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Information and Communication Technology and Environmental Degradation Global Perspective: A Panel Data Analysis

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ABSTRACT

The linkage between ICT and environmental degradation has an important role in today's environmental debates. This research empirically scrutinizes the ecological dimension of ICT at the global level by using different key indicators. This paper conducts an analysis to provide comprehensive documentation regarding ICT impact on environmental degradation from 1984 to 2019. The empirical findings are based on Ordinary Least Square (OLS), Pooled OLS, Two-Stage Least Squares (2SLS), and Generalized Method of Moment (GMM) techniques. By applying cross-sectional and panel data, this research found evidence that ICT is an effective tool to alleviate environmental degradation. The study points out many policy implications drawn from its findings.

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1. Introduction

Ecological dimension of ICT deals with the relationship between ICT and environment. The contribution of ICT in environmental degradation also becomes an important subject recently. Due to natural resource depletion and frequent environmental degradation across the globe, the attention of policymakers and researchers has turned toward the causes of environmental degradation. The attainment of a healthy environment has become a global challenge. Scientists have been debating on the quantity of greenhouse gas (GHG) emissions in total and warned that these emissions are making the globe worse gradually. In fact the emerging environmental problems have produced several controversies and public debates. It is hard to claim that the global eco-system is not under pressure because of environmental degradation and global warming. There is large quantity of GHG emitted by different economic sectors including industrialization, electricity, agriculture forestry and other land use (AFOLU), transport, heat production and so on.

Its importance lies on the fact that different economic activities which are performed by humans are intrinsically linked with the environment that provides natural resources and also help in prevention of waste. Natural resources are scarce and the services of ecosystem are under pressure. Unfortunately, the 15 out of 24 natural ecosystem services are degraded

and used unsustainably as well (Assessment of Millennium Ecosystem, 2003). Environmental degradation is an immense concern across the world.

The relation of ICT with environment is rather complex. Figure 1 presents that how ICT can effect environmental degradation in two ways. On the one hand the disposal of ICT products, their use and products increases the environmental degradation. For instance e-waste and larger energy use in production of ICT products deteriorates the environmental quality (Houghton, 2015). ICT life cycle theory also suggests that several stages of the ICT life result in pollution. This theory (life cycle theory of ICT) related products spans over 'transport, production, delivery disposal and use of ICT (Yi & Thomas, 2007; Zhang & Cheng, 2009).

On the other hand, ICT can also mitigate the environmental degradation like air pollution, water pollution through awareness among people and environment friendly technology (Lashkarizadeh & Salatin, 2012; Plepys, 2002). ICT has capacity to decouple economic growth from environmental deprivation. The literature shows that ICT is important to create balance between growth and environment by reducing CO2 emissions (Bekaroo, Bokhoree, & Pattinson, 2016; Gonel & Akinci, 2018; Ozcan & Apergis, 2018). The previous literature has documented economic outcomes for increasing utilization of information and communication technology (ICT) (Batool et al., 2019; Majeed, 2018) Importance of internet usage for environment is also present in previous research (Salahuddin, Alam, & Ozturk, 2016).

Larger use of e-banking and e-commerce is facilitating online transaction system which in return reduce physical travel which ultimately results in greenhouse gas and CO2 emissions reduction. ICT is very helping in offering intelligent and automated solution in several sectors like agriculture, manufacturing and power generation. The contribution of ICT for environment protection is considered as 'low carbon enabler' and fundamental determinant of environment sustainability which can reduce carbon dioxide emissions (CO2) in various sectors for instance transportation, power and building.

The significance of ICT services to greening other sectors could be seven times more than the worse impacts of ICT. Which is confirmed by recent "SMARTer 2020" report (Lu, 2018; Ozcan & Apergis, 2018). ICT related applications are also provide help to manage and predict risks which are associated with environment. For instance, computerized simulation tools can create learning of the "learning by simulation" to stop the serious consequences of trial and error and also facilitate the decision related procedure. Another side of ICT is internet network that positively affect the knowledge of environment.

The ICT and environment relationship is also based on the rebound effects the rebound effect theory implies that the beneficial impacts of technology can be offset not in the short but in long run. For example developments in ICT results in cheaper production that results in product demand increase, thereby rising more pollution. These rebound effects (direct, indirect and systematic) are included in ecological dimension of ICT that create unclear impacts of ICT for environment. ICT based solutions are considered beneficial for better environment as they help to manage and decrease greenhouse gas emissions (Uddin & Rahman, 2012). The empirical findings of present research also demonstrate that ICT reduces CO2 emissions for example our empirical results show that 1 percent rise in e-government index will decrease 2.9 CO2 emissions. Similarly according to report the expected abatement through e-government is approximately 3.48 million tCO2e that is more than the emissions abated (0.15 million tCO2) through ICT in 2011.

There are fourteen ICT services and their role in abatement of GHG emissions is identified in Korea (more advance and top ranked country in ICT out of 155 countries).Smart grids, e-logistics, real time navigation (RTN), electric motor, e-government, e-civil service, e-commerce, e- learning, e-healthcare, telepresence, home energy management system (HEMS), bus information system (BIS), smart work and digital contents. The report presents the expected total amount of GHG emissions abatement through 14 mentioned ICT services.

According to the report the total expected abatement in GHG emissions is approximately 118.4 million tCO2e that is 11 times more than the emissions abated (10.3 million tCO2) through ICT in 2011.

Likewise, the dematerialization effect of ICT implies a shift from delivering physical products to delivering online services, for instance, the more utilization of e-mail communication results in decline of physical delivery of messages and paper usage. Similarly, increasing usage of technological advancements like, video conferencing and internet telephony offered various opportunities for society and business to reduce commuting, thereby diminishing greenhouse gas emissions.

Moreover, recently vehicular network is being developed to offset the harmful effects of road traffic and accidents. This intelligent transport system will allow vehicles in different regions to communicate with each other. According to an estimate the amount of cars will reach to 1.5 billion by 2035. If these cars are connected with each other through vehicular network then ICT pressure will rise on the earth. Since the 2016 various mobile devices has outpaced the humans on earth this ratio of all devices is even high which is likely to rise in future as technology is progressing at very high rate. Consequently, along with e-waste the ICT industry is now becoming a power drainer and contributor of 2 percent of carbon emissions (CO2) globally as well. New advancements and increase in technology around the world is becoming more interconnected ultimately increasing the ICT power consumption and carbon emissions.

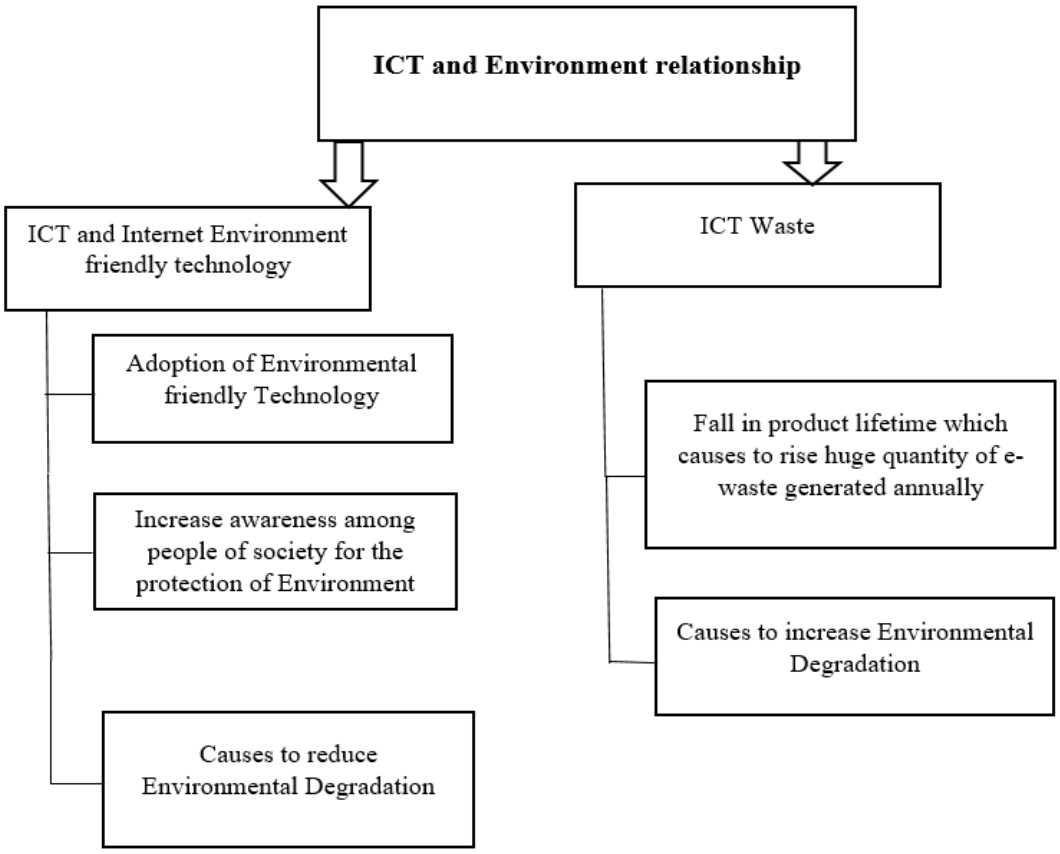

Figure 1: ICT can effect Environmental Degradation in two Ways

The role of ICT is important that is included in the ecological dimension of ICT. The previous research has revealed that climate change has large impacts on average temperature of earth these changes result in natural disaster around the world I n form of droughts and floods (Guha-Sapir, Vos, Below, & Ponserre, 2012). The existing literature on

ICT and environment is based on specific regions and limited measures of ICT and specific econometric technique. Present research contributes in literature on information and communication technology (ICT) and environmental degradation by utilizing six different important proxies of ICT. This study is not limited in number of countries rater it is giving global picture of ICT and environment relationship. The empirical analysis is based on Ordinary Least Square (OLS), Pooled OLS (POLS), Two Stage Least Square (2SLS) and Generalized Method of Moments (GMM) techniques. To tackle the problem of endogeniety, the instrumental variable (research and development) is also used. Empirical results of this research indicate that investment in ICT is essential for sustainable environment across the globe.

The remaining part of this paper consisted as follows: section 2 presents the review of literature on the connection between ICT and environment. Section 3 provides the methodology and analytical framework. Section 4 shows the description and detail of variables and data sources. Section 5 gives the empirical results and finally section 6 concludes the paper and gives the policy recommendations.

2. Literature Review

Environmental degradation is one of the prevalent threats faced across the world these days. The decline of environment is an outcome of many economic activities like industrialization, over consumption, forest land use for agriculture and others. As Garber (2011) states that the take-off period of industrialization expansion and development leads to over exploitation of natural resources which causes pollution that ultimately accelerates environmental deterioration process. Similarly, according to Agena (2007) environmental degradation is a result of uncontrolled activities of humans at different stages of economic growth for instance, energy and agriculture production and transportation.

The connection between environment and ICT is complex because ICT can affect the environment in both positive and negative ways. There are many environmental challenges that both developed and developing countries are facing now days. These environmental challenges are including water and air pollution, loss of biodiversity, natural habitat loss, and waste management climate change and so on. ICT and related research communities can help to handle and tackle these environmental challenges. Houghton (2010) declares "ICTs are all but ubiquitous and the potential uses and impacts of ICT on environment are numerous and varied". According to Plepys (2002), ICT has capacity to decouple economic growth from environmental deprivation. Study suggests that information and awareness will help those decision makers who want to achieve balance between the sustainability and quality of environment and economic development.

Yi and Thomas (2007) represent the general picture of impact of ICT on environment. Study emphasizes that there is need of satisfactory research to explore the important factors of ICT which affect the environment. It provides the broad review that has based on different projects, project reports, journals, papers, thesis, conferences, symposia and websites to analysis the effects of e-business/ICT on the environment. Study also discusses that there are many challenges associated to the measurement of sustainability of environment and ICT effects on it. It emphasizes on the importance of the choice of indicators to determine the complete picture regarding different features of environment affected by ICT and e-business. Houghton (2015) investigates the connection between ICT and environment in developing countries. Study describes the ICT and internet role to address the challenges of environment in developing countries. It probes the recent environment friendly technologies and discusses the role of ICT especially in mitigation of environmental pressure, mitigation of climate change, adaptation of climate change and international.co-operation. It argues that it is not easy to bring all aspects of ICT impacts in a single research paper because there is much variation in ICT use. Study concludes that there should be the proper collection and interpretation of data transformation which make people able to do better and make smooth choices.

As Erdmann and Hilty (2010) are noted: "The characteristics of ICT –exceptional dynamics of innovation and diffusion, social embedment and cross section application, diverse and complex impact patterns are a challenge for macroeconomic studies that quantify ICT impacts on greenhouse gas emissions." Lashkarizadeh and Salatin (2012) investigate the relationship between environment and ICT and explore the contribution of ICT in minimizing the CO2 emissions for the panel of 43 developed and developing countries for the time period of 2003 to 2008. Study concludes that ICT is very important factor to reduce pollution. It shows that rise in ICT expenditure leads to decrease CO2 at a high rate in developed countries. It also suggests that international development community have to become more informed about ICT role in managing environmental issues. ICT add in to environmental deprivation both in positive and negative ways.

E-waste is a generic term including disposal of electronic or electrical waste. This electrical waste contains computers, CPUs, mobile phones, LCD screens, RCT screens, and disposal of all other electronic devices. Widmer, Oswald-Krapf, Sinha-Khetriwal, Schnellmann, and Böni (2005) analyze e-waste and its management issues in three countries, Beijing China, Johannesburg-South Africa and Delhi-India. They argue that there is lack of reliable data, lack of recycling WEEE which are main hurdles in e-waste management and suggest that there is need of proper policy and legislation framework and skills for proper management for the management of e-waste.

Liu, Tanaka, and Matsui (2006) examine the impacts of electronic waste and issues of e-waste management in China. They describe that the recycling process of e-waste has greater impact on health of humans and also on environment and it is not easy to adopt extended producer responsibility (EPR) principle for the e-waste management because there are many hurdles present in the regulations drafting. They suggest that there is need of large scale facilities, removal of informal e-waste recycling, and more research and proper e-waste management in China. Osibanjo and Nnorom (2007) examine the ICT growth which leads to increases and improve computers capacity but with simultaneously fall in product lifetime and finally results a major amount of e-waste generated annually. The study basically explores this problem in developing countries that import and use second hand technology without any confirmatory test of its functions. They argue that there are many challenges associated with e-waste management in developing countries like lack in proper infrastructure and improper framework. It suggests that the proper e-waste management is necessary in developing countries.

Kahhat et al. (2008) examine the hurdles in the way of e-waste future planning and management in United State. They discuss new approaches and new system for the recycling, collection and e-waste management in U.S and also explore the new ways to plan e-waste management and its regulations for future. They describe recycling system and two fundamental factors "landfill disposal", and "exportation of e-waste in U.S. Study suggests that there is need to pay attention to the new and proper recycling of the e-waste. They argue that policies and regulations on federal level are much essential for the management of e-waste. Study describes that e-market and returned deposit system will lead to decrease in environmental impacts and also reduces the environmental burden associated with new manufacturing of equipment.

Schluep et al. (2008) discuss the e-waste impacts on environment and its economic and social impacts. Basically study provides a guide line to researchers in making assessment study on e-waste. Kalana (2010) focuses on the e-waste management practice by households and identification of management of e-waste practices in Shah-Alam Selangor Malaysia by using sample size of 300 households (consumers as well as generators of e-waste) as target population community members aged 18 to 50 years. Study concludes that e-waste management in its early stages in Malaysia and there are many challenges associated with its management. They suggest that responsible authority must work properly and efficiently to increase the awareness in public and proper management of e-waste for the environmental sustainability.

Emmanouil, Stiakakis, Vlachopoulou, and Manthou (2013) try to explore the electronic waste management and also discuss the waste of electronics in landfill which dangerous for the environment. Study emphasizes on the importance of information flows to take efficient designs and suggests that not only material flow of absolute IT products to be considered but also information utilize by policy makers for the proper settlement of e-waste. Hilty et al. (2006) examine the effects of ICT and consider first order, second order and third order effects of ICT. The first order effect implies rising electronic waste stream, second order includes upgraded efficiency of energy production and third order encompasses rebound effects or product to service shifts in economy. Study shows that ICT has an impact on environmental sustainability in different levels it also finds the effects of ICT on GHG emissions linked with consumption of energy. Literature shows that ICT can affect environment in both positive and negative ways. It affects positively by environmental friendly technology while, negatively through e-waste.

The findings of Bekaroo et al. (2016) and Gonel and Akinci (2018) also highlight the importance of ICT for ecosystem and environmental problems. Batool et al. (2019) also present the importance and encourage the role of ICT to mitigate environmental degradation for South Korean economy over the period 1973-2016. Salahuddin et al. (2016) assess the effects of internet usage on carbon emissions by utilizing a sample of OECD countries from 1991-2012. They found positive relationship between ICT and carbon emissions in long run while no link in the short-run. The scope of this study is limited as they use only "internet use" as proxy of information communication technology. Moreover sample size is limited.

Asongu, Le Roux, and Biekpe (2017) find that ICT complements CO2 emissions to effect inclusive human development by using 44 sub-Saharan African countries from 2002 to 2012. By employing Generalized Method of Moments (GMM) as an estimation technique they define that ICT can be utilized to mitigate CO2 emissions. Similarly Ozcan and Apergis (2018) explore that ICT reduces Carbon emissions. Lu (2018) also highlight ICT importance in reduction of CO2 emissions. Atsu, Adams, and Adjei (2021) examine the connection between ICT, carbon emissions and energy consumption for South Africa over the period 1970-2019. They utilized Autoregressive Distributed Lag (ARDL), fully modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) for estimations. They find that fossil fuel and ICT enhance carbon emissions while, financial development and renewable energy consumption reduce carbon emissions. They argue that there is no evidence for threshold ICT impacts on carbon dioxide emissions (CO2). On the other hand Chien et al. (2021) find that ICT mitigate carbon emissions (on lower quantiles) in BRICS countries. They also confirms the EKC hypothesis presence based on empirical findings.

Avom, Nkengfack, Fotio, and Totouom (2020) analyze direct and indirect effects of ICT on environmental degradation for sub-Saharan African (SSA) countries over the period 1996-2014. They find both direct and indirect effects of ICT are positive on carbon emissions. The negative indirect effects of ICT are only possible through trade openness. Overall their empirical findings show that the total effect of ICT worseness the environment quality (SSA).

According to Khan, Sana, and Arif (2020) ICT encourages environment sustainability in developed countries while inversely affect environment quality in developing countries by enhancing carbon emissions (CO2). They found these outcomes for 91 developed and developing countries over the period 1990-2017. Similarly Xinmin et al. (2020) argue that technological improvement and trade openness help to mitigate carbon emissions (CO2) in Chinese economy. They emphasize on efficient ICT equipment and green energy to tackle environment issues. Mehrjo, Satari Yuzbashkandi, Eskandari Nasab, and Gudarzipor (2022) also depict positive ICT role for mitigation of carbon emissions for Iran by utilizing Quantile regression (QR) and autoregressive distributed lag (ARDL) model as an econometric techniques. By using same estimation technique (ARDL) and panel pooled mean group N'dri, Islam, and Kakinaka (2021) explore the ICT impact for 58 developing countries from 1994 to 2014. They found positive effects of ICT to mitigate carbon emissions (CO2) for low income developing countries while no evidence found for high income developing countries. Shobande and Ogbeifun (2022) also emphasize the importance of ICT through different mechanism

including education, foreign direct investment, institution quality and transportation for panel of 24 OECD countries. The findings of Bekaroo et al. (2016) and Gonel and Akinci (2018) also highlight the importance of ICT for ecosystem and environmental problems.

All above is an overview related to completed and recorded research work which fits to a topic. It helps to identify some relevant methods and techniques for the research and to reveal the existing gaps in the literature. It paves the ways for the better understanding to explore the need of some additional research on existing work in a proper way. In the light of all above discussed literature, it can be concluded that ICT contributes in environment as literature illustrates both positive and negative impacts of ICT on environment.

In earlier economic theory it is believed that increased economic growth causes more environmental degradation Galeotti, Manera, and Lanza (2009); Meadows, Meadows, Randers, and Behrens III (1972); Selden and Song (1994). However later the EKC hypothesis have made this argument weak by claiming that the economic growth is both reason and cure to environmental degradation. There is also growing stuff of literature shows mix results concerning economic progress and environmental degradation linkage. It also shows that it is difficult to draw conclusions concerning the correlation between environmental degradation and economic growth. Some discover that economic growth positively affects environment while others depict negative and varied association between economic growth and environmental deprivation.

Nevertheless, this study aims to conduct research by using theoretical framework of previous literature by empirically scrutinizing the impact of ICT on environmental degradation by utilizing several important and innovative indicators of ICT and large number of countries. In order to attain more ICT benefits and other technical advancements benefits well there is a need to present new broad regulatory policies which would help us to work together for better cleaner environment and fast growing economy. It will pave the way to construct better policies for the future regarding better environment, ICT use. All of these factors are most important for the progress of any economy.

This research work is about impact of ICT on environmental degradation. There are some gaps exist in literature. For instance, various studies have been incorporated for limited time span and small number of countries for example Yandle, Bhattarai, and Vijayaraghavan (2004) explore the connection between real GDP and Sulphur dioxide emissions in only 12 MENA countries. Hilty et al. (2006); Houghton (2010); Lin and Liscow (2013) and Holian (2014) adopt the theoretical approach of measuring ICT role in environment. Lashkarizadeh and Salatin (2012) focus and primary utilize panel estimation technique to examine ICT impacts on air pollution. These are some of the gaps found in literature which need to be addressed.

Various literature is considered above shows that there is no proper empirical work available on the measurement of ICT impacts on different environmental aspects. For example according to Lopez (2017) and Hettige, Mani, and Wheeler (2000) there is further need of innovative methods and some latest techniques to capture the ICT impacts on environment. As concluded by Erdmann and Hilty (2010) the coming studies on macroeconomics in which modeling of environmental impact of ICT included will get more strength.

Present study is going to contribute in literature in different forms. Firstly, this study empirically explores the ecological aspects of ICT by using novel indicators rather than restricting the analysis to a single variable. Secondly, present research does not rely on a short time span along this it also gives a global picture of analysis by utilizing large number of countries. Thirdly, this paper utilizes different econometric techniques to provide better empirical estimations. Finally, this research conducts robustness analysis to evaluate soundness of data, variables and empirical findings.

3. Methodology

Present study specifies a model by considering the traditions of the literature for example Grossman and Helpman (1993); Selden and Song (1994) and Emmanouil et al. (2013) with accumulation of appropriate variables in accordance with our analytical concern. Initially we model the EKC following Grossman and Helpman (1990).

$$Log\ C_{it} = \beta_{o+} \beta_1\ Log\ GDP_{it} + \beta_2\ Log\ GDP^2{}_{it} + \epsilon_{it} \quad (1)$$

The contribution of ICT in environmental degradation also becomes an important subject recently. There exists complex relationship among ICT and environment. The usage and disposal of ICT products increases the environmental degradation. E-waste and larger energy use in manufacturing of ICT products deteriorates environmental quality (Houghton, 2015; Schluep et al., 2008). ICT can also mitigate the environmental degradation like air pollution, water pollution through environmental friendly technology and through promoting awareness among people. ICT has capacity to decouple economic growth from environmental deprivation (Plepys, 2002). Houghton (2010) stated "ICTs are all but ubiquitous and the potential uses and impacts of ICT on environment are numerous and varied".

To scrutinize the impact of ICT on environmental degradation, this study uses a model by following Lashkarizadeh and Salatin (2012) study as described below.

$$Log\ C_{it} = \beta_{o+} \beta_1\ Log\ GDP_{it} + \beta_2\ Log\ GDP^2{}_{it} + \beta_3\ ICT_{it} + \beta_4\ log\ X_{it} + \epsilon_{it} \quad (2)$$

Where, C_{it} represents CO2 emissions (metric tons), GDP_{it} is GDP per capita (constant 2005 US$), $GDP2_{it}$ shows square of GDP per capita , ICT_{it} denotes six measures of ICT including fixed broadband subscriptions, fixed telephone subscriptions, telecommunication infrastructure index, online service index, e-government index and ICT PCA.

Where, X_{it} demonstrates matrix of control variables such as fossil fuel, energy use and urbanization (urban population). The expected coefficient signs of these control variables are positive because fossil fuel, energy use and urbanization, energy use increases CO_2 emissions. Finally ϵ it stands for error term.

There exists complex relationship between ICT and environment but there are more chances of ICT friendly technology dominant role in the mitigation of environmental degradation. This study basically focuses on the contribution of ICT and its benefits to protect the environment so according to the second hypothesis (H_2) of present study the expected sign of β_3 is negative and significant for environmental degradation.

3.1 Data Sources

The data starts from year 1984. Environmental degradation (CO2) data is collected through World Bank Indicators (2016). Likewise, data on independent focused and control variables are collected from ITU, WDI, and UNPAN (2016).

4. Results and Discussion

The cross sectional and panel data estimation techniques are utilized to discover the impact of ICT on environmental degradation.

4.1 Cross sectional Results

The OLS is the most common and useful technique to obtain the basic insights about the relationship between concerned variables.

Table 1 gives the OLS results of environmental degradation and ICT proxies for 149 cross sections averaged over 1984-2019. According to the OLS findings a negative and highly significant relationship is present between CO2 emissions and ICT. In Column 2 the co-efficient of fixed telephone subscriptions indicates that 1 percent increase in fixed telephone subscriptions (Fix-Tele-Subs) leads to decrease CO2 emissions by -0.0129 units the reason behind this is can be that the fixed telephone subscriptions are helpful to mitigate environmental degradation through increasing the awareness among people. These findings are consistent with the Lashkarizadeh and Salatin (2012).

Column 3 confirms the highly significant and negative relationship between fixed broadband subscriptions (Fix-Broad-Subs) and CO2 emissions. A one unit increase in fixed broadband subscriptions CO2 emissions reduces by -0.0202 units. The fixed broadband subscriptions are beneficial for environment by offering virtual alternatives which are very helpful to reduce the need of travel and transportation that ultimately cut CO2 emissions.

Column 4 illustrates the negative and highly significant connection in telecommunication and Infrastructure Index (Tele-Infra-Index) and CO2 emissions. A one unit increase in telecommunication infrastructure index causes to decrease CO2 emissions by -0.814 units because the reduction in communication gap is very helpful to reduce environmental pressure. As development in telecommunication infrastructure is very beneficial to reduce greenhouse gases and CO2 emissions because it substantially reduces the movement of vehicles. The direct contribution of telecommunications is through the rise in access to information which helps to develop new marketing and operating methods for agricultural goods. These advancements in new methods help to increase health and education system and also create employment opportunities in rural areas that help to stop the tide of migration toward cities. The reduction in migration from rural to urban sectors helps to reduce the pollution.

Column 5 demonstrates the negative and insignificant connection between online service index (Online-Ser-Index) and CO2 emissions. Column 6 presents the negative and highly significant relationship between e-government index (E-Gov-Index) and CO2 emissions with one unit increase in e-government index CO2 emissions decreases by -0.641units. These findings are consistent with the previous literature. Column 6 illustrates the positive and insignificant relationship between ICT PCA (ICT PCA) and CO2 emissions.

The results of control variables including GDP, GDP2, fossil fuel, urbanization, and energy use are also almost consistent with previous studies. GDP has positive and significant while GDP2 has negative and positive impacts on environmental degradation (CO2) in almost all 6 equations which confirms the validity of EKC along with ICT. A range of literature supports these findings by confirming the bell-shaped relationship between income and environment degradation (Brajer, Mead, & Xiao, 2008; Giles & Mosk, 2003; Grossman & Helpman, 1993; Panayotou, 1993; Selden & Song, 1994).

Fossil fuel has positive and highly significant impacts on CO2 emissions a one percent increase in fossil fuel increases CO2 emissions by 1.046, 1.023, 1.046, 1.056, 1.059, and 1.030. According to Sharma (2011) a rise in burning of fossil fuels being consumed in transportation and other things, leads to increase in CO2 emissions which in turn causes environmental degradation at greater rate.

Urbanization has inverse but insignificant impacts on CO2 emissions. Energy use is positively and significantly affects CO2 emissions as a one percent increase in energy use increases CO2 emissions by 0.914, 0.900, 0.922, 0.893, 0.916, and 0.856. Many scholars argue that other than GDP, there are some other factors which affect CO2 emissions such as energy use (Ang, 2007; Apergis & Payne, 2009; Dogan & Turkekul, 2016; Jalil & Mahmud, 2009). The R-square (R2) values of all six regressions are 0.963, 0.962, 0.961, 0.959, 0.960 and 0.960 respectively that shows almost more than 90% variation in model showed by the independent variables.

Table 1
OLS Results of CO_2 Emissions and ICT

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	**LCO2**	**LCO2**	**LCO2**	**LCO2**	**LCO2**	**LCO2**
GDP	1.185***	1.308***	1.240***	1.392***	1.447***	1.280***
	(0.250)	(0.250)	(0.260)	(0.261)	(0.260)	(0.267)
GDP^2	-0.0227	-0.0322**	-0.0269*	-0.0412***	-0.0419***	-0.0383**
	(0.0150)	(0.0147)	(0.0158)	(0.0150)	(0.0149)	(0.0151)
Fossil Fuel	1.046***	1.023***	1.046***	1.056***	1.059***	1.030***
	(0.0584)	(0.0597)	(0.0634)	(0.0646)	(0.0639)	(0.0616)
Urbanization	0.0105	0.00813	0.00994	0.0138	0.0153	0.00587
	(0.0171)	(0.0174)	(0.0181)	(0.0211)	(0.0192)	(0.0181)
Energy Use	0.914***	0.900***	0.922***	0.893***	0.916***	0.856***
	(0.0562)	(0.0570)	(0.0603)	(0.0603)	(0.0610)	(0.0581)
Fix-Tele-Subs	-0.0129***					
	(0.00324)					
Fix-Broad-Subs		-0.0202***				
		(0.00628)				
Tele-Infra-Index			-0.814**			
			(0.317)			
Online-Ser-Index				-0.274		
				(0.231)		
E-Gov-Index					-0.641**	
					(0.313)	
ICT PCA						0.0742
						(0.0539)
Constant	-16.00***	-16.22***	-16.18***	-16.50***	-16.85***	-15.51***
	(1.060)	(1.082)	(1.105)	(1.160)	(1.162)	(1.181)
Observations	132	132	125	125	125	131
R-squared	0.963	0.962	0.961	0.959	0.960	0.960

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.2 Two Stage Least Squares (2SLS) Analysis

Table 2 below, gives the 2SLS results for CO2 emissions and ICT indicators. The results of 2SLS are almost similar as OLS results illustrates in column 1 which contains estimated ICT measures along with control variables. According to these 2SLS findings there is negative and significant relationship present between CO2 emissions and ICT. In Column 2 the co-efficient of fixed telephone subscriptions shows that 1 percent increase in fixed telephone subscriptions (Fix-Tele-Subs) leads to decrease CO2 emissions by -0.0110 units. Fixed telephone subscriptions are beneficial to mitigate CO2 emissions through substantially eliminate the need of travel and also helpful to generate awareness among people. Column 3 confirms the highly significant and negative relationship between fixed broadband subscriptions (Fix-Broad-Subs) and CO2 emissions. A one unit increase in fixed broadband subscriptions CO2 emissions will decrease by -0.0202 units. ICT causes to reduce CO2 emissions (Lashkarizadeh & Salatin, 2012).

Column 4 proves the negative and highly significant linkage between telecommunication infrastructure index (Tele-Infra-Index) and CO2 emissions. A one unit increase in telecommunication infrastructure index decreases CO2 by -1.089 units. According to Houghton (2010) ICT and internet is very beneficial to address the challenges of environment through environmental friendly technologies. Column 5 shows the negative and insignificant connection between online service index (Online-Ser-Index) and CO2 emissions. Column 6 shows the negative and highly significant relationship between e-government index (E-Gov-Index) CO2 emissions with one unit rise in e-government index CO2 emissions decreases by -0.774 units. Government can monitor water consumption, production, manufacturing, energy use and other activities more efficiently by use of ICT that is very

beneficial to protect the environment of any economy. Column 7 shows the very significant and opposite relation between ICT PCA and CO2 emissions with one unit increase ICT PCA CO2 emissions decrease by -0.364 units. According to Plepys (2002), ICT has capacity to decouple economic growth from environmental deprivation. The results of control variables including GDP, GDP2, fossil fuel, urbanization, and energy use are also almost consistent with previous studies. GDP has positive and significant while GDP2 has adverse and significant impacts on environmental degradation (CO2) in almost all 6 equations which confirm the validity of EKC. These results are consistent with Giles and Mosk (2003).

Table 2
2SLS Results of 2nd CO_2 Emissions and ICT

VARIABLES	(1) LCO2	(2) LCO2	(3) LCO2	(4) LCO2	(5) LCO2	(6) LCO2
GDP	1.215***	1.514***	1.150***	1.361***	1.423***	1.714***
	(0.246)	(0.311)	(0.254)	(0.255)	(0.253)	(0.332)
GDP^2	-0.0256*	-0.0581***	-0.0192	-0.0390***	-0.0396***	-0.0512***
	(0.0151)	(0.0207)	(0.0156)	(0.0146)	(0.0144)	(0.0178)
Fossil Fuel	1.045***	1.063***	1.047***	1.059***	1.064***	1.067***
	(0.0569)	(0.0732)	(0.0613)	(0.0626)	(0.0618)	(0.0718)
Urbanization	0.00893	-0.0126	0.0182	0.0208	0.0227	-0.00543
	(0.0168)	(0.0225)	(0.0178)	(0.0225)	(0.0193)	(0.0212)
Energy Use	0.907***	0.817***	0.932***	0.893***	0.921***	0.893***
	(0.0555)	(0.0765)	(0.0585)	(0.0585)	(0.0593)	(0.0681)
Fix-Tele-Subs	-0.0110***					
	(0.00397)					
Fix-Broad-Subs		0.0294				
		(0.0224)				
Tele-Infra-Index			-1.089***			
			(0.332)			
Online-Ser-Index				-0.336		
				(0.289)		
E-Gov-Index					-0.774**	
					(0.345)	
ICT PCA						-0.364***
						(0.138)
Constant	-16.01***	-15.88***	-16.08***	-16.50***	-16.91***	-18.26***
	(1.033)	(1.297)	(1.068)	(1.142)	(1.135)	(1.570)
Observations	132	132	124	124	124	129
R-squared	0.963	0.943	0.962	0.960	0.961	0.944
Sargan (score) chi2	p = 0.2501	p = 0.2632	p = 0.2479	p = 0.2101	p = 0.2470	p = 0.1570
Basmann chi2 (2)	p = 0.3054	p = 0.3199	p = 0.3044	p = 0.2616	p = 0.3034	p = 0.1980

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Fossil fuel has positive and highly significant impacts on CO2 emissions as a one percent increase in fossil fuel CO2 emissions increases by 1.0451.063, 1.047, 1.059, 1.064, and 1.067 respectively. According to Marland and Rotty (1984) burning of fossil fuels leads to rise CO2 emissions which in turn causes environmental deprivation. Urbanization has negative and also positive but insignificant relationship with CO2 emissions. Energy use has positive and highly significant impacts on CO2 emissions a one percent increase in energy use increases CO2 emissions by 0.907, 0.817, 0.932, 0.893, 0.921, and 0.893. According to Dogan and Turkekul (2016) energy use causes to increase CO2 emissions. Test of over identified restrictions is also utilized to check the validity of instruments. P-values of Sargan test and Basmann accept null hypothesis showing that instruments are valid. R2 values of all

regressions are 0.963, 0.943, 0.962, 0.960, 0.961 and 0.944 respectively that shows almost more than 90 percent variation in model described by the independent variables.

4.3 Pooled OLS Regression Results

In Table 3 below, column 1 contains ICT measures along with control variables. According to the Pooled OLS findings there exists a negative and highly significant relationship between CO2 emissions and ICT. In Column 2, the co-efficient of fixed telephone subscriptions explains that 1 percent increase in fixed telephone subscriptions (Fix-Tele-Subs) leads to decrease CO2 emissions by -0.00714 units these findings are consistent with the Lashkarizadeh and Salatin (2012).

Column 3 also shows negative and very significant association in fixed broadband subscriptions (Fix-Broad-Subs) and CO2 emissions it can be possible through the ICT friendly technologies which are very helpful in the prevention of CO2 emissions. As column 3 gives a one unit increase in fixed broadband subscriptions CO2 emissions will decrease by -0.00225 units. Column 4 shows the negative and highly significant relationship among telecommunication Infrastructure Index (Tele-Infra-Index) and CO2 emissions.

Table 3
Pooled OLS Results of CO_2 Emissions and ICT

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	**LCO_2**	**LCO_2**	**LCO_2**	**LCO_2**	**LCO_2**	**LCO_2**
GDP	1.361***	1.556***	1.376***	1.518***	1.522***	1.599***
	(0.0533)	(0.0775)	(0.109)	(0.103)	(0.104)	(0.0783)
GDP^2	-0.0375***	-0.0530***	-0.0395***	-0.0504***	-0.0504***	-0.0555***
	(0.00322)	(0.00447)	(0.00679)	(0.00592)	(0.00594)	(0.00455)
Fossil Fuel	1.036***	1.052***	1.083***	1.091***	1.090***	1.044***
	(0.0120)	(0.0196)	(0.0266)	(0.0265)	(0.0266)	(0.0200)
Urbanization	0.00832**	-0.00244	0.00951	0.0143*	0.00982	0.000924
	(0.00386)	(0.00521)	(0.00765)	(0.00827)	(0.00797)	(0.00535)
Energy Use	0.938***	0.960***	1.006***	0.999***	1.003***	0.966***
	(0.0125)	(0.0191)	(0.0271)	(0.0270)	(0.0273)	(0.0195)
Fix-Tele-Subs	-0.00714***					
	(0.000670)					
Fix-Broad-Subs		-0.00225**				
		(0.00113)				
Tele-Infra-Index			-0.462***			
			(0.138)			
Online-Ser-Index				-0.203***		
				(0.0740)		
E-Gov-Index					-0.232*	
					(0.119)	
ICT PCA						-0.00784
						(0.0150)
Constant	-16.51***	-17.15***	-17.05***	-17.55***	-17.50***	-17.39***
	(0.231)	(0.343)	(0.459)	(0.461)	(0.464)	(0.346)
Observations	2,694	1,269	598	598	598	1,225
R-squared	0.959	0.953	0.963	0.963	0.962	0.953

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

A one unit rise in telecommunication Infrastructure Index CO2 emissions will decrease by -0.462 units. Telecommunications promote video conferencing and voice communication instead of face to face interactions that substantially reduces use of vehicles and ultimately helps in the reduction of CO2 emissions. Column 5 shows the negative and highly significant connection between online service index (Online-Ser-Index) and CO2 emissions. A one

percent rise in online service index leads to decrease CO2 emissions by -0.203 units. Online services make customers able to buy variety of products at homes instead of visiting the stores and markets it reduce travelling of people as a result mitigate the CO2 emissions. Column 6 shows the negative and highly significant relationship among e-government index (E-Gov-Index) CO2 emissions with one unit increase in e-government index GDP increases by -0.232 units. The utilization of ICT in government sector make government able to monitor water consumption, production, manufacturing, energy use and other activities more properly that is very beneficial to protect the environment of any country.

Column 7 shows the negative but insignificant link between ICT PCA and CO2 emissions. The results of control variables including GDP, GDP2, fossil fuel, urbanization, and energy use are remain almost consistent with previous studies. GDP has positive and significant while GDP2 has negative and positive impacts on environmental degradation (CO2) in all 6 equations which confirm the validity of EKC (Brajer et al., 2008). Fossil fuel positive and highly significant impacts on CO2 emissions a one percent increase in fossil fuel increases CO2 emissions by 1.036, 1.052, 1.083, 1.091, 1.090, and 1.044.

Literature supports these findings such as Marland and Rotty (1984). Urbanization has significant and positive impact on CO2 emissions with coefficient 0.00832, and 0.0143 while negative but insignificant in other remaining equations. A large number of transport, cars, buses and other vehicles are much intensively utilized in the urban areas that cause pollution (Cole & Neumayer, 2004). Energy use has positive and highly significant impacts on CO2 emissions a 1% increase in energy use increases CO2 emissions by 0.938, 0.960, 1.006, 0.999, 1.003, and 0.966 respectively. Due to increase in human activities and energy usage, CO2 emissions increase (Ang, 2007). R2 values of all regressions 0.959, 0.953, 0.963, 0.963, 0.962, 0.961 and 0.953 respectively that confirms more than ninety percent variation in model explained by the independent variables.

4.4 Generalized Method of Moments (GMM)

There is chance of causality in ICT and environmental conditions because rise in ICT equipment's can increase or decrease environmental degradation. Additional degradation in form of dust, smoke can also cause to damage the electronic equipment's (Keene & Deller, 2015).

Secondly, in panel data there is issue of heterogeneity. Endogenity and heterogeneity issues need to be addressed because OLS estimates become and inefficient and biased. To tackle the above issues, present study incorporates the instrumental variable technique Generalized Method of Moments (GMM) on panel data. GMM method provides efficient and reasonable results even in the presence of endogenity and heterogeneity. An instrument is the exogenous variable that is highly correlated with endogenous variable and uncorrelated with error term. We apply test of over identifying restriction to check the validity of instruments. P-values of all Hansen's J test are insignificant that shows the instruments used are valid.

Table 4 illustrates the GMM results of ICT and CO2 emissions indicators for panel of 149 countries. Column 1 contains estimated coefficients of CO2 emissions and ICT measures along with control variables. According to the GMM findings there exists a negative and highly significant relationship between CO2 emissions and ICT. In Column 2 the co-efficient of fixed telephone subscriptions shows that 1 percent increase in fixed telephone subscriptions (Fix-Tele-Subs) leads to decrease CO2 emissions by -0.00713 units. Our findings are consistent with the Lashkarizadeh and Salatin (2012). Column 3 shows the negative and highly significant linkage between fixed broadband subscriptions (Fix-Broad-Subs) and CO2 emissions.

A one unit increase in fixed broadband subscriptions causes to decrease CO2 emissions by -0.00376 units. Fixed telephone subscriptions are beneficial for environment by offering

virtual alternatives which are very helpful to reduce the need of travel and transportation that ultimately cut CO2 emissions. Column 4 demonstrates the highly significant and negative relationship between telecommunication infrastructure index (Tele-Infra-Index) and CO2 emissions. A one unit increase in telecommunication infrastructure index leads to mitigate CO2 emissions by -0.877 units. The development in telecommunication infrastructure is very beneficial to reduce greenhouse gases and CO2 emissions because it substantially reduces the movement of vehicles.

Column 5 incorporates the negative and highly significant relationship among online service index (Online-Ser-Index) and CO2 emissions. A one unit increase in online service index causes to decrease CO2 emissions by -0.441 units. Online services create easiness for buyers to purchase variety of products at homes instead of visiting the stores and markets it reduce use of vehicles and ultimately helps to mitigate the CO2 emissions.

Column 6 provides the highly significant and opposite relationship between e-government index (E-Gov-Index) CO2 emissions with one unit increase in e-government index CO2 emissions decreases by -0.569 units. Adoption of ICT in public sector make government able to monitor water consumption, production, manufacturing, energy use and other activities more properly that is very advantageous to protect the environment.

Table 4
GMM Results of CO_2 Emissions and ICT

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	**LCO_2**	**LCO_2**	**LCO_2**	**LCO_2**	**LCO_2**	**LCO_2**
GDP	1.279***	1.448***	0.932***	1.278***	1.257***	1.195***
	(0.0755)	(0.133)	(0.268)	(0.197)	(0.195)	(0.170)
GDP^2	-0.0330***	-0.0467***	-0.0105	-0.0349***	-0.0330***	-0.0143
	(0.00462)	(0.00769)	(0.0176)	(0.0118)	(0.0118)	(0.0116)
Fossil Fuel	1.058***	1.086***	1.121***	1.129***	1.136***	0.989***
	(0.0187)	(0.0335)	(0.0489)	(0.0530)	(0.0536)	(0.0406)
Urbanization	0.0141***	0.00171	0.0225**	0.0365***	0.0264**	0.0171**
	(0.00358)	(0.00524)	(0.00940)	(0.0142)	(0.0106)	(0.00761)
Energy Use	0.941***	0.960***	0.994***	0.992***	1.002***	1.002***
	(0.0126)	(0.0180)	(0.0353)	(0.0338)	(0.0355)	(0.0250)
Fix-Tele-Subs	-0.00713***					
	(0.000818)					
Fix-Broad-Subs		-0.00376**				
		(0.00149)				
Tele-Infra-Index			-0.877***			
			(0.325)			
Online-Ser-Index				-0.441***		
				(0.162)		
E-Gov-Index					-0.569**	
					(0.236)	
ICT PCA						-0.559***
						(0.101)
Constant	-16.35***	-16.90***	-15.67***	-17.05***	-16.84***	-17.28***
	(0.275)	(0.485)	(0.889)	(0.668)	(0.697)	(0.562)
Observations	2,690	1,131	241	241	241	1,222
R-squared	0.959	0.951	0.966	0.966	0.965	0.900

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Column 6 illustrates the negative and highly significant relationship between ICT PCA CO2 emissions with one unit increase in ICT PCA as a result CO2 emissions decreases by -0.559 units. According to Plepys (2002), ICT has capacity to decouple economic growth from environmental deprivation. The results of control variables including GDP, GDP2, fossil fuel, urbanization, energy use are also almost consistent with previous studies. GDP has positive

and significant while GDP2 has negative and positive impacts on environmental degradation (CO2) in almost all 6 equations which confirms the validity of EKC. A number of literature supports these findings by confirming the U-shaped relationship of income with environment degradation (Brajer et al., 2008; Giles & Mosk, 2003; Grossman & Helpman, 1993; Panayotou, 1993; Selden & Song, 1994).

Fossil fuel positive and highly significant impacts on CO2 emissions, as a 1% increase in fossil fuel increases CO2 emissions by 1.058, 1.086, 1.121, 1.129, 1.136, and 0.989. According to Sharma (2011) a rise in burning of fossil fuels being consumed in transportation and other things, leads to increases the CO2 emissions which in turn causes environmental degradation at greater rate. While, urbanization has positive and significant influence on CO2 emissions with coefficients 0.0141, 0.0225, 0.0365, 0.0264 and 0.0171 because a large number of transport, cars, buses and other vehicles are much intensively utilized in the urban areas that create pollution (Cole & Neumayer, 2004). A large number of transport, cars, buses and other vehicles are much intensively utilized in the urban areas that generate pollution (Cole & Neumayer, 2004).

Energy use has highly significant and positive impacts on CO2 emissions as a one percent rise in energy use increases CO2 emissions by 0.941, 0.960, 0.994, 0.992, 1.002, and 1.002. Many scholars argue that other than GDP, there are some other factors which affect CO2 emissions such as energy use (Ang, 2007; Apergis & Payne, 2009; Dogan & Turkekul, 2016; Jalil & Mahmud, 2009). The R-square (R2) shows almost more than ninety percent variation in model explained by the independent variables.

5. Conclusion

Present age of technological advancements and industrial revolution has transferred the debate of economic growth towards environmental friendly growth. Advancements in technology and industrial developments foster the economic growth but it also raises Green-house Gases (GHGs) that creates pollution and ultimately degrading the environment.

The rise in GHGs emissions is expected to continue drastically which leads to increase global pollution rate day by day. The depletion of environment is a global issue that requires attention and different important measures to tackle it. To handle the environmental degradation, ICT can play an important role. ICT is very important and significant to handle the environmental degradation through "Green ICT" which refers as, the usage of smart technology and tools to make other processes more efficient. Green ICT is included smart grids, smart metering, e-logistics, real time navigation (RTN), electric vehicles, e-government, e-civil service, e-commerce, e- learning, smart agriculture and ICT for management of smart building.

This research has met its objectives of exploring ICT role in environmental degradation by employing both cross sectional and panel data sets for 149 countries from the time period 1984 to 2019. The estimations are based on OLS in cross section data in the first stage to empirically examine the impacts of ICT. The 2SLS model is also used to tackle the problem of endogenity. In second step of estimations this study employs panel data sets and OLS technique through pooling the data and finally it applies the Generalized Method of Moments (GMM) by using research and development expenditures (R&D) as an instrumental variable to improve the results. ICT boost the technological development through (R&D), new innovations and knowledge. Investment in R&D positively influence the ICT such as broadband penetration. R&D is used as instrument for ICT (Kahhat et al., 2008).

Almost all econometric findings confirm the positive ICT role in mitigation of CO2 emissions. Different important indicators of ICT such as a fixed telephone subscriptions, fixed broadband subscriptions, online service index, e-government index ICT PCA and telecommunication infrastructure index have significant and negative impact on environmental degradation. This study concludes that ICT is very helpful in reducing

environmental degradation (CO2 emissions).Through robustness and sensitivity analysis study finds that the existing variables are robust and not sensitive to the additional variables included in econometric analysis. The concept of EKC is also considered in this study by empirically examines the connection between economic growth and environmental degradation and gives some important findings of EKC along with ICT.

5.1 Contribution of Study

The ICT connection with environmental degradation is an emerging field of research. Considering previous gaps in literature present research contributes in different ways. Firstly, this study empirically explores the ecological aspects of ICT by using novel indicators rather than restricting the analysis to a single variable. Secondly, this paper utilizes different econometric techniques to provide better empirical estimations. Thirdly, this research conducts robustness analysis to evaluate soundness of data, variables and empirical findings. Finally, present research does not rely on a short time span along this it also gives a global picture of analysis by utilizing large number of countries.

5.2 Policy Implications

Economists and Environmentalists have established several theories regarding environment connection with different economic activities, these theories are Pollution hypothesis and Kuznets Curve. However, little attention has been given to environmental degradation and ICT relation. The previous literature offers Greening through ICT hypothesis to understand ICT impacts on ecosystem. Empirical and theoretical literature predicts both beneficial and harmful impacts of ICT on ecosystem. A comprehensive analysis of this study offers the ICT and environment theoretical and empirical relation on global level.

This research gives different policy recommendations. ICT adoption in a proper way in policy related decisions can improve the environmental quality across the world. In this regard expenditures on Research and Development (R&D) should be increases to enhance and boost the growth of ICT. Likewise, in public sector ICT infrastructure implantation can be improve for the better environmental quality government need to decouple economic growth from environmental degradation and make appropriate steps towards the management of e waste where it is needed. Government should spend considerable amount on ICT installation in public sector and also promote online services to properly monitor the different economic activities that are essential for sustainable development and environment protection. Moreover, online services must be improve to reduce physical travel of humans in different sectors to mitigate greenhouse gas emissions to promote healthy environment. Instead of depending on primitive techniques policy makers should introduce e-procurement, e-commerce in order to accelerate sustainable economic growth. In the light of empirical findings and all above discussion this research suggests that the ICT is an effective tool for policy makers that help to mitigate the environmental degradation and to promote the sustainable development.

Authors Contribution

Tayba Ayub: study design and concept, literature search, data collection, analysis, drafting, critical revision, incorporation of intellectual content.

Conflict of Interests/Disclosures

The authors declared no potential conflicts of interest w.r.t the research, authorship and/or publication of this article.

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