

Sustainable Development in OIC Countries: Evaluating the Role of ICT in Environmental Conservation

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ABSTRACT

In recent decades, the world has witnessed an enormous increase in digitalization among businesses and individuals. This is because the adoption of information and communication technology (ICT) brought numerous advantages to human beings in the form of improved communication, productivity, and research. In the 21st century, computing has become a key resource in many sectors to help in various purposes, including information retrieval, processing, and automation. However, as the use of ICT has been continuously increasing, concerns are growing about its effects on the natural environment and climatic conditions. Theoretically environmental effects of ICT are ambiguous. To assess it empirically, this study explores the ICT-environment nexus for Organization of Islamic Cooperation (OIC) economies. The empirical analysis is based on novel measures of ICT. The results showed a favorable role of ICT penetration on environmental quality in OIC countries. Thus, the empirical findings support the **‘greening through ICT’** hypothesis. Moreover, the **‘environmental Kuznets curve’** is also validated in OIC countries.

ملخص

شهد العالم خلال العقود الأخيرة تسارعا كبيرا في التحول الرقمي، سواء على مستوى الأفراد أو الشركات، نتيجة لاعتماد تقنيات المعلومات والاتصالات (ICT) التي جلبت فوائد واسعة للبشرية، من أبرزها تحسين التواصل، وزيادة الإنتاجية، وتعزيز البحث العلمي. وفي القرن الحادي والعشرين، أصبحت الحوسبة موردا أساسيا في العديد من القطاعات، تُستخدم لأغراض متعددة تشمل استرجاع المعلومات، ومعالجتها، وأتمتة العمليات. ومع ذلك، فإن التوسع المستمر في استخدام تقنيات المعلومات والاتصالات أثار مخاوف متزايدة بشأن آثارها على البيئة والظروف المناخية. ومن الناحية النظرية، تظل العلاقة بين تكنولوجيا المعلومات والبيئة علاقة غامضة وغير محسومة. ومن أجل تقييم هذه العلاقة بشكل تجريبي، تستقصي هذه الدراسة العلاقة بين تقنيات المعلومات

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والاتصالات والبيئة في اقتصادات دول منظمة التعاون الإسلامي (OIC)، استنادا إلى مؤشرات جديدة ومبتكرة لقياس تكنولوجيا المعلومات. وقد أظهرت النتائج دورا إيجابيا لاختراق تقنيات المعلومات والاتصالات في تحسين جودة البيئة في دول المنظمة، مما يدعم فرضية "التحول الأخضر من خلال التكنولوجيا". كما تؤكد النتائج صحة فرضية "منحنى كوزنتس البيئي" في سياق دول منظمة التعاون الإسلامي.

RESUMÉ

Au cours des dernières décennies, le monde a connu une augmentation considérable de la numérisation dans les entreprises et chez les particuliers. Cela s'explique par le fait que l'adoption des technologies de l'information et de la communication (TIC) a apporté de nombreux avantages à l'humanité, notamment une amélioration de la communication, de la productivité et de la recherche. Au 21^e siècle, l'informatique est devenue une ressource clé dans de nombreux secteurs pour aider à diverses fins, notamment la recherche d'informations, le traitement et l'automatisation. Cependant, avec l'utilisation croissante des TIC, leurs effets sur l'environnement naturel et les conditions climatiques suscitent de plus en plus d'inquiétudes. En théorie, les effets des TIC sur l'environnement sont ambigus. Afin de les évaluer de manière empirique, cette étude explore le lien entre les TIC et l'environnement dans les économies de l'Organisation de la coopération islamique (OCI). L'analyse empirique repose sur de nouvelles mesures des TIC. Les résultats ont montré que la pénétration des TIC avait un effet favorable sur la qualité de l'environnement dans les pays de l'OCI. Les conclusions empiriques confirment donc l'hypothèse du "*Verdissement grâce aux TIC*". En outre, la "*Courbe environnementale de Kuznets*" est également validée dans les pays de l'OCI.

Keywords: ICT, E-Waste, Environmental Degradation, CO₂ Emissions, OIC Countries

JEL Classifications: C23; L86; Q53

1. Introduction

Environmental concerns have attracted the global attention of research scholars and policymakers. Preserving environmental quality is one of the key global issues. Research suggests that if present emissions are not mitigated, trillion tons of carbon dioxide will be omitted by 2050, having adverse effects on human life (Lashkarizadeh and Salatin, 2012). It is imperative to find the factors that can help to prevent CO₂ emissions. The literature has identified the role of economic growth and energy consumption in influencing emissions. The importance of information

and communication technology (ICT) in shaping economic gains and climatic changes has been highlighted in the literature. The research, however, mainly focused on the economic prosperity effects of ICT (Niebel, 2018; Majeed and Ayub, 2018). The ecological dimension of ICT, however, has received the least attention in the empirical literature.

ICT and the environment are connected in many intricate ways. On the one side, ICT development damages the environment by enhancing the production, usage, and disposal of ICT commodities. For instance, rising e-waste and increased energy use in the industry have a negative impact on the environment (OECD, 2010; Houghton, 2015; Chatti and Majeed, 2022a). According to the ICT life cycle theory, different stages of the lifespan of ICT-related products covering “production, delivery, transport, use, and disposal” produce pollution (Yi and Thomas, 2007; Zhang and Liu, 2015). ICT devices and infrastructure consume a significant amount of energy, which can contribute to greenhouse gas (GHG) emissions and climate change.

ICT, on the other hand, is seen as an instrument to strengthen environmental protection and to ameliorate the negative effects of anthropogenic activities on the environment. ICT can help to mitigate environmental damage by raising awareness of environmental issues and utilizing environmentally friendly technology (Plepys, 2002; Lashkarizadeh and Salatin, 2012; Chatti and Majeed, 2022a). ICT applications support in predicting and managing environmental associated threats and risks. For instance, computerized simulation tools can be used to teach "learning by simulation" to simplify decision-making processes and avoid the negative effects of trial and error. The "internet network," another component of ICT, has a favorable impact on environmental awareness.

The association between ICT and environmental quality can also be explained using the insights of rebound effects theory. According to this theory, the favorable effects of technology on the environment can be offset in the long term as ICT growth leads to efficient and cheap production which in turn increases demand and production, overburdening the environment. Besides, the dematerialization impact of ICT implies “a shift from delivering physical products to delivering services” (Webb, 2008; Majeed, 2018; Rieger, 2021; Chatti and Majeed, 2022a). For instance, digital modes of communication such as e-mail,

WhatsApp, and other online tools reduce the need and use of print and physical modes of communication. Similarly, the increasing usage of digital technologies such as internet telephony and video conferencing have created several opportunities for businesses and socialization, thereby reducing commuting and GHG emissions.

In addition, growing e-commerce and e-banking usage is enabling online transactions which are reducing physical travel. In such a situation, GHG emissions are mitigated as pressure on the transport sector is alleviated (Chatti and Majeed, 2022b). Furthermore, in addition to reducing reliance on physical travel, ICT is assisting in the provision of intelligent and automated solutions in many sectors, including manufacturing, power generation, and agriculture. As a result, ICT is seen as a low-carbon enabler and a crucial factor in determining the sustainability of the environment, which can help reduce carbon emissions in a variety of sectors like power, transportation, and buildings. According to the smart 2020 report, ICT has the potential to reduce greenhouse gas emissions by 2020 (Webb, 2008).

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

Consequently, as technology is increasing and the world is becoming more interconnected, the power consumed, and carbon emitted by ICT are also increasing. The ICT industry is becoming a power drainer and contributes 2 % of global carbon emissions. This value represents a total carbon footprint of 830MtCO_{2e} as of the year 2007. This amount of carbon footprint is equivalent to the carbon footprint emitted by the 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 footprint of ICT has become a growing concern for societies because carbon emissions influence climate which affects the natural environment and society.

The growing literature on ICT has produced conflicting evidence. Besides, the extant literature on ecological dimensions of ICT is based on qualitative analysis. Some of the studies focus on country-specific evidence. The evidence on developing economies is largely neglected. Particularly, an empirical analysis of Organization of Islamic Cooperation (OIC) economies is missing in the current stream of literature. This study contributes to the emerging literature on ICT and the environment by analyzing the effects of ICT on the environment using different measures of ICT. Besides, this study also tests the presence of the environmental Kuznets curve (EKC) in OIC economies. The empirical analysis is conducted using pooled ordinary least squares (POLS), fixed effects, random effects, and system generalized method of moments (SGMM) estimation techniques.

The developing world is more vulnerable to environmental issues than the developed world. However, the developing world in general, and OIC economies, in particular, have received little attention in the literature. OIC economies having their geographic location within the developing world also face several environmental challenges. According to the OIC environment report (2021), between 1990 and 2017, global GHG emissions rose by 43%, reaching 50 Gt-CO₂ equivalent. Likewise, OIC economies have demonstrated a 77% incline in GHG emissions from 1990 to 2017, reaching 9 Gt-CO₂ equivalent. With this incline in emissions, OIC economies' share in world GHG emissions has reached 18.1%.

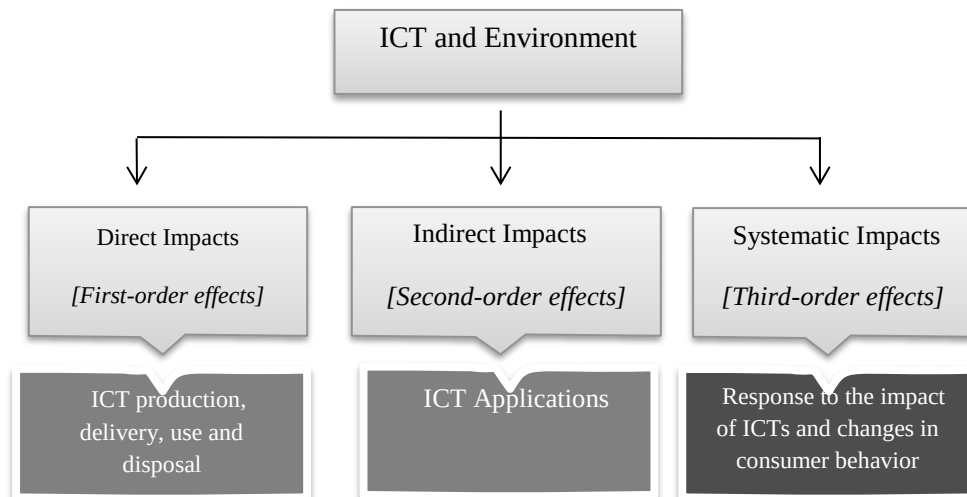
OIC nations are generally at higher risk and less equipped to deal with the repercussions of climate change. This increases their vulnerability to the effects of climate change and endangers the well-being of society. In effect, more than half of OIC nations are more climate change sensitive than the average country worldwide. In addition, eighty percent of OIC nations are not in a position to manage the effects of climate change (OIC environment report, 2021). Thus, assessing their environmental problems remains an important research agenda. Besides, within the context of the OIC, Islamic economies have reiterated their responsibility to conserve the environment.

Against this milieu, this study contributes to the literature by addressing the following research questions: 1): How does ICT influences environmental quality in OIC economies? 2): Do different measures of

ICT influence the environment differently? 3): Does the EKC hypothesis hold for OIC economies? 4): Are the empirical findings sensitive to alternative estimation approaches?

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

Figure 1: Ecological Dimensions of ICT



2. Literature Review

The issue of environmental loss has become a major global threat. Economic activities such as industrialization are associated with increased exploitation of natural resources, compromising environmental quality (Garber, 2011). Environmental loss is linked with uncontrolled anthropogenic activities at diverse stages of economic prosperity such as transportation, agriculture, and energy production (Agena, 2007; Siddique and Majeed, 2015; Majeed and Mumtaz, 2017; Iqbal et al., 2021). Recently, the increasing usage of ICT is also becoming a global economic activity. In effect, ICT is penetrating all spheres of socioeconomic and political aspects of life. It is playing a key role in uplifting economic prosperity and development.

The economic gains from ICT are well realized across developed and developing economies (Niebel, 2018; Majeed and Khan, 2018). Does ICT matter for managing environmental quality? This important question, however, has received little attention. The existing literature on ICT and climate change predicts the diverse outcomes of ICT expansion. Linkages between ICT and the environment are complex and conflicting. Therefore, it is important to examine the actual way of a relationship to provide a better understanding of the phenomenon. The present global economy is facing numerous environmental issues such as e-waste management, natural habitat loss, loss of biodiversity, and water and air pollution.

The literature on ICT and CO₂ emissions can be classified into three strands based on the outcomes of the analyses under consideration. The first strand looks at the research on the beneficial effects of ICT development on environmental sustainability. The second strand reviews the literature verifying the detrimental effects of ICT development on environmental sustainability. The third strand of literature reviews the studies that suggest mixed or conditional effects of ICT on environmental quality.

Regarding the beneficial effects of ICT on sustainability, the studies Yi and Thomas (2007), Houghton (2015), Bekaroo et al. (2016), and Gonel and Akinci (2018) are important. They believe that ICT is a vital instrument for regulating environmental resources and efficiency and that it plays a significant role in determining ecological and environmental challenges. ICT, in particular, improves environmental sustainability through two main channels: “greening of ICTs” and “greening through ICTs” (see, Figure 2). The term “greening of ICTs” refers to reducing the carbon intensity of the ICT sector, whereas “greening through ICTs” refers to achieving de-carbonization in other sectors through the adoption of ICT services. Because the ICT sector accounts for 2% of global emissions, “greening through ICTs” may have a greater influence on environmental sustainability than its own footprint. According to Webb (2008), “greening through ICTs” services might have a sevenfold constructive impact on GHG emissions.

These theoretical arguments are also supported by empirical evidence. For instance, by using the data of 43 developed and developing nations

over the period from 2003 to 2008 Lashkarizadeh and Salatin (2012) concluded that ICT investments reduce CO₂ emissions in the sampled economies. Zhang and Liu (2015) focusing on the gross production of electronics, and the information and manufacturing industry have provided an empirical analysis of the Chinese economy. They reported similar findings while covering the period from 2000 to 2010. For the panel of 20 emerging economies, Ozcan and Apergis (2018) documented similar findings. The study of Lu (2018) shows the parallel findings that ICT assists in reducing carbon emissions. The scope of these studies is limited since they only utilize “internet use” as a proxy for ICT and ignore the broader dimensions of ICT. Furthermore, the sample size in these studies is small.

The **second strand** of literature considers ICT development to be detrimental to environmental sustainability. The main idea is that the manufacturing of ICT-related items contributes to climate change. The ICT industry is becoming a power drainer, accounting for 2% of worldwide carbon emissions. Furthermore, e-waste handling is seen as a negative cause of climate change. It is another dimension of ICT infrastructure, which comprises the disposal of numerous ICT-related items including computers, cell phones, LCD screens, and RCT screens. According to Widmer et al. (2005), e-waste is a rising worldwide concern as well as an economic opportunity since it comprises both harmful and useful materials. They also claim that e-waste is poorly managed, putting a strain on the environment.

Liu et al. (2006) investigated the environmental impact of e-waste using Chinese economic data. According to them, recycling e-waste has harmful effects on the environment and human health since electronic waste recycling is not handled appropriately. The problem is further exacerbated by the illicit importation of e-waste from other nations into China. They claim that 60% of the e-waste was sold to private collectors, which was passed into informal recycling processes. For e-waste recycling, more than 90% of Chinese people are unwilling to pay.

According to Osibanjo and Nnorom (2007), ICT progress is responsible for the generation of a substantial quantity of e-waste each year by increasing computer capacity at the expense of computer life. They point out that third-world nations rely heavily on imports of used or refurbished electrical and electronic equipment (EEEs) that have not been tested for

operation. Resultantly, developing nations are presently handling a significant volume of e-waste while facing several issues such as a lack of suitable e-waste infrastructure, insufficient e-waste legal policy, and the lack of any frameworks for adopting extended producer responsibility (EPR).

In this situation, better e-waste management is required to lessen environmental strain (Emmanouil et al., 2013). Salahuddin et al. (2016) conducted an important empirical investigation in this regard. They analyzed data from OECD economies to investigate the influence of internet usage on carbon emissions. Their findings, which span the years 1991 through 2021, support the deleterious impact of internet use on the environment.

The **third strand** of literature views the link between ICT development and the environment as ambiguous due to rebound effects. According to the theory of rebound effects, the beneficial impacts of ICT in the short term might be offset in the long run. If, for example, ICT advancements result in cheaper production, product demand would rise, resulting in greater pollution. These ICT rebound effects have unspecified consequences for sustainability (Hilty et al. 2006; Rieger, 2021).

Hilty et al. (2006) divided the rebound impacts of ICT on the environment into three tiers. The first-order effect implies more e-waste, the second-order effect means greater energy efficiency, and the third-order effect indicates a structural transformation of an economy from product to service. As a result, the impact of ICT growth on the environment can be both beneficial and harmful. The beneficial impacts come from environmentally friendly technology, whereas the negative consequences come from e-waste. Rieger (2021) evaluates whether ICT results in dematerialization in European countries from 2005 to 2017. The author argued that ICT can have both positive and negative effects on material use. However, the analysis did not confirm any relationship.

Raheem et al. (2020) demonstrated that the direct effect of ICT on emissions is positively significant but the combined effect of ICT and FDI is negatively significant in G-7 economies. Chien et al. (2021) suggested that the effect of ICT on emissions varies across the distribution of ICT from 1995 to 2018. They found out that ICT alleviates emissions only in lower quantiles. N'dri et al. (2021) showed that ICT improves the

environment in relatively low-income developing countries and does not have any effect in relatively high-income developing economies for a panel of 58 developing economies from 1990-2014.

Figure 2: Greening ICTs & Greening through ICTs

Greening ICTs	• Lower power consumption of ICT equipment (such as server, router, terminal device) • Typical abatement levers • Ultra lower power device, optical router, sleep mode • Creation of applicable green energy in the IT sector
Greening through ICTs	• Contribution of ICT services in reducing industrial and societal energy consumption leveraging of ICT to make various activities more efficient • Examples: e-commerce, video conferencing; paperless office; BEMS; HEMS; smart grid; smart cities; smart manufacturing

The following research shortcomings are evident in the above literature reviewed on ICT and the environment. First, the nature of research on ICT and disruptions to the environment is largely qualitative and descriptive (Yi and Thomas, 2007; Houghton, 2015; Bekaroo et al., 2016; Gonel and Akinci, 2018). Some studies focus on a case study of an individual country which cannot be generalized for a group of economies (Zhang and Liu, 2015). Third, the literature has mainly focused on developed economies (Salahuddin et al., 2016; Rieger, 2021). Fourth, some empirical studies question the favorable role of ICT on the environment (Widmer et al., 2005; Liu et al., 2006). Fifth, some studies offer regional-specific evidence which cannot be generalized (Ozcan and Apergis, 2018; Lu, 2018). Sixth, the extant empirical studies mainly focus on one aspect of ICT, internet usage, which cannot be applied to other aspects of ICT (Salahuddin et al., 2016; Ozcan and Apergis, 2018; Lu, 2018). Seventh, the studies overlooked the concern of endogeneity.

It can be concluded from the above discussion that ICT infrastructure plays an important role in determining environmental degradation.

However, the direction of the relationship is not 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 the environment.

The theoretical effects of ICT on the environment are ambiguous. Particularly, the environmental effects of ICT in developed economies cannot be generalized to the rest of the world. This study explores the association between ICT and environmental quality for OIC economies from 1980-2018. This study employs unique measures of ICT such as e-government and online service. To the best of the author's knowledge, this research is the first of its kind that addresses this issue for OIC economies. Besides, the issue of endogeneity is also resolved.

3. Data and Methodology

The theoretical foundations of this study are based on the pioneer studies of Grossman and Krueger (1991) and Seldon and Song (1994) who proposed a nonlinear association between economic development and environmental quality.

$$\text{Log } CO_{2i,t} = \beta_0 + \beta_1 \text{Log } GDP_{i,t} + \beta_2 \text{Log } GDP_{i,t}^2 + \varepsilon_{i,t} \quad (1)$$

Where, $CO_{2i,t}$ shows carbon dioxide emissions (metric tons), $GDP_{i,t}$ is GDP per capita (constant 2011 US\$), $GDP_{i,t}^2$ shows the square of GDP per capita and $\varepsilon_{i,t}$ is an error term. Theoretically, the association between ICT and environmental quality is not clear a priori. On the one side, ICT damages the environment owing to improper e-waste management and excessive energy use in the production of ICT-related items (Schluep et al., 2008; OECD, 2010; Houghton, 2015). On the other side, ICT helps to preserve the environment by diffusing environmental information and supporting green technologies.

To model the role of ICT, Equation 1 is rewritten as follows:

$$\begin{aligned} \text{Log } CO_{2i,t} = & \beta_o + \beta_1 \text{Log } GDP_{i,t} + \beta_2 \text{Log } GDP^2_{i,t} + \beta_3 ICT_{i,t} + \\ & \beta_4 \text{log } X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2)$$

Where, $ICT_{i,t}$ denotes information communication technology (ICT). Different measures are used to reflect ICT. Since the impact of ICT on the environment is not clear a priori, signs of the coefficient of ICT can be positive or negative, or insignificant ($\beta_3 > 0$; $\beta_3 < 0$; $\beta_3 = 0$). The term $X_{i,t}$ demonstrates a row matrix of control variables which are energy use, urbanization, and trade. The expected coefficient signs of these three control variables are positive because urbanization, energy use, and fossil fuel increase CO₂ emissions. Equation 2 can be extended for different measures of ICT as follows:

$$\begin{aligned} \text{Log } CO_{2i,t} = & \alpha_o + \alpha_1 \text{Log } GDP_{i,t} + \alpha_2 \text{Log } GDP^2_{i,t} + \alpha_3 FTS_{i,t} + \\ & \alpha_4 \text{log } X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2.1)$$

$$\begin{aligned} \text{Log } CO_{2i,t} = & \gamma_o + \gamma_1 \text{Log } GDP_{i,t} + \gamma_2 \text{Log } GDP^2_{i,t} + \gamma_3 FBS_{i,t} + \\ & \gamma_4 \text{log } X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2.2)$$

$$\begin{aligned} \text{Log } CO_{2i,t} = & \delta_o + \delta_1 \text{Log } GDP_{i,t} + \delta_2 \text{Log } GDP^2_{i,t} + \delta_3 TCI_{i,t} + \\ & \delta_4 \text{log } X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2.3)$$

$$\begin{aligned} \text{Log } CO_{2i,t} = & \theta_o + \theta_1 \text{Log } GDP_{i,t} + \theta_2 \text{Log } GDP^2_{i,t} + \theta_3 OSI_{i,t} + \\ & \theta_4 \text{log } X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2.4)$$

$$\begin{aligned} \text{Log } CO_{2i,t} = & \sigma_o + \sigma_1 \text{Log } GDP_{i,t} + \sigma_2 \text{Log } GDP^2_{i,t} + \sigma_3 EGI_{i,t} + \\ & \sigma_4 \text{log } X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2.5)$$

$$\begin{aligned} \text{Log } CO_{2i,t} = & \varphi_o + \varphi_1 \text{Log } GDP_{i,t} + \varphi_2 \text{Log } GDP^2_{i,t} + \varphi_3 ICT_{i,t} + \\ & \varphi_4 \text{log } X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2.6)$$

Where ICT measure is disaggregated into fixed telephone subscriptions $FTS_{i,t}$, fixed broadband subscriptions ($FBS_{i,t}$), telecommunication infrastructure index ($TCI_{i,t}$), 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.

3.1. Data and Variables Description

The empirical analysis is based on unbalanced panel data. The data is retrieved from different databases. The ICT construct is measured using diverse indicators, namely telephone, broadband, telecommunication infrastructure, online service and e-government. Table 1 provides the summary of variables used for empirical analysis.

Table 1: Summary of Variables

Variables	Definition of Variables	Source
Dependent Variable		
CO2	The outcome variable CO2 is measured in metric tons.	[1]
Independent Variables (Control Variables)		
GDP per capita	Economic prosperity is measured using the data on real GDP per capita. The data on real GDP per capita is constructed at 2011 constant prices (US\$).	[4]
Energy Use	“The control variable ‘energy’ use refers to the use of primary energy before transformation to other end-use fuels.”	
Urbanization	It is the share of population living in urban areas.	[1]
Trade	It is the ratio of the sum of exports and imports as GDP	[1]
Different Measures of Focused Variables (ICT)		
Mobile-cellular Telephone Subscriptions	“Mobile cellular telephone subscriptions (per 100 people) are divided into the number of repaid active accounts (that have utilized during last three months) and number of postpaid subscriptions to a public telephone service”	[2]
Internet Users	“Persons that are used the internet (through any location) in the last twelve months are called internet users.” The internet users are per 100 people.	[1]
Fixed Telephone Subscriptions	“Fixed telephone subscriptions (per 100 people) is the sum of fixed public payphone, fixed wireless local loop, voice over IP subscriptions and ISDN voice channel equivalents.”	[1]
Fixed Broadband Subscriptions	“Satellite broadband, DSL, cable modem, and other broadband subscriptions are part of this variable. Organization subscriptions and residential subscriptions both are included in fixed broadband subscriptions.” It is also measured as per 100 people.	[1]
Telecommunication Infrastructure Index	“This variable is an arithmetic mean of five (standardized) indicators including internet users, mobile subscriptions, fixed broadband subscriptions, fixed telephone lines, and the number of mobile subscriptions.”	[3]
Online Service Index	“Online service index value to a given country that is equivalent to the score (actual total) less the lowest score (total) and divided with a range of total score value for every country.”	[3]
E-Government Index	“E-Government index is constructed using normalized scores weighted average on three dimensions of e-government namely telecommunication infrastructure (telecommunication infrastructure index), human capital index, and quality and scope of online services (online service index).”	[3]
ICT	A combined measure of ICT indicators is extracted using Principal Component Analysis (PCA). The PCA is conducted using four measures of ICT namely fixed telephone subscriptions, fixed broadband subscriptions, internet users & mobile telephone subscriptions.	[1] [2]
Instrumental Variables		
Research and Development (R&D) Expenditure	“R&D covers experimental development, basic and applied research. R&D expenditures are capital and current expenditure including both private and public on the creative work to promote knowledge.”	[1]
Lag values	The lag values of focused variables are also used as instrument variables.	[1][3]

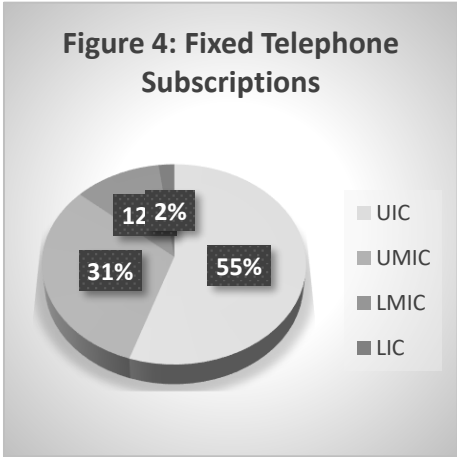
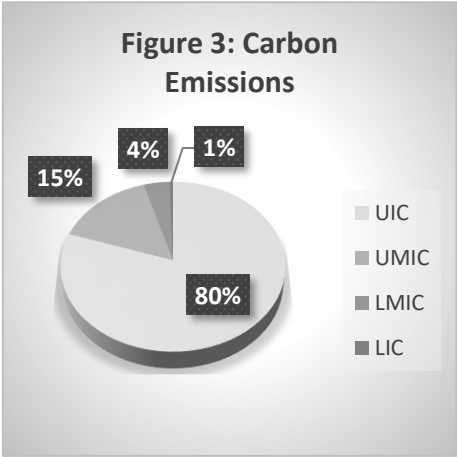
[1] World Bank (2021) [2] International Tele. Union (2021) [3] United Nations (2021) [4] Feenstra *et al.*, (2015)

The original study sample was based on all OIC economies. However, after the screening process, a sample of 45 OIC economies is finalized from 1991 to 2020. Table 2 presents the descriptive analysis of the data. On average, OIC economies emit 5.90 metric tons of emission. However, the standard deviation of these emissions is considerably high (9.47). The lowest value of emissions is 0.05 and the highest value of emissions is 62.

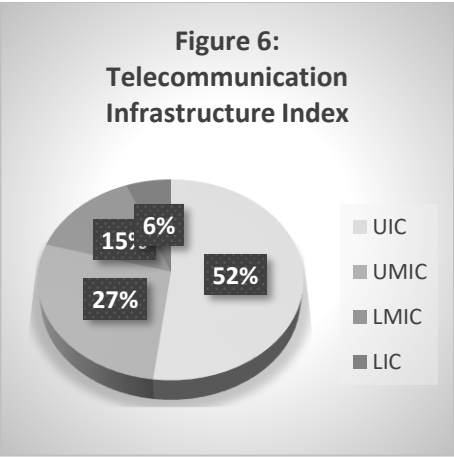
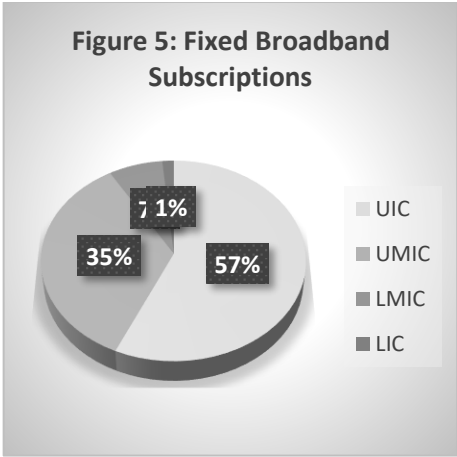
Table 2: Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
CO2	818	5.895	9.471	.0565	61.989
Income	818	6070	10801	175	62138
Energy	818	180.25	164.595	28.071	1197.448
Urban	818	53.828	21.085	16.186	98.812
Trade	818	64.722	32.631	7.994	243.111
Telephone	818	8.919	8.588	0.18169	36.814
Broadband	353	1.490	2.699	0	22.550
Internet	690	9.149	14.775	0	78
Mobile	491	44.655	41.740	0.01865	194.512
Infrastructure	301	0.11161	0.11032	0.00356	0.58551
Online service	301	0.23281	0.16589	0	0.73015
E-government	301	0.33865	0.13985	0	0.73625

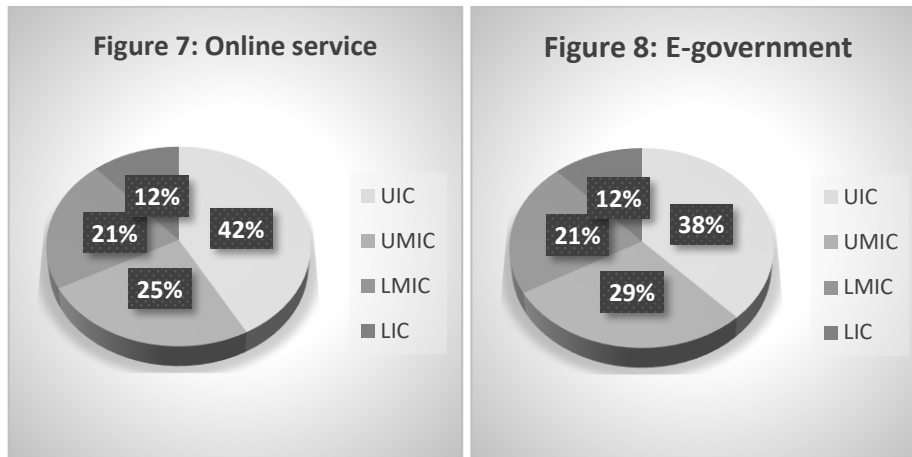
Figure 3 shows that 80% of CO₂ emissions are associated with upper-income countries (UIC) while 15%, 4%, and 1% contribution to total emissions in OIC economies come from upper-middle-income countries (UMIC), low-middle-income countries (LMIC), and low-income countries, respectively. Thus, rich OIC countries contribute more to the pollution than that poor OIC economies. Particularly, the share of LIC countries is just about 1 %. Figure 4 indicates fixed telephone subscriptions covering the study period. It shows that 55%, 31%, 12%, and 2% are associated with UIC, UMIC, LMIC, and LIC, respectively. Similarly, Figures 5, 6, 7, and 8 also demonstrate a similar pattern of alternative ICT indicators.



Source: Author’s own analysis



Source: Author’s own analysis



Source: Author's own analysis

4. Results and Discussion

Table 4 provides empirical outcomes based on pooled ordinary least squares (POLS) regression analysis. The results show that the effects of income and income square on CO₂ are positively and negatively significant, respectively. This finding supports the EKC which suggests that initially developing economies prioritize economic growth ignoring the pollution and later after achieving a certain threshold level of income, society values the environment. Thus, the relationship between income and CO₂ emissions follows an inverted U-shaped relationship. This finding is consistent with Grossman and Krueger (1991), Seldon and Song (1994), Majeed and Mazhar (2020), and Farooq et al. (2022).

Column 2 shows that the parameter estimate on fixed telephone subscriptions (0.524) is positive and significant at a one percent level of significance. This finding is consistent with Liu et al. (2006). The effect of mobile phones, however, is negatively significant which is consistent with Lashkarizadeh and Salatin (2012). Increasing usage of mobile phones increases awareness about the environment, thereby preserving the environment. Column 4 presents the impact of the online service index (-0.107) on CO₂ emissions. This measure of ICT also helps to reduce CO₂ emissions. Increasing utilization of online services reduces the visits to shops and the movement of vehicles, thereby alleviating the burden on the environment. In column 5 e-government, another measure of ICT has an insignificant impact (0.466) on CO₂ emissions. The baseline results confirmed that ICT has an important role in influencing environmental quality in OIC economies. The direction of effects, however, showed a mixed relationship.

Since POLS ignores country-specific effects and unobserved heterogeneity, the results may show a biased conclusion. In the next step, fixed and random effects techniques of estimation are used which take care of country-specific effects and random effects, respectively.

Table 4: ICT and CO2 Emissions (POLS Results)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income	1.134*** (0.168)	2.692*** (0.292)	2.949*** (0.232)	2.966*** (0.256)	2.769*** (0.393)	2.906*** (0.377)	2.812*** (0.386)	2.703*** (0.288)
Income^2	-0.0271*** (0.0100)	-0.100*** (0.0175)	-0.115*** (0.0142)	-0.115*** (0.0156)	-0.102*** (0.0249)	-0.114*** (0.0230)	-0.110*** (0.0233)	-0.100*** (0.0175)
Energy	0.486*** (0.0337)	0.773*** (0.0724)	0.748*** (0.0505)	0.646*** (0.0585)	0.633*** (0.0861)	0.637*** (0.0863)	0.633*** (0.0861)	0.777*** (0.0727)
Urban	0.0748*** (0.0135)	0.0776*** (0.0235)	0.100*** (0.0203)	0.0892*** (0.0217)	0.0969*** (0.0328)	0.0909*** (0.0344)	0.0787*** (0.0323)	0.0821*** (0.0238)
Trade	0.00154** (0.000650)	0.00210 (0.00131)	0.00357*** (0.00101)	0.00513*** (0.00115)	0.00680*** (0.00192)	0.00597*** (0.00180)	0.00520*** (0.00181)	0.00185 (0.00141)
Telephone	0.524*** (0.0209)							
Broadband		0.0143 (0.0149)						
Internet			-0.00232 (0.0111)					
Mobile				-0.0397** (0.0197)				
Infrastructure					-0.944 (0.804)			
Online service						-0.107 (0.318)		
E-government							0.466 (0.450)	
ICT-index								0.0260 (0.0680)
Constant	-10.84*** (0.741)	-19.02*** (1.281)	-20.47*** (0.975)	-19.89*** (1.063)	-19.32*** (1.572)	-19.63*** (1.585)	-19.06*** (1.629)	-19.18*** (1.234)
Observations	818	348	646	492	301	301	301	349
R-squared	0.912	0.872	0.842	0.858	0.873	0.872	0.872	0.871

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

Fixed effects model can control for unobserved heterogeneity. That is, a fixed effects model includes cross-sectional-specific fixed effects and controls for unobserved characteristics that vary across cross-sectional units but are not included in the model. The estimation of the parameters of interest is less biased and more efficient than POLS. Table 5 provides empirical outcomes based on the fixed effects model. Column 1 shows that the parameter estimate (-0.001) on fixed telephone subscriptions is negative and significant at a one percent level of significance. This finding is consistent with Yi and Thomas (2007), Lashkarizadeh and Salatin (2012), (2015), Bekaroo et al. (2016), and Gonel and Akinici (2018). Similarly, columns (2-6) show the effects of other measures of ICT on CO₂ emissions. All selected measures demonstrate a negative influence of ICT on CO₂ emissions. Finally, the ICT index confirms a negative and significant influence on CO₂ emissions in OIC economies.

Fixed broadband subscriptions increase awareness about the environment, thereby preserving the environment. Telecommunication facilitates video and voice conferencing instead of in-person communication. Consequently, the use of vehicles decreases substantially and the burden on the environment alleviates in developed countries. Increasing utilization of online services reduces the visits to shops and the movement of vehicles, thereby lessening the burden on the environment. The adoption and utilization of ICT infrastructure in the public sector improve the efficiency of the government (Majeed and Malik, 2016a, 2016b). Moreover, ICT applications in the public sector improve the management of government for monitoring environmental-related activities such as water consumption, production, manufacturing, and other activities. Finally, column 8 shows the results for the PCA measure of ICT and CO₂ emissions. The negative and significant influence PCA measure of ICT on carbon emissions confirm that overall ICT helps to improve environmental quality by mitigating CO₂ emissions.

Table 5: ICT and CO2 Emissions (Fixed Effects Results)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income	2.054***	1.198***	2.135***	1.552***	1.458***	1.471***	1.445***	1.260***
	(0.273)	(0.346)	(0.298)	(0.277)	(0.462)	(0.460)	(0.464)	(0.347)
Income^2	-0.0652***	-0.0145	-0.0711***	-0.0381**	-0.0320	-0.0314	-0.0318	-0.0153
	(0.0170)	(0.0202)	(0.0184)	(0.0167)	(0.0277)	(0.0276)	(0.0277)	(0.0201)
Energy	0.831***	0.877***	0.818***	0.812***	0.866***	0.868***	0.863***	0.898***
	(0.0563)	(0.0597)	(0.0544)	(0.0585)	(0.0926)	(0.0883)	(0.0887)	(0.0605)
Urban	-0.0247	0.135**	0.0539	0.0786	0.0648	0.0816	0.0572	0.203***
	(0.0344)	(0.0626)	(0.0479)	(0.0569)	(0.0796)	(0.0703)	(0.0714)	(0.0699)
Trade	0.000814*	-0.000204	0.000505	0.000582	0.000803	0.000941	0.000792	-0.000108
	(0.000439)	(0.000602)	(0.000476)	(0.000485)	(0.000830)	(0.000832)	(0.000831)	(0.000622)
Telephone	-0.000755							
	(0.00251)							
Broadband		-0.00379						
		(0.00363)						
Internet			-0.00127*					
			(0.000759)					
Mobile				-0.000102				
				(0.000265)				
Infrastructure					-0.0179			
					(0.244)			
Online service						-0.0988		
						(0.0815)		
E-government							0.0295	
							(0.121)	
ICT-index								-0.0488**
								(0.0221)
Constant	-14.92***	-13.97***	-16.29***	-14.18***	-13.86***	-14.26***	-13.66***	-15.61***
	(1.137)	(1.659)	(1.262)	(1.559)	(2.254)	(2.085)	(2.133)	(1.903)
Observations	818	353	691	492	301	301	301	349
R-squared	0.443	0.527	0.455	0.466	0.493	0.498	0.493	0.535
Number of id	46	45	46	46	45	45	45	45

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

Table 6: ICT and CO2 Emissions (Random Effects Results)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income	2.128***	1.617***	2.248***	1.752***	1.902***	1.906***	1.898***	1.644***
	(0.255)	(0.312)	(0.276)	(0.261)	(0.396)	(0.394)	(0.398)	(0.315)
Income^2	-0.0687***	-0.0370**	-0.0761***	-0.0469***	-0.0548**	-0.0544**	-0.0549**	-0.0371**
	(0.0159)	(0.0185)	(0.0171)	(0.0158)	(0.0241)	(0.0240)	(0.0242)	(0.0186)
Energy	0.839***	0.892***	0.837***	0.844***	0.895***	0.885***	0.893***	0.898***
	(0.0493)	(0.0539)	(0.0489)	(0.0499)	(0.0708)	(0.0700)	(0.0703)	(0.0541)
Urban	-0.0194	0.0732*	0.0366	0.0619	0.0384	0.0478	0.0345	0.104**
	(0.0286)	(0.0430)	(0.0375)	(0.0408)	(0.0465)	(0.0448)	(0.0449)	(0.0456)
Trade	0.000837*	2.46e-06	0.000595	0.000744	0.00105	0.00123	0.00104	0.000122
	(0.000435)	(0.000583)	(0.000471)	(0.000478)	(0.000801)	(0.000806)	(0.000806)	(0.000612)
Telephone	-0.000524							
	(0.00241)							
Broadband		-0.00219						
		(0.00314)						
Internet			-0.00128*					
			(0.000696)					
Mobile				-0.000189				
				(0.000221)				
Infrastructure					-0.0609			
					(0.219)			
Online service						-0.117		
						(0.0800)		
E-government							-0.00459	
							(0.118)	
ICT-index								-0.0320*
								(0.0179)
Constant	-15.35***	-14.98***	-16.64***	-15.05***	-15.60***	-15.74***	-15.50***	-15.71***
	(1.065)	(1.421)	(1.171)	(1.285)	(1.737)	(1.688)	(1.716)	(1.520)
Observations	818	353	691	492	301	301	301	349
Number of id	46	45	46	46	45	45	45	45

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

A fixed effects model assumes that the group-specific effects are fixed, while a random effects model allows for the group-specific effects to vary across groups. In the next step, estimation output based on the random effects model is reported in Table 6. The results confirm the baseline findings. The coefficients on income and income square variable robustly support the EKC for OIC economies. Furthermore, the results also confirm the environment-improving role of ICT in OIC economies.

Finally, Table 7 reports empirical results based on the SGMM estimation approach. The results are relatively improved as all measures of ICT exert a negative and significant influence on CO2 emissions. All measures, excluding fixed telephone subscriptions, have a negative and significant influence on CO2 emissions. Thus, it can be concluded that the greening through ICT hypothesis is accepted in the case of OIC countries. Besides the EKC is also validated in OIC countries.

Table 7: ICT and CO2 Emissions (SGMM Results)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CO2 _(t-1)	0.393*** (0.0117)	0.406*** (0.0341)	0.480*** (0.0240)	0.0564 (0.0483)	0.993*** (0.0133)	0.995*** (0.0136)	1.000*** (0.0141)	0.367*** (0.0318)
Income	2.160*** (0.163)	1.813*** (0.473)	1.960*** (0.210)	3.387*** (0.643)	0.0291 (0.103)	0.118 (0.0953)	0.130 (0.0974)	1.816*** (0.418)
Income ²	-0.108*** (0.00994)	-0.0640** (0.0271)	-0.0774*** (0.0114)	-0.137*** (0.0373)	0.000414 (0.00630)	-0.00622 (0.00537)	-0.00696 (0.00547)	-0.0592** (0.0240)
Energy	0.624*** (0.0495)	0.384*** (0.0883)	0.766*** (0.0637)	0.700*** (0.156)	-0.0196 (0.0143)	-0.0153 (0.0136)	-0.0133 (0.0134)	0.363** (0.145)
Urban	0.199*** (0.00828)	0.0800** (0.0375)	0.160*** (0.0206)	0.103 (0.0725)	0.0103** (0.00513)	0.0163** (0.00751)	0.0121** (0.00609)	0.105* (0.0564)
Trade	0.00413*** (0.000433)	- 0.00705*** (0.00114)	-0.00157*** (0.000350)	-0.00181 (0.00157)	0.000555 (0.000406)	0.000250 (0.000321)	0.000291 (0.000340)	-0.00744*** (0.00104)
Telephone	0.0406*** (0.00172)							
Broadband		-0.0180*** (0.00603)						
Internet			-0.00154*** (0.000302)					
Mobile				-0.00213*** (0.000612)				
Infrastructure					-0.498** (0.238)			
Online service						-0.213** (0.0853)		
E-government							-0.253* (0.152)	
ICT-index								-0.0708** (0.0317)
Constant	-16.41*** (0.773)	-12.29*** (2.126)	-16.15*** (1.403)	-21.86*** (3.728)	-0.280 (0.410)	-0.653* (0.396)	-0.615 (0.411)	-12.88*** (2.197)
Observations	816	301	617	454	301	301	301	297
Number of id	46	44	45	46	45	45	45	44

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

5. Conclusion

The development of technology over the past few decades has greatly boosted economic expansion. However, increasing usage of technology in production activities also enhances GHG emissions which damage the environment. While expanding ICT manufacturing has added to the environmental pressure on the earth, it also has the potential to alleviate that burden by raising awareness and encouraging the use of "Green ICT," which refers to the use of smart tools and technology. This study explores ICT-environment nexus using a panel data set of 45 OIC economies. The analysis is based on POLS, fixed effects, random effects, and SGMM econometric techniques. Besides, the issue of the potential endogeneity problem is resolved. This study concludes that ICT can support environmental preservation. It is imperative that OIC economies collectively frame policies to harness the benefit of ICT to preserve the environment.

The association between ICT and environmental preservation is a newly emerging field of research. The existing literature is limited, and the studies have demonstrated conflicting outcomes. The existing literature mainly focuses on developed economies, small groups of economies, and country-specific experiences. To our knowledge, no prior study has focused on OIC economies in this respect. Most importantly, the empirical literature has mainly used the measure of internet users to proxy the construct of ICT. However, the outcomes of this measure cannot be generalized for other measures. It is imperative to trace out the environmental effect of different measures of ICT and particularly to utilize an index that can provide a more comprehensive picture of the said relationship. The present study fills these research gaps and provides evidence of the ICT-environment nexus for OIC economies using novel measures of ICT. Besides, PCA is also conducted to provide a comprehensive measure of ICT. This study takes care of the possible endogeneity issue and employs alternative econometrics techniques to provide more robust evidence.

This study also has some limitations. Firstly, the data for some OIC economies was not available, therefore, the analysis is limited to 45 OIC economies. Secondly, this study mainly focuses on CO₂ emissions to measure environmental quality. However, this is just one dimension of environmental quality and cannot be generalized for other dimensions of environmental degradation. Thirdly, this study considered OIC economies as different from the rest of the economies. However, the OIC

economies also possess significant heterogeneity within their group which is not captured by this study.

5.1 Theoretical/Policy Implications

To comprehend the connection between economic activity and environmental sustainability, economists and environmentalists have devised a variety of hypotheses, including the EKC and the pollution haven hypotheses. The relationship between ICT and environmental sustainability, however, has been overlooked. To comprehend the connections between ICT and the environment, the literature provides Greening ICT and Greening through ICT hypotheses. Theoretical and empirical research has offered conflicting effects of ICT on the environment. This study offers different policy ramifications for OIC economies. ICT-supporting policies can aid in raising environmental standards in OIC economies. In this sense, spending on research and development can be raised to encourage the development of ICT infrastructure. Additionally, putting ICT infrastructure in the public sector can significantly lessen environmental deterioration. The governments of OIC nations need to decouple the association between economic growth and environmental pollution. Besides, collective and national policies need to be designed to manage e-waste. For instance, e-waste can be better managed by increasing public awareness and education about the proper disposal of e-waste. Similarly, governments need to encourage the development of circular economy principles in the ICT sector by promoting the repair, refurbishment, and recycling of ICT devices.

5.2 Directions for Future Research

This study also offers some directions for future research. For instance, this study employs CO₂ emissions as a proxy for environmental quality, however, future studies can employ additional GHG measures such as nitrous oxide, methane, and fluorinated gases. Future studies may also examine the potential applications of other cutting-edge technologies, including the internet of things, robots, and artificial intelligence. Future research might also compare regional analyses of ICT and the environment to learn more about how ICT is used in various demographic and economic contexts around the world. Future studies should concentrate more on the probable factors that weaken ICT's ability to protect the environment in underdeveloped nations.

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