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The Human Development–Sustainable Development Nexus: Global Evidence and Policy Implications

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Abstract

Human development and sustainable development are closely interconnected, yet the relative contributions of human development components to the achievement of the Sustainable Development Goals (SDGs) remain insufficiently quantified. This study examines the empirical relationship between human development and sustainable development outcomes, with particular attention to education and innovation capacity. Using a global panel dataset covering 167 countries from 2015 to 2022, we analyse how the Human Development Index (HDI) and its core components influence overall SDG performance and selected goal-specific outcomes. Employing panel regression techniques with pooled, fixed-effects, and random-effects estimators, the results reveal a strong and robust positive association between human development and SDG achievement. Improvements in the HDI are consistently associated with higher SDG Index scores, both across and within countries over time. Disaggregated analysis shows that education-related variables, mean years of schooling and expected years of schooling exert the strongest and most immediate impact on sustainable development outcomes, while short-term variations in health indicators play a more limited role. Innovation-related outcomes are particularly sensitive to accumulated human capital, highlighting the importance of long-term investment in education for knowledge-based development. Additional convergence analysis indicates that countries with lower initial SDG performance tend to experience faster progress, suggesting meaningful catch-up potential when human development improves. Overall, the findings confirm that human development, particularly education, is a foundational driver of sustainable development and provide critical policy insights for countries seeking to strengthen sustainability outcomes and competitiveness in education- and innovation-driven sectors.

Keywords

human development, sustainable development goals, education, human capital, HCI, HDI

1 Introduction

Over the past three decades, development has increasingly been understood as a multidimensional process that extends beyond economic growth alone. Rising income levels, while important, have proven insufficient to guarantee social well-being, resilience, or long-term sustainability. In response, the global development discourse has progressively shifted toward more comprehensive frameworks that integrate economic, social, and institutional dimensions of progress. Human development and sustainable development have emerged as two of the most influential paradigms within this broader reorientation, shaping policy agendas, measurement systems, and international cooperation.

Human development emphasises the expansion of individuals' capabilities through improved education, health, and living standards, thereby enabling people to lead productive and meaningful lives. Sustainable development, in turn, focuses on balancing economic development with social inclusion and environmental responsibility to safeguard the welfare of future generations. Although these concepts originate from distinct intellectual traditions,

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they are inherently interdependent. Human development enhances societies' capacity to pursue sustainability goals, while sustainable development creates the structural conditions under which human capabilities can be preserved and expanded over time.

This interdependence is explicitly reflected in the United Nations Sustainable Development Goals (SDGs), which embed human development priorities, such as quality education, decent work, and reduced inequalities, within a universal sustainability framework. Nevertheless, despite the conceptual consensus on their mutual reinforcement, empirical evidence on how human development translates into concrete SDG outcomes remains fragmented. Existing studies often focus on individual dimensions, regions, or short time horizons, leaving open questions regarding the relative importance of education, health, and income in driving sustainable development performance across countries.

Education deserves particular attention within this nexus. As both a core component of human development and a direct policy objective of the SDGs, education plays a dual role: it improves individual capabilities while simultaneously strengthening innovation capacity, institutional quality, and economic resilience. In an increasingly knowledge-driven global economy, the accumulation of human capital through education is also closely linked to countries' ability to compete in high-value sectors such as research, innovation, and advanced services. Understanding the extent to which educational attainment shapes sustainable development outcomes is therefore critical for both development policy and economic strategy.

Against this background, the present study provides a comprehensive empirical assessment of the relationship between human development and sustainable development. Using a global panel dataset covering 167 countries from 2015–2022, we examine how overall human development and its key components influence SDG performance at both aggregate and goal-specific levels. By applying panel-data methods and convergence analysis, the study offers new insights into the dynamic relationships among education, innovation, and sustainability, and highlights policy-relevant pathways for countries seeking to align human development investments with long-term sustainable development objectives.

2 Literature review

Human capital refers to the collective skills, knowledge, and health attributes of individuals that contribute to their economic productivity and societal well-being. Measuring human capital requires a multidimensional approach that encompasses education, health, cognitive skills, and economic participation (NBER, 2021).

Fig. 1 demonstrates a clear positive association between HCI and GDP per capita, suggesting that countries with higher human capital generally achieve greater economic productivity.

This relationship reinforces the idea that investments in human capital (such as education, health, and skills development) are critical drivers of economic progress. As highlighted in the second visualisation, clustering data points by region underscores disparities across different continents, with developed nations consistently achieving higher HCI and GDP per capita. These findings highlight the necessity of prioritising human capital development, particularly in low – and middle-income countries, to foster sustainable economic growth and global competitiveness.

Human capital, defined as individuals' skills, knowledge, and experience, underpins the achievement of the Sustainable Development Goals (SDGs) and is particularly crucial for highly competitive sectors that generate significant profits. Industries such as technology, finance, and healthcare thrive on innovation and expertise, making human capital a resource and the central pillar of their success. These sectors can sustain their competitive edge by investing in education, training, and employee development while contributing to societal progress.

As Di Fabio and Peiró (2018) explored, the concept of human capital sustainability leadership underscores the importance of nurturing positive workplace environments that enhance employee autonomy, well-being, and creativity. Such leadership approaches are vital in high-stakes, knowledge-intensive industries, where talent retention and innovation drive profitability. By fostering organisational

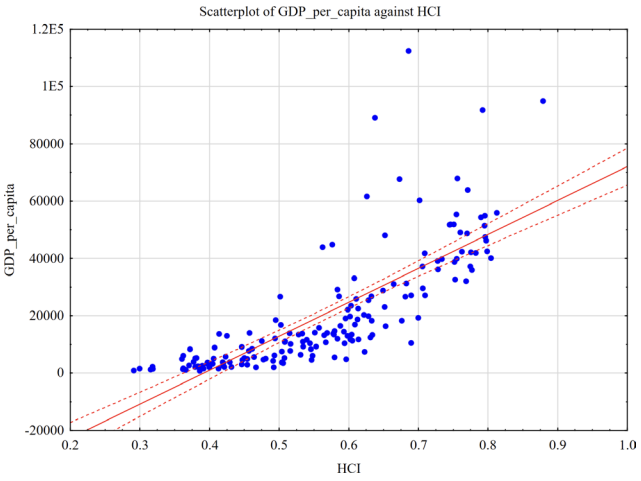

Fig. 1 Dependence of GDP p.c. from Human Capital Index (Source: Our World in Data (Global Change Data Lab, online); World Bank (World Bank Group, online))

health, this model supports individual flourishing and aligns sustainable development objectives, promoting long-term economic resilience and societal advancement.

As sustainability encompasses social equity and environmental stewardship, its connection to human capital becomes even more pronounced. Vásquez Roldán and Henao (2017) highlight the transition from a narrow focus on economic growth to a broader framework that integrates diverse dimensions of development. This holistic view is essential in competitive, high-profit sectors to address global challenges like climate change, inequality, and resource constraints while maintaining economic viability. The United Nations' SDGs further illustrate the necessity of balancing financial, social, and environmental priorities (Herrero et al., 2021), which depends heavily on a skilled and adaptable workforce.

A rights-based perspective, as advanced by Choondassery (2017), strengthens this link by advocating for equitable access to resources and opportunities. Ensuring inclusivity and social justice in human capital development is particularly relevant for high-profit industries, as disparities in access to education and training can hinder societal progress and limit the potential for innovation. Addressing these inequities lays the groundwork for sustainable progress that benefits all.

Corporate social responsibility (CSR) also plays a crucial role in high-profit sectors, where businesses have significant influence (Volchek et al., 2024). Bombiak and Marciniuk-Kluska (2018) argue that ethical and transparent business practices, combined with investments in human capital, can drive sustainable development. By prioritising workforce well-being and aligning corporate strategies with sustainability principles, organisations can ensure that their pursuit of profit is balanced with social and environmental responsibilities, enhancing long-term economic and societal well-being. In conclusion, human capital is the bedrock of development, especially in competitive and high-profit industries. By prioritising investments in talent development, fostering equitable access to opportunities, and aligning corporate practices with sustainability, societies can harness the potential of these sectors to drive economic growth and social progress. Integrating these principles into policy and practice is essential to address the multifaceted challenges of our time and to ensure inclusive, equitable, and sustainable development for future generations (Liashenko and Dluhopolskyi, 2024; Zhukovska et al., 2025).

Human and sustainable development are deeply interlinked concepts that reinforce one another to foster long-term economic growth and social well-being. Human development focuses on enhancing individuals' capabilities by improving education, health, and quality of life, while sustainable development addresses the need to balance economic growth, environmental sustainability, and social equity. Together, these approaches contribute to a holistic development model that promotes economic resilience and societal progress, providing a foundation for knowledge-driven exports like education and research and development (R&D). Human development is grounded in the idea that expanding individuals' capabilities and opportunities leads to broader social and economic benefits. According to the United Nations Development Programme (UNDP), human development goes beyond economic growth, focusing on "creating an environment in which people can develop their full potential and lead productive, creative lives by their needs and interests" (UNDP, 1990). Improving human capital through education, health, and skill development empowers people to contribute effectively to the economy, essential for knowledge-intensive sectors such as education and R&D exports (Sen, 1999).

Investment in human development is particularly crucial for countries aiming to expand their role in the global knowledge economy. As Sen's Capability approach highlights, enhancing human capabilities through education and skill development increases people's potential to innovate, create, and engage with complex global markets (Sen, 1999). In this context, the country's efforts to develop its education and R&D sectors as exportable services depend heavily on its ability to foster a highly educated and skilled workforce. Empirical studies have shown that countries with strong human development indices, particularly in education and innovation, are more likely to succeed in exporting knowledge-intensive goods and services (Barro and Lee, 2013).

As defined by the Brundtland Report, sustainable development emphasises "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). This concept is multidimensional, incorporating economic, environmental, and social sustainability. Sustainable development recognises that economic growth must be pursued alongside social equity and environmental stewardship to ensure long-term prosperity. It fosters resilience in financial systems, thereby creating a stable foundation that supports sustained growth across sectors, including education and R&D exports.

By integrating sustainable practices, nations can create conditions where education and R&D can thrive as industries. Sustainable development encourages policies that reduce environmental impacts, promote social inclusion, and emphasise equitable access to resources. This broad-based stability is crucial for education and R&D exports, as these sectors benefit from sustainable infrastructure, stable socio-economic conditions, and long-term investment in human capital (Sachs, 2015). The interconnectedness of SDG 4 and SDG 17, as discussed by Liashenko and Dluhopolskyi (2024), highlights the importance of forming global educational partnerships to foster mutual growth and sustainability. For example, Poland's commitment to the Sustainable Development Goals (SDGs), such as Quality Education (SDG 4) and Decent Work and Economic Growth (SDG 8), provides a supportive framework for the expansion of its education and R&D services internationally.

The synergy between human and sustainable development creates a reinforcing cycle that benefits knowledge-driven exports such as education and R&D. Investing in human development enhances workforce skills and competencies, increases innovation capacity, and supports high-value sectors. At the same time, sustainable development ensures that economic growth is maintained in a balanced and equitable manner, protecting resources and promoting social welfare, thereby providing a stable environment for human development (Anand and Sen, 2000).

While higher levels of human development generally facilitate progress toward the Sustainable Development Goals, the relationship is not uniformly positive across all sustainability dimensions. Rising educational attainment and income are frequently accompanied by increased consumption, energy demand, mobility, and material use, which may place additional pressure on natural ecosystems. This phenomenon reflects the well-documented "environmental Kuznets" and "consumption footprint" debates, suggesting that improvements in human development do not automatically translate into environmental sustainability. Consequently, the quality of institutions, technological innovation, and patterns of responsible consumption become critical mediating factors that determine whether higher human development contributes to or undermines environmental outcomes.

Governance quality significantly influences the success of human development strategies by fostering a stable and enabling environment for sustainable progress. Liashenko et al. (2024) examine this dynamic, highlighting how governance effectiveness and social development intersect to classify countries by their developmental achievements. These insights are particularly relevant for understanding how education and R&D exports can thrive in governance-optimised contexts.

The knowledge economy is susceptible to this synergy. High levels of education and skill development are required to produce high-quality research, technological innovations, and advanced education systems – assets that can be exported internationally. At the same time, a sustainable approach to development encourages long-term investments in human capital and infrastructure, which helps sustain these knowledge-based exports (Florida, 2005). For instance, countries such as Finland and South Korea have leveraged this synergy by investing heavily in education, technology, and sustainability initiatives, achieving high human development indices and significant success in knowledge-based exports (OECD, 2018).

Integrating human and sustainable development is essential for countries that strive to position education and R&D as exportable goods. As a growing economic hub in Central Europe, Poland exemplifies this opportunity. By enhancing human capabilities through robust education systems and sustainable economic policies, it can create a competitive edge in the global market for education and R&D services. These sectors rely on a skilled, innovative workforce and a stable, sustainable socio-economic environment, both fostered by a commitment to human and sustainable development.

Knowledge-driven exports, such as education and R&D, are economically valuable and contribute to international collaboration and knowledge exchange. They can enhance a country's reputation as a knowledge economy, attract foreign students and researchers, and create partnerships that further reinforce its education and R&D sectors. Research shows that countries that have invested in human capital and sustainable development have a comparative advantage in knowledge-based exports, as they are better equipped to innovate, adapt, and compete in international markets (Porter, 1990).

In Table 1, we summarise the key concepts of human capital, human development, and sustainable development, focusing on their main intersections.

We can assume the main intersections to be as follows:

1. Human capital and human development both emphasise the importance of education and health but differ in scope. Human capital is narrowly focused on increasing productivity and economic outcomes, while human development encompasses a broader set of capabilities, including personal freedom, well-being, and social equity.

Table 1 Comparison of human capital, human development and sustainable development concepts

Aspect	Human capital	Human development	Sustainable development
Core focus	Investment in skills, knowledge, and health to increase productivity and economic value	Expanding people's capabilities and freedoms to lead fulfilling lives, beyond just economic outcomes	Balancing economic growth with environmental protection and social equity for long-term resilience
Primary goal	Enhance productivity and economic growth	Improve quality of life, well-being, and opportunities	Ensure present needs are met without compromising future generations' ability to meet their needs
Key indicators	Education level, skill acquisition, health status	Access to education, health, income equality, personal freedoms	Economic stability, environmental sustainability, social inclusion
Role in economic growth	Directly increases workforce productivity, driving economic growth	Indirectly supports growth by enhancing individual capabilities and social well-being	Promotes long-term economic resilience through sustainable practices and resource management
Intersec-tion with social goals	Limited, primarily focused on economic outcomes	Strong emphasis on social well-being, equity, and empowerment	Strong emphasis on social equity and inclusive growth
Environ-mental considera-tions	Limited; does not inherently account for environmental impact	Indirect; focuses on social outcomes but can intersect with environmental well-being	Core component; emphasises ecological balance, renewable resources, and reducing environmental degradation
Key scholars / concepts	Gary Becker (Human Capital Theory)	Amartya Sen (Capability Approach)	Brundtland Report (WCED, 1987)
Connection to knowledge economy	Skills and knowledge are essential to support knowledge-driven industries	High-quality education and personal development foster innovation and competitiveness	Encourages sustainable and responsible knowledge-based industries that do not deplete natural resources
Importance in export growth	Enhances capacity to export high-value goods and services by increasing workforce skill levels	Builds a population capable of participating in global markets through education and empowerment	Ensure that growth in exports does not harm social equity or environmental resources, supporting sustainable trade policies
Link to SDGs	Linked to SDG 8 (Decent Work and Economic Growth) and SDG 4 (Quality Education)	Linked to multiple SDGs, particularly SDG 4 (Quality Education) and SDG 3 (Good Health and Well-being)	Central to all SDGs, particularly SDG 12 (Responsible Consumption), SDG 13 (Climate Action), and SDG 10 (Reduced Inequalities)
Overall intersections	Focuses on skill enhancement that contributes to economic productivity, indirectly supporting social goals	Emphasises human well-being and freedoms, which support sustainable economic and social development	Integrates environmental, economic, and social goals, directly supporting sustainable human and economic development

Source: Authors' development

2. Human development's focus on well-being, equality, and capabilities aligns closely with sustainable development's emphasis on social equity and inclusive growth. Both promote social welfare and quality of life and align particularly with the Sustainable Development Goals (SDGs), including Quality Education, Good Health and Well-being, and Reduced Inequalities.
3. While human capital primarily drives economic productivity, sustainable development encompasses broader environmental and social considerations. Both concepts intersect in the knowledge economy, where sustainable practices in high-skill industries contribute to responsible economic growth, particularly through knowledge-driven exports such as education and R&D.

These intersections collectively highlight that an integrated approach, combining elements from human capital, human development, and sustainable development, can foster economic growth that is productive, socially inclusive, and environmentally responsible (Liashenko et al., 2024).

This finding underscores the critical role of human development, including factors such as education, health, and economic participation, in driving sustainable development outcomes. The near-linear trend suggests that investments in improving HDI metrics, such as access to quality education and healthcare, will likely yield significant improvements in sustainable development performance, aligning with global goals. Consequently, these findings emphasise the importance of integrating human development into strategies for achieving sustainable development.

Improvements in education, skills, and innovation are critical drivers of human development and can enhance a country's competitive edge, particularly in high-value export sectors such as education and R&D services. A well-educated, skilled, and innovative population supports domestic growth and establishes a country as a viable player in the global knowledge economy. Here, we analyse how each factor (education, workforce skills, and innovation ecosystems) contributes to human development and strengthens a country's position in the export of education and R&D.

Educational institutions are central to human development, as they equip individuals with the knowledge and skills needed to participate effectively in the economy. High-quality education systems contribute directly to a country's competitive advantage by building a robust foundation for knowledge-intensive industries. For example, countries with globally recognised universities and research institutions, such as the United States, the United Kingdom, and Germany, attract international students and research partnerships, transforming education into a valuable export product (Marginson, 2010).

Education is a tool for individual empowerment and a significant factor in human capital development. This development translates into a skilled labour force capable of producing high-value goods and services, particularly in sectors that rely on knowledge and research. High-ranking universities and specialised research institutions also enhance a country's reputation in the international education market, which attracts talent and resources from around the world (Knight, 2011).

A skilled workforce is essential for countries seeking to export knowledge-based services, such as education and R&D. Workforce development programmes that focus on skills training, particularly in STEM (science, technology, engineering, and mathematics), are crucial to building a talent pool capable of contributing to research-intensive industries and higher education institutions. Skills development increases individual productivity and raises the output standard in R&D sectors, making the country's educational and research services more internationally competitive (Hanushek and Woessmann, 2012). Vocational training and lifelong learning initiatives are critical in equipping the workforce with practical skills and adapting to evolving industry demands. Countries such as Germany and South Korea have successfully leveraged robust skills development systems to create highly competent workforces, enabling them to become leaders in exporting technical education and R&D-intensive services (Busemeyer and Trampusch, 2012; Syhyda et al., 2023). These skills-based education models boost productivity and enhance innovation capabilities – both critical factors for maintaining a competitive edge in international markets.

Innovation ecosystems, which include research institutions, industry partnerships, and government support, are essential for fostering an environment that drives knowledge creation and technological advancement. A robust, innovative ecosystem supports human development by providing opportunities for advanced research, encouraging entrepreneurship, and facilitating knowledge transfer between academia and industry (Etzkowitz and Leydesdorff, 2000; Shyron et al., 2026).

Countries with well-developed innovation ecosystems, such as Finland and Singapore, have been able to transform R&D into a significant export sector. Government policies encouraging R&D investment, public-private partnerships, and intellectual property protections are instrumental in building an export-ready environment for research services (Fagerberg et al., 2010). Moreover, innovative ecosystems create synergies between educational institutions and industry, enabling the commercialisation and export of research findings as high-value services or products. This ecosystem approach helps countries achieve a reputation for excellence in innovation and attracts international collaborators and investors. In summary, education, skills development, and innovation ecosystems are interconnected drivers of human development that collectively enhance a country's competitive advantage in exporting education and R&D services. High-quality educational institutions contribute to human capital development; skills training creates a competent workforce for knowledge-based industries; and a robust innovation ecosystem supports continuous advances in research and technology. Together, these factors provide a foundation for sustained human development and position countries as leaders in the global education and R&D services markets.

Table 2 summarises how education, skills development, and innovation ecosystems are interconnected with drivers to boost sustainable development.

Together, education, skills development, and innovation ecosystems create a virtuous cycle that supports sustainable development by empowering individuals, enhancing economic resilience, and driving technological advancements that align with environmental goals. Education provides the groundwork, skills development creates a capable workforce, and innovative ecosystems fuel ongoing improvements, collectively contributing to social, economic, and environmental sustainability.

Table 2 Roles played by education, skills development and innovation ecosystems in sustainable development

Driver	Role in sustainable development	Key contributions	Outcomes for sustainability
Education	Provides foundational knowledge and cognitive skills necessary for individuals to engage in the economy and society effectively.	• Develops human capital for knowledge-based industries • Encourages environmental awareness and social responsibility	• Enhances social equity through equal access • Builds a skilled, informed population to support sustainable industries
Skills development	Equips the workforce with specific competencies and practical abilities to meet evolving labour market demands.	• Increases productivity and adaptability • Supports green jobs and sustainable practices in industries	• Drives economic resilience • Creates a workforce that supports eco-friendly and resource-efficient sectors
Innovation ecosystems	Facilitates research, collaboration, and technological advancement through public and private sector partnerships.	• Promotes R&D in sustainable technologies • Encourages entrepreneurship and knowledge transfer	• Fosters eco-innovation and green technologies • Enables continuous improvement in sustainable production and services

Source: Authors' development

3 Methodology

This study utilises a merged dataset combining the Sustainable Development Report database and the UNDP Human Development database for the period 2015-2022. The final sample comprises 1,329 country-year observations from 167 countries after excluding observations with missing values on key variables.

The dependent variable is the SDG Index Score, which measures a country's overall performance across all 17 Sustainable Development Goals on a 0–100 scale. Independent variables include the Human Development Index (HDI) and its components: life expectancy at birth (LE), expected years of schooling (EYS), mean years of schooling (MYS), and gross national income per capita (GNIpc). We also examine individual SDG goal scores, particularly SDG 4 (Quality Education), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), and SDG 17 (Partnerships for the Goals).

We employ panel data regression methods to account for unobserved heterogeneity across countries. The baseline model specification is:

$$\mathrm{SDG}_{it} = \alpha + \beta \cdot \mathrm{HDI}_{it} + \mu_i + \varepsilon_{it}, \tag{1}$$

where SDG_{it} represents the SDG Index Score for country i at time t, HDI_{it} is the Human Development Index, μ_i captures country-specific fixed effects, and ε_{it} is the idiosyncratic error term. We estimate this model using Pooled OLS, Fixed Effects (FE), and Random Effects (RE) estimators. The Hausman test is employed to determine the appropriate estimator.

To disaggregate the effects of human development components, we estimate an extended model:

$$\begin{aligned}\mathrm{SDG}_{it} &= \alpha + \beta^1 \cdot \mathrm{LE}_{it} + \beta^2 \cdot \mathrm{EYS}_{it} \\ &+ \beta^3 \cdot \mathrm{MYS}_{it} + \beta^4 \cdot \ln\left(\mathrm{GNIpc}_{it}\right) + \mu_i + \varepsilon_{it}.\end{aligned} \tag{2}$$

All standard errors are clustered at the country level to account for potential serial correlation within panels. We also test for beta-convergence in SDG achievement by regressing growth rates on initial SDG scores.

4 Results

4.1 Descriptive statistics

Table 3 presents descriptive statistics for key variables in the analysis.

The SDG Index Score ranges from 38.14 to 86.42, with a mean of 66.48, indicating substantial cross-country variation in sustainable development performance. The HDI displays similar variation (0.37–0.97, mean 0.72), with a standard deviation of 0.158 indicating considerable heterogeneity in human development levels across the sample.

Table 3 Descriptive statistics

Variable	*N*	Mean	Standard deviation	Min	Max
SDG Index Score	1,329	66.482	10.365	38.14	86.42
Human Development Index	1,329	0.719	0.158	0.37	0.97
Life Expectancy (years)	1,329	71.90	7.887	51.1	84.8
Expected Years of Schooling	1,329	13.40	3.056	5.64	23.2
Mean Years of Schooling	1,329	8.77	3.325	1.25	14.3
GNI per capita (PPP$)	1,329	19,959	19,946	641	99,811
SDG 4: Quality Education	1,329	73.72	24.82	1.23	99.96
SDG 9: Innovation	1,329	49.75	25.57	0.15	99.19

To provide time-series context for the panel dataset, Fig. 2 compares average SDG Index trajectories for the world, EU-27, and Poland.

In parallel, Fig. 3 shows the evolution of HDI over 2015–2022 for the world, the EU-27, and Poland.

Education indicators show notable patterns. Expected years of schooling averages 13.4 years with substantial cross-country variation (SD = 3.06), while mean years of schooling averages 8.77 years. The SDG 4 (Quality Education) score has the highest mean (73.72) among the individual goals examined, whereas SDG 9 (Innovation) shows both the lowest mean (49.75) and the highest variation (SD = 25.57), suggesting that innovation capacity remains a significant differentiator across countries.

4.2 Correlation analysis

Table 4 presents the correlation matrix for key variables. The HDI exhibits a strong positive correlation with the overall SDG Index Score (r = 0.891, p < 0.001), providing preliminary evidence for the nexus between human development and sustainable development. Among HDI components, life expectancy (r = 0.842), expected years of schooling (r = 0.834), and mean years of schooling (r = 0.829) all demonstrate strong positive associations with SDG performance.

As shown in Fig. 4, overall SDG performance is strongly positively associated with human development across countries. To complement Table 2, Fig. 5 provides a visual heatmap of the correlation structure among key variables.

Notably, the correlation between the HDI and SDG 9 (Innovation) is particularly strong (r = 0.901), underscoring the critical role of human capital in driving innovation. SDG 17 (Partnerships) shows the weakest correlation with HDI (r = 0.384), suggesting that partnership formation may be driven by factors beyond domestic human development levels.

4.3 Panel regression results

Table 5 presents the main panel regression results. Model 1 examines the aggregate relationship between the HDI and the SDGs using three estimation approaches. The Pooled OLS coefficient indicates that a 0.1-unit increase in HDI

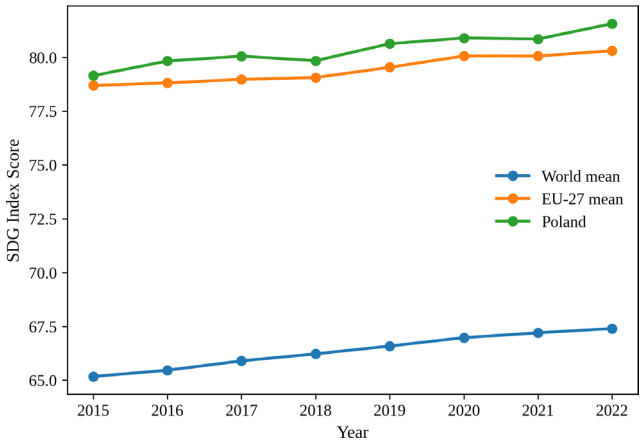

Fig. 2 SDG Index score dynamics (2015–2022) (Source: authors' development based on Sachs et al. (2025))

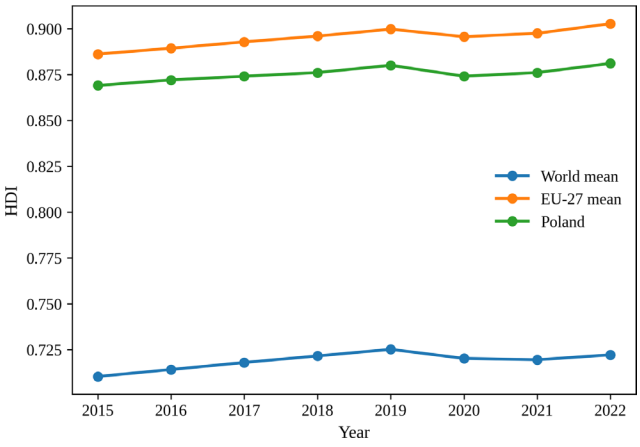

Fig. 3 HDI dynamics (2015–2022) (Source: authors' development based on UNDP (online))

Table 4 Correlation matrix

	SDG	HDI	LE	EYS	MYS	SDG4	SDG8	SDG9
SDG	1.000							
HDI	0.891***	1.000						
LE	0.842***	0.920***	1.000					
EYS	0.834***	0.905***	0.803***	1.000				
MYS	0.829***	0.915***	0.759***	0.791***	1.000			
SDG 4	0.860***	0.876***	0.808***	0.846***	0.798***	1.000		
SDG 8	0.594***	0.528***	0.512***	0.525***	0.482***	0.519***	1.000	
SDG 9	0.828***	0.901***	0.834***	0.829***	0.791***	0.757***	0.566***	1.000

Note: SDG Index: SDG; Human Development Index: HDI; Life Expectancy: LE; Expected years at school: EYS; Mean years at school: MYS; Goal 4 Education: SDG4; Goal 8 Work: SDG8; Goal 9 Innovation: SDG9
*** p < 0.01

Fig. 4 Relationship between HDI and SDG Index score (2015–2022) (Source: authors' development based on Sachs et al. (2025) and UNDP (online))

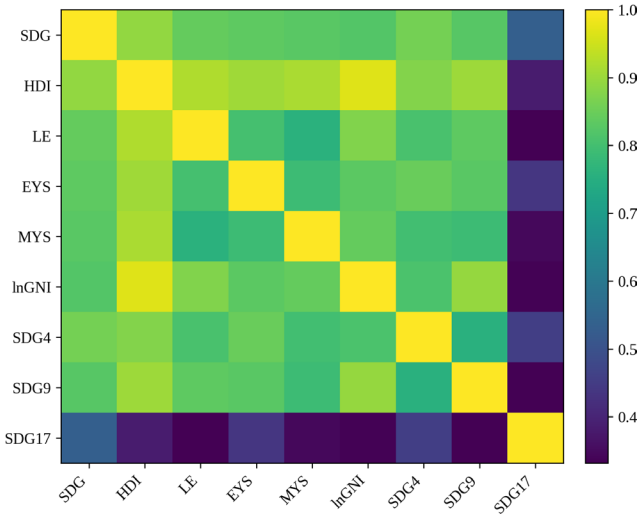

Fig. 5 Correlation heatmap for key variables (pooled 2015–2022) (Source: authors' development)

Table 5 SDG Index score as dependent variable

Variable	Pooled OLS	Fixed effects	Random effects
	Model 1	Model 1	Model 1
HDI	58.498***	60.079***	59.127***
Constant	24.425***	–	23.968***
R-squared	0.793	0.262 (within)	0.450
N	1,329	1,329	1,329

Note: *** $p < 0.01$. Clustered standard errors at country level. Hausman test $\chi^2 = 0.025$, $p = 0.874$, suggesting Random Effects preferred.

is associated with a 5.85-point increase in the SDG Index Score. The Fixed Effects estimate ($\beta = 60.08$, $p < 0.01$) controls time-invariant country characteristics and indicates that within-country variation in HDI significantly predicts SDG performance changes over time.

The Hausman test ($\chi^2 = 0.025$, $p = 0.874$) indicates that the Random Effects estimator is consistent and efficient, suggesting that unobserved country effects are uncorrelated with the regressors. However, we also report Fixed-Effects results for robustness, as the FE estimator remains consistent under both the null and alternative hypotheses.

Table 6 presents Model 2 results, which examine the disaggregated effects of the HDI components. The Fixed-Effects estimates indicate that educational attainment variables have the strongest impact on SDG performance. Mean years of schooling show the largest coefficient ($\beta = 1.79$, $t = 8.36$, $p < 0.01$), indicating that each additional year of average schooling in a country is associated with a 1.79-point increase in SDG Index score. Expected years of schooling also demonstrates a significant positive effect ($\beta = 0.59$, $t = 3.26$, $p < 0.01$).

The logarithm of GNI per capita also shows a significant positive relationship ($\beta = 2.13$, $t = 2.85$, $p < 0.01$), suggesting that income improvements contribute to SDG progress, although the relationship is concave due to the log transformation. Interestingly, life expectancy does not show a significant within-country effect ($\beta = 0.02$, $t = 0.42$), suggesting that year-to-year variations in health outcomes may take longer to translate into measurable improvements in SDG outcomes than education investments.

The positive association between income and SDG performance should nevertheless be interpreted with caution. Although higher income facilitates investments in education, healthcare, innovation, and institutional quality, it may simultaneously stimulate consumption-intensive lifestyles associated with higher carbon emissions and greater resource use. Therefore, the observed positive relationship reflects the aggregate SDG Index rather than uniformly favourable outcomes across all environmental dimensions. This finding reinforces the importance of decoupling economic prosperity from environmental degradation through green innovation and sustainable consumption policies.

4.4 Convergence analysis

Given the focus on education and R&D export competitiveness, we examine SDG 4 (Quality Education) and SDG 9 (Innovation) as dependent variables.

Table 6 Fixed effects regression: HDI components

Variable	Coefficient	Std. error	t-statistic
Life Expectancy	0.019	0.045	0.42
Expected Years of Schooling	0.588***	0.180	3.26
Mean Years of Schooling	1.792***	0.214	8.36
ln(GNI per capita)	2.134***	0.748	2.85
R-squared (within)	0.399		
N	1,329		

Note: *** $p < 0.01$. Country fixed effects included. Clustered standard errors at country level

Table 7 presents these targeted regressions.

For SDG 4 (Quality Education), expected years of schooling shows the primary influence ($\beta = 1.96$, $t = 3.11$, $p < 0.01$), while current mean years of schooling is not statistically significant. This suggests that improvements in educational quality are forward-looking, driven by investments in future educational capacity rather than by existing attainment levels.

For SDG 9 (Industry, Innovation and Infrastructure), both education variables demonstrate significant positive effects, but mean years of schooling have a larger effect ($\beta = 7.30$, $t = 8.04$, $p < 0.01$). This finding aligns with the theoretical expectation that innovation capacity requires an accumulated stock of human capital rather than merely educational system capacity. Income also contributes significantly to innovation outcomes ($\beta = 6.08$, $t = 2.22$, $p < 0.05$), reflecting the role of economic resources in R&D investment. We test for beta-convergence in SDG achievement by regressing the 2015–2022 growth rate on initial (2015) SDG scores. The convergence coefficient is negative and highly significant ($\beta = -0.125$, $t = -6.70$, $p < 0.001$), providing strong evidence of conditional convergence. Countries with lower initial SDG scores achieved faster progress rates, with each 10-point lower initial score associated with approximately 1.25 percentage points higher growth over the period.

The convergence pattern discussed above is illustrated in Fig. 6. This convergence finding has important policy implications: it suggests that developing countries have significant catch-up potential if appropriate investments in human capital are made. The model explains 21.5% of the variation in growth rates, indicating substantial remaining heterogeneity in country performance trajectories.

4.5 Regional and HDI classification analysis

Table 8 presents SDG performance disaggregated by HDI classification. ANOVA testing confirms highly significant differences across groups ($F = 1046.9$, $p < 0.001$).

Table 7 Fixed effects regressions: education and innovation outcomes

Variable	SDG 4 (Education)	SDG 9 (Innovation)
Expected Years of Schooling	1.963*** (3.11)	1.802*** (3.03)
Mean Years of Schooling	0.800 (1.20)	7.300*** (8.04)
ln(GNI per capita)	–	6.078** (2.22)
R-squared (within)	0.049	0.361

Note: *** $p < 0.01$, ** $p < 0.05$. t-statistics in parentheses. Country fixed effects included.

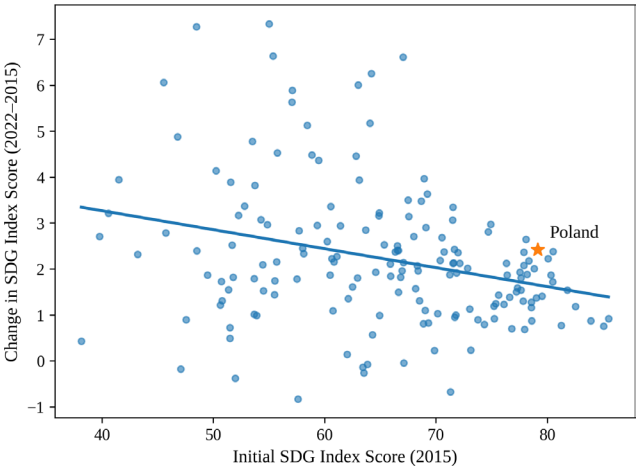

Fig. 6 Beta-convergence in SDG performance: change in SDG Index Score (2022–2015) *vs.* initial level (2015) (Source: authors' development)

Table 8 SDG performance by HDI classification

HDI Category	SDG mean	SDG Std.	N	Goal 4	Goal 9
Very High HD (≥0.80)	75.06	6.66	488	92.49	76.06
High HD (0.70–0.79)	69.49	3.76	317	83.29	47.79
Medium HD (0.55–0.69)	61.24	5.77	263	65.87	32.34
Low HD (<0.55)	52.06	5.39	261	34.91	20.50

Very High Human Development countries achieve mean SDG scores of 75.1, compared with 52.1 for Low Human Development countries – a 23-point gap.

The cross-group distribution of SDG performance by HDI category is summarised in Fig. 7.

The gap in innovation (SDG 9) is particularly stark: Very High HD countries score an average of 76.1, whereas Low HD countries score 20.5. This 55.6-point gap underscores

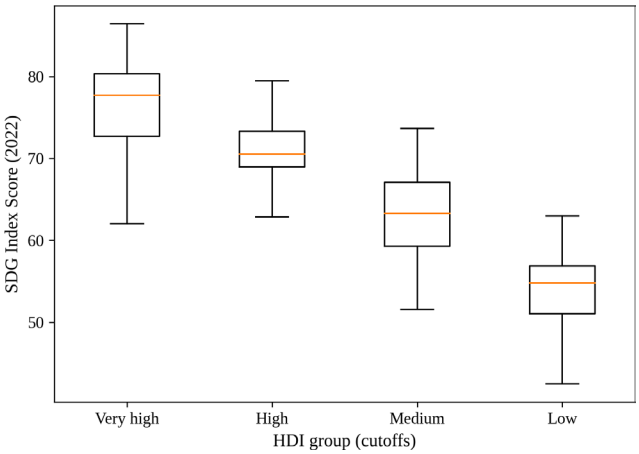

Fig. 7 SDG Index score distribution by HDI group (2022) (Source: authors' development)
Note: ANOVA F-statistic = 1046.9, $p < 0.001$

the critical role of human capital accumulation in building innovation capacity and suggests that developing countries face substantial barriers to entering knowledge-intensive export markets.

Regional analysis reveals that Europe leads with a mean SDG score of 79.8, followed by Oceania (75.4), the Americas (69.3), Asia (67.3), and Africa (56.7). European dominance in both education (Goal 4 mean = 93.7) and innovation (Goal 9 mean = 82.5) metrics positions the region as the primary source of global education and R&D exports.

5 Poland's case study

The empirical results consistently support a strong nexus between human development and the sustainable development nexus across countries during 2015–2022. The correlation analysis shows a tight positive association between the SDG Index score and the Human Development Index (HDI), indicating that countries with higher overall human development tend to achieve better SDG outcomes. This pattern is not only cross-sectional; the panel estimates confirm that within-country changes in human development over time are systematically linked to changes in SDG performance, even after controlling for time-invariant national characteristics using fixed effects.

A central contribution of the econometric results is the disaggregation of HDI into its core components, which reveals that education-related variables are the most robust predictors of SDG progress. In the fixed-effects component model, mean years of schooling (MYS) and expected years of schooling (EYS) are statistically significant drivers of improvements in the SDG Index, whereas life expectancy does not have a statistically significant within-country effect over this relatively short panel horizon. Substantively, this suggests that education investments may translate into measurable sustainability improvements more quickly than health improvements, which often operate through longer-term channels and may require more time to be reflected in composite SDG performance indicators.

The targeted regressions focus on SDG 4 (Quality Education) and SDG 9 (Industry, Innovation and Infrastructure), further refining this interpretation. SDG 4 is most strongly associated with EYS, consistent with the idea that forward-looking education system capacity (e.g., expected schooling) is closely tied to education outcomes at the SDG level. In contrast, SDG 9 is particularly sensitive to MYS, implying that innovation performance depends more on the accumulated stock of human capital than on contemporaneous expansion of the education system alone. This distinction is important for the paper's broader focus on education and R&D export competitiveness: education exports are likely supported by system capacity and quality signals (captured by SDG 4 and EYS), while R&D- and innovation-intensive exports depend more directly on deeper human capital accumulation (captured by MYS and SDG 9).

The convergence analysis provides additional nuance by showing evidence of beta-convergence in SDG achievement: countries starting from lower SDG levels experienced faster progress during 2015–2022. This result is encouraging from a development-policy perspective, as it implies that "catch-up" in sustainable development is feasible. However, convergence does not imply uniformity: the regional and HDI-group comparisons demonstrate persistent and sizeable gaps, especially in innovation-related outcomes. The disparity in SDG 9 across HDI categories is particularly pronounced, indicating that countries with lower human development face structural barriers to building innovation capacity and moving into knowledge-intensive growth paths.

Overall, the findings reinforce a policy-relevant interpretation: human development, especially education, functions as both a direct enabler of progress toward the SDGs and a foundational input into innovation capacity. In practical terms, strategies aimed at improving sustainable development outcomes and strengthening education and R&D export potential should prioritise educational attainment and system capacity, complemented by policies that translate human capital into innovative performance (e.g., stronger linkages among higher education, R&D activity, and industry).

Poland presents an instructive case study for examining how a middle-income European country can leverage human development investments to enhance education and R&D export competitiveness. Our empirical analysis enables benchmarking of Poland's performance against regional and global standards.

Table 9 compares Poland's 2022 performance against EU averages and top performers. Poland's overall SDG Index score (81.6) ranks 8th among 25 EU countries, exceeding

Table 9 Poland's SDG performance: EU comparison

Indicator	Poland	EU mean	EU max	Rank
SDG Index Score	81.56	80.25	86.42	8/25
HDI	0.881	0.905	0.952	18/25
SDG 4: Quality Education	99.89	95.93	99.89	1/25
SDG 8: Decent Work	83.80	79.75	84.30	2/25
SDG 9: Innovation	80.67	85.18	98.15	18/25
SDG 17: Partnerships	68.94	65.46	82.08	9/25

the EU mean (80.3). This positions Poland favourably for developing education and R&D export strategies.

For a quick benchmark, Fig. 8 compares Poland's 2022 outcomes with the EU-27 average.

Poland's performance reveals a distinctive pattern with significant policy implications. The country ranks 1st in the EU for SDG 4 (Quality Education) with a near-perfect score of 99.89, and 2nd for SDG 8 (Decent Work) at 83.80. These strengths position Poland as a credible destination for international students seeking quality education at competitive costs.

However, Poland's relative weakness in SDG 9 (Innovation), ranked 18th out of 25, constitutes a significant barrier to R&D export competitiveness. The 17.5-point gap between Poland (80.7) and the EU top performer, Sweden (98.2), reflects Poland's lower R&D investment as a percentage of GDP (approximately 1.4% versus the EU average of 2.3%).

Our regression findings provide empirically grounded policy recommendations for Poland. The significant coefficient on mean years of schooling for SDG 9 (β = 7.30) suggests that expanding tertiary education completion rates could substantially boost innovation capacity. Each additional year of average schooling is associated with a 7.3-point increase in innovation scores, implying that if Poland could increase its mean years of schooling from current levels toward Nordic country benchmarks, significant improvements in R&D competitiveness could follow.

The convergence analysis indicates that catch-up growth is feasible but requires targeted investment. Poland's above-average performance in education provides a foundation that could be leveraged through increased R&D funding for sustainability-focused projects, expanded lifelong learning programmes to enhance workforce adaptability, strategic international partnerships with innovation leaders, and the development of English-language programmes in green technology and environmental science.

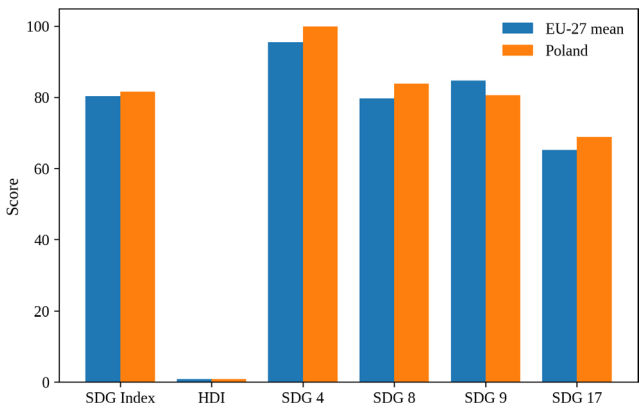

Fig. 8 Poland *vs.* EU-27 average (2022) for SDG Index, HDI and selected SDG goals (Source: authors' development)

The strong empirical link between expected years of schooling and SDG 4 (β = 1.96) suggests that continued investment in the educational system capacity will maintain Poland's competitive advantage in attracting international students. Poland attracted more than 85,000 international students, according to recent OECD data (OECD, 2025), primarily from Eastern Europe, and could expand this market by developing sustainability-focused curricula aligned with global demand.

According to the latest data, Poland is actively developing its capabilities in exporting education and R&D services, but it still faces several challenges and opportunities to further integrate human and sustainable development into its strategy.

Poland has made significant strides in becoming an attractive destination for international students, particularly from neighbouring countries like Ukraine, Belarus, and other parts of Eastern Europe. The number of international students in Poland has steadily increased over the past decade, with over 85,000 foreign students, according to recent statistics (OECD, 2022).

However, Poland's share of international students remains relatively small compared with other EU countries, such as Germany and the Netherlands. While Polish universities offer competitive tuition rates and relatively low living costs, Poland still lacks the strong global brand that countries such as the UK and Australia have developed in the education export market. Additionally, there is a limited selection of English-language programmes, which limits the country's appeal to a broader range of international students (Erudera, 2024).

Poland's investment in R&D as a share of GDP remains below the EU average. According to the European Commission, Poland's R&D spending was approximately 1.4% of GDP in 2021, compared with the EU average of approximately 2.3% (European Commission, 2022). This low investment limits the country's capacity for high-level scientific research and innovation, which are critical for boosting exports in R&D services.

Despite these challenges, there have been initiatives to increase R&D funding, particularly in areas aligned with the EU's Green Deal and Horizon Europe programmes. Poland has been working to strengthen its R&D ecosystem by promoting collaboration among academia, industry, and government, although the integration of the Sustainable Development Goals into R&D remains limited.

Poland has made progress in incorporating sustainability concepts into its educational and research frameworks, but this integration remains in its early stages relative to other European countries. For instance, while some universities place a growing emphasis on environmental science and renewable energy research, sustainability is not yet a core focus across all educational and research institutions. This creates a gap in meeting the demands of the global market for sustainability-focused education and research services.

Some universities, such as the University of Warsaw and AGH University of Science and Technology, have developed programmes in environmental studies, energy management, and sustainable business. However, Poland lacks a comprehensive, nationwide strategy to integrate sustainability into all levels of education and research. The absence of a well-developed "green campus" culture, for example, contrasts with other European countries where universities are adopting eco-friendly practices and promoting environmental awareness.

Poland faces challenges in promoting lifelong learning and reskilling among its adult population, which is essential for adapting to changes in the global economy. According to the OECD, Poland's adult participation in lifelong learning programmes remains low compared to other EU countries (OECD, 2021). This gap limits the workforce's ability to acquire new skills, particularly in green technologies and digital competencies, which are essential for sustainability and economic resilience.

The Polish government has launched initiatives such as the "Skills Poland" programme to encourage lifelong learning and support vocational training. However, these programmes must be expanded and integrated with industry needs, especially in the sustainability and green technologies sectors. Polish universities and research institutions participate in various EU programmes, such as Erasmus+ and Horizon Europe, which help fund international collaborations. However, compared to Western European countries, Poland's performance in securing competitive research funding through programmes like Horizon 2020 has been relatively modest. This indicates a need for more significant capacity-building in grant writing, international collaboration, and project management skills.

Furthermore, while Poland benefits from EU structural funds and has access to networks supporting sustainable development, more could be done to strengthen international partnerships focused on sustainability. Establishing deeper ties with leading research institutions and sustainability-oriented organisations would help Poland leverage international expertise and enhance its R&D capabilities.

To enhance Poland's competitiveness in exporting education and R&D services, policymakers can more effectively integrate human development and sustainable development goals into the national export strategy. By focusing on education, sustainability, research, and international collaboration, Poland can strengthen its position in the global knowledge economy. In Table 10, we organise the practical recommendations for the development of the knowledge economy.

By implementing these recommendations, Poland can integrate human and sustainable development goals into its education and R&D export strategy. Focusing on lifelong learning, increased research funding, sustainability in education, and international partnerships will position Poland as a leader in sustainable development. This approach enhances Poland's global competitiveness and aligns with international efforts to address environmental and social challenges. Such a strategy strengthens Poland's reputation as a responsible and innovative knowledge economy, attracting international students, research partnerships, and investment to support long-term sustainable growth.

Table 11 summarises the key challenges and opportunities for improvement Poland's education and R&D export strategy.

Poland is progressing toward positioning itself as a player in the international education and R&D markets, but significant opportunities remain to more effectively integrate human and sustainable development goals into its export strategy. By increasing R&D investment, prioritising sustainability in education, promoting lifelong learning, and fostering international partnerships, Poland can build a more competitive, resilient, and sustainable economy that appeals to both global students and research collaborators.

6 Conclusions

This study provides rigorous empirical evidence on the relationship between human development and sustainable development outcomes, paying specific attention to education and R&D export competitiveness. Using panel data from 167 countries over 2015–2022, we demonstrate that human development, particularly educational attainment, is a critical determinant of SDG performance.

Our key findings include:

1. A strong positive correlation (r = 0.891) exists between HDI and SDG Index scores, with fixed effects regression confirming the relationship holds within countries over time;

Table 10 Knowledge economy development recommendations

Category	Recommendations	Key benefits
1. Promote lifelong learning and skills development	*Expand lifelong learning programmes*: Offer continuous education and skill upgrading, especially in digital skills, green technology, and entrepreneurship.	Adapts the workforce to evolving job markets and boosts global competitiveness.
	Incentivise vocational and technical training: Fund programmes in renewable energy, circular economy, and sustainable agriculture.	Builds a skilled workforce for sustainable industries, attracting foreign companies and investors.
	Digital learning platforms: Develop online learning platforms to make education accessible in remote or underserved regions.	Equips students and professionals with global-standard skills for a knowledge-based economy.
2. Increase research funding and support for sustainability-focused projects	*Allocate funding to sustainability research*: Invest in areas like clean energy, waste reduction, and eco-friendly materials.	Enhances Poland's reputation in green R&D and attracts international partners and investors.
	Create a national green research fund: Support sustainable industry practices and promote green technologies for export.	Positions Poland as a leader in sustainable development research and innovation.
	Encourage private sector involvement in R&D: Offer tax incentives to encourage R&D partnerships between companies and universities.	Drives innovation through public-private collaboration and boosts sustainable technology exports.
3. Integrate sustainability into educational curricula	*Introduce sustainability education at all levels*: Incorporate topics like climate change and resource management in core curricula.	Builds a workforce that values and understands sustainability practices.
	Develop specialised degree programmes in green technologies: Focus on green technology, environmental management, and sustainable business.	Attracts international students and positions Poland as a leader in eco-education.
	Promote green campuses: Implement eco-friendly infrastructure and procurement policies in universities.	Enhances Poland's image as a responsible study destination for environmentally conscious students.
4. Build and strengthen international partnerships	*Establish bilateral agreements for education and R&D*: Partner with sustainability leaders like Germany and Sweden.	Facilitates student exchanges, collaborative research, and dual degree programmes.
	Leverage EU programmes for international collaboration: Utilise Erasmus+, Horizon Europe, and the European Green Deal.	Expands resources, networks, and expertise for advancing sustainable R&D.
	Encourage participation in global research consortia: Collaborate on climate change and public health projects.	Increases Poland's visibility and supports global knowledge transfer.
5. Enhance Poland's brand as a sustainable education Hub	*Position Poland as a centre for sustainable education*: Highlight strengths in renewable energy and environmental science.	Attracts international students and establishes Poland as a knowledge economy leader.
	Provide scholarships for international students in sustainability fields: Support students from countries with environmental challenges.	Builds global talent pipelines and fosters sustainable solutions.
	Promote Polish R&D Achievements in Green Innovation: Showcase successful green R&D projects internationally.	Strengthens Poland's reputation as a leader in sustainable R&D exports.
6. Create incentives for sustainable industry partnerships	*Encourage Green Industry-Academia Collaborations*: Provide grants or tax breaks for joint sustainability research.	Fosters collaboration in renewable energy, waste management, and sustainable agriculture.
	Develop Innovation Hubs Focused on Sustainability: Create clusters for academic, industry, and government partnerships.	Positions Poland as a central player in sustainable technology innovation.
	Support Startups in Green Sectors: Fund and mentor startups in green technology and climate innovation.	Drives job creation, innovation, and attracts global partnerships.

2. Education variables, mean years of schooling and expected years of schooling, have the largest impact on SDG achievement, with mean years of schooling showing a coefficient of 1.79 points per additional year;
3. Innovation (SDG 9) outcomes are particularly sensitive to human capital accumulation, with mean years of schooling yielding a 7.30-point increase per additional year;
4. Evidence of beta-convergence suggests countries with lower initial SDG scores can achieve faster progress through targeted human capital investment.

Poland exemplifies both the opportunities and challenges facing middle-income countries seeking to develop education and R&D exports. While ranking 1st in the EU for education quality (SDG 4), Poland's 18th-place ranking in innovation (SDG 9) highlights the need for increased R&D

Table 11 Challenges and opportunities for improvement Poland's education and R&D export strategy

Key challenges	Opportunities for improvement
Limited global brand: Poland lacks a strong reputation as a global education and R&D hub compared to Western Europe.	*Develop a stronger global education brand*: Invest in international marketing campaigns to promote Poland as a destination for affordable, high-quality education, emphasising green technologies and sustainability.
Insufficient investment in R&D: R&D spending as a percentage of GDP is below the EU average, limiting innovation.	*Increase R&D funding*: Align R&D investment with the EU average, prioritising funding for sustainability-related research in clean energy, resource management, and climate resilience.
Lack of comprehensive sustainability integration: Sustainability is not yet a core focus across Polish universities and research institutions.	*Enhance sustainability education*: Integrate sustainability into all levels of education and develop "green campuses" to showcase environmental responsibility.
Low participation in lifelong learning: Workforce adaptability is hindered by limited access to lifelong learning programmes.	*Expand lifelong learning programmes*: Strengthen lifelong learning initiatives focused on green skills and digital literacy to prepare the workforce for a sustainable economy.
Modest Success in International Funding Programmes: Poland has limited success in securing EU research funds and international collaborations.	*Strengthen International Partnerships*: Actively pursue collaborations within the EU and beyond, focusing on sustainability and human development goals, and increase participation in global research consortia.

investment and strengthened international partnerships. The empirical findings suggest that expanding tertiary education, promoting lifelong learning, and integrating sustainability into curricula could enhance Poland's competitive position.

Poland is a valuable case study, illustrating the challenges and opportunities of aligning human and sustainable development goals. Despite progress in attracting international students and regional innovation, Poland faces barriers such as insufficient R&D investment, limited global branding, and low participation in lifelong learning. By implementing targeted recommendations – such as expanding vocational training, creating green research funds, and leveraging EU programmes – Poland can enhance its position as a global hub for sustainable education and green innovation. These lessons provide actionable insights for other countries aiming to align development goals with economic competitiveness in the evolving global market.

However, policymakers should recognise that human development alone is not sufficient to ensure environmental sustainability. While improvements in education and income strengthen innovation capacity and social welfare, they may also increase ecological pressures if accompanied by unsustainable consumption patterns. Policies should therefore complement investments in human development with measures promoting resource efficiency, circular economy principles, renewable energy, and responsible consumption to ensure that gains in human development are environmentally sustainable.

More broadly, our results support the theoretical proposition that human and sustainable development goals are mutually reinforced. Countries that invest strategically in human capital lay the foundation for knowledge-economy competitiveness while advancing broader sustainability objectives. As global demand for sustainability-focused education and green innovation grows, countries that successfully integrate human development and sustainability strategies will be best positioned to capture emerging opportunities in education and R&D export markets.

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