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Exploring the Relationship between ICT Development and Environmental Degradation in Developing Countries

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Abstract:
The whole world is facing several environmental & climate change issues, deteriorating water quality, air pollution, loss of natural habitats, and waste management. Information and telecommunication technology (ICTs) is rapidly growing in developing countries. ICT improvement is the solution to the environmental degradation problem. The current study is focused on checking the relationship between ICT and environmental degradation. Secondary data from 67 developing countries is used from 2000 to 2021. Developing countries are classified into four panels: low, lower-middle, upper-middle, and high-income countries. The environmental Kuznets Curve (EKC) hypothesis is used to check the relationship between ICT development and environmental degradation. The Hausman test is used for the selection of the most suitable model for regression analysis. Random Effect and Fixed Effect regression models are used for regression analysis. The results of the study demonstrated that an increase in ICT development will decrease CO_2 emissions and decrease environmental degradation. Therefore, the study concluded that the sustainable environment may be linked to greater development of the ICT sector. The study also suggested that developing countries should start smart industrial process, build electrical grid stations, and introduce online transportation systems to mitigate the issue of environmental degradation.

Keywords: ICT; Environment; CO_2 emission; developing countries; Environmental Kuznets Curve.

1. Introduction:

Advanced economies in the world are constantly improving their economic conditions and paying more attention to the key areas of development[1]. In the current era, knowledge, sustainability, research, competitiveness, and development are main concern of every country around the globe. Sustainability is based on the idea of efficient allocation of resources. Sustainability is a challenging issue for the whole world in the current scenario. Sustainable development is broadly defined but not defined exactly. Sustainable development is identified as the key indicators that are suitable to enhance economic growth [2]. Brundtland first time gave the idea of sustainable development in his report published in 1987; "it is the way of establishing the nation by utilizing their resources in proper manners without compromising the skill of future generation". Sustainable development has addressed three important issues of the world: environmental, social[3], and economic issues. Most countries of the world focused their attention on solving the issue of sustainable development in two directions of development; innovation of modern technology and improved their available resources [4] ICT is the main pillar of sustainable development [5].

In the current era, the whole world is facing many environmental & climate change issues such as deteriorating water quality, air quality index and natural habitats [6]. Infrastructure, human lifestyle, natural resources and agriculture are also the responsible of environmental degradation [7] . Information & Communication Technology (ICTs) is rapidly growing and contributes to different areas of the economy. Therefore, environment is one of the main area of the economy [8]. ICT improvement has direct or indirect impact on the environment; it may be positive or negative. It is observed that 2 % of GGH emissions is produced due to ICT sector [9]. ICT improvement is the solution to the environmental degradation problem. Therefore, ICT is dealing with environmental challenges and climatic changes. ICT is playing an important role in controlling CO_2 emissions through smarter city buildings, smart industrial processes, electrical grid stations, and efficient and online transportation systems [10]. It also decreased transportation costs by using smart applications and increasing efficiency in businesses. Moreover, the cost of transportation is saved by using mobile phones online applications, and the internet. By using ICT, CO_2 emissions are reduced which is associated with transport. Therefore, ICT also helps in sharing and collecting information and reduces CO_2 emissions **[11].** ICTs-related applications monitor climate change; it can mitigate the adverse greenhouse effects. Secondly, the ICT industry is considered as a priority to minimize the adverse impacts on the environment. CO_2 emissions may arise due to electronic waste and uses of ICTs equipment. According to a report, uses of large number of mobile phones is a threat to environmental degradation[12]**.** According to the Global e-Sustainability report, 2.8% of CO_2 emissions were produced by ICT in 2020 but ICT may also reduce 15% of CO_2 emissions. ICT provides opportunities to establish smart buildings, grids, and smart logistic systems [11]**.** Information regarding health promotion, healthy & quality of life, nutritional foods, and health care centers are provided to the people through ICT. ICT helps prevent people from harmful diseases**.**

The part of ICT is very crucial in the development of the industrialization sector in developing countries. ICT increases energy consumption which harms the environment. The fast growth in industrial development has brought environmental pollution and adversely affects people's health [13]**.** Environmental degradation is a big challenge around the globe. CO_2 emission is the main cause of climatic changes. The effect of ICT on the environment is a widely debatable issue. Initially, ICT development may decline the environmental quality but at one stage it improves by reducing CO_2 emissions [9]**.** An advanced ICT technology improves environmental quality by introducing a new modern system. The advanced uses of ICT in the industrial sector reduce CO_2 emissions and air pollution by using of internet and mobile phone applications. ICT significantly decreases CO_2 emissions when people use internet networks for different purposes like online shopping, jobs, and pay to the bill [14]**.** However, ICT is an important factor in environmental sustainability despite the source of commercial and financial development. Climate has gradually changed due to environmental issues all over the world. ICT is used as a medium of environmental sustainability. The impact of ICT on the environment is more in developed nations as compared to developing economies. The reason behind this is that internet speed in developing countries is slow and less number of internet users [15].

ICT is used to minimize CO_2 emission by different means such as (a) improving transportation systems, (b) building smarter cities, (c) smart electrical grid stations, (d) improving an industrial process, and (e) improving the management system at the household level. ICT increases the efficiency of energy consumption in the production system, it changes the worse environment into a friendly environment. It has a positive impact on the transport sector. The reduction in CO_2 emissions has a favorable effect on climate change from the perspective of reducing global warming [16]. ICT increases the efficiency of energy consumption in the production system, it changes the worse environment into a friendly environment. The reduction in CO_2 emissions has a favorable effect on climate change from the perspective of reducing global warming [16]**.** ICT is the foremost part of the resolution that deals with climate and environmental-related matters. ICT provides a possible solution to environmental-related issues. It is the main hope to improve the environmental quality [17]**;** [18**]**. The net influences of ICT development on emissions of CO_2 have not yet been broadly explored in the world. It highly needs to explore the connection between ICT and environmental in developing economies. Effective steps are taken by international organizations, governments, companies, and individuals to improve environmental quality [19]**;** [20**].**

The Environmental Kuznets Curve (EKC) explores that use of ICT related technology firstly deteriorates the environment of developing economies and ultimately enhances the financial condition which is the result of limited effects and then at one stage improves environmental quality [21]**;** [22]; [23]**.** EKC hypothesis explored that, there are three effects such as scale, output, inputs, and technology effect. Scale effect initially increases the CO_2 emissions by enhancing economic growth. In 2nd effect such as the output effect; in this stage reduction of CO_2 emissions took place due to a change in the structure of production. In this effect, the traditional industrial system has been changed into more refined value-added activities. In the 3rd effect such as the input effect, producing units of inputs have changed which ultimately reduced the CO_2 emissions, in this stage fewer environmentally damaging inputs are used in production. Technology effect is the 4th effect of the EKC hypothesis, the production process has improved. EKC is inverted U-shaped which explains the combination of scale, output, input, and technology effects [24]**.** In the scale effect, ICT is the main part of industrial expansion and raises CO_2 emissions. The use of heavy machinery related to ICT could increase emissions in contrast the use of communications devices has reduced CO_2 emissions.

The uses of ICT as a capital enhance the production level, improve the efficiency of working, reduce the emission of harmful gases through the effect of technology, and facilitate the industry to use environmentally friendly inputs. The publication industries shifted to online publication systems like online newspapers and advertisements instead of print media [9]**;** **[**25**].**

1.1. Research Gap:

Environmental degradation is an emerging issue in developing countries. In the current study, this issue is mitigated by introducing ICT technology in developing countries. Previous studies used Environmental Kuznets Curve (EKC) to estimate the relationship between ICT, economic growth, and GHG emission [9] but in the current study, EKC is first time used to check the relationship between ICT and CO_2 emission in developing economies by using Pooled Ordinary Least Square (POLS), fixed effect (FE) and random effect (RE) methods. There is a vast gap in the literature about the studies in developing economies. Through this study, an attempt is made to fulfill the remaining gap in the literature. The whole world particularly developing countries faces the serious issues of environmental degradation. ICT has positive and negative impact on the environment. The current study address the environmental issues and mitigate these issues by using ICT technology. ICT development is very helpful to mitigate the issue of environmental degradation.

2. Review of Literature:

[26] Investigated the link between financial growth and environmental degradation at the global perspective. Panel data were used of 131 countries for the period of 1995-2019. The result of the study explored that financial growth has significant impact

on the CO2 emission. It was concluded that ICT has negative moderating effect on the link between financial growth and CO2 emission.

[27]has depicted that climate change has serious threat for the world. The research explored the effect of ICT on the environmental degradation among the selected countries. Panel data of 110 selected countries were used for the duration of 2000 to 2018. IV-GMM technique were used for the estimation. The finding of the study revealed that ICT enhanced the environmental sustainability among the selected countries. The causality analysis of the study explored that bi-directional causality exist between CO2 emission and moderate ICT quality while Unidirectional causality observed between less quality of ICT and CO2 emission. It was concluded that improvement in ICT help to mitigate the environmental degradation.

[28]investigated the direct and indirect impact of ICT on environment, renewable energy, financial growth, innovation, and trade. Sixteen emerging countries were selected for the study panel data were used for the period of 2000 to 2018. EKC were used for exploring the impact of ICT and environment. The result depicted that increasing the trade and trend of internet uses has significantly reduced the CO2 emission. It was also revealed that consumption of renewable energy reduced the CO2 in the selected emerging countries. The study concluded that the use of green innovation and renewable technology mitigate the adverse impact on the environment.

[29]the increasing use of information and communication technology (ICT) in the digital era and its interlinkage with other economic and environmental factors has gained the attention of researchers. ICT tools are important in economic activities such as international trade, the financial sector, and foreign direct investment. They are essential and linked to innovation and energy use. However, ICT in these activities influences the ecological footprint, especially in emerging economies such as BRICS (Brazil, Russia, India, China, South Africa) countries. Thus, this subject has received the attention it deserves among researchers and policy implementers to the effect of ICT and economic growth activities on environmental quality. Therefore, during this study, I tend to assess the impact of information and communication technology, renewable energy consumption, and innovation on carbon dioxide emission in BRICS countries over the period of 1990-2019 by using the cointegration, generalized least square, and panel corrected standard errors model. The results are obtained to show that two ICT variables, mobile cellular subscription, and fixed broadband subscription, decreased carbon emissions with economic growth and financial development.

[30] The proliferation of information and communication technology (ICT) has expanded in the developing world, yet many developed nations still face significant shortfalls. Despite these advances, substantial disparities remain in the availability and necessity of ICT infrastructure. Previous studies on the relationship between ICT and CO2 emissions suggest that ICT can have both positive and negative impacts on emission levels. In this context, the influence of ICT and education on environmental quality is critically examined in this study. This analysis controls for the effects of globalization, income, and financial development in developing countries during the period from 1996 to 2019. We employ second-generation econometric techniques to address issues such as variable heterogeneity in our empirical analysis. The Westerlund cointegration test confirms a cointegration relationship among the study variables. Long-term estimates from the Cup-FM and Cup-BC models show that ICT enhances environmental quality by reducing emissions, whereas education, income, financial development, and globalization have detrimental effects on environmental quality. Therefore, it is crucial for policymakers to promote the development of ICT infrastructure, implement advanced information systems, utilize the financial sector to formulate policies that fund ICT projects at reasonable interest rates, and increase public pressure on political leaders to reduce unsustainable practices that negatively impact environmental quality.

The world is facing the challenge of environmental issues due to rapid climate change. CO_2 emission is the main cause of climate change. Several studies have investigated the impact of ICT on environmental degradation. The association between ICT and environment was examined from three aspects in the literature; direct, indirect, and outcome of both impacts [31].

The 1st aspect (direct impact), the ICT impact on CO_2 emission was studied by [32]. Panel data of ASEAN economies was used for the period of 1991 to 2009. ICT related variables comprised four indicators; fixed and wireless internet users, mobile phone and fixed telephone subscriptions, GDP, and the human capital index the composite index included primary, secondary, and tertiary enrolment of children while CO_2 emission was a dependent variable. Unit root test was used for checking the stationary in data, Pedroni test was applied for cointegration while FMOLS & DOLS techniques were used for regression analysis. The study examined short and long-run equilibrium relationships by using cointegration regression. It was concluded that long-run association occurs among selected variables and development in the ICT sector has improved the quality of the environment. The study indicated that ICT has significant impact on CO_2 emissions in ASEAN countries.

[33**]** Investigated the impact usage of internet in OECD countries for the period of 1991 to 2012. Pooled data were used for analysis. Internet and mobile phone users, electricity, energy consumption, and industry were used as explanatory variables, and CO_2 emissions as dependent variables. The Pedroni test was used to estimate cointegration among variables. Study demonstrated that a significant link exists between usage of internet and emissions of CO_2. There was no causal relationship between the two. The internet usage stimulates CO_2 emissions and promotes finance development and opening of trade of a country. These findings supported the argument that OECD countries promoted the use of the internet by paying too much attention without causing the environmental consequences of economic growth in OECD countries. It was concluded that ICT reduced CO_2 emissions and improved environmental quality.

[34] Investigated the impact of internet on CO_2 emission in 77 selected countries. Selected countries are divided into two panels as developing and developed economies. Data from these countries were collected from UNDP, WB database, and ITU from 2000 to 2013. GMM and 2SLS methods were applied for the analysis of the data. GDP, urbanization, electricity consumption (EC), trade openness, internet user, and speed were taken as explanatory variables while CO_2 emission was as dependent variable. Results found mixed effects of the internet on CO_2 emission in selected economies. GDP, EC, and trade have increased the emission of CO_2 in developed and developing economies. Internet usage had a significant impact on CO_2

emissions in developed countries but an insignificant impact in developing economies. It reduced CO_2 emissions in developed economies and improved environmental quality.

[35] Explore the nexus between energy consumption, urbanization, financial development, trade and GHG emission in 34 upper middle income countries by using panel data for the period of 2001 to 2014. The results of the study depicted that greenhouse gas emission increased by urbanization, renewable energy and financial development. It has significant impact on the environmental degradation.

[36] Investigated the direct impact of ICT on CO_2 emission in 20 selected developing countries for the period 1990 to 2015. Panel data was used for the study. Number of internet users along with four controlled variables such as GDP, energy consumption, financial development, and trade openness. CO_2 emission was used as a proxy of pollution which was used as the dependent variable. Cross-sectional dependence and heterogeneity were checked across the countries then estimated cointegration among variables by using Westerlund and Edgerton test. It was explored that internet used reduced CO_2 emissions in the long run, increased in GDP and energy consumption enhanced emission of CO_2. Causality test results indicated unidirectional causality exists among ICT and CO_2 emissions. It was concluded that an increase in ICT investment had reduced air pollution.

[37] Studied the link between agriculture, electricity, renewable energy and GHG emission in Pakistan for the period of 1981 to 2015. VECM, FMOLS and Causality test were used for the analysis of the data. The results of the study explored that agriculture value addition and forest has significant impact on reduction of GHG emission while electricity production and renewable energy increased GHG emission in Pakistan. The study shows that GHG emission has direct impact on the environmental degradation.

[38] Explained the link among CO_2 emissions, Total Factor Productivity (TFP) and ICT in Tunisian from 1975 to 2017. Data was collected from UNDP, WB, and ITU websites. ARDL regression analysis method was used for analysis. The results presented that the ARDL model in short-term correlation with breakpoints obtained a higher long-term TFP coefficient. Therefore, the impact of ICT has significant impact on CO_2 emissions. Tunisian policymakers had focused not only on increasing their overall factor productivity but also on expanding ICT penetration.

The 2nd aspect (indirect impact of ICT) was measured by using Environmental Kuznets Curve (EKC). [9] Depicted the association between ICT & environment around the globe. In the study, researchers used panel data of 140 countries including advanced and emerging economies for 1995-2010. CO_2 emission was dependent on the ICT index and its square, GDP and its square, and some covariates such as industry share, regulation quality, population density, Kyoto, education, cars, and government effectiveness. Data of the selected variables were collected from WDI, WB database, ITU, and UNFCC transportation database system. POLS, FE, and RE methods were used for regression analysis. Study results explored that ICT had a positive and negative effect on the environment. It was observed that ICT and its square had a significant impact on CO_2 emission with an alternative sign. The study observed that CO_2 emission increased by using ICT devices and machinery in production, but its square decreased the CO_2 emission. Reused of electronic waste and energy consumption increased CO_2 emission and also reduced on an international level by creating an online transportation system, smart electrical grid station, and efficient industrial processes. The study depicted that ICT helped resolve the problem of global warming around the globe. The indirect impact of ICT on carbon dioxide emission in forty-four African economies for the duration of 2000 to 2012 was investigated by [16]. Panel data were taken from the World Bank data bank. CO_2 emission was used as a dependent variable while ICT along with four controlled variables like GDP, population growth, educational, and regulation quality were taken as explanatory variables. ICT was measured by mobile phone and internet penetration rates. GMM technique was used for regression analysis. Results explored that GDP and population growth had a significant impact on CO_2 emission and had improved the environmental quality. Mobile phones and internet penetration have reduced CO_2 emissions. Increases in CO_2 emissions have worsened the environment. The results explored that ICT hurt environmental degradation. ICT has improved the environmental conditions in Sub-Saharan African countries.

[39] Conducted an estimation of developed and developing economies between ICT and environment for duration of 1980-2016. The empirical analysis was based on POLS and GMM. The study investigated the different consequences of ICT on the environment of developing and developed states. Research results showed that ICT could determine the future of the world's ecology. However, only developed had observed good results in ICT on the environment, while in developing countries, there were generally adverse effects. The empirical results confirmed the hypothesis that developed countries had adopted a good environment to achieve greenness technology through ICT. Different results of ICT between developing and developed countries were observed.

[40] Explored the link of GHG emission with financial development, renewable energy, trade and tourism in 35 high income economies. The panel data were used for the period of 1997 to 2017. Causality test and Augmented Mean Group analysis explored the results of the study. Results of the study showed financial development has great impact on GHG emission in 11 high income countries while renewable energy in 22 countries. GHG emission has significant impact on the environmental degradation.

[31] explained relationship among environmental quality as well as ICT. The study expanded the stochastic influence of ICT on emissions of CO_2 to estimate the influence and spread of ICT in 21 African countries from 1998 to 2016 by mediating the analysis. The results presented that the internet penetration and mobile phone usage had a significant link with CO_2 emissions. However, it was observed that ICT had worsened the environmental quality of SSA. To reduce the negative association between environmental quality and ICT, the government had promoted green technology.

[41] Investigated the link among industrialization, globalization, ICT and environmental degradation in Malaysia. Data were used for the period of 1970 to 2019. Causality test VEC approach were used to investigate the relationship among these variable. The result of the study explored that improvement in ICT, industrialization and globalization have significant impact on the environmental degradation in Malaysia.

The 3rd aspect (direct as well as indirect impact of ICT) investigated the association among ICT and environmental. Many studies were conducted on these prospects. [42] studied that developing and developed countries related to environmental changes, levels of climate change, air pollution, quality of water and biodiversity. The study describes that ICT and the internet helped mitigate the environmental issues. It was explored that smart energy infrastructure, efficient transportation, and the motor system improved the environmental quality.

[15] Studied the effects of ICT on CO_2 emissions in developing economies from 1990 to 2015. CO_2 emission was taken as a dependent variable while ICT, GDP, FDI, energy consumption and urban population as independent variables. The combined impact of these variables; ICT*FDI, and ICT*GDP was also observed on CO_2 emissions. Mobile phones and internet users were taken as ICT variables, other variables were taken as controlled variables. Data on the selected variables were taken from ITU and WB websites. The methodology comprised four methods: first estimated CD, 2nd unit root test by using CIPS, 3rd Cointegration test, and 4th regression analysis techniques. It was concluded that combined impact of ICT and GDP decrease the pollution and improve the environmental quality. Energy consumption and urbanization also increased the pollution level. It was recommended that Investment in ICT was required to reduce CO_2 emission level and introduce green ICT projects.

[43] Investigated the relationship among tourism, financial development, trade, renewable energy, sanitation and total reserve in 19 Asian countries by using panel data for the period of 1995-2015. VEC and FMOLS model were used for the analysis of the data. The results of the study explored that enhancement in financial development, trade and tourism improved the condition of sanitation. Sanitation condition has direct impact on the environment. Improvement in sanitation condition has decreased the environmental degradation.

[44] Explained the impact of ICT on CO_2 emissions in 91 countries around the globe for the duration of 1990 to 2018. ICT index was conducted. After descriptive analysis of the data, cross-sectional dependency was checked in the data by using the Friedman and Pesaran test. The study used POLS, FE model, and system universal moment estimation method with panel calibration standard error (PCSE) for regression analysis. The research explored that ICT had reduced emissions of CO_2 in the entire national sample. However, comparative studies of developing and developed countries display that ICT encourages environmental sustainability in developed countries while developing countries have found the opposite result. The results of this study were helpful for legislators to encourage investment in ICT in developing countries because ICT had focused on environmental sustainability with higher levels of development.

[45] Investigated the impact of tourism, urbanization, renewable energy on footprint and natural resources in 128 countries. The data were collected for the period of 1995-2019. Selected countries were divided into four panels on the basis of income level. Environmental Kuznet Curve hypothesis was used for the analysis of the data. The results of the study explored that increase in urbanization, use of renewable energy and culture globalization reduced foot print in high income countries. Foot print level increased by increasing GDP and trade.

Table1: Literature Review

Year	Dependent Variable	Independent Variables	Findings
1995-2019	CO2 Emission	Financial Growth, ICT	Financial growth impacts CO2 emission. ICT has a negative moderating effect between financial growth and CO2 emission.
2000-2018	Environmental Sustainability	ICT, Climate Change	ICT improves environmental sustainability. Bi-directional causality between moderate ICT quality and CO2 emission; unidirectional causality with low ICT quality and CO2 emission.
2000-2018	CO2 Emission	ICT, Renewable Energy, Trade	Increased trade and internet use reduce CO2 emission. Renewable energy consumption reduces CO2 in emerging countries.
1990-2019	CO2 Emission	ICT, Renewable Energy, Innovation, Economic Growth, Financial Development	Mobile and fixed broadband subscriptions reduce CO2 emissions in BRICS countries with economic growth and financial development.
1996-2019	Environmental Quality	ICT, Education, Income, Financial Development, Globalization	ICT reduces emissions, while education, income, financial development, and globalization negatively impact environmental quality.
1991-2009	CO2 Emission	ICT (fixed & wireless internet, mobile & fixed phone subscriptions), GDP, Human Capital Index	Long-run association between ICT and CO2 reduction in ASEAN countries.
1991-2012	CO2 Emission	Internet Use, Mobile Phone Users, Electricity Consumption, Energy, Industry	Internet usage increases CO2 emissions but also promotes financial development and trade in OECD countries.
2000-2013	CO2 Emission	GDP, Urbanization, Electricity Consumption, Trade Openness, Internet Use and Speed	Mixed effects on CO2; internet reduces emissions in developed countries but has an insignificant impact in developing countries.
2001-2014	GHG Emission	Urbanization, Renewable Energy, Financial Development	Greenhouse gas emissions are increased by urbanization and renewable energy in 34 upper-middle-income countries.

1990-2015	CO2 Emission	Internet Users, GDP, Energy Consumption, Financial Development, Trade Openness	ICT use reduces CO2 emissions in the long run, with GDP and energy consumption increasing emissions.
1981-2015	GHG Emission	Agriculture, Electricity Production, Renewable Energy	Agriculture reduces GHG, but electricity production and renewable energy increase GHG emissions in Pakistan.
1975-2017	CO2 Emission	Total Factor Productivity (TFP), ICT	ICT has a significant impact on CO2 emissions in Tunisia.
1995-2010	CO2 Emission	ICT Index, GDP, Industry Share, Regulation Quality, Population Density	ICT has both positive and negative effects on the environment; e-waste and energy consumption increase emissions, while ICT systems help reduce global warming.
2000-2012	CO2 Emission	ICT (mobile & internet penetration), GDP, Population Growth, Education, Regulation Quality	ICT improves environmental quality in Sub-Saharan Africa by reducing CO2 emissions.
1980-2016	Environmental Quality	ICT, Economic Development	ICT adoption supports environmental quality improvements in developed countries, but mixed results are observed in developing countries.
1997-2017	GHG Emission	Financial Development, Renewable Energy, Trade, Tourism	Financial development impacts GHG emissions; renewable energy reduces emissions in high-income countries.
1998-2016	CO2 Emission	Internet Penetration, Mobile Phone Usage	ICT worsens environmental quality in Sub-Saharan Africa; government promotes green technology to mitigate negative effects.
1970-2019	Environmental Degradation	ICT, Industrialization, Globalization	ICT, industrialization, and globalization have significant negative impacts on environmental quality in Malaysia.
1990-2015	CO2 Emission	ICT, GDP, FDI, Energy Consumption, Urban Population	ICT combined with GDP reduces pollution and improves environmental quality in developing countries.
1995-2015	Sanitation Condition	Financial Development, Trade, Tourism	Improved sanitation conditions reduce environmental degradation in Asian countries.
1990-2018	CO2 Emission	ICT Index, Cross-sectional Dependency	ICT promotes environmental sustainability globally, with different impacts in developed and developing countries.
1995-2019	Footprint	Urbanization, Renewable Energy, Globalization, GDP, Trade	Urbanization and renewable energy reduce footprints in high-income countries; GDP and trade increase footprint levels.

3. Material and Method:

3.1 Sources of Data:

According to the availability of data, a total number of 67 developing countries were included in the data set and classified into four panels based on income according to World Bank criteria. They are categorized as low income (14 countries), lower middle income (20 countries), upper middle income (23 countries), and high income (10 countries). A list of countries is mentioned in Appendix 1. Different indicators like World Development Indicators (WDI), World Governance Indicators (WGI), and World Telecommunication Indicators (WTI) were used in the study. Data for the duration of 2000 to 2021 extracted from several sources such as World Bank (WB), International Telecommunication Union (ITU) websites, Yearbook of Statistics (published yearly by ITU), United Nations Development Program (UNDP), and World Information Technology & Services Alliance (WITSA). The issue of missing values is obvious in panel data. To resolve this issue two approaches are commonly used taking an average of the previous two values and extrapolating the missing data in Stata.

3.2 Description of the Variables:

The link between CO_2 emission and ICT development is explored by using Environmental Kuznets Curve. It is assumed that there are inverted U-shaped relationships that exist among CO_2 emission and ICTD. It is expected that ICT development increase CO_2 emissions, but an advanced stage of ICT may decline CO_2 emissions [34]. Industrial share and foreign direct investment are used as covariates. These covariates have influenced carbon dioxide emissions. Industrial share and Foreign Direct Investment have a major impact on CO_2 emissions [46]**;** **[**16]. The use of advanced ICT technology and an increase in FDI improved the environmental quality by reducing CO_2 emission [46]; [14]**;** [8]**.**

3.3 Data Framework:

Table 1 explains the name, symbol, unit, and definition of each variable and explores the source of the variables.

Table 1; Data Framework.

Variable Name	Symbol	Unit	Definition	Source
Carbon dioxide emission	CO_2	Metric ton (MT)	CO_2 emission is created during the consumption of solid, liquid, and gas fuels, the manufacture of cement, and the burning of fossil fuels.	WDI, World Bank
ICT development index	ICTDI		ICTDI is comprised of 11 indicators; these indicators are divided into three subgroups such as ICT access, use, and skill.	ITU
Foreign Direct Investment	FDI	current US$	It refers to direct investment equity flows in an economy	WDI, World Bank
Industry Share	Ind.S	% of GDP	Total value-added share of the industry.	WDI, World Bank

3.4 Model Specification:

The concept of the Environmental Kuznets Curve (EKC) implies finding out the relationship between CO_2 emission and the ICT development index. EKC hypothesis indicates that environmental quality initially degrades then it becomes improves by improving ICT development [21];[22];[23].

Hypothesis: An inverted U-shaped relationship exists between ICT and CO_2 emissions. ICT development has a positive impact on CO_2 emission then may have a negative impact at advanced stages of ICT development.

The Random effects (RE) and Fixed effect (FE) models are used to estimate the panel regression analysis. Then find the most appropriate model between these two models by using the Hausman test[47]. Hausman test is used to see the appropriate model between the FE and RE models [48].

The empirical estimation of the impact of ICT on CO_2 emissions is based on the EKC framework. In EKC, ICT square, industrial share, and FDI are introduced as an additional explanatory variable with the ICT development index[49, 50]; [9]. However, EKC has some limitations, it has explored that empirical literature of EKC is not econometrically comprehensive. There are so many environmental issues such as ground water pollution, loss of natural resources, disturbance of marine life, soil erosion and desertification. EKC model address only main pollutants such as CO2, NO2 and SO2 emission. It's not focus on other pollutants. EKC is not tested the relationship of income with many pollutants. EKC is not Pareto efficient [51].

3.5 Econometric procedure:

The following equation is used to investigate the relationship between CO_2 emission and ICTDI:

Equation: 1

$$Log(CO_2)_{it} = a_{it} + \beta_1 Log(ICTDI) + \beta_2 Log(ICTDI^2)_{it} + \beta_3 Log(Ind.S)_{it} + \beta_4 Log(FDI)_{it} + \varepsilon_{it}$$

In the above equation, α is the intercept parameter, subscripts i refer to country, and ˛ t refer to time. ICTDI represents the ICT development index, Ind.S refers to the industrial share and FDI represents foreign direct investment. β_1, β_2, β_3, and β_4 are the coefficients to be estimated and ε_{it} is the stochastic error term of the model.

3.5.1 Test for the Selecting of the Appropriate Regression Model:

There are different tests used for choosing the regression model. One test of these is explained as under.

Hausman Test:

The Hausman test is used to select the most suitable model between Fixed effect (FE) and Random effects (RE). FE and RE models are the most useful and general panel data models. Hausman test is used under the null hypothesis that one of the models gives efficient and consistent results and the second model provides consistent results but inefficient results. The alternative hypothesis is that the first model provides inconsistent results and the second gives consistent results. It is most useful for panel data [52].

The general form of the Hausman test is as under:

Equation: 2 $$H= (\boldsymbol{\beta}^{I}-\boldsymbol{\beta}^{II})' [\,Var\,(\boldsymbol{\beta}^{I}) - Var\,(\boldsymbol{\beta}^{II})^{-1} (\boldsymbol{\beta}^{I}-\boldsymbol{\beta}^{II})$$

Hausman statistic is calculated from the formula:

Equation: 3 $$H= (\boldsymbol{\beta}^{RE}-\boldsymbol{\beta}^{FE})' [\,Var\,(\boldsymbol{\beta}^{RE}) - Var\,(\boldsymbol{\beta}^{FE})]^{-1} (\boldsymbol{\beta}^{RE}-\boldsymbol{\beta}^{FE})$$

In the above equation, $\boldsymbol{\beta}^{RE}$ and $\boldsymbol{\beta}^{FE}$ are vectors of coefficient estimates for RE and FE models respectively.

The null hypothesis is that the preferred model is RE while the alternative model is FE.

H_0: The appropriate model is RE. No correlation between the error term and explanatory variables in the panel model.
$Cov\,(\alpha_i, \boldsymbol{x_{it}}) = 0$

H_1: The appropriate model is FE. The correlation between explanatory variables and the error term is statistically significant in the model.

$Cov\ (\alpha_i,) \neq 0$

The null hypothesis is rejected if the value of the Hausman statistic is greater than the critical value.

3.5.2 The test used for Regression Analysis:
There are many tests used for regression analysis, but the current study will use the following tests:
(i) Fixed Effect (FE):
FE model is used to determine the impact of variables that vary over time. It provides consistent results for the estimates. It demonstrated the relationship between the predictor and outcome variables within an entity. It eliminates the impact of time-invariant characteristics. It is used to assess the effect of predictors on the outcome variables. The time-invariant characteristics of the FE model are distinctive and not associated with other individual characteristics. The error and constant term are different for each variable and could not resemble other variable characteristics. If the error term is correlated, then the FE model is not appropriate. The FE model deals with unobserved heterogeneity [53]. It is expressed in the following way:

Equation: 4 $y_{it}=\alpha_i+\beta_1 x_1,+\beta_2 x_{2,it}+\cdots+\beta_k x_{k,it}+\varepsilon_{it}$

In the FE model equation, there is no constant term. α determines as an intercept for each individual and $_i$ are slope parameters which are the same for all individuals [52].

(ii) Random Effect (RE):
The error term of RE is not correlated with estimators. It is time-invariant. In the RE model $\boldsymbol{\alpha}$ is not treated as a parameter and not being estimated. It is considered as a random variable with mean μ and variance $\sigma^2\alpha$[54].
The random effects model is written as:

Equation: 5 $y_{it}=\mu+\beta_1 x_1,+\beta_2 x_{2,it}+\cdots+\beta_k x_{k,it}+ (\alpha_i-\mu) + \varepsilon_{it},$

Where μ is the average individual effect. Let $u_{it}= \alpha_i-\mu +\varepsilon_{it}$
RE is rewritten as:

Equation: 6 $y_{it}=\mu+\beta_1 x_1,+\beta_2 x_{2,it}+\cdots+\beta_k x_{k,it}+u_{it},$

The RE model assumptions are as follows:
1) The model is correct: $(u_{it})=E\ ((\alpha_i-)+\varepsilon_{it})=E\ (\alpha_i-\mu)\ +E(\varepsilon_{it})=0+E(\varepsilon_{it})\ =0$
2) Full rank: $(\boldsymbol{X})\ =rank\ (\boldsymbol{X}'\boldsymbol{X})\ =K;$
3) Exogeneity: $(u_{it}\ |\boldsymbol{x}_i,)\ =0;\ (\alpha i-\mu|\ )\ =E\ (\alpha i-\mu\ )=0;$
$(u_{it},\boldsymbol{x}_{it})=(\alpha_i,\boldsymbol{x}_{it})+Cov(\varepsilon_{it},\boldsymbol{x}_{it})=0;$
4) Homoscedasticity: $(u^2_{it}\ |\ \boldsymbol{x}_i,)\ =\sigma^2_u\ ;(^2_i\ |\ \boldsymbol{x}_i)\ =\sigma^2_\alpha;$
5) Normal distribution of the disturbances u_{it}.
If the criteria of assumptions 1 and 3 are fulfilled then the RE model is consistent [52].

4. RESULTS AND DISCUSSION

The environmental Kuznets curve (EKC) hypothesis is applied to investigate the relationship between ICT and the environment. According to the EKC hypothesis, initially, ICT worsens the environment but at one stage it improves the environmental condition [21]**;** [22]. CO_2 emissions worsen the environment**.** Therefore, CO_2 emission is used in this objective to investigate the environmental condition of developing countries[55]. The contribution of ICT in the expansion of industries, and CO_2 emissions increased through the scale effect. When ICT is used as capital, it enhances the production process and increases energy efficiency. CO_2 emissions are reduced through technology effect [9]. The following steps are involved in the analysis:

4.1 Descriptive Statistics:

Tables 2, 3, 4, and 5 explain the descriptive analysis of Low-income countries (LIC), Lower middle-income countries (LMIC), Upper middle-income countries (UMIC) and High-income countries (HIC) respectively.
Table 2 describes the descriptive statistics of variables in low-income countries. The mean value of CO_2 is 0.223 (Metric ton), the ICT development index is 1.226, the square of ICTDI is 1.878, the industrial share (Ind.S) is 21.277 (% of GDP) and foreign direct investment (FDI) is 5.15E+08 (US dollar). The maximum values of CO_2, ICTDI, $ICTDI^2$, IndS, and FDI are 1.090, 3.230, 10.432, 52.797, and 6.70E+09 respectively. The minimum values of CO_2, ICTDI, $ICTDI^2$, IndS, and FDI are 0.049, 0.132, 0.017, and 9.435 respectively. The value of the standard deviation of CO_2 is 0.233, ICTDI is 0.612, $ICTDI^2$ is 1.673, IndS is 8.290 and FDI is 8.84 E+08.

Table 2: Descriptive Statistics of LIC:

Variable	Mean	Max.	Min.	Std.Dev.
CO_2 (MT)	0.223	1.090	0.049	0.233
ICTDI (index)	1.226	3.230	0.132	0.612
$ICTDI^2$ (index)	1.878	10.432	0.017	1.673
Ind.S (% of GDP)	21.277	52.797	9.435	8.290
FDI (US $)	5.15E+08	6.70E+09	190000.0	8.84E+08

Table 3 explains the descriptive analysis of variables in lower-middle-income countries. The mean values of CO_2, ICTDI, $ICTDI^2$, Ind.S, and FDI are 1.537, 2.258, 6.920, 26.714, and 3.41E+09 respectively. The maximum, minimum, and standard deviation values of CO_2 are 13.447, 2.78E-17, and 1.839 respectively. The maximum values of ICTDI, $ICTDI^2$, Ind.S, and FDI are 6.450, 41.602, 48.060, and 4.45 E+10 respectively. The minimum values of ICTDI, $ICTDI^2$, IndS, and FDI are 0.225, 0.050, 15.015, and 5302623 respectively. The values of standard deviation of ICTDI are 1.350, ICTDI2 is 7.570, Ind.S is 6.257and FDI is 6.97 E+09.

Table 3: Descriptive Statistics of LMIC:

Variable	Mean	Max.	Min.	Std.Dev.
CO_2 (MT)	1.537	13.447	2.78E-17	1.839
ICTDI (index)	2.258	6.450	0.225	1.350
$ICTDI^2$ (index)	6.920	41.602	0.050	7.570
Ind.S (% of GDP)	26.714	48.060	15.015	6.257
FDI (US $)	3.41E+09	4.45E+10	5302623	6.97E+09

Table 4 describes the descriptive statistics of the selected variables in UMIC. The mean, maximum, minimum, and standard deviation values of CO_2 emission are 4.251, 15.646, 0.016, and 3.345 respectively in UMIC. The mean values of ICTDI, $ICTDI^2$, Ind.S, and FDI are 3.423, 15.104, 31.964, and 1.46 E+ 10 respectively. The maximum and minimum values of ICTDI, $ICTDI^2$, Ind.S, and FDI are 7.550, 57.002, 66.160, 2.91 E+11 and 0.902, 0.010, 15.346, and 7300000 respectively. The standard deviation values of ICTDI, $ICTDI^2$, Ind.S, and FDI are 1.842, 13.431, 8.682, and 3.90 E+10.

Table 4: Descriptive Statistics of UMIC:

Variable	Mean	Max.	Min.	Std.Dev.
CO_2 (MT)	4.251	15.646	0.016	3.345
ICTDI (index)	3.423	7.550	0.101	1.842
$ICTDI^2$ (index)	15.104	57.002	0.010	13.431
Ind.S (% of GDP)	31.964	66.160	15.346	8.682
FDI (US $)	1.46E+10	2.91E+11	7300000	3.90E+10

Table 5 shows the descriptive statistics of variables in HIC. Table explores the mean (10.069), maximum (28.051), minimum (1.383), and standard deviation (7.664) values of CO_2 emission in HIC. The maximum and minimum values ICTDI, $ICTDI^2$, Ind.S, and FDI are 7.550, 57.002, 66.160, 2.91 E+11 and 4.463 0.813, 17.739 and 5201560 respectively. The mean and standard deviation values of ICTDI, $ICTDI^2$, Ind.S, and FDI are 1.646, 14.381, 16.693, 1.20E+10, and 1.646, 14.381, 16.693, and 1.20 E+10 respectively.

Table 5: Descriptive Statistics of HIC:

Variable	Mean	Max.	Min.	Std.Dev.
CO_2 (MT)	10.069	28.051	1.383	7.664
ICTDI (index)	4.463	7.730	0.902	1.646
$ICTDI^2$ (index)	22.620	59.752	0.813	14.381
Ind.S (% of GDP)	38.392	74.113	17.739	16.693
FDI (US $)	6.98E+09	7.51E+10	5201560.	1.20E+10

4.2 Regression Analysis Tests:
The following tests are used in regression analysis.

4.2.1 Hausman Test:
Table 6 explains the Hausman test results. The null hypothesis (Ho) is that the random effect (RE) model is more suitable than the fixed effect (FE) model. The test result shows that the probability value is < 0.05 which rejects the Ho. Hausman test results depict that the FE model is preferable in LIC and LMIC. UMIC and HIC than RE model. So, the FE model is more appropriate for regression analysis [52]**.**

Table 6: Hausman Test Results:

Panels	Chi^2	Prob.	Preferred Model
LIC	26.68	0.000	Reject Ho. FE model is more appropriate than RE model.
LMIC	29.97	0.000	FE
UMIC	35.65	0.000	FE
HIC	23.42	0.000	FE

4.2.2 Random Effect (RE) and Fixed Effect (FE) Regression Analysis:
Tables 7 and 8 explore the results of random effect and fixed effect regression analysis in LIC, LMIC, UMIC, and HIC respectively.

Both models fulfill the criteria of EKC but according to the Hausman test's results, the FE model is more appropriate than the RE model in regression analysis. The results explore that ICTDI and $CTDI^2$ are significant in both random effect and fixed effect regression models with alternate signs of significance. The results of RE regression show that a 1% increase in ICTDI will increase 4.32 % CO_2 emission in LIC, 0.070 % in LMIC, and 0.092 % in UMIC while the results of FE show that, 4.423 % CO_2 emission will increase in LIC, 0.074 in LMIC and 0.069 % in UMIC by increasing 1 % ICTDI. RE regression results explain that a 1 % increase in $ICTDI^2$ will decrease 2.042 % in LIC, 0.053 % in LMIC, and 0.266% in UMIC while FE results explore that, a 2.093 % decrease in CO_2 emissions in LIC, 0.525% in LMIC and 0.253% in UMIC by increasing 1% in $ICTDI^2$. The results show that initially, ICT has a positive impact on environmental degradation by increasing the CO_2 emission but an increase in ICT development hurts environmental degradation by decreasing the CO_2 emission. RE and FE regression results do not fulfill the criteria of EKC. The result shows that ICT and $ICTDI^2$ hurt CO_2 emissions in HIC. ICT is a very important factor in environmental degradation. It is very helpful in decreasing CO2 emissions. CO_2 emission is the main cause of environmental degradation. Previous studies explored that ICT development solved the issue of environmental degradation by reducing CO_2 emissions [56].
It is also found that ICT development reduced CO_2 emissions in a knowledge-based new economy [32]. Two control variables such as industrial share (Ind.S) and FDI have also an impact on CO_2 emissions. RE and FE regression results show that Ind.S is positively significant in both LIC and LMIC while insignificance in UMIC and HIC. Similarly, FDI is positively significant in LIC and UMIC while insignificance in LMIC and HIC. The literature explored that industrial share has also impact on CO_2 emission in Bangladesh[57]. The results show that an increase in industrial share and FDI will increase CO_2 emissions. It is found that FDI and CO_2 emission have a long-run relationship in the Middle East and North African countries [33].

Table 7: Random Effect Analysis Results:

Variable	**LIC**			
	Coeff.	**Stand. Error**	**Z-Value**	**Prob.**
LogICTDI	4.320	1.741	2.48	0.013
$LogICTDI^2$	-2.042	0.871	-2.34	0.019
LogInd.S	0.276	0.085	3.21	0.001
LogFDI	0.039	0.009	4.10	0.000
_cons	-1.943	0.143	-10.33	0.000
	LMIC			
LogICTDI	0.070	0.028	2.46	0.014
$LogICTDI^2$	-0.053	0.010	-5.33	0.000
LogInd.S	0.107	0.011	9.49	0.000
LogFDI	0.297	0.094	1.05	0.279
_cons	3.046	0.177	17.13	0.000
	UMIC			
LogICTDI	0.092	0.043	3.01	0.002
$LogICTDI^2$	-0.266	0.114	-2.31	0.021
LogInd.S	0.001	0.008	0.14	0.888
LogFDI	0.063	0.012	4.92	0.000
_cons	-0.528	0.213	-2.48	0.013
	HIC			
LogICTDI	-1.152	0.206	-5.58	0.000
$LogICTDI^2$	-2.532	0.852	-3.96	0.005
LogInd.S	0.967	0.456	0.30	0.766
LogFDI	0.052	0 .029	0.82	0.645
_cons	-1.074	0.364	-4.25	0.003

Significance level at 1%*, 5 %** and 10 %***

Table 8: Fixed Effect Analysis Results:

Variable	**LIC**			
	Coeff.	**Stand. Error**	**T-test**	**Prob.**
LogICTDI	4.423	1.726	2.56	0.011
$LogICTDI^2$	-2.093	0.863	-2.42	0.016
LogInd.S	0.004	0.001	2.54	0.012
LogFDI	0.041	0.009	4.36	0.000
_cons	-1.250	0.081	-15.34	0.000
	LMIC			
LogICTDI	.0743	0.026	2.82	0.005
$LogICTDI^2$	-0.525	0.089	-6.02	0.000
LogInd.S	0.045	0.016	2.77	0.006
LogFDI	0.075	0.120	0.63	0.530
_cons	**-** 3.388	0.096	35.28	0.000

	UMIC			
LogICTDI	0.069	0.023	2.98	0.003
LogICTDI²	-0.253	0.116	-2.17	0.031
LogInd.S	-0.009	0.010	-0.11	0.910
LogFDI	0.061	0.013	4.68	0.000
_cons	-0.486	0.204	-2.38	0.018
	HIC			
LogICTDI	-1.074	0.214	-4.29	0.000
LogICTDI²	-2.831	0.891	-4.32	0.004
LogInd.S	0.671	0.062	0.83	0.341
LogFDI	0.012	0.019	0.62	0.535
_cons	-1.045	0.332	-3.15	0.002

Significance level at 1%*, 5 %** and 10 %***

5. Conclusion:

Environmental Kuznets Curve (EKC) hypothesis is used to check the relationship between ICT development and environmental degradation. The study used the Random effect and Fixed effect model to explore the effects of ICT on CO_2 emissions in four panels such as LIC, LMIC, UMIC, and HIC of selected developing countries. Hausman test is used for the selection of a model between the Random Effect and Fixed effect model. The test results demonstrated that the FE model is more suitable than the RE model. The empirical results of this objective explored that ICT contributed positively to the reduction of CO_2 emissions at the threshold level of ICT development. The current study found an inverted U-shape relationship between the ICT and CO_2 emissions. Reduction in CO_2 emissions has also decreased environmental degradation. Random effect and Fixed effect test results fulfill the criteria of EKC in LIC, LMIC, and UMIC. The results show that ICTDI has a positive significance in LIC, LMIC, and UMIC but has a negative significance in high-income countries. $ICTDI^2$ is significant in four panels and has a negative impact on CO_2 emission. Industrial share is significant in LIC and LMIC but has a positive impact on CO_2 emissions. FDI is significant in LIC and UMIC but has a positive impact on CO_2 emissions. The results demonstrate that an increase in ICT development will decrease CO_2 emissions and decrease environmental degradation. The results from the developing countries suggest that the relationship between ICTDI and environmental degradation is a positive and linear one. Therefore, from the analysis of the current study, we could also conclude that the sustainable environment may be linked to greater development of the ICT sector, and it also changes in the structure of the entire economy of the developing countries.

6. Policy Recommendations:

It is one of the biggest challenges to be encouraged and support developing countries entering the global ICT market to play a more active role in combating the global warming. ICT is very important factor to reduce the CO_2 emission. Therefore, improvement in ICT sector is the solution of environmental degradation problem. Developing countries should develop smarter cities building, start smart industrial process, build electrical grids station and introduce online transportation systems. These measurements will also reduce the production cost and mitigate the issue of environmental degradation.

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Appendix 1

List of Countries

Upper middle-income economies	**High-income economies**	
Albania	Bahrain	
Algeria	Brunei Darussalam	
Argentina	Chile	
Armenia	Croatia	
Belarus	Hungary	
Botswana	Oman	
Brazil	Panama	
Bulgaria	Poland	
China	Saudi Arabia	
Colombia	Uruguay	
Costa Rica		
Ecuador		
Kazakhstan		
Mauritius		
	Mexico	
	Paraguay	
	Peru	
	Philippines	Romania
	Tunisia	Russian Federation
	Ukraine	South Africa
		Sri Lanka
		Thailand
		Venezuela, RB