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Sustainability through economic diversity: Examining the role of trade diversification, productive population, and foreign direct investment in selected Asian countries

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Abstract

This study explore the pertinent role of sustainability, trade direction diversification, productive population, and foreign direct investment across selected countries of Asia is viewed of leveraging on a battery of estimators i.e. Augmented Mean Group (AMG), Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares, and Standard Errors by Driscoll and Kraay methods for robust estimates and accounting for endogeneity and cross-sectional dependence for the selected bloc. Empirical results that foreign direct investment (FDI) exerts a negative effect on sustainability. Thus, implying that FDI growth in the study area dampens economic sustainability while productive population and trade engenders sustainability in the selected Asian blocs. These outcomes have inherent polices implications which highlights the need for robust trade and productive population strategies and policies which will trigger increased sustainability. More insights are renders in the concluding section.

Keywords: FDI, GDP, TRD, productive population and sustainability

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通过经济多元化增强韧性：贸易多元化、经济活动人口及外国直接投资对亚洲各国发展的影响分析

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简介

该研究通过计量经济学方法（如扩展中位数组AMG、完全修正最小二乘法FMOLS、动态面板模型及Driscoll-Kraay标准误模型）系统分析了贸易韧性、劳动力生产率与外国直接投资对亚洲各国经济发展的影响。该分析纳入了研究对象国内部各行业间的因果关联与相互依存关系。实证数据显示，外国直接投资对贸易韧性水平产生了负面影响。 因此可以推断，外国直接投资流入某一地区会削弱其经济稳定性。相反，经济活跃人口的存在以及活跃的贸易往来则有助于增强亚洲国家的经济韧性。研究结果具有重要的政策意义，突显了制定有效贸易战略和措施的必要性，这些措施应旨在提升经济活跃人口的韧性。

关键词：外国直接投资、国内生产总值、贸易、经济活跃人口、可持续发展

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Introduction

Sustainability being the inevitable reality has become a global agenda for modern business management, emphasising the importance of practicing sustainable practices in global operations [Martins et al., 2023]. The global world faces the challenge of balancing environmental conservation and economic growth [El Khoury et al., 2025]. Economic development is essential for addressing issues related to poverty and human well-being, but it often damages the environmental. Nations prioritise material luxury over environmental sustainability [Hunjra et al., 2024]. Economic development often leads to environmental degradation, climate change, and greenhouse gas emissions, which require urgent attention from regulators and policymakers [Cheng et al., 2024]. Therefore, the debate about finding the optimal balance between environmental protection remains a widely discussed issue across all levels of discussion [El Khoury et al., 2025]. The modern economic landscape is increasingly driven by the dual goals of sustainable growth, technological advancement, and integration of innovation with renewable energy [Xuan, 2025].

The increased interest in economic development within the context of environmental research highlights the significance of contributors towards sustainability, such as foreign direct investment (FDI), trade, productive populations and gross domestic product [Yun et al., 2024; Xuan, 2025]. The available opportunities in the global economy encourage businesses and nations to invest in foreign markets [Singh, Kapuria, 2022]. In the past decades, it was found that FDI has considerably increased in the African market over the last two decades [Seker et al., 2015]. However, recent studies reported a decline in global FDI flows in 2016 and for three consecutive years, as well as a decrese in FDI from 5.63% in 2007 to 1.57 in Asian markets in 2018 [Singh, Kapuria, 2022]. The shift in FDI inflows was due to uncertainties in policies for foreign investors, the fragilty of the global economy, and increased geopolitical risks. The FDI flows for developed economies declined by 27%, while developing countries saw a surge of 46% from 2017 to 54% in 2018 [Singh, Kapuria, 2022]. FDI is recognised as a driver of economic growth for the host country, and nations are keen to attract FDI for economic development [Chandran, Tang, 2013]. Though FDI is considered to be a significant contributor to economic development, it also raises the debate about potential environmental degradation [Pao, Tsai, 2010]. Recent studies have necessitated research into examine the relationship between FDI and GDP, as well as sustainability-related variables such as renewable energy [Xuan, 2025] in order to better understand the combined effect of these factors.

The Asian countries are suitable for studying FDI flows as they are the leading recipient region, with a significantly positive growth of $ 493 billion in 2017 and $ 512 billion in 2018 [Singh, Kapuria, 2022]. The higher growth can be attributed to the strong liquidity and low borrowing costs in the region with significant economic growth [Zahonogo, 2017]. To promote economic globalisation, this region has pushed for sustainable development, and countries have opened their FDI policies [Aust et al., 2020]. The lack of sustainable considerations such as low-level investment governance, shortages of natural resources, and environmental pollution have resulted in a complex relationship between environment, development, and trade [Wang, Luo, 2020].

The productive population is a representation of the working population that contributes to the national economy [Shahabadi, Pouran, 2023]. Statistical figures show that Asia is the most populous country, representing 59.08% of the global population. This large proportion of Asia's productive population can boost economic growth. The analysis shows an incremental trend in Indian and Chinese populations from 1990 to 2020. The numbers increased from 747 million and 504 million to approximately 978 million and 938 million respectively [Ajmi et al., 2025].

The acceleration of globalisation has created a space for trade openness, specifically for emerging markets such as Africa and Asia [Demiral et al., 2022]. This has resulted in the expansion of international trade, which has grown by 75% between 2000 and 2020. The reports from the World Bank showed that the proportion of international trade in GDP grew from 25 to 52% from 1970 to 2020 respectively [Wang et al., 2024]. While trade openness contributes to economic development and is associated with GDP, it is also linked with sustainability concerns [Zhong et al., 2021]. For instance, it has been reported that global carbon dioxide emissions in 2019 reached 34.34 million kt, indicating a 67% increase from 1990 [Wang et al., 2024]. This alarming situation has led global stakeholders to take actions and put an obligation on regulators to set goals for sustainable development [Yang et al., 2020]. The pandemic situation of COVID-19 and the Russia-Ukraine war have hit the global economy, forcing countries to take protective measures such as non-tariff barriers and raise tariffs to protect their industrial competitiveness and economic interests [Burgess et al., 2021]. This scenario raises the complexity of international trade and requires the intervention of the IMF and WB to promote diversification strategies and trade openness [Wang et al., 2024]. Trade diversification is used to accelerate exports and support competitiveness. However, this strategy may result in increased energy consumption to support production processes [Sun et al., 2023]. The implementation of trade diversification may damage sustainability concerns, but it may be effective in certain industries such as metal and cement, to reduce carbon emissions and achieve sustainability goals. Therefore, it is necessary to conduct a thorough examination to explore the relationship between sustainability and trade.

For this reason, balancing economic growth (trade, investments, productive population) and sustainability has become a pressing concern for Asia [Singh, Kapuria, 2022]. The productive population also drives income growth and technological innovation, which results in economic development [Ajmi et al., 2025]. Therefore, current research on the relationship between sustainability, trade direction diversification, productive population, and foreign direct investment across selected Asian countries is viewed using Fully Modified Ordinary Least Squares (FMOLS) methods along with standard errors. The research is organised into five sections. The first section introduces the topic, followed by a brief explanation of theoretical literature and hypothesis development. The third section describes the research methodology, and the fourth section presents the findings of research. The fifth section discusses the findings of the study, along with their implications and conclusion.

1. Literature review

Sustainable development is at the top of the agenda in recent global forums [Ajmi et al., 2025]. The development of a sustainable future attracts the attention of global stakeholders and encourages them to set specific targets and long-term goals to achieve sustainable development [Halkos, Gkampoura, 2021]. Sustainable development prioritises traditional development because it offers several benefits through a balanced approach that considers future generations' needs while exploiting environmental, economic, and social resources [Tan et al., 2024]. The UN calls on all nations to work together regardless of their economic status to achieve SDGs in order to promote global well-being and protect the planet [Grzebyk et al., 2023]. The SGDs are a topic of discussion due to their importance and inconsistencies. Specifically the SDG8 'Decent Work and Economic Growth' is of interest [Ajmi et al., 2025]. Available literature shows that economic growth comes at the cost of ecological sustainability [Grzebyk et al., 2023]. Therefore, it is essential to examine the relationship between economic growth, trade diversification, productivity, foreign direct investment and sustainability in order to address certain contradictions and provide policymakers with empirical evidence.

The date of economic literature shifted from economic growth to sustainable growth [Feng et al., 2019] and provided a research avenue to explore the relationship between FDI and sustainability [Singh, Kapuria, 2022]. The relationship between FDI and sustainability has been widely explored under the theories of pollution haven hypotheses [Feng et al., 2019] and Environment Kuznets Curve [Ren et al., 2014]. Research studies have found a significant relationship between FDI, trade and consumption of natural resources [Tang, Jiang, 2024]. Recent studies have also highlighted the importance of research on FDI in the context of sustainability and established a negative relationship between the two constructs [Xuan, 2025]. It was found that FDI represents the growth-pollution nexus in two ways: first, it can increase the national output, resulting in pollution, and second, FDI can be used for the deployment of efficient production technologies to reduce pollution [Pata et al., 2022]. So, there are no conclusions about the relationship between FDI and sustainability, which requires further investigation.

Available literature examined the association between trade openness and carbon emissions as a proxy for sustainable development [Wang et al., 2024]. Research studies found that there is a significant relationship between trade and sustainability in the context of economic integration and globalisation [Wang et al., 2023]. The existing literature establishes this relationship based on two opposing propositions: the first is the pollution haven, which argues that industrialised countries seek to exploit overseas manufacturing facilities for cost-effective access to raw materials, labour and land [Taylor, 2005]. Most of these countries develop with inexpensive resources and labour, and have weak environmental standards [Solarin et al., 2017]. Consequently, in the context of globalisation, countries with less strict environmental regulations and cheap resources are more attractive to investors, which leads to the worst environmental damage in these countries [Wang et al., 2024]. Contrary to this, the environmental Kuznets curve suggests that industrialisation has a significant and positive effect on pollution at a certain stage, after which countries begin to invest in environmental protection, resulting in a decline in environmental damage [Kaika, Zervas, 2013]. Studies also establish the impact of trade on carbon emissions [Liddle, 2018] and found that the consumption of energy in different countries varies [Jayanthakumaran et al., 2012]. This difference in utilisation of energy consumption for production leads to importing energy-intensive goods from other countries, reducing carbon footprints in the host countries [Wang et al., 2024]. In available literature a significant association was found between trade and carbon emissions. One stream of research found a positive and significant relationship between trade openness and carbon emissions [Shahbaz et al., 2017]. The second stream of research found a significant negative relationship between these variables [Ansari et al., 2020].

2. Data and methodology

To operationalise the present study's objectives. This study relies on panel data analysis, which combines both cross-sectional analysis of selected Asian economies and time series data from 1990 to 2022. The sample size was respected due to the availability of data. Details about the data, variables, and sources can be found in the appendix section, due to lack of space.

The preposition on the endogenous impact of technological residuals in enhancing long-term economic growth is the theological basis for the present study. Additionally, the present study also draws on the existing growth literature from the studies of [Sampene et al., 2024]. Thus, this study complements these studies and advances recent research by incorporating interaction terms for a more robust analysis of the topic under review

$$INCOME = f(PP, TECH, SUS, FDI, PC, TRD).$$

The operational model is appended below:

Model 1

Sustainability = f(Economic growth, trade, Productive Population FDI);

Model 2

Sustainability = f(Economic growth, trade, Productive Population, FDI, Trade × Productive Population).

The graphs illustrate the trends in key variables such as sustainability, economic growth measured by GDP, population growth, foreign direct investment and trade for selected Asian countries. Figure 1 shows changes in sustainability levels over time by country. On this graph, some countries show upward trends and improved sustainability, while others remain relatively stable. Figure 2 highlights variations in economic growth, and distinct periods of acceleration or deceleration can be identified. Figure 3 shows the population growth trends, which, in some cases are very different and represent demographic dynamics. Figure 4 depicts the flow of FDI with upward or volatile investments depending on the country. Finally, Figure 5 presents trade trends, where some countries have consistent growth and others have fluctuations. These graphs together depict very diverse economic and demographic patterns that are essential for understanding how these factors interact with each other and sustainability.

3. Cross-sectional dependency (CSD) assessment

The study examines the sustainability effects of trade diversification, productive population, and foreign direct investment in several Asian countries. Most countries are highly interdependent due to trade relations, investment flows, and shared regional economic factors, leading to a high likelihood of CSD [Voumik et al., 2023]. Correlated error terms can be interpreted as one country's trade pattern, financial structure, or foreign investment activities influencing others in the region [Li et al., 2022; Sampene et al., 2024]. Such interdependence is worth considering, as it may lead to bias in estimates and inhibit proper identification of the actual effects of variables in question. For instance, an improvement in trade diversification in one country may spur or augment trade diversification among neighboring countries due to regional trade agreements or the typical expansion of global supply chains. Therefore, the CSD test allows for examination of whether economies are affected by external influences in a way that violates the independence assumption in panel data models [Pesaran et al., 2008]. Thus, we adopt the general assessment formula of [Pesaran et al., 2008] in Equation (1):

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{j=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho} ij\right). \quad (1)$$

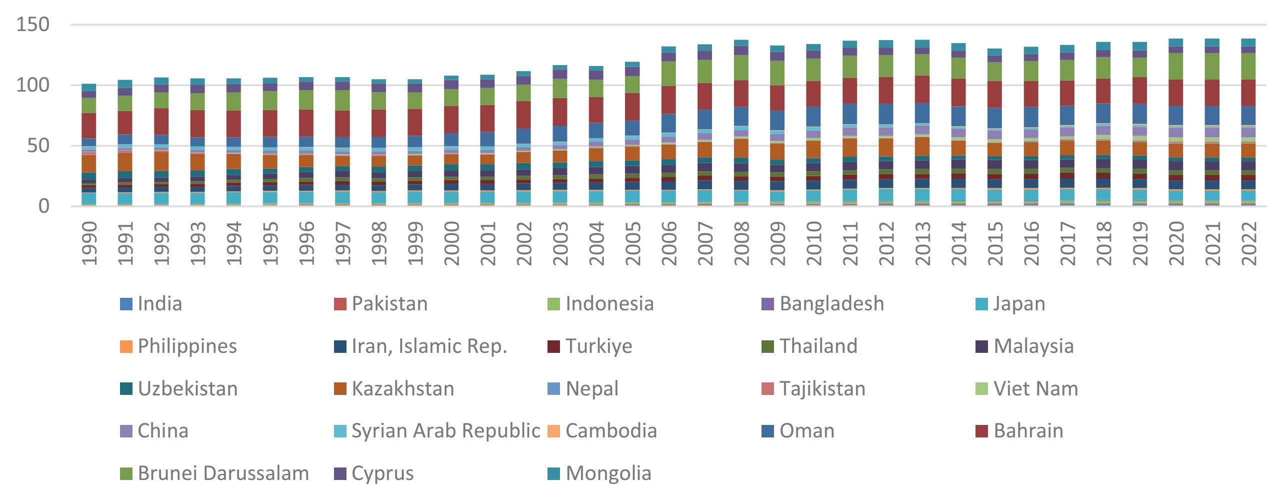
The Slope Homogeneity Test (SHT) is an investigation that helps determine the level of consistency among linkages of trade diversification, productive population, and foreign direct investment in selected Asian countries. Given the diverse economic structures, policies, and development stages characterise Asian countries [Shang et al., 2023], it is essential to ascertain whether coefficients of these variables are identical or different across countries. The tests for slope homogeneity determine whether one-model allocation to countries regarding standard coefficients is sufficient, or whether separate models are required for each country (or group of countries). If the slopes are found to have heterogeneous distributions, this implies that the effects in question will differ from country to country. Thus, the need for adjusting the model according to each country arises. [Pesaran, Yamagata, 2008] establish an estimation model to test for homogeneity among constructs. Therefore, the equations are as follows:

$$\Delta SHT = N^{\frac{1}{2}} 2K^{\frac{-1}{2}} \frac{1}{N} S - K, \quad (2)$$

$$\Delta ASHT = N^{\frac{1}{2}}\left(\left(\frac{2k(T-k-1)}{T+1}\right)^{\frac{-1}{2}}\right)\left(\frac{1}{N}S - K\right). \quad (3)$$

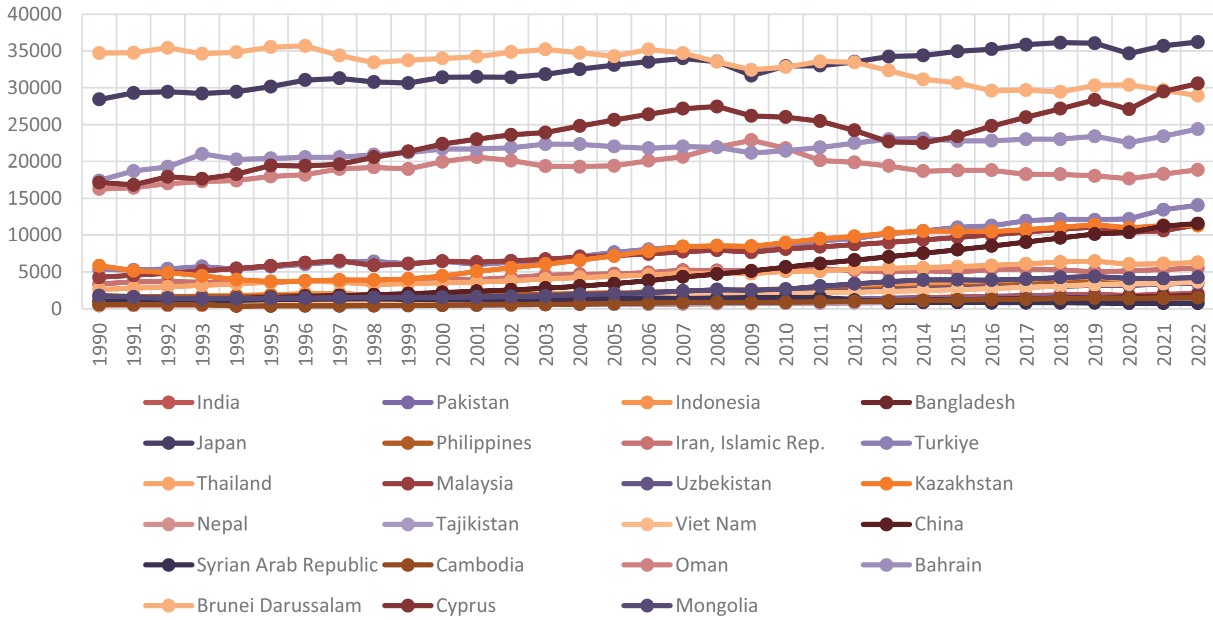
The standard unit root approach, such as the Augmented Dickey-Fuller (ADF) test [Sims et al., 1990; Im et al., 2003], becomes useless when CSD exists. This problem can be addressed by adjusting the classical ADF method by integrating cross-sectional mean adjustments of lagged terms and rearranging structures [He et al., 2021]. This leads to a novel panel unit root assessment that accommodates CSD and heterogeneity. [Pesaran et al., 2008] advanced a cross-sectionally improved CIPS stationarity examination based on the usual individual CADF assessments for the entire group. This identifies certain factors relevant to the CIPS test:

Fig. 1. Trend analysis of sustainability for selected Asian countries



Sourse: [Sampene et al., 2024].

Fig. 2. Trend analysis of economic growth for selected Asian countries



Sourse: [Sampene et al., 2024].

$$CIPS(N,T)\frac{1}{N}\sum_{i=1}^{N} t_i(N,T), \tag{4}$$

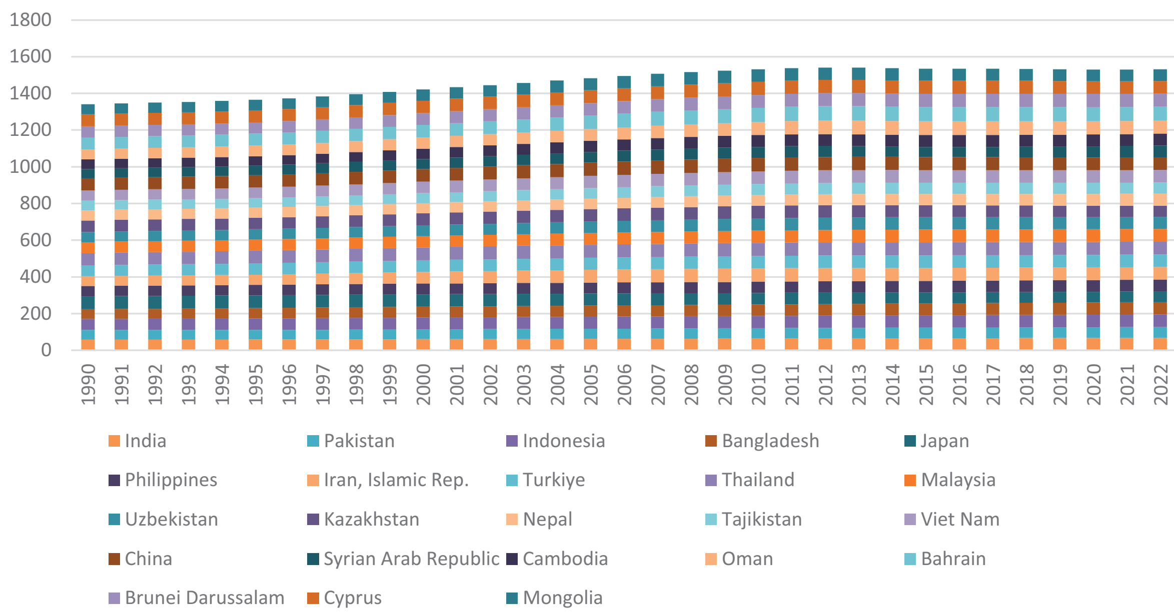
$$CADF = \gamma x_{it} = a_{it} + \beta_{it-1} + \delta_1 T + \sum_{j=1}^{N} \gamma_{ij}\, x_{it-j} + \mathcal{E}_{it}. \tag{5}$$

[Kao et al., 1999] based on a cointegrating regression model. It examines the long-run equilibrium link between dependent and many explanatory variables, allowing for individual-specific coefficients and intercepts. The Kao equation is presented in Equation (6):

$$y_{it} = \beta_{it} + \beta_{1it}\, x_{1it} + \beta_{2it}\, x_{2it} + \ldots + \beta_{kit}\, x_{kit} + \epsilon_{it}, \tag{6}$$

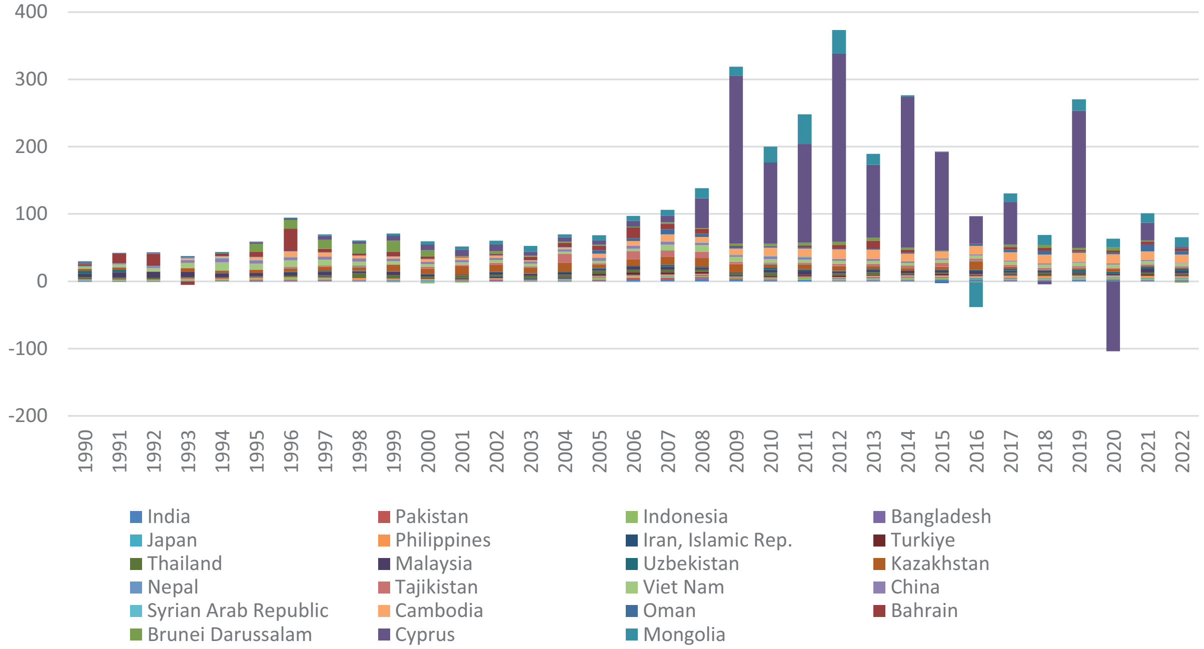
where y_{it} denotes the outcome variable for the individual I at time t, β_{it} is the individual-specific intercept term, β_{1it}, β_{2it}, and β_{kit} are the individual-specific slope coefficients consistent with the respective explanatory variables x_{1it}, x_{2it}, and x_{kit} are the expounding variables or regressors for individual i at time t and ϵ_{it} is the error term for individual i at time t. [Westerlund, Edgerton, 2007] show Equation (7):

Fig. 3. Trend analysis of population growth for selected Asian countries



Sourse: [Sampene et al., 2024].

Fig. 4. Trend analysis of foreign direct investment for selected Asian countries



Sourse: [Sampene et al., 2024].

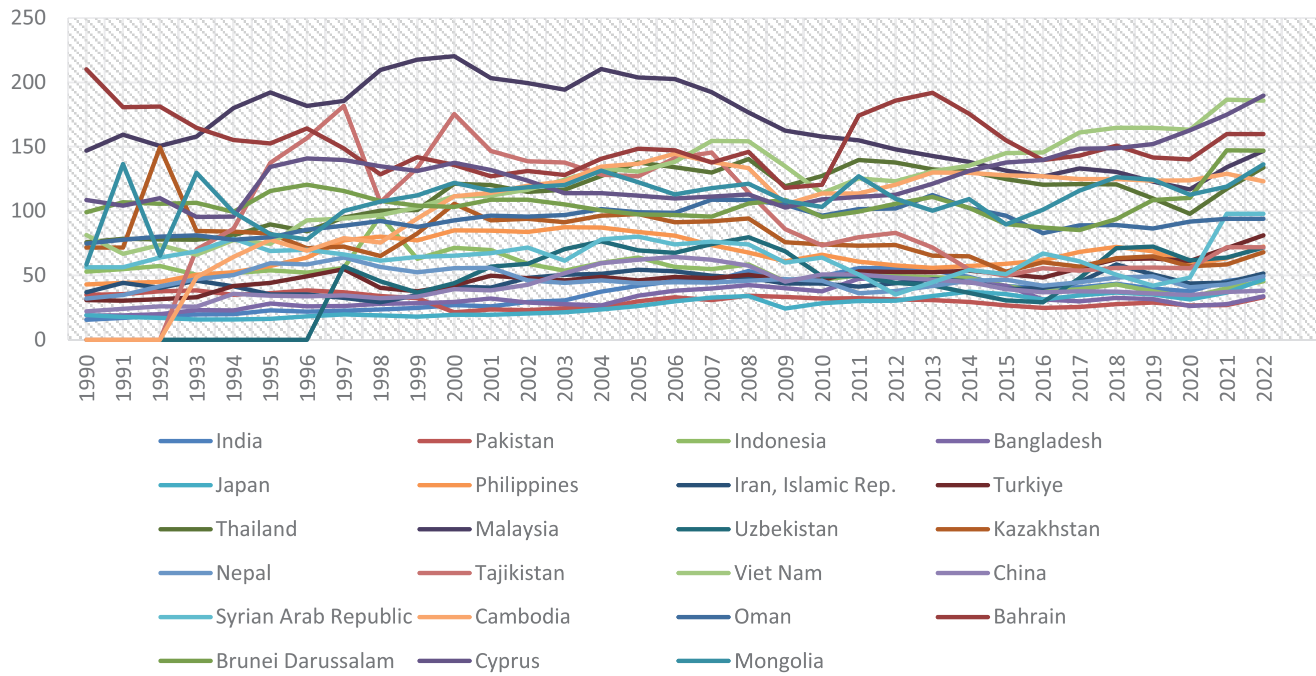
$$\Delta Y_{it} = \psi_i d_i + a_i (Y_{it-1} - \beta_i X_{it-1}) + \sum_{j=1}^{p_i} a_{ij} \Delta Y_{it-j} + \sum_{j=-p_i}^{p_i} \varphi_{ij} \Delta X_{i,t-j} + \mu_{it}. \quad (7)$$

Such that $d_i = (1,t)$ gives trend elasticity measure $\psi_i = \psi_i$ and ψ_{2i} labels the constant term for the states and i and t specifies the CSD period. Test statistics are visible in equations (8)–(11):

$$G_t = \frac{1}{4}\sum_{i=1}^{N} \frac{n_i}{S.E(\eta_i)}, \quad (8)$$

$$G_a = \frac{1}{N}\sum_{i=2}^{N} \frac{T\eta_i}{1 - \sum_{j=1}^{k} \eta_{ij}}. \quad (9)$$

Fig. 5. Trend analysis of trade for selected Asian countries



Sourse: [Sampene et al., 2024].

The cointegration is shown as follows:

$$P_\tau = \frac{\eta_i}{S.E\,(\eta_i)}, \quad (10)$$

$$P_a = T\eta_i, \quad (11)$$

where G_τ and G_a demonstrations of the group mean figures, P_τ and P_a also specifies the statistics in the panel, η_i shows the change from short to long-term equilibrium speed.

The examination of sustainability, trade direction diversification, productive population, and foreign direct investment across selected countries in Asia is conducted using Fully Modified Ordinary Least Squares (FMOLS) methods along with standard errors [Driscoll, Kraay, 1998]. The FMOLS method is suitable for panel data analysis of non-stationary variables, which may include endogeneity and serial correlation. The FMOLS method assumes a common intercept across panels since different countries may have different serial correlations. [Driscoll, Kraay, 1998] provide robust estimates consistent with autocorrelation and cross-section dependencies. In addition to being both potentially serially correlated and cross-sectionally dependent, the Augmented Mean Group (AMG) estimator is a distinct estimator that solves the common problems of serial correlation, cross-section dependency, heteroskedasticity, and slope heterogeneity. These are common in panel data studies involving several countries with different economic structures. Thus, the AMG estimator frees the results from any bias regarding these issues and reflects the genuine relationships of the variables under consideration in the analyzed model. The AMG estimation and the heterogeneous panel estimation of [Eberhardt, Bond, 2009; Eberhardt, Teal, 2010] inspired this analytical estimation, as shown in Equation (12):

$$\Delta Y_{it} = a_i + \beta_i \Delta X_{it} + \sum_{t=1}^{T} \pi_t D_t + \varphi_i UCF_t + \mu_{it}. \quad (12)$$

The OLS model of alteration is applied to the AMG test. This is expressed in Equation (13), in that φ symbolizes the estimated slope parameters of X_{it} factors are shown in Equation (12).

$$AMG = \frac{1}{N}\sum_{i=1}^{N} \varphi_i. \quad (13)$$

4. Results and discussion

4.1. Preliminary estimations

These descriptive statistics in Table 1 provide a general overview of the variables used in the analysis. The dependent variable, sustainability (SUS), has a mean of 5.31 and a standard deviation of 5.77. This indicates that the values in the sample are widely dispersed. The skewness (1.50) and kurtosis (4.58) indicate that the distribution is positively skewed with heavier tails than a normal distribution. The GDP exhibits significant variation around the mean among countries, as shown by the high mean of 8,072.09 and standard deviation of 10,218.82. Consequently, with a value of 1.46 for skewness and 3.78 for kurtosis, further deviations from normality are manifested. On the one hand, FDI ranges from -103.16 to 280.15, while the average value is 4.85. This variable has a highly positive skewness of 9.20, with a very high kurtosis of 105.14; hence, strong outliers may be present. The POPPG has an average of 63.73 and a standard deviation of 5.91, which is relatively steady and less dispersed. Its skewness is -0.08, and kurtosis is 2.33, closer to the typical distribution values. Trade - TRD shows an average of 78.39 with a standard deviation of 45.38, while its skewness is 0.66 and kurtosis is 2.74, showing mild positive skewness and near-normal distribution. Jarque-Bera normality

Table 1
Descriptive statistics

Variables	SUS	FDI	GDP	POPPG	TRD
Mean	5.311670821	4.8542876	8072.092173	63.72871976	78.38762717
Median	3.40963401	1.661436481	3130.910641	64.12880776	66.94695239
Maximum	23.15740473	280.1455104	36202.63927	77.72366532	220.406789
Minimum	0.047857598	-103.1566865	353.95657	50.55155749	0
Std. Dev.	5.770507691	20.62511339	10218.81504	5.912995085	45.38266389
Skewness	1.49932422	9.201524871	1.458621833	-0.079916743	0.664349343
Kurtosis	4.581868034	105.1391583	3.784804331	2.332411426	2.739309265
Jarque-Bera	363.5040414	340635.4018	288.6169744	14.90237195	57.98127044
Probability	1.16E-79	0	2.13E-63	0.000580752	2.57E-13
Sum	4031.558153	3684.404289	6126717.959	48370.0983	59496.20903
Sum Sq. Dev.	25240.45933	322449.6391	79153529066	26502.34124	1561166.326
Observations	759	759	759	759	759

Source: compiled by the authors.

Table 2
Correlation matrix

Variables	SUS	FDI	GDP	POPPG	TRD	TRD*POPPG
SUS	1	0.054906582	0.758104941	0.540653703	0.375917189	0.44672
FDI	0.054906582	1	0.168644949	0.167950374	0.176009476	0.195192
GDP	0.758104941	0.168644949	1	0.42638011	0.229297719	0.28511
POPPG	0.540653703	0.167950374	0.42638011	1	0.346237598	0.473373
TRD	0.375917189	0.176009476	0.229297719	0.346237598	1	0.986319
TRD_POPPG	0.446720318	0.19519182	0.285110187	0.473372559	0.986318603	1

Source: compiled by the authors.

test is highly significant ($p < 0.05$) for all variables indicating distributions not expected.

The correlation matrix provides a relation among the variables reported in Table 2. SUS has shown a high positive correlation with GDP and a medium positive correlation with POPPG, TRD, and their interactive term. This indicates that these variables may influence the sustainability of the country. FDI has weak positive correlations with all variables, suggesting limited direct relationships among them. GDP is moderately correlated with POPPG while trade and interactive terms show stronger associations with. As expected, due to its construction, TRD × POPPG is highly correlated with trade. The matrix suggests that interrelationships should be best investigated using regression analysis to determine causality and significance.

Table 3 summarises the series of tests for cross-sectional dependency and homogeneity of slope. The statistics from [Breusch, Pagan, 1980; Pesaran et al., 2004; 2008; Pesaran, Yamagata, 2008; Pesaran, 2014] are all significant for the variables SUS, FDI, GDP, POPPG, and TRD. These results indicate the presence of cross-sectional dependence, so the observations across countries are interrelated. The Delta tilde and adjusted Delta tilde statistics reiterate the heterogeneity of slopes, indicating that the relationships between variables vary across nations with respect to sustainability. Therefore, these characteristics of the dataset support the use of econometric models that incorporate cross-sectional dependencies and the heterogeneity of slopes, such as AMG and DSKE models, for reliable inference.

Table 4 summarises the results of panel unit root tests, PURT, using the CIPS and CADF methods in testing for stationarity. The test statistics are insignificant for most variables, such as SUS, GDP, TRD, and the interaction term TRD × POPPG were non-stationary at their levels, I(0). Only FDI and POPPG exhibit stationarity at the 5% significance level in one or both tests. However, after the first differencing I(1)-all variables become stationary with significant test statistics under both the CIPS and the CADF methods. This confirms that the variables are integrated in order 1, I(1). The result indicates that the series are underpinned by a unit root process. Consequently, all these variables are non-stationary, with their mean and variance changing over time. These findings lead to long-run equilibrium

Table 3
CSD and SHT Outcomes

Variable	Breusch-Pagan LM Stat (*p*-value)	Pesaran scaled LM Stat (*p*-value)	Bias-corrected scaled LM Stat (*p*-value)	Pesaran CD Stat (*p*-value)
SUS	3666.368***	151.743***	151.383***	21.380***
FDI	662.291***	18.195186779196***	17.836***	7.4160***
GDP	5887.768***	250.496002199176***	250.1366***	52.577***
POPPG	6251.415***	266.662084843274***	266.302***	63.990***
TRD	1502.869***	55.5634759853373***	55.204***	15.0961***
Delta tilde	28.165***			
Delta tilde adjusted	31.137***			

Notes. Significance levels: *** – $p < 0.01$, ** – $p < 0.05$, * – $p < 0.1$.
Source: compiled by the authors.

Table 4
PURT outcomes

Variables	CIPS			CADF		
	First level I(0)	Fist Diff. I(I)	Status	First level I(0)	Fist Diff. I(I)	Status
SUS	-1.978	-4.285***	I(1)	-1.978	-2.645***	I(1)
FDI	-2.587***	-5.657***	I(0)	-1.965	-3.534***	I(1)
GDP	-1.517	-3.291***	I(1)	-1.515	-2.176**	I(1)
POPPG	-2.333**	-2.504***	I(0)	-1.755	-2.116**	I(1)
TRD	-1.84	-4.924***	I(1)	-1.81	-3.016***	I(1)
TRD*POPPG	-1.784	-4.886***	I(1)	-1.801	-2.894***	I(1)

Notes. Significance levels: *** – $p < 0.01$, ** – $p < 0.05$, * – $p < 0.1$.
Source: compiled by the authors.

relationships between the variables, making the cointegration approach appropriate for further work.

Table 5 presents the results of panel cointegration tests using the [Kao et al., 1999; Westerlund, Edgerton, 2007] tests to see if there is long-run equilibrium relationships between the variables. The ADF statistic from the Kao test for the no-interaction model is significant at the 5% level, suggesting the possibility of cointegration. The model with interaction also provides a significant Kao test result at 10% and, therefore, shows weaker evidence of cointegration in that specification. The Westerlund test provides more substantial evidence of cointegration in both models. All four test statistics, Gτ and Gα, Pτ, and Pα, are significant enough to confirm cointegration for a model without interaction. Also, in the case of a model with interaction, all test statistics are highly significant at $p < 0.01$, reinforcing the notion that there is usually a long-run relationship between dependent and independent variables when there is an interaction term. Generally, the Westerlund test results indicate strong evidence of cointegration in both models, consistent with the Kao's results. That means that estimation of long-term dynamics is appropriate in the panel framework.

4.2. Regression results

The results from Table 6, without the interactive term AMG, indicate that FDI is negatively related to sustainability, though insignificantly. However, robustness checks through DKSE, FMOLS, and DOLS show that FDI significantly influences sustainability negatively at the 1% significance level. This suggests that higher magnitudes of FDI, as captured in this study, are unlikely to contribute positively to sustainability and may even increase unsustainable practices in the selected Asian countries. Robustness measures support the reliability of this finding, pointing to possible adverse environmental or social consequences of FDI in this context.

Table 5
Cointegration results

Kao Test	Model without interaction		Model with interaction		
	t-Statistic	Prob.		*t*-Statistic	Prob.
ADF	-1.638043528**	0.050706	ADF	-1.35967*	0.086967
Residual variance	0.28118657		Residual variance	0.280524	
HAC variance	0.243900575		HAC variance	0.222615	
Westerlund	**Model without interaction**		**Model with interaction**		
	***t*-Statistic**	**Prob.**	***t*-Statistic**	**Prob.**	
Gτ	-1.6572**	0.0487	-3.412***	0.000	
Gα	-2.1541**	0.0156	-2.453***	0.000	
Pτ	-1.0426***	0.000	-3.412***	0.000	
Pα	-1.2875***	0.000	-3.345***	0.000	

Notes. Significance levels: *** – $p < 0.01$, ** – $p < 0.05$, * – $p < 0.1$.
Source: compiled by the authors.

The AMG results indicate that GDP positively affects sustainability with a small, statistically insignificant coefficient. This implies that economic growth positively impacts achieving sustainability in selected countries. Robust models such as DKSE, FMOLS and DOLS confirm this observation with statistically significant coefficients across all measures, reinforcing the evidence for the importance of economic growth in enhancing sustainability. These findings agree that higher GDP allows for investment in sustainable practices and environmental management.

The coefficient of the productive population with respect to sustainability is positive and significant, indicating that an increase in the proportion of the productive workforce enhances sustainability. This correlation proves to be highly robust across the DKSE, FMOLS, and DOLS series, with latter having statistically significant positive coefficients. Among these the DKSE has the most significant effect. These findings imply that a productive population is instrumental in achieving developmental development goals due to its high level of labour output and its contribution to social and economic development.

While trade shows a positive, but statistically insignificant, relationship with sustainability in the AMG model, DKSE and DOLS show a positive and significant relationship. Thus, trade enhances sustainability in these countries. Interestingly, the FMOLS model yields an insignificant and slightly negative coefficient, reflecting some variability. Significant findings in DKSE and DOLS indicate that, if well governed, trade could be a vehicle for sustainability, by encouraging the diffusion of green technologies and sustainable practices.

While the AMG model provides a first-order insight into the relationships, robustness checks add extra reliability. Whereas the AMG model indicates general trends, the consistent results from DKSE, FMOLS and DOLS support strong positive effects of GDP and POPPG on sustainability and negative impact of FDI. Trade results suggest that the role of trade in sustainability may need further investigation, since its effect is related to the structure and nature of trade in the selected Asian countries. In general, the findings of this study show that balancing foreign investments, economic growth, productive use of the population, and managing trade will help achieve sustainability.

In the presence of interaction term interplay from Table 7, the AMG model presents FDI as inversely related to sustainability and SUS, though the result is not statistically significant. However, other robustness models, such as DKSE, FMOLS and DOLS consistently show that FDI negatively affects sustainability at a 1% significance level. The DKSE model shows the most significant negative coefficient, indicating that an increase in FDI could work against sustainability in Asian countries. This could mean that FDI in these countries does not aim to achieve sustainability goals due to profit-driven activities without responsibility towards the environment or society. Furthermore, from Table 7, AMG estimates a positive coefficient that is statistically significant but small in magnitude, indicating that GDP supports sustainability. DKSE, FMOLS and DOLS also confirm this finding, showing a similar positive impact of GDP on sustainability at 1% significance. This evidence shows that higher economic growth enables more investments in sustainable projects, technologies and infrastructures, which lead to better environmental and social outcomes.

The coefficient of POPPG is positive and statistically significant in the AMG model, indicating that an increase in the productive population contributes positively to sustainable development. This result is further supported by robust models FMOLS and DOLS, which show significant and favorable coefficients. However, the DKSE model reports a weaker but still positive relationship. These findings underline the importance of an active and productive population in ensuring

Table 6
AMG, DSKE, FMOLS, and DOLS outcomes without interaction

Regression estimates without interaction	AMG	DKSE	FMOLS	DOLS
FDI	-0.0412173 (0.0532)	-0.034082*** (0.0059819)	-0.0113*** (0.0039)	-0.0500*** (0.0124)
GDP	0.0005144*** (0.00013)	0.0003626*** (0.706)	0.00017*** (0.00004)	0.00038*** (2.772)
POPPG	0.0860785** (0.04217)	0.2225497*** (0.05554)	0.14943*** (0.01946)	0.0187* (0.0100)
TRD	0.004508 (0.00475)	0.0217624*** (.003481)	-0.00192 (0.0036)	0.0278*** (0.00731)
Trend	0.8831587* (0.50072)			
Constant	-3.369436 (2.873)	-13.33878*** (3.499409)		
R Squared			0.963	0.897
Adjusted R Squared			0.962	0.846

Notes. Significance levels: *** – $p < 0.01$, ** – $p < 0.05$, * – $p < 0.1$, () – standard error.
Source: compiled by the authors.

Table 7
AMG, DSKE, FMOLS, and DOLS outcomes with an interaction term

Regression estimates with interaction	AMG	DKSE	FMOLS	DOLS
FDI	-0.0338687 (.0430409)	-0.0361492*** (.0062149)	-0.0069*** (0.0016)	-0.0063 (0.0041)
GDP	0.0005159*** (.000148)	0.000356*** (0.806)	0.00016*** (1.918)	0.00016*** (4.693)
POPPG	0.1418228** (.0715899)	0.0155808 (0.0706297)	0.10015*** (0.0145	0.0976*** (0.0349)
TRD	0.0370655 (.0455598)	-0.1505141*** (0.0211308)	-0.0353*** (0.0094)	-0.0418* (0.0228)
TRD*POPPG	-0.0004803 (.0006879)	0.0026855*** (0.0003791)	0.000578*** (0.00015)	0.00066* (0.00037)
Trend	0.9841526** (.4983889)			
Constant	-6.606663 (4.958739)	-0.2461911 (4.196837)		
R Squared			0.964	0.962
Adjusted R Squared			0.963	0.961

Notes. Significance levels: *** – $p < 0.01$, ** – $p < 0.05$, * – $p < 0.1$, () – standard error.
Source: compiled by the authors.

sustainable economic and social development, possibly due to increased labour and resource efficiency. Whereas the AMG model shows a positive but insignificant relationship between trade and sustainability, DKSE shows a significantly negative impact of trade. FMOLS, on its part, reveals a significantly positive impact, while DOLS shows a small but significant negative impact. This could indicate that the impact of trade on sustainability depends on the nature of trade activities, and whether they involve sustainable practices or pollution-sensitive industries. The impact of trade may be context-specific, and further research is needed to understand this better.

The coefficient of the interaction term representing trade and the productive population, TRD × POPPG, is harmful and insignificant in the AMG model. At the same time, robust models, such as DKSE, FMOLS, and DOLS show that the combined effect of trade and a productive workforce is positive and significant. The finding suggests that, while trade may have numerous effects, it can couple better with an active workforce to ensure more sustainable outcomes through responsible trade and productivity. Notably, the interaction term (TRD × POPPG) is significant; the DKSE, FMOLS, and DOLS models are all substantial and positive, meaning that the interaction

Appendix
Table A1
Variable Description

Variable name	Measurement unit	Source
Income growth (INCOME)	Gross domestic product (GDP) per capita ($)	World development indicator (2023)
Productive population (PP)	Population ages 15-64, total	World development indicator (2023)
Technological innovation (Tech)	The combination of patent applications by residents and non-residents	World development indicator (2023)
Sustainability (SUS)	Renewable energy use as a share of total energy use	World development indicator (2023)
Technological innovation – Productive population interaction (TECH × PP)	Captured with technological innovation × × Productive population interaction	Derived
Foreign direct investment (FDI)	Foreign direct investment net inflows (% of GDP)	World development indicator (2023)
Physical capital (PC)	Gross fixed capital formation (% of GDP)	World development indicator (2023)
Trade openness (TRD)	Trade in (% of GDP)	World development indicator (2023)

Source: compiled by the authors.

between trade and a productive population creates scope for fostering sustainable outcome results. This finding highlights an essential aspect of integrating workforce development with a strategic trade policy for maximum sustainable benefits. The results underscore the need to manage economic growth, trade, and foreign investment strategically, drawing on workforce productivity to achieve sustainability goals.

5. Conclusion and policy implications

The quest for sustainability remains urgent to globally cater to current needs and future prosperity of generations. However, the debate about appropriate policy measures and strategies for promoting sustainability that communities and nations can adopt is controversial. In this respect, we examine the interplay between sustainability, trade direction diversification, productive population and foreign direct investment across selected countries in Asia. The study used a panel series covering 23 selected Asian countries between 1990 and 2022. We analysed the data employing a battery of estimators, including Augmented Mean Group (AMG), Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares, as well as Standard Errors [Driscoll, Kraay, 1998] methods to obtain robust estimates and account for endogeneity and cross-sectional dependence syndromes associated with the data.

Following the data analysis, we discovered that FDI has a negative relationship with sustainability. This suggests that FDI retards the advancement of sustainability in selected Asian countries. GDP, the productive population, and trade all have a positive impact on sustainability. This indicates that GDP growth in the selected Asian countries promotes sustainability in the region. Moreover, the positive impact of the productive population on the selected region indicates that the share of the productive population in the sample countries is substantially contributing to the growth of sustainability. However, while trade has a positive effect on the levels of sustainability in the selected Asian countries, the impact is not significant. Additionally, by interacting with trade diversification and a productive population (TRD × POPPG), we find that the interplay significantly enhances the levels of sustainable development in these countries. This suggests that trade and a productive population create the potential for sustainable outcomes. Therefore, it emphasises the importance of integrating workforce development into a strategic trade policy to achieve maximum sustainable benefits.

Following the findings, the study proposes policies for sustainability improvement in Asian countries based on evidence. First, sustainability in Asian countries could be improved through government regulation of FDI, by implementing environmental standards and creating a friendly business environment that encourages eco-friendly investment through FDI. Governments should promote FDI towards renewable energy initiatives, sustainable infrastructure development, and circular economy projects, through strengthened environmental standards to ensure compliance by foreign investors. Secondly, for the countries to maximise sustainable growth through their economic expansion, the study suggests integrating green policies into the national development plans of regional economies. Thirdly, the government authorities can enhance the sustainability strategy in sample countries by providing tax benefits and financial incentives for research and clean technology development (R&D). Through R&D, the government can support workforce development, which is essential for providing green capabilities to employees and supporting sustainability-oriented entrepreneurs. They can also create universal access to training programmes.

Fourth, the outcome of evidence indicates that the advancement of sustainability relies heavily on trade diversification, because it drives sustainable product exports and develops sustainable production incentives within regional trade agreements. Therefore, regional and national authorities should simplify the process of digital trade and e-commerce in order to reduce environmental damage caused by conventional trade operations. Furthermore, combining workforce development programmes with trade policies can lead to maximum sustainability through public-private networks that connect training to environmentally friendly market opportunities. This integration can strengthen green skill development critical to executing sustainable trading practices and fostering overall sustainability level.

The findings of our study support robust policy implications for sustainability, but there is a major drawback: the sample size of the selected Asian countries. We have collected data from 23 of the 48 Asian countries for analysis, and the results of our findings may not be universal as a one-size-fits-all approach for the remaining economies that were excluded. However, our sample size covers about 70% of the Asian economy, which therefore reflects the characteristics of the region. Moreover, the findings are robust, align with the literature and support practical policies for sustainability drive.

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