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Digital Transformation, Institutional Quality, and Environmental Sustainability: Evidence from SAARC Countries

Saif ur Rehman[1], Abid Rashid Gill[2]

[1] PhD Scholar, Department of Economics, The Islamia University of Bahawalpur, Bahawalpur, Pakistan. Email: saifarian2002@gmail.com

[2] Associate Professor, Department of Economics, The Islamia University of Bahawalpur, Bahawalpur, Pakistan. Email: abid.rashid@iub.edu.pk

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ABSTRACT

The ecological changes i.e., global warming and climate change is uprising the apprehensions regarding environment degradation in the developing economies. The consequences of carbon emission and ecological deficit are not only problematic for one country but these are affecting the whole region. Therefore, this study assesses the influence of ICT-enabled digital transformation, IQ (institutional quality), energy consumption, and economic growth on the ecological footprint under the framework of EKC (Environment Kuznets Curve) in the South Asian Association for Regional Cooperation, (SAARC) economies over 1990 to 2018. Additionally, this analysis estimates the interaction term effect (ICT*IQ) on environment sustainability. We employed cross-section dependence (CD), second generation panel unit root (CIPS &CADF), and Wasteland's cointegration econometric techniques. Further, the long and short run estimate concluded though PMG estimator. The PMG-ARDL results exhibited that ICT individual and combine impact lessen the environmental degradation. Moreover, the empirical results validate EKC hypothesis SAARC economies. But, institutional quality, economic growth (GDP) and energy consumption intensify environmental degradation by increasing the ecological footprint. The empirical estimates propose that ICT- enabled digital transformation innovation, diffusion and utilization in institutional framework can achieve the SDGs goals of environmental sustainability.

Corresponding Author's Email: saifarian2002@gmail.com

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1. Introduction

Currently, the ecological changes i.e., global warming and climate change is uprising the apprehensions regarding environment degradation in developing Asian economies. The menace of global warming along with other extensive ecosystem changes, resource depletion, soil erosion, water and air pollution has compelled the stakeholders to think about the sustainability character of information system technologies (Papagiannidis & Marikyan, 2022). The consequences of carbon emission and ecological deficit are not only problematic for one country but these are affecting the whole region. The inevitable beset of climate changes are needed to address collectively. The SDG endeavor of sustainable human and economic development call on, to promote biodiversity, to control environmental degradation and to preserve the ecosystem (Nathaniel & Adeleye, 2021).

Vial (2019) recognized that digital equipment & technologies i.e. artificial intelligence (AI), IoT, mobile technologies, social platforms, and big data analytics prompt constructive enhancements for industry and society. ICT is the main driver of these digital technologies. The ICTs have both damaging and constructive impacts on environment sustainability, in an indirect, direct, and rebound way. Numerous studies have recognized a direct and indirect damaging impression of ICT on environmental sustainability; increasing the share of CO_2 and greenhouse gases emission (Belkhir & Elmeligi, 2018). In SAARC economies internet connectivity has increased in last two decades i.e., in 2005 internet connectivity was 3 %, then 14% in 2015 and now 43 % in 2021. Similarly mobile internet connectivity has also increased from 17% in 2014 to 34% in 2018. The use of ICT raise the demand of electricity that indirectly amplifies the CO_2 emission level (Salahuddin & Alam, 2016), the penetration of ICT positively and significantly play a part in carbon emission (Atsu, Adams, & Adjei, 2021).

ICT led economic growth boost the economic activities but also contributes in achieving the intent of environment sustainability through energy efficient and conservation technologies. (Usman, Ozturk, Hassan, Zafar, & Ullah, 2021). In the finale stages of the development, the penetration of ICT firmly sustain the environment (Khan, Sana, & Arif, 2020). ICT expansion can gain the target of energy efficiency and introduction of 'green IT' has the potential to constraint the electricity consumption specifically in data centers due to ICT use (Salahuddin & Alam, 2016). Digitalization and green ICT products are enhancing the environment sustainability by shifting the economy from physical to information resources (Wei & Ullah, 2022). The expansion and penetration of ICT in most polluting sector transportation and manufacturing can strengthen the environment sustainability (Caglar, Mert, & Boluk, 2021).

The second main concern of the study is to investigate the influence of IQ (institutional quality) on environment sustainability. In a broader spectrum institutional quality means individual rights, laws, and blue-ribbon government directive and services (Iheonu, Ihedimma, & Onwuanaku, 2017). Institutional quality can improve the environmental health through feasible and operational environmental policies. In developing economies environmental degrading factor at the end of institution, are lacking the establishment of regulatory institutions, absence of punitive legislation regarding environmental pollutants emission, deficiency in the implementation of restrictive and preventive rules and regulation in manufacturing polluting activities, opportunistic and high level corrupt behavior in the exploitation of natural resources (Akhbari & Nejati, 2019). Similarly, institutional quality (IQ) has also an imperious character in environmental sustainability. As, the constructive impact of institutional quality is to reduce carbon emissions and decrease ecological footprint(Hussain & Dogan, 2021a). Moreover, institutional quality weaken the environmental quality by accelerating the carbon emission, escalating energy utilization, and increasing the ecological footprint (Azam, Liu, and Ahmad (2021).

Moreover, ICT can moderate the relation between IQ and EF. ICT-based stratagem through e-government ensure transparency and implementation of laws (Relly & Sabharwal, 2009), reduce the corruption, openness and transparency (Bertot, Jaeger, & Grimes, 2010). The ICT technologies (sensing , communication, display, analysis and storage) can be used for institutional administrative efficiency such as, organization of information, enhancement of effectual communication and planning system, upgrade monitoring network, and managed the instruction order (Onyije & Opara, 2014). So, ICT-enabled digital transformation can invigorate the process of political development; accelerate the efficiency of general administration, and moderate the bureaucracy domination, more transparency, boost the public realization, and participation.

The appealing and compelling element for the investigation of SAARC economies is that these economies are highly populated, resource-intensive, ecologically deficit and affected of global warming. In SAARC region severe climate changes are observing as changing in the intensity of rainfall, extreme flood occurrence, rising the sea level and glacier melting (Mani, Bandyopadhyay, Chonabayashi, & Markandya, 2018), severe water scarcity in response to ecological imbalances (Kant, 2018), health issues due to heat waves, dehydration and flooding (Losos, Pfaff, Olander, Mason, & Morgan, 2019). But these economies have a potential to adopt sustainable ICT-enabled digital transformation in the field of agriculture, manufacturing, and services. Further, by ameliorating the institutional quality and stringent environmental regulations can sustain the environment.

The study has resulting contributions: firstly, to be evaluated that ICT and IQ have any contributing role in the environment sustainability of SAARC economies. Additionally, a comprehensive index in respect of institutional quality (IQ) is used to get dependable conclusions. Secondly, as earlier discussed the novelty of analysis, is to evaluate joint effect (ICT and IQ) on environmental sustainability in SAARC economies. Thus, the outcome will provide the new dimensional impact of ICT- IQ on environment sustainability and will suggest some possible options for policymakers in SAARC economies. Thirdly, ecological footprint is used as proxy for environmental sustainability. Why choose EF (ecological footprint)? In ecological economics EF is a futurist and new approach that measure energy and non- energy activities (Shahzad, Fareed, Shahzad, & Shahzad, 2021). Fourthly, the study employed second generation estimation techniques due to realization of panel data concernments i.e. cross-sectional dependency, stationarity, cointegration, endogeneity, heterogeneity, and serial correlation. Finally, the spirit of the analysis is, to have some valuable addition in the literature of sustainable development. Hence, the research work is structured as follows; literature review conferred in section two. Whereas, section three, is discussed theoretical basis, specification of model, data description & source, and estimation process. Then section four reported estimated findings & discussions. Finally, in last, conclusions and implications regarding policies are debated.

2. Literature Review

2.1. Nexus between ICTs and Environmental Sustainability

In the circle of researchers and investigators ICTs have direct and negative (destructive) footprint on environmental quality. Atsu et al. (2021) in a study on South Africa during the period 1970-2019 by employing ARDL technique and resulted that ICT positively and significantly play a part in carbon emission. Mekhum (2020) assessed the impact of ICT on CO in ten selected Asian countries , using PCSE and System GMM technique and find that ICT development increase the carbon emission and compromise the environment quality. Avom, Nkengfack, Fotio, and Totouom (2020) did a study on 21 sub Saharan African countries, sample period of 1990-2024, applied panel ARDL model and estimated that the penetration of ICT in SSA aggravate the environment sustainability. Magazzino, Porrini, Fusco, and Schneider (2021) examine the link between ICT, economic growth and air pollution in 16 selected countries of European Union during the period 1990-2017, using PMG-ARDL model, analyzed that ICT penetration along with economic growth effect on environment are adverse to boost the carbon emission.

The indirect and positive footprint of ICT- enabled digital transformation has occurred i.e. in urbanized areas through smartification of cities , the installation of energy control, monitoring, and energy efficient ICT devices is improving the living standards of individuals, efficiently utilizing the resources and categorically contributing in environment sustainability (Aamir et al., 2014; Bacco, Delmastro, Ferro, & Gotta, 2017; Neirotti, De Marco, Cagliano, Mangano, & Scorrano, 2014), in the agriculture field smart farming reducing the operating and sustaining the environment by reducing the volume of water, space and light (Kalantari, Mohd Tahir, Mahmoudi Lahijani, & Kalantari, 2017), in household case the utilization of teleworking tools i.e. web conference, online office , remote working, and email are reducing the emission and sustaining the energy resources (Papagiannidis, Harris, & Morton, 2020; Papagiannidis & Marikyan, 2020). The digital transformation in energy sector by regulating the electric network and avoiding the fluctuation through ICT devices IOT and Cloud computing may substantially minimize the power consumption (Das, Chanda, & De, 2020), smart interconnection of power grid may safer the operation (Mohammadi, Safdarian, Mehrtash, & Kargarian, 2018), the efficient smart power grid based on IOT (internet of Thing) energy management framework control the energy balance with minimal cost (Golpîra & Bahramara, 2020), in smart cities IOT network can control the energy efficiently (Baz, 2018). Caglar et al. (2021) inquired the association between ICT, economic growth, nonrenewable energy consumption and ecological footprint in top ten polluting economies over the period 1990-2017, using PMG-ARDL method , and investigated that ICT penetration and activities enhance the ecological footprint in these top polluting economies.

2.2. Nexus between Institutional quality and Environmental Sustainability

Government institutions curb the menace of corruption through good governance, effective judicial system, efficient law execution and institutional support which indirectly strengthen the enforcement of environment regulation (Liu, Latif, Latif, & Mahmood, 2021) Control of corruption, good governance, legislation regarding green energy consumption are strengthening factor of institution quality to control the environmental complications (Bakhsh, Yin, & Shabir, 2021). Democracy level, civil liberties and governing system of a country control the environmental hazard but at the same time boost the environmental quality of neighboring countries through spillover effect (Hosseini & Kaneko, 2013). The development of institutional structure and strong policies, at the end of government, to launch less carbon-intensive technologies can meliorate the environmental disclosure (Tamazian & Rao, 2010). Environmental governance mechanism and designing and implementation of growth oriented policy strategy can curb the pollution (Lau, Choong, & Ng, 2018). Uzar (2021) made a significant effort to assessed the impact of institutional quality on ecological footprint in E-7 economies ranging from 1992-2015, used CCEMG and AMG estimators, investigated that Wang, Zhang, and Wang (2018) in a study probed the moderating character of control of corruption on economic growth and CO_2 nexus in BRICS economies over the period 1996-2015, used PLS modeling , deduced that control of corruption weaken the economic growth-carbon emission nexus by lessening the CO_2 emission.

Numerous empirical evaluations inferred that the influence of institutional quality (IQ) reported negative in environment quality. Mehmood, Tariq, Ul-Haq, and Meo (2021) in a country specific study of three developing economies (India, Pakistan, and Bangladesh) the independent role of institutional quality on CO_2 emission by employed ARDL model over the period 1996-2016, inferred that institutional quality has positive relationship with carbon emission. Teng, Khan, Khan, Chishti, and Khan (2021) employed the PMG-ARDL method to evaluate the impression of IQ on CO_2 emission along with control variables during the period 1985-2018, evaluated that IQ, economic growth and consumption of electricity adversely affect the environment sustainability. Gyamfi, Ampomah, Bekun, and Asongu (2022) in a study reviewed the influence of ICT and IQ on climate change in E-7 economies during the period 1995 to 2016 by employing AMG and CCEMG estimation technique, concluded that both ICT penetration and institutional quality deteriorate the environment and do not contribute in the mitigation of the climate change.Öztürk and Le (2020) in a study investigated the relationship between energy use and institutional quality in 47 EMDEs economies, employed AMG, and CCEMG estimators, concluded that IQ and energy utilization multiply the environmental pollution. Azam, Liu, and Ahmad (2020) in a study probed the impact of institutional quality on different indicators of environment degradation by using system GMM in 66 developing economies, during the period 1991-2017, and figure out that institutional quality positively degrade the environment by increasing CO_2 and CH_4 emission.

2.3. ICT moderating role in Institutional quality and Environmental Sustainability

The utilization of e-government application, use of internet in the implementation of rule of law Jianguo, Ali, Alnori, and Ullah (2022)examine the nexus between institutional quality, technological innovation and environment quality in 37 OECD economies ranging from 1998 to 2018, applied two step system GMM estimation technique and resulting that both institutional quality and technological innovation significantly meliorate the environment sustainability.

Bakhsh et al. (2021)evaluate the relationship among technological innovation, carbon emission and institutional quality in 40 Asian economies over the period 1996 to 2016, utilized GMM technique and acquired that institutional quality and technological advancement dampen the environmental degradation aspect of carbon emission. Liu et al. (2021)investigate the moderating role of ICT in corruption- carbon emission nexus in a panel of 33 Asian economies, using FMOLS and DOLS estimator, during the period 2000 to 2015, find out that the interaction outcome of ICT and Corruption has fruitful impact on environment sustainability by reducing the polluting agent i.e. CO_2 emission. Ulucak, Danish, and Khan (2020) used the globalization channel to evaluate the relationship between CO2 emission and ICT development in BRICS economies over the period 1990-2015, employed CUP-FM and CUP- BC estimator, revealed that ICT development has favorable footprint on carbon emission

Consequently, at the theoretical periphery, no unanimity; the ICT and IQ effect on environment sustainability is constructive, destructive, or inapt. Therefore, it is called-for, revaluation the ICT and IQ footprint on environment sustainability at theoretical and empirical end.

2.4. Research Gap

(i) The reviews of literature depict that numerous studies employed CO_2 emissions as proxy of environmental sustainability but this study is utilizing ecological footprint that is a comprehensive and better proxy of environmental sustainability (ii) The literature also identified the ICT-enabled digital transformation and IQ effects regarding environmental sustainability is investigated limitedly in case of SAARC economies. It is the need of time to investigate further. (iii) In prior studies empirically joint effect of ICTs and IQ did not estimate in SAARC economies. This study will explore the joint influence (ICT*IQ) on the sustainability of environment.

3. Theoretical Framework

The theoretic analysis of study based on the acknowledged EKC (Environmental Kuznets Curve). In developing economies EKC hypothesized that sustainability of environment aggravate at preliminary stage of development and continue to meet its peak point, and afterwards begin to improve as economy grow. The standings of EKC explicate that technological advancement and institutional arrangements improve the environment sustainability.

On the theoretical front, ICT-enabled digital transformation has damaging (negative) role on the environment sustainability i.e. the use of ICTs equipment increase the share of total electricity consumption that produce through the utilization of inefficient sources i.e. fossil fuels (Danish, Khan, Baloch, Saud, & Fatima, 2018), in-efficient ICTs application, equipment's, production, and services increase CO_2 emission (Park, Meng, & Baloch, 2018), e-waste of ICT infrastructure and products have adverse effects on environment (Vishwakarma et al., 2022). The positive character of ICT- enabled digital transformation, designed new prototypes of business by sustaining the environment i.e. use of smartphone application in transportation reduce the traffic congestion and carbon emission(Gloet & Samson, 2022), in developing economies mobile application utilization by farmers updated their information about market prices, weather and agriculture devices and in return multiplying the income and upgrading the crop quality (Kramer & Porter, 2011), online shopping, telework , video conferencing, and e-marketing improved the individual welfare, even handed approach to goods and services and escalate convenience by reducing fuel consumption, road traffic and business operating cost (Hilty & Aebischer, 2015).

Institutional quality is also conclusive element that has an ability to improve the environmental sustainability through policy measures. The institutional framework of civil and political liberties, and perfect awareness about environmental sustainability have decisive role in curbing the pollution (Abid, 2017). Political stability promotes the clean energy consumption and retrieve the environment sustainability (Sohail, Majeed, Shaikh, & Andlib, 2022). Further, incapacitated institutional set-up afford rent-seeking in investor favor and overlook the rigorous environmental policies execution (Baloch & Wang, 2019). As, developing economies have weak and poor institutional framework i.e. corruption, various forms of bribery, inefficient bureaucratic system, no transparency in policy making, loopholes in environmental laws and regulations constraint the promotion of environment innovation activities in industrial sector (Nam & Thanh, 2021).

3.1. Model Specification

As discussed earlier, re-assessing the ICT and IQ impact on environment sustainability in SARRC economies, the empirical framework is specified as follows:

$$LEF_{it} = \delta_0 + \delta_1 LGDP_{it} + \delta_2 \mathrm{L}GDP_{it}^2 + \delta_3 \mathrm{L}EC_{it} + \delta_4 ICT_{it} + \delta_5 IQ_{it} + \omega_{it} \qquad (1)$$

Here, δ_0 denotes intercept, δ_1- δ_4 are parameters and ω is error term. Then, subscripts i and t are country and time dimension respectively. Here, ecological footprint (LEF) proxy for environment sustainability. The economic growth is GDP, and EKC is measured through quadratic term of GDP. ICT index estimated through four ICT measuring indicators, i.e., the subscriber of (internet users, mobile cellular, fixed telephone, and fixed broadband). Further, IQ (institutional quality) is proxy of about 12 divergent indicators. More, EC is determining the energy consumption.

Furthermore, originality of research work is to assess moderating effect of ICT in the relation between IQ and EF in SAARC economies. The eq (1) incorporated $(ICT^{*}IQ)$interaction term. Thus, the empirical framework in eq. (2) specifies the assessment of ICT as moderator in the relation between IQ and EF.

$$LEF_{it} = \delta_0 + \delta_1 LGDP_{it} + \delta_2 \mathrm{L}GDP_{it}^2 + \delta_3 \mathrm{L}EC_{it} + \delta_4 ICT_{it} + \delta_5 IQ_{it} + \delta_6 (ICT^{*}IQ)_{it} + \omega_{it} \qquad (2)$$

The predictable economic growth (GDP) sign positive on EF ($\boldsymbol{\delta_1 = \frac{\Delta EF}{\Delta GDP} > 0}$)**,** and the squared term of GDP in term of EKC is probably have –ve impression on EF ($\boldsymbol{\delta_2 = \frac{\Delta EF}{\Delta GDP^2} < 0}$). EC (Energy consumption) of non-renewable has noticeable effect in degrading the environment quality. Consequently, EC (energy consumption) the predictable impression on EF will positive ($\boldsymbol{\delta_3 = \frac{\Delta EF}{\Delta EC} > 0}$). ICT has both negative and positive impression on EF($\boldsymbol{\sigma_4 = \frac{\Delta EF}{\Delta ICT} > 0 / < 0}$)**.** Additionally, another imperative variable institutional quality (IQ) enriches the environment quality over environmental legislation and implementation of policy recommendations. Further, it is expected, institutional quality (IQ) will have negative outcome on EF($\boldsymbol{\delta_5 = \frac{\Delta EF}{\Delta IQ} < 0}$)**.** Henceforth, the join effect of IQ and ICT is anticipated that –ve influence on EF($\boldsymbol{\delta_6 = \frac{\Delta EF}{\Delta (ICT^{*}IQ)} < 0}$).

3.2. Data Description

The data sample of the study, due to data constraint, is consist of four SAARC economies Bangladesh, India, Pakistan and Sri Lanka a panel of annual observations over the period 1990–2018. The dependent or response variable EF is acquired from the GFN (Global Footprint Network database 2020). In ecological economics EF is a futurist and new approach that measure energy and non- energy activities (Shahzad et al., 2021).

Constant with the current ICT literature the study employed ICT index calculated through four ICT determining indicators, i.e., internet user subscription, mobile cellular subscriber, fixed telephone subscriber, and fixed broadband subscriber. These pertinent measures are taken per 100 people. The principal component analysis (PCA) utilized to develop ICT index as employed by(Ulucak et al., 2020). Furthermore, a comprehensive index employed as 12 indicators of institutional quality (IQ) provided by ICRG as described in Table (1). The IQ index is calculated by taking all indicators sum such as applied (Hussain & Dogan, 2021b). Then the controlled variables, as energy consumption (EC) considered energy use (kg of oil equivalent per capita) and GDP (economic growth) is taken as per capita GDP (at constant $2010).

We collected the data from different sources as response variable EF (ecological footprint) is attained from Global Footprint Network database (GFN 2020). Further, GDP per capita, ICT, and EC is obtained from WDI (World Development Indicator 2020). IQ (Institutional quality) proxy of 12 different indicators collected through PRS publishing group of ICRG (International Country Risk Guide).

Table 1
Variables description and Measurements

Variables	Unit Measurement	Data Source
Environmental Sustainability	EF is calculated in global hectares per capita)	GFN (Data base Global Footprint 2020)
(Information and Communication Technology) ICT	ICT index as Internet penetration rate (per 100 people), fixed broadband subscriptions (per 100 people), Mobile phone penetration rate (per 100 people), and fixed telephone subscriptions (per 100 people).	World Development Indicator (WDI) (World Bank 2020)
Institutional Quality	(IQ) index proxy of 12 divergent indicators "government stability, law and order, corruption, socioeconomic condition, bureaucratic quality, democratic accountability, investment profile, external conflicts, military in politics, religious tension, ethnic tension, and internal conflicts"	ICRG (International Country Risk Guide) published by the PRS group (2020)
Economic Growth	Per capita GDP (constant $2010)	WDI (World Development Indicator) (World Bank 2020)
Energy Consumption	Energy in use (per capita kg of oil equivalent).	WDI (World Development Indicator) (World Bank 2020)

3.3. Estimation Process

In the estimation process, especially in regional analysis, CSD (cross sectional dependence) test is employed. The issue of CSD arises in penal data due to globalization and economic inter-dependence among regional economies (Caglar et al., 2021). Therefore, Pesaran (2004) CD and Scaled LM test employed for empirical inquiry . The CD statistic in equation is specified as:

$$CSD = \frac{\sqrt{2T}}{N(N-1)} \left(\sum_{i=0}^{N-1} \quad \sum_{j=i+1}^{N-1} \vartheta ij \right) N(0,1) \tag{3}$$

The stationarity of model variables is estimated through 2nd generation unit root tests Pesaran (2007) CADF(Cross-sectional Augmented Dickey–Fuller) and CIPS (Cross-sectional augmented Im–Pesaran–Shin). In the scenario of cross sectional dependency and heterogeneity above said test are efficient. The equation the test as:

$$\delta CA_{it} = \omega_i + \omega_i Z_{i,t-1} + \omega_i \overline{CA_{t-1}} + \sum_{i=0}^{n} \omega_{il} \delta \overline{CA_{t-1}} + \sum_{i=0}^{n} \omega_{il} \delta CA_{i,t-1} + \sigma_{it} \tag{4}$$

Here, $\overline{\boldsymbol{\delta CA_{t-1}}}$ and $\overline{\boldsymbol{CA_{t-1}}}$ are the averages of cross section. Further, the statistics of CIPS test is written as

$$\widehat{CIPS} = \frac{1}{N} \left(\sum_{i=1}^{p} CADF_i \right)$$

The null hypothesis of CADF and CIPS tests presume non-stationarity as compared to stationarity in alternative hypothesis in the penal variables.

As compared to common cointegration test i.e. Kao (1999) and Pedroni (2000), the study employed Joakim Westerlund (2007) cointegration technique due to cross dependency among the estimated variables in regional analysis. Furthermore, as Westerlund and Edgerton (2007) bootstrapping reduces the bias of the asymptotic test. Thus, the null hypothesis assumes, no cointegration irrespective to alternative hypothesis of cointegration.

Finally, to assess the long-run and short-run linkages in EF, GDP, EC, ICT, and IQ, the study employed Panel ARDL-PMG (Pooled mean group) econometric method that originated by Pesaran and Smith (1995) and Pesaran, Shin, and Smith (1999).The PMG-ARDL method has robustness in case of heterogeneous and cross-sectional model.

As followed Adedoyin, Gumede, Bekun, Etokakpan, and Balsalobre-Lorente (2020) the PMG_ARDL model (1,1,1,1,1,1) is written as:

$$LEF_{it} = \tau_{ij} + \vartheta LEF_{it-1} + \sum_{j=1}^{n} \pi_{10i} \Delta \mathrm{L}(EF)_{it-j} + \sum_{j=1}^{n} \pi_{11i} \Delta \mathrm{L}(GDP)_{it-j} + \sum_{j=1}^{n} \pi_{12i} \Delta \mathrm{L}(GDP^2)_{it-j} + \sum_{j=1}^{n} \pi_{13i} \Delta \mathrm{L}(EC)_{it-j} + \sum_{j=1}^{n} \pi_{14i} \Delta \mathrm{ICT}_{it-j} + \sum_{j=1}^{n} \pi_{15i} \Delta \mathrm{IQ}_{it-j} + \gamma_{10} \mathrm{L} EF_{it-1} + \gamma_{11} \mathrm{L}(GDP)_{it-1} + \gamma_{12} \mathrm{L}(GDP^2)_{it-1} + \gamma_{13} \mathrm{L}(EC)_{it-1} + \gamma_{14} ICT_{it-1} + \gamma_{15} IQ_{it-1} + \mu_i + \epsilon_{it} \tag{5}$$

Here, τ_{ij} intercept term and ϑ depict coefficient of lagged values of response variable. Further, π_{10} to π_{15} be coefficients of short run and γ_{10} to γ_{15} indicate long run coefficients of explained and independent variables. Moreover, $\epsilon_{it}$is error term and group effect is μ .

4. Results and Discussion

As of Table 2, Pesaran CD and Pesaran Scaled LM, ratify the cross-sectional dependency in all variables. Hence, significant p values validated the CD test alternative hypothesis assumption of cross-sectional dependency.

Moreover, on the suggestion CD test outcome, we employed 2nd generation panel unit root tests Pesaran (2007) CIPS and CADF. The table (3) results of CADF and CIPS with constant and trend indicate that the order of integration in mostly variables is I (1). There is a mix order of integration or stationary level is I(0) and I (1).

Table 2
CD Test Results

Variables	Pesaran Scaled LM		Pesaran CD	
	Statistic	*P*-value	Statistic	P-value
LEF	19.753***	0.0000	7.705***	0.0000
LGDPPC	46.108***	0.0000	13.027***	0.0000
$LGDPPC^2$	46.042***	0.0000	13.028***	0.0000
LEC	45.720***	0.0000	12.975***	0.0000
ICT	25.813***	0.0000	9.789***	0.0000
IQ	32.217***	0.0000	11.022***	0.0000

Note: The symbol *** represents the significance level at 1%.

Table 3
Unit Root Test

Variables	CIPS Panel unit root test				CADF Panel unit root test			
	Constant		Trend		Constant		Trend	
	Level	1st Difference	Level	1st Difference	Level	1st Difference	Level	1st Difference
LEF	-2.810*	__	-2.744	-5.591*	-2.498***	__	-2.365	-3.183**
LGDPPC	-1.599	-4.001*	-2.678	-4.208*	-1.293	-3.063*	-2.097	-3.541*
LGDPPC2	-1.471	-3.887*	-2.322	-4.065*	-1.184	-2.867**	-1.815	-3.282**
LEC	-2.278	-5.341*	-2.321	-5.274*	-2.335	-3.677*	-2.183	-3.671*
ICT	-0.562	-3.340*	0.299	-3.519*	-1.660	-3.809*	-2.037	-3.777*
IQ	-2.843*	__	-2.843**	__	-2.766**	__	-2.97***	_

***, **, *Significance at 10%, 5% and 1% respectively. The particular test is being performed initially by using intercept & trend at level and then used 1st difference of all parameters.

The Westerlund (2007) cointegration test outcomes in table (4), under bootstrapping by using 300 replications, expounded it in model (1) group statistics Gt, Ga and Pt, Pa panel statistics are significant at robust p values. Correspondingly, in model (2) Gt and Pt and Pa are significant on robust P value.

Table 4
Westerlund (2007) Cointegration Test

	Model 1			Model 2		
Statistics	Z-value	P. Value	R P. Value	Z-value	P. Value	R P. Value
Gt	-3.475*	0.000	0.000	-2.827*	0.002	0.003
Ga	1.409***	0.921	0.100	2.134	0.984	0.183
Pt	-3.307*	0.001	0.003	-2.942*	0.002	0.007
Pa	0.564***	0.714	0.083	1.310***	0.905	0.097

Notes: ***, **, and * indicate significance at 10%, 5%, and 1% percent. Bootstrapping is done by using 300 replications.

The cointegration relationship affirmation in both model then the coefficient estimation technique PMG-ARDL applied. The calculated long run and short coefficients long run and results are write down in Table 5. As that the requisite of long run link among variables is that ECT (Error correction term) should be less than one, negative and significant. The -0.62 and –0.92 Value of ECT in model 1 & 2 specify that imbalance or ecological deficit is being annually corrected at a speed of 62 and 92 %.

From table (5) the GDP positively and significant p values conclude that ecological deficit is increasing. More specifically, 1% increase in GDP depreciates the environment quality approximately 2.48 %. This depreciation or ecological deficit will continue till the threshold level.

The estimated outcome supports the preceding studies (Latief, Kong, Javeed, & Sattar, 2021; Naseem & Guang Ji, 2021; Pata, Yilanci, Hussain, & Naqvi, 2022). Further, the –ve sign of GDP^2 endorses the existence of EKC in SAARC economies for the duration of the sample period. The negative coefficients of GDP^2 exponent that a 1% ascends in GDP^2 are shrinking the EF in long term by 0.184% in model (1) and 0.210% in model (2) respectively.

Table 5
PMG- ARDL Estimates

	Variables	Model 1			Model 2		
		Coef.	**S.E.**	**Prob.**	**Coef.**	**S.E.**	**Prob.**
Long Run Equation	LGDPPC	2.848*	1.007	0.010	3.086*	0.967	0.002
	LGDPPC^2	-0.184*	0.069	0.010	-0.210*	0.0708	0.004
	LEC	0.195**	0.094	0.041	0.204*	0.055	0.000
	ICT	-0.024*	0.222	0.006	-0.227**	0.072	0.002
	IQ	0.115*	0.036	0.002	0.090*	0.021	0.000
	ICT*IQ	__	__	___	-0.050*	0.017	0.005
Short Run Equation	ECT	-0.620*	0.130	0.000	-0.926*	0.349	0.010
	D(LGDPPC)	11.181	23.47	0.635	35.654	52.44	0.499
	D(LGDPPC^2)	-0.846	1.708	0.149	-2.670	3.855	0.4991
	D(LEC)	0.075	0.041	0.171	-0.0823	0.198	0.678
	D(ICT)	0.031	0.025	0.217	0.0258	0.173	0.881
	D(IQ)	0.074	0.015	0.321	0.0708	0.027	0..112
	ICT*IQ	__	__	___	0.006	0.041	0.8705
	C	-8.397	1.751	0.000*	-12.94*	4.913	0.010

Note: *, **, *** denote 1%, 5% & 10% significant level.

As that, the rationality of EKC theory in SAARC economies is constant to former investigations (Kiani, Sabir, Qayyum, & Anjum, 2022; Sabir, Qayyum, & Majeed, 2020; Verma, Kumari, & Giri, 2023).

In connection with the main variable effect of ICT; the outcomes of ICT coefficients in both models reveal negative and significant relationship with EF in long run. Further, 1 % dissemination of ICT shrinks the ecological footprint and boosts the environment sustainability normally 0.024% and 0.227% in both models individually. The dynamics of short run regarding ICT coefficients exhibits positive but insignificant relationship that means ICT diffusion at primary stage devalue the environment quality in respect to 'use effect'. In the long run and latter stages of the development, the diffusion of ICT firmly sustain the environment (Khan et al., 2020). As Kouton (2019) analyzed that ICT-based solution for environment sustainability such as internet associated sensor based light and temperature monitoring system in buildings and households, continuous inform system of energy consumption, automation at power grids and infrastructure, reduces the demand of fossil fuel in energy production. These estimated outcomes regarding ICT on EF in SAARC economies are parallel to other studies as (Chien et al., 2021; Rehman, Gill, & Ali, 2023; Verma et al., 2023).

Furthermore, the institutional quality impression on ecological footprint is positive and significant that infers, 1 % change in IQ will depreciate the environment quality in the long-term about 0.115 % and 0.090 in both models respectively. It specifies that environment devaluation and non-implementation of environmental laws in SAARC countries is because of poor institutional control. Political instability, conflict and violence not only dwindles the macroeconomics performance but at the same time lessen the implementation of environment regulations (Al-Mulali & Ozturk, 2015). These empirical endings are constant with former findings (Kakar, Khan, & Khan, 2023; Mehmood et al., 2021; Teng et al., 2021).

Lastly, as earlier discussed the novelty of analysis, is to evaluate joint effect (ICT and IQ) on environmental sustainability in SAARC economies. The negative and significant (ICT* IQ) interaction term coefficient is deducing that one percent change in (ICT*IQ) diminishes the ecological footprint about 5 % in long run. These empirical findings regarding ICT moderating effect on environment sustainability and institutional quality relationship is relatively new and can be incorporated in academic literature. Further, provides new prospect regarding ICT penetration rectify institutional arrangement via E- government, administrative control and public cognizance about climate variation in SAARC economies. The interaction outcome of ICT and Corruption has fruitful impact on environment sustainability by reducing the polluting agent i.e. CO_2 emission (Liu et al., 2021).

5. Conclusion and Recommendations

The objective of exploration to assess the effect of ICT enabled digital transformation and institutional quality on environmental sustainability in SAARC economies during 1990-2018. The second-generation empirical test utilized for cross-sectional dependence (CD) as the Pesaran (2004), and for panel unit root tests Pesaran (2007) (CADF and CIPS). The J Westerlund (2007) cointegration technique is used to evaluate the long run equilibrium association among variables.

The empirical endings concluded the long-term group and panel equilibrium connections among the variables. Further, panel PMG-ARDL estimators validate the EKC existence in SAARC economies. Consequently, the coefficients of ICT enabled digital transformation infer that the penetration of ICT in the long run moderating the ecological footprint. Moreover, the coefficients of IQ deduce that poor institutional set-up in SAARC economies degrade the environment due to positive association to ecological footprint. Further, ICT moderating character between EF and IQ sustain the environment by lessening EF and improving IQ. Lastly, economic growth and non-renewable consumption of energy rises the ecological footprint.

The finding of study suggested that an escalation in economic activities in SAARC economies escort to excessive utilization of fossil fuel energy sources, increasing the ecological footprint by reducing the forest land, cropland, and grazing land which ultimately negatively devastate the environmental standard. The economic growth of SAARC economies is observing scale effect in its economic activities which means that these economic activities are not considering environment friendly and energy efficient technologies. However, the squared of GDP carries a negative sign in the long run, confirming the validity of the inverted U-shaped environmental Kuznets curve hypothesis. In SAARC there are emerging and developing economies own immense prospects for ICT-enabled digital transformation, penetration, development and expansion. In the economic growth triggering process, the policy makers are required to design more rigorous environment sustainable policies and arrangement. The policy makers should encourage and facilitates the transfer of ICT based greener technologies from developed economies. The ICT based application should be introduced to create awareness among public about environment sustainability. These measure and efforts will ensure the environment sustainability at low income level. Moreover, ICT moderating character has the ability strengthen the institutional structure through e-government that will in turn improve the government effectiveness, implementation of rule of law, control corruption, transparency, awareness among citizen regarding climate change and environment sustainability.

There are some limitations regarding study scope that is; (i) limited to SAARC economies, (ii) included limited variables for evaluation. The future research prospect possibly will consider the new variables like, foreign direct investment, urbanization, renewable energy, financial development and globalization. Furthermore, in future exploration at regional level, different income group economies, and state level economies can investigate to validate the connotation among EF, ICT, and IQ.

Author contribution

Saif ur Rehman: Introduction, Data Curation, original draft writing, Methodology
Abid Rashid Gill: Supervision, Writing_ review, Interpretation & editing

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