



San Martín Region: Trilogy (AAE) of Water, Agriculture, Energy, and Economic Growth

Región San Martín: trilogía (AAE) agua, agricultura, energía y crecimiento económico

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ABSTRACT

Water resources are a problem in the San Martín region, reaffirming the purpose of directing actions towards an integrated management, with a territorial approach to respond to climate change. The objective was to demonstrate that the trilogy (AAE) water, agriculture and energy through econometric calculation is related to economic growth. Type of basic research, under the non-experimental-correlational research design. The water footprint was used to indicate the availability of water resources, allowing changing opinions regarding water scarcity linked to food and energy security in the region. A multiple linear econometric model was established to compare the relationship between the availability of water resources, agricultural productivity, energy supply and economic growth in the San Martín region, applying the ordinary least squares method. The regression shows that there is a coefficient of determination equal to 97.09%, showing that economic growth is explained by the availability of water resources, agricultural productivity and energy supply, and there is also a strong relationship between these variables since a correlation coefficient of 0.98532 is determined between economic growth and the other variables.

Keywords: energy expenditure; water management; water footprint; agricultural productivity; water resources

RESUMEN

El recurso hídrico es un problema en la región San Martín, reafirmando el propósito de direccionar acciones hacia una gestión integral, con un enfoque territorial para responder al cambio climático. El Objetivo fue demostrar que la trilogía (AAE) agua, agricultura y energía mediante el cálculo econométrico tiene relación con el crecimiento económico. Tipo de investigación básica, bajo el diseño de investigación no experimental-correlacional. Se utilizó la huella hídrica como indicador para la disponibilidad del recurso hídrico, la misma que permitirá cambiar las opiniones respecto a la escasez de agua vinculada a la seguridad alimentaria y energética en la región. Se estableció un modelo econométrico lineal múltiple permitiendo comparar la relación existente entre la disponibilidad del recurso hídrico, productividad agrícola, el suministro energético y el crecimiento económico en la región San Martín, aplicando el método de mínimos cuadrados ordinarios. La regresión realizada muestra que existe un coeficiente de determinación igual al 97.09% mostrando que el crecimiento económico es explicado por la disponibilidad del recurso hídrico, productividad agrícola y el suministro energético, existiendo además una relación fuerte entre dichas variables, pues se logra determinar un coeficiente de correlación del 0.98532 entre crecimiento económico y las demás variables.

Palabras clave: gasto energético; gestión hídrica; huella hídrica; productividad agrícola; recurso hídrico



1. INTRODUCTION

Rapid urbanization and climate change are increasing demand across all water uses (Nguyen et al., 2023). Cities in developing countries will need to meet the demand of an additional 70 million people each year over the next 20 years (Nieuwenhuijsen, 2020). By 2030, 45% more water will be required solely to meet food needs (Nhamo et al., 2025). In addition, more than 1.3 billion people worldwide still lack access to electricity, and closing the energy gap has implications for water use, including its use in fuel extraction, cooling processes, and hydroelectric power generation (Ijoma et al., 2022). In response to these growing pressures, many countries are introducing integrated water resources management approaches at the basin level, including improvements in institutional arrangements and working practices (Koop et al., 2022).

The rationale for studying the water, agriculture, and energy (AAE) trilogy lies in jointly analyzing these three variables. Water resource availability represents a major challenge that is not only linked to climate change and the resulting physical scarcity of water, but also to the need for appropriate management (Hamidov & Helming, 2020). Surface water constitutes the expression of water supply for productive purposes, of which only a portion is actually used. The analysis also focuses on the role of water as an input in productive processes and on its contribution to regional economic growth through the assessment of water resource availability using the agricultural and livestock water footprint, thereby identifying key factors for the growth of the region and the country (Yano et al., 2015).

In Peru, water demand is classified into consumptive uses (agricultural, domestic, industrial, and mining) and non-consumptive uses (energy generation and fisheries). Although the sectors that contribute most to national GDP are industry, mining, commerce, and construction, the agricultural sector accounts for the greatest demand for water, representing approximately 90% of the country's water footprint (Autoridad Nacional del Agua, 2015). MINAGRI classifies agriculture into subsistence agriculture, small rural businesses, commercial production, agro-export production, and intensive agriculture. This sector constitutes the main livelihood of 80% of rural households and is also present in urban areas. Likewise, livestock production, aimed at producing meat, milk, and eggs, depends heavily on water use for both animal rearing and the production of forage crops (Weishaupt et al., 2020).

Agriculture is a fundamental activity for rural populations in Peru and plays a central role in the country's productive structure (Baylon Salvador & Quispe Cusi, 2023; Benavente Cárdenas et al., 2018; Patiño-Ramírez & Valiente-Saldaña, 2023). According to Berchoux et al. (2019) and Kapur (2019), this activity constitutes the main source of employment in rural areas, where it serves as a key support for food provision and the supply of raw materials. Its impact also extends to the national irrigation system, with which it is closely linked, thereby reinforcing its strategic role in food security and territorial development (Pawlak & Kołodziejczak, 2020).

Energy supply is a cross-cutting factor that supports both primary activities and the industrial and service sectors (Deshmukh et al., 2023). Energy not only enables productive processes to operate but is also an essential component of human well-being. As indicated by Al Kez et al. (2024), economic and social development is conditioned by access to and appropriate use of energy, particularly electricity, which is essential for improving quality of life in both rural and urban settings. Within this context, increasing energy demand reflects population growth and the expansion of economic activities.

Economic growth is traditionally measured through changes in Gross Domestic Product (GDP), which represents the production of goods and services during a given period. Jansen et al. (2024) point out that this indicator should be complemented by social variables such as access to healthcare, education, and nutrition, which provide a more comprehensive perspective on development. In addition, the

incorporation of natural resources into economic models has become increasingly relevant, recognizing their direct influence on long-term growth and environmental sustainability processes.

Within this context, the San Martín Region faces a series of climate change-related challenges that directly affect access to drinking water, sanitation systems, agricultural irrigation, and hydroelectric power generation. These impacts compromise both agricultural productivity and the population's quality of life. At the same time, the region has high agricultural production potential that requires optimization of its natural resources, particularly water and energy, in order to advance toward sustainable industrialization and efficient productive diversification.

The rational use of water and energy resources is therefore an essential component of territorial socioeconomic development. The interaction between the agricultural and livestock sector, the energy sector, and demographic, urban, and industrial dynamics requires integrated management capable of responding to increasing pressures on water resources. In this context, the objective of this study was to demonstrate that the trilogy comprising water, agriculture, and energy (AAE) has a significant relationship with economic growth, as assessed through econometric estimation techniques. This approach makes it possible to demonstrate the combined effect of these three factors on productive dynamics and the sustainable development of the region.

2. MATERIALS AND METHODS

The present study was conducted in the San Martín Region and was framed as basic research with an explanatory scope. Its objective was to demonstrate, through econometric analysis techniques, the existence of a significant relationship between the water, agriculture, and energy (AAE) trilogy and regional economic growth during the 2006–2015 period. According to Hernández Sampieri et al. (2014), this level of research is aimed at identifying the causes of social or natural phenomena, establishing the conditions under which they occur, and determining relationships among variables. A non-experimental correlational research design was adopted.

The research was based on the analysis of secondary data obtained from official sources, specifically the databases of the Ministry of Agriculture and Irrigation (MINAGRI), the San Martín Regional Directorate of Agriculture (DRASAM), the National Institute of Statistics and Informatics (INEI), and the Central Reserve Bank of Peru (BCRP). The independent variables considered were water resource availability, agricultural productivity, and energy supply, while the dependent variable was economic growth.

Information was collected through documentary review and data-recording techniques, using textual records and documentary guides prepared in accordance with the methodological guidelines established by the aforementioned institutions. Data processing and analysis were carried out using the statistical software packages Stata® V25 (StataCorp, College Station, Texas, USA) and EViews®, which made it possible to develop appropriate econometric models to test the proposed hypotheses and establish significant relationships among the study variables.

3. RESULTS AND DISCUSSION

3.1. Water resource availability in the San Martín Region

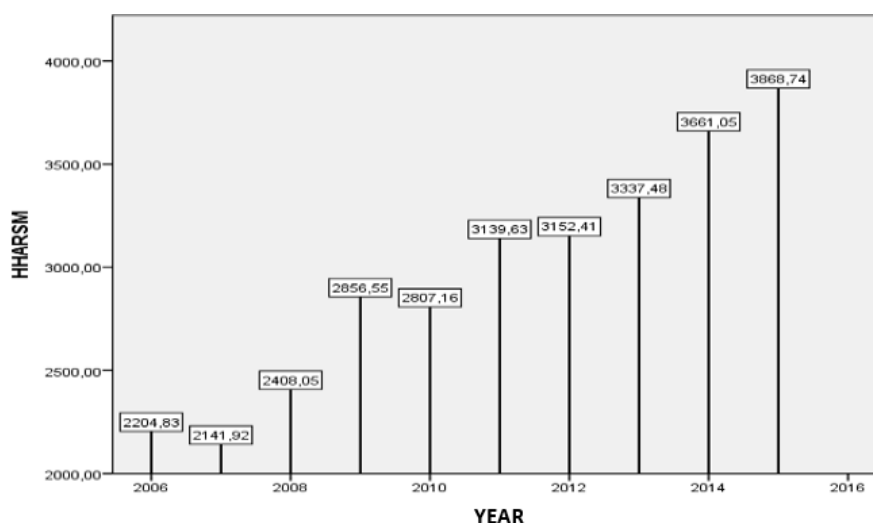
Water resource availability in the San Martín Region is directly influenced by the water demand of the main crops and agricultural and livestock products produced within its territory. The water footprint makes it possible to quantify the total volume of water used at each stage of production, reflecting the pressure exerted by each product on water resources. Table 1 presents the most relevant agricultural and livestock products in the region together with their respective water footprints, thereby illustrating their impact on water management.

Table 1. Products with the highest water footprint

Product	Rice	Cassava	Banana	Oil palm	Yellow corn	Cocoa	Coffee	Beef
Water footprint	733.81	157.48	782.07	440.78	243.01	808.86	449.95	361.72

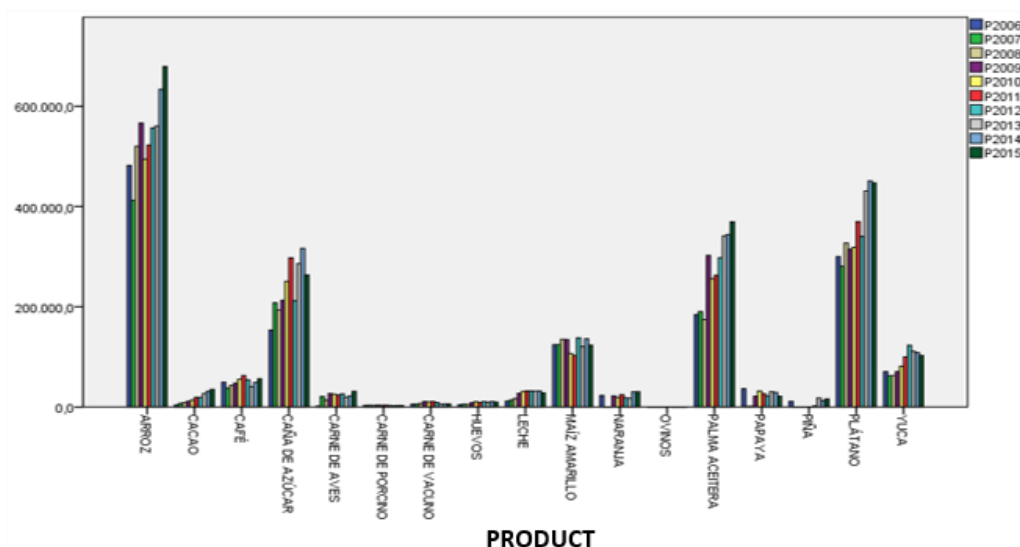
The water footprint is assessed in terms of the amount of water used in agricultural and livestock production processes. Although there is a deeply rooted perception that rice production requires the greatest amount of water, the indicators used show that cocoa has the largest water footprint, followed by banana, rice, coffee, oil palm, beef, yellow corn, and cassava, respectively, expressed in cubic hectometers.

Agriculture is the region's main economic activity and is generally concentrated in rural areas, where higher levels of poverty and extreme poverty are also observed.

**Figure 1.** Variation in the agricultural and livestock water footprint in the San Martín Region

The concentration of water consumption is represented by the water footprint of agricultural and livestock production, which shows a sustained upward trend consistent with the increase in production and, consequently, with the need to meet consumption requirements. This variation is expressed in cubic hectometers.

3.2. Agricultural production in the San Martín Region

**Figure 2.** Agricultural and livestock production in the San Martín Region

Production during the 2006–2015 study period exhibited specific characteristics and important production trends. Rice showed the greatest growth dynamism, followed by banana, oil palm, sugarcane, yellow corn, and cassava, respectively.

Lalawmpuii & Rai (2023) state that water is required for energy generation, crop cultivation, and food production, while energy is simultaneously required for food production and access to water sources. This creates a dynamic relationship among these components, which must operate jointly to ensure the viability of decisions aimed at achieving sustainable growth and development.

3.3. Energy production in the San Martín Region

Table 2. Total energy production in the San Martín Region

Description	Electricity generation (GWh)	Electricity generation (GWh)	Electricity generation (GWh)
Year	Hydroelectric	Thermal	Total
2006	32.00	84.00	116.00
2007	37.00	100.00	137.00
2008	40.00	114.00	154.00
2009	46.00	121.00	167.00
2010	28.00	150.00	178.00
2011	35.00	10.00	45.00
2012	46.00	6.00	52.00
2013	43.00	7.00	50.00
2014	49.00	10.00	59.00
2015	49.00	13.00	62.00

The water footprint generated by electricity production through both thermal and hydroelectric generation, expressed in cubic hectometers, varies according to regional energy production levels, taking into account the reduction in thermal generation and the limited increase in hydroelectric generation, as well as the region's dependence on the National Interconnected Electric System (SEIN).

The San Martín Region has considerable hydroelectric potential. As established in the updated energy policy for the 2015–2030 period, the region has a theoretical hydroelectric potential of 5,392 MW, of which only 0.14% is currently being utilized. This corresponds to the GERA I and GERA II hydroelectric power plants, with production capacities of 6 and 2 GW, respectively. Electricity coverage reaches 87.8%, placing the region 14th among Peru's 24 departments according to the Regional Competitiveness Index published by the Peruvian Institute of Economics. At the same time, the region ranks 23rd in terms of electricity costs, with some of the highest electricity prices in the country.

3.4. Economic growth and water resource availability, agricultural productivity, and energy supply in the San Martín Region, 2006–2015

Table 3. GDP and the water, agriculture, and energy trilogy in the San Martín Region

Year	San Martín regional GDP (thousands of soles)	Water footprint of agricultural and livestock production and drinking water in the San Martín Region (hm ³)	San Martín agricultural GDP (thousands of soles)	Water footprint of regional hydroelectric and thermal power generation (hm ³)
2006	3076384.00	2221.08	747368.00	0.00000464
2007	3266254.00	2158.77	1168921.00	0.00000548
2008	3774422.00	2425.62	1267532.00	0.00000616
2009	4024391.00	2874.68	1343600.00	0.00000668
2010	4333975.00	2824.81	1430381.00	0.00000712
2011	5050535.00	3157.87	1648959.00	0.00000180
2012	5590778.00	3169.69	1780238.00	0.00000208
2013	5805907.00	3355.72	1698331.00	0.00000200

2014	6720198.00	3678.72	1845168.00	0.00000236
2015	7289942.00	3886.52	2009633.00	0.00000248

The table shows that as GDP (thousands of soles) increased, the water footprint associated with agricultural and livestock production and drinking water also increased, as did the water footprint of hydroelectric and thermal electricity generation and agricultural GDP in the San Martín Region.

3.5. Econometric estimation of the relationship between the water, agriculture, and energy (AAE) trilogy and economic growth in the San Martín Region

Table 4. Correlation matrix

	Correlation			
	REGIONAL_GDP	WF_AGRICULTURE	AGRICULTURAL_GDP	WF_ENERGY
REGIONAL_GDP	1.000000	0.978937	0.939686	-0.724358
WF_AGRICULTURE	0.978937	1.000000	0.930899	-0.675746
AGRICULTURAL_GDP	0.939686	0.930899	1.000000	-0.645420
WF_ENERGY	-0.724358	-0.675746	-0.645420	1.000000

The relationships between each independent variable—the water footprint of drinking water and agricultural and livestock production, San Martín agricultural GDP, and the water footprint of hydroelectric and thermal energy production—and the dependent variable, San Martín regional GDP, can be observed. Each independent variable was strongly correlated with the dependent variable. The water footprint of drinking water and agricultural and livestock production (97.89%) and San Martín agricultural GDP (93.96%) showed a direct relationship with San Martín regional GDP. In contrast, the water footprint associated with hydroelectric and thermal energy production showed an inverse or negative relationship with San Martín regional GDP, with a correlation of approximately 72.43%.

Table 5. Parameters for the equation

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1191640.	904349.7	-1.317676	0.2357
Water resource availability	1762.994	485.3936	3.632091	0.0109
Agricultural productivity	0.762466	0.730910	1.043174	0.3371
Energy supply	-7.35E+10	6.34E+10	-1.157869	0.2909
R-squared	0.970870	Mean dependent var		4893279.
Adjusted R-squared	0.956304	S.D. dependent var		1441207.
S.E. of regression	301262.6	Akaike info criterion		28.35853
Sum squared resid	5.45E+11	Schwarz criterion		28.47956
Log likelihood	-137.7926	Hannan-Quinn criter.		28.22575
F-statistic	66.65680	Durbin-Watson stat		1.660106
Prob(F-statistic)	0.000053			

Table 5 presents the parameters used to determine the equation based on the study variables.

Considering the following linear equation:

$$Y = a + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \mu$$

Where:

Y : Economic growth

$$a = - 1'191,640$$

X₁ : Water resource availability

$$\beta_1 = 1762.994$$

X₂ : Agricultural productivity

$$\beta_2 = 0.762466$$

X₃ : Energy supply

$$\beta_3 = - 73,500'000,000$$

The estimated regression equation was:

$$Y = -1'191,640 + 1,762.994 X_1 + 0.762466 X_2 - 7.35E + 10 X_3 + \mu$$

with a coefficient of determination of **0.970870** and a correlation coefficient of **0.98532**.

The regression analysis yielded a coefficient of determination of 97.09%, indicating that economic growth was largely explained by water resource availability, agricultural productivity, and energy supply. A strong relationship was also observed among these variables, as evidenced by a correlation coefficient of 0.98532 between economic growth and the variables analyzed.

The regression equation indicates that for each additional cubic hectometer of water allocated to agricultural and livestock production, economic growth would increase by 1,762.994 soles, reaffirming the importance of appropriate water management. Likewise, each additional ton of agricultural and livestock production contributes 0.762466 soles to economic growth. Regarding energy supply, the model indicates a negative effect on economic growth for each level of energy used. This finding reinforces the region's dependence on interconnected electricity systems and highlights the importance of shifting the energy supply system toward greater use of the region's own energy-generation potential. The model also indicates an autonomous effect of -1,191,640 soles on economic growth in the San Martín Region in the absence of water resource availability and agricultural and livestock production.

CONCLUSIONS

The econometric analysis demonstrated a significant relationship between water resource availability, agricultural productivity, energy supply, and economic growth in the San Martín Region during the 2006–2015 period. The statistical model yielded a coefficient of determination of 97.09%, indicating that these three variables largely explain the observed variability in economic growth. Likewise, the correlation coefficient obtained (0.98532) confirms a strong relationship among the factors analyzed, supporting the theoretical framework of the water–agriculture–energy trilogy as a basis for understanding regional economic development.

During the study period, sustained growth in agricultural GDP was observed, driven mainly by crops such as rice, banana, and oil palm. However, the water footprint analysis revealed considerable pressure on water resources, particularly from crops such as cocoa and banana, highlighting the need to implement efficient water management strategies. In addition, the progressive decline in local energy generation, combined with the limited expansion of hydroelectric sources, indicates increasing dependence on the National Interconnected Electric System (SEIN), which represents a challenge for the region's energy sustainability. These findings underscore the importance of adopting an integrated approach to water, agriculture, and energy management in order to promote a sustainable and resilient economic growth model.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to the subject matter of this study.

AUTHOR CONTRIBUTIONS

Conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, writing – original draft, and writing – review and editing: Sánchez-Dávila, K., Pezo-Carmelo, E., Arévalo-Cueva, O. A., Ríos-Lozano, K., and Landacay-Jaramillo, J. L.

REFERENCES

- Al Kez, D., Foley, A., Lowans, C., & Del Rio, D. F. (2024). Energy poverty assessment: Indicators and implications for developing and developed countries. *Energy Conversion and Management*, 307, 118324. <https://doi.org/10.1016/j.enconman.2024.118324>
- Autoridad Nacional del Agua. (2015). *Huella hídrica del Perú. Sector agropecuario*.
- Baylon Salvador, E. G., & Quispe Cusi, Y. (2023). Agricultura familiar y el desarrollo sostenible como medios de garantía para mantener la seguridad alimentaria. *Revista Alfa*, 7(20). <https://doi.org/10.33996/revistaalfa.v7i20.225>
- Benavente Cárdenas, C., Camargo Salcedo, P., Sarmiento Sarmiento, G., & Mena Chacón, L. (2018). Evaluación del desarrollo de la agricultura periurbana y propuesta de gestión integral en el distrito de Cayma, Arequipa, Perú. *Idesia (Arica), ahead*, 0–0. <https://doi.org/10.4067/S0718-34292018005001101>
- Berchoux, T., Watmough, G. R., Hutton, C. W., & Atkinson, P. M. (2019). Agricultural shocks and drivers of livelihood precariousness across Indian rural communities. *Landscape and Urban Planning*, 189, 307–319. <https://doi.org/10.1016/j.landurbplan.2019.04.014>
- Deshmukh, M. K. G., Sameeroddin, M., Abdul, D., & Abdul Sattar, M. (2023). Renewable energy in the 21st century: A review. *Materials Today: Proceedings*, 80, 1756–1759. <https://doi.org/10.1016/j.matpr.2021.05.501>
- Hamidov, A., & Helming, K. (2020). Sustainability Considerations in Water–Energy–Food Nexus Research in Irrigated Agriculture. *Sustainability*, 12(15), 6274. <https://doi.org/10.3390/su12156274>
- Hernández Sampieri, R., Fernández Collado, C., & Baptista Lucio, P. (2014). *Metodología de la investigación* (McGraw-Hill Education (ed.); Sexta Edic).
- Ijoma, G. N., Mutungwazi, A., Mannie, T., Nurmahomed, W., Matambo, T. S., & Hildebrandt, D. (2022). Addressing the water-energy nexus: A focus on the barriers and potentials of harnessing wastewater treatment processes for biogas production in Sub Saharan Africa. *Heliyon*, 8(5), e09385. <https://doi.org/10.1016/j.heliyon.2022.e09385>
- Jansen, A., Wang, R., Behrens, P., & Hoekstra, R. (2024). Beyond GDP: a review and conceptual framework for measuring sustainable and inclusive wellbeing. *The Lancet Planetary Health*, 8(9), e695–e705. [https://doi.org/10.1016/S2542-5196\(24\)00147-5](https://doi.org/10.1016/S2542-5196(24)00147-5)
- Kapur, R. (2019). Employment Opportunities in Rural Areas. *Acta Scientific Agriculture*, 3(8), 58–65. <https://doi.org/10.31080/ASAG.2019.03.0564>
- Koop, S. H. A., Grison, C., Eisenreich, S. J., Hofman, J., & van Leeuwen, K. (2022). Integrated water resources management in cities in the world: Global solutions. *Sustainable Cities and Society*, 86, 104137. <https://doi.org/10.1016/j.scs.2022.104137>
- Lalawmpuii, & Rai, P. K. (2023). Role of water-energy-food nexus in environmental management and climate action. *Energy Nexus*, 11, 100230. <https://doi.org/10.1016/j.nexus.2023.100230>
- Nguyen, T. P. L., Virdis, S. G. P., & Vu, T. B. (2023). “Matter of climate change” or “Matter of rapid urbanization”? Young people’s concerns for the present and future urban water resources in Ho Chi Minh City metropolitan area, Vietnam. *Applied Geography*, 153, 102906. <https://doi.org/10.1016/j.apgeog.2023.102906>
- Nhamo, L., Mpandeli, S., Liphadzi, S., & Mabhaudhi, T. (2025). Catalyzing sustainable development goals through the water-energy-food nexus. *IScience*, 28(2), 111902. <https://doi.org/10.1016/j.isci.2025.111902>

- Nieuwenhuijsen, M. J. (2020). Urban and transport planning pathways to carbon neutral, liveable and healthy cities; A review of the current evidence. *Environment International*, 140, 105661. <https://doi.org/10.1016/j.envint.2020.105661>
- Patiño-Ramírez, S., & Valiente-Saldaña, Y. M. (2023). Identificación de factores que determinan el desarrollo rural en comunidades campesinas, 2018-2023: Revisión sistemática. *Revista Arbitrada Interdisciplinaria Koinonía*, 8(1), 242–256. <https://doi.org/10.35381/r.k.v8i1.2783>
- Pawlak, K., & Kołodziejczak, M. (2020). The Role of Agriculture in Ensuring Food Security in Developing Countries: Considerations in the Context of the Problem of Sustainable Food Production. *Sustainability*, 12(13), 5488. <https://doi.org/10.3390/su12135488>
- Weishaupt, A., Ekardt, F., Garske, B., Stubenrauch, J., & Wieding, J. (2020). Land Use, Livestock, Quantity Governance, and Economic Instruments—Sustainability Beyond Big Livestock Herds and Fossil Fuels. *Sustainability*, 12(5), 2053. <https://doi.org/10.3390/su12052053>
- Yano, S., Hanasaki, N., Itsubo, N., & Oki, T. (2015). Water Scarcity Footprints by Considering the Differences in Water Sources. *Sustainability*, 7(8), 9753–9772. <https://doi.org/10.3390/su7089753>