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Economic and Environmental Determinants of Human Development: A Panel Data Analysis of the 30 Largest Economies from 1992 to 2022

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Determinantes Econômicos e Ambientais do Desenvolvimento Humano: Uma Análise de Dados em Painel das 30 Maiores Economias de 1992 a 2022

RESUMO
Objetivo: Este estudo busca analisar os determinantes econômicos e ambientais do desenvolvimento humano nas maiores economias mundiais entre 1992 e 2022, explorando como diferentes fatores contribuem para o Índice de Desenvolvimento Humano (IDH).
Metodologia: A pesquisa utiliza um modelo de dados em painel, considerando o IDH como variável dependente e variáveis independentes como PIB per capita, maquinário agrícola, produtividade agrícola, conservação ambiental (área florestal), entre outros.
Originalidade/relevância: Este trabalho preenche uma lacuna teórica ao integrar fatores econômicos e ambientais em uma análise abrangente do desenvolvimento humano, abordando as inter-relações entre sustentabilidade e crescimento econômico.
Resultados: Os resultados demonstram que PIB per capita, uso de maquinário agrícola, produtividade agrícola, conservação ambiental e acesso à eletricidade em áreas rurais têm efeitos positivos no IDH, enquanto práticas agrícolas intensivas e insustentáveis, como uso excessivo de fertilizantes e alta retirada de água potável, apresentam impactos negativos.
Contribuições teóricas/metodológicas: Este estudo reforça teorias que defendem a necessidade de práticas agrícolas mais sustentáveis e infraestrutura básica como determinantes para o desenvolvimento humano.
Contribuições sociais e ambientais: As descobertas destacam a importância de políticas públicas voltadas ao equilíbrio entre crescimento econômico e sustentabilidade ambiental, promovendo um desenvolvimento humano mais equitativo.

PALAVRAS-CHAVE: Desenvolvimento humano. Sustentabilidade Econômica. Conservação Ambiental. Agricultura Sustentável. Dados em Painel.

Economic and Environmental Determinants of Human Development: A Panel Data Analysis of the 30 Largest Economies from 1992 to 2022

ABSTRACT
Objective: This study seeks to analyze the economic and environmental determinants of human development in the world's largest economies between 1992 and 2022, exploring how different factors contribute to the Human Development Index (HDI).
Methodology: The research uses a panel data model, considering the HDI as the dependent variable and independent variables such as GDP per capita, agricultural machinery, agricultural productivity, environmental conservation (forest area), among others.
Originality/relevance: This work fills a theoretical gap by integrating economic and environmental factors into a comprehensive analysis of human development, addressing the interrelationships between sustainability and economic growth.
Results: The results demonstrate that GDP per capita, use of agricultural machinery, agricultural productivity, environmental conservation, and access to electricity in rural areas have positive effects on the HDI, while intensive and unsustainable agricultural practices, such as excessive fertilizer use and high withdrawal of freshwater, have negative impacts.
Theoretical/methodological contributions: This study reinforces theories that advocate the need for more sustainable agricultural practices and basic infrastructure as determinants of human development.
Social and environmental contributions: The findings highlight the importance of public policies aimed at balancing economic growth and environmental sustainability, promoting more equitable human development.

KEYWORDS: *Human Development. Economic Sustainability. Environmental Conservation. Sustainable Agriculture. Panel Data.*

Determinantes económicos y ambientales del desarrollo humano: un análisis de datos de panel de las 30 economías más grandes de 1992 a 2022

RESUMEN

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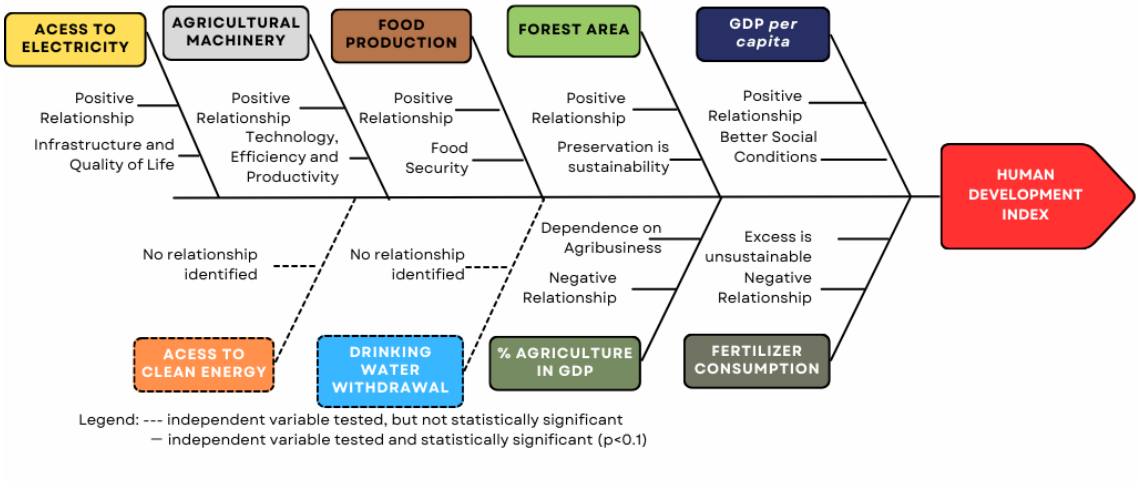
Objetivo: Este estudio tiene como objetivo analizar los determinantes económicos y ambientales del desarrollo humano en las mayores economías mundiales entre 1992 y 2022, explorando los factores que influyen en el Índice de Desarrollo Humano (IDH).
Metodología: La investigación utiliza un modelo de datos de panel, considerando el IDH como variable dependiente y variables independientes como el PIB per cápita, maquinaria agrícola, productividad agrícola, conservación ambiental (superficie forestal), entre otros.
Originalidad/relevancia: Este trabajo aborda una brecha teórica al integrar factores económicos y ambientales en un análisis exhaustivo del desarrollo humano, destacando las interacciones entre sostenibilidad y crecimiento económico.
Resultados: Los resultados muestran que el PIB per cápita, el uso de maquinaria agrícola, la productividad agrícola, la conservación ambiental y el acceso a la electricidad rural impactan positivamente en el IDH. Por el contrario, las prácticas agrícolas intensivas e insostenibles, como el uso excesivo de fertilizantes y la alta extracción de agua potable, afectan negativamente al desarrollo humano.
Contribuciones teóricas/metodológicas: Este estudio refuerza teorías que abogan por prácticas agrícolas más sostenibles y la infraestructura básica como determinantes clave del desarrollo humano.
Contribuciones sociales y ambientales: Los hallazgos destacan la importancia de políticas públicas que equilibren el crecimiento económico y la sostenibilidad ambiental para lograr un desarrollo humano equitativo.

PALABRAS CLAVE: *Desarrollo humano. Sostenibilidad económica. Conservación Ambiental. Agricultura Sostenible. Datos del Panel.*

RESUMO GRÁFICO



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1 INTRODUCTION

Agriculture is one of the fundamental sectors of the global economy, playing an essential role not only in food production but also in promoting economic development, environmental conservation, and human development (Yurui et al., 2021). However, the sector faces growing challenges as it tries to balance the need to increase productivity with the preservation of natural resources and the promotion of social justice (Mio, Panfilo; Blundo, 2020). The complexity of these interactions demands an interdisciplinary approach that considers the dynamics between economic growth, sustainable agricultural practices, and social well-being (Giller et al., 2021; Ikram et al., 2021).

With population growth and changing consumption patterns, the demand for food has increased significantly, highlighting the urgency of rethinking agricultural practices to integrate economic efficiency, environmental responsibility, and social justice (Lu et al., 2021; Piñeiro et al., 2020). In this context, concepts such as agricultural productivity, environmental conservation, and social equity become central to analyses seeking to promote sustainable development (Scoones et al., 2020; Javaid et al., 2022). Productivity measures efficiency in agricultural production, while environmental conservation emphasizes the sustainable management of natural resources (Jiakui et al., 2023). Social equity, in turn, refers to the fair distribution of resources and opportunities within the agricultural sector (Menton et al., 2020).

Despite efforts to promote sustainable agricultural practices, there remains a clear tension between increasing production to meet global food demand and the need to mitigate adverse environmental impacts and ensure social well-being (Barret et al., 2021; Garcia et al., 2020). Understanding these complex dynamics is essential for formulating policies that ensure long-term sustainability in agriculture.

Therefore, the main objective of this study is to analyze the economic and environmental determinants associated with the Human Development Index (HDI) in the world's largest economies between 1992 and 2022, using a panel data model. To this end, panel data on environmental and social variables were used to provide insights for formulating more responsible public policies and agricultural practices..

This article contributes to the literature by integrating indicators that reflect sustainable development in agriculture, offering a comprehensive analysis of previously untested variables together, applying a panel data model that evaluates hypotheses about the interrelationships between agricultural productivity, economic development, the relationship between agricultural machinery and environmental conservation, and the human development provided by access to technologies in rural areas.

This article is structured as follows: in addition to this introduction, the subsequent section presents a review of the relevant literature, highlighting key concepts and recent advances. Next, the methodology adopted is detailed, followed by an analysis of the results obtained and discussions. Finally, the concluding remarks discuss the main findings and offer recommendations for future research and policy interventions in the field of sustainable agriculture.

2 LITERATURE REVIEW

The literature review on sustainable development in agriculture explores recent approaches that combine productivity, environmental conservation, and social equity as essential elements for sustainability (D'Amato; Korhonen, 2021; Hysa et al., 2020; Padilla-Rivera et al., 2020). Practices such as precision agriculture, agroforestry systems, and organic agriculture are highlighted, which seek to integrate these interdependent elements (Anderson et al., 2021; Oberč, 2020).

2.1 Agricultural Productivity and Sustainability

Agricultural productivity is fundamental to sustainable development, reflecting efficiency in the production of food and other agricultural products (Movilla-Pateiro et al., 2021; Velasco-Muñoz et al., 2021). Innovative practices, such as precision agriculture and sustainable technologies, are important for optimizing resource use and increasing production without compromising the environment (Kamble et al., 2020). However, maximizing productivity without negatively affecting soil health, biodiversity, and other natural resources remains a challenge (Lal et al., 2021; Yang et al., 2020). There is evidence that the intensive use of agricultural machinery can lead to negative impacts, such as air pollution, soil compaction, and increased flood risk, even though, in some regions, agricultural activity may have positive effects on environmental quality (Aneja et al., 2009; Pingali; Plavšić, 2022; Rasheed et al., 2023).

2.2 Environmental Conservation in Agriculture

Environmental conservation is intrinsic to the sustainable management of natural resources. Practices such as crop rotation, agroforestry, and organic agriculture are pointed out in the literature as effective strategies for preserving ecosystems, minimizing soil degradation, and reducing the use of chemical inputs (Page et al., 2020). However, the implementation of these practices faces challenges, such as resistance to change and economic pressures (Kannan et al., 2022). The relationship between environmental conservation and fertilizer use, for example, suggests that sustainable practices can reduce greenhouse gas (GHG) emissions and contribute to maintaining climate balance (Li et al., 2021; Raihan et al., 2023; Santos et al., 2025). Studies indicate that efficient management of water resources in agriculture is essential for production resilience in the face of climate change, especially during drought periods (Hameed, 2019; Piroli; Elias; Elias, 2025; Metwally et al., 2024).

2.3 Human Development and Sustainability

To achieve human development, rural social equity must also be observed, which refers to the fair distribution of resources and benefits among rural populations, agricultural workers, and local communities (Janker; Mann, 2020). Inclusive business models, such as cooperatives and family farming, have been recognized for promoting economic efficiency and equitable distribution of benefits (German et al., 2020; Xie; Huang, 2021). Studies suggest that the Human Development Index (HDI) can serve as a measure to compare social equity in the

context of sustainable development, although it does not capture projections for future generations (Ibrahim, 2022; Kinnunen et al., 2019).

2.4 Research Hypotheses

Based on the reviewed literature, the following hypotheses are proposed for investigation:

- H1: There is a positive relationship between Gross Domestic Product per capita and the Human Development Index (HDI). Although it may seem redundant, it is important to verify if there are deviations caused by differences in access to education and health.

- H2: There is a positive relationship between the use of agricultural machinery and the HDI, indicating that mechanization can contribute to human development.

- H3: There is a negative relationship between the share of agriculture, forestry, and fishing in GDP and the HDI, suggesting that economies overly dependent on the agricultural sector face challenges in human development. Although there are developed countries dependent on agriculture with advanced and widely diversified economic structures, these are exceptions that allow maintaining this hypothesis.

- H4: There is a positive relationship between food production and the HDI, demonstrating that increased agricultural production can improve human development.

- H5: There is a positive relationship between environmental conservation (measured by forest area) and the HDI, indicating that environmental preservation is an important factor for sustainable human development.

- H6: There is a negative relationship between the use of chemical fertilizers and the HDI, suggesting that agricultural practices intensive in chemical inputs can reduce gains in human development.

- H7: There is a positive relationship between annual water withdrawals for agriculture and the HDI, indicating that this factor may show that large agricultural production can be a determinant for human development in these contexts.

- H8: There is a positive relationship between access to clean fuels and technologies for cooking in rural areas, as countries that are less dependent on unclean fuels in rural areas are at a more advanced stage of human development.

- H9: There is a positive relationship between access to electricity in rural areas and the HDI, highlighting the importance of rural electrification for improving living conditions and human development.

These hypotheses are fundamental to understanding the complex interactions between agricultural productivity, environmental conservation, and social equity, contributing to a more sustainable model of agricultural development.

3 METHODOLOGY

This research adopts a quantitative approach to assess sustainable development in agriculture. The methodology comprises a literature review, data collection and analysis, and the proposal of an integrative model to examine the relationships between economic,

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environmental, and social indicators.

A comprehensive review of relevant studies on agricultural productivity, environmental conservation, and human development in agriculture was conducted. The review included academic databases, scientific journals, and other pertinent sources, aiming to identify recent advances and gaps in existing knowledge.

The literature review used the Scopus and Web of Science databases, covering the period from 2004 to 2024, as a significant increase in academic production related to sustainable development was observed, especially in the agricultural sector, due to the intensification of global discussions on climate change, food security, and environmental conservation. It also coincides with the advancement of international policies aimed at the United Nations' sustainable development goals, which gained global traction after 2000.

Development indicators were collected from the World Bank. Quantitative analysis was conducted using statistical methods, including panel data analysis and correlation, with the help of RStudio software. The analysis involved the interpretation of emerging patterns and the discussion of the implications of the studied agricultural practices.

Variables considered important for explaining human development in agriculture were defined. Data availability and suitability were evaluated to ensure the sample was large enough for asymptotic statistical significance and a balanced panel. Thus, the 30 largest economies were selected based on the availability of reliable World Bank data for the period from 1992 to 2022. The variables were chosen and justified based on the literature, as detailed in Table 1.

Table 1 – Variable Definition and Expected Sign

Dependent variable: Human Development Index (HDI)		
Independent Variable	Expected Relationship (Sign)	Previous Research
GDP per capita in US$ (GDPpc)	+	Gsim; Es-Saked, 2024; Janik; Tóth-Naár, 2021; Kraemer *et al.,* 2020; Loft, 2021; Schwegler, 2021
Value added of Agriculture, forestry and fishing in GDP in US$ (AGRI)	-	Bhatia; Cumming, 2020; Fakhri; Alqahtani; Jamee, 2024; Fossaceca, 2020; Madi *et al.,* 2020; Tanjung, 2021
Agricultural Machinery in tractor/m² of arable land (LM)	+	Dhahri; Omri, 2020; Madi *et al.,* 2020; Shen; Zhao; Song, 2022
Agricultural productivity % (Food Production Index) (PROD)	+	Awad, 2023; Loft, 2021; Moreira, 2020; Mughal; Sers, 2020
Environmental conservation (forest area in km²) (FOREST)	+	Chhibber, 2020; Dextre-Martinez *et al.,* 2024; Loft, 2021; Shaqiri; Vasa, 2020; Stoian; Brad; Zaharia, 2022
Fertilizer consumption (kg/ha of arable land) (FERT)	-	Chen *et al.,* 2021; Lobo *et al.,* 2020; Stoian; Brad; Zaharia, 2022; Stenberg, 2023
Annual Freshwater Withdrawal (% of total freshwater) (WATER)	+	Marín Puyuelo, 2023; Shen; Zhao; Song, 2022; Simpson *et al.,* 2023
Access to clean fuels (% of population) (CCLEAN)	+	Acheampong; Erdiaw-Kwasie; Abunyewah, 2021; Batbyamba, 2022; Brecha, 2019; Khan *et al.* 2024
Access to electricity in rural areas (% of rural population) (ACELEC)	+	Batbyamba, 2022; Marín Puyuelo, 2023; Sarkodie; Adams, 2020; Shen; Zhao; Song, 2022; Simpson *et al.,* 2023

Source: elaborated by the authors based on literature (2024).

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Data analysis was performed using a fixed effects model, after Breusch-Pagan and Hausman tests. The proposed equation to evaluate sustainable development integrated economic, environmental, and social indicators. The coefficients of the equation were determined based on literature and statistical data analysis. The equation was used to verify the validity of the proposed hypotheses about the performance of agricultural practices.

Equation 1 integrates the economic, environmental, and social indicators to evaluate development, according to the described methodology, and can be formalized as:

$$IDH_{it} = \beta 0 + \beta 1(GDPPC)_{it} + \beta 2(AGRI)_{it} + \beta 3(LM)_{it} + \beta 4(PROD)_{it} + \beta 5(FOREST)_{it} + \beta 6(FERT)_{it} + \beta 7(WATER)_{it} + \beta 8(ACCLEAN)_{it} + \beta 9(ACELEC)_{it} + \epsilon_{it} \quad (1)$$

The coefficients (β_i) help indicate the magnitude and direction of the effect of the respective independent variable on the HDI. The equation allowed testing whether the selected variables contribute significantly to explaining the variation in HDI, providing insights into sustainable agricultural practices and their implications for economic, social, and environmental development. The formal structure of the model is based on Wooldridge (2010), where a more detailed formalization of the model applied here can be found.

4 RESULTS AND DISCUSSION

The presented data include descriptive statistics of different variables related to human, economic, and environmental development, as follows in Table 2:

Table 2 – Descriptive Statistics of Economic, Environmental, and Human Development Indicators

	HDI	GDP*pc*	AGRI	LM	PROD
Min	0,44	301,5	0,55	1,85	39,58
1st Q	0,75	7618,6	1,40	146,39	83,01
Median	0,85	23670,7	2,45	590,45	94,37
Mean	0,82	26000	4,65	846,53	91,26
3rd Q	0,90	40781,9	5,66	1232,94	100,77
Max	0,96	103553,8	27,05	4707,97	185,23
Unavailable			28	512	8
	FOREST	**FERT**	**WATER**	**ACCLEAN**	**ACELEC**
Min	0,045	9,26	0,15	1,8	36,06
1st Q	12,55	103,32	10,65	84,83	100
Median	30,27	177,40	55,19	100	100
Mean	30,19	250,79	45,33	87,99	96,9
3rd Q	38,70	294,12	73,93	100	100
Max	69,55	1886,03	95,94	100	100
Unavailable	8	2	71	240	25

Source: Elaborated by the authors (2024).

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The data show significant variations between countries in terms of human development, wealth, use of natural resources, and infrastructure. The wide variability in economic and environmental variables reflects disparities in economic development, agricultural practices, and access to essential resources, such as clean water and electricity. The asymmetric distribution of some variables, such as GDP per capita and chemical fertilizer use, highlights the extreme differences between developed and developing countries. The means close to the medians for variables like forest cover and agricultural productivity indicate a more uniform distribution around certain median values.

Considering the result of the panel data analysis, the investigation resulted in the relationships between economic, agricultural, environmental, and social equity variables and the HDI in 160 observations, using the fixed effects model. This model was identified as the most appropriate after performing the Lagrange Multiplier (Breusch-Pagan) and Hausman tests, which indicated $p<0.05$, suggesting that the fixed effects model shows greater consistency compared to the random effects model.

The Breusch-Pagan and Hausman tests presented in Table 3 indicate the presence of significant effects in the model and the inconsistency of the random effects model, justifying the choice of the fixed effects model. The Lagrange Multiplier (Breusch-Pagan) test shows a chi-square value of 200.65 ($p < 2.2e-16$), while the Hausman test indicates a chi-square of 49.314 ($p = 1.449e-07$), reinforcing the adequacy of the fixed effects model for the analysis.

Based on these results, we present below the estimates generated by the fixed effects model, as detailed in Table 3.

Tabela 3 – Panel estimates (the response variable is HDI)

Dependent Variable		**HDI**	
Independent Variable	**Coefficient**	**Standard Error**	**Significance**
GDPPC	0.00000	(0.00000)	***
AGRI	-0.003	(0.001)	***
LM	0.0001	(0.00001)	***
PROD	0.001	(0.0002)	***
FOREST	0.006	(0.002)	**
FERT	-0.0001	(0.00003)	**
WATER	-0.0002	(0.0005)	
ACCLEAN	-0.0004	(0.0004)	
ACELEC	0.002	(0.001)	***
Observations		160	
R^2		0.720	
Adjusted R^2		0.644	
F-Statistic	35.749		***
Note: *p<0.1; **p<0.05; ***p<0.01			

Test	**Chi-Square Statistic**	**Degrees of Freedom**	**p-value**	**Alternative Hypothesis**
Lagrange Multiplier Test (BP)	200.65	1	< 2.2e-16	Significant effects
Hausman Test	49.314	9	1.449e-07	One model is inconsistent

Source: Elaborated by the authors (2024).

The results indicate significant relationships, which are discussed below:

1. **GDP per capita (GDPPC):** A positive and significant relationship ($p<0.01$) was found between GDP per capita and HDI, corroborating the hypothesis (H1) that a higher GDP per capita is associated with a higher HDI. This reinforces the idea that economic growth, measured by GDP per capita, contributes to improvements in social conditions and population quality of life.
2. **Use of agricultural machinery (LM):** A positive and significant relationship ($p<0.01$) was identified between the use of agricultural machinery per area of arable land and HDI. This finding corroborates H2 that increased use of agricultural machinery would have a positive impact on HDI. This suggests that the use of technology in agriculture may be associated with efficiency and productivity gains that contribute to human development.
3. **Share of agriculture in GDP (AGRI):** The analysis showed a significant negative relationship ($p<0.01$) between the share of agriculture in GDP and HDI. This indicates that greater dependence of the economy on agriculture may be associated with a lower HDI. This result may suggest that economies heavily dependent on the agricultural sector face structural challenges that limit their human development, such as low economic diversification and vulnerability to external shocks.
4. **Food production (PROD):** Food production showed a significant positive relationship ($p<0.01$) with HDI, confirming H4 that higher agricultural productivity is associated with greater human development. This suggests that increases in agricultural productivity, possibly resulting from better practices and technologies, can contribute to food security and economic well-being.
5. **Forest area (FOREST):** There was a significant positive relationship ($p<0.05$) between the percentage of area covered by forests and HDI, suggesting that forest conservation is associated with higher levels of human development. This result reflects the importance of environmental preservation as a critical component for sustainability and quality of life.
6. **Fertilizer consumption (FERT):** A significant negative relationship ($p<0.05$) was observed between fertilizer consumption and HDI. This result corroborates H6 that increased consumption of chemical fertilizers, especially in excess, can have adverse impacts on environmental sustainability and, consequently, on human development. The intensive use of fertilizers can lead to soil degradation and water contamination, reducing the quality of life of rural populations.
7. **Water withdrawal for agriculture (WATER):** No significant relationship was identified between freshwater withdrawal for agricultural use and HDI, rejecting H7. This result may be related to variations in regional contexts, where in some regions sustainable agriculture does not depend on high water withdrawal, contrary to what happens in others.
8. **Access to clean fuels and technologies (ACCLEAN):** The variable of access to clean fuels and technologies for cooking in rural areas did not show statistical significance ($p > 0.1$), rejecting H8. Although the initial hypothesis suggested a positive relationship with HDI, the results indicate that, in this specific model, the variable is not a clear determinant for human development.

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9. **Access to electricity (ACELEC):** The positive and significant relationship ($p<0.01$) found between access to electricity in rural areas and HDI confirms H9 that rural electrification is associated with greater human development. This result highlights the importance of basic infrastructure for improving quality of life in rural areas, promoting greater social equity.

The results of the analysis show that multiple factors influence human development in a complex way. The positive relationship between GDP per capita and HDI reaffirms the relevance of economic growth as a driver of social improvements. However, excessive dependence on traditional agriculture seems to be associated with lower human development, suggesting the need for policies that encourage economic diversification.

On the other hand, environmental conservation, represented by forest area, proves to be fundamental for sustainable human development, reinforcing the importance of policies that integrate agricultural productivity with preservation practices. The use of technologies, both in agricultural production and in access to essential services such as electricity, plays a positive role, indicating that innovation and infrastructure are fundamental to achieving higher levels of HDI.

These findings suggest that sustainable development policies must balance economic growth with healthy environmental and social practices. Investments in efficient agricultural technologies, promotion of clean energy, and improvements in rural infrastructure are strategic to raise HDI, while preserving the environment and promoting fairer living conditions.

5 CONCLUSION

The results of the panel data analysis using fixed effects models suggest that most of the variables identified in the literature significantly influence the Human Development Index (HDI). However, annual water withdrawals for agriculture and access to clean fuels and technologies for cooking in rural areas did not show statistical significance. This may indicate that, when considering the largest economies from 1992 to 2022, there is a set of variables that can be extrapolated to other economies, suggesting that similar factors tend to cause similar effects on HDI in different economic contexts.

It is important to emphasize that the growing participation of agribusiness (including agriculture, forestry, and fishing) in the Gross Domestic Product (GDP) can have adverse effects on HDI, indicating that economies overly dependent on agriculture face significant challenges in improving their human development. Therefore, while agricultural mechanization can contribute positively to development, it is essential that increases in food production occur through gains in productivity, minimizing the intensive use of chemical inputs such as fertilizers, which can reduce advances in HDI.

Environmental conservation, represented by forest area, showed a positive correlation with HDI, reinforcing the importance of environmental preservation as an essential component for sustainable development. Although water use in agriculture did not prove to be a central concern for human development in the 30 economies studied, it may be a more relevant factor in smaller economies, where water resources are more limited.

Access to electricity in rural areas demonstrated a significant positive relationship with HDI, underlining the relevance of rural electrification for improving living conditions and human

development of rural workers. On the other hand, access to clean fuels and technologies for cooking in rural areas was not statistically significant, which suggests that other factors may be more determinant for social equity in these contexts.

In summary, the study confirmed that economic, technological, and environmental factors play roles of fundamental importance in human development. The analysis showed that, although mechanization and productivity in the agricultural sector can bring benefits, intensive agricultural practices and a high dependence on agribusiness can generate negative effects. Environmental preservation and rural infrastructure, especially regarding access to energy, are fundamental to promoting more equitable and sustainable human development.

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DECLARATIONS

CONTRIBUTION OF EACH AUTHOR

When describing the participation of each author in the manuscript, use the following criteria:

- **Study Conception and Design:** Willian dos Santos Flores.
- **Data Curation:** Gabriela Vilela dos Santos Mantovani.
- **Formal Analysis:** Willian dos Santos Flores, with support from Gabriela Vilela dos Santos Mantovani and Paulo Henrique de Oliveira Hoeckel.
- **Funding Acquisition:** Willian dos Santos Flores (CAPES grantee), Gabriela Vilela dos Santos Mantovani (FUNDECT-MS grantee).
- **Investigation:** Willian dos Santos Flores and Gabriela Vilela dos Santos Mantovani.
- **Methodology:** Willian dos Santos Flores, with support from Gabriela Vilela dos Santos Mantovani and Paulo Henrique de Oliveira Hoeckel.
- **Writing - Initial Draft:** Willian dos Santos Flores, with contributions from Gabriela dos Santos Mantovani.
- **Writing - Critical Review:** Paulo Henrique de Oliveira Hoeckel, Jonathan Gonçalves da Silva and Clandio Favarini.
- **Review and Final Editing:** Gabriela Vilela dos Santos Mantovani, with contributions from Willian dos Santos Flores.
- **Supervision:** Paulo Henrique de Oliveira Hoeckel, Jonathan Gonçalves da Silva and Clandio Favarini.

CONFLICT OF INTEREST DECLARATION

We, **Willian dos Santos Flores, Gabriela Vilela dos Santos Mantovani, Paulo Henrique de Oliveira Hoeckel, Jonathan Gonçalves da Silva, Clandio Favarini Ruviaro**, declare that the manuscript entitled "Economic and Environmental Determinants of Human Development: A Panel Data Analysis of the 30 Largest Economies from 1992 to 2022":

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2. Professional Relationships: The authors maintain institutional links with UFMS and UFGD, where they work as technical-administrative staff or professors. Such links did not influence the design, analysis, or interpretation of the results.

3. Personal Conflicts: No personal conflict of interest related to the content was identified.