



## Original Article

# The Role of Technological Innovation and ICT in Ecological Footprint: Evidence from Asian Countries

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## ABSTRACT

The study investigated the technological innovation, information and communication technology (ICT), gross domestic product (GDP), trade openness, and urban population on ecological footprints in Asian countries. The data from 1990-2023 was used to estimate the mentioned objective. The study employed an autoregressive distributed lag (ARDL) model. To assess the robust results and comparison, the study used three models, including pooled mean group (PMG), mean group (MG), and dynamic fixed effect group (DFE). The resulting statistics obtained from the test suggested the pooled mean group and dynamic fixed effect to be superior to the mean group. Findings suggest that technological innovation and ICT have a negative and significant relationship with ecological footprints in the long run in Asian countries. The coefficient for economic growth, trade and urbanisation demonstrated a positive association with ecological footprints and held statistical significance in Asian countries. To mitigate ecological footprints, Asian countries must establish and enforce strict environmental regulations that promote the adoption of green technologies and discourage environmentally harmful practices.

**Keywords:** *Asian countries, Ecological footprint, ICT, Technological innovation*

## INTRODUCTION

A carbon footprint (including carbon dioxide and methane) encompasses the cumulative release of greenhouse gases into the atmosphere through various human activities e.g., industrial processes, machinery operations, and the production of goods. While numerous ecological and environmental studies have attempted to assess carbon footprints, precise calculations remain elusive due to the absence of a standardized measurement scale and our limited understanding of the continuous carbon emissions stemming from diverse sources (Abbas et al., 2021). Roughly 30% of carbon dioxide (CO<sub>2</sub>) emissions can be attributed to the lifestyles of residents and the economic activities that cater to their needs (Ahmad et al., 2021). Hence, there is a pressing need for a comprehensive metric that can address the challenges of sustainable development and its deterioration. The environmental footprint has been widely adopted to evaluate the state of the environment and its long-term viability, as discussed by Adom and Matsui (2024). It acts as a useful tool for monitoring and measuring the use of resources from nature within a community. Natural resources have attracted substantial worldwide interest in academic circles because of their profound economic implications, as evidenced by the works of Sachs and Warner (1995), and Auty (2000).

It helps lead to the augmentation of a country's overall economic production by fostering the creation of technology-related products and services. Various estimates place the contribution of IT to the overall GDP at constant prices between 2.5% and 4.5% (Caglar et al., 2021). Even with a relatively small market share, IT possesses the potential to boost economic output significantly. The advent of computers and other technology and communication gadgets have seen

a significant increase in the economy of the nation (Haftu, 2019). As of 2016, there were 1.74 million patent applications related to technological advancements in emerging nations, up from 0.11 million in 1980. In contrast to the contextual framework of this study, the current research aims to investigate the influence of Information and Communication Technologies (ICT) and economic complexity on the ecological footprint within the G-seven economies (Khan & Ximei, 2022). In this era of digitalization, numerous environmental economists have explored the significant role of ICT in both environmental quality and economic growth. ICT supports true economic progress in three key areas along the route of economic growth. Firstly, the emergence of ICT reduces total factor costs (TFC) by facilitating efficient communication with lower transaction expenses. Examples include online businesses, internet banking, e-commerce, Online trading, and a plethora of smartphone applications (Datta & Agarwal, 2004).

ICT exerts both direct and indirect beneficial benefits on CO<sub>2</sub> emissions through its linkages to financial growth, energy consumption, and trade openness, according to a study by Avom et al. (2020) that was done across 21 SSA nations. A different study focused on how environmental factors in OECD economies are impacted by information and communication technology (ICT), while the former examined energy consumption and trade openness during the period from 1991 to 2012 (Salahuddin et al., 2016). Utilizing Their findings suggest that ICT does not negatively impact ecological well-being when using the PMG technique. Additionally, Danish (2020) recognizes the significance of ICT in helping to mitigate ecological degradation in 59 countries along the Belt and Road initiative. Urbanization presents significant opportunities for economies to make effective use of natural resources

on a large scale. However, the urbanization process, coupled with increased production levels driven by urbanization and economic growth, not only results in higher CO<sub>2</sub> emissions but also poses threats to both sustainable development and human health. Trade openness can potentially influence the ecological footprint through various channels, and this impact may be either positive or negative, contingent upon the level of development and industrialization within a country.

Against the said background, research on the relationships between technological innovation, information and communication technology, and population continues to expand particularly within large economies. Additionally, investigations into these aspects within Asian countries have limited literature. Consequently, the main objectives of this study are to evaluate the impact of technological innovation (TI), information and communication technology (ICT), trade, economic growth and urbanization on the ecological footprints in Asian countries. Rest of the paper is organized as follows. The second section provides literature review; third section is about materials and methods. Fourth part contains results and discussion, and last section is elaborated with conclusion and policy suggestions.

## LITERATURE REVIEW

Dogan and Pata (2022) investigated the influence of the effects of Information and Communication Technology (ICT), Research and Development (R&D) spending, and the use of renewable energy on environmental quality. To carry out this research, they employed the estimator It includes the Durbin-Hausman cointegration test and autoregressive distributed delays on a cross-sectional basis, analysing data over the period spanning from 1986 to 2017 in the G7 nations. The empirical findings of the study found that ICT, R&D spending, and renewable energy all have a positive impact on environmental quality.

Memon et al. (2022) carried out a study with a focus on the G7 nations. Which are currently grappling with significant challenges related to increasing urbanization, a rising ecological footprint, and diminishing biocapacity. These nations have urban areas serving for economic operations and the utilization of resources. The main goal of this research is to ascertain how urbanization and human capital affect ecological footprints. within the G7 countries. To achieve this goal, the study employs advanced panel data estimation techniques, namely Continuously Updated Full Modification (CUP-FM) and Continuously Updated Bias-Correction (CUP-BC), utilizing data

spanning between 1971 and 2014. The outcomes show that the procedure of urbanization contributes to an increase within the context of the ecological footprint, whereas human capital has a mitigating effect, reducing the ecological footprint.

Nizam et al. (2020) shed light on the critical role application of information and communication technologies (ICTs) to the management of environmental resources, igniting a pertinent discussion among policymakers regarding the promotion deployment of sustainable technologies to mitigate substantial carbon emissions. The research findings show that in the short run energy demand positively impacts economic growth but has a long-term detrimental impact on economic growth. The study also finds that while the country's economic growth experiences a substantial increase with rising trade openness and mobile-telephone subscriptions (ICTs) in the short term, this connection transforms the long run because of a rise in carbon emissions over the specified timeframe.

Khan and Ximei (2022) conducted a study focusing on the contemporary digital economy the crucial roles played by Information and communication technology (ICT) and the intricacies of the economy in addressing environmental sustainability and shaping policies to address ecological concerns. Their research aimed to examine the impact of ICT and economic complexity on the ecological footprint in G-Seven countries (digital economies) during the period from 2001 to 2018. In this study, they employed both first-generation and second-generation unit root testing methods. The results from both cross-sectional dependence testing approaches by Pesaran & Smith, (1995) and (Pesaran et al., 1999) confirmed the existence of cross-sectional dependence across all G-seven economies and confirmed that there is no inconsistency in the results.

Destek and Sinha (2020) emphasized the significance of the role of information and communication technologies (ICT) in promoting economic expansion while acknowledging the environmental consequences associated with their usage. Consequently, the study sought to scrutinize the effects of ICT, energy use, economic development, and financial growth's effects on air quality in Pakistan. By utilizing data spanning from the researchers used the Nonlinear Autoregressive Distributed Lag model to analyse data from 1976 to 2018. The findings unveiled the existence of substantial unequal co-integration between ICT and CO<sub>2</sub> emissions. These findings from the analysis highlighted the favourable surge in ICT.

Caglar et al. (2021) conducted a study with the primary objective of investigating the impacts of various

factors, including the impact on the environment of information and communication technology (ICT), energy consumption (renewable and not), financial development, and economic growth. Across ten nations are experiencing significant deterioration of the environment. The following 10 countries are represented: China, Brazil, Germany, Indonesia, India, Japan, Mexico, the Russian Federation, the United States, and the United Kingdom. In contrast to Prior empirical research. This research aimed to make use of the 29 ecological footprints, a more thorough environmental quality indicator, they evaluate the validity of the environmental Kuznets curve hypothesis (EKC). Additionally, in this study, the function of ICT was examined for the first time in this context. Some authors have seen the relationship between ecological footprints with ICT, and some have explored technological innovation with different countries, sample and data. The current study explored the said

relationship altogether with a large sample of 12 Asian countries.

## METHODOLOGY

This study consists of panel data analysis to check the impact of technological innovation on the ecological footprint in Asian countries. The data of 12 countries out of the 49 Asian countries was gathered from the World Bank and global footprint network, other countries' data was found missing for multiple years. For empirical estimation, panel data of 33 years was collected from 1990–2023.

### Model Description

The econometric model is constructed with the aim of research. The study aims to attain the current research objective, so we use a model for empirical analysis. Which is written as in equation 1:

$$EF_{2it} = \beta_0 + \beta_1 ICT_{it} + \beta_2 GDP_{it} + \beta_3 TI_{it} + \beta_4 TR_{it} + \beta_5 UP_{it} + \varepsilon_{it} \quad (1)$$

where “i” denotes the country aspect, and “t” signifies the temporal dimension in panel estimations. The ecological footprint, measured in global hectares per capita, is computed as the aggregate of cropland, forestryland, fishingground, built-upland, grazingland, and carbon footprint. This is an independent variable, and the source of this variable is Global Footprint

Network. Dependent variables are ICT, measured through ICT goods import & ICT goods export, GDP (gross domestic product), TI (technological innovation) measured through patent application (resident & non-resident), TR stands for trade openness and UP denotes urban population, and the source of these variables is World Bank data.

**Table 1**  
Data Description

Variables	Unit of Measurement	Mean	Std. Dev	Minimum	Maximum
EF	global hectares per capita	2.983	7.124	13922.42	4.428
ICT	% of total goods export & import	1.537	11.055	-45.712	195.227
GDP	Current US\$	1070127	2240906	415.586	1.460
TI	In Hundreds (Numbers)	70412.54	208077.5	-17491	1542002
UP	% of total population	2.3545	3.9807	29.547	1.546
TR	% of GDP	89.61517	90.417	15.506	437.326

Note: The study uses 396 total observations

The above table reveals significant variations across key economic variables. The variable of Ecological footprints differs widely, with higher values in industrialized economies. ICT adoption shows substantial disparities, reflecting uneven digital infrastructure development. GDP exhibits considerable economic inequality, with some nations demonstrating significantly higher output. Technological innovation (TI) varies across countries, indicating differences in research and development efforts. Trade openness (TR) fluctuates, with negative values suggesting trade

restrictions or measurement adjustments. Urban population (UP) remains relatively stable, though some nations experience higher urbanization. These findings highlight the interplay between economic growth, technological progress, and sustainability across different income groups.

### Panel Unit Root Analysis

Panel data have many estimations and implication problems as they contain cross-segment and time sequences. So, the problem that epidemic the cross-

section and time series are autocorrelation respectively or essential to address. Through the acceptance of the ARDL model, not all variables do not have to have the same direction integration 4(4). This model is feasible to conduct the stationary test to resist combining the indicators to order 2(2). Then the numerous unit root test is documented as the most common for panel data Pesaran et al., (1999) and Augmented Dickey-Fuller (ADF) test.

### Autoregressive Distributed Lag (ARDL) Model

Autoregressive Distributed Lag (ARDL) Modelling Approach is used in this study. The ability to analyse long-run relationships is one of the critical advantages of the ARDL model, regardless of whether the underlying variables are variables exhibit stationarity primarily at the second difference or only at the first level, first difference, or both. Models require that all variables be at the same level due to many types of co-integration. This is one of the most significant justifications for choosing the ARDL approach for this investigation. The Autoregressive Distributed Lag (ARDL) approach model to revise the long run association, irrespective of regardless of whether the variables 1(0), 1(1), or a combination of both. In such circumstances, using the ARDL model will give accurate and effective estimates model is used. To capture the long-term and short-term dynamic connections among these variables the study utilizes the ARDL model to check the robustness of the result this study employs three-panel data techniques in the context of ARDL models. These approaches address the critical trade-off between homogeneity and heterogeneity in dynamic panels (Pesaran et al., 1999).

The pooled mean group (PMG) estimator imposes the constraint that the long-run coefficients are identical across all cross-sectional units (homogeneous), while allowing the short-run dynamics and error variances to differ (heterogeneous), making it efficient if the long-run equilibrium is indeed common. On the other hand,

**Table 2**

Unit Root Test Using Pesaran Panel Approach Results

Variables	CIPS* Results			
	At level		1st Difference	
	Trend	Non-Trend	Trend	Non-Trend
EF	-1.486	-1.245	-4.904**	-5.041
ICT	-3.926**	-3.210	-5.383	-5.164
GDP	-0.870	-1.743	-3.81***	-2.952
TI	-2.710	-2.588	-4.431**	-4.047
UP	--2.285	-1.270	-4.116**	-3.661
TR	-2.479	-2.551	-4.326**	-4.070

The result of the above table showed that all the variables employed in this present study are stationary

the mean group (MG) estimator estimates distinct regressions for individual units and then averages the coefficients, imposing no homogeneity restrictions and thus offering consistent estimates regardless of whether the true parameters are heterogeneous or homogeneous, albeit with a potential loss of efficiency if the long-run slopes are similar (Pesaran & Smith, 1995). In contrast, the dynamic fixed effect (DFE) model imposes homogeneity on both the long-run and short-run parameters, as well as the speed of adjustment, which yields efficient estimates if all parameters are truly identical but leads to significant bias if this strong assumption is violated. Consequently, the choice between these estimators is fundamentally an empirical issue, often guided by Hausman-type tests to determine the validity of the long-run homogeneity restriction imposed by the PMG estimator.

## RESULTS & DISCUSSION

This section provides all the results and discussion in line with the objective of this study to investigate the relationship between ecological footprints, ICT, technological innovation, trade, urbanization and economic growth in Asian countries. To proceed with ARDL models analysis, firstly the study checked the unit root problem in the variables. Secondly this part provides the results of three ARDL models.

### Unit Root test Results

To avoid the unit problem the stationarity test is applied otherwise the result may be spurious. The present study used the Pesaran method to examine the stationary of the data. The data encompasses all variables utilized in the study Ecological footprints (EF), Gross Domestic Product (GDP), information and communication technology (ICT), Technological Innovation (TI), Urban Population (UP), and Trade (TR). The outcomes from the Pesaran panel unit root test in Table 2 reveal that all variables become stationary at the first difference, and the variable ICT remains stationary at the level.

at the first difference. So, the next is to examine both the enduring and immediate connections in the research,

the variables were analysed using the subsequent approaches: the ARDL technique model is applied, and the results are displayed in the below tables.

**Auto Regressive Distributive Lag (ARDL) TEST**

**Table 3**  
Result of Long-Run Estimates of PMG, MG, DFE

Variables	Coefficient (PMG)	Coefficient (MG)	Coefficient (DFE)
ICT	-85.75 (-0.35)	1.634 (1.38)	-10.356* (-0.57)
GDP	509.0173*** (9.86)	332.677**** (3.72)	521.3718*** (9.27)
TI	-23.564*** (-6.10)	-98.277 (-0.65)	-26.35*** (-5.41)
TR	33.45*** (3.18)	295696.3 (0.68)	46.17*** (0.06)
UP	2.837*** (4.32)	2.00e+07 (-0.96)	4.68*** (-2.78)

Notes: \*\*\*, \*\* and \*: Significant at the 1%-, 5%- and 10%-level.

The Autoregressive Distributed Lag (ARDL) model results show that the estimated coefficient of ICT goods import and export in Asian countries is adverse and significant in dynamic fixed estimator. The estimate demonstrates a 1% change increase in ICT % of total imports and exports will decrease the 10.356%. The findings are in line with the results mentioned by Caglar et al. (2021). The table shows the GDP current US\$ has a positive relationship with ecological footprints and it is statistically significant and robust in all three methods.

These estimate that a 1% rise in GDP current US\$ will lead to a will result in a higher ecological footprint by 509.0173 US\$ in Asian countries. The same results occurred in the work of Hussain et al. (2021), Memon et al. (2022), and Khan and Ximei (2022). TI (the patent application of resident and non-resident) has an adverse and statistically meaningful relationship

ARDL approach provides a reliable and well-organized estimator, and it is used to eliminate the endogeneity problem by including lag length in both endogenous and exogenous variables. ARDL model applies to ascertain the long run connection among the variables. The result of ARDL models is given below.

with ecological footprints in PMG and DFE tests. The estimates indicate a 1% rise in the patent application of residents and non-residents to decrease in -23.564 % in ecological footprints of Asian countries. These same results occurred in the work of Ahmad et al. (2020) and Mazhar et al. (2022). Trade openness exhibits a strong correlation with statistical significance between ecological footprints estimates in Asian countries. Kongbuamai et al. (2020) support the positive impact of trade on ecological footprints. The urban population has an adverse and noteworthy relationship. The estimation indicates for Asian countries, that a 1% rise in an urban population of the total population increases the ecological footprints -2.83% in MPG test and 4.68% in DFE test. These results are same as found by Danish and Hassan (2023), Ahmad et al. (2020), and Sahoo and Sethi (2021).

**Table 4**  
Result of Short-Run Estimates of PMG, MG, DFE

Variables	Coefficient PMG	Coefficient MG	Coefficient (DFE)
Error Correction	-0.01045* (-1.73)	-0.751*** (-12.25)	-0.1196*** (-4.04)
ICT (D1)	3.252 (1.09)	6612399 (1.61)	62783.83 (0.44)
GDP (D1)	63.137 (1.15)	-42.42903 (0.61)	284.152*** (7.94)
TI (D1)	-1087.244 (-0.31)	-169.1436 (-0.06)	-555.267*** (-5.88)
TR (D1)	446887.1 (1.14)	295696.3 (0.69)	-68829.14 (-0.60)
UP (D1)	6049470 (0.56)	2.00e+07 (0.47)	7.382461 (1.13)

Notes: \*\*\*, \*\* and \*: Significant at the 1%-, 5%- and 10%-level.

The error term equation value coefficient is negative in MPG short run estimate, meaning that the variable of ecological footprints converges to the equilibrium in the respective models. Data of Asian countries on

an annual base. We can interpret that the dependent variable converges that 10% to the equilibrium at a significant level of 0.10% every year due to a change in other independent variables in the model. In MP short

run estimation, the dependent variable converges 75% to the equilibrium at a 0.01% significant level every year due to a change in other independent variables in the model. According to the DFE short run model, the dependent variable, ecological footprints, converges that 11% to the equilibrium at a 0.01% significant level every year due to a change in another independent variable in the model.

## CONCLUSION

In a world increasingly concerned about ecological sustainability, this research investigates the crucial interaction between technological innovation, ICT, trade, economic growth, urbanization and ecological footprint in the context of Asian countries. By examining these specific factors, the study aims to shed light on the potential pathways for reducing environmental degradation while fostering technological progress. Technological innovation is often regarded as the latest manifestation within an ongoing series of developments in information and communication technology. It is widely acknowledged as the primary catalyst behind economic growth in contemporary societies. Moreover, it aims to enhance and clarify the expansive, and at times, vague notion of innovation. Digital technology expedites the generation of novel ideas and concurrently enhances efficiency.

The primary goal of this study is to investigate the said relationship for 12 Asian countries. To accomplish this, the study utilizes panel data spanning from 1990 to 2023. The research primarily employs the autoregressive distributed lag (ARDL) model. To accomplish this goal, the first step involves assessing the stationarity of all variables using the Pesaran et al. (1999) method. In this study, all variables are determined to be stationary first difference except ICT is stationary at level. Consequently, the subsequent phase focuses on identifying the long-term and short-term connections between these variables, employing the ARDL model to uncover both the long-run and short-run relationships among them. The study employs three tests of ARDL to check the robustness of the estimates.

The results denote that the technological innovation and ICT have negative and significant relationship with ecological footprints in long run in Asian countries. The outcomes indicate that the coefficient for economic growth, Trade and urbanization demonstrates a positive association with ecological footprints and holds statistical significance in Asian countries. In light of mentioned results, the study recommends the Asian countries forces must be redirected towards

sustainability. To achieve this, policymakers must adopt “Green ICT” strategies that use technology for energy efficiency. Enforce rigorous environmental provisions in trade deals to prevent becoming a pollution haven, and stimulate dense, public transit-oriented urban growth to curb sprawl. Achieving this goal aims to uncouple economic activity from ecological destruction by nurturing circular economies with sustainable innovations and ensuring that future innovations are inherently sustainable.

## Competing Interest

The authors had no competing interests.

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