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ORIGINAL

Renewable Energy and the Utilization of Agricultural Waste in Chiclayo

Energía renovable y utilización de residuos agrícolas in Chiclayo

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ABSTRACT

In the current context of growing dependence on sustainable energy sources, this study assesses the viability of using agricultural waste as a source of renewable energy in Chiclayo. It analyzes how by products such as rice husks can contribute both economically and environmentally by preventing burning those releases greenhouse gases. The methodology included surveys of residents in the Chiclayo district, involved in agriculture and renewable energy management, using a quantitative approach to establish correlations between the use of agricultural waste and the production of renewable energy. The results showed that there is a significant positive correlation between the level of utilization of agricultural waste and the generation of renewable energy. It is concluded that agricultural waste represents an underutilized resource with significant potential to generate clean energy, promoting sustainability and reducing dependence on fossil fuels. The implementation of policies that support the conversion of this waste into energy is recommended, providing a regulatory and financial framework that facilitates this transition.

Keywords: Renewable Energy; Agricultural; Waste; Environment; Biomass.

RESUMEN

En el contexto actual de creciente dependencia de las fuentes de energía sostenible, este estudio evalúa la viabilidad de utilizar los residuos agrícolas como fuente de energía renovable en Chiclayo. Analiza cómo los subproductos, como la cascarilla de arroz, pueden contribuir tanto económica como medioambientalmente al evitar la quema que libera gases de efecto invernadero. La metodología incluyó encuestas a residentes del distrito de Chiclayo, involucrados en la agricultura y la gestión de energías renovables, utilizando un enfoque cuantitativo para establecer correlaciones entre el uso de residuos agrícolas y la producción de energía renovable. Los resultados mostraron que existe una correlación positiva significativa entre el nivel de utilización de residuos agrícolas y la generación de energía renovable. Se concluye que los residuos agrícolas representan un recurso infrautilizado con un potencial significativo para generar energía limpia, promoviendo la sostenibilidad y reduciendo la dependencia de los combustibles fósiles. Se recomienda la implementación de políticas que apoyen la conversión de estos residuos en energía, proporcionando un marco regulatorio y financiero que facilite esta transición.

Palabras clave: Energía Renovable; Agricultura; Residuos; Medio Ambiente; Biomasa.

INTRODUCTION

In recent years, a growing interest in the adoption of renewable energies has been observed in Peru, particularly through projects involving solar photovoltaic and wind energy; this trend is primarily driven by the high cost of conventional fuels, such as oil and electricity. However, it is crucial to recognize that numerous agricultural enterprises generate organic waste that holds considerable potential as a source of renewable energy. This research proposes the use of agricultural waste, such as rice husks, to capitalize on the economic and environmental benefits associated; this proposal includes preventing these wastes from being discarded or sold at prices that do not reflect their true energy value.

Internationally, it has been noted that in Ecuador, agriculture is a key piece in the national economy, contributing significantly to the Gross Domestic Product (GDP) and supporting the income of over 25 % of the population. Despite its importance, this activity is also one of the major emitters of atmospheric pollutants in the country; it is estimated that, in Ecuador, the release of harmful gases, such as carbon dioxide (CO2), reaches nearly 160 million tons annually, representing approximately 28 % of the total greenhouse gas emissions; a significant proportion of these emissions comes from the burning and degradation of agricultural waste. Faced with this challenge, there emerges an opportunity to use these residues as an energy source. Initially, this could achieve a substantial reduction of greenhouse gases generated by the combustion and decomposition of agricultural waste, thus promoting the production of renewable energy and decreasing the dependency on fossil fuels.[1]

In Colombia, rice production continues to increase, which leads to an increase in the generation of by products such as rice husk, a result of the rice polishing process. Currently, rice husk is recognized to have great potential as an alternative energy source, used for the production of heat, steam, and electricity. Considering that both in Colombia and globally, the energy matrix is predominantly based on fossil fuels, it is crucial to implement measures that promote the transition to renewable energy sources. The introduction of energy generation alternatives in Colombia allows for diversifying primary energy sources, offering options largely independent of conventional fuels; thus, rice husk represents an opportunity with significant advantages and considerable potential for this nascent industry.[2]

Velázquez Contreras et al.[3] indicate that, globally and particularly in the Caribbean region, the implementation of an integrated approach to waste management, with a special emphasis on agricultural waste, is imperative. Consequently, the scientific community faces the pressing challenge of developing technologies that allow for more efficient use of renewable energy sources at reduced costs and that facilitate access to by products with utilizable potential.

The predominant practice among farmers of burning straw in the fields leads to the emission of high amounts of carbon dioxide (CO2) into the atmosphere. Moreover, incorporating straw into the soil triggers natural decomposition processes that release methane, among other gases. In a context of growing concern for the energy and environmental situation, biogas technology emerges as a flexible source of renewable energy. This technology allows the substitution of fossil fuels in the generation of energy and heat, and more recently, as fuel for vehicles; using agroindustrial residues and urban solid wastes as raw materials, the by products of the process are converted into highquality stable sludges, usable as biofertilizers.[3]

Nationally, Aldana et al.[4] highlight that abundant and widely harvested crop, such as sugarcane, rice husk, and corn residues, have significant capacity to be used in renewable energy generation. These crops have a notable presence in the coastal area, making this region a prominent source of residual biomass with energy potential.

Huaytalla Galindo[5] pointed out that residual biomass, a frequent by product of agricultural harvests, is a reality in various regions of the country; this phenomenon has captured considerable attention due to its high energy potential and as it represents a source of utility for residents lacking access to basic services such as electricity or heating.

Gil Mullisaca et al.[6] emphasize the importance of conducting a life cycle analysis of renewable energies, especially in the context of biofuels. This approach allows measuring the environmental implications associated with all stages of product development, as well as evaluating the environmental effects generated by bioenergy production in various geographical locations of the country using agricultural residues.

In the Lambayeque region, Sanchez Loli reports that renewable energy systems are scarce and are mainly located in rural areas where electrical service has not yet arrived. The goal is to expand the presence of renewable energy systems throughout the region due to the high cost of conventional fuels, such as oil and electric energy, especially in agroindustrial plants that can utilize agricultural waste to produce biomass usable as fuel.[7]

It is also highlighted that a wide range of biomass is available that can be converted into renewable energy. This biomass varies from solid wastes to specific crops like sugarcane and rice. Through advanced techniques such as pyrolysis, gasification, hydrothermal processes, and carbonization, it is possible to obtain energy from this diverse organic matter, providing a reliable alternative in the face of potential fluctuations in the availability of other renewable energies such as photovoltaic solar, thermal solar, and wind.[8]

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Similarly, we must also consider as a reference other regions that present similar characteristics and equivalent needs to generate, according to research, the necessary tools to maximize the use of agricultural waste and convert it into renewable energy. Our region, which significantly contributes to environmental pollution through the burning of agricultural waste like rice straw, could utilize these residues as biomass and, in turn, as a source of renewable energy.[9]

After developing the problematic reality, the following general question is established: What is the relationship between renewable energy and the utilization of agricultural waste in Chiclayo, 2023? And as specific research questions: (1) What is the relationship between the dimension of biomass as a source of renewable energy and the environmental dimension of the utilization of agricultural waste in Chiclayo, 2023? (2) What is the relationship between the dimension of solar panels as a source of renewable energy and the agronomic dimension of the utilization of agricultural waste in Chiclayo, 2023? (3) What is the relationship between the dimension of energy saving as a component of renewable energy and the dimension of the type of residue in the utilization of agricultural waste in Chiclayo, 2023?

The research aspires to contribute to the study, debate, and academic reflection about the challenges posed by the use of renewable systems in the Chiclayo region for the year 2023. The project focuses on a sustainable approach to energy acquisition, aiming to determine the best option and develop a feasibility study for the use of agricultural waste in the generation of renewable electrical energy. These wastes can be employed in various ways to produce renewable energy, thus enhancing their energy value and sustainability.[10]

The research also presents a practical justification; it is expected to contribute significantly to the analysis, conclusions, and results related to the specific issue of medium and small agricultural estates. The knowledge generated could be applied effectively and transparently in these estates, as well as in other similar plots or institutions, contributing to analogous studies and facilitating the search for practical solutions to maximize the utilization of agricultural waste.[11,12]

From a methodological perspective, the research focuses on technology, adopting procedures and standards that are designed to achieve our objectives efficiently. This work incorporates the standardization of procedures and offers a thorough analysis of the problem from its inception to its resolution. The approach adopted in this study is a literature review, grounded on a series of systematic searches with variations in the terminology used, which ensures a deep and uptodate understanding of the subject matter.[13]

The objective presented is to determine the relationship between renewable energy and the utilization of agricultural waste in Chiclayo, 2023. Furthermore, the specific objectives are as follows: (1) Analyze the relationship between the dimension of biomass as a source of renewable energy and the environmental dimension of the utilization of agricultural waste in Chiclayo, 2023. (2) Analyze the relationship between the dimension of solar panels as a source of renewable energy and the agronomic dimension of the utilization of agricultural waste in Chiclayo, 2023. (3) Analyze the relationship between the dimension of energy saving as a component of renewable energy and the dimension of the type of residue in the utilization of agricultural waste in Chiclayo, 2023.

The study posits as a general hypothesis that renewable energy is significantly related to the utilization of agricultural waste in Chiclayo, 2023. Additionally, as specific hypotheses: HE1. The dimension of biomass as a source of renewable energy is significantly related to the environmental dimension of the utilization of agricultural waste in Chiclayo, 2023. HE2. The dimension of solar panels as a source of renewable energy is significantly related to the agronomic dimension of the utilization of agricultural waste in Chiclayo, 2023. HE3. The dimension of energy saving as a component of renewable energy is significantly related to the dimension of the type of residue in the utilization of agricultural waste in Chiclayo, 2023. This study will be verified with the use of statistical techniques and instruments. The results achieved will provide us with sufficient information to generate renewable energy by taking advantage of agricultural waste.

Literature review

Renewable energy, derived from inexhaustible natural sources such as the sun, wind, water, and biomass, offers a more sustainable alternative with lower environmental impact compared to nonrenewable energy sources like fossil fuels. Agricultural waste, including crop residues and organic materials, is properly managed to generate renewable energy and reduce greenhouse gas emissions.

Internationally, the transition towards renewable energy sources has been prioritized as a key strategy to combat climate change. The increase in energy production from renewable sources is crucial to keep global warming within safe limits. Germany and Denmark stand out as leaders in this process, thanks to their policies and technologies that promote the adoption of clean energies.

In the last decade, the capacity to generate energy from renewable sources has surpassed that of nonrenewables, marking a significant milestone in the energy transition. Countries like China play a vital role in this advancement, leading global investments in renewable energies.

Kazimierski[14] emphasizes that the responsible management of agricultural waste has become a central concern both in the energy and environmental fields. In Brazil, for example, the production of biogas from these wastes offers great prospects.

In Peru, the promotion of renewable energies is essential to ensure sustainability in the energy sector and to reduce greenhouse gas emissions. The National Energy Plan 2014-2025 emphasizes the importance of diversifying the energy matrix by integrating clean and sustainable sources.[15]

The management of agricultural waste is a growing concern in Peru. The Ministry of Agriculture and Irrigation (MINAGRI) has stressed the importance of implementing effective strategies for the collection and utilization of these residues, not only to promote agricultural sustainability but also to use them as a resource in generating renewable energy.[16]

The "Sustainable Energy for All" program of the Ministry of Energy and Mines (MINEM) in Peru seeks to promote access to sustainable energy sources and strengthen energy security at the national level; this reflects the country's commitment to a more sustainable and equitable energy model.[17]

In Chiclayo, the promotion of renewable energies is a priority to foster sustainability and mitigate the negative impact on the environment. Guzman[18] highlights the importance of integrating clean technologies and encouraging the adoption of renewable energies in the region, underlining the local commitment to a sustainable energy transition, especially in the agricultural sector.

The management of agricultural waste in Chiclayo is key in the search for energy and environmental solutions; the implementation of projects that utilize these residues to generate renewable energy can significantly contribute to the agricultural and energy sustainability of the region.[19]

The adoption of renewable energy in Chiclayo aligns with the sustainable development goals at the local level. Arroyo et al.[9] indicate that the promotion of sustainable energy sources and the optimization of the use of agricultural resources are key pillars in the city's energy planning, demonstrating Chiclayo's commitment to a more sustainable and resilient future.

METHOD

Research type and design

The methodological approach selected for this study on renewable energy and the utilization of agricultural waste in Chiclayo was applied in nature. Applied research is oriented toward providing solutions to specific problems or the practical application of knowledge; this type of research is active and focuses on generating knowledge that is directly applicable in reallife situations[20] which was essential for our objective of not only understanding the dynamics between renewable energy and agricultural waste but also applying this knowledge effectively to improve management practices in Chiclayo.

A nonexperimental design was chosen because it allowed for the analysis of the relationship between renewable energy and the utilization of agricultural waste in their natural state, without manipulations or interventions. As described by Kerlinger et al.[21], in this type of research, variables are not deliberately manipulated nor are subjects randomly assigned to different conditions. This approach allows for the observation of the interactions of variables in their original context, without altering existing conditions.

Additionally, a crosssectional approach was adopted, essential for capturing a current view of the conditions and perceptions in Chiclayo during the year 2023. This method, according to Polit et al.[22], involves collecting data at a single point in time, allowing for an "instantaneous snapshot" of the phenomenon under study, which is very effective for assessing situations and formulating policies based on current data.

The study also classified at a correlational level, aiming to identify significant relationships between the use of renewable energy and the utilization of agricultural waste. Correlational research examines the relationships between two or more variables to determine if there is an association between them, which is useful for identifying patterns of relationship without inferring direct causality.[23]

Finally, a quantitative approach was implemented, necessary for measuring and analyzing the relationships between the mentioned variables numerically. This approach provided a solid basis for rigorous statistical analysis, allowing for objective and precise evaluation of interactions. The quantitative approach is ideal for collecting and analyzing numerical data, using statistical methods to understand patterns and relationships and reach objective conclusions.[20]

Population, sample, sampling and unit of analysis

The target population for this study encompassed the residents of the Chiclayo district, Peru, especially those involved in agriculture and the management or use of renewable energies. The population is the total group from which study subjects are selected and on which findings are intended to be generalized. Identifying this population is fundamental for understanding local and regional interactions in the context of renewable energy and agricultural waste management.[24]

The inclusion criteria focused on individuals residing in the Chiclayo district with specific technical knowledge in biomass, solar panels, and energy saving. Specifically, those directly involved in agricultural activities or in the management and use of renewable energies who were willing to actively participate in the research by providing data relevant for quantitative analysis.

Conversely, the exclusion criteria eliminated residents outside the Chiclayo district, those lacking specific technical knowledge in renewable energy and agricultural waste management, those unwilling to collaborate or provide necessary information for the study, and those who do not participate in agricultural activities nor in the management and use of renewable energies.

As explained by Trochim and Donnelly, the sample is a selected part of the total population that participates in a study. For this study, a sample of 30 people was selected through convenience sampling, a type of nonprobabilistic sampling where participants are chosen based on their accessibility and availability. Although this method may limit the ability to generalize the results to the entire population, it is a practical and efficient option for studies with limited resources and time, and is particularly useful in exploratory or preliminary studies where an initial understanding of trends and relationships between variables is sought.[25]

The unit of analysis is the basic element from which information is collected and on which analysis is focused.[26] In this study, the unit of analysis were the residents of the Chiclayo district involved in agricultural activities or in the management and use of renewable energies. This selection was justified by the importance of understanding the attitudes and perceptions of these individuals regarding renewable energy and agricultural waste management, key elements for assessing the relationship between these variables. By focusing on these individuals, the study was able to obtain detailed and specific information, crucial for achieving the research objectives.

Data collection techniques and instruments, validity and reliability

The primary data collection technique used in this research was the survey. The survey is a method that involves requesting information from a sample of individuals through questionnaires, which can be structured or semistructured; this systematic approach allows for data collection from a specific population and analysis of the responses to deduce conclusions about the group as a whole.[27] The decision to use surveys was based on their effectiveness in collecting a large amount of information over a relatively short period and their ability to facilitate the quantitative analysis of data, crucial aspects for identifying trends and correlations relevant to the research objectives.

For this study, a questionnaire distributed via Google Forms was used, consisting of two sections focused on the study variables, with a total of 18 items per section. The choice of Google Forms was due to its accessibility and ease of use for both researchers and participants, which promotes broad participation and efficient data collection. The questionnaire was carefully designed to collect detailed and specific information on each variable, allowing for a deep and accurate analysis of the relationships and perceptions related to renewable energy and agricultural waste management.

The questionnaire is effective for collecting both quantitative and qualitative data, offering a variety of response types, from closed options to open responses. It is crucial that its design be meticulous to ensure the validity and reliability of the responses, key elements for the accuracy of the collected data.[28]

La The validity of the instrument was ensured through the review by three experts in the field, who evaluated each item of the questionnaire to confirm that the questions were relevant, clear, and suitable for measuring the concepts associated with each study variable. This collaboration was essential for reinforcing the content validity of the instrument, ensuring that the items fully covered the fundamental aspects of renewable energy and the utilization of agricultural waste.

To ensure the reliability of the questionnaire, a scale with a considerable number of items that demonstrated a reliability value of 0,953, as shown in figure 1, was used. This high level of reliability is crucial for sustaining the validity of the results obtained, allowing the study to accurately reflect the investigated phenomenon.

Cronbach's Alpha	Number of Items
,953	36

Figure 1. Reliability Statistics for Study Variables

Procedures

The process of this research began with the meticulous design of two distinct questionnaires, one for each study variable: renewable energy and agricultural waste utilization, with 18 items each. These questionnaires were created to collect detailed and relevant information about the respondents' perceptions, attitudes, and knowledge regarding the mentioned variables.

To validate these instruments, collaboration from three experts in the field of renewable energy and agricultural waste management was enlisted. This expert review ensured that the questions were pertinent and appropriate for the topics studied. Subsequently, a pilot test was conducted with a sample of 10 people from the target population to assess the reliability of the questionnaire and make necessary adjustments based on feedback received.

The data collection phase began with the distribution of the final questionnaires using Google Forms, facilitating their distribution and access to the selected participants. Thirty participants were chosen through convenience sampling, ensuring they met the defined inclusion criteria. During a set period, responses were actively collected, paying special attention to the response rate and the quality of the data obtained.

Once data collection was completed, the analysis of the collected information commenced. First, the database was structured using Microsoft Excel. Subsequently, statistical analysis was performed using SPSS V26, evaluating trends, patterns, and relationships among the study variables. This quantitative analysis was conducted using appropriate statistical tools to ensure the accuracy and relevance of the results.

The results of this analysis were fundamental for the preparation of the final research report. This report presented in detail the findings, conclusions, and recommendations, based on the objectives and research questions posed at the beginning of the study.

Ethical aspects

In the development of this study, meticulous attention was given to several ethical aspects to ensure the protection and respect of the participants' rights.

Before their inclusion in the study, participants were provided with clear and detailed information about the purpose of the research, the nature of their participation, and the handling and use of the collected data. Informed consent was obtained from each one, ensuring that their participation was voluntary and based on a complete and accurate understanding of what the research entailed.

Anonymity and confidentiality of the participants were maintained at all times. The data collected, whether through Google Forms or other means, were treated with the highest confidentiality. No report or publication disclosed names or any other information that could directly identify the individuals involved.

The research team committed to using the data exclusively for the purposes of the study. Access to the data was restricted to those not involved in the research and was protected against any unauthorized access or improper disclosure.

Special care was taken to ensure that the research did not harm the participants. It was assessed that the potential benefits of the study, such as the contribution to knowledge in the field of renewable energy and agricultural waste management, adequately compensated for any risks or inconvenience that might arise during the research.

A stance of transparency and accountability was adopted throughout all phases of the research. This included a willingness to share the study's results with the participants and the scientific community, as well as the responsibility to report the findings honestly and accurately

RESULTS

Regarding the descriptive results of the research, they were analyzed according to the distribution of each variable and their respective dimensions. Subsequently, they were related according to the general and specific objectives in a crosstabulation table.

Figure 2 presents a rating scale for renewable energy, detailing its different dimensions and corresponding scores. This scale is designed to measure various dimensions related to renewable energy, including biomass, solar panels, and energy saving, each with a score range varying from 6 to 30. These ranges are divided into three levels: low, medium, and high. For the overall variable of "Renewable Energy," the score range is broader, ranging from 18 to 90. The levels for this variable are defined as follows: a score of 18 to 41 is considered low, 42 to 65 as medium, and 66 to 90 as high.

Variables and Dimensions	Scores		Levels		
	Minimum	Maximum	Low	Medium	High
Renewable Energy	18	90	18-41	42-65	66-90
Biomass	6	30	6-13	14-21	22-30
Solar Panels	6	30	6-13	14-21	22-30
Energy Saving	6	30	6-13	14-21	22-30

Figure 2. Rating Scale for Renewable Energy Variable with Its Dimensions

Figure 3 provides a detailed analysis of the distribution of responses for the variable "renewable energy," categorized into three levels: low, medium, and high. Out of a total of 30 responses, 6 (20 %) were classified in the low level, indicating that onefifth of the participants or units of analysis evaluated renewable energy at this level. The medium category, on the other hand, recorded the highest frequency with 19 responses,

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representing 63,3 % of the total. This suggests that the majority of participants or units of analysis perceived renewable energy at a medium level. Finally, 5 responses (16,7 %) were placed in the high level, completing the dataset.

		Frequency	Percentage	Valid Percentage	Cumulative Percentage
Valid	Low	6	20,0	20,0	20,0
	Medium	19	63,3	63,3	83,3
	High	5	16,7	16,7	100,0
	Total	30	100,0	100,0	

Figure 3. Distribution of Variable 1 Renewable Energy

Figure 4 displays the distribution of dimensions for the variable "renewable energy," which includes biomass, solar panels, and energy saving, broken down into three assessment levels: low, medium, and high. Each dimension has a total of 30 responses, distributed among these levels. For the biomass dimension, 6 responses (20 %) were classified as low, 15 (50 %) as medium, and 9 (30 %) as high. This indicates that the majority of responses were located at the medium level, with a relatively balanced distribution between the low and high levels. In the solar panels dimension, 8 responses (26,7 %) were classified at the low level, 12 (40 %) at the medium level, and 10 (33,3 %) at the high level. This pattern shows a more uniform distribution among the three levels, although with a slight predominance of the medium level. Regarding energy saving, 4 responses (13,3 %) were placed in the low level, 18 (60 %) in the medium level, and 8 (26,7 %) in the high level. Here, the majority of responses lean towards the medium level, with a significantly lower proportion in the low level and a moderate proportion in the high level.

	Low		Medium		High		Total	
	N	%	N	%	N	%	N	%
Biomass	6	20	15	50	9	30	30	100%
Solar Panels	8	26,7	12	40	10	33,3	30	100%
Energy Saving	4	13,3	18	60	8	26,7	30	100%

Figure 4. Distribution of Dimensions for Variable 1 Renewable Energy

Variables and Dimensions	Scores		Levels		
	Minimum	Maximum	Bajo	Minimum	Maximum
Utilization of Agricultural Waste	18	90	18-41	42-65	66-90
Environmental	6	30	6-13	14-21	22-30
Agronomic	6	30	6-13	14-21	22-30
Type of Waste	6	30	6-13	14-21	22-30

Figure 5. Rating Scale for Solid Waste Utilization Variable with Respective Dimensions

In figure 5, a rating scale for the variable "solid waste utilization" is detailed, specifying its dimensions and corresponding score ranges and levels. The main variable is "Utilization of Agricultural Waste," with a score range from 18 to 90. This range is divided into three levels: low (18-41), medium (42-65), and high (66-90), providing a clear structure for evaluating the utilization of agricultural waste. Additionally, three specific dimensions related to this variable are identified: Environmental, Agronomic, and Type of Waste. Each of these dimensions has an identical score range, ranging from 6 to 30. For each dimension, the low level is defined with scores from 6 to 13, the medium level from 14 to 21, and the high level from 22 to 30.

Figure 6 presents the distribution of the variable “solid waste utilization,” categorized into three levels: low, medium, and high. It also displays the frequency and corresponding percentages of each level, along with the cumulative percentage. Out of a total of 30 responses, 7 (23,3 %) were classified in the low level, indicating that approximately a quarter of the participants or units of analysis evaluated solid waste utilization as low. The majority of responses, 18 (60 %), were located in the medium level; this suggests that a significant proportion perceives solid waste utilization at a medium level. Additionally, 5 responses (16,7 %) were classified in the high level. The cumulative percentage increases consistently: it starts at 23,3 % for the low level, rises to 83,3 % with the inclusion of the medium level, and finally reaches 100 % when adding the high level.

		Frequency	Percentage	Valid Percentage	Cumulative Percentage
Valid	Low	7	23,3	23,3	23,3
	Medium	18	60,0	60,0	83,3
	High	5	16,7	16,7	100,0
	Total	30	100,0	100,0	

Figure 6. Distribution of Dimensions for Variable 2 Solid Waste Utilization

Figure 7 depicts how responses are distributed for the different dimensions of the variable “solid waste utilization,” including environmental aspects, agronomic aspects, and type of waste. Each dimension is assessed at three levels: low, medium, and high, with a total of 30 responses for each dimension. In the environmental dimension, 4 responses (13,3 %) were classified as low, 16 (53,3 %) as medium, and 10 (33,3 %) as high; this indicates that the majority of responses were concentrated at the medium level, with a significant proportion also at the high level and a lesser representation at the low level. For the agronomic dimension, 8 responses (26,7 %) were placed in the low level, 17 (56,7 %) in the medium level, and 5 (16,7 %) in the high level; similar to the environmental dimension, the majority of responses clustered at the medium level, although with a higher representation at the low level and a lower one at the high level compared to the environmental dimension. Regarding the type of waste dimension, 9 responses (30 %) were categorized in the low level, 15 (50 %) in the medium level, and 6 (20 %) in the high level; this distribution shows the highest proportion of responses at the medium level among the three dimensions, and, like the others, the majority of responses are situated at the medium level.

	Low		Medium		High		Total	
	N	%	N	%	N	%	N	%
Teams and protection	4	13,3	16	53,3	10	33,3	30	100%
Pollution and awareness	8	26,7	17	56,7	5	16,7	30	100%
Pollutants at risk of	9	30	15	50	6	20	30	100%

Figure 7. Distribution of Dimensions for Variable 2 Solid Waste Utilization

Figure 8 presents the crosstabulation of the variables “renewable energy” and “solid waste utilization,” showing how responses are distributed based on these two aspects. For renewable energy at the low level, 5 responses correspond to low solid waste utilization, none to medium, and 1 to high, totaling 6 responses. In the medium level of renewable energy, 2 responses correspond to low solid waste utilization, 16 to medium, and 1 to high, totaling 19 responses. In the high level of renewable energy, there are no responses corresponding to low solid waste utilization, 2 to medium, and 3 to high, for a total of 5 responses. In the totals row, it is observed that 7 responses were classified in the low level of solid waste utilization, 18 in the medium, and 5 in the high, totaling 30 responses.

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		Solid Waste Utilization			
		Low	Medium	High	Total
Renewable Energy	Low	5	0	1	6
	Medium	2	16	1	19
	High	0	2	3	5
Total		23	7	18	5

Figure 8. Two-dimensional Table of Variables Renewable Energy and Solid Waste Utilization

Figure 9 shows the crosstabulation of the dimension's "biomass" and "environmental," both related to renewable energy and solid waste utilization. For the biomass dimension at the low level, 2 responses align with a low level in environmental, 3 with a medium level, and 1 with a high level, totaling 6 responses. For the medium level of biomass, 2 responses align with a low level in environmental, 8 with the medium level, and 5 with the high level, totaling 15 responses. In the high level of biomass, there are no responses that align with a low level in environmental, but 5 are associated with the medium level and 4 with the high level, for a total of 9 responses. The totals per row indicate that 4 responses were classified in the low level of environmental, 16 in the medium, and 10 in the high, reaching a total of 30 responses.

		Environmental			
		Low	Medium	High	Total
Biomass	Low	2	3	1	6
	Medium	2	8	5	15
	High	0	5	4	9
Total		5	4	16	10

Figure 9. Cross-Tabulation Table of Dimensions Biomass - Environmental

Figure 10 presents the crosstabulation relating the dimensions of "solar panels" and "agronomic," both belonging to the broader category of renewable energy and solid waste utilization. In the solar panels dimension at the low level, 5 responses align with a low level in agronomic, 2 with a medium level, and 1 with a high level, totaling 8 responses. For the medium level of solar panels, 1 response aligns with a low level in agronomic, 10 with the medium level, and 1 with the high level, totaling 12 responses. In the high level of solar panels, 2 responses align with a low level in agronomic, 5 with the medium level, and 3 with the high level, for a total of 10 responses. The totals per row show that 8 responses were classified in the low level of agronomic, 17 in the medium, and 5 in the high, reaching a total of 30 responses.

		Agronomic			
		Low	Medium	High	Total
Panels	Low	5	2	1	8
	Medium	1	10	1	12
	High	2	5	3	10
Total		5	8	17	5

Figure 10. Cross-Tabulation Table of Dimensions Solar Panels - Agronomic

Figure 11 illustrates the relationship between the dimensions of "energy saving" and "type of waste," both associated with energy and waste management. In the energy saving dimension at the low level, all 4 responses align with a low level in type of waste, with no responses in the medium or high levels. For the medium level of energy saving, 4 responses align with a low level in type of waste, 11 with a medium level, and 3 with a high level, totaling 18 responses. In the high level of energy saving, there is 1 response aligning with a low level in type of waste, 4 with a medium level, and 3 with a high level, summing up to a total of 8 responses. The totals indicate that 9 responses were classified in the low level of type of waste, 15 in the medium, and 6 in the high, completing a total of 30 responses.

		Type of Waste			
		Low	Medium	High	Total
Energy Saving	Low	4	0	0	4
	Medium	4	11	3	18
	High	1	4	3	8
Total		4	9	15	6

Figure 11. Cross-Tabulation Table of Dimensions Energy Saving - Type of Waste

Figure 12 presents the results of the Shapiro-Wilk normality test for the variables and their dimensions related to renewable energy and solid waste utilization. For each variable and dimension, the Shapiro-Wilk statistic, degrees of freedom (df), and significance value (Sig.) are provided. In all cases, the degrees of freedom are 30, and the significance value is 0,000; consequently, the alternative hypothesis that the figures do not follow a normal distribution is accepted.

	Shapiro-Wilk		
	Statistic	gl	Sig.
Renewable energy	,772	30	,000
Biomass	,807	30	,000
Solar panels	,807	30	,000
Energy saving	,778	30	,000
Solid waste utilization	,785	30	,000
Environmental	,789	30	,000
Agronomic	,794	30	,000
Type of waste	,807	30	,000

Figure 12. Normality Test of Variables and Their Dimensions

			Renewable energy	Solid waste utilization
Spearman's Rho	Renewable energy	Correlation coefficient	1,000	,614**
		Sig. (two-tailed)	.	,000
		N	30	30
	Solid waste utilization	Correlation coefficient	,614**	1,000
		Sig. (two-tailed)	,000	.
		N	30	30

Figure 13. General Hypothesis Test

Figure 13 displays the results of a Spearman correlation test (Spearman's Rho) between the variables "renewable energy" and "solid waste utilization." In this case, the pvalue of 0,000 is less than 0,05, leading to the rejection of the null hypothesis (H0) and acceptance of the alternative hypothesis (H1). The correlation coefficient of 0,614 indicates a moderate positive correlation between the two variables. This means that, in the context of this study, as the level of renewable energy increases, the level of solid waste utilization also tends to increase, or vice versa. The statistical significance of this relationship suggests that this result is

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unlikely to be a coincidence.

Figure 14 presents the results of a Spearman correlation test between the dimensions of "biomass" as a source of renewable energy and the "environmental" dimension of agricultural waste utilization. In this case, the pvalue of 0,103 is greater than 0,05. Therefore, the null hypothesis (H0) is accepted, and the alternative hypothesis (H1) is rejected. This means that there is not enough evidence to claim that there is a significant relationship between the biomass dimension as a source of renewable energy and the environmental dimension of agricultural waste utilization in Chiclayo, 2023. The weak correlation of 0,303 suggests that, while there is a positive relationship, it is not strong enough to be considered significant in the context of this study.

			Biomass	Environmental
Spearman's Rho	Biomass	Correlation coefficient	1,000	,303
		Sig. (two-tailed)	.	,103
		N	30	30
	Environmental	Correlation coefficient	,303	1,000
		Sig. (two-tailed)	,103	.
		N	30	30

Figure 14. Specific Hypothesis Test 1

Figure 15, the results of a Spearman correlation test between the dimensions of "solar panels" as a source of renewable energy and the "agronomic" dimension of agricultural waste utilization are displayed. In this case, the pvalue of 0,062 is greater than 0,05. Therefore, the null hypothesis (H0) is accepted, and the alternative hypothesis (H1) is rejected. This means that, according to these data, there is not enough evidence to claim that there is a significant relationship between the dimension of solar panels as a source of renewable energy and the agronomic dimension of agricultural waste utilization in Chiclayo, 2023. The correlation coefficient of 0,344 indicates a positive relationship between the dimensions, but this relationship is not strong enough to be statistically significant in this context.

			Solar panels	Agronomic
Spearman's Rho	Solar panels	Correlation coefficient	1,000	,344
		Sig. (two-tailed)	.	,062
		N	30	30
	Agronomic	Correlation coefficient	,344	1,000
		Sig. (two-tailed)	,062	.
		N	30	30

Figure 15. Specific Hypothesis Test

Figure 16, the results of the Spearman correlation test are presented to analyze the relationship between the "energy saving" dimension as a component of renewable energy and the "type of waste" dimension in agricultural waste utilization. In this case, the pvalue of 0,007 is less than 0,05. Therefore, the null hypothesis (H0) is rejected, and the alternative hypothesis (H1) is accepted. This implies that there is enough evidence to claim that there is a significant relationship between the energy saving dimension as a component of renewable energy and the type of waste dimension in agricultural waste utilization in Chiclayo, 2023. The correlation coefficient of 0,484 suggests that there is a moderate positive association between these two dimensions, meaning that changes or variations in one dimension tend to be associated with changes or variations in the other.

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			Energy saving	Type of waste
Spearman's Rho	Energy saving	Correlation coefficient	1,000	,484**
		Sig. (two-tailed)	.	,007
		N	30	30
	Type of waste	Correlation coefficient	,484**	1,000
		Sig. (two-tailed)	,007	.
		N	30	30

Figure 16. Specific Hypothesis Test 3

DISCUSSION

In the study conducted in Chiclayo during 2023, a significant relationship was observed between the categories "renewable energy" and "agricultural waste utilization," with medium and high levels respectively, of 63,3 % and 60 %. These findings, when contrasted with ideas presented by Vega Quezada[29], highlight the beneficial interaction between agriculture and bioenergy as strategies for territorial development, especially in the binational region between Peru and Ecuador. Between 2016 and 2028, these synergies are suggested to potentially produce considerable economic benefits for both the private and public sectors, as well as significant environmental improvements by reducing CO2 emissions and creating jobs, thereby contributing to the reduction of poverty in the affected areas. These results underscore the importance of advancing technologies for the production of biofuels and developing innovative strategies that convert waste into useful byproducts, aligned with the principles of the circular economy.

Rincón Martínez et al.[30] emphasize the need for any energy generation project using energy crops to consider sustainability requirements and access to necessary technology. The combination of renewable energy and the utilization of agricultural waste is emerging as a global strategy to confront energy and environmental challenges, suggesting research that fosters awareness and effective implementation towards a more sustainable future.

Regarding the first specific objective of analyzing the relationship between biomass as a source of renewable energy and the environmental dimension of agricultural waste utilization, the hypothesis testing results indicated that there is insufficient evidence to assert a significant relationship. This suggests that other factors may be influencing this phase.

From the perspective of López[31] the use of agricultural biomass is seen as a friendly and sustainable process that takes advantage of a variety of forest and agricultural residues, and each of these resources should be evaluated and analyzed for their energy contribution and potential to reduce environmental impact.

In relation to the second specific objective concerning solar panels as a source of renewable energy and the agronomic dimension of agricultural waste utilization, the results showed a positive correlation, but not strong enough to be significant in this study context. Although the importance of using solar panels and their benefits for agronomy are recognized, it becomes evident the need to explore other factors that may influence this relationship.

Finally, the third specific objective regarding the relationship between energy saving and the type of residue identified several combinations of levels that suggest a moderate positive association, indicating that variations in one dimension tend to be associated with changes in the other. This demonstrates that energy saving and the type of residue are interrelated and have a joint impact.

CONCLUSIONS

The evaluation of the validity and reliability of the questionnaire designed to measure the relationship between renewable energy and the utilization of agricultural waste in Chiclayo showed a significant correlation. The correlation coefficient was 0,614 with a pvalue of 0,000, which is below the significance level α (0,05). This indicates that there is a positive and statistically significant relationship: as the level of renewable energy increases, the level of solid waste utilization in the region also tends to increase.

The analysis using Spearman's correlation coefficient for the first specific objective did not show a significant relationship between "biomass" as a source of renewable energy and the "environmental" dimension of agricultural waste utilization. The correlation coefficient was 0,303 with a pvalue of 0,103, both above α (0,05). This suggests that while there is a positive trend, it is not strong enough to be considered statistically significant in this context.

For the second specific objective, the analysis with Spearman's correlation coefficient revealed a coefficient of 0,344 and a pvalue of 0,062, both above the threshold of α (0,05). This indicates that there is not enough evidence to assert a significant relationship between the use of solar panels and the agronomic dimension of agricultural waste utilization in Chiclayo.

Finally, for the third specific objective, a significant relationship was found between the "energy saving" dimension and the "type of residue." The correlation coefficient was 0,484 with a pvalue of 0,007, which is less than 0,05. This confirms that there is sufficient evidence to assert that there are statistically significant associations between energy saving and the type of residue in the utilization of agricultural waste in Chiclayo, which could have important implications for policy and practice in the region.

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