Does ICT diffusion make human development sustainable in the era of globalization? An empirical analysis from SAARC economies

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Research Article

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Abstract

This study intends to examine the impact of ICT diffusion, globalization, financial development, government effectiveness, and economic growth on sustainable human development (SHD) i.e., the development of human capital adjusted against the human ecological footprint, using 2005-2020 panel data of SAARC economies. The methodology involves econometric techniques robust to cross-sectional dependence (CSD) such as Pesaran's CSD tests, second-generation unit root test, Pedroni, Kao, Westerlund cointegration tests, FMOLS, DCCE-MG, Driscoll-Kraay (DK) regression, and DH causality test. The findings of the cointegration tests demonstrate that the variables are cointegrated and have long run equilibrium relationship. The results from DCCE-MG and DK regression, indicate that ICT diffusion has a significant, favorable impact on SHD. Similarly, globalization and economic growth also have a significant positive impact on SHD. On the other hand, the impact of government effectiveness and financial development was found to be insignificant. In addition, the DH causality test results show the presence of a unidirectional causality running from ICT diffusion to SHD and globalization to SHD. A bidirectional causal link is detected between economic growth and SHD. Therefore, the study concludes that in order to resolve the undesirable consequences of environmental degradation on human development in the globalized era, it is essential for SAARC economies to tackle challenges for adequate ICT infrastructure, particularly: access and affordability. By eliminating these significant barriers to ICT access, CO2 emissions can be reduced, and human development can be sustained simultaneously.

Keywords: ICT diffusion, Sustainable human development, Cross-sectional dependence, DCCE, DK regression, SAARC

JEL code: C23, O15, 033, O40

Introduction

Development discourse nowadays is dominated by the objective of meeting the Sustainable Development Goals (SDGs). However, many economies continue to confront obstacles or view the corresponding objectives with despair, particularly when their development efforts do not adhere to the desired/targeted timeframes. The adjournments in fulfilling the incremental milestones leading to the fulfillment of SDGs can be attributed to several factors. These include, but are not limited to, the lack of a mechanism for disseminating information, which would help minimize the amount of ignorance around the procedures and methods required to achieve these goals (Latif et al. 2017). The advancements in information and communication technology (ICT) have proffered a plethora of options to disseminating information through the internet, mobile phones, fixed landlines, and other technological channels.

Increasing ICT adoption has a wide range of economic implications, including faster economic growth, financial sector development, educational efficiency, and ecological sustainability (Alimi and Adediran 2020; Verma and Giri 2020). Simultaneously, while these impacts differ by industry, the influence on sustainable development has attracted significant academic attention in recent years. Globalization has led to a greater spread of ICTs among geographically dispersed countries, creating new possibilities for inclusive and sustainable development (Pérez-Castro et al. 2021). It is essential, however, that the outputs of sustainable development be designed and built in such a way that the economic, social, as well as ecological dimensions of sustainable development, are all addressed equitably. Additionally, economic activity has an environmental impact; therefore, policymakers must examine this and establish policies that favor ecologically sustainable technologies in order to reduce the environmental impact (Jayaprakash and Pillai 2021).

When it comes to the environment, ICT diffusion can have both positive and negative ecological repercussions. ICT can help households and businesses save money by lowering transactional and transportation expenses associated with CO2 emissions. Moreover, ICT minimizes the problem of asymmetric information linked with environmental conservation by reducing information costs linked with CO2 emissions (Chien et al. 2021). It is further envisaged that ICT will also help reduce carbon footprint through the establishment of smart cities; infrastructure; power stations; industrial operations; or rather emission reduction (Higón et al. 2017).

Contrastingly, ICT diffusion increases energy consumption by households and corporations, resulting in increased CO2 emissions. In addition, ICT strengthens the financial industry and dissemination of information, resulting in increased financial integration as well as boosting economic activity. Increased economic activity results in an increase in CO2 emissions (Avom et al. 2020). Thus, given the circumstances, ICT may have an adverse or favorable impact on environmental sustainability. This has prompted several researchers to conclude that the two notions are connected through an inverted U-curve (Cheng et al. 2021; Khan et al. 2020).

Apart from ecological issues, ICT diffusion has a range of implications for social development. ICT, particularly smartphone technology, has revolutionized lives through advanced apps and services. As a result, current research has placed a strong emphasis on the economic and human development impact of ICT (Shehata 2017; Badri et al. 2019). Thus, owing to its favorable influence on globalization as well as CO2 emissions, ICT has the potential to help accelerate human capital development (Asongu 2021). Likewise, education can be used in conjunction with ICT and mobile technologies to promote inclusive human development. However, this favorable effect of ICT diffusion varies according to the ICT dynamics, human development defined, available resources, or even proximity to the sea (Nchofoung and Asongu 2022). Another line of research examines the idea of social development in the context of population health. In this context, various academics have investigated the impact of ICT on health status. It has contributed to the regionalization of healthcare networks and bringing doctors and patients closer together (Dutta et al. 2019). According to Chib et al. (2008), digital inclusion is a key component of health initiatives. However, in an effort to improve lifestyle through ICT diffusion, its deployment model should be adapted to promote the basic rights, privacy, and security of individuals on the web (Hughes et al. 2017).

Similarly, ICT diffusion for sustainable human development (SHD) may be accomplished from an economical perspective. By increasing productivity and lowering transaction costs, ICT diffusion can boost growth in the economy (Aghaei and Nasab 2009). It can also increase financial development (Comin and Nanda 2019), with positive externalities on the economic expansion (Ibrahim and Alagidede 2018; Alshubiri et al. 2019). Adoption of ICTs, which in turn boosts economic growth by improving economies of scale, might thus help to accelerate globalization (Ahmed & Al-Roubaie 2013; Haseeb et al. 2019; Pérez-Castro et al. 2021).

However, without economic restructuring, ICT could be detrimental to economic growth (Verma and Giri 2020).

The literature frequently asserts that ICT exclusively benefits the economies of advanced countries. And that, the requisite human resource for managing ICT is lacking in emerging countries, particularly in low-income countries. Thus, ICT can be detrimental to overall development through its social, environmental, and economic elements. However, due to the interconnectedness of these factors, formulating sound economic policy can be challenging at times. For example, ICT development contributes to both economic growth (Verma and Giri 2020) and CO2 emissions (Danish et al. 2018). Increased CO2 emissions are detrimental to health outcomes (Khan et al., 2020), hinder inclusive development (Antonio and Tuffley 2014), exacerbate inequality (Richmond and Triplett 2018), and reduce overall welfare (Omri and Belaïd 2021).

The main objective of the present study is to examine the impact of ICT diffusion on SHD. The fundamental linkages among ICT diffusion and various measures of sustainability, demonstrated in the literature, highlight the importance of studying this relationship. The idea of sustainable development is crucial since it serves as the main focus of the United Nations' 2030 Sustainable development Agenda (United Nations 2016). SHD, as explained in the following section, is defined as the development of human capital adjusted against the human ecological footprint. It incorporates the concept of development that occurs without causing environmental deterioration. Besides, the extant literature on ICT is overwhelmingly oriented toward advanced economies and mostly overlooks emerging economies (Khan et al. 2020). Moreover, the existing studies often measure ICT using a single dimension, mainly mobile phone and internet usage which cannot be generalized for other indicators of ICT (Lenka and Barik 2018; Noor and Hoque 2021) Also, the existing literature on ICT generally ignores the presence of cross-sectional dependency (CSD) within the dataset (Chatterjee and Das 2019; Verma and Giri 2020). However, ignoring CSD may result in decreased estimator efficiency and biased results. Consequently, it is recommended that the findings of the studies that overlook endogeneity and CSD should be evaluated cautiously.

The above gaps in the ICT literature serve as the impetus for our study. Our research adds to the extant literature in a variety of ways. First, while previous researches have examined the relationship between ICT and specific facets of human development, this paper takes a different approach by examining how ICT affects SHD i.e., human development adjusted for human carbon footprint, rather than looking at a particular component. Second, the study develops an ICT index using principal component analysis instead of focusing exclusively on a single ICT indicator. Finally, the study tackles the problem of CSD by utilizing estimators such as dynamic common correlated effects mean group (DCCE-MG) and Driscoll Kraay (DK) standard errors approach, which accounts for CSD and provides heteroskedasticity and autocorrelation-consistent standard errors.

The remaining segment of the study has been arranged in this manner: “Literature review” section presents a brief review of available literature while the “Data and model” section presents the data source and definition of variables. The “Methodology” section presents the methodological framework for the analysis while the “Empirical results and discussion” section outlines the estimated findings of the study. Lastly, the “Conclusion” section draws the inference of the study and recommends policy initiatives.

Literature review

The 'Virtuous Triangle' of ICT diffusion (Figure 1) extends well beyond the obvious cost-effective advantages, evolving the significance of ICT as a critical driver of sustainable human development. Therefore, the review of literature is organized into three major pillars, namely social, economic, and environmental aspects of the goals. The environmental segment is primarily concerned with the impact of ICT diffusion on CO2 emissions; the social segment is concerned with the impact of ICT diffusion on different facets of human development such as education, well-being, and inequality; and the economic segment is concerned with the impact of ICT diffusion on economic development because of growth and poverty alleviation.

*** Insert Figure 1 here***

ICT diffusion and environment

ICT has gradually spread evolved and penetrated different economic and sociological domains, becoming a significant driver of worldwide economic growth in the contemporary industrial and technological revolution (Erumban and Das 2016; Arvin et al. 2021). Simultaneously, global warming and the degradation of the ecosystem continue to be a major concern. Scholars throughout the world are focusing on the right judgment and comprehension of the link among ICT diffusion and CO_2 emissions (Haseeb et al. 2019). Theoretically, ICT diffusion impacts CO_2 emissions by raising production and energy consumption efficiency efficacy and by reducing the cost of energy consumption (Moyer and Hughes 2012). In the digital age, data acquisition and resource evaluation using ICT have become an integral aspect of every corporate operation in terms of increasing production efficiency. May et al. (2017) stated that ICT automates the manufacturing process which thereby increases productivity and reduces energy consumption. In terms of boosting energy efficiency, Takase and Murota (2004) discovered that ICT can help Japan and the United States improve their energy efficiency. Pradhan et al. (2020) added to this by attributing the aforementioned phenomena to the substantial effect of ICT's "virtualization" and "digitalization" on productivity and lifestyle. In terms of cost savings associated with energy usage, Khan et al. (2018) suggested that ICT enables the development of an intelligent energy management system and the subsequent reduction of energy consumption. Additionally, Kumari et al. (2020) noted that ICT in the power sector has transformed the existing infrastructure, resulting in the formation of a smart grid capable of meeting customer demand and lowering energy costs through the bi-directional exchange of electricity and data.

The academic community has not yet established a consensus on whether ICT diffusion is advantageous for carbon reduction. According to some scholars, ICT can boost economic growth and enhance energy efficiency. However, the CO_2 and other toxic compounds generated during its installation and use will constitute a severe danger to economic development on a sustainable basis (Lee et al. 2017; Park et al. 2018). For example, Salahuddin and Gow (2016) discovered that OECD countries are unable to efficiently utilize ICT, resulting in a rise in CO_2 emissions. Shabani and Shahnazi (2019) employed a panel causality model to investigate the relationship between ICT and CO_2 emissions, and the results showed that ICT considerably increased CO_2 emissions. In comparison, some experts assert that ICT helps to minimize CO_2 emissions and promotes sustainable development (Danish et al. 2018; Lee & Brahmasrene 2014; Nchofoung & Asongu 2022). Nchofoung and Asongu (2022) found that ICT can lower the risk of environmental contamination to SHD. Haseeb et al. (2019) used panel data from BRIC countries from 1994 to 2014 and assessed the impact of ICT, energy use, and financial markets development on environment quality and found detrimental impact of ICT on CO_2 emissions. Moreover, as research content has expanded, some scholars have concluded that the relationship between ICT and CO_2 emissions is nonlinear (Higón et al., 2017; Ozcan & Apergis, 2018).

ICT diffusion and social development

Another body of literature discussed about the impact of ICT diffusion on social development. Various studies have analyzed the perceived social sustainability with reference to inclusive human development (Andrés et al. 2017; Asongu and Le Roux 2017; Nchofoung and Asongu 2022). Policies aimed at accelerating ICT diffusion will lead to an increase in inclusive human development, the magnitude of which will vary according to the level of income, institutional quality, legislative origin, oil revenue, and geographic location (Asongu and Le Roux 2017). In addition, it can be used to diminish the negative impact of CO_2 emissions on development. Furthermore, better health outcomes may be considered as an indicator of social development (Chib et al. 2008; Dutta et al. 2019). To put it another way, Lee et al. (2016) contend that ICT diffusion is linked to an increase in life span and a decrease in infant mortality.

Another facet of social progress is the use of ICT to enhance quality of education and alleviate social inequalities. While higher penetration of mobile and the internet improves the standard of education, increase in internet usage has a negative net effect on education quality in countries with above-average educational quality (Asongu and Odhiambo 2019). Adams and Akobeng (2021) argue that ICT reduces inequality, and a well-designed governance system enhances this link. However, the effect of ICT diffusion on inequality varies significantly depending on the kind of ICT and the inequality indicator selected.

ICT diffusion and economic development

The final body of research looks at the impact of ICT on economic development. ICT has become an integral part of the manufacturing process and technical advancement, since it serves as both “an intermediate input and an investment good" (Hwang and Shin 2017). Furthermore, ICT contributes to output through both neutral and non-neutral effects by altering the production function and lowering capital output elasticity as it promotes capital-intensive technology upgrades (Zhang and Sun 2019). Additionally, productivity improvements and economic growth enable emerging economies to benefit from improved living standard as a result ICT sector expansion (Erumban and Das 2016). Global investment in the ICT industry may have been boosted due to the proliferation of mobile phone technology (Lam and Shiu 2010). Indeed, mobile devices have become ingrained in our daily lives and are altering the way businesses and markets operate, opening up new revenue streams (Cardona et al. 2013). As a result, empirical researches have constantly demonstrated that ICTs have a favorable and significant impact on economic growth (Lam and Shiu 2010; Verma and Giri 2020; Arvin et al. 2021). However, some research indicate that as an economy develops, the influence of mobile phones gradually diminishes due to marginal returns and the emergence of the Internet (Ward and Zheng 2016)(Ward & Zheng, 2016). Also, ICT may actually be detrimental to development, in the destitute of economic reform (Albiman and Sulong 2017).

Data and model

This study intends to examine the impact of ICT diffusion on sustainable human development by incorporating the role of globalization in the SAARC economies for the time period 2005-2020. The periodicity of the variables is restricted by the available data at the time of this research. The dependent, independent, and control variables were selected based on existing literature (Asongu et al. 2017; Verma and Giri 2020; Nchofoung and Asongu 2022). The data source includes World Bank, International Telecommunication Union (ITU), and Hickel (2020).

SHD index, based on Hickel (2020), is the dependent variable in our study. The index is calculated as a quotient of two indices, namely, the index of human development (HDI) and the index of environmental impact (EII). While HDI is constructed as the geometric mean of indices of education, life expectancy, and modified income, EII considers the extent to which material footprint and CO2 emissions from consumption-based activities, exceeds per capita shares of planetary boundaries. The computations are presented in Equations (1), (2), and (3) for the SDH, HDI, and EII, respectively.

$$SDH_{it} = \frac{Human\ Development\ Index_{it}}{Ecological\ Impact\ Index_{it}} \tag{1}$$

$$HDI_{it} = (Life\ Expectancy\ Index * Education\ Index * Income\ Index)^{\frac{1}{3}} \tag{2}$$

$$EII_{it} = 1 + \frac{e^{AO} - e^{1}}{e^{4} - e^{1}} \tag{3}$$

Where AO denotes the average overshoot, which is defined as the proportion of the material footprint and each emission value to their corresponding per capita planetary boundaries.

ICT diffusion (ICT) is the independent variable of interest which is measured through an index constructed using PCA to avoid the problem of multicollinearity. The index is based on five indicators which include fixed telephone subscriptions, mobile cellular subscriptions, fixed broadband subscriptions, individuals using the internet, and internet bandwidth (Arvin et al. 2021; Cheng et al. 2021; Khan et al. 2020). PCA is a technique (with a solid statistical foundation) for reducing the dimensionality of a dataset, increasing its interpretability, and minimizing information loss. PCA is based on the presumption of standardized data and linear correlations among the variables and has been frequently used in previous ICT research (Verma and Giri 2020; Arvin et al. 2021). The index was further screened for sampling adequacy using the Kaiser-Meyer-Olkin (KMO) test (Kaiser 1974). The overall KMO score for the dataset is 0.80, indicating that our PCA produces accurate and reliable results.

The control variables are selected in light of existing literature on the factors affecting inclusive and SHD. Financial development (FD) proxied by domestic credit to the private sector is the first control variable which is expected to have a favorable impact on SHD. ICT may have an impact on the environment through the growth of financial markets (Chien et al. 2021). Besides, globalization has a beneficial effect on SHD in the socio-economic, and the political domains (Nchofoung and Asongu 2022). Therefore, globalization is proxied by trade openness (TRD) and foreign direct investment (FDI) which is likely to have a positive impact on SHD. Another variable that must be taken into consideration is good governance which is a prerequisite to SHD. It is anticipated that the governance proxy of government effectiveness (GOV) will have a favorable impact in this study. Finally, the study also includes economic growth (GDP) proxied through per capita GDP. Indeed, no economic development is possible without growth. While growth is a proxy for development, it is also critical to social and environmental sustainability (Nchofoung and Asongu 2022). This variable may have a beneficial or detrimental influence.

As a result, an ICT-based theoretical model for SHD can be derived as as in Equation (4):

$$lnSHD_{it} = f(lnICT_{it}, lnFD_{it}, lnTRD_{it}, lnFDI_{it}, lnGOV_{it}, lnGDP_{it}) \tag{4}$$

where FD stands for financial development; TRD represents trade openness; FDI is the foreign direct investments; GEC and GDP signify the government effectiveness and economic growth, respectively. The basic regression model is given as:

$$lnSHD_{it} = \alpha_{it} + \beta_1 lnICT_{it} + \beta_2 lnFD_{it} + \beta_3 lnTRD_{it} + \beta_4 lnFDI_{it} + \beta_5 lnGOV_{it} + \beta_6 lnGDP_{it} + \theta_{it} + \varepsilon_{it} \quad (5)$$

where I = 1, 2,...,N represents the economy in the panel, t = 1, 2,...,T indicates the timeframe, β1, β2, β3, β4, β5, and β6 are the parameters indicating long-run elasticity estimates of SHD with respect to ICT diffusion and other control variables, and αit & θit denotes the fixed country effects and the deterministic trend, respectively and εit is the error term.

Methodology

Cross-sectional dependence

Generally, panel data estimation methodologies overlook the issue of CSD, which can result in biased and misleading data and unreliable findings (forecasting error). The possibility of a CSD arises because of a certain overlooked component, common to all economies and impacting each one of them, although potentially in diverse ways. Examples include the advancement of technology, the fluctuation of global pricing, such as the price of oil, or risk-free interest (Usman et al., 2020). Thus, it is imperative that this critical CSD issue be thoroughly investigated, regardless of whether it occurs or not across all cross-sections. As a result, we used second generation unit root tests that assume the presence of CSD, namely Pesaran CD (Pesaran, 2004), Breusch-Pagan LM (Breusch and Pagan 1980), Pesaran scaled LM (Pesaran, 2004), and Bias-corrected scaled LM (Baltagi et al. 2012). The null hypothesis (H0) of the CSD test is presented as follows:

$$H_0 : \eta_{ij} = corr\,(\varepsilon_{it}; \varepsilon_{jt}) = 0 \forall i \neq j$$

The mathematical expression of the CSD test (Pesaran, 2004) is as follows:

$$\mathrm{CD}_P = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{p}_{ij} \right) \to N(0,1)\ i, j$$

$$R = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{p}_{ij}\right)\frac{(T-k)\,\hat{p}_{ij}^2 - E\,(T-k)\,\hat{p}_{ij}^2}{\mathrm{Var}\,(T-k)\hat{p}_{ij}^2}$$

where i is the specific cross section, t depicts the time dimensions and the term $\hat{p}_{ij}$ signifies the projected multivariate correlation of the error-term across all cross-sections i and j.

Panel unit root tests

After examining the CSD, the subsequent step is to determine the order of integration and level of stationarity for all the variables. The key drawback of first-generation unit root tests is their inability to account for the CSD issue in the dataset. Therefore, the study employs the second-generation unit root tests, which account for CSD across all cross-sections in the heterogeneous panels. Pesaran (2007) suggested two second-generation panel unit root tests: cross-sectional augmented Dickey Fuller (CADF) and cross-sectional augmented Im Pesaran and Shin (CIPS) which are incorporated in this study.

As per Pesaran (2007), the unit-root test can be depicted as:

$$x_i = \alpha_{it} + \beta_i x_{it-1} + \rho_i t + \sum_{j=1}^{n} \theta_{ij}\Delta x_{i,t-j} + \varepsilon_{it}$$

Where, α_{it} refers to the intercept, t denotes the time, Δ is the difference operator, x_{it} represents the variables under study and ε_{it} is the error term. The null hypothesis asserts that the series under study are non-stationary.

Cointegration tests

After validating the unit root properties, the next stage in panel data analysis is to check for long-run cointegration between series. The study included first- and second-generation co-integration techniques, such as Kao (1999), Pedroni (2004), and Westerlund (2007). Pedroni (2004) presents a distinct set of statistics, one based on panel statistics within dimensions and the other on statistics between dimensions. In addition, the Kao residual-based test has been used in the study to validate the results of the Pedroni test. However, we also use the Westerlund (2007) technique to address the issue of CSD and heterogeneity, which gives more reliable and accurate information regarding long run cointegration relationships among the variables. The test focuses on two types of group (Gτ and Ga) and panel (Pτ and Pa) statistics. The presence of long run relationship is established by rejecting the null hypothesis of 'No Cointegrating'. The error correction system of Westerlund test is as follows:

$$\Delta Y_{it} = \delta'_i d_t + \alpha_i (Y_{it-1} - \beta'_i x_{it-1}) + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{it-j} + \sum_{j=-p_i}^{p_i} \gamma_{ij} \Delta x_{i,t-j} + \mu_{it}$$

Model estimation

After confirming the long-run cointegration between the variables, the study employs a fully modified ordinary least squares (FMOLS) technique to estimate the magnitude of long-run elasticity (Pedroni 2004). FMOLS solves the issues of serial correlations, simultaneity biases, and endogeneity in the panel datasets. Moreover, it generates robust results when small sample size is used (micro-numerosity), demonstrating the non-parametric approach of this regression estimation.

However, traditional methodologies, such as random effect, fixed effect, FMOLS, DOLS, and GMM methodology, presumes homogeneity and only enables modification of intercepts of the cross-sections, when in the real sense, the panel members are heterogeneous. Thus, considering the sensitive nature of CSD, the present study employs DCCE-MG estimator developed by Chudik and Pesaran (2015). It is based on the ideas of PMG (Pesaran et al. 1999), MG (Pesaran and Smith 1995), and CCE estimation (Pesaran 2006). According to Chudik and Pesaran (2015), the CSD effects, also known as common correlated effects (CCE), maybe mitigated using a cross-section average,

$$lnU_{it} = \sum\nolimits_{i=0}^{p} \alpha_{it} U_{it-1} + \sum\nolimits_{i=0}^{p} \delta_{it} V_{it-1} + \sum\nolimits_{i=0}^{p} \Upsilon_{it} \overline{W}_{it-1} + \varepsilon_{it}$$

where, $\overline{W}_{t-1} = (\overline{U}_{it-1}, \overline{V}_{it-1})$

U_{it} is used for SHD as a dependent variable whereas V_{it-1} indicates all independent variables, i.e., ICT, FD, TRD, FDI, GOV and GDP. The average of both dependent and independent variables is indicated as $\overline{W}_{t-1}$to ease the CSD problem (t-1). While p represents the lag of each variable. One of the key advantages of this technique is its robustness in the presence of structural breakdowns. Furthermore, by applying the jackknife correction strategy, this approach is equally relevant in cases of a small sample size. Also, the DCCE-MG model works well when the panel data is unbalanced.

Finally, in order to check the robustness of these tests, the study also incorporates the DK standard error approach proposed by Driscoll and Kraay (1998) in addition to DCCE-MG. This strategy offers long run estimates and can counter CSD, heteroscedasticity, as well as spatial/serial correlation in the data. This non-parametric regression is extra efficient with large time frames because it is flexible and does not require any assumptions. In addition, the DK approach may provide estimates in both unbalanced as well as balanced panel and is more efficient if the data set contains missing values (Park et al. 2018).

Causality test

The final stage in the empirical analysis is to determine if any causal relationship exists among the variables under the study. As a corollary, the present study used Dumitrescu and Hurlin (DH) causality test proposed by Dumitrescu and Hurlin (2012), which addresses the concern of CSD in the dataset and is subjected on individual wald statistic of average non causal relationship across all individual units (Usman et al. 2020). All coefficients are assumed to vary among cross-sections in this test. The following is the baseline regression equation given by Dumitrescu and Hurlin (2012):

$$y_{it} = \alpha_i + \sum_{k=1}^{K} \beta_{ik} y_{it-k} + \sum_{k=1}^{K} \gamma_{ik} x_{it-k} + \varepsilon_{it}$$

Where, the lag order of K is assumed to be the equivalent for all panel members, and the panel must be balanced. The null hypothesis asserts that there is no causal relationship among the variables.

Empirical results and discussion

Table 1 summarizes the statistical information for the sample variables. Variance inflation factor (VIF) tests are used to test for the presence of multicollinearity among the variables. The results indicate that the VIF spans between 1.47 and 4.35 and that the mean VIF score is 2.76, which is less than 5, indicating that our models are not susceptible to multicollinearity (Khan et al., 2020; Salahuddin & Gow, 2016).

Insert Table 1 here

Subsequently, the study tests for CSD using Pesaran CD (Pesaran, 2004), Breusch-Pagan LM (Breusch and Pagan 1980), Pesaran scaled LM (Pesaran, 2004), and Bias-corrected scaled LM (Baltagi et al. 2012) for the SAARC economies. Table 2 shows the outcomes of the CSD test, which strongly reject the null hypothesis stating absence of CSD in the dataset. This indicates that our panel data exhibit CSD in the data. Thus, it is necessary to address the CSD problem to produce robust estimation findings.

* Insert Table 2 here*

The non-stationary nature of economic variables often leads to biased results. Therefore, to obtain valid and unbiased results, the study uses second-generation CIPS and CADF test to examine the stationarity properties. Both these tests are designed to address the issue of homogeneity in panel unit root testing. Additionally, these tests are unaffected by CSD or heterogeneity in the data. According to the results in Table 3, the variables fulfil the precondition of cointegration tests i.e., the variables at stationarity at first difference I(1).

* Insert Table 3 here*

Consequently, it is crucial to confirm the existence of cointegration among the variables prior to regression analysis. Table 4 presents the results of Kao (1999) and Pedroni (2004) cointegration tests, which confirms the existence of cointegration relationship among the variables. However, because of CSD and heterogeneity in the data, the study favors the Westerlund (2007) test of cointegration, which assists in offsetting the CSD in the dataset. Table 5 displays the results of the Westerlund (2007) cointegration.

* Insert Table 4 here*

* Insert Table 5 here*

Table 6 shows the empirical findings of regression using FMOLS and DCCE-MG. To ensure the results are robust, we additionally employ DK standard error approach. The empirical evidence in Table 6 demonstrates that ICT has a considerable positive influence on SHD, regardless of the estimating methodology used. The finding of DK standard error approach shows that a 1% growth in ICT diffusion induces a 0.34% increase in the SHD index. ICTs have the potential to promote inclusive human capital development (Asongu and Le Roux 2017), accelerate economic growth (Verma and Giri 2020), reduce environmental impacts (Arshad et al. 2020), and alleviate inequality (Ruhyana and Essa 2020). ICT contributes to SHD by enhancing the environmental, socio-economical components of sustainability. ICTs, such as the internet and telephone, provides the ideal medium for disseminating knowledge of the impact of achieving long-term development goals. It makes trading and investing easier, boost economic activity, and allows for larger economies of scale. Consequently, the level of income in the economy rises, which may then be utilized to fund the SDGs outlined by the UN.

* Insert Table 6 here*

Additionally, the control variables like GDP, government effectiveness, FDI, and trade openness all demonstrate a favorable and significant impact on SHD in the long run. It is now imperative for SAARC countries to become more open to global commerce and integration. Increased economic progress may contribute to improvements in health, education, and life expectancy. Health and education are more accessible to persons who have a higher income since they have more money to spend. SHD and globalization are intertwined as trade and commerce can improve standard of living, increase business possibilities, ensure sustainability as well as boost production, all of which have an impact on human capital in one way or another. Mukherjee and Chakraborty (2010) demonstrate that trade openness and a decent standard of life are causally related. Financial development, on the other hand, has a detrimental effect on SHD.

Table 7 presents the results of the DH causality test which shows unidirectional causal relationship running from ICT diffusion to SHD, implying that an increase in ICT boosts SHD in an economy. The study also found the unidirectional causality running from TRD to SHD, which implies that an increase in trade will increase SHD in these countries. Furthermore, it is seen that there is an existence of a bidirectional causal relationship between GDP and SHD suggesting that both the economic growth and SHD influence each other in the SAARC countries. Likewise, bidirectional causality was observed between government effectiveness and SHD.

* Insert Table 7 here*

Conclusion

The primary objective of this study is to assess the dynamics between ICT diffusion and SHD in the SAARC economies for the period from 2005 to 2020, the most extensive data obtained. To address the issue of CSD in the data, the second-generation stationarity tests were utilized. The DCCE-MG and DK standard error approach was used for empirical estimation, which yields robust results in the presence of CSD. Empirical findings suggest favorable and significant impact of ICT diffusion on SHD. Moreover, economic growth, and globalization through trade and FDI contribute significantly to the SHD in SAARC economies. Furthermore, a unidirectional causal link running from ICT diffusion and globalization via trade has been detected towards SHD. Moreover, economic growth and SHD have a bidirectional causal relationship.

In the light of the above, in the globalization era, in order to resolve the undesirable consequences of environmental degradation on human development in the globalized era, it is essential for SAARC economies to tackle challenges for adequate ICT infrastructure, particularly: access and affordability. By eliminating these significant barriers to ICT access, CO_2 emissions can be reduced, and human development can be sustained simultaneously. As a result, ICT is an ideal instrument for developing SHD projects. It is quite unlikely that many of the current global advantages would have been realized without the use of ICT. To this extent, developing economies can leverage ICT to their advantages. ICT can help businesses attain cost competitiveness by mitigating extenuating factors. Remote locations would have been unable to afford modern technologies without the use of ICT. Consequently, achieving SHD through ICT initiatives is a reality that only those who really desire more equitable societies need to embrace.

The policy implications of this study necessitate that policymakers include ICT diffusion in their pursuit of attaining the sustainable development goals. It is recommended that policymakers in the SAARC countries consider the following: It is imperative that (i) ICTs are accessible to all; (ii) greater investment is made in the promotion of ICT (iii) introduction of e-culture to promote education, health, and standard of living; (iv) better connectivity is provided to all; and (v) lower prices for ICT equipment are made available so that the masses can benefit from technology.

However, the study has significant limitations. Future research in this field should incorporate additional mediators, such as institutional governance. In addition, individual country specific research might be conducted to provide policymakers with more detailed guidance. As a result, future research should investigate more inclusive and sustainable metrics in addition to the ones used in this study, which are not exhaustive.

Statements and Declarations

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical Approval NA

Consent to Participate As Corresponding Author, I confirm that the manuscript has been read and approved for submission by all the named authors.

Consent to Publish We give our consent for the article to be published in ESPR. We declare that this manuscript is original, has not been published before and is not currently being considered for publication to a preprint server prior to submission on ESPR.

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Tables

Table 1 Descriptive statistics and pairwise correlation							
	SHD	ICT	GDP	FD	GOV	FDI	TRD
Mean	4.943	0.001	2464.775	35.974	-0.45	4.88E+09	37884.93
Median	2.990	-0.349	1351.672	36.736	-0.456	4.57E+08	3657.272
Maximum	16.300	3.729	10207.490	78.945	0.632	5.06E+10	324778.4
Minimum	0.990	-0.962	359.899	3.229	-1.496	995123.9	161.6000
Std. dev.	4.135	1.000	2601.870	17.144	0.553	1.16E+10	83809.27
Skewness	1.245	1.843	1.827	-0.213	-0.041	2.640788	2.585039
Kurtosis	3.108	5.981	5.069	2.584	2.156	8.569	8.242
Jarque-Bera	31.092	112.384	88.240	1.770	3.595	294.553	271.072
Probability	0.000	0.000	0.000	0.041	0.016	0.000	0.000
SHD	1						
ICT	0.168	1					
GDP	0.059	-0.153	1				
FD	0.300	0.249	-0.032	1			
GOV	0.612	0.405	0.107	0.470	1		
FDI	-0.078	-0.012	0.103	0.277	0.306	1	
TRD	0.243	0.285	0.121	-0.077	0.565	-0.246	1
*, **, and *** indicates levels of significance at 1%, 5%, and 10%, respectively.							

Table 2 Cross-sectional dependence test

Series	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
lnSHD	193.010*	22.050*	21.765*	10.045*
lnICT	378.594*	46.850*	46.564*	19.444*
lnGDP	340.633*	41.777*	41.492*	18.365*
lnFD	190.878*	21.766*	21.480*	0.452
lnGOV	43.539*	2.077*	1.791*	0.427*
lnFDI	111.609*	11.173*	10.887*	1.349
lnTRD	177.065*	19.920*	19.634*	10.960*

* Indicates levels of significance at 1%

Table 3 Second generation unit root test

Variable	CIPS		CADF	
	I(0)	I(1)	I(0)	I(1)
lnSHD	-1.780*	-2.057*	-2.992*	-3.144*
lnICT	-1.599	-1.924**	-0.961	-1.794**
lnGDP	-0.311	-2.572*	-1.163	-3.102*
lnFD	-1.487	-2.374*	-1.904	-2.724*
lnGOV	-2.743**	-3.324*	-2.512**	-3.195*
lnFDI	-2.162*	-3.899*	-2.944	-3.943*
lnTRD	-1.672**	-2.173*	-1.314	-2.354**

*, **, and *** indicates levels of significance at 1%, 5%, and 10%, respectively.

Table 4 Traditional cointegration tests			
Pedroni test			
	NIT	I	IT
Panel v-statistic	-1.638	-0.375	-0.766
Panel rho-statistic	1.754	2.026	3.650
Panel PP-statistic	-2.225*	-4.482*	-4.712*
Panel ADF-statistic	-1.774**	-3.573*	-2.827*
Group rho-statistic	2.829	3.322	4.773
Group PP-statistic	-6.767*	-7.002*	-7.746*
Group ADF-statistic	-3.965*	-3.926*	-3.325*
Kao test	ADF t-stat	-2.775*	
* Indicates levels of significance at 1%			
Abbreviations: NIT, no trend and intercept; IT, both trend and intercept; I, only intercept			

Table 5 Westerlund cointegration test			
	Value	Z value	Robust P value
Gt	-1.763	1.839	0.000*
Ga	-0.449	4.546	0.000*
Pt	-4.814	1.004	1.000
Pa	-0.747	2.991	0.000*
* Indicates levels of significance at 1%			

Table 6 The results of long-run elasticity estimates						
Variables	FMOLS-MG		DCCE-MG		Driscoll Kraay Regression	
	Coefficient	P value	Coefficient	P value	Coefficient	P value
lnICT	0.281	0.226	0.477*	0.000	0.349**	0.015
lnGDP	0.394*	0.000	0.702**	0.031	0.422*	0.001
lnFD	-0.136*	0.000	-0.112***	0.084	-0.122*	0.002
lnGOV	0.614	0.222	0.556	0.247	0.648	0.198
lnFDI	0.017**	0.050	0.018*	0.004	0.016**	0.014
lnTRD	0.028	0.549	0.035	0.597	0.014***	0.082
R-squared	0.79		0.79		0.77	
Root MSE	-		0.03		0.02	
Prob>f	-		0.00		0.00	
Groups	8		8		8	
Observation	128		128		128	
*, **, and *** indicates levels of significance at 1%, 5%, and 10%, respectively.						

Table 7 Pairwise Dumitrescu and Hurlin panel causality test				
Null hypothesis:	W-Stat.	Zbar-Stat.	Prob.	Remarks
lnICT ⇎ lnSHD	6.775	3.066	0.002	ICT→SHD
lnSHD ⇎ lnICT	3.031	0.273	0.784	
lnGDP ⇎ lnSHD	3.346	0.510	0.061	GDP↔SHD
lnSHD ⇎ lnGDP	2.611	0.041	0.096	
lnFD⇎ lnSHD	4.390	1.293	0.195	FD⇎SHD
lnSHD⇎ lnFD	3.685	0.764	0.447	
lnGOV ⇎ lnSHD	16.679	10.509	0.000	GOV↔SHD
lnSHD ⇎ lnGOV	8.858	4.643	0.000	
lnFDI⇎ lnSHD	4.390	1.293	0.195	FDI⇎SHD
lnSHD ⇎ lnFDI	3.685	0.764	0.447	
lnTRD ⇎ lnSHD	6.890	3.167	0.001	TRD→SHD
lnSHD ⇎ lnTRD	4.028	1.021	0.307	
*, **, and *** indicates levels of significance at 1%, 5%, and 10%, respectively and the symbol →, ↔ and ⇎ indicates unidirectional, bidirectional and no causality relationship, respectively.				

Figures

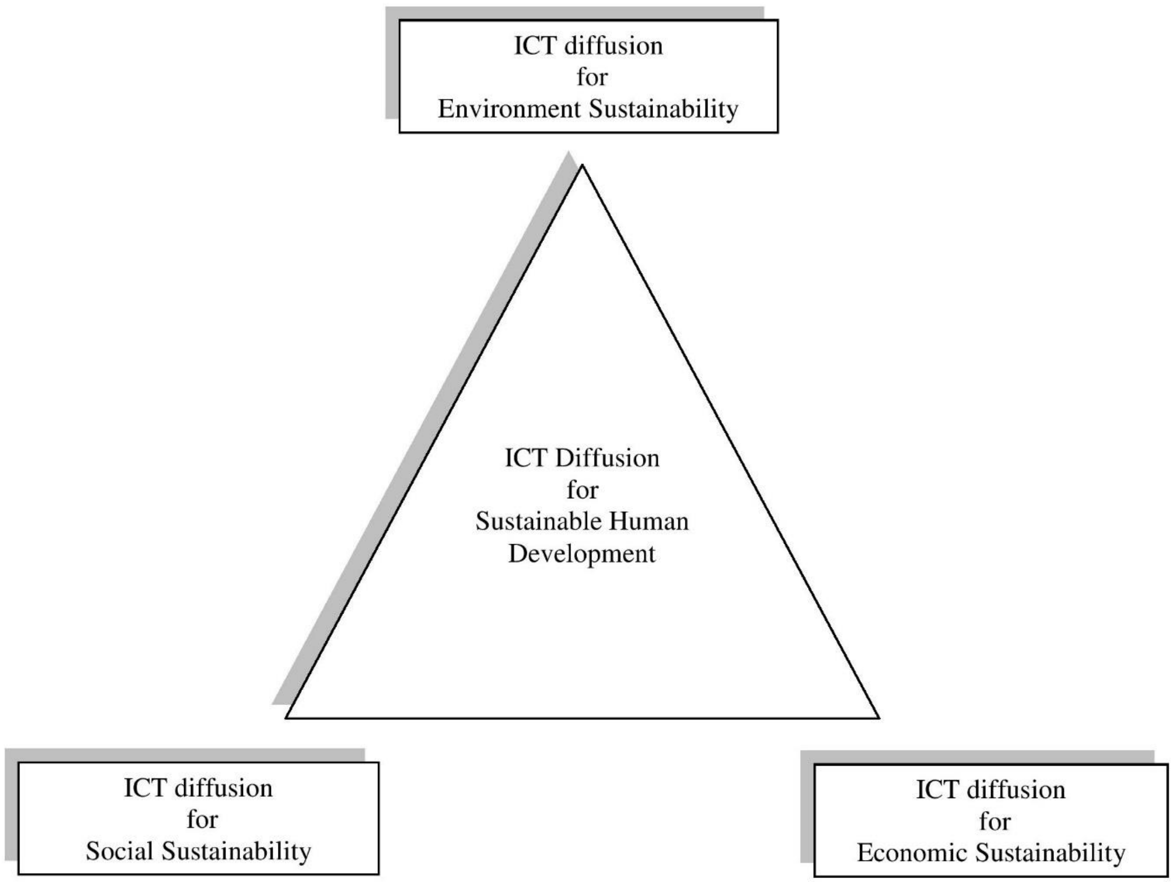

Figure 1 Virtuous triangle of ICT diffusion for sustainable human development