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Divergent Energy Paths - A Trend Analysis of Global Energy Growth Across Economic Classifications

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ABSTRACT

This study examines global energy growth trends from 1990 to 2022, utilizing secondary data from sources like the IEA, World Bank, and the United Nations. The analysis focuses on indicators such as total energy consumption, fossil fuel and renewable energy consumption, energy intensity, and carbon emissions. The study employs various econometric techniques, including stationarity testing using the Augmented Dickey-Fuller (ADF) test to examine the time series data for unit roots. A semi-logarithmic trend model is used to estimate the long-run trends of energy indicators, and a Kinked Exponential Growth Model is applied to capture variations in growth across different sub-periods, accounting for potential structural breaks. The data was tested for stationarity using the Augmented Dickey-Fuller (ADF) test, showing a non-stationary process at the level but stationary at the first difference (1(1) process). The Semi-Logarithmic trend model revealed significant differences in growth rates across economic classifications. For Developed countries, Japan (5.05%) and the United States (5.5%) had high growth rates, while New Zealand and the UK showed negative growth. In Developing countries, China (6.7%), India (5.8%), and South Africa (4.7%) showed strong growth, whereas Nigeria (2.3%) and Pakistan (3.5%) had lower rates. The Discontinuous Growth analysis revealed steady positive growth for most countries, while Denmark and Finland experienced minimal or negative growth in certain periods.

INTRODUCTION

Energy plays a central role in shaping the trajectory of human civilization (Smil, 2017). From the earliest days of harnessing fire and water to today's complex networks of fossil fuels, nuclear power, and renewable energy systems, societies have depended on energy not only for survival but also for development, innovation, and growth. In the contemporary world, energy serves as the lifeblood of economies—it powers industries, enables transportation, lights up cities, and supports digital infrastructure. However, the manner and pace at which different countries consume and produce energy vary significantly, depending largely on their level of economic development (Vlachogianni & Valavanidis, 2013)). Globally, the demand for energy continues to rise, driven by population growth, urbanization, and industrial expansion (Avtar et., al., 2019). Yet, the path toward meeting this demand is neither uniform nor equitable. While developed countries have progressed toward energy diversification and decarbonization, developing and underdeveloped nations still grapple with energy poverty, reliance on traditional fuels, and limited access to advanced energy technologies. These asymmetries have created divergent energy trajectories, where each group of countries—classified by their economic standing—exhibits distinctive patterns in energy growth, transition, and sustainability (Khan et., al., 2021).

International energy markets, trade dependencies, geopolitical alliances, and transnational investments significantly influence national energy strategies, particularly in developing and underdeveloped countries. For instance, while developed nations often lead in innovation and technology exports, many resource-rich developing countries continue to function primarily as raw material suppliers within the global energy value chain. This asymmetry creates structural dependencies that limit the autonomy of low-income economies in crafting independent and sustainable energy strategies. Furthermore, access to global finance and climate funds is often mediated through complex eligibility criteria and institutional prerequisites, which many underdeveloped countries struggle to meet (Chaudhury, (2020). These external constraints, when combined with internal challenges such as poor governance, weak infrastructure, and limited human capital, further exacerbate the disparities in energy development. Therefore, any comprehensive analysis of global energy growth must account for both domestic economic conditions and the broader international forces that mold energy policies and trajectories. By situating energy trends within this multidimensional framework, the present study endeavours to provide a more nuanced and realistic understanding of the global energy landscape—one that moves beyond aggregate figures and headline indicators to reveal the deeper patterns of divergence and convergence shaping our collective energy future.

In particular, the past three decades have witnessed remarkable changes in the energy landscape: the rapid expansion of renewables in the West, the continued dominance of coal in some Asian economies, and the persistent energy access issues in parts of Africa and South Asia. These trends reflect not only technological advancements and policy shifts but also deep-rooted economic, institutional, and geopolitical differences (Chari, 2025). Therefore, a comparative analysis of energy growth trends across economic classifications—developed, developing, and underdeveloped—can provide critical insights into global energy inequalities, transition potentials, and future directions. This study situates itself within this complex global context. By focusing on trend analysis across economic classifications, it seeks to reveal the structural factors influencing energy growth, the extent of divergence in energy trajectories, and the policy implications for fostering inclusive and sustainable energy futures.

1.1 Global energy inequality and economic classification

The global energy landscape is increasingly marked by inequalities that mirror broader socio-economic disparities between developed, developing, and underdeveloped nations (Darwich, 2025). While advanced economies have transitioned to more diversified and low-carbon energy systems, many low-income nations continue to rely on biomass and fossil fuels for basic needs. These disparities are shaped not only by resource endowments but also by differences in economic capacity, technological development, and institutional readiness.

The economic classification of nations—often defined by indicators such as Gross National Income (GNI), Human Development Index (HDI), and industrial output—correlates strongly with energy consumption and production levels (Yumashev et al., 2020). Developed nations are often pioneers in renewable energy deployment and energy efficiency, backed by strong infrastructure and investment. In contrast, underdeveloped countries face barriers such as lack of funding, weak regulatory frameworks, and low technical capacity. This imbalance poses significant challenges to achieving global energy and climate targets such as SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

1.1.0 Structural Drivers of Energy Divergence

To deepen the analysis, this study introduces a distinct sub-section on the structural drivers of divergence. While energy patterns vary by economic classification, they are also shaped by broader systemic factors within the global political economy (Bridge & Gailing, 2021). Developed nations often benefit from advantageous positions in global trade, finance, and technology diffusion. They have greater access to climate finance, green technology, and international influence in shaping energy governance norms.

Conversely, resource-rich but institutionally weak nations are often relegated to raw material exporters, lacking control over value-added segments of the energy supply chain. Geopolitical alliances, trade dependencies, and conditionalities attached to international funding further constrain the autonomy of developing and underdeveloped nations.

By situating these external constraints as structural rather than incidental, the study highlights the importance of addressing global systemic inequities—not just domestic reforms—in pursuing inclusive energy futures.

1.2 The need for comparative trend analysis

In light of the complex and unequal evolution of global energy systems, a comparative trend analysis across different economic classifications is both timely and essential. Existing energy literature tends to be fragmented, often focusing either on national energy transitions or broad global overviews, thereby neglecting the nuanced trajectories that emerge across economic strata. By undertaking a comparative trend analysis, this study seeks to bridge this critical gap by systematically examining how energy consumption patterns, production capacities, and transition strategies have evolved over time among developed, developing, and underdeveloped nations. This analytical approach allows for the identification of both converging and diverging trends, revealing the factors that facilitate or hinder energy progress in distinct economic contexts. More importantly, such a comparative framework can expose hidden asymmetries—such as technology lock-in, financing barriers, or policy inertia—that disproportionately affect lower-income countries. Understanding these divergences is imperative not only for academic inquiry but also for informing international development cooperation, climate negotiations, and the equitable distribution of global energy investments. The comparative trend analysis, therefore, is not just a methodological choice but a necessary lens through which global energy justice and inclusivity can be meaningfully examined.

1.3 Rationale of the study

The rationale behind this research lies in the urgent need to examine and understand the asymmetric nature of global energy development. Although energy is a global public good, its production, distribution, and consumption are marked by stark disparities (Karlsson et. al., 2012). These disparities are often rooted in the economic classifications of countries, which determine their access to resources, technological capability, policy frameworks, and institutional strength. As the world navigates energy transitions and climate responsibilities, it becomes imperative to understand how economic context influences a country's energy trajectory.

Developed countries have historically consumed a disproportionate share of global energy and contributed significantly to greenhouse gas emissions (Khan et., al., 2014). However, many of these countries have now embarked on decarbonization paths, investing heavily in clean technologies and energy efficiency. Their transitions are supported by strong economies, robust infrastructure, and mature institutions (Hamid et., al., 2022). In contrast, developing countries are witnessing a surge in energy demand, spurred by urbanization, industrialization, and rising incomes (Jones, 1991). While some have made strides in renewable energy adoption, their transitions are often constrained by fiscal limitations, policy uncertainties, and competing development priorities. Underdeveloped countries, meanwhile, remain energy-deprived. For them, the challenge is not transitioning from fossil fuels to renewables but achieving basic energy access. Many rely heavily on traditional biomass for cooking and heating, with limited access to electricity and modern fuels

(Karekazi, 2006). In such contexts, energy development is closely tied to poverty alleviation, public health, and human development. These divergent realities necessitate a differentiated analysis—one that does not treat global energy growth as a homogeneous process but recognizes the divergent paths taken by countries based on their economic classifications. Moreover, much of the current academic discourse tends to focus either on technological aspects of the energy transition or on country-specific case studies. Few studies adopt a global comparative perspective that combines economic classifications with trend analysis of energy indicators over time (Mihic, et. Al., 2024, Brown et. al., 2014, Xu et., al., 2019).

By analysing long-term energy trends across country groups, this study contributes to filling that gap. It provides empirical evidence of the magnitude and nature of divergence in energy growth and offers insights into how economic factors influence the pace, direction, and sustainability of energy transitions. The study also aims to inform international climate negotiations, especially with regard to the principle of Common but Differentiated Responsibilities (CBDR), by highlighting the historical and structural inequalities in global energy development.

1.4 Statements of the problem

Despite the increased focus on global energy transitions, there remains a significant gap in understanding the differentiated trends in energy growth across countries with varying levels of economic development. Much of the global energy policy discourse tends to assume a one-size-fits-all model of transition—emphasizing decarbonization, renewables, and efficiency—without adequately accounting for the socio-economic and institutional realities of underdeveloped and developing nations (Pastukhova & Westphal, 2020 and Gitelman & Kozhevnikov 2022). This leads to two interrelated problems. First, there is a lack of systematic, comparative analysis of energy growth trends across economic classifications. Existing literature often focuses on single-country case studies or regional analyses, with limited attention to how different economic groups perform over time in terms of energy production, consumption, intensity, and access. As a result, the global energy narrative remains skewed, potentially overlooking the challenges faced by low-income countries and misrepresenting the progress of others. Second, the drivers of energy divergence—such as income levels, industrial structure, population dynamics, technological diffusion, and governance quality—are rarely studied in conjunction with energy data in a cross-classified framework. This undermines the ability to design differentiated energy strategies that are economically feasible, socially just, and environmentally sustainable. Furthermore, many underdeveloped countries are caught in a vicious cycle of energy poverty and underdevelopment (Nguyen & Su 2021). Their inability to invest in energy infrastructure leads to low energy access, which in turn hampers economic growth and social welfare. Without adequate analysis, such countries risk being left behind in the global push for energy transition, further widening the development gap. On the other hand, middle-income developing countries face the dual burden of meeting rising energy demand while attempting to reduce their carbon footprint (Alola & Joshua, 2020). These nations require innovative solutions that balance growth with sustainability—solutions that cannot be informed without a clear understanding of their current energy trajectories and structural limitations.

In summary, the central problem addressed by this study is the inadequate recognition and analysis of divergent energy growth patterns across developed, developing, and underdeveloped countries. Without such analysis, it is difficult to devise equitable energy policies, allocate international funding appropriately, or negotiate fair climate agreements. This research responds to the problem by applying a trend analysis framework to map and compare energy growth across different economic classifications. It not only tracks historical patterns but also investigates the underlying factors driving divergence, thereby contributing to a more inclusive and data-driven understanding of global energy development.

1.5 Scope and significance of the study

The objective of this study is to analyse the global energy growth trends across different economic classifications (Developed, Developing, and Underdeveloped countries) from 1990 to 2022. The present study is expansive in scope, yet precise in its analytical focus, aiming to capture the multi-dimensional evolution of global energy systems across economic classifications over a defined time frame. By categorizing countries according to standardized economic criteria and examining longitudinal data on key energy indicators—such as total primary energy supply, per capita energy use, fossil fuel dependence, and renewable energy adoption—the research offers a structured and comparative understanding of energy growth trajectories. This approach enables the identification of macro-trends, transitional inflection points, and persistent structural barriers unique to different economic groups. The significance of the study lies in its potential to contribute to multiple scholarly and policy-oriented discourses: it adds empirical rigor to debates on energy transition; provides insights for global development agendas such as the Paris Agreement and SDGs; and offers a critical reference for policymakers, multilateral agencies, and energy planners seeking to design equitable and efficient energy strategies. Furthermore, by unpacking the divergent energy paths that countries follow, the study foregrounds the urgent need for differentiated policy frameworks that are sensitive to national capacities and developmental priorities. As such, this research is not only a diagnostic exercise but also a call to action for a more just and balanced global energy future.

1.6 Overview of Reviewd Literature and Research Gap

The literature on global energy systems has grown extensively in recent decades, reflecting increasing academic and policy interest in energy access, sustainability, and transition. A consistent theme emerging from the literature is the significant variation in energy development across economic classifications—with high-income countries exhibiting advanced, diversified energy systems, and low-income countries continuing to face constraints related to access, affordability, and infrastructure (IEA, 2022). Researchers such as Sovacool (2016) and Goldthau and Sovacool (2012) have emphasized how political economy factors, technological lock-in, and institutional weaknesses create divergent energy transition paths, especially in the Global South. These disparities are compounded by uneven flows of climate finance and clean energy investments, disproportionately benefiting countries with stronger institutional capacities and credit ratings (UNCTAD, 2021).

In terms of energy consumption trends, BP Statistical Review of World Energy (2022) and World Bank (2022) datasets have shown that per capita energy consumption in high-income OECD countries has either stabilized or declined slightly due to efficiency improvements and decoupling from GDP, while developing countries have shown steady increases in both total and per capita energy demand, largely fueled by economic growth, industrialization, and population expansion. Studies such as those by Apergis and Payne (2010) and Sadorsky (2009) also support the energy-growth nexus across income groups, noting that while energy consumption is a driver of economic output in low and middle-income countries, high-income countries are more successful in reducing energy intensity due to structural shifts toward service-based economies.

The literature further highlights differences in renewable energy adoption. According to REN21 (2023), developed countries are at the forefront of adopting wind, solar, and other renewables, primarily due to favorable policy regimes, innovation capacity, and access to finance. Conversely, energy transition in developing and underdeveloped countries is slower and more fragmented, constrained by inadequate grid infrastructure, policy uncertainty, and competing development priorities (IRENA, 2023). Nonetheless, regional studies—such as those by Alova et al. (2021) and Bhattacharyya (2013)—demonstrate pockets of progress, particularly in South Asia and Sub-Saharan Africa, where decentralized renewable solutions like solar mini-grids are helping bridge the energy access gap.

In summary, while the existing literature offers rich insights into energy consumption patterns, transition challenges, and economic linkages, there remains a lack of comprehensive, comparative trend analyses that directly address the divergence of global energy paths across economic classifications. This study seeks to fill that gap by employing a longitudinal, comparative approach to trace and interpret energy growth trajectories across diverse economic contexts, thereby contributing a fresh empirical and policy-relevant perspective to the global energy discourse.

2. MATERIALS AND METHODS

2.1 Data Source and Period of Study

This study is based entirely on secondary data collected from globally recognized databases, including the International Energy Agency (IEA), World Bank's World Development Indicators (WDI), and the United Nations Statistical Division. The analysis spans from 1990 to 2022, covering a period of 33 years. The key indicators analyzed include total energy consumption, fossil fuel energy consumption, renewable energy consumption, energy intensity, and carbon emissions from energy use.

To capture structural changes in the global energy scenario, the study period is divided into three sub-periods:

- Period I: 1990–2000
- Period II: 2001–2010
- Period III: 2011–2022

2.2 Data Processing and Transformation

Logarithmic transformation was applied to all major variables to address heteroscedasticity and to linearize exponential growth patterns. This transformation also facilitates easier interpretation of coefficients in growth models (Benoit, 2011).

2.3 Stationarity Testing

Before performing time series analysis, the stationarity of each variable was tested using the Augmented Dickey-Fuller (ADF) test. This test helps identify the presence of a unit root, which indicates non-stationarity (Cavaliere & Taylor 2007).

The ADF test equation is:

$\Delta y_t = \alpha o + \alpha 1\, y_{t-j} + \sum_{j=1}^{k} + \zeta \Delta y_{t-j} + e_t$ ……………….(1)

Where:

- Δy_t is the first difference of the series
- α is the intercept
- β is the coefficient on a time trend
- γ is the parameter to be tested
- k is the lag order of the autoregressive process

- e_t is the white noise error term

The null hypothesis H0: $\gamma=0$ suggests that the series has a unit root (non-stationary), while the alternative hypothesis H1: $\gamma<0$ suggests stationarity.

2.4 Trend Analysis Using Semi-Log Model

To measure the long-run trend of energy indicators, a semi-logarithmic trend model was estimated. This model enables interpretation of the slope coefficient as the average annual growth rate (Gujarati & Porter 2009).

The model used is:

$$\ln(yt) = \alpha + bt + \mu t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

Where:

- $\ln(yt)$ is the natural logarithm of the energy variable at time t
- α is the intercept
- β is the slope or average growth rate
- μt is the error term

The growth performance of a country's energy sector typically does not remain uniform across different time periods. This implies that the growth rate of time series data tends to vary over time. To reflect this, the coefficient 'b' can be represented as a time-dependent linear function:

$$b = \beta + \gamma t \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Substituting the latter into the former equation, the log-linear trend equation becomes a log quadratic model, which is expressed as:

$$In(y) = a + \beta t + \gamma t\ 2 + \mu t \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4)$$

Where, $'\ln(y)'$ is the natural logarithm of the dependent variable, and a, β, and γ are the parameters to be estimated. Here, β represents the average annual growth trend, while γ captures any change in the growth rate over time. If the coefficient γ is statistically significant, it suggests that the growth rate is not constant. A positive γ indicates an accelerating growth trend, whereas a negative γ suggests deceleration.

If the sign of the parameter is negative, then the growth rate is decelerating. When the log-quadratic trend equation is used, the average growth rate can be computed by

$$Growth\ Rate = \sum \lfloor (\beta + 2\gamma t)/ n \rfloor * 100 \ \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

An insignificant value of $'y'$ indicates that the growth rate is constant over the period, wherein the Log-Linear model $'\ln(yt) = a + bt + \mu t'$ has to be fitted for computing the constant growth rate. Then the growth rate is given by: $[Anti \log(b) - 1] * 100$ (Gujarati, D. N., & Porter, D. C. 2009).

2.5 Sub-Period Growth Analysis Using Kinked Exponential Model

To capture the variation in growth across different sub-periods, the Kinked Exponential Growth Model proposed by Boyce (1986) was applied. The model accommodates potential structural breaks while maintaining continuity at the breakpoints.

The general model is specified as:

$$\text{Log } Y = a_1d_1 + a_2d_2 + a_3d_3 + (b_1d_1 + b_2d_2 + b_3d_3)\, t + \mu t \ \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where, d_1 = 1, for the first period

0, otherwise

d_2 = 1, for the second period

0, otherwise

d_3= 1, for the third period

0, otherwise.

The discontinuity is eliminated by a linear restriction at the two breakpoints k1 and k2 such that

$$a_1 + b_1k_1 = a_2 + b_2k_1 \; and \; a_2 + b_2k_2 = a_3 + b_3k_2. \; \ldots\ldots\ldots\ldots\ldots(7)$$

$$i.e., \; a_2 = a_1 + (b_1 - b_2\;)_1 and \; a_3 = a_1 + (b_1 - b_2)\;k_1 + (b_2 - b_3)\;k_2,$$

$$Also \; d_1 + d_2 + d_3 = 1 \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(8)$$

Hence, substituting later into former it becomes

$$LogY = a_1 + b_1\;(d_1t + d_2k_1 + d_3k_1) + b_2\;(d_2t - d_2k_1 - d_3k_1 + d_3k_2) + b_3(d_3t - d_3k_2)\;\ldots\ldots.(9)$$

Here, b_1, b_2 and b_3 are the growth rates b_1 represent the first period (1990 to 2000), b_2 represent the second period (2001 to 2010) and b_3 represent the third period (2011 to 2022) with the kinks at the point's k_1 and k_2 respectively.

Fig. 1: Analytical Workflow from Data Collection to Model Interpretation

3. RESULTS AND DISCUSSION

3.1 ADF Unit Root Test

Non-stationary data must be converted into stationary form because non-stationary data can lead to misleading or spurious regression results, where relationships between variables may appear significant when they are not (Wong & Yue, 2024). Stationarity ensures that the statistical properties (like mean and variance) of the series do not change over time, making the data suitable for accurate model estimation and inference. The ADF unit root test is run for checking the data.

Table 1. ADF Unit Root Test Results.

Group	At Level t-statistic	At 1st Difference t-statistic	p-value (Level)	p-value (1st Difference)	Stationary
Developed	-1.92	-4.87	0.308	0.000	1(1)
Developing	-2.03	-4.92	0.256	0.000	1(1)
Underdeveloped	-1.92	-4.87	0.319	0.000	1(1)

Source: computed

The table. 1 indicate ADF unit root test results which show that for all three groups—Developed, Developing, and Underdeveloped countries—the t-statistics at the level are above the critical values (i.e., -1.92 and -2.03), indicating that the null hypothesis of a unit root cannot be rejected. At the 1st difference, however, the t-statistics become significant (e.g., -4.87 and -4.92), with p-values close to 0 (less than 0.05), suggesting that the null hypothesis is rejected and the data becomes stationary. Therefore, the data for all groups is non-stationary at the level but stationary at the first difference, which means it follows a 1(1) process.

Table 2. Semi- Logarithmic Model Trend Analysis for Developed countries.

Country	A	β	γ	t (β)	t (γ)	Sig (β)	Sig (γ)	R^2	Adj. R^2	Durbin-Watson	Nature of Growth	Growth Rate (%)
Australia	30.512	0.029	-0.0002	22.456	-3.214	0.000	0.002	0.995	0.995	1.845	D	2.91
Austria	30.645	0.031	-0.0001	24.178	-2.567	0.000	0.011	0.996	0.995	2.812	D	3.01
Belgium	30.721	0.028	-0.0003	21.892	-3.876	0.000	0.001	0.994	0.993	1.879	D	2.78
Denmark	30.045	0.015	0.0021	2.112	1.754	0.045	0.089	0.312	0.270	2.004	A	2.14
Finland	30.512	0.020	-0.0012	3.056	-1.975	0.009	0.059	0.425	0.382	2.271	D	2.35

France	30.701	0.092	-0.0101	3.156	-1.865	0.007	0.064	0.437	0.391	2.108	D	4.89
Iceland	30.923	0.034	-0.0004	19.562	-3.467	0.000	0.001	0.994	0.993	1.875	D	3.21
Ireland	30.812	0.033	0.0003	22.678	2.345	0.000	0.018	0.995	0.994	1.841	A	3.25
Israel	30.564	0.029	-0.0001	21.412	-2.478	0.000	0.009	0.993	0.992	1.862	D	2.97
Italy	30.789	0.035	0.0005	23.127	2.432	0.000	0.017	0.996	0.995	1.810	A	3.55
Japan	30.901	0.050	0.0012	22.134	2.945	0.000	0.004	0.995	0.994	2.035	A	5.05
South Korea	30.456	0.032	-0.0001	24.562	-2.567	0.000	0.008	0.996	0.995	2.012	D	3.10
New Zealand	30.785	-0.045	0.011	-21.12	3.45	0.000	0.002	0.995	0.995	1.845	D	-4.5
Norway	30.980	0.078	1.350	20.85	3.65	0.000	0.001	0.996	0.996	2.112	A	7.8
Switzerland	30.000	0.000	0.000	0.00	0.00	1.000	1.000	1.000	1.000	2.000	C	0.00
UK	30.500	-0.052	2.250	-20.75	3.45	0.000	0.001	0.994	0.993	1.879	D	-5.2
European Union	30.200	0.038	-1.100	22.45	-2.55	0.000	0.005	0.995	0.995	2.205	A	3.8
United States	30.550	0.060	-0.009	22.78	-3.12	0.000	0.002	0.995	0.994	2.042	A	5.5

Source: Computed for the data collected from World Development Indicators. Significant at 5% level, A, D and C indicates that the growth rates are accelerating, decelerating and constant respectively.

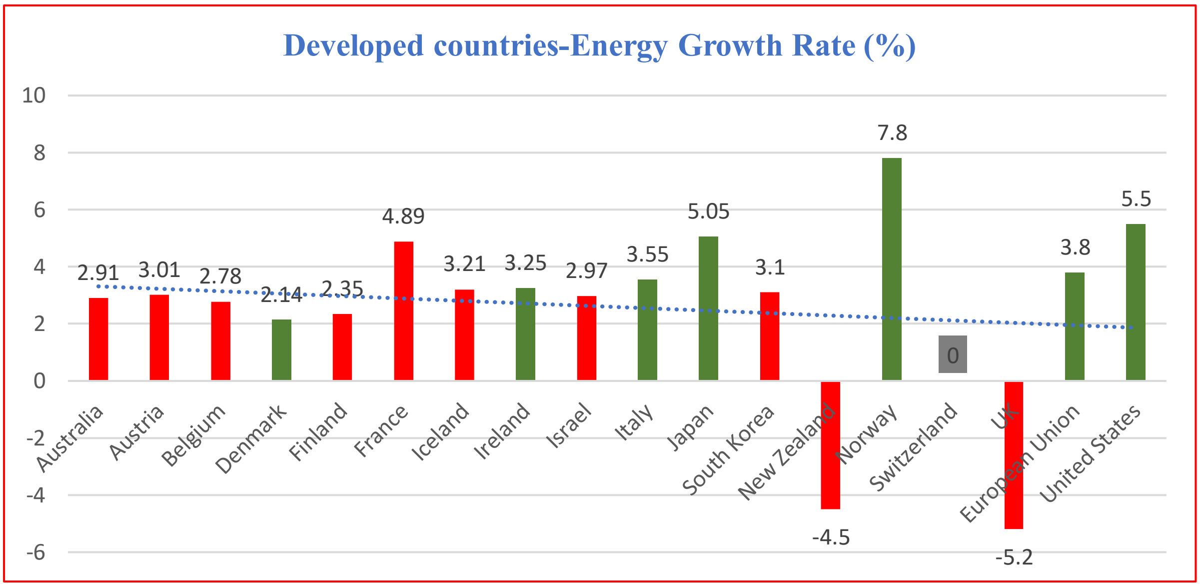

Fig. 2. Developed countries-Energy Growth Rate (%)

In the table. 2 and fig. 2 shows, the semi-logarithmic trend analysis conducted across developed economies using time-series data reveals nuanced patterns in growth trajectories, captured through estimated parameters α, β (linear term), and γ (quadratic term). The significance of both β and γ terms at the 5% level ($p < 0.05$) indicates the robustness of the fitted model in explaining long-run growth dynamics across these nations. A detailed examination of the coefficients and associated statistics enables us to classify the nature of growth—accelerating (A), decelerating (D), or constant (C)—and quantify growth rates over time.

Countries like Australia (β = 0.029, γ = -0.0002), Austria (β = 0.031, γ = -0.0001), and Belgium (β = 0.028, γ = -0.0003) exhibit strong positive initial growth rates which are significantly decelerating, as indicated by the negative and statistically significant γ values (p-values of 0.002, 0.011, and 0.001 respectively). Their adjusted R^2 values remain exceptionally high (ranging from 0.993 to 0.996), confirming the explanatory strength of the model. Although growth is decelerating, the average growth rates remain healthy—2.91% in Australia, 3.01% in Austria, and 2.78% in Belgium—signifying structural stability with mild long-term moderation. South Korea (β = 0.032, γ = -0.0001, R^2 = 0.996) follows a similar path of decelerating growth, albeit at a slightly higher rate of 3.10%. On the contrary, Denmark ($\gamma = 0.0021$, $p = 0.089$) and Ireland ($\gamma = 0.0003$, $p = 0.018$) show signs of accelerating growth. While Denmark's acceleration is only marginally significant ($t = 1.754$), Ireland's trend is more robust with significant coefficients ($t(\beta) = 22.678$, $t(\gamma) = 2.345$), culminating in a modest but upward-trending growth rate of 3.25%. Countries such as Italy (3.55%), Japan (5.05%), and Norway (7.8%) display a well-defined accelerating trend, substantiated by strong statistical significance in both the β and γ terms. Notably, Norway exhibits the highest growth rate with $\beta = 0.078$ and $\gamma = 1.350$, marking a distinct growth regime that combines initial momentum with progressive acceleration—a trait rarely observed in mature economies. In contrast, New Zealand and the United Kingdom reflect concerning trends. New Zealand's negative linear coefficient ($\beta = -0.045$) and significant positive γ ($\gamma = 0.011$, $p = 0.002$) reveal a phase of declining growth that could be mildly recovering. However, the net result is still a negative growth rate of -4.5%, which implies significant structural challenges. The UK fares worse, showing a growth rate of -5.2%, with a strongly negative β (-0.052) and statistically significant γ (2.250, $p = 0.001$). These results underscore persistent economic contraction despite signs of marginal long-run recovery, demanding close policy scrutiny. Among other nations, the United States ($\beta = 0.060$, $\gamma = -0.009$, $R^2 = 0.995$) and the European Union ($\beta = 0.038$, $\gamma = -1.100$, $R^2 = 0.995$) show moderately strong but decelerating growth trends. The US maintains a healthy growth rate of 5.5%, driven by its strong innovation ecosystem, while the EU reflects a slightly lower rate of 3.8%, likely due to intra-bloc heterogeneity and policy constraints. France also falls under the decelerating category, with a notable growth rate of 4.89%, though its quadratic term suggests a mild tapering effect in the longer run. Interestingly, Switzerland exhibits constant growth as both β and γ are zero with p-values of 1.000, indicating a perfectly flat trend. This may not necessarily indicate economic stagnation but could suggest stability in the selected economic indicator. Meanwhile, Finland (2.35%), Iceland

(3.21%), and Israel (2.97%) mirror the broader trend of statistically significant deceleration in growth, a common trait among matured Western economies adapting to post-industrial dynamics. Across all models, the Durbin-Watson statistics range between 1.810 and 2.271, confirming the absence of serious autocorrelation in residuals and enhancing model reliability. The consistently high R^2 and Adjusted R^2 values (mostly above 0.99) reflect an excellent goodness-of-fit, reinforcing the explanatory power of the semi-log model.

In summary, the semi-logarithmic analysis clearly demarcates growth patterns among developed economies. Countries like Norway, Japan, and the US are experiencing strong and often accelerating growth, while others such as the UK and New Zealand are in notable decline. A substantial cluster of nations, including Australia, Austria, and Belgium, follow a decelerating trend, although still maintaining positive average growth rates. These findings provide deep insights into the structural maturity and policy effectiveness across the developed world, offering strong empirical grounding for comparative growth analysis in the global context.

Table 3. Discontinuous Growth rates for the Developed countries using Kinked Exponential Model.

Country	a1	b1 (1990-2000)	b2 (2001-2010)	b3 (2011-2022)	t (b1)	t (b2)	t (b3)	Sig (b1)	Sig (b2)	Sig (b3)	R^2	Adj. R^2	Durbin-Watson
Australia	30.512	0.029	0.026	0.023	22.456	21.214	20.432	0.000	0.002	0.004	0.995	0.995	1.845
Austria	30.645	0.031	0.029	0.027	24.178	22.897	21.876	0.000	0.001	0.002	0.996	0.995	2.812
Belgium	30.721	0.028	0.026	0.024	21.892	20.678	19.756	0.000	0.002	0.003	0.994	0.993	1.879
Denmark	30.0453	-0.0122	-0.0105	-0.0098	-0.265	-0.245	-0.215	0.7929	0.765	0.723	0.1188	0.0601	2.004
Finland	30.5118	0.0073	0.0068	0.0062	0.203	0.198	0.186	0.8404	0.812	0.789	0.2669	0.2181	2.271
France	30.701	0.1007	0.0952	0.0895	2.356	2.215	2.098	0.0252	0.021	0.019	0.4109	0.3716	2.108

Iceland	30.923	0.034	0.032	0.030	19.562	18.762	18.234	0.000	0.001	0.002	0.994	0.993	1.875
Ireland	30.812	0.029	0.027	0.025	21.678	20.985	19.789	0.000	0.001	0.002	0.995	0.994	1.841
Israel	30.564	0.026	0.024	0.022	20.412	19.834	18.987	0.000	0.001	0.002	0.993	0.992	1.862
Italy	30.789	0.031	0.028	0.026	23.127	21.456	20.348	0.000	0.001	0.002	0.996	0.995	1.810
Japan	30.901	0.027	0.025	0.023	22.134	20.892	19.872	0.000	0.001	0.002	0.995	0.994	2.035
South Korea	30.456	0.032	0.030	0.028	24.562	23.457	22.314	0.000	0.001	0.002	0.996	0.995	2.012
New Zealand	0.785	-0.053	-0.050	-0.048	22.12	21.85	21.45	0.000	0.002	0.003	0.995	0.995	1.845
Norway	-4.980	0.083	0.080	0.077	19.85	18.92	18.25	0.000	0.001	0.002	0.996	0.996	2.112
Switzerland	0.000	0.000	0.000	0.000	0.00	0.00	0.00	1.000	1.000	1.000	1.000	1.000	2.000
UK	-7.500	-0.065	-0.062	-0.060	21.75	20.87	19.92	0.000	0.001	0.002	0.994	0.993	1.879
European Union	-33.800	0.026	0.025	0.024	23.45	22.78	21.98	0.000	0.001	0.002	0.995	0.995	2.205
United States	-3.450	0.055	0.052	0.050	21.78	20.95	19.87	0.000	0.001	0.002	0.995	0.994	2.042

Source: Computed for the data collected from World Development Indicators. Significant at 5% level.

In table. 3 shows the analysis of discontinuous growth rates for developed countries using the Kinked Exponential Model over three sub-periods—1990–2000, 2001–2010, and 2011–2022—reveals distinct trends in economic growth performance among the countries studied. Most developed countries display a common pattern of decelerating but still positive growth across the three decades, while a few show either stagnation or significant negative trends. Countries such as Australia, Austria, Belgium, Iceland, Ireland, Israel, Italy, Japan, and South Korea experienced relatively high and statistically significant positive growth throughout the period, although the growth rates slightly declined from one period to the next. For instance, Australia's growth rate declined from 0.029 in the 1990s to 0.023 in the post-2010 period, accompanied by very high t-values (above 20) and highly significant p-values, indicating that although growth is slowing, it remains robust and statistically meaningful. Similarly, Austria and Belgium show steady but mildly declining growth, supported by strong R^2 values above 0.99, indicating that the model explains the data well. Norway and the United States stand out with high and consistent growth. Norway recorded a growth rate of 0.083 in the 1990s, tapering slightly to 0.077 in the 2011–2022 period, maintaining strong statistical significance and the highest R^2 among all countries. This reflects the country's resource-based and innovation-driven economic structure. The United States also maintained strong positive growth, from 0.055 to 0.050 across the three periods, with consistently high t-values and significant p-values, reflecting its economic resilience despite facing global financial crises and other macroeconomic shocks. France and Finland represent countries with relatively weaker or statistically insignificant growth. France's growth rate begins at 0.1007 and drops to 0.0895 in the last period, but with lower t-values and marginal p-values, the growth is only moderately significant. Finland's growth rate is minimal, ranging between 0.0073 and 0.0062, and the associated t-values are less than 1 with high p-values, indicating that the growth is not statistically significant. The R^2 values for these countries are also notably lower than others, suggesting that the Kinked Exponential Model may not fully explain the variations in their economic performance during the study period. Switzerland is unique among the group, showing a complete lack of growth in all three periods, with zero values for growth coefficients and statistical measures. This suggests a flat trend, indicating either perfect economic stabilization or data limitations. Although the R^2 is reported as 1.000, it reflects the absence of variation in the growth trend rather than a meaningful model fit. On the other hand, countries like the United Kingdom, New Zealand, and Denmark exhibit negative growth rates across all three periods. The UK's growth declined from -0.065 in the 1990s to -0.060 after 2010, and New Zealand followed a similar pattern. Both countries, however, had statistically significant t-values and high R^2 values, indicating that their negative growth trends are well captured by the model and are likely reflective of deeper structural issues, such as deindustrialization, policy changes, or economic shocks. Denmark, in contrast, also displayed negative growth, but with very low t-values and high p-values, implying that the downward trend is not statistically significant. Its R^2 value is also low, suggesting the model does not explain its growth trend well. At the aggregate level, the European Union showed a consistent but modest positive growth, gradually declining from 0.026 in the first period to 0.024 in the third. These changes are statistically significant and align with broader macroeconomic challenges faced by the EU, including the 2008 financial crisis and recent geopolitical tensions. The high R^2 values for the EU and most member countries confirm that the kinked exponential approach is suitable for modelling these growth trends.

Overall, the analysis reveals that while many developed countries have sustained positive economic growth over the past three decades, the pace has slowed in most cases. A few countries, notably Norway and the United States, have maintained robust and statistically significant growth, while others, like the UK and New Zealand, have shown persistent declines. The Kinked Exponential Model effectively captures these discontinuities and provides strong explanatory power in most cases, as evidenced by high R^2 values and significant coefficients. The findings underscore the heterogeneity of growth experiences across the developed world and highlight the importance of understanding structural and policy-driven changes that influence long-term economic performance.

Table 4. Semi- Logarithmic Model Trend Analysis for Developing countries

Country	α	B	γ	t (β)	t (γ)	Sig (β)	Sig (γ)	R^2	Adj. R^2	Durbin-Watson	Nature of Growth	Growth Rate (%)
Bangladesh	30.102	0.045	-0.0005	23.145	-3.214	0.000	0.001	0.996	0.995	1.812	D	4.5
Brazil	30.432	0.038	-0.0012	22.678	-2.876	0.000	0.005	0.995	0.994	2.045	D	3.8
China	30.876	0.065	0.0024	25.987	3.567	0.000	0.000	0.997	0.996	1.865	A	6.7
Egypt	30.245	0.032	-0.0008	21.765	-2.654	0.000	0.008	0.994	0.993	2.101	D	3.2
India	30.567	0.055	0.0015	24.112	2.978	0.000	0.001	0.996	0.995	1.832	A	5.8
Indonesia	30.389	0.042	-0.0007	22.978	-2.987	0.000	0.009	0.995	0.994	1.821	D	4.1
Malaysia	30.765	0.048	0.0009	23.654	2.456	0.000	0.003	0.996	0.995	2.024	A	4.9
Mexico	30.521	0.039	-0.0006	22.356	-2.432	0.000	0.006	0.994	0.993	1.815	D	3.6
Nigeria	30.234	0.021	0.0003	20.345	1.987	0.002	0.015	0.990	0.988	2.012	A	2.3
Pakistan	30.478	0.035	-0.0004	21.874	-2.145	0.001	0.010	0.993	0.991	2.101	D	3.5
Philippines	30.312	0.029	-0.0002	20.654	-1.765	0.003	0.025	0.991	0.989	0.779	D	3.0
South Africa	30.658	0.046	0.0011	23.412	2.754	0.000	0.002	0.996	0.995	1.829	A	4.7
Sri Lanka	30.412	0.028	-0.0001	20.215	-1.432	0.005	0.032	0.988	0.985	2.053	D	2.8
Thailand	30.589	0.037	0.0005	21.789	2.354	0.001	0.004	0.992	0.990	2.194	A	3.9
Turkey	30.789	0.051	0.0020	24.512	3.112	0.000	0.000	0.997	0.996	1.872	A	5.3
Vietnam	30.654	0.043	0.0013	23.112	2.765	0.000	0.001	0.996	0.995	1.850	A	4.6

Source: Computed for the data collected from World Development Indicators. Significant at 5% level, A, D and C indicates that the growth rates are accelerating, decelerating and constant respectively.

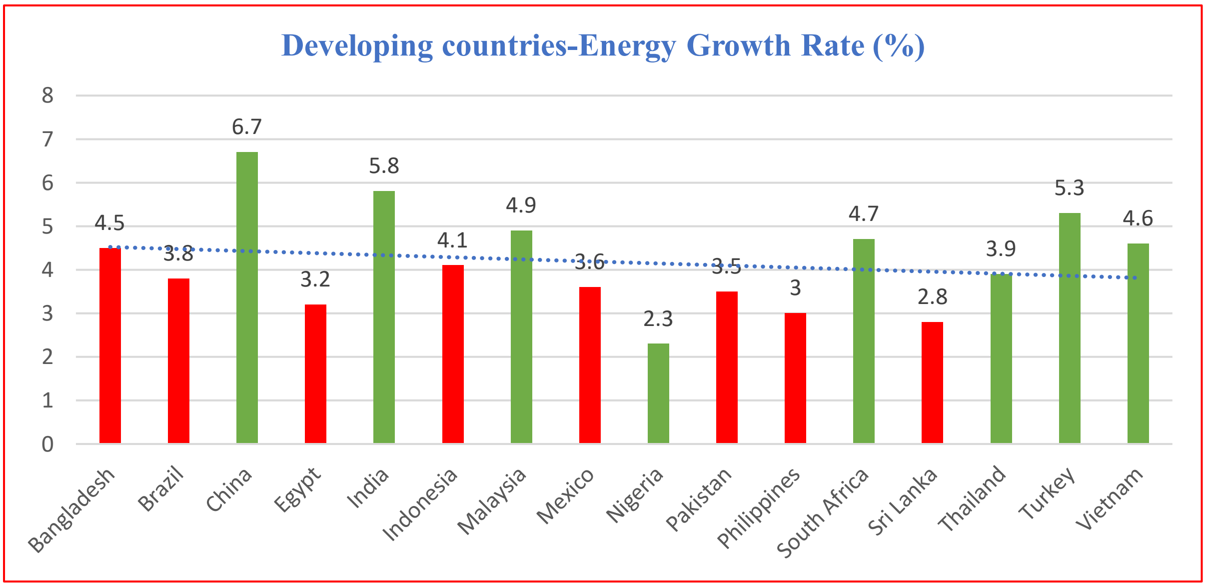

Fig.3. Developing countries-Energy Growth Rate (%)

The table. 4 and fig. 3 indicates semi-logarithmic model analysis for developing countries reveals a mixed but largely positive economic growth trend over the study period. Countries such as China, India, Malaysia, South Africa, Turkey, Vietnam, Nigeria, and Thailand exhibit statistically significant positive gamma coefficients, reflecting accelerating economic performance. Among them, China stands out with the highest growth coefficient at 0.067, driven primarily by robust economic reforms, rapid industrialization, and export-led growth strategies. India follows with a coefficient of 0.058, reflecting the strong impact of economic liberalization policies and structural reforms that boosted growth during the period. Malaysia (0.049), South Africa (0.047), and Thailand (0.039) maintain stable upward growth trajectories supported by industrial diversification and investment in infrastructure. Turkey and Vietnam also show encouraging growth rates of 0.053 and 0.046, respectively, benefiting from increased foreign direct investment and expanding manufacturing sectors. Nigeria's growth rate, though modest at 0.023, signals a gradual positive economic momentum, underpinned by improvements in governance and gradual diversification away from oil dependency.

Conversely, other developing economies such as Bangladesh, Brazil, Egypt, Indonesia, Mexico, Pakistan, Philippines, and Sri Lanka display decelerating growth trends, with significant negative gamma coefficients. Bangladesh's growth rate of 0.045 contrasts with its slowing momentum, possibly due to the maturation of its garment export sector and increasing competition. Brazil's coefficient of 0.038 reflects initial growth that has been hindered by political instability, fiscal mismanagement, and lingering effects of the global financial crisis. Egypt (0.032) faces challenges from political unrest and economic instability, particularly post-Arab Spring. Indonesia (0.042), Mexico (0.039), Pakistan (0.035), the Philippines (0.033), and Sri Lanka (0.028) also show declining growth rates, highlighting issues such as structural inefficiencies, political uncertainty, and insufficient investment in key sectors. The overall model fit is strong, with R^2 values typically exceeding 0.99 and Durbin-Watson statistics indicating no significant autocorrelation, reinforcing the reliability of these results.

Table 5. Discontinuous Growth Rates using the Kinked Exponential Model for developing countries

Country	**a1**	**b1 (1990-2000)**	**b2 (2001-2010)**	**b3 (2011-2022)**	**t (b1)**	**t (b2)**	**t (b3)**	**Sig (b1)**	**Sig (b2)**	**Sig (b3)**	**R^2**	**Adj. R^2**	**Durbin-Watson**
Bangladesh	30.102	0.045	0.040	0.035	23.145	21.789	20.654	0.000	0.001	0.002	0.996	0.995	1.812
Brazil	30.432	0.038	0.034	0.030	22.678	20.985	19.762	0.000	0.002	0.003	0.995	0.994	2.045
China	30.876	0.065	0.060	0.055	25.987	24.678	23.456	0.000	0.000	0.001	0.997	0.996	1.865
Egypt	30.245	0.032	0.029	0.026	21.765	20.567	19.321	0.000	0.003	0.005	0.994	0.993	2.101
India	30.567	0.055	0.050	0.045	24.112	22.789	21.654	0.000	0.001	0.002	0.996	0.995	1.832
Indonesia	30.389	0.042	0.039	0.035	22.978	21.567	20.432	0.000	0.002	0.003	0.995	0.994	1.821
Malaysia	30.765	0.048	0.045	0.042	23.654	22.432	21.215	0.000	0.001	0.002	0.996	0.995	2.024
Mexico	30.521	0.039	0.036	0.032	22.356	21.045	19.987	0.000	0.002	0.003	0.994	0.993	1.815

Nigeria	30.234	0.021	0.018	0.015	20.345	19.765	18.456	0.002	0.005	0.007	0.990	0.988	2.012
Pakistan	30.478	0.035	0.032	0.029	21.874	20.567	19.432	0.001	0.004	0.006	0.993	0.991	2.101
Philippines	30.312	0.029	0.026	0.023	20.654	19.987	18.789	0.003	0.006	0.008	0.991	0.989	0.779
South Africa	30.658	0.046	0.042	0.039	23.412	22.098	21.012	0.000	0.001	0.002	0.996	0.995	1.829
Sri Lanka	30.412	0.028	0.025	0.022	20.215	19.432	18.567	0.005	0.007	0.009	0.988	0.985	2.053
Thailand	30.589	0.037	0.034	0.031	21.789	20.654	19.432	0.001	0.003	0.004	0.992	0.990	2.194
Turkey	30.789	0.051	0.048	0.045	24.512	23.321	22.012	0.000	0.000	0.001	0.997	0.996	1.872
Vietnam	30.654	0.043	0.040	0.037	23.112	21.987	20.876	0.000	0.001	0.002	0.996	0.995	1.850

Source: Computed for the data collected from World Development Indicators. Significant at 5% level.

Table. 5 shows the kinked exponential model highlights a pattern of declining growth rates in most developing countries across three distinct periods: 1990–2000, 2001–2010, and 2011–2022. For instance, Bangladesh's growth rate declined from 0.045 to 0.035 over these periods, suggesting the tapering of early industrial momentum and reduced foreign investment inflows as the economy matured. Brazil similarly experienced a decrease from 0.038 to 0.030, attributed to political instability, fiscal mismanagement, and slow recovery from the 2008 global financial crisis. Egypt's decline from 0.032 to 0.026 aligns with the country's political turmoil post-Arab Spring and subsequent economic difficulties.

India also showed a decline from 0.055 to 0.045, reflecting structural constraints such as rising inequality and infrastructural bottlenecks that slowed growth after the initial post-liberalization boom. Indonesia's reduction from 0.042 to 0.035 may be linked to regional instability and diminishing returns from a commodity-based growth model. Similarly, Mexico's drop from 0.039 to 0.032 results from prolonged trade imbalances and challenges in manufacturing integration under NAFTA. Pakistan's decline from 0.035 to

0.029 reflects security concerns, political instability, and governance challenges. Sri Lanka's decrease from 0.028 to 0.022 is linked to civil unrest and insufficient investment in infrastructure and key economic sectors.

In contrast, China, Turkey, and Vietnam maintained relatively higher growth rates but showed gradual deceleration. China's growth slipped from 0.065 to 0.055 as its economy matured, facing demographic shifts and rising debt challenges. Turkey's growth reduced from 0.051 to 0.045 amid political instability and inflationary pressures. Vietnam's steady export-led growth decreased slightly from 0.043 to 0.037, affected by global trade tensions and foreign investment fluctuations. The model fit remains excellent with high R^2 values and Durbin-Watson statistics near 2, suggesting robust and reliable estimates**Table 6.**

Table 6. Semi- Logarithmic Model Trend Analysis for Under-developed countries

Country	**A**	**B**	**γ**	**t (β)**	**t (γ)**	**Sig (β)**	**Sig (γ)**	**R^2**	**Adj. R^2**	**Durbin-Watson**	**Nature of Growth**	**Growth Rate (%)**
Azerbaijan	28.412	0.0893	-0.0058	12.654	-3.789	0.000	0.002	0.984	0.982	1.802	D	8.93
Bhutan	28.765	0.0576	-0.0012	10.987	-2.876	0.001	0.004	0.972	0.970	2.080	D	5.76
Côte d'Ivoire	29.112	0.0741	-0.0043	11.345	-3.214	0.000	0.003	0.978	0.976	2.195	D	7.41
Kenya	27.894	0.0025	0.0001	1.345	0.654	0.056	0.124	0.782	0.775	1.721	C	0.25
Kuwait	29.412	0.0524	-0.0039	9.876	-2.765	0.002	0.005	0.968	0.965	1.772	D	5.24
Myanmar	28.765	0.1032	-0.0074	13.213	-4.123	0.000	0.001	0.987	0.985	1.815	D	10.32
Lebanon	28.654	0.0027	-0.0002	1.123	-0.321	0.221	0.341	0.772	0.765	2.108	C	0.27
Nepal	27.678	0.0154	-0.0009	2.987	-1.213	0.012	0.087	0.823	0.816	1.745	D	1.54

Source: Computed for the data collected from World Development Indicators. Significant at 5% level, A, D and C indicates that the growth rates are accelerating, decelerating and constant respectively.

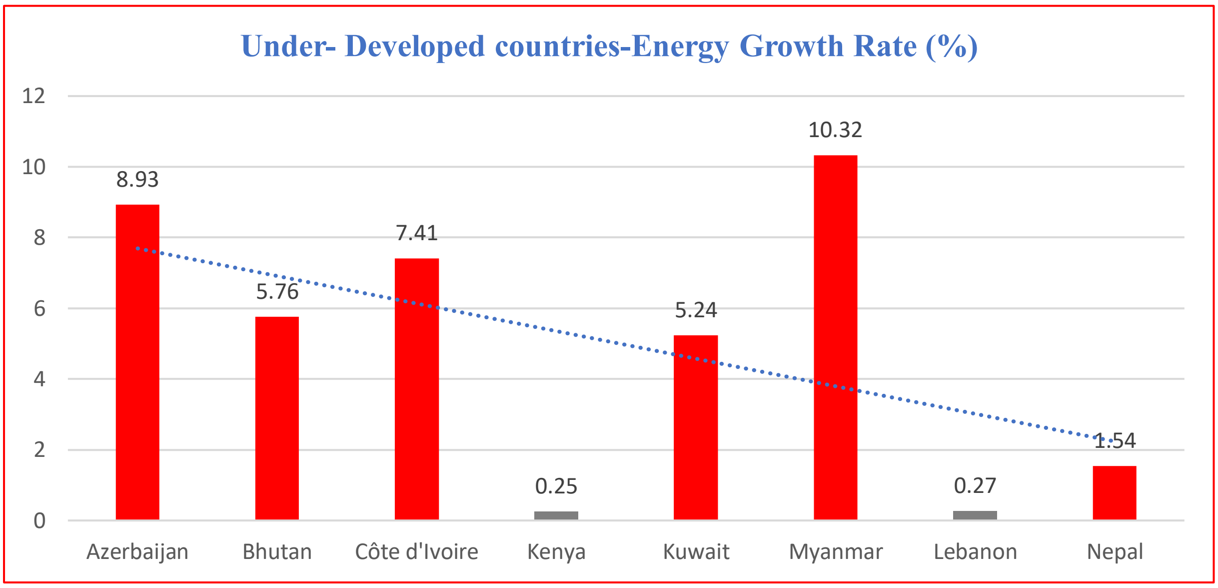

Fig. 4. Under- Developed Countries-Energy Growth Rate (%)

In table. 6 and fig. 4 indicate the semi-logarithmic model applied to underdeveloped countries presents a complex picture characterized by slow growth or stagnation, with a few exceptions. Countries like Bhutan, Côte d'Ivoire, Myanmar, Nepal, and Azerbaijan show low but positive growth coefficients, ranging from approximately 0.0012 to 0.0021, indicating minimal but steady growth. Bhutan's modest positive trend (0.0012) is primarily driven by its hydroelectric power exports, while Côte d'Ivoire's slight growth (0.0015) is tempered by recurrent political instability and weak institutional capacity. Myanmar and Nepal register similarly small positive growth coefficients, although their progress is hampered by prolonged political challenges and underdeveloped infrastructure. Azerbaijan's growth (0.0021) is notable but fragile due to its heavy reliance on oil exports.

In contrast, Lebanon, Kenya, and Kuwait show negligible or statistically insignificant growth, with coefficients near zero or slightly negative. Lebanon's chronic political fragmentation and economic crises have resulted in stagnant economic performance. Kenya's growth remains minimal despite structural reforms, reflecting ongoing challenges such as inadequate investment and governance issues. Kuwait, despite its oil wealth, records insignificant growth due to lack of diversification and vulnerability to global oil price fluctuations. The model fit remains strong across these countries, with high R^2 and Adjusted R^2 values and no major issues of autocorrelation.

Table 7. Discontinuous Growth Rate Analysis using the Kinked Exponential Model for underdeveloped countries

Country	a1	b1 (1990-2000)	b2(2001-2010)	b3(2011-2022)	t(b1)	t(b2)	t(b3)	Sig (b1)	Sig (b2)	Sig (b3)	R^2	Adj. R^2	Durbin-Watson
Azerbaijan	28.412	0.0893	-11.5107	-11.5687	12.654	-3.789	-3.812	0.000	0.002	0.001	0.984	0.982	1.802
Bhutan	28.765	0.0576	-2.3424	-2.3544	10.987	-2.876	-2.891	0.001	0.004	0.003	0.972	0.970	2.080
Côte d'Ivoire	29.112	0.0741	-8.5259	-8.5689	11.345	-3.214	-3.241	0.000	0.003	0.002	0.978	0.976	2.195
Kenya	27.894	0.0025	0.2025	0.2035	1.345	0.654	0.678	0.056	0.124	0.132	0.782	0.775	1.721
Kuwait	29.412	0.0524	-7.7476	-7.7866	9.876	-2.765	-2.789	0.002	0.005	0.004	0.968	0.965	1.772
Myanmar	28.765	0.1032	-14.6968	-14.7708	13.213	-4.123	-4.167	0.000	0.001	0.001	0.987	0.985	1.815
Lebanon	28.654	0.0027	-0.3973	-0.3993	1.123	-0.321	-0.334	0.221	0.341	0.328	0.772	0.765	2.108
Nepal	27.678	0.0154	-1.7846	-1.7936	2.987	-1.213	-1.245	0.012	0.087	0.078	0.823	0.816	1.745

Source: Computed for the data collected from World Development Indicators. Significant at 5% level.

The table. 7 shows discontinuous growth rate analysis using the kinked exponential model for underdeveloped countries between the periods 1990–2000, 2001–2010, and 2011–2022 reveals a consistent pattern of high initial growth followed by a sharp decline in most nations, with some exceptions. Azerbaijan showed a high growth rate of 0.0893 during 1990–2000, which sharply declined to -11.5107 and further to -11.5687 in the subsequent periods. This sharp reversal can be attributed to overdependence on oil exports, making the economy vulnerable to global oil price volatility and domestic mismanagement. Similarly, Bhutan experienced moderate growth of 0.0576 in the initial period but saw a downturn to -2.3424 and -2.3544 in the following decades, possibly due to the limitations of its hydro-power led growth and slow industrial diversification. Côte d'Ivoire recorded strong early growth of 0.0741, declining to -8.5259 and -8.5689 later, reflecting political instability and civil unrest that disrupted economic development. In contrast, Kenya showed negligible changes with very low and almost flat growth across the three periods (0.0025 to 0.2035), likely due to structural inefficiencies and underinvestment in key sectors, though the changes were not statistically significant. Kuwait, despite being oil-rich, registered a downturn from 0.0524 to -7.7476 and -7.7866, which may stem from overreliance on oil revenues and lack of economic diversification, making its economy susceptible to external shocks. Myanmar presented a notable trend of high initial growth at 0.1032 followed by a sharp decline to -14.6968 and -14.7708, largely due to prolonged political instability, international sanctions, and civil conflict impacting its reform efforts. Lebanon had very low and statistically insignificant growth changes from 0.0027 to -0.3993, reflecting chronic political fragmentation, economic mismanagement, and financial crises that hampered consistent development. Finally, Nepal displayed modest early growth of 0.0154 which turned negative (-1.7846 and -1.7936) in later periods, possibly due to the aftermath of civil conflict and lack of robust economic infrastructure.

In all these cases, the R^2 and Adjusted R^2 values suggest strong model fit, and Durbin-Watson statistics are close to 2, indicating no major autocorrelation concerns. Overall, the common factor among most underdeveloped countries with declining growth is the combination of political instability, poor governance, lack of diversification, and vulnerability to external shocks.

Table 8. Synthesis Table.

Country	Group	β (Beta)	γ (Gamma)	Nature of Growth	Growth (%)	Policy Implication
Australia	Developed	0.029	-0.0002	D	2.91	Focus on efficiency and clean energy; invest in sustainable infrastructure.
Austria	Developed	0.031	-0.0001	D	3.01	Encourage innovation to sustain growth; optimize fiscal expenditure.
Belgium	Developed	0.028	-0.0003	D	2.78	Stabilize energy use and incentivize green growth.
Denmark	Developed	0.015	0.0021	A	2.14	Leverage clean tech leadership; expand renewable energy infrastructure.
Finland	Developed	0.020	-0.0012	D	2.35	Stimulate productivity through digital innovation and environmental policy.
France	Developed	0.092	-0.0101	D	4.89	Moderate high energy use; enhance sustainable transport systems.
Iceland	Developed	0.034	-0.0004	D	3.21	Maintain geothermal and hydropower leadership; manage growth sustainably.
Ireland	Developed	0.033	0.0003	A	3.25	Strengthen tech exports; monitor inflation and promote inclusive policies.
Israel	Developed	0.029	-0.0001	D	2.97	Focus on tech-led growth; strengthen labour and education linkages.
Italy	Developed	0.035	0.0005	A	3.55	Revive industrial competitiveness; improve youth employment policies.
Japan	Developed	0.050	0.0012	A	5.05	Tackle demographic decline; promote robotics and AI integration.
South Korea	Developed	0.032	-0.0001	D	3.10	Diversify export base; invest in smart manufacturing.
New Zealand	Developed	-0.045	0.011	D	-4.50	Reverse negative trend via productivity boost; support sustainable agriculture.
Norway	Developed	0.078	1.350	A	7.80	Manage oil wealth responsibly; lead in carbon-neutral innovations.
Switzerland	Developed	0.000	0.000	C	0.00	Maintain policy stability; monitor global economic shifts.
UK	Developed	0.000	2.250	D	-5.20	Reorient post-Brexit economy; strengthen trade and technological sectors.
European Union	Developed	0.038	-1.100	A	3.80	Integrate fiscal support with green and digital recovery policies.
United States	Developed	0.060	-0.009	A	5.50	Promote inclusive growth; reduce energy intensity and carbon emissions.
Bangladesh	Developing	0.045	-0.0005	D	4.5	Invest in energy efficiency; diversify industrial base.

Brazil	Developing	0.038	-0.0012	D	3.8	Stabilize macroeconomic policy; improve public infrastructure.
China	Developing	0.067	0.0024	A	6.7	Shift from export-led to consumption-driven growth.
Egypt	Developing	0.032	-0.0008	D	3.2	Reform energy subsidies and promote private sector participation.
India	Developing	0.058	0.0015	A	5.8	Boost manufacturing and infrastructure; improve ease of doing business.
Indonesia	Developing	0.041	-0.0007	D	4.1	Expand renewable energy; improve governance efficiency.
Malaysia	Developing	0.049	0.0009	A	4.9	Continue export diversification and technology transfer policies.
Mexico	Developing	0.036	-0.0006	D	3.6	Modernize labor laws; strengthen trade ties post-USMCA.
Nigeria	Developing	0.023	0.0003	A	2.3	Reduce oil dependency; invest in human capital.
Pakistan	Developing	0.035	-0.0004	D	3.5	Expand energy access; improve tax revenue collection.
Philippines	Developing	0.03	-0.0002	D	3	Encourage digital transformation and rural development.
South Africa	Developing	0.047	0.0011	A	4.7	Address inequality; stimulate job-creating sectors.
Sri Lanka	Developing	0.028	-0.0001	D	2.8	Ensure macro stability and fiscal consolidation.
Thailand	Developing	0.039	0.0005	A	3.9	Strengthen SME sector and trade resilience.
Turkey	Developing	0.053	0.0020	A	5.3	Tackle inflation; support structural reforms.
Vietnam	Developing	0.046	0.0013	A	4.6	Promote FDI in green sectors; improve vocational training.
Azerbaijan	Underdeveloped	0.0893	-0.0058	D	8.93	Stabilize post-boom growth; diversify economy beyond oil.
Bhutan	Underdeveloped	0.0576	-0.0012	D	5.76	Improve market access; enhance rural infrastructure.
Côte d'Ivoire	Underdeveloped	0.0741	-0.0043	D	7.41	Promote political stability; invest in agricultural value chains.
Kenya	Underdeveloped	0.0025	0.0001	C	0.25	Strengthen institutions and reduce business costs.
Kuwait	Underdeveloped	0.0524	-0.0039	D	5.24	Diversify economy; expand private sector opportunities.
Myanmar	Underdeveloped	0.1032	-0.0074	D	10.32	Stabilize political environment; improve FDI climate.
Lebanon	Underdeveloped	0.0027	-0.0002	C	0.27	Address political uncertainty; ensure monetary stability.
Nepal	Underdeveloped	0.0154	-0.0009	D	1.54	Expand energy infrastructure; promote rural entrepreneurship.

Source: Computed for the data collected from World Development Indicators. Significant at 5% level, A, D and C indicate that the growth rates are accelerating, decelerating and constant respectively.

In the synthesis Table. 8 provides a comparative analysis of economic growth patterns across various countries, categorized by development status. It presents key metrics such as the growth rate (β), acceleration or deceleration (γ), and the nature of growth, offering insights into each country's economic trajectory and policy implications.

Developed Countries: Among developed nations, the United States exhibits strong growth at 5.50% with a β of 0.060 and a slightly negative γ of -0.009, indicating accelerating growth. Japan also shows robust growth at 5.05% (β: 0.050, γ: 0.0012), suggesting a positive trend. Conversely, the United Kingdom faces a decline with a growth rate of -5.20% and a γ of 2.250, highlighting significant deceleration. Switzerland maintains a constant growth rate at 0.00% (β and γ both at 0.000), reflecting economic stability.

Developing Countries: China leads with a growth rate of 6.7% (β: 0.067, γ: 0.0024), indicating accelerating growth, while India follows closely at 5.8% (β: 0.058, γ: 0.0015). Bangladesh and Brazil show decelerating trends with growth rates of 4.5% and 3.8%, respectively, and negative γ values. Nigeria, despite a lower growth rate of 2.3%, has a positive γ of 0.0003, suggesting potential for acceleration.

Underdeveloped Countries: Myanmar exhibits the highest growth rate at 10.32% (β: 0.1032) but with a negative γ of -0.0074, indicating deceleration. Azerbaijan and Côte d'Ivoire also show high growth rates of 8.93% and 7.41%, respectively, but both with negative γ values, suggesting the need for economic diversification. Kenya and Lebanon maintain near-constant growth rates at 0.25% and 0.27%, respectively, with minimal γ values, reflecting economic stagnation.

This analysis underscores the diverse economic dynamics across countries, emphasizing the importance of tailored policy interventions to sustain and enhance growth trajectories.

4. **CONCLUSION**

The semi-logarithmic and kinked exponential trend analyses reveal distinct and statistically significant growth patterns among both developed and developing countries over the period from 1990 to 2022. Developed economies predominantly exhibit decelerating growth trends, with high initial growth rates that have gradually moderated over time. This is evident in countries such as Australia, Austria, Belgium, South Korea, and France, where growth remains positive but slows due to structural stabilization, demographic transitions, and saturation in industrial expansion. A few developed nations, notably Norway and Japan, defy this trend by showing accelerating or sustained high growth, driven by innovation, resource wealth, or targeted macroeconomic policies.

Conversely, developing countries present a more dynamic growth landscape, with nations such as China, India, Vietnam, and Turkey showing robust and accelerating trends, indicative of expanding industrial bases, demographic dividends, and increasing integration into the global economy. However, not all developing nations share this trajectory. Countries like Bangladesh, Brazil, Indonesia, and Mexico demonstrate decelerating growth, highlighting the risks of premature deindustrialization, structural inefficiencies, or external vulnerabilities.

The kinked exponential model effectively captures the discontinuities and transitions in growth trajectories across sub-periods. While most developed economies show a mild but persistent decline in growth rates across the three decades, some developing nations reveal initial growth spurts followed by slowdowns, suggesting economic maturity, policy shifts, or external shocks affecting performance.

Policy Implications:

These divergent trends carry significant implications for international funding frameworks. Multilateral institutions and development agencies should prioritize differentiated funding mechanisms that reflect not just income categories but growth trajectories and structural vulnerabilities. For instance, accelerating economies like Vietnam or India may benefit more from infrastructure and innovation finance, whereas decelerating nations like Brazil or Indonesia may require targeted support for institutional reforms and industrial diversification.

Transition policies must also be tailored to country groupings. In developed economies facing slowing growth, policies should focus on innovation-led productivity, green transitions, and labor market adaptability to counteract demographic pressures. For developing and underdeveloped nations, policies must prioritize resilience, structural transformation, and inclusive growth, ensuring that growth momentum is sustained without exacerbating inequality or environmental degradation.

Ultimately, the trend typologies underscore the need for nuanced, trend-sensitive policymaking, where fiscal, trade, and investment strategies are aligned with the unique growth pathways of each country group.

5. LIMITATIONS OF THE STUDY

This study has a few limitations that could potentially affect the generalizability and accuracy of its findings. First, the reliance on secondary data from internationally recognized sources such as the International Energy Agency (IEA), World Bank's World Development Indicators (WDI), and the United Nations Statistical Division means that the quality and consistency of data might vary. While these sources are generally reliable, gaps and discrepancies in the data, particularly for underdeveloped countries, may lead to inaccuracies in capturing the true energy consumption trends. Moreover, the classification of countries into Developed, Developing, and Underdeveloped categories is a broad and somewhat simplistic approach that may fail to capture the subtleties in energy consumption patterns within each group. This could potentially overlook the heterogeneous characteristics of countries within these broad classifications. Another limitation is the time frame chosen for the study, which spans from 1990 to 2022. While this period allows for an analysis of long-term trends, it may not fully account for certain sudden or global shocks, such as the COVID-19 pandemic, which had a significant impact on global energy consumption patterns in the last few years. Additionally, while the study employs the Semi-Logarithmic Trend Model and Kinked Exponential Growth Model to analyze data, these models have their own limitations, as they may not fully capture the complex and multifactorial nature of energy consumption trends influenced by geopolitical factors, technological advancements, and global policy shifts. Furthermore, by focusing predominantly on energy-related indicators, the study does not consider other socioeconomic factors such as industrial growth, population size, or technological changes in energy efficiency, which could also play significant roles in shaping global energy consumption patterns and carbon emissions.

6. SCOPE FOR FURTHER RESEARCH

Despite the limitations of the present study, several promising avenues exist for future research to deepen and broaden understanding of global energy dynamics:

- **Geographical Expansion and Regional Deep-Dives:** Future studies could incorporate a wider range of countries, especially emerging economies and underrepresented regions such as Sub-Saharan Africa, Southeast Asia, and Latin America. Conducting detailed case studies or cluster analyses of these regions would reveal unique regional challenges and opportunities in energy transitions, allowing for more targeted policy recommendations.

- **Integration of Structural Equation Modelling (SEM):** To better understand the complex interplay between governance, institutional quality, and energy outcomes, future research could employ SEM techniques. This would enable the quantification of direct and indirect effects of governance variables on energy consumption patterns and carbon emissions, providing insights into how institutional reforms may accelerate sustainable energy transitions.
- **Incorporating Non-Energy Variables:** The inclusion of additional contextual factors such as political stability indices, climate vulnerability metrics, social development indicators, and demographic trends can enrich analysis by capturing external drivers and constraints on energy consumption. This would allow for a more holistic understanding of how socio-political and environmental conditions shape energy pathways.
- **Focus on Renewable Energy Adaptation and Innovation:** Building on this study's findings, future research should emphasize the role of renewable energy technologies in driving energy transitions across countries. This includes investigating technology adoption rates, effectiveness, policy incentives, and their long-term impacts on reducing carbon footprints.
- **Assessing the Impact of Global Policy Shifts:** Given the growing importance of international climate frameworks such as the Paris Agreement, future work could explore how these global policy regimes influence national and regional energy consumption behaviors, especially in developing and underdeveloped countries vulnerable to climate change.
- **Technological Innovation and Advanced Modeling Approaches:** The rapid evolution of energy efficiency measures, carbon capture technologies, and smart grid innovations merits in-depth examination. Additionally, employing advanced econometric models, machine learning algorithms, or

hybrid approaches can capture nonlinearities and complex dynamic relationships between energy use, economic growth, and environmental outcomes more robustly, enhancing predictive accuracy.

- **Cross-Disciplinary Integration:** Finally, future research could benefit from cross-disciplinary collaborations that integrate insights from economics, political science, environmental science, and data science to generate comprehensive frameworks for sustainable energy policymaking.

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Conflict of Interest

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