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Education for sustainable development as a driver of enhanced human development: a cross-country analysis

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Abstract

Background The Human Development Index serves as the primary benchmark for measuring progress across its three dimensions: education, health, and income. However, it relies on limited education indicators, with the economic aspect being significantly more prominent. This dominance restricts the capacity of the Human Development Index to adequately reflect development that focuses on sustainability. Education for Sustainable Development is underrepresented within Human Development Index frameworks, which can be attributed in part to a lack of comprehensive global data. This research utilizes Transformative Learning Theory to contend that the exclusion of Education for Sustainable Development overlooks essential competencies needed to tackle sustainability challenges and risks. This omission exacerbates inequalities in access to quality education among countries with different Human Development Index levels. The inadequate quality of education and the absence of responsible educational approaches in certain countries pose substantial barriers to the development of effective long-term strategies for sustainability.

Results Using panel regression analysis across 15 emerging economies globally for the period 2000–2023, this study examines how Education for Sustainable Development-related indicators can be integrated into the Human Development Index. Findings consistently indicate that all education variables—pre-primary, secondary, and tertiary—alongside adult literacy rate and internet penetration, are statistically significant Human Development Index drivers. Results remain robust and show consistent positive effects across the sample, while inefficient education spending and closely related labor market indicators show structural challenges that may hinder development. Among all education variables, adult literacy arises as the most substantial contributor.

Conclusions The findings emphasize the importance of integrating Education for Sustainable Development into the education component of the Human Development Index. This integration is crucial for accurately reflecting inclusive and sustainable development pathways. Strengthening Education for Sustainable Development enhances human development outcomes and tackles inequalities in both the quality and accessibility of education. This approach is particularly relevant for countries at various stages of development and with differing priorities. This study offers insights for governments, educational institutions, and other organizations on how to integrate Education for Sustainable Development into national and international developmental strategies. It also highlights the need

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for future research focused on measuring competencies related to Education for Sustainable Development and understanding long-term sustainability transitions, which will ultimately benefit future generations. Furthermore, the study underscores the necessity for future policymakers and experts across diverse fields to acquire relevant knowledge and skills, as well as the importance of engaging the broader community in this initiative.

Keywords Education for Sustainable Development, Human Development Index, Panel Regression, Emerging Economies

Background

Sustainability emerged as a crucial paradigm at the end of the 20th century, driving the growing movement to recognize the interdependence of economic development, environmental integrity, and social equity. Despite the intensification of environmental pressures since the Industrial Revolution, the latter half of the 20th century saw an increase in industrial production and general overconsumption, which exacerbated human impact on the environment. The increasing recognition of these repercussions necessitated action, resulting in the introduction of sustainable development as a broader societal concept going beyond merely business concerns [1]. Sustainable development provides a comprehensive framework designed to reconcile the requirements of current generations with the ability of future generations to meet their needs, as articulated in the 1987 Brundtland Report [2]. Further global initiatives arose, such as the United Nations' Sustainable Development Goals (SDGs) [3], an expanded version of the Millennium Development Goals; Doughnut Economics [4], which embodies the principle of a circular economy; and the Triple Bottom Line approach [5].

The Human Development Index (HDI) established by the United Nations Development Programme in 1990 [6] encompasses three key dimensions: health, education, and income. The health dimension is measured by life expectancy at birth; education is assessed via the years of schooling for adults aged 25 and older and expected years of schooling for children beginning their education. The economic dimension is assessed using gross national income per capita, adjusted for purchasing power parity, to compare the living standards across countries. Although the HDI represents a significant advancement towards more holistic, human-centric development metrics, it possesses certain limitations: it does not incorporate environmental sustainability; additionally, the inclusion of educational and health quality, rather than solely duration, could provide a substantial rationale for revising and potentially enhancing the existing HDI dimensions.

This paper is motivated by the understanding that the HDI primarily utilizes quantitative educational indicators, along with those related to health and income. Specifically, it focuses on predicted years of schooling and mean years of schooling and is widely used as a global development metric [7, 8]. This study argues that these indicators do not capture the qualitative aspects of development in education, such as critical thinking and a sustainability mindset, which have been increasingly emphasized in education for sustainable development (ESD) [9, 10]. The emergence of sustainability paradigms, particularly the SDGs, has garnered international attention regarding the role of education in fostering awareness, skills, and competencies related to sustainable development [3]. This situation has emphasized the necessity to examine whether elements of education linked to sustainability contribute to human development outcomes in a qualitative manner, rather than solely focusing on the quantitative results represented in the HDI framework.

To connect educational systems and practices with long-term social progress, specifically in relation to sustainability and education, the Transformative Learning Theory has been widely applied [11]. It is used in this paper to provide a theoretical foundation, together with the analyzed literature, to examine how integrating ESD in education impacts human development as reflected in the HDI. Despite these frameworks and efforts, challenges remain in spreading awareness, accurately measuring, and translating sustainability concepts into action. Traditional economic measurements like Gross Domestic Product (GDP) were also criticized for their inability to capture social equity, environmental challenges, and equitable progress [12]. Sustainability measurement remains methodologically complex, particularly in relation to the selection of indicators, data processing, and interpretation of results, with increasing recognition that measurement approaches should be adapted to countries at different levels of development [13]. Alternative frameworks and metrics have developed that transcend GDP, which focuses exclusively on economic growth. The HDI has emerged as one of the most significant and extensively employed indices.

This research study utilizes panel regression to empirically examine the relationship between the integration of ESD in national and higher education systems and levels of human development. These levels are measured by the HDI dimensions, particularly focusing on the education index. The analysis is based on a dataset of 15 countries, with observations covering a period of 23 years (2000–2023). The study examines whether the integration of

ESD directly contributes to a country's higher HDI. If this integration does not have a direct impact, the research seeks to identify ESD proxies and measure them to ascertain their contribution to the HDI. The aim is to provide a data-driven approach to understanding the role of ESD and the education index, with the goal of enhancing the traditional HDI and laying the groundwork for a new framework called the E-HDI.

Several scientists have explored how education, income, and life expectancy influence human development outcomes. While there is strong justification for shifting away from GDP as the sole measure of progress, and despite its widespread acceptance, the HDI has faced ongoing criticism for oversimplifying the intricate nature of human development by relying on a narrow set of indicators [14]. Similarly, Ranis at al. [15] revisited the concept of the HDI and its scope, asserting that it is incomplete and labeling it as a reductionist measure. They argue that HDI simplifies a range of complex concepts into a limited set of indicators. More recently, Singh et al. [16] conducted an analysis of health expenditure, the infant mortality rate (measured per 1,000 live births), education expenditure, and average years of schooling. They utilized regression analyses to investigate how these variables impact the HDI. However, previous studies have not thoroughly assessed the effects of sustainability integration and sustainability awareness on human development.

Building on previous studies and addressing this gap, this research utilizes proxy indicators for Quality Education to measure key dimensions of SDG Target 4.7. This target ensures that learners acquire the necessary knowledge and skills to promote sustainable development, including ESD, ethical considerations, human rights, and responsible decision-making. Given the unavailability of comparable cross-country data on ESD, the study investigates both the direct and indirect effects of these proxies on the HDI.

The structure of this paper comprises five sections, including this Introduction. Section 2 reviews the relevant literature. Section 3 outlines the methodological framework, detailing the approach and research design, as well as the sample and data sources and the selected econometric modeling. Section 4 presents and discusses the empirical results, including the outcomes of the panel regression analysis. Finally, Sect. 5 concludes the study by addressing contributions, policy and framework implications, limitations, and a proposal for further research.

Literature review

Recently, there have been several studies exploring the gap in the relationship between human development and sustainability. Moreover, one of the main concerns of researchers is to incorporate sustainability indicators in the human development components to align the HDI with the SDGs, thereby overcoming interconnected global tensions and optimizing the future for the upcoming generations. In a pioneering work, Fuentes-Nieva and Pereira [17] provided a theoretical framework for discussing the disconnection between human development and sustainability. They enumerated several examples that indicate the incompatibility of sustainability indicators with components of human development. Furthermore, their argument on "sustainable human development" emphasizes the necessity of new measurement methods to conceptualize potential relationships.

In another study, Gorobets [18] proposed an alternative approach for human development that incorporates natural indicators—both physical and biological—into the HDI formula. Additionally, Üstün and Ürey [19] examined the Trends in International Mathematics and Science Study (TIMSS), a periodic assessment of the quality of mathematical and scientific education, within the framework of sustainability. The study revealed that the "Environmental Awareness Scale" in TIMSS, which evaluates students' awareness of environmental issues, represents a step toward enhancing ESD. Mathematics and statistics are recognized as powerful tools for enhancing education for sustainability, depending on teachers' ability to effectively convey relevant topics and materials [20]. A comprehensive report has been provided that highlights the importance of integrating environmental topics into educational systems, which is beneficial for educational policymakers [21].

Moreover, Stryzhak et al. [22] analyzed the quality of the institutional environment using the World Governance Indicators (WGI) and found a positive correlation between the HDI and the WGI. Extensive research conducted by Cling and Delecourt [23] indicates that the differences in SDG indicators among countries are primarily influenced by their level of economic development, as measured by GNI per capita. Despite the universal intent behind the SDGs, concerns have emerged regarding the cross-country evaluation of their performance, largely due to varying regional contexts and local priorities. These issues align with findings from another study by Kumar et al. [24], which explored the relationship between the HDI and CO_2 emissions, alongside several indices such as income inequality and the Economic Complexity Index. The study highlighted the significant role of policymakers in balancing economic development, which is essential for addressing environmental challenges arising from economic growth and income inequality. In a case study conducted in China, Li and Kang [25] underscored the substantial impact of higher education on the region's sustainable development. Specifically, they identified a positive correlation between the number of higher education graduates and the increase

in GDP per capita. Improved access to higher education is considered a key factor in optimizing economic growth.

The status of ESD in the Arab region has been analyzed in several dimensions. For instance, a United Arab Emirates-based study revealed a strong positive attitude of students toward ESD and the environment [26]. A case study in primary-level education in Egypt uses two directions to analyze education for sustainability in terms of curriculum alignment and teachers' familiarity with the requirements of effective ESD implementation [27]. Based on content analysis and interviews, the author identified sustainability-related content; however, integration of ESD is still limited and needs to overcome general cultural attitudes and perceptions regarding education. Arab universities in high-income countries have been shown to be instrumental in the achievement of the SDGs by employing effective teaching and learning practices at the higher education level. The Arab higher education sector in the Gulf Cooperation Council region has made significant contributions through several key initiatives. These include offering academic courses and programs focused on sustainability to enhance understanding of related issues, providing adequate funding for relevant projects, and establishing strong partnerships between Arab universities and local communities, industries, non-governmental organizations, and governments [28].

Research has sought to address this gap by incorporating sustainability into the HDI framework as part of its metrics or by suggesting additional dimensions that would align with and complement the HDI. For instance, Grisolia et al. [29] suggest incorporating data on reading, math, and science skills from assessments like PISA into the education index (EI) of the HDI. This addition would enhance measurement by capturing the actual quality and effectiveness of learning, rather than just the number of years of schooling. The modified index is designated as EI*, and the revised HDI is referred to as HDI*. Additionally, Torchio et al. [30] propose linking the HDI with greenhouse gas emissions and particulate matter (PM2.5). They introduced an Environmental Cost Index, a metric that complements the HDI, allowing for a more comprehensive assessment of human development when used together. Their case study in Italy indicated that a high HDI score does not necessarily mean strong well-being outcomes, i.e., economic growth does not automatically translate to higher life satisfaction or happiness.

Despite ongoing efforts to integrate sustainability into development metrics, education—one of the core pillars of HDI—has faced criticism for lacking sustainability competence. Although education is a core component of the HDI, it is currently mainly measured by the mean years of schooling and the expected years of schooling. Critics argue that this approach overlooks qualitative dimensions, such as sustainability-related competencies. They contend that the HDI's education pillar is mainly input-based, emphasizing quantity (i.e., years spent in school) rather than quality, the transformative potential of learning, and relevance. This focus may fail to adequately capture how education fosters essential skills, such as ethical reasoning, systems thinking, and ecological awareness, which are crucial for sustainable development. Starting from early critical contributions, Sagar and Najam [31] argue that the HDI only partially fulfills its original conceptual mandate. A discrepancy is identified between the index's foundational normative objectives and its empirical operationalization. Specifically, the education component of the HDI inadequately represents broader developmental dimensions, including its connections to sustainability. The critique broadly highlights the limited scope of the chosen indicators, pointing out their limited ability to capture essential aspects of human development, including equality, freedom, quality, and sustainability. Grisolia et al. [29] build on this criticism by advocating for a proactive approach that seeks to redefine the HDI.

ESD, as reflected in SDG 4 on Quality Education, is included in Target 4.7 and endorsed by UNESCO. It emphasizes transformative learning that promotes responsible citizenship and leadership, critical thinking, ethical decision-making, and ecological consciousness, among other important aspects. Torchio et al. [30] argue that incorporating ESD into the Educational Index (EI) could enhance the index's effectiveness in promoting quality education worldwide, thereby fostering sustainable human development. In practice, these skills are evident beyond formal education and are particularly visible and useful in business contexts.

The competencies needed for sustainability-oriented business transformation, including strategic thinking, system-based decision-making, and digital integration, have been increasingly encouraged in practice [32]. However, the traditional education indicators within the HDI framework do not adequately capture these competencies. Rather than viewing ESD as an additional or external goal, it should be integrated into the HDI's educational sub-index. This integration would reformulate the metric to account for the quality and purpose of learning, rather than merely measuring its duration or level of attainment.

Transformative Learning Theory, first proposed by Jack Mezirow, is an essential framework for comprehending how education—particularly in adult and tertiary education—can meaningfully foster human development by promoting values-driven and more profound learning experiences. The initial context of this theory pertained to adult women re-entering education via community

college programs. During that period, the founder of this theory focused on the processes through which adults reexamined their perspectives, drawing from personal experience, engaging in dialogues, and practicing critical reflection [33]. Subsequently, Mezirow [11] proposed a ten-phase process that begins with a disorienting dilemma, progressing through reorientation, and culminating in a transformed perspective. Although this theory is rooted in adult education, it has also demonstrated its value in the contexts of lifelong learning and tertiary education [34]. Unlike traditional HDI measurements that emphasize only years of schooling, this approach highlights the qualitative aspects and the transformation of learners. This supports the notion that certain forms of education are more effective in shaping long-term human development. The analysis presented in this research paper seeks to incorporate transformative learning, aiming to transcend traditional quantitative metrics of education. It focuses on assessing education as a catalyst for sustainable, ethical, and inclusive development.

A review of empirical studies in this field reveals a relatively consistent set of variables used to examine the relationship between human development and sustainability. The HDI is most commonly treated as the dependent variable, as it captures holistic development outcomes [31, 35]. Among the independent variables, education-related indicators appear to be the most frequent—particularly secondary and tertiary enrollment rates, years of schooling, and, in recent articles, quality-oriented measures including learning outcomes from international assessments such as PISA or TIMSS [9, 36]. Governance variables, especially those derived from the World Bank [37], are also widely used to reflect institutional quality [22]. Environmental indicators—such as carbon dioxide emissions and air pollution—are generally included to reflect sustainability challenges, while socio-economic variables like income levels (GNI per capita), inequality, and economic complexity are often used as control variables [7, 35]. These variables are used to frame the broader development context, although they may not be the primary focus of the analysis.

However, it appears quite consistently across the literature that the direct measurement of ESD remains limited, which is highlighted in UNESCO reports [9, 10] stating that most existing frameworks focus on policy integration or curriculum presence, not on whether sustainability-related competencies are developed. There is a gap that might not always be obvious, but is persistent.

Therefore, most studies rely on proxy variables, and this research study follows a similar approach. The selected variables are consistent with those typically found in the literature, focusing specifically on education, governance, and selected socio-economic factors. The selection is informed by theoretical frameworks as well as the practical availability of comparable data. Thus, there is a gap between the ideal measurements and what the data can show [37].

Simultaneously, the study makes a deliberate effort to extend the education dimension beyond its usual interpretation, and thus education is not treated only as access or attainment but as a space where sustainability-oriented skills may begin to form. Notwithstanding these challenges, the approach allows the analysis to move slightly beyond the standard HDI framework [10].

Consequently, the study aims to contribute to an ongoing discussion of whether the education component of the HDI can reflect more than years of schooling. More specifically, the research asks whether the education component can, at least partially, capture the kind of learning that supports long-term, inclusive, and sustainability-oriented human development while promoting peace and human rights [7].

Methodology

The objective of this study is to analyze to which extent ESD indicators contribute to human development outcomes. This research is designed to address the limitations mentioned in the previous section, specifically the fact that traditional measures of the HDI seem to be failing to reflect the qualitative dimensions of education, especially related to those skills that are necessary for sustainable development. Additionally, the HDI appears to be overlooking the role of governance and institutional and ecological factors in shaping long-term human development [17, 30, 31].

Building on the discussed insights from the literature and guided by the Transformative Learning Theory, the research paper proposes the following hypotheses:

H1: Countries with higher enrollment in education levels aligned with ESD show higher HDI scores.

H2: Political stability positively affects the HDI and strengthens the effect of education indicators on it.

H3: Education expenditure, as a percentage of GDP, is significantly associated with the HDI, i.e., it leads to a higher HDI score.

H4: Internet usage/availability is marginally associated with the HDI.

H5: Tertiary education enrollment demonstrates a positive association with the HDI.

This study uses a panel data regression model to examine the relationship between ESD and human development outcomes in the chosen countries.

The dataset used in this paper covers 15 countries representing different HDI levels, with observations spanning a 23-year period (2000–2023). The chosen countries are Oman, Jordan, Kenya, Rwanda, Egypt, India, Pakistan, Sri Lanka, the Philippines, Vietnam, Brazil, Costa Rica, Ukraine, Serbia, and Georgia.

The selection process was based on theoretical and empirical rationale, with a goal to capture developmental variability, geographic diversity, and policies related to the ESD. The panel comprises countries from seven global regions (Eastern Europe, Sub-Saharan Africa, the Middle East and North Africa, South Asia, Southeast Asia, Latin America, and the Caucasus region). There was a threefold rationale for including these countries.

First of all, alignment with SDG 4 and national strategies that promote ESD were prioritized. Some of the countries—Oman, Sri Lanka, Costa Rica, and the Philippines—have some published documented efforts to integrate global citizenship, sustainability, or environmental education into policy reform, curricula, or teacher training frameworks. In addition, Oman's Vision 2040 provides a comprehensive approach to embedding sustainability in economic planning and education. Additionally, Costa Rica has shown environmental leadership by implementing sustainability into the national educational system. This study analyzes how sustainability-oriented education systems relate to broader human development outcomes by including countries with ESD-related policies.

Secondly, the selection of these countries aimed to encompass a broad range of HDI rankings, as indicated in Table 1, along with considerations of regional development conditions and income levels [38]. This approach would facilitate an analysis of whether the relationship between governance, education, and HDI varies across different national contexts. For instance, countries like Pakistan, Rwanda, and Kenya represent contexts where access to and the quality of basic education continue to pose significant development challenges. In contrast, nations such as Oman, Georgia, and Costa Rica have transitioned to classifications as middle- and upper-middle-income countries, boasting better-developed educational infrastructures. The objective was to identify patterns across diverse economic and institutional landscapes, with the heterogeneity of the selected nations providing a comparative advantage.

Table 1 HDI levels of the selected countries, overviewUnited Nations Development Programme (UNDP), Human Development Report 2023/2024

Country	HDI (2023)	HDI Category
Oman*	0.858	Very High
Georgia	0.844	Very High
Costa Rica	0.833	Very High
Serbia	0.833	Very High
Brazil	0.786	High
Ukraine	0.779	High
Sri Lanka	0.776	High
Vietnam	0.766	High
Jordan	0.754	High
Egypt	0.754	High
Philippines	0.720a	High
India	0.685	Medium
Kenya	0.628	Medium
Rwanda	0.578	Medium
Pakistan	0.544	Low

*Even though some countries have high HDI and high-income levels according to the World Bank (such as Oman), they are still considered developing by some agencies, such as the International Monetary Fund [39], which classifies Oman as an 'emerging market and developing economy'. Additionally, the UNCTAD Database treats Oman as a developing country [40]

Thirdly, the selection of countries was guided by their relevance, particularly regarding policies and the availability of data. The study focused on countries that provided consistent, longitudinal data. The countries were assessed based on their monitoring and reporting processes, along with their involvement in the SDGs. This assessment was conducted through national reporting mechanisms and relevant organizations, such as UNESCO and UNDP.

This study intentionally uses a smaller sample size, as it is does not aim for global representation, which would require a randomized, larger sample. Instead, the research aims to identify meaningful contrasts and patterns relevant to the central research question: To what extent do education frameworks that incorporate ESD contribute to enhancing the HDI, particularly its education dimension, on an international scale? The countries chosen for this study provide a solid basis for testing theory-driven hypotheses and generating context-sensitive insights into the role of ESD in shaping the educational dimensions of the HDI.

Due to the lack of standardized and comparable cross-country data related to SDG 4.7, this paper utilizes proxy variables related to access to education, educational quality, and investment in education to approximate the ESD role. Although these variables do not directly measure ESD skills, they foster an environment that promotes the development of such competencies. The HDI serves as the dependent variable, representing overall development performance. The independent variables encompass education-related factors (including government education expenditure, enrollment rates in pre-primary, secondary, and tertiary education, pupil-teacher ratio, and adult literacy rate); governance indicators (political stability, government effectiveness, voice, and accountability); as well as demographic and technological variables (urban population and internet penetration).

Control variables are those associated with unemployment, such as youth unemployment and general

unemployment, as well as urban population figures. These factors reflect labor market dynamics and socioeconomic conditions. Incorporating these variables allows for a more accurate estimation of the impact of education-related indicators on the HDI.

As shown in Table 2, the dependent variable is the HDI, which includes education (mean and expected years of schooling), life expectancy at birth, and income indicators, such as GNI per capita [7]. The HDI has been widely used in development research, although it has seen criticism for failing to include equity, educational quality, and sustainability-related skills and competencies [31]. This study keeps the HDI as the dependent variable while empirically and critically examining how better-aligned education variables, the proxies for ESD used here as independent variables, may influence its dynamics.

The independent variables selected as the focus of this study revolve around quality, sustainability, and access to education. The percentage of enrollment in tertiary education serves as a proxy for access to higher education, where skills such as analytical thinking, ethical reasoning, systems thinking, and global citizenship—essential components of ESD—are typically developed and reinforced [10, 11]. Additionally, enrollment in pre-primary education reflects crucial foundational stages for socio-emotional development and the establishment of value systems, aligning closely with SDG 4, particularly target 4.2, which emphasizes access to and quality of early childhood and pre-primary education. Furthermore, the focus of Transformative Learning Theory is on creating learning environments that foster empathy and reflection.

Table 2 Selected variables.Source: The authors' selection based on relevant data

Variable Name	Abbreviation	Source
Human Development Index	HDI	UNDP
Internet access, % of population	INT	World Bank
Gov. education expenditure, % of GDP	GEE	World Bank
Secondary school enrollment, % gross	SSE	World Bank
Tertiary education enrollment, % gross	TSE	World Bank
Pre-primary enrollment, % gross	PPE	UNESCO UIS
Adult literacy rate, % ages 15+	ALR	World Bank
Pupil-teacher ratio, primary	PTR	UNESCO UIS
Political stability	PS	World Bank WGI
Government effectiveness	GEFF	World Bank WGI
Voice and accountability	VA	World Bank WGI
Unemployment, % of labor force	UNEMP	World Bank
Urban population, % of total population	URB	World Bank
Youth unemployment, % ages 15–24	YUNEMP	World Bank

In addition, further education-related variables comprise adult literacy, secondary enrollment rates, and the pupil-teacher ratio at the primary level. All these reflect a broader context of system performance, with the pupil-teacher ratio serving as a proxy for educational quality. However, consistent with critiques by Hanushek and Woessmann [41], such input variables may not fully explain learning outcomes unless analyzed alongside governance and contextual conditions. Literature about political economy and development studies suggests that countries with strong government effectiveness and higher political stability may be more likely to deliver effective and sustained education reforms and public services that increase human development [42]. Additionally, Huynh (2009) highlights how political stability and a straightforward legal system align with economic and institutional development.

Internet access (as a percentage of the population) acts as a proxy variable that reflects digital and infrastructural factors, highlighting a global transition toward digital learning and access to knowledge systems. However, recent academic research in Information and Communication Technologies for Development suggests that having that technology infrastructure alone may not be sufficient for achieving positive development outcomes. Ahuja [43] emphasizes the necessity of inclusive design and digital literacy to complement meaningful access to digital education and equity. Eyieyien et al. [44] argue that ICT initiatives should incorporate literacy training and stakeholder engagement to promote genuinely inclusive development, while some scholars believe that digital equity goes beyond access to include affordability and skills [45]. Finally, Kane [46] warns that strategies focused exclusively on infrastructure must also prioritize digital literacy and affordability; their effectiveness may diminish.

Youth unemployment (the percentage of individuals aged 15–24), urban population (the percentage of the total population), and general unemployment (the percentage of the labor force) are included as control variables because they may reflect socioeconomic conditions that could affect education and, in return, development outcomes. For instance, high youth unemployment in a country could limit the returns on formal education, indicating that the labor market is not effectively absorbing skilled graduates.

Variables were selected by both theoretical logic and practical data availability. Some of the variables, specifically life expectancy, had to be excluded to avoid circular reasoning, as they are already directly embedded within the HDI system.

The baseline specification is defined as follows:

$$\begin{aligned}\mathrm{HDI}_{it} = {} & \alpha + \beta_1 \mathrm{GEE}_{it} + \beta_2 \mathrm{SSE}_{it} + \beta_3 \mathrm{TSE}_{it} + \beta_4 \mathrm{PPE}_{it} + \beta_5 \mathrm{ALR}_{it} \\ & + \beta_6 \mathrm{PTR}_{it} + \beta_7 \mathrm{GEFF}_{it} + \beta_8 \mathrm{PS}_{it} + \beta_9 \mathrm{VA}_{it} + \beta_{10} \mathrm{INT}_{it} \\ & + \beta_{11} \mathrm{URB}_{it} + \beta_{12} \mathrm{UNEMP}_{it} + \mu_i + \lambda_t + \varepsilon_{it}\end{aligned}$$

To account for heterogeneity across countries and over time, several panel data estimators were applied, including the pooled OLS model, the between-effects estimator, the fixed effects model (FE), the random effects model (RE), and the first-difference model (FD). Each specification is used to capture different aspects of the data and allows for robustness checks across alternative assumptions. The pooled OLS model provides a simple benchmark by assuming homogeneity across countries and ignoring country-specific effects. The between-estimator focuses on variation across countries using time-averaged values. Conversely, the FE model controls for unobserved, time-invariant country characteristics by allowing each country to have its own baseline level, while the RE model treats these country-specific effects as random and assumes they are not correlated with the explanatory variables. Finally, the FD model examines changes over time, removing time-invariant effects by focusing on year-to-year differences.

To determine the appropriate specification between the FE and RE models, the Hausman test was employed, whose function is to evaluate if the country-specific effects are correlated with the explanatory variables. If that correlation exists, the FE is preferred; otherwise, the RE model is considered appropriate. Finally, the robustness of the results was assessed by comparing findings across the different model specifications, and the model selection was further supported by R^2, adjusted R^2, and F-statistics.

This scientific research is more problem-driven than method-driven, guided by the hypotheses that sustainability-related education and governance have an important role in influencing the HDI beyond traditional economic growth measures. The research method uses a quantitative, comparative, and longitudinal research design—analyzing numerical factors by comparing 15 countries in different regions over a period of 23 years. This way, the paper aims to explore the impact of ESD on the HDI by using panel data regression, which was chosen because of its strong analytical capacity and ability to capture temporal and cross-sectional dynamics while controlling for unobserved heterogeneity. Panel regression is an econometric model tailored to panel data, a methodology that also allows, in the case of chosen variables, a more accurate estimation of HDI determinants in comparison to, as discussed by Hsiao [47], single-dimension models (single-equation time series or cross-sectional models). The method also offers a larger number of observations and greater variation of the given data. This helps increase the precision of the results while the risk of biased estimates is reduced. It also addresses omitted variable bias by taking into account country characteristics that do not change over time, like history, geography, and culture, which facilitates more reliable causal interpretation [48]. Control of these 'hidden factors' improves the identification process and yields a more accurate estimate of the influence of ESD proxy variables on human development. Furthermore, the panel data methods that have evolved over the past few decades, employing increasingly sophisticated techniques such as factor structures and dynamic modeling, enhance the application of this approach in research [48].

While panel regression offers significant advantages, such as the ability to control for unobserved heterogeneity, it also has limitations that must be acknowledged in this paper. Concerns associated with fixed-effects models include measurement error, low statistical power, limited external validity, and the potential for biased or incorrect coefficient estimates. According to Hill et al. [49], implementing fixed effects without thorough evaluation can lead to misleading p-values and erroneous causal inferences. Therefore, the selection of panel model specifications—primarily fixed and random effects—and the execution of careful diagnostic testing are critical to guaranteeing a reliable interpretation of the HDI factors.

To address the potential shortcomings of the models, several methodological precautions were taken in the analysis of the data in this paper. Firstly, the low statistical power concerns were reduced by implementing a balanced panel covering 15 countries across 23 years (2000–2023), which resulted in 360 observations, providing sufficient variation for the analysis. Secondly, challenges of omitted variable bias and unobserved heterogeneity were addressed by estimating both random effects and fixed effects models and applying the Hausman test to determine the more efficient specification. In addition, potential multicollinearity concerns were examined, as shown in the correlation and variance inflation factor (VIF) analysis. Thirdly, robustness checks were conducted using alternative estimators that included first-difference models and pooled OLS, which helped validate result consistency across specifications. Finally, measurement errors and external validity concerns were mitigated by using exclusively standardized and internationally recognized data sources such as the World Bank, UNDP, and Worldwide Governance Indicators. All these strategies together strengthened the validity of the paper's findings while addressing the limitations found by Hill et al. [49].

Results

The results indicate substantial variation across the countries and over time (Table 3), which is particularly evident in variables that are related to public expenditure on education (GEE), secondary school enrollment (SSE), and

Table 3 Descriptive statistics.Source: Authors' calculations

Variable	*N*	Mean	St. Dev.	Min.	Max.
INT	360	31.067	27.24	0.063	95.3
GEE	360	3.999	1.336	1.204	7.397
SSE	360	79.987	24.971	9.514	141.203
TSE	360	32.25	20.758	1.164	84.798
PPE	360	58.242	24.411	2.648	105.103
ALR	360	86.103	13.896	50	100
PTR	360	25.965	13.318	8.68	69.286
URB	360	49.926	23.246	14.926	92.02
UNEMP	360	8.118	5.047	0.398	24
YUNEMP	360	19.512	10.982	0.82	51.244
GEFF	360	−0.154	0.372	−1.213	0.791
PS	360	−0.57	0.824	−2.81	1.121
VA	360	−0.352	0.7	−1.566	1.152
HDI	360	0.689	0.108	0.34	0.858

internet access (INT). The HDI values range from 0.34 to 0.858, with a mean of 0.689; these figures demonstrate the diversity in the sample of countries and their varying levels of development. Governance indicators (GEFF, PS, VA) show negative mean values, which indicate that there are overall institutional challenges within the sample. In addition, unemployment—and especially youth unemployment—varies greatly across countries.

Following the descriptive analysis above, the relationships among the variables are examined before moving on to regression analysis. Table 4 presents the correlation matrix that provides initial insights into the strength and direction of associations between variables and allows for the detection of possible multicollinearity—variables that may capture similar underlying dynamics.

The correlation analysis provides a preliminary view of how the variables relate to one another, helping to identify any substantial overlap. A significant issue arises with unemployment (UNEMP) and youth unemployment (YUNEMP), as the correlation coefficient reaches 0.92. This correlation suggests substantial overlap between the two variables. Therefore, retaining both in the model would contribute additional essential information and could compromise the reliability of the estimates. As a result, YUNEMP was excluded to ensure clarity and stability in the findings.

There are other strong relationships observed among the education variables. For instance, secondary school enrollment (SSE) is closely linked to the pupil–teacher ratio (PTR) (r = −0.86) and adult literacy rate (ALR) (r = 0.83).

The governance indicators (GEFF, PS, and VA) exhibit moderate relationships with one another. The highest correlation among these indicators is 0.57, which falls short of the commonly accepted threshold of 0.80.

To further examine whether the relationships observed in the correlation analysis might impact the model, the VIF was calculated, and the results are presented in Table 5 below. After removal of YUNEMP, all VIF values are below usually accepted threshold of 10. Additionally, SSE (7.09) and PTR (5.19) have relatively higher values compared to other variables.

The selection between FE and RE models was guided by the Hausman specification test. After removing YUNEMP, the test produced a χ^2 value of 20.89 with a p-value of 0.052. Since this is slightly above the conventional 0.05 threshold, the null hypothesis was not rejected, which supports the use of the RE model as the more efficient model specification for this dataset. As presented in Table 6, the RE model explains a substantial share of variation in the HDI with an adjusted R^2 of 0.784.

Looking at the results above, it can be observed that adult literacy (ALR), pre-primary (PPE), secondary (SSE), tertiary (TSE) enrollments as well as government effectiveness (GEFF), voice and accountability (VA), and internet access (INT) are positively associated with HDI in the RE and are statistically significant. Government education expenditure (GEE) is negatively associates with HDI while political stability (PS), urbanization (URB) and unemployment (UNEMP) are not statistically significant in the RE specification.

To illumine understanding and interpretation of the statistically significant coefficients, Table 7 below shows their marginal effects.

Discussion

Looking at the results more closely, education clearly emerges as the most consistent and stable contributor to human development, while adult literacy (ALR) shows the strongest and most substantive effect—an increase of 10% points in literacy is associated with roughly a 0.03 increase in the HDI. This is considerable, as it points to a fundamental insight: basic capabilities, not just

Table 4 Correlation matrix of independent variables.Source: Authors' calculations

INT	INT	GEE	SSE	TSE	PPE	ALR	PTR	URB	UNEMP	YUNEMP	GEFF	PS	VA	HDI
	1													
GEE	0.27	1												
SSE	0.55	0.26	1											
TSE	0.61	0.37	0.71	1										
PPE	0.37	0.16	0.41	0.44	1									
ALR	0.48	0.24	0.83	0.7	0.38	1								
PTR	−0.52	−0.17	−0.86	−0.72	−0.38	−0.73	1							
URB	0.52	0.37	0.62	0.67	0.16	0.53	−0.66	1						
UNEMP	0.17	0.06	0.22	0.36	−0.26	0.25	−0.2	0.33	1					
YUNEMP	0.25	0.01	0.42	0.42	−0.17	0.32	−0.41	0.36	0.92	1				
GEFF	0.38	−0.05	0.48	0.19	0.11	0.4	−0.34	0.33	0.17	0.27	1			
PS	0.32	0.4	0.53	0.26	0	0.49	−0.4	0.43	0.11	0.15	0.57	1		
VA	0.14	0.29	0.4	0.4	0.49	0.36	−0.29	0.32	0.2	0.29	0.29	0.11	1	
HDI	0.28	−0.01	0.21	0.2	0.25	0.05	−0.26	0.29	−0.02	0	0.13	0.16	−0.07	1

Table 5 Variance inflation factor (VIF)Source: Authors' calculations

Variable	Updated VIF	Status
SSE	7.09	Cautionary (Acceptable)
PTR	5.19	Cautionary (Acceptable)
TSE	4.43	Acceptable
ALR	3.7	Acceptable
URB	2.7	Acceptable
PPE	2.59	Acceptable
GEFF	2.56	Acceptable
PS	2.89	Acceptable
VA	2.23	Acceptable
INT	2.25	Acceptable
GEE	2.06	Acceptable
UNEMP	1.77	Excellent

formal years of schooling, remain central to development outcomes.

All levels of education—pre-primary (PPE), secondary (SSE), and tertiary (TSE)—are positively associated with HDI (they are positive and significant). The individual effects are smaller, but importantly, they are consistent, which suggests that development is not driven by a single stage of education; rather, it unfolds cumulatively. Early exposure and continued participation matter, and higher education appears to consolidate these gains. Taken together, these patterns reinforce the idea of education as a continuous system rather than a set of isolated levels. When viewed through the lens of ESD, the model does not directly measure sustainability-related competencies—such as critical thinking, ethical reasoning, or global awareness. Nevertheless, the results indicate a strong association between the underlying conditions that enable such competencies and higher human development. Access, participation, and basic literacy appear to form the foundation upon which more complex skills can develop. ESD, therefore, does not emerge independently; it depends on a functioning, inclusive, and sufficiently developed education system.

This is particularly relevant in the context of this study, as the findings suggest that the education dimension of the HDI may extend beyond a narrow focus on years of schooling, capturing—at least indirectly—elements of learning outcomes such as literacy and capability development. In this respect, the results point toward a broader interpretation of human development, one that begins to align with sustainability-oriented, inclusive, and long-term development pathways.

One result that requires more careful interpretation is government education expenditure (GEE), which appears negative and statistically significant. At first glance, the result seems counterintuitive; however, the finding does not necessarily imply that higher spending is detrimental but that it may reflect inefficiencies in allocation,

Table 6 Panel regression results.Source: Authors' calculations

Variable (Abbreviation & Full Form)	POLS (1)	BE (2)	FE (3)	RE (4)	FD (5)
GEE: Gov. education expenditure	−0.014*** (0.005)	−0.035 (0.055)	−0.003** (0.001)	−0.008*** (0.002)	−0.001 (0.001)
SSE: Secondary school enrollment	0.001 (0.001)	0.003 (0.006)	−0.00001 (0.0001)	0.001*** (0.0002)	0.0002 (0.0001)
TSE: Tertiary school enrollment	0.0001 (0.0005)	0.0003 (0.005)	0.001*** (0.0002)	0.001*** (0.0002)	0.0004** (0.0002)
PPE: Pre-primary enrollment	0.002*** (0.0003)	0.004 (0.004)	−0.0001 (0.0001)	0.001*** (0.0001)	0.0001 (0.0001)
ALR: Adult literacy rate	−0.004*** (0.001)	−0.007 (0.005)	0.0001 (0.0004)	0.003*** (0.0004)	−0.0002 (0.0005)
PTR: Pupil–teacher ratio	−0.0003 (0.001)	−0.002 (0.008)	0.0002 (0.0003)	0.001*** (0.0004)	0.0001 (0.0002)
GEFF: Government effectiveness	−0.006 (0.020)	−0.132 (0.208)	0.002 (0.004)	0.013** (0.006)	0.002 (0.003)
PS: Political stability	0.032*** (0.010)	0.205 (0.128)	0.005** (0.002)	0.003 (0.003)	−0.001 (0.002)
VA: Voice and accountability	−0.053*** (0.010)	−0.087 (0.108)	−0.005 (0.005)	0.013* (0.007)	0.003 (0.003)
INT: Internet penetration	0.0001 (0.0003)	−0.015 (0.006)	−0.0005*** (0.0001)	0.001*** (0.0001)	−0.0003*** (0.0001)
URB: Urban population	0.002*** (0.0003)	0.006 (0.003)	−0.0003 (0.0004)	−0.0003 (0.001)	−0.0001 (0.001)
UNEMP: Unemployment rate	0.003** (0.001)	0.013 (0.015)	0.0002 (0.0004)	−0.0002 (0.001)	−0.001*** (0.0003)
Constant	0.790*** (0.076)	1.089 (0.918)	—	0.319*** (0.052)	0.006*** (0.001)
Hausman Test (p-value)	Significant	Not Significant	Significant	Significant	Significant
Observations	360	15	360	360	345
R2	0.326	0.851	0.296	0.791	0.104
Adj. R2	0.303	−0.044	0.184	0.784	0.071
F-Statistic	13.997***	0.95	10.842***	1,311.341***	3.206***

Table 7 Marginal effects interpretation (based on RE model).Source: Authors' calculations

Variable	Coefficient	Marginal Interpretation
Adult Literacy (ALR)	0.003***	10% ↑ → +0.03 HDI
Government Effectiveness (GEFF)	0.014**	1 pt ↑ → +0.014 HDI
Secondary Enrollment (SSE)	0.001***	10% ↑ → +0.01 HDI
Tertiary Enrollment (TSE)	0.001***	10% ↑ → +0.01 HDI
Pre-primary Enrollment (PPE)	0.001***	10% ↑ → +0.01 HDI
Internet Access (INT)	0.001***	10% ↑ → +0.01 HDI
Gov. Education Expenditure (GEE)	−0.008***	1% ↑ → −0.008 HDI

Significance levels: *** $p < 0.01$, ** $p < 0.05$

differences in how resources are utilized, or time lags between investment and observable outcomes. In several countries within the sample, increased expenditure may also be a response to existing structural challenges, which complicates the observed relationship.

A similarly nuanced pattern is observed for the pupil–teacher ratio (PTR), showing a small positive effect, which is not the expected direction, as lower ratios are typically associated with improved learning environments. However, within the context of this study, the result may indicate that expanding access to education—even if it temporarily leads to more crowded classrooms—has a stronger immediate impact on development than optimizing classroom conditions. Thus, broadening participation may, at least in the short term, outweigh improvements in efficiency.

Institutional quality also contributes to development outcomes, although more moderately and less uniformly. Namely, government effectiveness (GEFF) is positive and statistically significant, which aligns with expectations—more effective institutions are better able to translate resources into tangible outcomes. Political stability (PS) and voice and accountability (VA) show less consistent significance, but their positive coefficients still support the broader argument that governance quality reinforces development processes.

The positive and significant coefficient of internet access (INT) and other technological factors indicate that human development is facilitated by increased connectivity. This is likely due to the improved access to information, digital learning opportunities, and broader

participation in economic and social society. Therefore, internet access can be understood not only as a technological variable but also as an enabling condition for both education and development more broadly.

By contrast, once education and institutional variables are accounted for, urbanization (URB) and unemployment (UNEMP) do not appear statistically significant in the RE model. The statement does not imply that these factors lack importance; rather, it suggests that their effects may already be captured by other variables, particularly those related to education and governance.

Overall, the results point clearly to the fact that human development in the selected countries appears to be strongly associated with education—not only in terms of access but also in terms of accumulated capabilities, especially literacy, while institutional quality and digital access further support this process. Taken together, these findings provide a solid empirical basis for the next stage of the research, which will move more directly toward examining ESD, particularly within tertiary education systems where higher-order skills and competencies are more likely to emerge. However, while education and awareness are essential in shaping sustainability-oriented values, they may not be sufficient to drive behavioral change in isolation. Empirical evidence suggests that when energy prices remain low, consumers have limited economic incentive to adjust their consumption patterns, which can constrain the overall contribution to sustainable development outcomes [50]. Similarly, the effectiveness of decarbonization strategies appears to vary across countries, with greater vulnerability observed in those highly dependent on energy imports, facing constraints in the deployment and utilization of renewable energy sources, and characterized by weaker socio-economic conditions [51]. In line with these broader structural constraints, the results of this study suggest that while education and awareness are essential in shaping sustainability-oriented values, they may not be sufficient to drive behavioral change in isolation. Empirical evidence further indicates that when energy prices remain low, consumers have limited economic incentive to adjust their consumption patterns [51]. Income inequality further shapes energy consumption and emissions patterns, reinforcing disparities in environmental outcomes [52].

Conclusion

The aim of this study was to empirically examine how sustainability-related education variables affect human development outcomes measured by the HDI. Panel regression analysis was used across a sample of 15 countries with emerging economies for the period 2000–2023. The results indicate that a few education-related variables, which are not fully captured by the current HDI framework, specifically related to tertiary and secondary education enrollment, show a statistically significant positive association with human development outcomes. Specifically, adult literacy emerges as the most consistent and substantively significant contributor, while the levels of education—pre-primary, secondary, and tertiary—show positive and significant effects. These findings show the cumulative and continuous role of education in shaping human development outcomes. Once the model specification was refined, the study excluded youth unemployment because of its significant overlap with total employment, as confirmed by correlation and VIF analysis. The Hausman test was further deployed, and it guided model selection, which indicated that RE specification was the most appropriate for this study. This adjustment improves the reliability of the study and its estimates, and it also ensures that the results are not distorted by redundant variables.

The findings indicate that certain education-related variables, which are often neglected by the traditional HDI framework—such as tertiary enrollment—demonstrate a statistically significant positive effect on human development. This supports the hypothesis that the qualitative aspects of the educational dimension in the HDI significantly contribute to human development outcomes. The results also confirm the hypothesis of the positive association of secondary enrollment, which represents the time young people have to develop competencies such as critical thinking, ethical decision-making, ecological awareness, and systems thinking, as emphasized within ESD frameworks. The findings of this study indicate that the education dimension of the HDI may encompass more than merely the average years of schooling. Although this study did not directly measure the competencies of ESD, the roles of literacy and participation imply that the HDI may reflect aspects of capability development associated with sustainability-oriented learning.

At the same time, secondary education enrollment emerges as a critical stage, as it is the time young learners develop competencies like critical thinking, ethical decision-making, ecological awareness, and systems thinking—core elements emphasized by ESD. This study's findings suggest extending the education dimension of the HDI beyond a narrow focus on mean years of schooling. Although ESD-related competencies are not directly measured, the strong literacy role, as well as participation, indicates the HDI may possibly capture elements of capability development associated with sustainability-oriented learning. The impact of governance variables on the HDI was found to be more complex. Political stability was found to have a generally positive but not consistently significant relationship with the HDI. Government effectiveness and voice and accountability showed mixed or even negative relationships; the

complexity of institutional impact on development outcomes is reflected in these results. Government expenditure on education was also expected to have a highly positive impact but was found to be either insignificant or negative in many areas.

An additional insight that emerged is the positive association between pupil-teacher ratio and HDI. Although this finding may seem counterintuitive, it suggests that expanding access to education should be a priority in emerging economies. This reflects increased participation, which may have a stronger developmental impact than improvements in classroom conditions.

Demographics and digital factors are included to provide additional explanatory dimensions. Internet access exhibits a positive effect; however, this is only true when it is paired with digital literacy and equitable access, aligned with the Internet and Communication for Development movement, which promotes caution in infrastructure-focused approaches. Further, urbanization shows a positive but marginal contribution, while there is a paradox within the labor market—unemployment rates overall show a positive association with the HDI in pooled models, while youth unemployment has a negative effect, which indicates weaknesses in the transition from education to employment. The results suggest that the current structure of the Human Development Index (HDI) fails to consider the quality of education and governance that align with sustainability, as highlighted in literature. Based on Transformative Learning Theory and both contemporary and previous literature, the findings of this paper indicate that integrating sustainability-oriented, critical, and reflective competencies into the education system significantly impacts development. Equally importantly, it also establishes the background for further studies, one of which is already planned—a country-level case study, which will test and refine the E-HDI framework in practice. This new study seeks to offer policymakers, both in the selected country and on a global scale, actionable guidance for aligning human development strategies through educational policies and practices with the SDGs and other sustainability paradigms.

Despite the beneficial findings and contributions, the study has also encountered challenges and limitations that should be acknowledged. Firstly, a relatively small sample of countries is used; this may limit the wide applicability/generalizability of the findings to many countries across different continents. This limitation may particularly influence the study's relevance to developed economies. Secondly, the data used are secondary international datasets. The limitation here is the partial capture of the exact dimensions of education for sustainable development, such as curriculum, pedagogy, and the depth of sustainability competencies acquired. Finally, several proxy variables had to be used, which might affect the depth, accuracy, and multifaceted concepts of ESD.

The study establishes a foundation for a new HDI framework, termed the Enhanced Human Development Index (E-HDI). However, given the identified limitations, several areas for further research are recommended: conducting longitudinal studies on ESD impact; redefining the HDI to incorporate an ESD index dimension; exploring the connection between ESD, employment, and green innovation; and finally, carrying out country-specific case studies to gain deeper contextual insights into how ESD, if adopted, can influence knowledge, attitudes, behaviors, and human development outcomes within a specific cultural, economic, and social context.

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Author contributions
A.M. is responsible for conceptualization, resources, writing the original draft, and project. S.F. contributed to literature synthesis, validation, and interpretation of findings within the sustainability policy context. M.N. developed the methodological framework, conducted the analysis and data interpretation. All authors reviewed the manuscript.

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