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Moderating Role of Governance in Growth-Technology-Environment Nexus: Evidence from Developing Economies

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ABSTRACT

Competition among economies to attain maximum economic growth has led to environmental degradation. At the same time, technological innovations are empirically validated for having a role in achieving sustainable development. Good governance could make appropriate measures to design frameworks, develop instruments, and set targets to protect the environment. The current study intends to check the nexus among technological innovations, energy consumption, economic growth, and environmental degradation for a panel of 40 developing countries. The panel data of developing economies for a period of 25 years (from 1996 to 2020) was collected. The relationship was theoretically and econometrically modeled and finally analyzed using the dynamic panel Generalized Method of Moments (GMM). The empirical results of the dynamic panel GMM technique reveal significant and insightful relationships between the variables and their impact on environmental degradation (CO2 emissions). Technological innovations and renewable energy consumption negatively affect CO2 emissions, while economic growth, financial development, and globalization have positive effects. By moderating the growth-technology-environment nexus, governance enhances the positive impact of technological innovations and renewable energy consumption while mitigating the adverse effects of economic growth on CO2 emissions. These findings have important implications for policymakers addressing environmental issues and promoting sustainable development.

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1. Introduction

1.1. Background and Context

Since the industrial revolution, economies have been trying to attain the maximum possible economic growth. This exceptional competition has led to environmental degradation, especially through the rise generally in greenhouse gas emissions and specifically through carbon emissions which finally caused ozone depletion and global warming (Tang et al., 2015) —one of the opposing effects of economic development. Hence, the anthropogenic effect is evident in the form of environmental degradation.

Regarding aggregate total greenhouse gas emissions for developing countries, carbon dioxide is the main GHG emissions followed by NO2 and CH4 whereas the leading causes are agriculture and energy (UNE, 2015). According to the estimates (EIA, 2016), by 2040, developing nations are expected to release 127% more CO_2 than developed countries. The Pacific and Asia have the maximum aggregate GHG emissions within the developing nations. Suppose additional steps are not made to minimize climate change. In that case, the Organization for Economic Cooperation and Development (OECD) has predicted that greenhouse gas emissions will increase by 52% by 2050 has anticipated 52% rise in greenhouse gas emissions by 2050 (Sohag, Al Mamun, Uddin, & Ahmed, 2017).

Theoretical and empirical literature conducted worldwide has investigated the economic growth-technology-environment nexuses by developing different functional forms of the models and has applied different tools and estimation techniques on different data sets to investigate the relationships among economic growth, environmental degradation, governance, and technological innovation. Some glimpses of the literature are given below.

1.2. Energy Consumption, Economic Growth and Environment

In their 2016 study, Dogan and Turkekul (2016) examined the long-term environmental damage in the USA caused by rising urbanization and energy consumption. Additionally, the study showed an invalid EKC hypothesis in the USA as the actual output level rises with environmental developments. However, GDP^2 raises the emissions. CO2 emissions in Nigeria are dynamically related to variables like GDP growth, trade openness, energy consumption, and urbanization, according to research by Ali, Law, and Zannah (2016). Economic growth and energy consumption have significant and positive effects on carbon emissions. Trade openness decreased environmental pollution, specifically CO_2 emissions.

Ma et al. (2016) examined and modeled the variables influencing renewable energy consumption in a developing country (China). The study's findings showed that while the lobby for conventional energy, financial development, and openness diminish the proportion of renewable energy in overall energy consumption, financial and economic development boosts renewable energy consumption. Apergis, Jebli, and Youssef (2018), using a sample of 42 Sub-Saharan Africa (SSA), looked at how health spending and the use of renewable energy affect the climate. The study's results showed that, in the long run, CO2 emissions and health care costs are linked in two ways. The Dynamic OLS (DOLS) and fully modified OLS (FMOLS) results showed that the amount of carbon emissions goes down when money is spent on health care and when renewable energy is used, but goes up when the economy grows.

In an empirical study, Haseeb, Xia, Baloch, Abbas, and Research (2018) found that financial development and energy consumption increase emissions, whereas urbanization and globalization decrease them in BRICS states. Shittu, Musibau, and Hassan (2018) inspected the existence of the EKC postulate in Malaysia, along with the cooperating roles of urbanization and deforestation in the environs. Rafindadi and Usman (2019) examined the globalization index and incorporated energy consumption to reconsider the poison of emissions and thus regulate the EKC framework for South Africa. The finding showed the presence of upward EKC, which showed the larger use of fossil fuel energy consumption. In the short term globalization reduces environmental degradation unrelated to economic growth.

From 1990 to 2015, Baye et al. (2021) analyzed the impact of renewable energy usage across 32 nations in sub-Saharan Africa. With the aid of the least square dummy estimator (LSDVC), the study aimed to investigate the effects of governance, energy use, climate change, economic progress, and technological innovation. The study found that while urbanization and economic globalization raised barriers to using renewable energy, GDP per capita increased consumption of this type of energy. Mouraviev (2021) examined the governance challenges for renewable energy consumption in Kazakhstan. The study's objective was to use the active power of the central government to design policies. The study argued that acceptance of renewable energy was not common in Kazakhstan; however, when the government adopted laws and regulations to develop renewable energy, that provoked public skepticism, so the government might not be efficient in developing the renewable energy industry (Karatayev, Hall, Kalyuzhnova, Clarke, & Reviews, 2016).

By estimating the mean causal impacts of an action on a consequence of the reasons climbing up from 2005 to 2019, Nawaz et al. (2021) looked at the green financing and climate change rationale in the N-11 nations. According to the study's findings, private sector investments in the energy sector, the Human Development Index (HDI), CO2, FID, and RESCON (consumption of renewable energy sources) all impacted reducing global warming and green funding.

1.3. Technological Innovation and Environment

Technological advancement in the digital era activates productivity and energy efficiency. In the energy sector, technology innovation is measured as a key to the environmental experiment of consuming technology groups (Al-Mulali, Ozturk, & Lean, 2015). The association between carbon emissions and technological progress or use is indecisive. Some studies showed that as technological progress or use rises, the emission level decreases (Gong et al., 2020; Telematics & Informatics, 2019), contrarily some studies suggest the damage of technology to the environment through its disposal and production (Ishida & Informatics, 2015; Williams, 2011). The transition from physical to informational resources has a beneficial and significant impact on energy use and environmental quality used for capital-light economies with lower resource demands (Toffel, Horvath, & Technology, 2004). The IT industry has contributed to a drop in overall emissions by encouraging using more energy-efficient tools across various industries (Ahmad, Muslija, Satrovic, & Research, 2021).

ICT significantly affects energy consumption and economic growth in industrialized nations. According to the research, developing economies are quiet at their initial stage. Energy consumption boosts during ICT infrastructure operation, including various machines and equipment (Chenet, Ryan-Collins, Van Lerven, & WP, 2019; Government of Pakistan, 2021), which upsurges CO_2 releases. ICT equipment production depends significantly on dangerous materials, i.e., computer system manufacturing uses around 1000 substances, and the environment is highly degraded due to these elements. Thus, ICT equipment production produces approximately 2 to 3 percent of CO_2 emissions globally (Shahnazi, Shabani, & Research, 2019).

Su et al. (2021), examined BRICS technological innovation and adoption of environmental Kuznets' curve evidence. Empirical estimates validated the U-shape EKC theory. The study found that fixed telephone and broadband subscriptions—two of the three technology innovation instruments—increase CO2 emissions. In BRICS economies, mobile device cellular contributions reduce CO2 emissions.

1.4. Governance and Environment

Good governance made appropriate measures to achieve the binding targets and instruments to design the energy governance framework. The basic task is to discover a political and suitable possible equilibrium concerning the averseness of economies to give up some of their choices to ultimately govern renewable energy utilization in their relevant authorities and a necessary decree to the charge to confirm the attainment of the combined renewable energy target for 2030.

As developing nations have practiced fast population growth and economic development, leading to an increase in energy demand. In 2015, energy use is estimated to rise from 575 quadrillion Btu (British thermal units) to 663 quadrillion Btu by 2030. Generally, this energy demand is anticipated to originate from developing nations. Therefore, here we need to improve the quality of energy use like the one the nation will move towards renewable energy sources instead of traditional nonrenewable energy resources. The government and regulatory authorities play a significant role in adopting those policies in the industrial sector zone.

Moreover, governance plays a significant role in this scenario because it has positively linked with renewable energy investment. Because bad governance is harmful to the adoption of renewable energy investment in relatively open economies (Bellakhal, Kheder, & Haffoudhi, 2019; Visscher, Meijer, Majcen, Itard, & Information, 2016). Langlois-Bertrand, Benhaddadi, Jegen, and Pineau (2015) divided energy efficiency challenges into three broad categories: contradicting guidelines, policy coordination issues, and governance structure politics. Delina (2012) looked into how governance can ensure that institutions are energy efficient.

1.5. Research Gap

In the literature, only a few studies have begun to look at how governance affects the environment, and even rarer focused on developing economies. Komendantova, Patt, Barras, and Battaglini (2012) underlined the significance of government effectiveness and environment. Pfeiffer and Mulder (2013) deliberate renewable energy technologies development for energy generation in developing countries and claim that renewable energy transmission upsurges with steady representative governments. On the other hand, the literature also delivers the adverse effects on energy policies of weak Governance (Ades & Di Tella, 1999; Blake & Martin-Rendon, 2002). Global governance systems usually fail to meet the standards of an operative institution. The supportive government strategies for energy efficiency to reduce emissions (Sovacool & Van de Graaf, 2018).

The development of renewable energy technologies for generating electricity in developing nations has been considered by (Beşe & Kalayci, 2019; Pfeiffer & Mulder, 2013; Zhang, Wang, Zhou, & Ding, 2019). They contend that the distribution of renewable energy rises with stable democratic regimes.

In light of this, governance and investment in renewable energy are positively correlated (Bellakhal et al., 2019). According to Baye et al. (2021), better governance has a favorable impact on the use of renewable energy.

The impact of governance on green investment has only been partially explored in the existing literature, with even less research focusing on developing economies. No previous research has integrated the effects of renewable and nonrenewable energy consumption, technological innovation, globalization, financial development, and economic growth on environmental degradation in developing, nor has it tested the governance and validity of the EKC hypothesis using governance indices.

To my knowledge, this study represents the first attempt to identify the factors contributing to environmental deterioration and the moderating effect of governance on economic growth and technological innovation in developing economies.

1.6. Research Problem

Most of the world's poorest nations run entirely on fossil fuels like petroleum, coal, and natural gas. Historically, industrialized nations have been blamed for contributing to global warming through their CO2 emissions; however, developing nations have recently attracted considerable attention due to their rapid economic growth and accompanying industrialization (Elum & Momodu, 2017). By 2040, developing nations will emit 127% more CO2 than the world's most developed economy. Therefore, now a day, the encounter between economic growth and the environment is severer, essentially in developing countries with the fast increase in human population moreover the mass poverty. Thus, the developing countries are making insistent efforts to set balances on their need for rapid economic development with the environmental alarms for protective their natural base collected (Omoju, 2014). Technological innovation, energy consumption, and governance are crucial factors for economic growth. Economic growth is associated with energy use and environmental degradation in developing economies. So, it is required to be investigated with fresh evidence.

The following research questions are what this study aims to address:

1) Does economic growth effect environmental degradation in developing economies?
2) Does technological innovation effect environmental degradation in developing economies?
3) Does governance have any effect on environmental degradation in developing economies?
4) How governance moderates the relationship between economic growth and environmental degradation?
5) How governance moderates the relationship between technological innovation and environmental degradation?

1.7. Significance and Scope of the Study

Environmental degradation is the most important global issue. Because it globally affects the economic situation of the nations, some factors directly or indirectly affect environmental degradation. Thus, this study investigates how technology innovation, economic growth, and the moderating influence of governance affect environmental degradation. Hence, many developing countries have experienced rapid economic development and population growth, leading to rising demand for energy. Rising energy demand leads to the environment degrading, but with good governance and technical innovations, it can be resisted.

The current study intends to check the nexus among economic growth, technological innovations, and environmental degradation for a panel of 40 developing countries. The panel data of developing economies for a period of 25 years (from 1996 to 2020) was collected. The said relationship was theoretically and econometrically modeled, and finally, The dynamic panel Generalized Method of Moments (GMM) was used to examine the data.

2. Theoretical Framework

The theoretical structure incorporates distinct concepts and theories from the literary analysis that are interrelated from different points of view. The material of this framework guides the valuable research approach and architecture for archiving essential insights into the subjects of technological innovations, economic growth, energy consumption, environmental degradation, and the role of governance. This theoretical context is a critical reference point for analyzing our observations and when these observational findings are compared with existing methods and principles.

2.1. The Malthus Hypothesis of 'Limit to Grow'

The Reverend "Thomas Malthus" first discussed economic activity and their impact on environmental quality in the 19th century while criticizing the poor relief program. Poverty alleviation programs, food security for the next generation, and the potential erosion of human capability are all interconnected in his mind as causes of environmental deterioration. On the other hand, some arguments link environmental health and human prosperity to economic growth, as suggested by the Malthusian notion of 'limit to grow' (the connection between progress in economics and improvements in the quality of the environment).

2.2. Energy Use-Economic Growth-Living Standard Nexus

However, Kraft and Kraft (1978) revealed fresh perspectives on the economic growth model and talked about literature, which is a crucial component of the manufacturing sector's production process. Increases in energy consumption go hand in hand with increases in economic growth, as both are necessary for achieving economic growth goals. While many economic growth and development theories have been proposed, energy's critical role in driving this progress has been overlooked.

Oil, natural gas, and coal are only some examples of the fossil fuels that Wen et al. (2021) looked at to determine the global energy supply and demand. According to the findings, fossil fuels account for between 85 and 93 percent of global energy output. In addition, Schurr, Darmstadter, Perry, Ramsay, and Russel (1979) and Rosenberg (1998) explained how increased energy consumption contributes to economic expansion and higher standards of life for the general public. According to Barney (2002) research, energy is crucial to industrial production and a significant factor in GDP growth.

2.3. Technological Advancement: An Important Component in Solow and Schumpeterian Growth Models

The importance of R&D to economic growth was further highlighted by (Grossman & Helpman, 1990) and Romer (1990). In the Solow growth model, technological innovation is one of the main drivers of economic expansion. The AK model discusses how raising the saving rate might boost economic growth. Similarly, Schumpeter's growth model views innovation and capital accumulation as the primary factors in economic expansion.

2.4. The Environmental Kuznets Curve (EKC) Theory: The Income-Pollution Relationship

EKC hypothesis defined that additional economic growth when the economy reached satisfactory economic growth, increased environmental degradation. Initial phases of economic growth, as prime production takes over, there is limited waste generation and plenty of natural resource stock because of limited economic motion. Through industrialization, the process of development there arises a significant reduction of waste accumulation and natural resources. Economic growth, environmental degradation, and income have an optimistic relationship for the duration of this phase. The association between income per capita and environmental degradation per capita is designed as an inverted U shape. It is related to the original curve recommended by Simon Kuznets (S. J. T. A. e. r. Kuznets, 1955) regarding the affiliation between economic growth and income inequality.

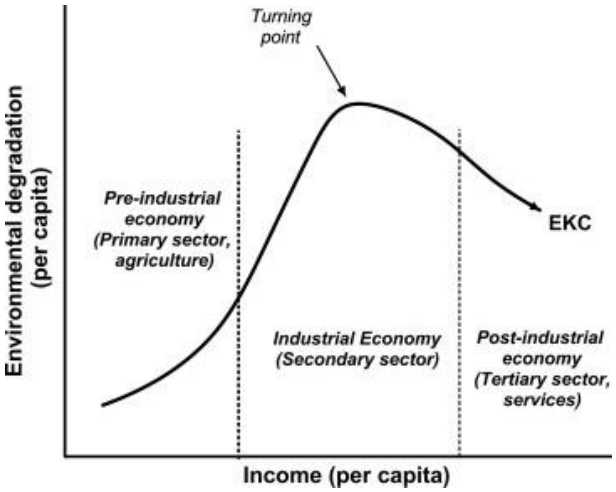

Figure 1: EKC Hypothesis

The Figure 1 turning point signifies the income level (per capita) out there from the process of economic growth, which environmental degradation can be de-linked. For upper income levels, economic growth recovers environment quality. For this, a clarification is that CO_2 emissions are linked with energy consumption which is crucial for economic growth that leads to environmental degradation. The study's conceptual framework is given in the figure below while going through different theories relating to the research question under exploration.

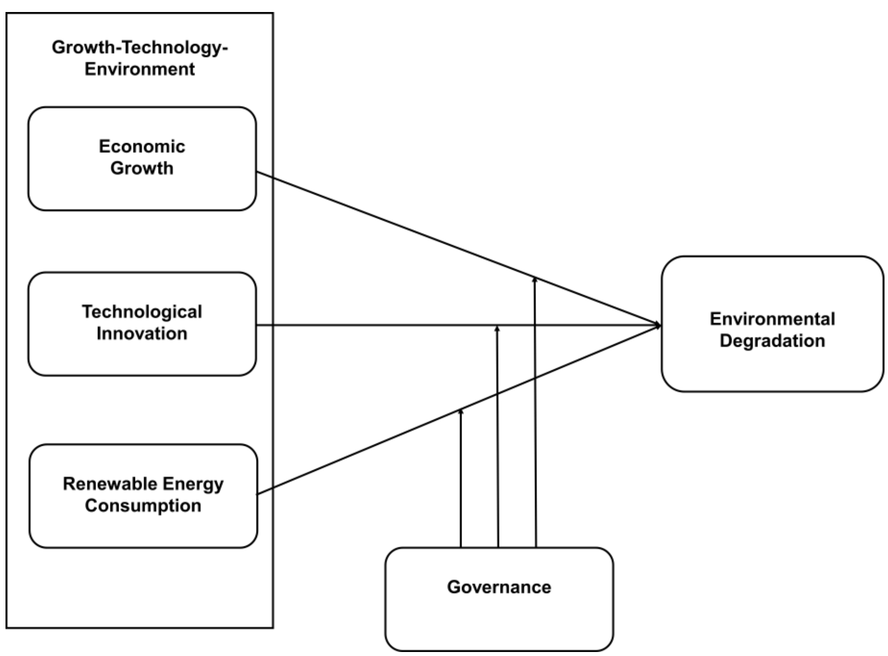

Figure 2: Conceptual Framework of the Study

3. DATA & METHODOLOGY

3.1. Characteristics of the Developing Economies

The table provided contains a list of the economies included in the current study. The table gives information about the name of the economy, its belongingness to the geographical region, and its classification under the income group. The World Bank Atlas method was used to convert local currency to US dollars, then to categorize countries by income. The World Bank classifies countries as either "high," "upper-middle," "low," or "low-middle" income. (The World Bank, 2023, unknown).

At the same time, developing economies are grouped into different geographical regions based on location and proximity. The geographical regions in this table include Middle East & North Africa, Europe & Central Asia, South Asia, Latin America & Caribbean, East Asia & Pacific, and Sub-Saharan Africa. For example, Korea, Saudi Arabia, Panama, and Singapore are the high income developing economies. Algeria belongs to the Middle East & North Africa region and is classified under the lower middle-income group. Armenia belongs to Europe & Central Asia and is classified under the upper middle-income group. Bangladesh belongs to South Asia and is classified under the lower middle-income group. Brazil belongs to Latin America & Caribbean region and is classified under the upper middle-income group. Egypt, Arab Rep. belongs to the Middle East & North Africa region and is classified under the lower middle-income group. El Salvador belongs to Latin America & Caribbean region and is classified under the upper middle-income group. Ethiopia belongs to the Sub-Saharan Africa region and is classified under a low-income group, and so on. For more detail, see the appendix.

3.2. Model Specification

As for the expected signs of variable coefficients, it is widely accepted that according to the EKC hypothesis, economic growth's positive effect on environmental degradation and negative effect of economic growth square on environment degradation. Renewable energy has a positive on environmental degradation. While technology innovation, governance, financial development, and globalization negatively affect environmental degradation. The study will also investigate the moderating effect of governance, interconnected with TI, EG, and REC, to evaluate the coupling effect on Environmental Degradation. The functional form of the model is as follows;

$$CO_2 = f\ (EG, EG^2, REC, TI, GOV, FD, GLOB, GOV * EG, GOV * REC, GOV * TI) \tag{1}$$

CO^2 is carbon dioxide which is a proxy of environmental degradation measured in metric ton, EG and EG^2 is economic growth and square of economic growth (Alola & Ozturk, 2021; Pablo-Romero, Sánchez-Braza, & Gil-Pérez, 2023; Wang, Zhang, Nathwani, Yang, & Shao, 2022). Further, REC is used to measure energy consumption which is measured by Renewable energy consumption (% of total final energy consumption) (Pata & Kartal, 2023; Voumik, Rahman, & Akter, 2022), and GOV is governance index used by (Kaufmann, Kraay, & Mastruzzi, 2010) based on six indicators such as (control of corruption, voice, and accountability, political stability, Government Effectiveness, Regulatory Quality, Rule of Law), TI is technological innovation measured by Patent applications, residents (Abid, Mehmood, Tariq, & Haq, 2022; Chen, Gao, Mangla, Song, & Wen, 2020; Yu & Du, 2019), with some control variables like FD is financial development and GLOB is globalization for developing countries the data constructed from world development indicator and Swiss Economic Institute. Further, use the interaction term of governance with economic growth (GOV*EG), renewable energy consumption (GOV*REC), and technological innovation (GOV*TI) to measure the moderating rule of governance on carbon emission.

3.3. Description of the Variables

The Table 1 provides information on the variables used in an econometric model to discover what factors contribute to environmental deterioration and what effects they have respectively. An explanation of each variable in the context of the model is given in this section.

CO2 is the dependent variable that measures carbon dioxide emissions measured in metric tons, a standard indicator of environmental degradation and greenhouse gas emissions. The data for this variable is obtained from the World Development Indicators (WDI) dataset. EG represents GDP growth, measured annually in percentage terms, which indicates economic growth and development.

Table 1
Description and Source of Data

Code	Variables	Operational Description	Data Sources	Variable Type
CO2	Environmental Degradation	CO2 emission measured in a metric ton	WDI	Dependent
EG	Economic Growth	GDP growth (annual %)	WDI	Independent
REC	Renewable Energy Consumption	Renewable energy consumption (% of total final energy consumption)	WDI	Independent
TI	Technological Innovation	Patent applications, residents	WDI	Independent
GOV	Governance	Composite Index (the rule of law, control of corruption, government effectiveness, regulatory quality, and political stability)	WGI	Independent
FD	Financial Development	Domestic credit to the private sector (% of GDP)	WDI	Independent
GLOB	Globalization	KOF Index	Swiss Economic Institute	Independent

REC represents the percentage of renewable energy consumption from the total final energy consumption. It measures the extent to which a country relies on renewable energy sources. TI represents the number of patent applications filed by residents of the country. It serves as a proxy for technological innovation and research and development activity. GOV represents a composite index that includes various governance dimensions, such as the rule of law, control of corruption, government effectiveness, regulatory quality, and political stability. The data for this variable is obtained from the Worldwide Governance Indicators (WGI) dataset. FD represents the percentage of domestic credit to the private sector as a proportion of GDP. It serves as an indicator of the level of financial development and access to credit in the economy. GLOB represents the KOF Index, developed by the Swiss Economic Institute to measure globalization. It includes various aspects of economic, social, and political globalization. The data for this variable is obtained from the Swiss Economic Institute.

3.4. Dynamic Panel GMM: The Estimation Technique

The study includes a panel of 40 countries with 26 years. According to the Generalized Method of Moments (GMM), properties are that having the number of cross sections (n) is greater than the number of years (t).

The generalized method of moments (GMM) is a method for constructing estimators analogous to maximum likelihood (ML). GMM uses assumptions about specific moments of the random variables instead of assumptions about the entire distribution, which makes GMM more robust than ML at the cost of some efficiency. The assumptions are called moment conditions. GMM generalizes the method of moments (MM) by allowing the number of moment conditions to be greater than the number of parameters. Using these extra moment conditions makes GMM more efficient than MM. When there are more moment conditions than parameters, the estimator is said to be overidentified. GMM can efficiently combine the moment conditions when the estimator is overidentified.

In this study, we have a sufficient number of cross sections and T, so the dynamic panel system GMM results are efficient because GMM efficiently minimizes the problem of endogeneity and autocorrelation (Arellano & Bover, 1995; Blundell & Bond, 1998, 2000). The System GMM equation is as follows:

$$CO_{2it} = \alpha_o + \alpha_1 CO_{2i,t-1} + \alpha_2\, EG_{it} + \alpha_3\, EG^2{}_{it} + \alpha_4\, REC_{it} + \alpha_5 TI_{it} + \alpha_6 GOV_{it} + \alpha_7 FD_{it} + \alpha_8 GLOB_{it} + \alpha_9 GOV_{it} * EG_{it} + \alpha_{10} GOV_{it} * REC_{it} + \alpha_{11} GOV_{it} * TI_{it} + \mu_{it} \quad (2)$$

4. Results and Discussion

4.1. Growth-Technology-Environment Status of the Developing Economies

The interpretation in this section is based on comparing the developing economies concerning their mean values on different variables. The mean value of each variable is obtained from its 25 different values for a period of 25 years, ranging from the year 1996 to the year 2020. The developing economies are also mutually compared (regarding mean values of the variables) concerning their income levels.

Table 2
Comparison in between the Developing Countries

Type of the economy	Economy	CO2 emission	GDP growth	Renewable energy consumption	Technological innovation	Domestic credit to the private sector	KOF Index	Governance index
Low income	Ethiopia	0.09	8.08	94.23	1.7	14.95	39.04	-0.67
	Mozambique	0.13	6.94	89.49	1.87	17.28	45.04	-0.54
	Sudan	0.36	5	68.65	3.1	7.95	40.64	-1.34
Lower middle income	Algeria	3.02	2.94	0.29	4.59	14.44	53	-0.71
	Bangladesh	0.32	5.77	44.55	4.22	34.24	45	-1.02
	Egypt	2.15	4.54	6.51	6.53	39.14	64.08	-0.6
	Haiti	0.23	1.87	75.83	0.79	10.39	39.76	-1.29
	Honduras	0.96	3.29	51.25	2.46	48.02	58	-0.8
	India	1.26	5.93	43.58	8.93	41.75	55.68	-0.38
	Iran	6.66	2.54	0.88	7.81	46.27	47.68	-0.56
	Jordan	2.92	3.96	2.67	4.1	74.79	71.36	0.1
	Kenya	0.28	4.16	76.01	4.1	28.65	52.16	-0.92
	Lebanon	4.02	2.33	5.35	5.39	86.34	65.12	-0.77
	Mongolia	5.08	5.77	4.32	4.64	33.78	55.84	-0.3
	Nicaragua	0.77	3.29	51.35	2.05	24.96	55.56	-0.74
	Nigeria	0.65	4.87	85.81	5.33	11.01	52.56	-1.18
	Pakistan	0.8	3.9	47.88	5.03	21.26	51.2	-0.98
	Philippines	1	4.54	30.2	5.88	37.32	63.52	-0.53
	Sri Lanka	0.71	4.73	56.93	5.24	35.13	56.32	-0.29
Upper middle income	Armenia	1.53	5.75	14.8	4.29	22	59.2	-0.51
	Azerbaijan	3.84	7.76	2.77	4.77	121.75	55.04	-1.02
	Brazil	1.94	2.04	45.74	8.59	46.97	60.28	-0.1
	Costa Rica	1.5	3.74	38.22	3.47	41.57	65.2	0.65
	Dominican Republic	2.16	4.81	16.96	3.16	29.61	51.68	-0.62
	Ecuador	2.13	2.56	16.09	3.06	26.33	58.28	-0.69
	El Salvador	1.06	1.65	35.49	3.43	49.42	60.64	-0.42
	Guatemala	0.89	3.36	64.5	2.93	28.98	55.72	-0.7
	Indonesia	1.7	4.13	40.44	6.49	32.8	60.64	-0.71
	Iraq	4.01	7.12	0.88	5.2	4	42.8	-1.46
	Jamaica	3.33	0.14	13.65	2.79	27.05	62.36	-0.11
	Kazakhstan	11.22	5.24	1.87	6.75	71.42	55.52	-0.78
	Malaysia	6.56	4.47	5.63	6.84	121.59	77.36	0.31
	Mexico	3.92	2.2	9.9	7.19	23.85	63.48	-0.39
	Paraguay	0.84	2.82	64.64	3.45	28.17	57.4	-0.99
	Peru	1.38	3.78	29.38	4.5	31.39	63.92	-0.35
High income	Korea	10.69	4.07	27.04	1.41	11.42	115.95	72.20
	Panama	2.21	4.87	53.90	27.77	3.42	91.68	65.00
	Saudi Arabia	14.17	2.74	22.62	.01	5.59	37.11	62.76
	Singapore	8.91	4.69	39.66	.60	7.13	106.83	81.36

The Table 2 compares the developing economies based on their mean values of different variables over 25 years (1996-2020).

High CO2 emission is observed in countries like Saudi Arabia (14.17 metric tons), Kazakhstan (11.22 metric tons), and Malaysia (6.56 metric tons). Lower CO2 emissions are seen in countries like Ethiopia (0.09 metric tons), Mozambique (0.13 metric tons), and Sudan (0.36 metric tons). CO2 emission levels vary significantly across the economies, indicating differences in carbon-intensive activities.

The highest GDP growth rate on average is found in Azerbaijan (7.76%), Iraq (7.12%), and Korea (4.07%). Lower GDP growth rates are observed in countries like Haiti (1.87%), El Salvador (1.65%), and Jamaica (0.14%). This shows that some economies have experienced higher economic growth over the years while others have faced challenges in achieving significant growth rates.

Countries like Ethiopia (94.23%), Nigeria (85.81%), and Kenya (76.01%) exhibit higher percentages of renewable energy consumption, indicating their efforts toward sustainable energy sources. Some economies like Algeria (0.29%), Iran (0.88%), and Iraq (0.88%) have relatively lower percentages of renewable energy consumption, suggesting a greater reliance on fossil fuels.

Higher technological innovation, measured through patent applications, is observed in countries like Malaysia (6.84 patents), Singapore (0.6 patents), and Korea (1.41 patents). Lower levels of technological innovation are seen in countries like Sudan (3.1 patents), Haiti (0.79 patents), and Bangladesh (4.22 patents).

High levels of domestic credit to the private sector as a percentage of GDP are seen in countries like Malaysia (121.59%), Azerbaijan (121.75%), and Panama (27.77%). Economies like Sudan (7.95%), Iran (46.27%), and Iraq (4%) have relatively lower access to domestic credit.

High levels of globalization, as measured by the KOF Index, are observed in countries like Singapore (106.83), Korea (115.95), and Malaysia (77.36). Lower levels of globalization are seen in economies like Iran (47.68), Nicaragua (55.56), and Haiti (39.76).

Positive governance index values are observed in countries like Singapore (81.36), Korea (72.2), and Malaysia (62.76), indicating better governance practices. Some economies like Sudan (-1.34), Iraq (-1.46), and Nigeria (-1.18) have negative governance index values, suggesting weaker governance.

The Table 2 shows significant variation in the mean values of different variables across the developing economies. Some countries demonstrate higher levels of environmental sustainability, economic growth, technological advancement, and governance, while others face challenges. Policymakers can utilize the findings to identify strengths and weaknesses in different economies and design targeted strategies for sustainable development, environmental protection, and economic growth.

It is important to note that these comparisons are based on the mean values of the variables over a period of 25 years (1996 to 2020). Mean values provide a sense of the central tendency of each variable for each country, but they do not capture the entire range of variability or trends over time. Different factors and historical contexts can influence the values of these variables for each country.

For a more comprehensive analysis, researchers and policymakers might consider conducting further statistical tests, correlation analyses, and exploring trends over time to understand the relationships and patterns among these variables in developing economies. Additionally, contextual factors and specific policy interventions can significantly shape the outcomes observed in each country.

4.2. Growth-Technology-Environment Scenario: Comparative Status of the Developing Economies

To compare the 35 developing economies', mean values on different variables based on their income levels, the economies are divided into three categories: low income, lower middle-income economies, and upper middle-income economies. Ethiopia, Mozambique, and Sudan fall under the category of low income economies. These economies generally have lower mean values of CO2 emissions, with Ethiopia having the lowest mean (0.09 metric tons) and Mozambique the highest (0.13 metric tons). The GDP growth rates for these economies range from 5% to 8.08%, with Ethiopia having the highest mean GDP growth rate. Renewable energy consumption is relatively high for low income economies, with Ethiopia having the highest mean (94.23% of total final energy consumption). Technological innovation, domestic credit to the private sector, and globalization are generally lower in these economies compared to the other income categories.

Algeria, Bangladesh, and India are examples of lower middle-income economies. These economies have a wide range of CO2 emissions, with Algeria having the highest mean (3.02 metric tons). The GDP growth rates range from 2.54% to 5.93%, with India having the highest mean GDP growth rate. Renewable energy consumption is moderate for these economies, with Bangladesh having the highest mean (44.55% of total final energy consumption). Technological innovation and domestic credit to the private sector are relatively higher for lower middle-income economies compared to low-income economies. The governance index values for lower middle-income economies vary, with some countries having negative values and others close to zero.

Armenia, Azerbaijan, and Brazil are examples of upper middle-income economies. CO2 emissions are generally higher for upper middle-income economies than low and lower middle-income economies, with Kazakhstan having the highest mean (11.22 metric tons). The GDP growth rates range from 0.14% to 7.76%, with Azerbaijan having the highest mean GDP growth rate. Renewable energy consumption is generally lower for upper middle-income economies, with Kazakhstan having the lowest mean (1.87% of total final energy consumption). Technological innovation and domestic credit to the private sector are relatively higher for upper middle-income economies compared to lower income categories. The governance index values for upper middle-income economies vary, with some countries having negative values and others close to zero.

High-income economies have significantly higher CO2 emissions than developing economies, with Saudi Arabia having the highest average emissions (14.17 metric tons). These economies show moderate GDP growth rates, with Singapore having the highest average GDP growth rate (4.69%). The percentage of renewable energy consumption varies, with Panama having the highest average (53.90%). Technological innovation is generally low in these economies. Domestic credit to the private sector is relatively low, indicating potential lower dependence on credit for economic activities. Governance index values for high-income economies are generally positive, suggesting better governance than developing economies.

The analysis shows that different income groups of developing economies exhibit different patterns in CO2 emissions, GDP growth rates, renewable energy consumption, technological innovation, domestic credit to the private sector, globalization, and governance index values. Each income group faces its unique challenges and opportunities, and further investigation is necessary to understand the specific factors influencing these variations and to develop targeted policy interventions accordingly.

4.3. Growth-Technology-Environment: Bivariate Correlation Matrix

The Table 3 presents the correlation matrix between the variables. CO2 represents the carbon dioxide emissions, EG represents GDP growth, REC represents the percentage of renewable energy consumption (out of the total final energy consumption), TI represents technological innovation, GOV represents Governance, FD represents the level of financial development and access to credit in the economy, and GLOB represents globalization. CO2 is intended to be kept as a dependent variable, while all the remaining variables are considered explanatory variables.

Table 3
Correlation Matrix

Variables	CO2	EG	EG Sq	REC	TI	FD	GLOB	GOV
CO2	1	-.016	.179	-.719**	.477**	.525**	.279	.189
EG	-.016	1	.633**	.131	.013	.051	-.373*	-.226
EG Sq	.179	.633**	1	-.208	.054	.005	-.327	-.363*
REC	-.719**	.131	-.208	1	-.446**	-.471**	-.494**	-.286
TI	.477**	.013	.054	-.446**	1	.344*	.371*	.229
FD	.525**	.051	.005	-.471**	.344*	1	.584**	.375*
GLOB	.279	-.373*	-.327	-.494**	.371*	.584**	1	.710**
GOV	.189	-.226	-.363*	-.286	.229	.375*	.710**	1

Note: ** and * respectively show that bivariate correlation is significant at the 0.01 and 0.05 level (2-tailed)

The correlation matrix provided shows the correlation coefficients between different variables used in the econometric model investigating the effect of independent variables on the dependent variable (CO2 emissions). The correlation coefficients measure the strength and direction of the linear relationship between pairs of variables.

The correlation coefficient between CO2 emissions and GDP growth is approximately -0.016. The weak and negative correlation suggests a very slight negative relationship between CO2 emissions and GDP growth. However, the correlation is not statistically significant at the 0.05 level.

The correlation coefficient between CO2 emissions and the percentage of renewable energy consumption is approximately -0.719. The correlation is strong and negative, indicating a significant negative relationship between CO2 emissions and the use of renewable energy. As the percentage of renewable energy consumption increases, CO2 emissions decrease.

The correlation coefficient between CO2 emissions and technological innovation (patent applications) is approximately 0.477. The correlation is moderate and positive, suggesting a significant positive relationship between CO2 emissions and technological innovation. As technological innovation increases, CO2 emissions also tend to increase.

The correlation coefficient between CO2 emissions and financial development (domestic credit to private sector) is approximately 0.525. The correlation is moderate and positive, indicating a significant positive relationship between CO2 emissions and financial development. As the level of financial development and access to credit increases, CO2 emissions also tend to increase.

The correlation coefficient between CO2 emissions and globalization (KOF Index) is approximately 0.279. The weak and positive correlation suggests a slight positive relationship between CO2 emissions and globalization. However, the correlation is not statistically significant at the 0.05 level.

The correlation coefficient between CO2 emissions and governance (composite index) is approximately 0.189. The weak and positive correlation indicates a slight positive relationship between CO2 emissions and governance. However, the correlation is not statistically significant at the 0.05 level.

Overall, the correlation matrix provides valuable insights into the relationships between the variables in the econometric model. It suggests that renewable energy consumption has a strong negative correlation with CO2 emissions, while technological innovation and financial development have moderate positive correlations with CO2 emissions. The correlations between CO2 emissions and GDP growth, globalization, and governance are relatively weaker and not statistically significant at the 0.05 level. These correlation results can guide further analysis and interpretation in the econometric model to understand the specific impacts of the independent variables on CO2 emissions and inform policy decisions related to environmental sustainability and economic development.

4.4. Results of Dynamic Panel GMM

The Table 4 presents the findings of the dynamic panel generalized method of moments (GMM) technique applied to find the effect of TI (technological innovations), EG (economic growth), REC (renewable energy consumption, GOV (Governance), FD (financial development), and GLOB (globalization) on environmental degradation (CO2). Furthermore, to investigate the moderating role of governance in the growth-technology-environment nexus, the interactions of governance with technological innovations (GOV*TI), economic growth (GOV*EG), and renewable energy consumption (GOV*REC) are also used as explanatory variables.

Table 4
GMM Estimates

Variable	Coefficient	Std. Err.	t-value
Cons	-0.428***	.0580	-7.38
CO2 L1	.975***	.005	181.63
TI	-.0512***	.0095	-5.38
EG	.0447***	.0007	64.60
EG^2	- .0003***	.0000	-6.92
REC	-.0040**	.0018	-2.21
GOV	-.1338**	.0586	-2.28
FD	.0091***	.0006	15.25
GLOB	.0042***	.0013	3.16
GOV*TI	-.0358***	.0089	-3.99
GOV*EG	.0286***	.0008	33.39
GOV*REC	-.0019*	.0011	-1.67
AR1		0.103	
AR2		0.400	
Sargan test		0.000	

Note: ***shows 1% significance level **shows 5% significance level * shows 10% significance level

The Table 4 presents the empirical results of the dynamic panel generalized method of moments (GMM) technique applied to investigate the effect of various variables on environmental degradation (CO2 emissions). The model includes technological innovations (TI), economic growth (EG), renewable energy consumption (REC), Governance (GOV), financial development (FD), and globalization (GLOB) as explanatory variables. Additionally, the interactions of governance with technological innovations (GOV*TI), economic growth (GOV*EG), and renewable energy consumption (GOV*REC) are also considered explanatory variables to investigate the moderating role of governance in the growth-technology-environment nexus. The interpretation of the findings is given below:

The lagged CO2 emissions (CO2 L1) coefficient is estimated to be .975. The positive value indicates a strong positive relationship between current CO2 emissions and past CO2 emissions.

This suggests that CO_2 emissions tend to persist over time, indicating the presence of autocorrelation in the model.

The coefficient of technological innovations (TI) is estimated at -.0512. The negative value indicates that technological innovations have a negative impact on CO_2 emissions. This suggests that as technological innovation increases, CO_2 emissions tend to decrease, which is a positive finding for environmental sustainability. Technology innovation reduces greenhouse gas emissions without impeding economic or social progress Moyer and Hughes (2012) and Al-Mulali, Saboori, and Ozturk (2015). Technological innovation (by raising energy efficiency and by reducing energy use (Ahmed, Uddin, & Sohag, 2016) helps abate CO_2 emissions (Cheng, Awan, Ahmad, & Tan, 2021; Ganda, 2019; Jianguo, Ali, Alnori, & Ullah, 2022). Technological progress can improve the recycling, recovery, and treatment of pollutants, thus reducing pollutant discharge and improving environmental efficiency. In addition, (Bakhsh, Yin, & Shabir, 2021; Godil, Yu, Sharif, Usman, & Khan, 2021; Ozcan & Apergis, 2018; Salahuddin & Gow, 2016; Sohag, Taşkın, & Malik, 2019) found an inverse relationship between the two.

The coefficient of economic growth (EG) is estimated to be .0447. The positive value indicates that economic growth positively impacts CO_2 emissions. This suggests that CO_2 emissions tend to increase as the economy grows, which is a concerning finding for environmental degradation. When GDP growth adds to increased environment pollution, as we discover, our results are confirmed by (Ben-Salha & Zmami, 2021; Chandran & Tang, 2013; Godil et al., 2021; Khan & Ozturk, 2020; Ma, Cai, Cai, & Dong, 2019).

The coefficient of the squared economic growth (EG2) is estimated at - .0003. The negative value suggests a non-linear relationship between economic growth and CO_2 emissions. The negative sign indicates that at very high levels of economic growth, the effect of growth on CO_2 emissions starts to diminish, possibly due to the adoption of cleaner technologies at advanced stages of development.

The environmental Kuznets curve (EKC) has also been used in increasing research examining the relationship between growth and environmental factors. The EKC assumes an inverse U-shaped link between pollution and economic development (S. Kuznets, 1955). The finding of Shafik and Shafik and Bandyopadhyay (1992) and (Panayotou, 1993) elaborate that When a nation enters a growth phase, the environment deteriorates due to environmental ignorance, a lack of infrastructure, and a lack of cognizance of environmentally friendly technologies, among other factors. Then, as economic growth reaches a certain level, environmental degradation decreases due to increased environmental consciousness, the use of environmentally favorable technologies, and the growth of the service sector (Dinda, 2004).

The coefficient of renewable energy consumption (REC) is estimated at -.0040. The negative value indicates that renewable energy consumption has a negative impact on CO_2 emissions. This suggests that as the share of renewable energy consumption increases, CO_2 emissions tend to decrease, which is positive for environmental sustainability. Renewable energy sources that do not produce a lot of carbon dioxide, like wind, solar, and water energy, are a key part of reducing our reliance on fossil fuels to stop climate change and global warming (De La Peña, Guo, Cao, Ni, & Zhang, 2022). Increased use of renewable energy (i.e., geothermal, solar, hydroelectric, biomass waste, biofuels, or wood) reduces CO_2 emissions, offering opportunities to increase environmental quality (Mujtaba, Jena, Bekun, & Sahu, 2022). This finding is also supported by (Acheampong, Adams, & Boateng, 2019; Bilgili, Koçak, & Bulut, 2016; Zafar, Shahbaz, Sinha, Sengupta, & Qin, 2020).

The coefficient of Governance (GOV) is estimated to be -.1338. The negative value suggests that governance has a negative impact on CO_2 emissions. This indicates that better governance practices are associated with lower CO_2 emissions, implying that effective governance may promote environmental protection. Good governance can enforce and regulate ecologically sound policies to lead societies and individuals toward environmentally sustainable practices (Wingqvist & Wolf, 2013). Good governance infrastructure is particularly relevant for reducing CO2 emissions (Abid, 2016; Ali, Bakhsh, & Yasin, 2019; Wang, Liu, Zhou, Hu, & Ou, 2017). The support also found in (Ozturk & Al-Mulali, 2015) that a well-defined governance system strengthens environmental regulations and improves environmental quality.

The coefficient of financial development (FD) is estimated to be .0091. The positive value indicates that financial development positively impacts CO2 emissions. This suggests that as financial development and access to credit increase, CO2 emissions tend to increase, possibly due to increased economic activities and energy consumption. Financial development boosts economic activity and energy use, resulting in environmental damage (Ahmad, Khattak, Khan, & Rahman, 2020). Financial development is used for capitalization in developing countries, i.e., to encourage the growth of industries starting on a small scale. Small industries benefit from economies of scale that reduce their use of resources and their contribution to pollution. Because of this, pollution has increased in several nations after economic progress (Jianguo et al., 2022). The positive relation is supported by existing literature (Ahmed & Ozturk, 2018; Bayar, Maxim, & Maxim, 2020; Neog & Yadava, 2020; Salahuddin & Gow, 2016; Zakaria & Bibi, 2019).

The coefficient of globalization (GLOB) is estimated to be .0042. The resultant positive number suggests that globalization reduces CO2 emissions. This shows that CO2 emissions tend to rise as globalization does, possibly due to increased international trade and transportation. Globalization also enhances pollution in developing countries. Globalization often leads to expanding industries and manufacturing activities in developing countries. Rapid industrialization can result in increased pollution due to the release of pollutants into the air, water, and soil.

The coefficients of the interaction terms involving Governance (GOV) and technological innovations (GOV*TI), economic growth (GOV*EG), and renewable energy consumption (GOV*REC) are estimated to be -.0358, .0286, and -.0019, respectively. These interaction terms indicate that the impact of technological innovations, economic growth, and renewable energy consumption on CO2 emissions is moderated by governance. The negative sign of GOV*TI and GOV*REC suggests that the effect of technological innovations and renewable energy consumption on reducing CO2 emissions is more substantial when governance is more effective. The positive sign of GOV*EG suggests that the positive impact of economic growth on CO2 emissions is amplified when governance is better.

AR1 and AR2 are the first and second-order autocorrelation coefficients, respectively. The values of 0.103 and 0.400 indicate the presence of positive autocorrelation in the model, meaning that CO2 emissions are influenced by their past values—the Sargan test with a value of 0.000 tests the overidentifying restrictions of the model. A low p-value suggests that the model's overidentifying restrictions are not violated, indicating that the model is well-specified and the instruments used in the GMM estimation are valid.

5. Conclusion & Policy Suggestions

The competition among developing economies to achieve maximum economic growth has often come at the cost of environmental degradation. However, the role of technological innovations in promoting sustainable development cannot be overlooked. Additionally, good governance is critical in developing effective strategies for environmental protection. This research investigates the nexus among economic growth, technological innovations, and environmental degradation in a panel of 40 developing countries. Specifically, it explores the moderating role of governance in shaping these relationships. The study utilizes panel data spanning 25 years, from 1996 to 2020, and employs dynamic panel GMM for rigorous analysis.

The research collected panel data for 40 developing economies, covering key variables such as CO2 emissions, GDP growth rates, renewable energy consumption, technological innovation, domestic credit to the private sector, globalization, and governance index values. These variables were then theoretically and econometrically modeled to understand their relationships and impacts on environmental degradation. The dynamic panel GMM technique was utilized to analyze the empirical data, offering robust insights into the interplay between economic growth, technological innovations, and environmental degradation.

Univariate descriptive statistics analyses revealed distinct patterns among different income groups of developing economies concerning various environmental and economic indicators. Each income group faced unique challenges and opportunities, highlighting the need for targeted policy interventions. The bivariate correlation matrix provided valuable insights into the relationships between variables in the econometric model. Notably, renewable energy consumption exhibited a strong negative correlation with CO2 emissions, while technological innovation and financial development had moderate positive correlations with CO2 emissions. The correlations between CO2 emissions and GDP growth, globalization, and governance were relatively weaker and not statistically significant at the 0.05 level.

The empirical results from the dynamic panel GMM technique yielded significant and insightful relationships between variables and their impact on environmental degradation (CO2 emissions). Economic growth, financial development, and globalization positively affected CO2 emissions, while technological innovation and renewable energy use had a negative effect. Governance emerged as a crucial moderating factor, enhancing the positive effects of technological innovations and renewable energy consumption while mitigating the adverse effects of economic growth on CO2 emissions. Consequently, the study concludes that even though growth and the environment are major issues for many developing nations, achieving growth targets could have environmental implications. Developing economies are in a pressing need for sustainable development. Technological innovations could serve as potential solutions to address these challenges.

Moreover, good governance could play a crucial role in formulating effective policies and frameworks for environmental protection. These findings offer valuable insights for policymakers seeking to address environmental issues and promote sustainable development in developing economies. They underscore the significance of good governance in formulating effective policies and frameworks to protect the environment while promoting economic growth and technological progress.

Authors Contribution

Snober Fazal: Complete the draft and incorporate the comments
Ali Azam: Supervise and proofread the final draft

Conflict of Interests/Disclosures

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Appendix

Name of the Developing Economy	Belongingness to the Geographical Region	Classification of the Developing Economy
Algeria	Middle East & North Africa	Lower middle income
Armenia	Europe & Central Asia	Upper middle income
Azerbaijan	Europe & Central Asia	Upper middle income
Bangladesh	South Asia	Lower middle income
Brazil	Latin America & Caribbean	Upper middle income
Costa Rica	Latin America & Caribbean	Upper middle income
Dominican Republic	Latin America & Caribbean	Upper middle income
Ecuador	Latin America & Caribbean	Upper middle income
Egypt, Arab Rep.	Middle East & North Africa	Lower middle income
El Salvador	Latin America & Caribbean	Upper middle income
Ethiopia	Sub-Saharan Africa	Low income
Guatemala	Latin America & Caribbean	Upper middle income
Haiti	Latin America & Caribbean	Lower middle income
Honduras	Latin America & Caribbean	Lower middle income
India	South Asia	Lower middle income
Indonesia	East Asia & Pacific	Upper middle income
Iran, Islamic Rep.	Middle East & North Africa	Lower middle income
Iraq	Middle East & North Africa	Upper middle income
Jamaica	Latin America & Caribbean	Upper middle income
Jordan	Middle East & North Africa	Lower middle income
Kazakhstan	Europe & Central Asia	Upper middle income
Kenya	Sub-Saharan Africa	Lower middle income
Korea	East Asia & Pacific	High income
Lebanon	Middle East & North Africa	Lower middle income
Malaysia	East Asia & Pacific	Upper middle income
Mexico	Latin America & Caribbean	Upper middle income
Mongolia	East Asia & Pacific	Lower middle income
Mozambique	Sub-Saharan Africa	Low income
Nicaragua	Latin America & Caribbean	Lower middle income
Nigeria	Sub-Saharan Africa	Lower middle income
Pakistan	South Asia	Lower middle income
Panama	Latin America & Caribbean	High income
Paraguay	Latin America & Caribbean	Upper middle income
Peru	Latin America & Caribbean	Upper middle income
Philippines	East Asia & Pacific	Lower middle income
Saudi Arabia	Middle East & North Africa	High income
Singapore	East Asia & Pacific	High income
Sri Lanka	South Asia	Lower middle income
Sudan	Sub-Saharan Africa	Low income