recognizes heterogeneity across the units. In environmental studies for instance, it implies that some countries perhaps based on the green adoption policy, or energy mix, and general environmental policies may exhibit similar CO_2 emissions trajectories over time (Alexiadis, 2012).

Many academic studies on convergence have adopted the club convergence approach since its introduction, with the most widely used method being that of (Phillips & Sul, 2007). To better understand the dynamics of carbon emissions for instance, Bhattacharya *et al*. (2020) applied club convergence hypothesis to examine the consumption and production-based carbon emissions across seventy countries. The study reports two different club convergence two clubs for consumption-based carbon emissions and three for production-based. The study further documented that the positive impact of the total factor productivity, renewable energy consumption, and urbanization enhanced the odds of being among the club of low carbon emissions. A related study examining 128 countries using club convergence found that two clubs converge to different steady pathways (Panopoulou & Pantelidis, 2009). A more specific study from Bai *et al*., (2019) focused on the emissions from the transportation sector in provinces in China. It found that two Chinese provinces diverged, while the remaining provinces converged into low carbon emissions, medium carbon emissions, and high carbon emissions. However, the result of the ordered logit regressions revealed that urbanization and high fixed asset intensity play a significant role in transportation emissions among the provinces in China.

Haider & Akram, (2019) used disaggregated level data to study club convergence in 53 countries from 1980 to 2016. Their findings support convergence into two clubs for total emissions and emissions from gas and petroleum, while emissions from coal indicate convergence into three clubs. The study further revealed that the club convergence follows the equality principle of participation in climate policy as developed countries were found to converge to the same club. Further, Erdogan & Okumus (2021) tested convergence using stochastic and club convergence for the sample of different income groups. The findings suggested multiple club convergence among income groups and these findings underscore the necessity of implementing varying environmental policies for effective mitigation. Akram *et al*., (2020) studied club convergence in per capita carbon emissions across Indian states. They found evidence of divergence when all 16 states were considered, although they formed multiple club convergence due to heterogeneity in per capita carbon emissions. These findings suggest that addressing the carbon emissions could be carried out according to the clusters and stage-wise.

Furthermore, the study of Yang *et al*. (2022) focuses on the countries that propose carbon neutrality to test whether they converge to a single club or otherwise. The study utilized data from 121 countries with carbon neutrality goals and found evidence of club convergence in multiple steady paths. The post-Kyoto Protocol period was instrumental in the movement of high-income countries to lower emissions levels, while some developing countries experienced elevation. In a related study focusing on developing countries by Payne & Apergis (2021), it was found that for the three income classifications, each income group exhibits convergence to different steady paths. The study further observed that many of the countries grouped within the respective convergence clubs are geographically close to one another.

H3: CO_2 in OIC countries do not converge to a single steady state, but exhibit club convergence

2.3. On the Determinants of CO_2 Emissions Convergence

Beyond testing the carbon emissions convergence hypothesis, several studies highlight factors influencing emissions trajectories. Economic variables such as growth, poverty, income inequality, and urbanization, alongside energy-related factors which play critical roles such as consumption patterns, efficiency, and intensity. Research indicates a strong link between economic development and rising emissions, particularly in rapidly industrializing countries, while urbanization often increases energy demand, further exacerbating emissions (Wang *et al*., 2024; Wollburg *et al*., 2023). However, the role of technological advancements and effective policy frameworks further shapes emissions dynamics, with innovations enhancing energy efficiency and regulatory measures guiding nations toward sustainable practices. Controversies surrounding carbon emissions convergence often center on equity and responsibility among nations. The imposition of stringent climate regulations by developed countries raises ethical questions about fairness, particularly for developing nations that may struggle to meet such standards without compromising economic growth (Onofrei *et al*., 2022).

Runar *et al*. (2017) examined the role of economic growth and institutions in the convergence of carbon emissions using both parametric and non-parametric methods. Their findings indicate that institutional mechanisms, when transmitted through economic growth, tend to enhance carbon emissions within OECD countries. Similarly, these results hold true for the global sample. Focusing on member states of the Association of the South East Asian Nations, Dogah & Churchill (2022) highlighted that understanding the source of emissions is essential for identifying its patterns and trajectories. More importantly, urbanization was found to be a pivotal factor influencing emission pathways. In a related study involving 39 American countries and employing club convergence analysis, Mikael & Heshmati (2022) demonstrated that economic growth, trade openness, renewable energy, and urbanization significantly determine club membership for emissions convergence. Furthermore, a study of OECD countries by Camarero *et al*., (2013) found that the carbonization index and energy intensity produce distinct convergence patterns, resulting in either a single club or multiple convergence clubs.

Analysis of Australian regional data to investigate the determinant of carbon emissions convergence revealed multiple convergence clusters in GHG emissions, but, international trade, income level, and urbanization are the key factors shaping emissions convergence in Australia (Ivanovski & Churchill, 2020). Similarly, De Souza Sá & da Silva Gomes, (2025) studied convergence arising from managed agricultural soil and its determinants in Brazilian states. Analysis revealed that two distinctive clubs were formed in the proportion of 9 (33 percent) and 18(67 percent). However, energy consumption, land use, labor industrial production, agricultural production, and rural credits are among the key drivers of agricultural emissions convergence among states in Brazil.

H3: Economic Growth, renewable energy usage and intensity significantly shape CO_2 trajectory in OIC

3. Data and Methods

3.1 Data

This study utilised secondary data exclusively sourced from World Development Indicators and the Energy Information Administration (EIA) of the United States (US). The optimal available data for econometric investigation in the databases ranges from 2000 to 2021. The main variable of interest is CO_2, measured in million tonnes of CO_2 equivalent (Mt CO_2e), excluding emissions from land use, land-use change, and forestry (LULUCF), and sourced from the (WDI). Independent variables include Renewable Energy referring to the share of the total energy consumption derived from renewable sources, measured in quadrillion British thermal units (quad Btu) and sourced from the EIA, and energy intensity, reflecting how efficiently energy is used in the economy, measured in megajoules per $2017 PPP GDP, also from WDI.

Additional variables include GDP per capita in current US dollars, population growth measured annually as a percentage change, and foreign direct investment (FDI) net inflows expressed as a percentage of GDP, all sourced from the WDI. These variables collectively allow for the analysis of the environmental impact of economic and demographic factors, with a focus on how economic activity, investment, and renewable energy use influence carbon emissions convergence in OIC.

Table 2 reports the descriptive statistics of the variables, where CO_2 show a wide range, with a mean of 77.91 million metric tons and a standard deviation of 132.4.

This indicates large disparities in emissions levels across observations, likely due to the differences between low and high-emitting countries. The GDP per capita proxy for economic growth also shows substantial dispersion, with an average of around USD 7,100 and a high standard deviation (12,993.95), suggesting wide economic differences among the countries or entities studied.

Energy intensity has a relatively moderate average of 5.69 with considerable variation of about 3.28, which may indicate different levels of energy efficiency across the sample. Renewable energy use, however, is quite low on average (mean = 0.02), with limited variation, signalling that most countries rely heavily on fossil fuels. FDI and population growth also display considerable spread, with population annual growth rate ranging from negative to highly positive values, reflecting diverse demographic trends.

Table 1. Variable Description and Measurement
Source: Author's compilation.

Variable	Code	Definition	Sources
Carbon emissions	CO_2	CO_2 emissions (total) excluding LULUCF (Mt CO_2e).	WDI
Renewable energy	RE	Total energy consumption from renewables and other (quad Btu)	EIA
Energy intensity	EI	Energy intensity level of primary energy (MJ/$2017 PPP GDP)	WDI
GDP	GD	GDP per capita (current US$)	WDI
Population growth	PG	Population growth (annual %)	WDI
FDI net inflow	FD	Foreign direct investment, net inflows (% of GDP)	WDI

3.2 Methods

The key objectives of this study are twofold: First, to examine if carbon emissions are converging across OIC member countries, and second, to examine the impact of key determinants shaping carbon emissions pathways. To achieve these aims, we employ several econometric techniques. We begin with stochastic convergence analysis using both time series and panel unit root tests to assess the convergence hypothesis. Next, we apply club convergence methods to determine whether emissions converge toward a single club or multiple clubs. Finally, we use the system GMM approach to evaluate the effects of renewable energy usage, energy intensity, and economic growth on carbon emissions pathways.

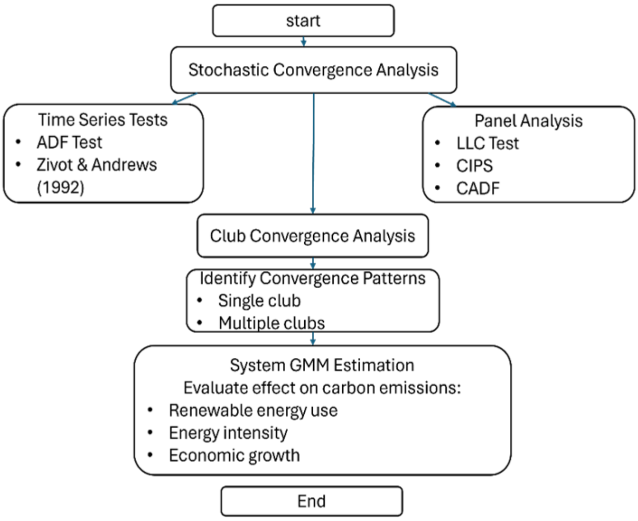

Figure 2. Econometrics Methodological Infographic

3.2.1. Time Series Approach

To test the convergence hypothesis using stochastic modeling, we use two approaches: the Augmented Dickey-Fuller (ADF) test and the Zivot-Andrews (Z&A) unit root test. The ADF test is chosen because it is the standard and most widely used method in time series analysis. The Z&A test is included to account for structural breaks caused by shocks in the data. Since we are interested in how quickly and to what degree the carbon emissions of a particular country are likely to catch up to the average carbon emissions across the OIC countries, The unit root tests are conducted on equation 1 following the construct of Chang & Lee (2008), Romero-Ávila (2008), and Solarin, (2014, 2019).

$$X_{it} = ln\left(\frac{CO_{2it}}{average\ CO_{2it}}\right) \text{......(1)}$$

Unit root test is conducted on equation 1 using ADF and Z&A unit root tests. If the series is stationary i.e. mean reverting, carbon emissions convergence holds.

3.2.2 Panel Approach

As argued by Pesaran, (2012), the panel unit root test performs better than the individual time series stationarity test. In addition, second-generation panel unit root tests such as the Cross-sectional Augmented Im, Pesaran and Shin (CIPS) test cater for cross-sectional dependence. Equation (2) presents the CIPS test statistics when N→∞.

$$\widehat{CIPS} = N^{-1}\sum_{i=0}^{n} CDF \text{ ......(2)}$$

3.2.3. Club Convergence Test

To estimate club convergence, we apply the method developed by Phillips and Sul (2007, 2009). This approach is chosen for two main reasons. First, when convergence to a single club is absent, the method allows for the endogenous formation of multiple clubs. This makes the results robust regardless of whether the panel sample exhibits stochastic stationarity. Second, the method emphasizes relative convergence within the sample, rather than absolute convergence.

Furthermore, the approach proposed a log t-convergence test where the natural log of the target variable is expressed as the product of a time-varying idiosyncratic factor loading parameter. The estimated equation is expressed as:

$$logy_{it} = \delta_{it}\mu_t \text{ ......(3)}$$

Where: δ_{it} represents a unit-specific indicator of the proportion of or deviation from the common emissions growth trajectory μ_t. For the following hypothesis testing, the relative transition coefficient h_{it} must be formulated, defined as the logarithm of a unit's emissions relative to the panel average at time t.

$$h_{it} = \frac{logy_{it} = \delta_{it}\mu_t}{N^{-1}\sum_{i=1}^{N}\log y_{it}} = \frac{\delta_{it}}{N^{-1}\sum_{i=1}^{N}\delta_{it}} \text{ .....(4)}$$

As expressed in Eq. (3), the common component μ_t is eliminated, making h_it the ratio of a unit's factor loading δ_{it} to the average δ_t. However, Philips and Sul (2007) relied on the semiparametric specification of δ_{it}.

$$\delta_{it} = \delta_i + \sigma_i\xi_{iy}L(t)^{-1}t^{-a} \text{ .....(5)}$$

Based on this, the following hypothesis is tested for log t convergence;

H_0 : δ = δ and α ≥ *0* against $H_0=\delta_i=\delta$ H_1: $\delta_i \neq \delta$, α < 0

3.2.4 Beta (β) – Convergence

Beta convergence offers a useful framework for examining whether carbon emissions in poorer economies grow at a faster rate than in wealthier ones (Barro *et al.*, 1991). Beta convergence occurs when there is a negative relationship between the growth rate of carbon emissions and their initial level indicating that economies with higher initial emissions tend to experience slower growth in emissions (see Criado *et al*. (2011) for details. Equation (6) serves a dual purpose: it is used to test for beta convergence and to evaluate the impact of other factors on the emissions trajectory.

$$X_{it} = \delta_i + \delta_1 C0_{2,it-1} + \delta_2 \ln GDit + \delta_3 RE_{it} + \delta_4 El_{it} + \delta_5 PG_{it} + \delta_6 FD_{ti} + \mu_t \quad ...(6)$$

Where:

X_{it} is defined in Equation 1

Explanatory variables as defined in table 1

δ_0 - δ_6 are the parameters of the model

μ_{it} is the disturbance term

To estimate Equation (6), we employ the two-step system GMM estimator proposed by Blundell and Bond (1998). This method is appropriate because the inclusion of the lagged dependent variable may lead to endogeneity, and system GMM effectively addresses this issue while providing robust and efficient estimates. Additionally, potential correlation between lagged and other explanatory variables further justifies the use of this estimator (Runar *et al.*, 2017)

4. Results and Discussions

4.1. Stochastic Convergence – Country Level Test

The results presented in Table 3 offer insightful evidence regarding the convergence hypothesis of carbon emissions across countries. The application of the ADF and Z&A unit root tests on the transformed variable (X_{it}) for each country aims to evaluate whether carbon emissions in these economies follow a stationary process, thereby implying convergence. A stationary series, in this context, suggests that shocks to carbon emissions are temporary and that emissions tend to revert to a long-run mean or common path over time, thereby supporting the convergence hypothesis. Conversely, non-stationarity would imply divergence, suggesting that emissions in some countries persistently deviate from the average behaviour of the group.

From the ADF test results, 33 out of the 50 countries in the sample reject the null hypothesis of a unit root (as shown in Figure 2), indicating stationarity and, by extension, carbon emissions convergence. This result suggests that a majority of countries are indeed moving toward similar long-run carbon emission levels, despite facing challenges such as institutional weaknesses, environmental policy inefficiencies, and slow adoption of renewable technologies. This finding aligns with prior studies such as Panopoulou & Pantelidis (2009) and Román-Collado & Morales-Carrión (2018), which emphasises that convergence in emissions can occur even in heterogeneous economic and environmental policy environments, particularly as countries integrate more deeply into the global economy and adopt international environmental standards.

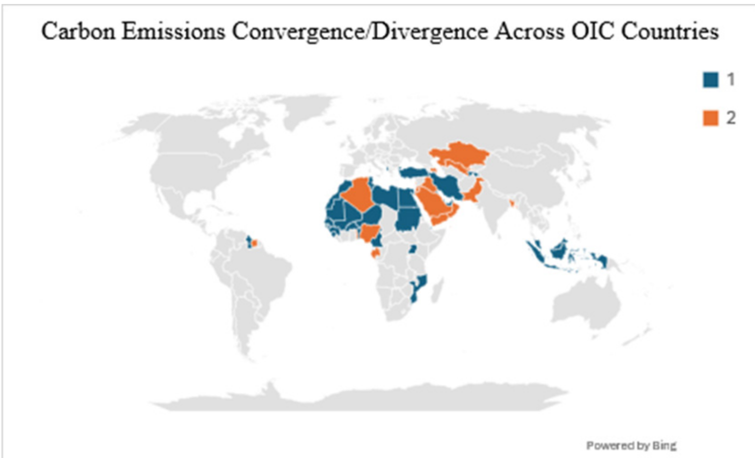

Figure 3. Carbon Emissions Convergence Status Across OIC Countries

However, when accounting for potential structural breaks using the Z&A test, which accommodates one endogenous break in the series, the results are more conservative. Only 13 countries show evidence of stationarity after adjusting for possible structural shifts in carbon emissions. This difference underscores the importance of structural dynamics in emissions trends. Structural breaks could arise from major economic policy reforms, transitions in energy systems, or global crises such as the COVID-19 pandemic. The Z&A test, therefore, refines the initial convergence results by revealing that emissions convergence may be overstated if structural breaks are not properly addressed

Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
EI	1100	5.69	3.28	1.66	26.91
CO_2	1100	77.906	132.4	.091	738.583
GD	1100	7100.317	12993.95	136.926	108470.38
PG	1100	2.352	1.857	-10.927	21.7
FD	1100	3.417	5.423	-11.192	55.073
RE	1100	.02	.047	-.002	.477

Source: Author's computation using STATA 17

Table 3. Measures of Stochastic Convergence [33/50]

Country	ADF	Z&A	
		t-stat	Break date
Albania	-4.6039***	-5.173**	2011
Algeria	-2.0415	-4.350	2012
Azerbaijan	-2.8858	-4.254	2009
Bahrain	-5.8697***	-5.602**	2005
Bangladesh	-2.8730	-3.709	2017
Benin	-3.1779***	-2.624	2006
Brunei	-2.6846	-4.391	2006
Burkina Faso	-3.5920***	-5.500**	2007
Cameroon	-2.3724**	-3.631	2007
Comoros	-1.9105*	-5.161	2007
Cote devoir	-1.8783*	-4.491	2003
Djibouti	-3.4335**	-5.469**	2013
Egypt	-2.7889*	-3.031	2009
Gabon	-1.9279	-2.842	2010
Gambia	-4.7549***	-4.433	2012
Guinea	-3.1398***	-5.930***	2018
Guinea Bissau	-1.7384*	-4.106	2017
Guyana	-1.8062*	-4.588	2005
Indonesia	-4.0481**	-6.404***	2015
Iran	-2.9725*	-4.691	2006
Iraq	-2.9897	-2.928	2009
Jordan	-0.8022	-3.306	2017
Kazakhstan	-1.5406	-3.426	2014
Kuwait	-5.0654***	-4.475	2005
Lebanon	0.7385	-2.401	2019

Libya	-4.4014***	-5.489**	2015
Malaysia	-2.6494*	-3.330	2007
Maldives	-3.6002***	-5.154**	2012
Mali	-5.3026***	-2.793	2016
Mauritania	-3.6788***	-4.472	2013
Morocco	-4.4822***	-5.531**	2014
Mozambique	-4.6362***	-4.137	2016
Niger	-3.0253***	-3.750	2012
Nigeria	-1.9604	-4.384	2011
Oman	-0.8459	-3.167	2011
Pakistan	-2.0135	-3.324	2010
Qatar	-1.8050*	-3.179	2013
Saudi Arabia	0.9130	-5.946***	2015
Senegal	-4.7725***	-5.250**	2016
Sierra Leone	-2.0364**	-4.721	2011
Sudan	-4.8931***	-2.678	2006
Suriname	-2.5483	-3.503	2012
Tajikistan	-2.3173**	-5.085**	2009
Togo	-2.0422	-3.407	2009
Tunisia	-3.1427***	-6.370***	2014
Turkey	-3.3903*	-5.307**	2006
Uganda	-6.3167***	-3.813	2005
UAE	-2.8665*	-3.700	2008
Uzbekistan	-2.0047	-4.473	2014
Yemen	-1.8129	-3.895	2015

NB: *, **, *** indicate the significance at 10%, 5% & 1%, lag length is based on the Schwarz Information Criteria (SIC). We include intercept, intercept & trend, and without intercept and trend. The significant variable is choosing using these three alternations. Z&A (1992) is estimated by allowing a break in both intercept and trend. Source: Author's computation using STATA 17.

Table 4. Measure of Group Carbon Emissions Convergence

Test type	Statistic	Lags	Decision
LLC	-2.4443***	2	Validate convergence
CADF	-1.866	2	Invalidate convergence
CIPS	-2.254**	1	Validate convergence

*, **, *** indicate the significant at 10%, 5% & 1%. LLC is based on Bartlett kernel, CIPS is based on joint F test. Source: Author's computation using STATA 17

Table 5. Measure of Club Convergence

	No of Countries	β	T-stat	SE
Full sample	50	-0.4406	-8.866	0.0497
Club 1 Iran, Saudi Arabia	2	0.5374	4.7233	0.1138
Club 2 Algeria, Bangladesh, Egypt, Kazakhstan, Malaysia, Pakistan, Qatar UAE	8	0.2673	2.7947	0.0956
Club 3 Kuwait, Mali, Morocco, Nigeria, Oman, Uzbekistan	6	0.0336	0.4181	0.0805
Club 4 Azerbaijan, Bahrain, Benin, Burkina Faso, Libya, Mozambique, Sudan, Tunisia, Uganda	9	0.3513	3.7024	0.0949
Club 5 Jordan, Lebanon, Maldives, Mauritania, Niger, Senegal, Tajikistan	7	0.3890	4.4095	0.0882
Club 6 Albania, Brunei, Cameroon, Cote D'Ivoire, Guinea, Yemen	6	-0.0061	-0.0801	0.0760
Club 7 Djibouti, Gabon, Gambia, Guinea Bissau, Guyana, Sierra Leone, Suriname, Togo	8	5.3282	5.8171	0.9160
Club 8 Comoros, Iraq	2	-0.0486	-0.7644	-0.0636
Divergence Indonesia, Turkey	2	-0.4989	0.0502	-9.9288

T-statistics at 5% significance level: -1.645, Source: Author's computation using STATA 17

4.2. Group Convergence Test

The full sample is tested for the convergence hypothesis using panel unit root tests namely, the Levin, Lin, and Chu (LLC) test, CIPS test, and CADF test. While the LLC test assumes cross-sectional independence, both the CIPS and CADF tests account for cross-sectional dependence. The LLC test rejects the null hypothesis at the 1 percent significance level, indicating that the panel is stationary and CO_2 convergence exists. However, the results of the CIPS and CADF tests are contradictory. Therefore, further testing is necessary to robustly validate the convergence behaviour of carbon emissions. When group convergence is achieved in OIC countries, it means that countries with high emissions are reducing their emissions at a faster rate than those with lower emissions, eventually leading to a more uniform level of emissions across the group. Such convergence can result from shared policies, technological diffusion, economic integration, or coordinated environmental efforts. However, similar findings on group convergence were reported in the study of Churchill *et al*. (2020) on the panel of emerging economies, and in Camarero *et al*., (2013) and Solarin (2019) on OECD countries.

Table 5 presents the results of the carbon emissions convergence analysis based on the log t-test proposed by Phillips and Sul (2007). The full sample test does not support the convergence hypothesis, indicating that carbon emissions across OIC countries do not converge as a whole. Instead, the analysis reveals the formation of distinct convergence clubs, with Indonesia and Turkey showing evidence of divergence. In total, eight unique convergence clubs are identified.

Some clubs particularly Clubs 3, 6, and 8 exhibit weak convergence, as indicated by estimated coefficients close to zero or, in some cases, negative values. Most of the clubs demonstrate conditional convergence, given that their estimated b-values fall within the range $0 \leq \beta < 2$. However, the low magnitude of these coefficients, except in Club 7, suggests that convergence is occurring at a relatively slow pace.

The pattern of club formation appears to reflect geographical proximity, economic structure, and resource endowments among OIC countries. These findings are consistent with a few previous studies that also report convergence clustering along such lines. (See Panopoulou & Pantelidis, 2009; Payne & Apergis, 2021; Rodríguez-Benavides *et al*., 2024; Yang *et al*., 2022).

4.3. β - Convergence and the Role of key Determinants of CO_2 Growth Pathway

In this section, we analyze the results of the conditional convergence in carbon emissions among OIC member countries, based on the theoretical underpinnings of the neoclassical growth model and its green growth extension by Solow. According to the conditional convergence hypothesis, countries will converge to their respective steady-state levels of carbon emissions provided they share similar structural characteristics, including institutional frameworks, energy mix, and technological capacities (Barro & Sala-i-Martin, 1995). Conditional β-convergence is established when the coefficient of the initial carbon emissions level (δ_2 in equation 6) is negative and statistically significant.

However, our empirical results reveal a significantly positive coefficient, indicating a divergence rather than convergence in carbon emissions across OIC countries. This outcome suggests that despite some shared religious and sociopolitical characteristics, structural and developmental heterogeneities remain substantial, thereby impeding convergence. Similar divergence patterns have been observed in prior studies, such as those by Camarero *et al*. (2013) and Panopoulou & Pantelidis (2009), who found evidence of emissions divergence in developing regions due to disparities in policy, technology, and energy infrastructure.

Further, the analysis highlights that the initial level of economic growth, exerts a positive and statistically significant influence on the growth rate of carbon emissions in OIC countries. This aligns with the EKC literature, where economic growth initially drives environmental degradation (Grossman & Krueger, 1995). The elasticity estimate of 0.04 percent suggests that even marginal increases in GDP are associated with incremental increases in emissions.

Interestingly, the role of renewable energy consumption appears to be negative but statistically insignificant. This observation is not unexpected given the slow transition toward renewable energy sources in many OIC countries, where fossil fuels continue to dominate energy production and consumption patterns. This result is supported by the work of Sadorsky (2009), who noted that renewable energy penetration remains limited in developing economies due to high initial costs, lack of infrastructure, and policy inertia. The insignificant effect observed in our model points to the need for stronger commitments toward energy transition and greater investment in renewable infrastructure to realize its environmental benefits.

Moreover, energy intensity indicating the amount of energy used per unit of output was found to have a positive and significant relationship with carbon emissions growth. This result confirms that energy-intensive production contributes more substantially to emissions growth than more energy-efficient processes. Consistent with findings by Ang (2004), this suggests that efforts to improve energy efficiency can yield substantial reductions in emissions over time. High energy intensity often reflects outdated technology and inefficient resource use.

Our model also reveals that FDI net inflows have a positive and significant impact on carbon emissions growth within OIC countries. This result aligns with the pollution haven hypothesis, which posits that multinational corporations tend to relocate polluting industries to countries with weaker environmental regulations. In the context of OIC countries, this implies that while FDI contributes to economic development, it may also exacerbate environmental degradation if not accompanied by stringent environmental oversight and green investment guidelines.

Lastly, population growth is positively related to carbon emissions growth, although the relationship is statistically insignificant in our sample. This may be attributed to demographic factors such as age distribution, urbanization levels, and labor force participation, which vary significantly across OIC countries. While the literature generally supports a strong link between population growth and emissions (Dietz & Rosa, 1997), this finding suggests that the demographic structure and economic roles of populations may mediate this effect. This warrants further disaggregated analysis to better understand the interaction between population dynamics and environmental pressures.

Table 6. Estimate of the Determinants of Carbon Emissions Trajectory

Variables	Coefficient	Std error
Initial CO_2 level	0.9176***	0.1119
RE	-0.0371	0.1211
EI	0.0046**	0.0020
Initial GD level	0.0378***	0.0090
FD	0.0020***	0.0006
PG	0.0025	0.0018
Constant	-4.4331***	0.06214
AR(1)	-4.39***	
AR(2)	0.62	
Sargan test	1170.43***	
Hansen test	47.12	

5. Conclusions

In this study, we investigated the dynamic behaviour of CO_2 emissions across OIC countries through the lens of the convergence hypothesis by applying a stochastic convergence test via ADF, Z&A unit root tests, beta convergence, and club convergence frameworks. Our empirical findings provide evidence that 33 out of 50 OIC countries exhibit stochastic convergence in carbon emissions, implying that their emission levels are reverting toward a common trend over time, while in the presence of structural breaks, a slight change was observed. The results from the β-convergence analysis further affirm the presence of conditional convergence, suggesting that while countries may be converging, this process is influenced by country-specific factors, such as differences in technology adoption, mitigation policy frameworks, and structural economic characteristics. Furthermore, the club convergence analysis uncovers the presence of eight distinct convergence clubs, highlighting heterogeneity in emissions dynamics within the OIC region. These clubs suggest the presence of differentiated trajectories of decarbonization, potentially aligned with variations in economic development, resource endowments, and energy strategies.

The second part of the analysis, employing two-step system GMM estimation to capture the effect of the key determinants of carbon emissions growth, indicates that economic growth positively contributes to the CO_2 emissions pathway, reaffirming the environmental trade-offs associated with output expansion in many OIC economies. Conversely, renewable energy consumption is found to significantly reduce emissions, affirming the environmental benefits of the clean energy transition and technologies across the region. Additionally, higher energy intensity is associated with increased emissions. Control variables such as FDI and population growth also show significant influences, with FDI potentially contributing to emissions depending on the environmental standards imposed and enforced within host countries.

These findings yield several vital policy implications. First, the existence of conditional and club convergence calls for targeted, context-specific climate and energy policies within the OIC framework rather than a one-size-fits-all strategy. Countries within the same convergence club could pursue regional cooperation, share best practices, and align efforts toward joint mitigation goals. Second, OIC policymakers must aggressively promote renewable energy investments, particularly in countries lagging in clean energy adoption. Leveraging Islamic finance instruments such as green sukuk can mobilize capital for renewable infrastructure, while shariah-aligned incentives could galvanise public and private sector participation.

Third, to decouple economic growth from environmental degradation, a shift toward energy-efficient production and consumption is critical. This includes promoting energy-saving technologies, restructuring subsidies that favor fossil fuels, and investing in energy-efficient transportation and urban infrastructure. Moreover, integrating carbon pricing mechanisms or environmental tax reforms, where politically and institutionally feasible, can guide market behavior towards sustainability.

Despite its strengths, this study has several limitations. First, the analysis is constrained by data availability and quality, particularly for smaller OIC economies. Second, while the club convergence methodology identifies groupings, it does not explain the precise causes behind club membership, calling for further qualitative and institutional analysis. Third, the GMM estimation, although robust to endogeneity, may be sensitive to instrument proliferation and weak identification, and the dynamic relationship may be better captured with longer time series or alternative estimation techniques. Finally, environmental policy is inherently multidimensional, and future research could integrate additional variables such as environmental regulation stringency, technological innovation indices, or sectoral energy use to deepen the analysis.

REFERENCES

Acaravci, A., & Erdogan, S. (2016). The convergence behavior of CO2 emissions in seven regions under multiple structural breaks. *International Journal of Energy Economics and Policy, 6*(3), 575–580.

Ahmed, K., & Long, W. (2013). An empirical analysis of CO2 emission in Pakistan using EKC hypothesis. *Journal of International Trade Law and Policy, 12*(2), 188–200. https://www.emerald.com/insight/content/doi/10.1108/JITLP-10-2012-0015/full/html

Akram, V., Rath, B. N., & Sahoo, P. K. (2020). Stochastic conditional convergence in per capita energy consumption in India. *Economic Analysis and Policy, 65*, 224–240.

Akyüz, M. K. (2025). Global warming potential and enviroeconomic impact of commercial flights: A pre- to post-COVID-19 analysis. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 47*(1), 624–641. https://doi.org/10.1080/15567036.2024.2443036

Aldy, J. E. (2006). Per capita carbon dioxide emissions: Convergence or divergence? *Environmental and Resource Economics, 33*(4), 533–555.

Aldy, J. E., & Armitage, S. C. (2022). *The Welfare Implications of Carbon Price Certainty* (Working Paper No. 30043). National Bureau of Economic Research. https://doi.org/10.3386/w30043

Alexiadis, S. (2012). *Convergence clubs and spatial externalities: Models and applications of regional convergence in Europe*. Springer Science & Business Media.

Ang, B. W. (2004). Decomposition analysis for policymaking in energy: Which is the preferred method? *Energy Policy, 32*(9), 1131–1139. https://www.sciencedirect.com/science/article/pii/S0301421503000764

Ashraf, S., P, J., & Umar, Z. (2022). The asymmetric relationship between foreign direct investment, oil prices and carbon emissions: Evidence from Gulf Cooperative Council economies. *Cogent Economics & Finance, 10*(1), 2080316. https://doi.org/10.1080/23322039.2022.2080316

Avis, W. (2021). Role of faith and belief in environmental engagement and action in MENA region.

Bai, C., Mao, Y., Gong, Y., & Feng, C. (2019). *Club convergence and factors of per capita transportation carbon emissions in China. Sustainability, 11*(2), 539.

Barak, D., Kocoglu, M., Jahanger, A., & Tan, M. (2024). Testing the EKC hypothesis for ecological and carbon intensity of well-being: The role of forest extent.

Science of the Total Environment, 945, 173794. https://www.sciencedirect.com/science/article/pii/S004896972403941X

Barro, R. J., & Sala-i-Martin, X. (1995). *Technological Diffusion, Convergence, and Growth* (Working Paper No. 5151). National Bureau of Economic Research. https://doi.org/10.3386/w5151

Barro, R. J., Sala-i-Martin, X., Blanchard, O. J., & Hall, R. E. (1991). Convergence across states and regions. *Brookings Papers on Economic Activity*, 107–182.

Berkhout, F., & Hertin, J. (2001). Impacts of information and communication technologies on environmental sustainability: Speculations and evidence. *Report to the OECD, Brighton, 21*, 23.

Bernard, A. B., & Durlauf, S. N. (1995). Convergence in international output. *Journal of Applied Econometrics, 10*(2), 97–108.

Bhattacharya, M., Inekwe, J. N., & Sadorsky, P. (2020). Consumption-based and territory-based carbon emissions intensity: Determinants and forecasting using club convergence across countries. *Energy Economics, 86*, 104632. https://www.sciencedirect.com/science/article/pii/S0140988319304293

Bibi, F., & Jamil, M. (2021). Testing environment Kuznets curve (EKC) hypothesis in different regions. *Environmental Science and Pollution Research, 28*(11), 13581–13594. https://doi.org/10.1007/s11356-020-11516-2

Bin Salman, A. M., & Asmanto, E. (2024). Islamic Environmental Stewardship: A Sociological Approach to Hadith and Legal Frameworks for Ecological Responsibility. *Volksgeist: Jurnal Ilmu Hukum Dan Konstitusi*, 361-378.

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics, 87*(1), 115–143. https://www.sciencedirect.com/science/article/pii/S0304407698000098

Bsoul, L., Omer, A., Kucukalic, L., & Archbold, R. H. (2022). Islam's perspective on environmental sustainability: a conceptual analysis. *Social Sciences, 11*(6), 228.

Butt, M. S. (2020). State of environmental protection in the OIC countries: Genesis, ongoing initiatives and recommendations from human rights perspective. *RUDN Journal of Law, 24*(3), 780-800.

Camarero, M., Picazo-Tadeo, A. J., & Tamarit, C. (2013). Are the determinants of CO2 emissions converging among OECD countries? *Economics Letters, 118*(1), 159–162.

Caporin, M., Cooray, A., Kuziboev, B., & Yusubov, I. (2024). New insights on the environmental Kuznets curve (EKC) for Central Asia. *Empirical Economics,* *66*(5), 2335–2354. https://doi.org/10.1007/s00181-023-02520-9

Carlino, G., & Mills, L. (1996). Convergence and The U.S. States: A Time Series Analysis*. *Journal of Regional Science, 36*(4), 597–616. https://doi.org/10.1111/j.1467-9787.1996.tb01120.x

Casey, G., & Galor, O. (2016). *Population Growth and Carbon Emissions* (Working Paper No. 22885). National Bureau of Economic Research. https://doi.org/10.3386/w22885

Chang, C.-P., & Lee, C.-C. (2008). Are per capita carbon dioxide emissions converging among industrialized countries? New time series evidence with structural breaks. *Environment and Development Economics, 13*(04). https://doi.org/10.1017/S1355770X08004361

Churchill, S. A., Inekwe, J., & Ivanovski, K. (2020). Stochastic convergence in per capita CO2 emissions: Evidence from emerging economies, 1921–2014. *Energy Economics, 86*, 104659.

Criado, C. O., Valente, S., & Stengos, T. (2011). Growth and pollution convergence: Theory and evidence. *Journal of Environmental Economics and Management, 62*(2), 199–214. https://www.sciencedirect.com/science/article/pii/S0095069611000362

Cui, Y., Khan, S. U., Deng, Y., & Zhao, M. (2022). Spatiotemporal heterogeneity, convergence and its impact factors: Perspective of carbon emission intensity and carbon emission per capita considering carbon sink effect. *Environmental Impact Assessment Review, 92*, 106699.

Demiral, M., Akça, E. E., & Tekin, I. (2021). Predictors of global carbon dioxide emissions: Do stringent environmental policies matter? *Environment, Development and Sustainability, 23*(12), 18337–18361. https://doi.org/10.1007/s10668-021-01444-7

Dietz, T., & Rosa, E. A. (1997). Effects of population and affluence on CO2 emissions. *Proceedings of the National Academy of Sciences, 94*(1), 175–179. https://doi.org/10.1073/pnas.94.1.175

Dogah, K. E., & Churchill, S. A. (2022). Carbon emissions convergence and determinant analysis: Evidence from ASEAN countries. *Journal of Environmental Management, 323*, 116299.

Erdogan, S., & Okumus, I. (2021). Stochastic and club convergence of ecological footprint: An empirical analysis for different income group of countries. *Ecological Indicators, 121*, 107123.

Evans, D. G. R., Huson, S. M., Donnai, D., Neary, W., Blair, V., Newton, V., & Harris, R. (1992). A clinical study of type 2 neurofibromatosis. QJM: An International

Journal of Medicine, 84(1), 603–618. https://academic.oup.com/qjmed/article-abstract/84/1/603/1561938

Gálvez-Rodríguez, J. F., Manzano-Hidalgo, M., & García-Luengo, A. V. (2025). Predicting Convergence of Per Capita Income in Spain: A Markov and Cluster Approach. *Economies, 13*(1), 17. https://www.mdpi.com/2227-7099/13/1/17

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics, 110*(2), 353–377. https://academic.oup.com/qje/article-abstract/110/2/353/1826336

Haider, S., & Akram, V. (2019). Club convergence of per capita carbon emission: Global insight from disaggregated level data. *Environmental Science and Pollution Research, 26*, 11074–11086.

Huang, Y., Kuldasheva, Z., & Salahodjaev, R. (2021). Renewable energy and CO2 emissions: empirical evidence from major energy-consuming countries. *Energies, 14*(22), 7504.

Islam, N. (2003). What have we learnt from the convergence debate? *Journal of Economic Surveys, 17*(3), 309–362.

Ivanovski, K., & Churchill, S. A. (2020). Convergence and determinants of greenhouse gas emissions in Australia: A regional analysis. *Energy Economics, 92*, 104971. https://www.sciencedirect.com/science/article/pii/S014098832030311X

Iwata, H., & Okada, K. (2014). Greenhouse gas emissions and the role of the Kyoto Protocol. *Environmental Economics and Policy Studies, 16*(4), 325–342. https://doi.org/10.1007/s10018-012-0047-1

Koehrsen, J. (2021). Muslims and climate change: How Islam, Muslim organizations, and religious leaders influence climate change perceptions and mitigation activities. *Wiley Interdisciplinary Reviews: Climate Change, 12*(3), e702.

Kula, E. (2001). Islam and environmental conservation. *Environmental Conservation, 28*(1), 1-9.

Li, C., Zuo, J., Wang, Z., & Zhang, X. (2020). Production-and consumption-based convergence analyses of global CO2 emissions. *Journal of Cleaner Production, 264*, 121723. https://www.sciencedirect.com/science/article/pii/S0959652620317704

Mikael, A. M., & Heshmati, A. (2022). Convergence of carbon dioxide emissions in the Americas and its determinants. *Latin American Economic Review, 31*, 1–33. https://latinaer.org/index.php/laer/article/view/49

Onofrei, M., Vatamanu, A. F., & Cigu, E. (2022). The relationship between economic growth and CO2 emissions in EU countries: A cointegration analysis. *Frontiers* *in Environmental Science, 10*, 934885. https://www.frontiersin.org/articles/10.3389/fenvs.2022.934885/full

Panopoulou, E., & Pantelidis, T. (2009). Club convergence in carbon dioxide emissions. *Environmental and Resource Economics, 44*, 47–70.

Payne, J. E., & Apergis, N. (2021). Convergence of per capita carbon dioxide emissions among developing countries: Evidence from stochastic and club convergence tests. *Environmental Science and Pollution Research, 28*, 33751–33763.

Pesaran, M. H. (2012). On the interpretation of panel unit root tests. *Economics Letters, 116*(3), 545–546. https://www.sciencedirect.com/science/article/pii/S0165176512001905

Phillips, P. C., & Sul, D. (2007). Transition modeling and econometric convergence tests. *Econometrica, 75*(6), 1771–1855. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1468-0262.2007.00811.x

Robério de Souza Sá, Á., & da Silva Gomes, L. (2025). Convergence and Determinants of Carbon Emissions in Brazilian Agriculture. *Revista Portuguesa de Estudos Regionais (RPER), 70*.

Rodríguez-Benavides, D., Andrés-Rosales, R., Álvarez-García, J., & Bekun, F. V. (2024). Convergence of clubs between per capita carbon dioxide emissions from fossil fuels and cement production. *Energy Policy, 186*, 114007. https://www.sciencedirect.com/science/article/pii/S0301421524000272

Román-Collado, R., & Morales-Carrión, A. V. (2018). Towards a sustainable growth in Latin America: A multiregional spatial decomposition analysis of the driving forces behind CO2 emissions changes. *Energy Policy, 115*, 273–280. https://www.sciencedirect.com/science/article/pii/S0301421518300193

Romero-Ávila, D. (2008). Convergence in carbon dioxide emissions among industrialised countries revisited. *Energy Economics, 30*(5), 2265–2282.

Runar, B., Amin, K., & Patrik, S. (2017). Convergence in carbon dioxide emissions and the role of growth and institutions: A parametric and non-parametric analysis. *Environmental Economics and Policy Studies, 19*(2), 359–390. https://doi.org/10.1007/s10018-016-0162-5

Sadorsky, P. (2009). Renewable energy consumption and income in emerging economies. *Energy Policy, 37*(10), 4021–4028. https://www.sciencedirect.com/science/article/pii/S0301421509003176

Sala-i-Martin, X. X. (1996). The classical approach to convergence analysis. *The Economic Journal, 106*(437), 1019–1036.

Solarin, S. A. (2014). Convergence of CO2 emission levels: Evidence from African countries. *Journal of Economic Research, 19*(1), 65–92.

Solarin, S. A. (2019). Convergence in CO2 emissions, carbon footprint and ecological footprint: Evidence from OECD countries. *Environmental Science and Pollution Research, 26*, 6167–6181.

Strazicich, M. C., & List, J. A. (2003). [No title found]. *Environmental and Resource Economics, 24*(3), 263–271. https://doi.org/10.1023/A:1022910701857

Tiwari, A. K., Kyophilavong, P., & Albulescu, C. T. (2016). Testing the stationarity of CO2 emissions series in Sub-Saharan African countries by incorporating nonlinearity and smooth breaks. *Research in International Business and Finance, 37*, 527-540.

Wang, Q., Zhang, F., Li, R., & Sun, J. (2024). Does artificial intelligence promote energy transition and curb carbon emissions? The role of trade openness. *Journal of Cleaner Production, 447*, 141298. https://www.sciencedirect.com/science/article/pii/S0959652624007455

Wang, X., Wang, Y., & Zhou, K. (2024). The impact of energy poverty alleviation on carbon emissions in countries along the Belt and Road initiative. *Sustainability, 16*(11), 4681. https://www.mdpi.com/2071-1050/16/11/4681

Wollburg, P., Hallegatte, S., & Mahler, D. G. (2023). Ending extreme poverty has a negligible impact on global greenhouse gas emissions. *Nature, 623*(7989), 982–986. https://www.nature.com/articles/s41586-023-06679-0

Yang, Z., Yuan, Y., & Tan, Y. (2022). Club Convergence of Economies' Per Capita Carbon Emissions: Evidence from Countries That Proposed Carbon Neutrality. *International Journal of Environmental Research and Public Health, 19*(14), 8336.

Zivot, E., and Andrews, D.W.K. (1992) Further evidence on the great crash, the oil price shock, and the unit root hypothesis, *Journal of Business and Economic Statistics, Vol.10*, No.3, pp.251-70