Pakistan Journal of Commerce and Social Sciences
2018, Vol. 12 (3), 758-783
Pak J Commer Soc Sci

Information and Communication Technology (ICT) and Environmental Sustainability in Developed and Developing Countries

Muhammad Tariq Majeed
School of Economics, Quaid-i-Azam University, Islamabad, Pakistan
Email: tariq@qau.edu.pk

Abstract

This study conducts a comparative empirical analysis of 132 developed and developing economies to explore the links of ICT with environment over the period 1980-2016. The empirical analysis is based on Pooled Ordinary Least Squares (POLS) and Generalized Method of Moments (GMM) estimation techniques. Theoretically environmental effects of ICT are ambiguous. To settle it empirically, this study points out the heterogeneous consequences of ICT for environment in developed and developing countries. Findings of the study suggest that ICT has the power to determine ecological future of the world. However, its favorable outcomes are observed only in developed countries while adverse impacts prevail in developing countries. The empirical results confirm 'Greening through ICT' hypothesis for developed countries implying that ICT is an effective tool to mitigate environmental degradation. Moreover, 'Environmental Kuznets' hypothesis is also confirmed which implies that the relationship between CO_2 emissions and GDP per capita is non-monotonic. The empirical analysis is based on novel measures of ICT such as online service, telecommunication infrastructure and electronic government unlike previous literature that generally emphasized only internet as a measure of ICT. Moreover, to the best of our knowledge, this is the first study of its kind that identifies heterogeneous outcomes of ICT between developed and developing countries. Findings of the study imply that investment in ICT infrastructure is essential for environmental sustainability only in the case of developed countries.

Keywords: ICT index, E-waste, environmental degradation, CO_2 emissions, green economy, environmental technology, E-government, greenhouse gas emissions, fossil fuels.

1. Introduction

The emerging environmental issues have created many controversies and public debates. Now environmental degradation has become a global challenge. The literature shows that if the trends of present emissions remained continue, an estimated trillion tons of carbon dioxide will be added by the year 2050 which could have adverse consequences for human life (Lashkarizadeh and Salatin, 2012).

The role and importance of ICT for different economic outcomes have been studied in recent years. The research has largely documented favorable economic outcomes of increasing use of information communication technology (ICT) (Niebel, 2018; Majeed and Ayub, 2018). However, the ecological dimensions of ICT have received least attention in the literature. In effect, ICT has influenced human life in many perspectives including ecological aspects of life.

The links of ICT with environment are rather complex. On the one hand, ICT growth deteriorates environment through increasing production, use and disposal of ICT products. For instance, increasing e-waste and larger use of energy in manufacturing cause adverse effects on the quality of environment (OECD, 2010; Houghton, 2015). Life cycle theory of ICT suggests that several stages of the life of ICT result in pollution. The life cycle of ICT related products spans over ‘production, delivery, transport, use and disposal’ (Yi and Thomas, 2007; Zhang and Liu, 2015).

On the other hand, ICT is considered a solution to reinforce environmental protection, to mitigate the adverse impacts created in the environment by human activities, and to address key environmental challenges such as climate change and sustainability. ICT can also help to mitigate the environmental degradation through increasing awareness of environmental issues and utilization of environmental friendly technology (Plepys, 2002; Lashkarizadeh and Salatin, 2012). ICT applications help to predict and manage environmental related risks. For example, computerized simulation tools can make learning of the “learning by simulation” to facilitate decisions making procedures and to prevent the serious consequences of trial and error. Another aspect of ICT is “internet network” that positively influence the knowledge of environment.

The links of ICT with environment also depend upon the rebound effects of ICT. Theory of rebound effects implies that the positive effects of technology can be offset in the long run. If, for instance, ICT developments lead to cheaper production, the demand for product will increase, thereby increasing more pollution. These rebound effects create unclear effects of ICT for environmental sustainability. Figure 1 indicates that the rebound effects of ICT can be categorized into three levels that are direct, indirect and systematic effects.

ICT based solutions are considered favorable for environment sustainability as they help to reduce greenhouse gas emissions (Webb, 2008; Uddin, 2012). The dematerialization effect of ICT implies ‘a shift from delivering physical products to delivering services’. For example, the increasing use of e-mail communication caused reduction in the use of paper and physical delivery of messages. Likewise, increasing use of advanced technologies such as internet telephony and video conferencing have provided numerous opportunities for businesses and the society to decrease commuting, thereby lessening greenhouse gas emissions.

Moreover, increasing use of e-commerce and e-banking is facilitating online transactions which in turn reduce physical travel, thereby reducing greenhouse gas emissions. Other than decreasing dependency on physical travelling, ICT is also helping in providing intelligent and automated solution in various sectors such as power generation, agriculture and manufacturing. As such ICT is considered as a low carbon enabler and a key determinant of environment sustainability which can facilitate reduction in carbon emissions in various sectors such as power, transportation and buildings. The smart 2020 report pointed out that ICT can cut greenhouse gas emissions by 2020 (Webb, 2008).

Since the 2014 number of mobile devices has outpaced the number of humans on earth. Moreover, the ratio of all devices to humans is even high. This ratio is likely to increase in future as technology is progressing at very fast rate. Furthermore, recently, vehicular network is being developed to offset the side effects of road traffic and accidents. This intelligent transport system will allow vehicles to communicate each other in different regions. According to an estimate the number of car will reach to 1.5 billion by 2035. If these cars are connected with vehicular network then ICT pressure will increase on the earth.

Consequently, as the technology is increasing and world is becoming more interconnected, the power consumed by ICT and carbon emitted by ICT is also increasing. The ICT industry is becoming power drainer and contributes 2% of global carbon emissions. This value represents a total carbon footprint 830MtCO_2e as of year 2007. This amount of carbon footprint is equivalent to the carbon footprint emitted by air industry. As a consequence of increasing technological developments, the carbon footprint of ICT is expected to grow by 75% which is equal to 1430MtCO_2e. The increasing carbon foot print of ICT has become a growing concern for societies because carbon emissions influence climate which affects natural environment and society.

The research has shown that climate changes affect average temperatures in the different regions across the globe. Such changes cause natural disaster across the globe. For instance, the study of Guha-Sapir et al. (2012) exposed that floods and droughts have increased in terms of magnitudes and impacts. They exhibited that economic damages from natural disasters were highest in 2011 amounted to approximately that is $b 614.1. This amount also showed a rise of 235% as compared to year averaged damage from 2001 to 2010. Furthermore, the number of victims of natural disaster increased from 14 million to 22 million in 2011. These natural disasters, in addition to climate change harmfully affect the society in terms of lifestyle, health and eating habits.

The extant literature on ecological dimensions of ICT (shown in Figure 1) is based on qualitative analysis. Some of the studies focus on country specific evidence. The evidence on developing economies is largely neglected. In particular a comparative analysis of developed and developing economies is missing in the current stream of literature. This study argues that the diverse effects of ICT infrastructure and its implications for environmental sustainability need to be focused differently for developed and developing economies.

This study contributes into the emerging literature on ICT and environment by analyzing the impact of ICT on environment using different measures of the ICT for a large number of developed and developing countries. The empirical analysis is conducted using POLS and GMM estimation techniques. To address the potential problem of endogeneity, the instrumental techniques of estimation are used. Findings of the study imply that investment in ICT infrastructure is essential for environmental sustainability in the case of developed economies to take the advantage of 'Greening through ICT'. In contrast, developing economies need protection from the adverse environmental consequences of ICT.

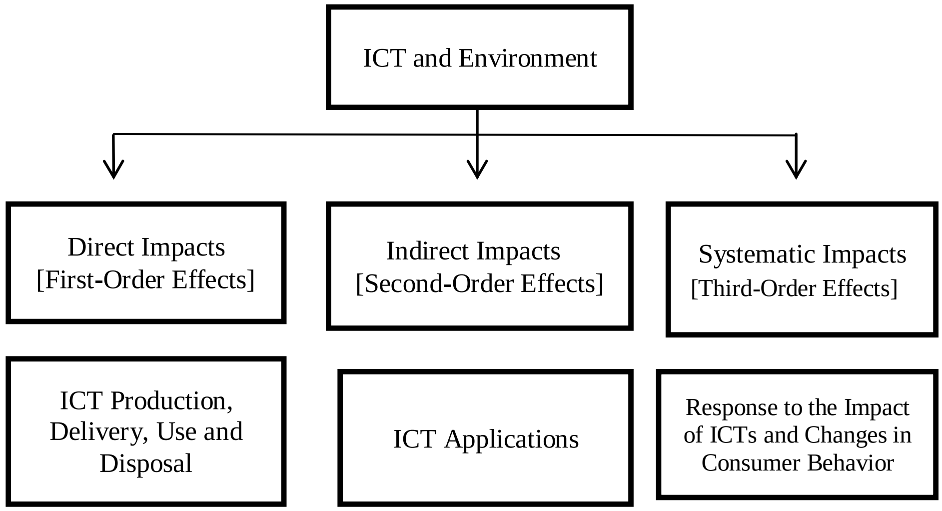

Figure 1: Ecological Dimensions of ICT

The remaining paper is structured as follows: Section 2 provides review of the literature on the links of ICT with environment. Section 3 illustrates the analytical frame work. Section 4 gives the description of data sources and variables used. Section 5 presents the empirical results. Finally Section 6 concludes the paper and offers policy implications.

2. Literature Review

Environmental degradation has become a global challenge as economic activities all over the world are contributing to this problem. Economic activities such as industrialization and development cause over exploitation of natural resources that create more pollution and accelerate the process of environmental degradation (Garber, 2011). Environmental degradation is an outcome of uncontrolled human activities at different phases of economic development and growth such as transportation, agriculture and energy production (Agena, 2007; Siddique and Majeed, 2015; Majeed and Mumtaz).

Another parallel development in recent decades is caused by expansion of ICT infrastructure to a varying degree across the globe. ICT infrastructure is taking central position in all economic activities such as production and consumption of goods and services. It is well thought that ICT plays a central role in boosting economic growth and development.

The potential benefits of ICT are well realized around the world (Niebel, 2018; Majeed and Khan, 2018). Little attention, however, has been paid to an equally important issue that how does ICT developments determine climate change. Moreover, the extant literature on ICT and climate change predicts diverse outcomes of ICT expansion. In effect the links of ICT and environment are complex and conflicting. Therefore it is important to examine the potential links and to provide empirical evidence to have a better understanding of this emerging issue. The world is facing various environmental challenges such as e-waste management, natural habitat loss, loss of biodiversity, water and air pollution.

The literature on ICT and CO_2 emissions can be classified into three strands. First strand of the literature views ICT development as favorable for sustainability. In contrast, the second strands views ICT development as unfavorable for environmental sustainability. The third strand of the literature considers that the links of ICT with environment remain unclear because of the ‘rebound effects’. Plepys (2002) argues that ICT has the capacity to decouple economic growth from environmental degradation. It can provide information and awareness to attain balance between environment sustainability and economic development.

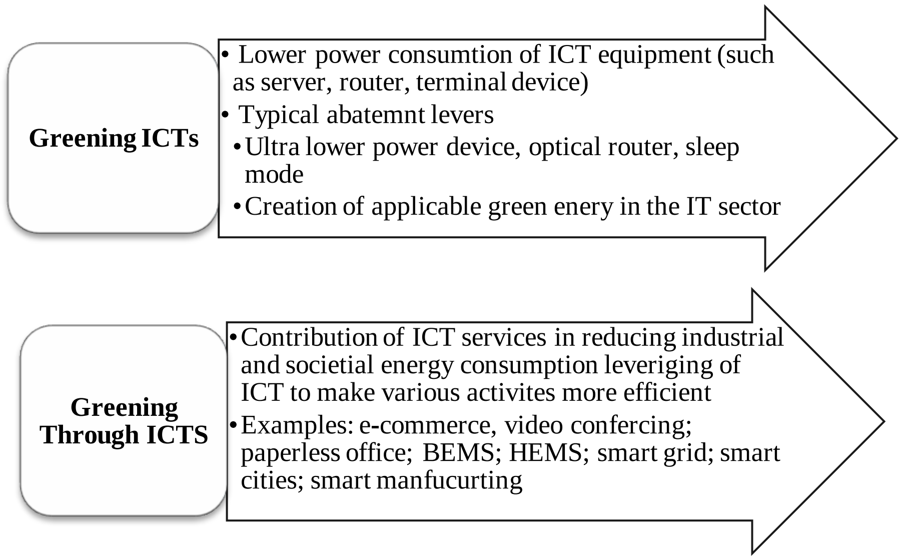

Figure 2: Greening ICTs & Greening through ICTs

The potential uses of ICT to enhance environmental sustainability can be classified into types of applications that are ‘Greening of ICTs’ and ‘Greening through ICTs’. ‘Greening of ICT’ means the reduction of carbon intensity of the ICT sector itself, while ‘Greening through ICT’ implies that achieving the de-carbonization in other sector through implementation of ICT services. Since ICT sector contributes 2% of global emissions, ‘Greening through ICTs’ may have larger impact on environment sustainability as compared to its own footprint. According to Webb (2008), greening trough ICT services could be seven times the negative impact of ICTs to greenhouse gas emissions.

The studies of Yi and Thomas (2007), Houghton (2015), Bekaroo et al. (2016) and Gonel and Akinci (2018) emphasize the importance of ICT for ecosystem and environmental issues. However, these studies do not provide empirical analysis. Lashkarizadeh and Salatin (2012) provide empirical evidence on the links of ICT with environmental degradation using the data of 43 developed and developing countries from 2003 to 2008. Findings of their study suggest that ICT expenditures lead to decrease in CO_2 emissions. Since the analysis is based on a short time period and a small sample, it cannot be generalized globally. Zhang and Liu (2015) find the negative effect of ICT industry on CO_2 emissions in the case of China over the period 2000-2010. However, they merely focus on gross production of electronic and information and manufacturing industry ignoring other dimensions of ICT.

Ozcan and Apergis (2018) show that information and communication technology reduces air pollution using a panel of 20 emerging economies over the period 1990-2015. Similarly, using a panel 12 Asian economies from 1993 to 2013, Lu (2018) shows that information communication technology reduces carbon emissions. The scope of these studies is limited as they use only 'internet use' as proxy of information communication technology. Moreover sample size of these studies is limited.

The second strand of the literature views ICT development negatively for environment sustainability. The basic argument is that production of ICT related products contribute to climate degradation. The ICT industry is becoming power drainer and contributes 2 % of global carbon emissions. Moreover, management of e-waste is also considered as a negative source of climate degradation.

E-waste, another dimension of ICT infrastructure, includes disposal of many ICT related goods such as computers, cell phones, LCD screens, and RCT screens. Widmer et al. (2005) argue that e-waste is an emerging global challenge and also a business opportunity because it contains both toxic and valuable material in them. They further argue that e-waste is poorly managed which causes burden on environment.

Liu et al. (2006) analyze the consequences of e-waste in China. They argue that recycling process of e-waste causes adverse effects on environment and human health. Moreover, they point out that illegal shipment of e-waste from other countries into the China aggravates the problems related to e-waste. They argue that e-waste recycling is not formally managed. In particular they find evidence that 60% of the e-wastes were sold to private collectors which was passed into informal recycling processes. In addition, they show that more than 90% Chines are not willing to pay for the recycling of their e-waste.

Osibanjo and Nnorom (2007) argue that ICT growth has caused improvement in the capacity of computers but at the cost of their life time. Consequently a major quantity of e-waste is generated annually. They point out that ICT development in third world countries largely depend on the imports of second hand or refurbished electrical and electronic equipments (EEEs) without the confirmatory testing for functionality. As a result a large quantity of e-waste is presently managed in developing countries. They also highlighted the challenges which developing countries face while managing e-waste. These challenges include lack of appropriate infrastructures for e-waste, inadequate legislation policy for e-waste, and an absence of any frameworks for implementation of extended producer responsibility (EPR). Emmanouil et al. (2013) also emphasize the better management of e-waste to reduce environmental burden.

Salahuddin et al. (2016) estimate the effects of internet usage on carbon emissions using a sample of OECD countries over the period 1991-2012. They found no relationship between internet usage and carbon emissions in the short-run and positive relationship in the long 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.

The third strand of the literature considers the relationship of ICT development with environment as uncertain because of the rebound effects. Theory of rebound effects suggests that the positive effects of ICT in the short run can be off set in the long run. If, for instance, ICT developments lead to cheaper production, the demand for product will increase, thereby increasing more pollution. These rebound effects of ICT create unclear effects on sustainability.

Hilty et al. (2006) classified rebound effects of ICT on environment into three levels. The first order effect suggests increasing e-waste, second order effect implies improved efficiency of energy and third order effect implies shifts from product to service in economy. Moreover, they argue that ICT development causes both positive and negative effects on environment. The positive effects come through environmental friendly technology while negative effects come through e-waste.

The literature discussed on ICT and environment exhibits following research gaps. First, the studies on ICT and environmental changes are qualitative and descriptive in their nature (Yi and Thomas, 2007; Houghton, 2015; Bekaroo et al., 2016; Gonel and Akinci, 2018). Second empirical analysis is generally conducted for a single country (Zhang and Liu, 2015). Third, the literature generally focuses on developed economies (Salahuddin et al., 2016). Fourth, some empirical studies question the favorable effects of ICT to carbon emissions (Widmer et al., 2005; Liu et al., 2006). Fifth, some studies provide regional specific evidence on ICT and environment nexus which cannot be generalized globally (Ozcan and Apergis, 2018; Lu, 2018). Sixth, the available empirical studies measure information communication technology with a single dimension such as internet usage which cannot be generalized for other dimensions (Salahuddin et al., 2016; Ozcan and Apergis, 2018; Lu, 2018). Seventh, empirical studies ignore the issue of endogeneity.

We conclude from the above discussion that ICT infrastructure plays an important role in determining environmental degradation. However, the direction of relationship is not a clear priori. Therefore, it is important to resolve this issue empirically. Some scholars emphasize the role of ICT in determining environmental degradation but do not provide empirical analysis. For instance, Li and Thomas (2007) and Houghton (2015) assert that new methods and approaches are required to understand the impacts of ICT on environment.

Theoretically environmental effects of ICT are ambiguous. To settle it empirically, this study points out the heterogeneous consequences of ICT for environment in developed and developing countries. Using a large panel data set of 48 developed and 84 developing economies, this study empirically examines the links of ICT with environment. The empirical analysis is based on novel measures of ICT such as online service and electronic government. Moreover, to the best of our knowledge, this is the first study of its kind that conducts a comparative empirical analysis of ICT-environment nexus at global level during the time period of 1980 to 2016. This research also tacks care of the endogeneity problem.

3. Methodology

The empirical model for this study is based on the studies of Grossman and Krueger (1991) and Seldon and Song (1994). Following Grossman and Krueger (1991), we model the environmental Kuznets Curve (EKC).

$$\text{Log}\, CO_{2i,t} = \alpha_{o} + \alpha_1 \,\text{Log}\, Y_{i,t} + \alpha_2 \,\text{Log}\, Y^2{}_{i,t} + \varepsilon_{i,t} \qquad (1)$$

Where, $CO_{2i,t}$ represents carbon dioxide emissions (metric tons), $Y_{i.t}$ is GDP per capita (constant 2011 US$), $Y^2{}_{i.t}$ shows square of GDP per capita and $\varepsilon_{i.t}$ is an error term. Recently, the links of ICT with environmental changes are getting attention. However, the relationship of ICT with environmental changes is not clear a priori. Theoretically, ICT causes diverse effects on environment. On the one hand, ICT deteriorates environment as a result of poor management of e-waste and excessive use of energy in manufacturing of ICT related products (Schluep et al., 2008; OECD, 2010; Houghton, 2015). On the other hand, ICT has the potential to mitigate environmental degradation by increasing awareness of climate changes and promoting environmental friendly technologies. Equation 1 can be extended as follows:

$$\text{Log } CO_{2i,t} = \alpha_{o} + \alpha_1 \text{ Log } Y_{i,t} + \alpha_2 \text{ Log } Y^2{}_{i,t} + \alpha_3 \, ICT_{i,t} + \alpha_4 \log X_{i,t} + \varepsilon_{it} \quad (2)$$

Where, $ICT_{i,t}$ is a measure of information communication technology comprising different proxies. Since the impact of ICT on environment is not clear a priori, signs of the coefficient of ICT can be positive or negative or insignificant ($\alpha_3 > 0$; $\alpha_3 < 0$; $\alpha_3 = 0$). The term $X_{i,t}$ demonstrates a row matrix of control variables that are fossil fuel, energy use and urbanization. The expected coefficient signs of these three control variables are positive because urbanization, energy use and fossil fuel increase CO_2 emissions. Equation 2 can be extended for different measures of ICT as follows:

$$\text{Log } CO_{2i,t} = \alpha_{o} + \alpha_1 \text{ Log } Y_{i,t} + \alpha_2 \text{ Log } Y^2{}_{i,t} + \alpha_3 \, fts_{i,t} + \alpha_4 \log X_{i,t} + \varepsilon_{i,t} \quad (2.1)$$

$$\text{Log } CO_{2i,t} = \alpha_{o} + \alpha_1 \text{ Log } Y_{i,t} + \alpha_2 \text{ Log } Y^2{}_{i,t} + \alpha_3 \, fbs_{i,t} + \alpha_4 \log X_{i,t} + \varepsilon_{i,t} \quad (2.2)$$

$$\text{Log } CO_{2i,t} = \alpha_{o} + \alpha_1 \text{ Log } Y_{i,t} + \alpha_2 \text{ Log } Y^2{}_{i,t} + \alpha_3 \, tii_{i,t} + \alpha_4 \log X_{i,t} + \varepsilon_{i,t} \quad (2.3)$$

$$\text{Log } CO_{2i,t} = \alpha_{o} + \alpha_1 \text{ Log } Y_{i,t} + \alpha_2 \text{ Log } Y^2{}_{i,t} + \alpha_3 \, osi_{i,t} + \alpha_4 \log X_{i,t} + \varepsilon_{i,t} \quad (2.4)$$

$$\text{Log } CO_{2i,t} = \alpha_{o} + \alpha_1 \text{ Log } Y_{i,t} + \alpha_2 \text{ Log } Y^2{}_{i,t} + \alpha_3 \, egi_{i,t} + \alpha_4 \log X_{i,t} + \varepsilon_{i,t} \quad (2.5)$$

$$\text{Log } CO_{2i,t} = \alpha_{o} + \alpha_1 \text{ Log } Y_{i,t} + \alpha_2 \text{ Log } Y^2{}_{i,t} + \alpha_3 \, ict_{i,t} + \alpha_4 \log X_{i,t} + \varepsilon_{i,t} \quad (2.6)$$

Where, ICT has been disaggregated into six important measures of fixed telephone subscriptions ($fts_{i,t}$), fixed broadband subscriptions ($fbs_{i,t}$), telecommunication infrastructure index ($tii_{i,t}$), online service index ($osi_{i,t}$), e-government index ($egi_{i,t}$) and information communication technology ($ict_{i,t}$). The index of ICT is constructed using Principal Component Analysis of all ICT measures. Since the effects of ICT on environment are likely to be heterogeneous between developed and developing countries, all ICT measures are interacted with the dummy variables of developed and developing countries to capture separate parameter estimates for developed and developing countries.

4. Data and Variables Description

The data used for empirical analysis has been drawn from various sources. The measures of ICT are telephone, broadband, telecommunication infrastructure, online service and e-government. Where telephone is measured as "fixed telephone subscriptions (per 100 people)", broadband is "fixed broadband subscriptions (per 100 people)". The data for these two measures is taken from World Development Indicators (2016). Telecommunication infrastructure index is "an arithmetic mean of five (standardized) indicators including internet users, mobile subscriptions, fixed broadband subscriptions, fixed telephone lines, and number of mobile subscriptions", online service index ranks the countries according to provision of online services and e-government index is "three normalized scores weighted average on three dimensions of e-government. The dimensions are telecommunication infrastructure (telecommunication infrastructure index), human capital index and quality and scope of online services (online service index)." The data for these three ICT measures is taken from International Telecommunication Union (2016) and United Nations (2016).

The outcome variable CO_2 (metric tons) is taken from World Development Indicators (2016). The data on real GDP per capita is constructed at 2011 constant prices (US$). The data is derived from Feenstra et al. (2015).The control variable 'energy' use refers to use of primary energy before transformation to other end-use fuels. Fossil fuel "comprises coal, oil, petroleum, and natural gas products." urbanization is share of population living in urban areas. These three variables are taken form World Development Indicators (2016). The original study sample was based on all countries of the world. However, after screening process a sample of 48 developed and 84 developing countries is shortlisted.

Table 1 provides the descriptive analysis of the data used for empirical analysis. Columns (1-5) provide description of the data for developed economies while columns (6-10) present the description of the data for developing countries. It is evident from the Table 1 that developed and developing countries are considerably different in terms of our focused variables of concern that are environmental degradation and ICT. CO_2 emissions on average are much higher in developing countries as compared to developed countries. In effect, on average, developed countries are experiencing negative CO_2 emissions. All indicators of ICT are considerably higher in developed countries as compared to developing countries.

Table 1: Descriptive Analysis of the Data

Variable	Developed Countries					Developing Countries				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
CO_2	1806	2.10	0.69	0.05	4.23	3963	-0.26	1.51	-7.45	2.96
Y	1994	9.99	0.71	7.97	11.97	4162	7.15	1.03	4.24	9.67
FF	1549	4.35	0.33	2.33	4.61	2772	3.86	0.81	0.58	4.61
UP	2445	14.09	2.49	8.46	19.39	4871	14.53	2.19	7.78	20.4
EU	1169	4.82	0.43	3.61	6.22	2093	4.98	0.64	1.61	7.09
FTS	2280	36.71	18.32	1.42	132.95	4573	7.06	9.50	0.00	88.7
FBS	917	15.90	12.48	0.00	61.74	1454	2.54	4.66	0.00	44.3
TCI	431	0.55	0.19	0.12	1.00	1000	0.13	0.13	0.00	0.66
OSI	431	0.57	0.23	0.03	1.00	1002	0.26	0.19	0.00	0.84
EGI	431	0.66	0.17	0.00	0.93	1002	0.34	0.16	0.00	0.73
ICT	815	0.89	0.85	-0.99	2.47	1239	-0.58	0.57	-1.16	1.49

Table 2 provides correlation matrix for developed economies. The correlation between CO_2 emissions and different measures of ICT is negative implying that 'Greening through ICT' hypothesis likely to hold in developed economies.

Table 2: Correlation Matrix for Developed Countries

	CO_2	Y	FF	UP	EU	FTS	FBS	TCI	OSI	EGI	ICT
CO_2	1.00										
Y	0.40	1.00									
FF	0.30	-0.09	1.00								
UP	-0.11	0.15	0.16	1.00							
EU	0.42	-0.15	-0.32	-0.27	1.00						
FTS	-0.14	0.62	-0.29	0.25	-0.21	1.00					
FBS	-0.12	0.48	-0.35	0.19	-0.12	0.45	1.00				
TCI	0.01	0.74	-0.37	0.25	-0.10	0.76	0.67	1.00			
OSI	-0.11	0.30	-0.12	0.46	-0.12	0.46	0.42	0.60	1.00		
EGI	-0.11	0.55	-0.30	0.41	-0.12	0.69	0.62	0.89	0.89	1.00	
ICT	-0.04	0.58	-0.44	0.17	-0.01	0.52	0.84	0.83	0.51	0.76	1.00

Table 3 provides correlation matrix for developing economies. The correlation between CO_2 emissions and different measures of ICT is positive. It is noteworthy that correlation between ICT measures and CO_2 emissions is negative in the case of developed economies, while it turns out to be positive in the case of developing economies. A simple correlation analysis substantiates our prior expectation that the relationship of ICT with environmental degradation is not homogenous in developed and developing countries.

Table 3: Correlation Matrix for Developing Countries

	CO_2	Y	FF	UP	EU	FTS	FBS	TCI	OSI	EGI	ICT
CO_2	1										
Y	0.81	1									
FF	0.86	0.67	1								
UP	0.21	0.06	0.17	1							
EU	-0.13	-0.49	-0.40	0.07	1						
FTS	0.70	0.67	0.53	0.08	-0.09	1					
FBS	0.40	0.43	0.27	0.08	-0.07	0.56	1				
TCI	0.66	0.74	0.48	0.09	-0.19	0.75	0.70	1			
OSI	0.48	0.48	0.46	0.40	-0.25	0.39	0.25	0.46	1		
EGI	0.71	0.72	0.62	0.24	-0.28	0.64	0.45	0.72	0.83	1	
ICT	0.50	0.56	0.39	0.08	-0.23	0.57	0.77	0.81	0.37	0.58	1

5. Results and Discussion

Table 4 presents empirical results for ICT and CO_2 using Pooled OLS regression. The results suggest that ICT inversely affects environmental degradation. Column 2 shows that the parameter estimate (-0.0076) on fixed telephone subscriptions is negative and significant at one percent level of significance. This finding is consistent with Lashkarizadeh and Salatin (2012).

Similarly, columns 3 and 4 show the impact of fixed broadband subscriptions (-0.0032) and telecommunication infrastructure index (-0.392) on CO_2 emissions. Both measures enter with negative and significant signs implying that ICT in the form of broadband and telecommunication infrastructure helps to reduce CO_2 emissions. Fixed broadband subscription increases awareness about the environment, thereby preserving the environment. Telecommunication facilitates video and voice conferencing instead of in person communication. Consequently, use of vehicles decreases substantially and the burden on environment alleviates in developed countries.

Column 5 presents the impact of online service index (-0.230) on CO_2 emissions. This measure of ICT also causes a negative and significant impact on CO_2 emissions. Increasing utilization of online services reduces the visits on shops and movement of vehicles, thereby lessening the burden on environment. In column 6 e-government, another measure of ICT, causes a negative and significant impact (-0.209) on CO_2 emissions. The adoptions and utilization of ICT infrastructure in public sector improves the efficiency of government (Majeed and Malik, 2016a, 2016b). Moreover, ICT applications in public sector improve management of government for monitoring of environmental related activities such as water consumption, production, manufacturing, and other activities. Finally column 7 shows the results for PCA measure of ICT and CO_2 emissions. The parameter estimate on ICT index (-0.0443) also validates the argument that ICT supports environmental sustainability in the case of developed countries.

Table 4: Pooled OLS Results of CO_2 Emissions and ICT in Developed Countries

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
Log Y	1.158***	1.528***	1.282***	1.395***	1.392***	1.547***
	(0.0586)	(0.0787)	(0.123)	(0.108)	(0.112)	(0.0810)
Log Y^2	-0.0244***	-0.0511***	-0.0342***	-0.0422***	-0.0420***	-0.0519***
	(0.00367)	(0.00457)	(0.00780)	(0.00650)	(0.00685)	(0.00473)
Fossil Fuel	1.017***	1.050***	1.083***	1.088***	1.088***	1.037***
	(0.0119)	(0.0196)	(0.0266)	(0.0265)	(0.0266)	(0.0201)
Urbanization	0.00680*	-0.00236	0.00683	0.00806	0.00531	0.00201
	(0.00383)	(0.00520)	(0.00756)	(0.00760)	(0.00756)	(0.00535)
Energy	0.919***	0.959***	1.001***	1.003***	1.004***	0.965***
	(0.0122)	(0.0191)	(0.0270)	(0.0270)	(0.0272)	(0.0194)
Telephone Subs	-0.00769***					
	(0.000644)					
Broadband Subs		-0.00317***				
		(0.00115)				
Tele. Infrastructure			-0.392***			
			(0.121)			
Online Service				-0.230***		
				(0.0734)		
E-government					-0.209**	
					(0.0817)	
ICT						-0.0443**
						(0.0179)
Constant	-15.59***	-17.03***	-16.62***	-17.06***	-17.01***	-17.18***
	(0.244)	(0.348)	(0.501)	(0.460)	(0.469)	(0.355)
Observations	2,694	1,269	598	598	598	1,225
R-squared	0.960	0.953	0.963	0.963	0.963	0.953

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

Empirical findings on different indicators of ICT are consistent with the studies which consider ICT as an important determinant of environmental sustainability (Yi and

Thomas, 2007; Houghton, 2015; Bekaroo et al., 2016; Gonel and Akinci, 2018). The direction of effect (negative) is consistent with the studies which consider ICT developments as favorable for environmental sustainability (Zhang and Liu, 2015; Ozcan and Apergis, 2018; Lu, 2018). The studies which doubt the environmental friendly effects of ICT are not supported with the empirical findings for developed economies (Widmer et al., 2005; Liu et al., 2006; Osibanjo and Nnorom, 2007).

The parameter estimates on selected control variables Y (1.158), Y^2 (-0.0244), fossil fuel (1.017), urbanization (0.007), and energy (0.919) are consistent with the earlier findings of the literature. The impact of GDP in a linear specification is positive while it turns out to be negative in a non-linear specification. It implies that environmental Kuznets curve holds which is broadly consistent with the earlier findings of the studies. The impact of fossil fuels is positive and significant in all regressions.

Urbanization creates environmental burden as vehicles such as cars and buses are intensively used in urban areas which create pollution (Cole and Neumayer, 2004). Energy use causes positive and significant impact on CO_2 emissions in all models. Increasing human activities and greater use of energy cause more pressure on environment (Ang, 2007). R^2 values of all regressions are greater than 0.90 implying that more than 90% variation in model is explained by the independent variables.

Table 5 presents results for developing economies. It is noteworthy that none of the ICT measures is helping to reduce environmental degradation. Thus empirical estimates confirm heterogeneous outcomes of ICT in developed and developing economies. The results broadly suggest that ICT positively affects environmental degradation. Column 2 shows that the parameter estimate on fixed telephone subscriptions (0.0018) is positive and significant at 5 percent level of significance. It implies that ICT in the form of fixed telephone subscription causes unfavorable effects on environment in the case of developing countries.

Similarly, column 2 shows the positive and significant impact of fixed broadband subscriptions on CO_2 emissions. Other measures of ICT are also indicating positive impact on environmental degradation. Though other measures are positive but their effect is statistically insignificant. However, their joint effect is positive and significant as it is evident from column 7 where PCA measure of ICT is causing positive and significant impact on CO_2 emissions. Developing countries lack the capacity to take the full advantage of ICT. Moreover, e-waste is poorly managed in developing countries.

Table 5: Pooled OLS Results of CO_2 Emissions and ICT in Developing Countries

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	CO_2	**CO_2**	**CO_2**	**CO_2**	**CO_2**	**CO_2**
Log Y	1.442***	1.529***	1.474***	1.483***	1.434***	1.555***
	(0.0574)	(0.0799)	(0.118)	(0.112)	(0.116)	(0.0797)
Log Y^2	-0.0470***	-0.0519***	-0.0491***	-0.0496***	-0.0463***	-0.0542***
	(0.00337)	(0.00457)	(0.00687)	(0.00656)	(0.00691)	(0.00448)
Fossil Fuel	1.022***	1.055***	1.093***	1.092***	1.091***	1.042***
	(0.0124)	(0.0195)	(0.0267)	(0.0267)	(0.0266)	(0.0198)
Urbanization	0.00294	-0.00374	0.00457	0.00400	0.00293	0.00126
	(0.00392)	(0.00520)	(0.00767)	(0.00801)	(0.00778)	(0.00533)
Energy	0.903***	0.960***	0.997***	0.998***	0.998***	0.960***
	(0.0127)	(0.0191)	(0.0273)	(0.0272)	(0.0272)	(0.0195)
Telephone Subs	0.00187**					
	(0.000884)					
Broadband Subs		0.00773**				
		(0.00357)				
Tele. Infrastructure			0.0933			
			(0.193)			
Online Service				0.0327		
				(0.0781)		
E-government					0.110	
					(0.0863)	
ICT						0.0700***
						(0.0260)
Constant	-16.35***	-17.02***	-17.21***	-17.25***	-17.07***	-17.05***
	(0.258)	(0.354)	(0.511)	(0.489)	(0.495)	(0.367)
Observations	2,694	1,269	598	598	598	1,225
R-squared	0.958	0.953	0.962	0.962	0.962	0.953

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Empirical findings on different indicators of ICT are consistent with the studies which consider ICT developments as unfavorable for environment sustainability (Widmer et al., 2005; Liu et al., 2006; Osibanjo and Nnorom, 2007). In the case of developing economies, the direction of effect (positive) is inconsistent with the studies which consider ICT developments as favorable for environmental sustainability (Zhang and Liu, 2015; Ozcan and Apergis, 2018; Lu, 2018).

Empirical results obtained using POLS become biased in the presence of endogeneity and heterogeneity. The problem of endogeneity is likely to prevail in our model because whereas ICT infrastructure influences environmental degradation, more degradation in the form of dust, smoke can also damage electronic equipment. Similarly, the chosen sample is cross-country and the issue of heterogeneity can also give the biased results. To address these issues, an alternative estimation technique Generalized Method of Moments (GMM) is used. GMM provides efficient and consistent results in the presence of heterogeneity and endogeneity. To assess the validity of instruments we apply the test of over identification.

Table 6 provides the results estimated using GMM. The baseline results remain same as all ICT measures significantly and negatively reduce CO_2 emissions in developed economies. Thus development of ICT infrastructure in developed economies is a potential source of mitigating environmental degradation. Moreover, findings also confirm the presence of EKC. A large number of studies have confirmed the presence of EKC (Grossman and Kruger, 1991; Selden and Song, 1994).

Table 6: GMM Results of CO_2 Emissions and ICT for Developed Economies

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
Log Y	1.041***	1.386***	0.832**	1.088***	1.055***	1.418***
	(0.0890)	(0.140)	(0.325)	(0.232)	(0.258)	(0.147)
Log Y^2	-0.0175***	-0.0427***	-0.00539	-0.0232	-0.0208	-0.0441***
	(0.00558)	(0.00815)	(0.0212)	(0.0146)	(0.0166)	(0.00867)
Fossil Fuel	1.043***	1.087***	1.117***	1.120***	1.123***	1.066***
	(0.0182)	(0.0330)	(0.0467)	(0.0456)	(0.0470)	(0.0331)
Urbanization	0.0128***	0.00198	0.0169*	0.0158*	0.0124	0.00742
	(0.00350)	(0.00517)	(0.00951)	(0.00916)	(0.00901)	(0.00532)
Energy	0.921***	0.956***	0.983***	0.987***	0.990***	0.967***
	(0.0128)	(0.0181)	(0.0342)	(0.0337)	(0.0336)	(0.0181)
Telephone Subs	-0.00815***					
	(0.000799)					
Broadband Subs		-0.00498***				
		(0.00156)				
Tele. Infrastructure			-0.718**			
			(0.305)			
Online Service				-0.340**		
				(0.155)		
E-government					-0.351**	
					(0.179)	
ICT						-0.0783***
						(0.0269)
Hansen's J chi2	0.567945 (p = 0.4511)	0.021771 (p = 0.8827)	0.679081 (p = 0.4099)	0.012277 (p = 0.9118)	0.400191 (p = 0.5270)	1.7746 (p = 0.1828)
Constant	-15.32***	-16.66***	-15.11***	-16.03***	-15.89***	-16.88***
	(0.326)	(0.511)	(1.116)	(0.809)	(0.899)	(0.533)
Observations	2,690	1,131	241	241	241	1,084
R-squared	0.960	0.951	0.966	0.966	0.966	0.951

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

The impact of fossil fuel on CO_2 emissions is positive and significant. Sharma (2011) argues that an increase in burning of fossil fuels used in transportations causes more CO_2 emissions, thereby deteriorating the environment. Urbanization creates environmental burden as vehicles such as cars, buses and others are intensively used in urban areas creating pollution (Cole and Neumayer, 2004).

Energy use also adversely affects climate degradation. Many scholars point out that energy use causes environmental degradation (Ang, 2007; Apergis and Payne, 2009; Dogan and Turkekul, 2016). R^2 values of all regressions are greater than 0.90 implying that more than 90% variation in model explained by the independent variables. P-values of Hansen's J test indicate that instruments are valid. Therefore, the empirical results are not suffering from the problem of endogeneity.

Table 7: GMM Results of CO_2 Emissions and ICT for Developing Economies

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	**CO_2**	**CO_2**	**CO_2**	**CO_2**	**CO_2**	**CO_2**
Log Y	1.352***	1.401***	1.201***	1.230***	1.175***	1.542***
	(0.0794)	(0.132)	(0.253)	(0.235)	(0.257)	(0.217)
Log Y^2	-0.0420***	-0.0449***	-0.0335**	-0.0354**	-0.0316**	-0.0531***
	(0.00458)	(0.00743)	(0.0147)	(0.0138)	(0.0154)	(0.0102)
Fossil Fuel	1.045***	1.100***	1.134***	1.139***	1.133***	1.058***
	(0.0182)	(0.0341)	(0.0506)	(0.0499)	(0.0487)	(0.0293)
Urbanization	0.00985***	0.000809	0.0125	0.0150	0.0109	0.00751
	(0.00355)	(0.00501)	(0.00888)	(0.0106)	(0.00951)	(0.00518)
Energy	0.906***	0.960***	0.979***	0.980***	0.979***	0.958***
	(0.0132)	(0.0177)	(0.0360)	(0.0353)	(0.0353)	(0.0231)
Telephone Subs	0.00232***					
	(0.000770)					
Broadband Subs		0.00894***				
		(0.00278)				
Tele. Infrastructure			0.0856			
			(0.343)			
Online Service				-0.0475		
				(0.116)		
E-government					0.0795	
					(0.153)	
ICT						0.0289
						(0.187)
Hansen's J chi2	0.567945 (p = 0.4511)	0.021771 (p = 0.8827)	0.679081 (p = 0.4099)	0.012277 (p = 0.9118)	0.400191 (p = 0.5270)	1.7746 (p = 0.1828)
Constant	-16.19***	-16.71***	-16.28***	-16.43***	-16.17***	-17.19***
	(0.317)	(0.493)	(0.981)	(0.927)	(0.980)	(1.153)
Observations	2,690	1,131	241	241	241	1,222
R-squared	0.958	0.951	0.965	0.965	0.965	0.953

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

Table 7 provides empirical results of CO_2 emissions and ICT for developing countries. The findings on the presence of EKC and control variables are similar to developed economies. That is, EKC holds in developing economies whereas fossil fuel, urbanization and energy use are contributing in environmental degradation. However, the usage of ICT as a vehicle to control environmental degradation is not substantiated in developing economies. Furthermore, some of ICT measures such as fixed telephones subscriptions, fixed broadband subscription are contributing significantly in environmental degradation rather than reducing it.

6. Conclusion

In recent decades technological advancements have significantly contributed in economic growth. However, increasing use of technology in the production process also raises greenhouse gases that create pollution and consequently deteriorate the quality of environment. Whereas growing production of ICT has also contributed into the ecological burden of this planet, it also has the ability to alleviate the burden on environment through increasing awareness and adoption of “Green ICT” that is usage of smart technology and tools.

Theoretically environmental effects of ICT are ambiguous. This study uses a large panel data set of 132 developed and developing countries and conducts a comparative empirical analysis. The analysis is based on OLS and GMM econometric techniques of estimations. Moreover, the issue of potential problem of endogeneity is addressed.

The empirical analysis shows that ICT can reduce environmental degradation but only in the case of developed economies. In the case of developing economies the role of ICT is either environmental damaging or insignificant. These findings are shown to be robust to various robustness checks. This study concludes that ICT has the potential to protect the environment form degradation. However, this effect is limited to only developed countries.

6.1 Contribution of the Study

The relationship of ICT with environment sustainability is an emerging field of research. The extant literature in this field is limited to qualitative and descriptive studies. Secondly empirical analysis is limited to a country specific or regional analysis. Thirdly, the literature generally focused on developed economies ignoring developing economies. Fourthly, the available empirical studies measured information communication technology with a single dimension such as internet usage which cannot be generalized for other dimensions of ICT. Considering these gaps in the literature on ICT and environment, this study contributes in a number of ways. Firstly, this study identifies the heterogeneous effects of ICT on environment in developed and developing countries. Secondly, this study uses diverse and novel measure of ICT rather than restricting the analysis to a single measure of ICT. Thirdly, this study provides global evidence using a large set of developed and developing countries over a long period of time. Fourthly, this study addresses the issue of endogeneity. Finally, this study utilizes alternative econometric techniques to provide better empirical estimates and conducts robustness analysis to assess the soundness of data, variables and empirical findings.

6.2 Heterogeneous Effects of ICT on Environment Sustainability

The comparative empirical analysis offers diverse effects of ICT on environment sustainability. The environmental effects of ICT are not mapped in a unique way. ICT has a potential to sustain the environment only in the case of developed countries. In contrast, ICT causes adverse effects on environment in the case of developing countries.

All measures of ICT cause negative and significant effect on carbon emissions in developed countries. However, comparatively the effect of telecommunication infrastructure and online service index is stronger as compared to other indicators of ICT.

Thus developed countries can sustain their environment by investing more in telecommunication infrastructure and in online services. Empirical findings suggest that all measures of ICT are positively associated with environmental degradation in developing countries. However, a comparative analysis indicates that the effect of fixed telephone subscription and broadband is important.

6.3 Limitations of the Study

This study has certain limitations. First, the data of many developing countries was missing. Second, this study uses only one dimension of environment that is carbon emissions. Third, panel Granger causality analysis is not conducted in this study. Fourth, heterogeneity of developed and developing countries is analyzed while the heterogeneity within the group of developed and developing countries is not investigated.

6.4 Theoretical/Policy Implications

Environmentalists and economists have developed various theories, such as Kuznets Curve and Pollution Hypothesis, to understand the relationship of economic activities with environmental sustainability. However, little attention has been paid to ICT and environmental sustainability nexus. The literature offers Greening ICT and Greening through ICT hypotheses to understand the links of ICT with ecosystem. Theoretical and empirical literature predicts conflicting effects of ICT on ecosystem. A comprehensive analysis of this study shows that the ICT-environment nexus sustainability differs between developed and developing countries. These are the developed countries which are gaining more from ICT in terms of environment sustainability. In contrast, environment sustainability is compromised with the increasing use of ICT in developing countries.

This study offers different policy implications for developed and developing countries. ICT supporting policies can help to improve the quality of environment in developed economies. In this regard research and development expenditures can be increased to foster the growth of ICT infrastructure. Moreover, implementation of ICT infrastructure in public sector can substantially alleviate environmental degradation. The governments of developing countries need to decouple economic growth from environmental degradation. In developing countries, appropriate polices need to be designed to manage e-waste.

6.5 Directions for Future Research

This study can be extended in many ways. For example, this research utilizes levels of carbon emissions to proxy environment sustainability whereas future research can utilize other greenhouse gases such as nitrous oxide, methane and fluorinated gases. Future research can also explore the scope of other emerging technologies such as internet of things, artificial intelligence and robots. In addition, future studies can conduct a comparative regional analysis of ICT and environment to discover the ICT role in different demographic and other economic conditions around the world. The role of income levels can be analyzed for better understanding of ICT and environment sustainability. Future research needs to focus more on the potential causes which undermine the strength of ICT to safeguard the environment in developing economies.

REFERENCES

Agena, T. (2007). The Relationship between Economic Activities and Environmental Degradation in Africa. *Journal of the Historical Society of Nigeria, 17*(1), 28-40.

Ang, J. B. (2007). CO_2 Emissions, Energy Consumption, and Output in France. *Energy Policy*, *35*(10), 4772-4778.

Apergis, N., & Payne, J. E. (2009). CO_2 Emissions, Energy Usage, and Output in Central America. *Energy Policy*, 37(8), 3282-3286.

Bekaroo, G., Bokhoree, C., & Pattinson, C. (2016). Impacts of ICT on the Natural Ecosystem: A Grassroot Analysis for Promoting Socio-Environmental Sustainability. *Renewable and Sustainable Energy Reviews, 57,* 1580-1595.

Cole, M. A., & Neumayer, E. (2004). Examining the Impact of Demographic Factors on Air Pollution. *Population and Environment, 26*(1), 5-21.

Dogan, E., & Turkekul, B. (2016). CO_2 Emissions, Real Output, Energy Consumption, Trade, Urbanization and Financial Development: Testing the EKC Hypothesis for the USA. *Environmental Science and Pollution Research*, *23*(2), 1203-1213.

Emmanouil, M. C., Stiakakis, E., Vlachopoulou, M., & Manthou, V. (2013). An Analysis of Waste and Information flows in an ICT Waste Management System. *Procedia Technology*, *8*, 157-164.

Feenstra, Robert C., Robert Inklaar and Marcel P. Timmer (2015). The Next Generation of the Penn World Table. *American Economic Review*, *105*(10), 3150-3182.

Garber, P. M. (2011).The Effect of Industrialization on the Environment. Cambridge: *MIT Press*.

Gonel, F., & Akinci, A. (2018). How Does ICT-Use Improve the Environment? The Case of Turkey. *World Journal of Science, Technology and Sustainable Development*, *15*(1), 2-12.

Grossman, G. M., & Krueger, A. B. (1991). Environmental Impacts of a North American Free Trade Agreement. *National Bureau of Economic Research*, *Working paper 3914*, 1-39.

Guha-Sapir, D., Vos, F., Below, R., & Ponserre, S. (2012). Annual disaster statistical review 2011: the numbers and trends. Centre for Research on the Epidemiology of Disasters (CRED).

Hilty, L. M., Arnfalk, P., Erdmann, L., Goodman, J., Lehmann, M., & Wäger, P. A. (2006). The Relevance of Information and Communication Technologies for Environmental Sustainability–A Prospective Simulation Study. *Environmental Modeling & Software*, *21*(11), 1618-1629.

Houghton, J. W. (2015). ICT, The Environment, and Climate Change. *The International Encyclopedia of Digital Communication and Society*, *76*, 39-60.

International Telecommunication Union (2016). ICT Indicators Database. Washington, DC: ITU. [Online] Available at: www.itu.int/en/ITU-D/statistics (February 26^{th}, 2018).

Lashkarizadeh, M., & Salatin, P. (2012). The Effects of Information and Communications Technology (ICT) on Air Pollution, *Elixir Pollution, 46*, 8058-8064.

Liu, X., Tanaka, M., & Matsui, Y. (2006). Electrical and Electronic Waste Management in China: Progress and the Barriers to Overcome. *Waste Management & Research*, *24*(1), 92-101.

Lu, W. C. (2018). The Impacts of Information and Communication Technology, Energy Consumption, Financial Development, and Economic Growth on Carbon Dioxide Emissions in 12 Asian Countries. *Mitigation and Adaptation Strategies for Global Change*, 1-15.

Majeed, M. T., & Ayub, T. (2018). Information and Communication Technology (ICT) and Economic Growth Nexus: A Comparative Global Analysis. *Pakistan Journal of Commerce and Social Sciences*, *12*(2), 443-476.

Majeed, M. T., & Khan, F. N. (2018). Do Information and Communication Technologies (ICTs) Contribute to Health Outcomes? An Empirical Analysis. *Quality & Quantity*, 1-24 [First Online: 15 March 2018].

Majeed, M. T., & Malik, A. (2016a). Does E-government Stimulate Press Freedom to Curb Corruption? A Cross-Country Study. *Pakistan Journal of Social Sciences, 36*(2). 1173-1183.

Majeed, M. T., & Malik, A. (2016b). E-government, Financial Development and Economic Growth. *Pakistan Journal of Applied Economics, 26*(2), 107-128.

Majeed, M. T., & Mumtaz, S. (2017). Happiness and Environmental Degradation: A Global Analysis. *Pakistan Journal of Commerce and Social Sciences, 11*(3), 753-772.

Niebel, T. (2018). ICT and Economic Growth–Comparing Developing, Emerging and Developed Countries. *World Development, 104*, 197-211.

OECD (2010). Greener and Smarter: ICTs, The Environment and Climate Change. Paris, France: Organization for Economic Co-operation and Development. [Online] Available at: www.oecd.org/ site/stitff/45983022 (May 23rd, 2018).

Osibanjo, O., & Nnorom, I. C. (2007). The Challenge of Electronic Waste (e-waste) Management in Developing Countries. *Waste Management & Research*, *25*(6), 489-501.

Ozcan, B., & Apergis, N. (2018). The Impact of Internet Use on Air Pollution: Evidence from Emerging Countries. *Environmental Science and Pollution Research*, *25*(5), 4174-4189.

Plepys, A. (2002). The Grey Side of ICT. *Environmental Impact Assessment Review*, *22*(5), 509-523.

Salahuddin, M., Alam, K., & Ozturk, I. (2016). The Effects of Internet Usage and Economic Growth on CO_2 Emissions in OECD Countries: A Panel Investigation. *Renewable and Sustainable Energy Reviews, 62,* 1226-1235.

Schluep, M., Rochat, D., Munyua, A. W., Laissaoui, S. E., Wone, S., Kane, C., ... & Network, K. I. A. (2008). Assessing the e-waste situation in Africa. In *Electronics Goes Green 2008+ and 1st World ReUse Forum*. Germany: Berlin.

Selden, T. M., & Song, D. (1994). Environmental Quality and Development: Is there a Kuznets Curve for Air Pollution Emissions? *Journal of Environmental Economics and Management*, *27*(2), 147-162.

Sharma, S. S. (2011). Determinants of Carbon Dioxide Emissions: Empirical Evidence from 69 Countries. *Applied Energy*, *88*(1), 376-382.

Siddique, H. M. A., & Majeed, M. T. (2015). Energy Consumption, Economic Growth, Trade and Financial Development Nexus in South Asia. *Pakistan Journal of Commerce and Social Sciences*, *9*(2), 658-682.

Uddin, M., & Rahman, A. A. (2012). Energy Eefficiency and Low Carbon Enabler Green IT Framework for Data Centers Considering Green Metrics. *Renewable and Sustainable Energy Reviews, 16*(6), 4078-4094.

United Nations (2016). UN E-government Database. [Online] Available at https://publicadministration.un.org/egovkb/en-us/Data-Center (March 17th, 2018).

Webb, M. (2008). Smart 2020: Enabling the low carbon economy in the information age. *The Climate Group. London*, *1*(1), 1-1.

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., & Böni, H. (2005). Global Perspectives on E-waste. *Environmental Impact Assessment Review*, *25*(5), 436-458.

World Bank (2016). World Development Indicators. Washington, DC: World Bank. [Online] Available at: http://data.worldbank.org/products/wdi (March 11th, 2018).

Yi, L., & Thomas, H. R. (2007). A Review of Research on the Environmental Impact of E-Business and ICT. *Environment International*, *33*(6), 841-849.

Zhang, C., & Liu, C. (2015). The Impact of ICT Industry on CO_2 Emissions: A Regional Analysis in China. *Renewable and Sustainable Energy Reviews*, *44*(1), 12-19.

Appendix

Table A1: Estimation for Sub-samples of Developed Countries

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	**CO_2**	**CO_2**	**CO_2**	**CO_2**	**CO_2**	**CO_2**
Log Y	1.682***	0.687	0.512	0.281	0.317	0.697
	(0.361)	(0.656)	(1.021)	(1.056)	(1.020)	(0.667)
Log Y^2	-0.0503***	-0.00843	0.00869	0.0122	0.0144	-0.00807
	(0.0184)	(0.0329)	(0.0513)	(0.0531)	(0.0513)	(0.0335)
Fossil Fuel	0.839***	0.952***	0.775***	0.923***	0.822***	0.926***
	(0.0328)	(0.0451)	(0.0772)	(0.0706)	(0.0727)	(0.0473)
Urbanization	-0.0271***	-0.0472***	-0.0169	-0.0195	-0.00447	-0.0451***
	(0.00589)	(0.00858)	(0.0145)	(0.0161)	(0.0155)	(0.00896)
Energy	0.881***	0.935***	0.981***	1.005***	0.990***	0.955***
	(0.0232)	(0.0368)	(0.0613)	(0.0633)	(0.0612)	(0.0373)
Telephone Subs	-0.0120***					
	(0.000875)					
Broadband Subs		-0.00355***				
		(0.00134)				
Tele. Infrastructure			-0.993***			
			(0.212)			
Online Service				-0.337**		
				(0.133)		
E-government					-1.132***	
					(0.240)	
ICT						-0.0597***
						(0.0212)
Constant	-16.55***	-11.67***	-11.14**	-10.18**	-9.923**	-11.82***
	(1.711)	(3.153)	(4.877)	(5.047)	(4.874)	(3.205)
Observations	970	549	220	220	220	525
R-squared	0.776	0.710	0.731	0.712	0.731	0.708

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

Table A2: Estimation for Sub-samples of Developing Countries

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	**CO_2**	**CO_2**	**CO_2**	**CO_2**	**CO_2**	**CO_2**
Log Y	1.302***	1.513***	1.216***	1.242***	1.154***	1.514***
	(0.125)	(0.182)	(0.220)	(0.220)	(0.225)	(0.180)
Log Y^2	-0.0377***	-0.0530***	-0.0336**	-0.0344**	-0.0301**	-0.0530***
	(0.00839)	(0.0121)	(0.0147)	(0.0146)	(0.0148)	(0.0119)
Fossil Fuel	1.021***	1.082***	1.133***	1.136***	1.132***	1.065***
	(0.0137)	(0.0203)	(0.0260)	(0.0258)	(0.0258)	(0.0204)
Urbanization	0.0428***	0.0418***	0.0433***	0.0498***	0.0411***	0.0481***
	(0.00500)	(0.00615)	(0.00847)	(0.00914)	(0.00866)	(0.00620)
Energy	0.875***	0.922***	0.953***	0.955***	0.949***	0.919***
	(0.0161)	(0.0216)	(0.0282)	(0.0273)	(0.0278)	(0.0214)
Telephone Subs	0.00165					
	(0.00119)					
Broadband Subs		0.00924***				
		(0.00345)				
Tele. Infrastructure			0.0671			
			(0.241)			
Online Service				-0.148*		
				(0.0832)		
E-government					0.155	
					(0.130)	
ICT						0.0741***
						(0.0229)
Constant	-16.32***	-17.49***	-16.71***	-16.95***	-16.45***	-17.45***
	(0.469)	(0.684)	(0.809)	(0.815)	(0.839)	(0.677)
Observations	1,724	720	378	378	378	700
R-squared	0.951	0.958	0.969	0.969	0.969	0.960

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

Table A3: List of Developed Countries

Australia	Finland	Kuwait	Saudi Arabia
Austria	France	Latvia	Singapore
Bahrain	Germany	Lithuania	Slovak Republic
Belgium	Greece	Luxembourg	Slovenia
Brunei Darussalam	Hong Kong	Malta	Spain
Canada	Hungary	Netherlands	Sweden
Chile	Iceland	New Zealand	Switzerland
Croatia	Ireland	Norway	Trinidad and Tobago
Cyprus	Israel	Oman	United Arab Emirates
Czech Republic	Italy	Poland	United Kingdom
Denmark	Japan	Portugal	United States
Estonia	Korea, Rep.	Qatar	Uruguay

Table A4: List of Developing Countries

Albania	Cuba	Kyrgyz Republic	Philippines
Algeria	Dominican Rep.	Lebanon	Romania
Angola	Ecuador	Libya	Russian Fed.
Armenia	Egypt, Arab Rep.	Macedonia, FYR	Senegal
Azerbaijan	El Salvador	Malaysia	Serbia
Bangladesh	Eritrea	Mauritius	South Africa
Belarus	Ethiopia	Mexico	Sri Lanka
Benin	Gabon	Moldova	Sudan
Bolivia	Georgia	Mongolia	Tajikistan
Bosnia	Ghana	Montenegro	Tanzania
Botswana	Guatemala	Morocco	Thailand
Brazil	Haiti	Mozambique	Togo
Bulgaria	Honduras	Namibia	Tunisia
Cambodia	India	Nepal	Turkey
Cameroon	Indonesia	Nicaragua	Ukraine
China	Iran	Niger	Uzbekistan
Colombia	Iraq	Nigeria	Venezuela
Congo, Dem. Rep.	Jamaica	Pakistan	Vietnam
Congo, Rep.	Jordan	Panama	Yemen
Costa Rica	Kazakhstan	Paraguay	Zambia
Cote d'Ivoire	Kenya	Peru	Zimbabwe