

Valorization of Rice Residues: A Systematic Review of the Uses of Rice Straw, Rice Husk, and Rice Bran

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Abstract

Global rice production generates large quantities of agricultural and agro-industrial residues annually, particularly rice straw, rice husk, and rice bran. These by-products remain largely underutilized despite their significant energy, agronomic, environmental, and industrial potential. This study presents a systematic review assessing the main valorization pathways of rice residues and their contributions to environmental and economic sustainability. A bibliographic search was conducted in the Scopus database using Boolean operators ("AND" and "OR") and keywords including "rice residues," "rice straw," "rice husk," "rice bran," "valorization," "environmental upcycling," "carbon," "utilization," "circular economy," and "biomass." The identified references were imported into Sysrev for deduplication, PRISMA-based screening, data extraction, and qualitative and quantitative synthesis. A total of 3,112 articles published between 2010 and 2025 were identified, of which 1,076 were retained after applying the inclusion criteria according to PRISMA guidelines. Rice straw (89.3%) was the most extensively studied residue, followed by rice husk (4.5%), rice bran (0.8%), and combinations of these residues (5.4%). The main valorization pathways were bioenergy (31.9%), agriculture (25.7%), biochemistry (13.2%), construction materials (11.2%), animal feed (7.6%), and other applications (10.4%). Publications were predominantly from Asia (49.16%), followed by Europe (23.14%), the Americas (17.94%), Africa (8.08%), and Oceania (1.67%). In Africa, Benin accounted for only 1.14% of publications, compared with 73.5% for Egypt and 25.3% for other African countries. This systematic review highlights the need to promote sustainable rice-residue valorization strategies to support the energy transition, reduce agricultural waste, and foster a circular economy in agri-food systems.

Keywords

Rice Straw, Rice Husk, Rice Bran, Rice Residue Valorization, Environmental Sustainability, Circular Economy

1. Introduction

Rice residues are among the most abundant agricultural by-products in rice-producing regions worldwide. Generated mainly during rice harvesting and processing, these residues include rice straw, rice husk, rice bran, and various other organic by-products. For a long time, these residues were considered agricultural waste and were often disposed of through open burning or left in fields. However, such practices contribute significantly to air pollution, greenhouse gas emissions, and the degradation of agricultural soils [1].

Recent research within the frameworks of sustainable development and the circular economy increasingly considers agricultural residues not as waste, but as valuable resources [2]. These studies highlight the potential of rice residues for high-value applications, including bio-based composites, food additives, and bio-fuels. For example, the valorization of rice straw can reduce the environmental impacts associated with its incineration while enabling the recovery of valuable compounds such as polyphenols and cellulosic fibers [3]. In agriculture, rice residues also play an important role in improving soil fertility. Studies conducted in West Africa have shown that rice-straw-based compost significantly improves lowland rice yields through the supply of organic matter and essential soil nutrients [4]. Similarly, studies on animal feed have shown that chemical or biological treatments of rice straw can improve its digestibility and nutritional value for ruminants [5].

Given these multiple valorization opportunities, the sustainable management of rice residues has become a major environmental and economic challenge. Converting these by-products into useful resources can not only reduce problems associated with their accumulation but also create new income-generating opportunities for farmers and local industries.

Therefore, this systematic review aims to synthesize the main scientific knowledge on rice residues, with particular emphasis on their different valorization pathways. It also aims to examine the potential of these biomasses in the context of sustainable agriculture and the circular economy.

2. Methodology

2.1. Selection of Scientific Publications

This systematic review was conducted following the recommendations of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. PRISMA provides a rigorous, transparent, and reproducible framework for identifying, screening, selecting, and reporting scientific studies included

in a systematic review [6]. The bibliographic data were collected from the Scopus database using a search strategy applied to the Title, Abstract, and Keywords fields (TITLE-ABS-KEY). The search query was structured around three thematic groups of keywords encompassing: i) rice by-products and residues, ii) valorization, utilization, and circular economy approaches, and iii) environmental aspects related to their management and use. To maximize the retrieval of relevant publications, both English and French keywords were included. The complete Boolean search string was as follows:

```
TITLE-ABS-KEY
(
("rice by-product*" OR "rice residue*" OR "rice waste*" OR
"rice husk" OR "rice hull*" OR "rice bran" OR
"rice straw" OR
"sous-produit* du riz" OR "résidu* de riz" OR
"déchet* de riz" OR "balle de riz" OR
"son de riz" OR "paille de riz")
AND
(value OR valorization OR valorisation OR utilization OR
utilisation OR biodegradable OR economy OR
"circular economy" OR circular OR upcycling)
AND
(environmental OR impact OR carbon OR
"low carbon" OR environnement* OR
impact* OR carbone)
)
```

The review considered scientific publications published worldwide between 2010 and 2025. This period was selected to provide a comprehensive overview of research activities conducted during the most recent fifteen-year period. The retrieved records were subsequently screened to retain only relevant original research articles published in English or French. Eligible publications were required to address the management, utilization, or valorization of rice residues and to fall within the selected study period (2010-2025). Review articles, conference proceedings, book chapters, editorials, duplicate records, studies outside the defined scope, and publications lacking sufficient information for analysis were excluded. Only publications meeting all eligibility criteria were retained for the final dataset. The identified records were exported and processed using Sysrev, a platform designed for systematic review management. This process facilitated duplicate removal, record organization, and screening according to predefined inclusion and exclusion criteria. The study-selection procedure followed the four main stages of the PRISMA framework: identification, screening, eligibility assessment, and inclusion. The literature search was conducted online between December 2025 and June 2026 and resulted in the identification of 3112 records. After duplicate removal and eligibility assessment based on the predefined inclu-

sion criteria and the objectives of the review, 1,076 publications were retained for the final analysis.

Initial screening was performed using publication titles, abstracts, and keywords. Publications containing one or more relevant search terms were retained for further evaluation. The abstracts and conclusions were subsequently examined to confirm their relevance to rice-residue valorization and utilization pathways. Each selected publication was manually coded based on the information provided in the title, abstract, keywords, and, when necessary, the full text. The documents were classified according to four variables (**Table 1**): i) type of rice by-product (rice straw, rice husk, or rice bran), ii) application sector (agriculture, energy, biochemistry, construction, animal feed, or other applications), iii) geographical region of the study (Africa, Asia, Europe, America, or Oceania), and iv) African country concerned when the study was conducted in or focused on an African context. The extracted information was recorded in an Excel 2016 database and analyzed descriptively to identify major research trends, geographical distributions, valorization pathways, and application sectors associated with rice residues. Duplicate records identified during the retrieval and screening processes were removed prior to the final analysis. Although the selected publications do not represent the entirety of the scientific literature on rice-residue valorization, they provide a broad and representative overview of the current state of research in this field.

2.2. Data Collection

Each selected publication was manually coded based on the information provided in the title, abstract, keywords, and, when necessary, the full text. The documents were classified according to four variables: (i) type of rice by-product, (ii) application sector, (iii) geographical region of the study, and (iv) African country concerned. The coding variables and the corresponding classification criteria used throughout the analysis are presented in **Table 1**.

The geographical location was defined as the place where the study was conducted. For studies involving more than one country, all countries concerned were included in the selection and subsequent analysis. The “Agriculture” category includes agronomic uses such as composting, mulching, fertilization, and soil improvement. The “Biochemistry” category covers applications related to the production of biofuels, biomolecules, biochar, and other bio-based products. The “Construction” category includes the use of rice residues in construction materials, insulation materials, and composite products. The “Animal Feed” category encompasses the use of rice residues as feed for livestock and other farm animals. The “Other” category comprises applications that do not fall within any of the aforementioned categories. When a publication addressed multiple applications, all relevant categories were considered during the coding process. Applications that did not correspond to any of the predefined categories were classified under the “Other” category.

Table 1. Coding variables and classification criteria for publications.

Variable	Category	Classification Criterion
Rice by-product	Rice straw	Study primarily focused on rice straw
	Rice husk	Study primarily focused on rice husk
	Rice bran	Study primarily focused on rice bran
Primary application sector	Energy	Bioenergy production, bioethanol, biogas, combustion, and related applications
	Agriculture	Composting, soil amendment, mulching, fertilization, and related agricultural uses
	Construction	Concrete, bricks, panels, composite materials, and other construction materials
	Biochemistry	Extraction of molecules, bioproducts, enzymes, and other biochemical applications
	Animal feed	Incorporation into livestock feed or feed supplements
	Other	Applications not falling within the previous categories
Geographical region of the study	Africa, Asia, Europe, America, Oceania	The geographical region corresponds to the location where the study was conducted
African country concerned	List of all African countries	Variable applied exclusively to studies conducted in or focused on African countries

Source: Research findings (2026).

2.3. Data Analysis

The selected publications were organized and coded in an Excel 2016 database to facilitate data analysis. R software version 4.0.2 (R Core Team, 2020) was used for descriptive statistical analysis, while ArcGIS version 9.3.1 was used to map the geographical distribution of the selected publications (**Figure 1**).

3. Results

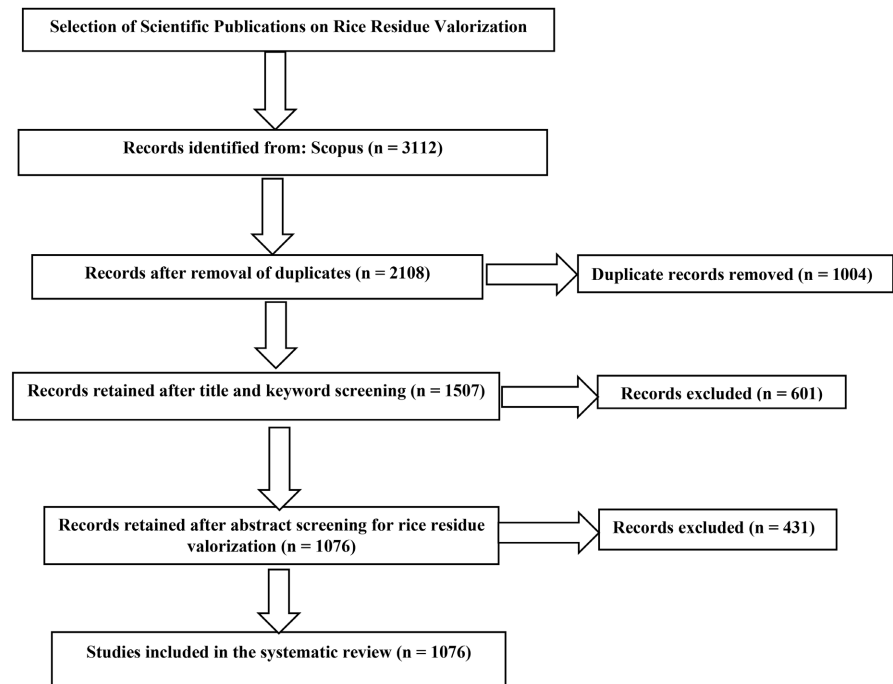
3.1. Selection of Publications

Figure 1 presents the publication-selection process and the number of studies included in this systematic review.

3.2. Geographical Distribution of Publications Worldwide

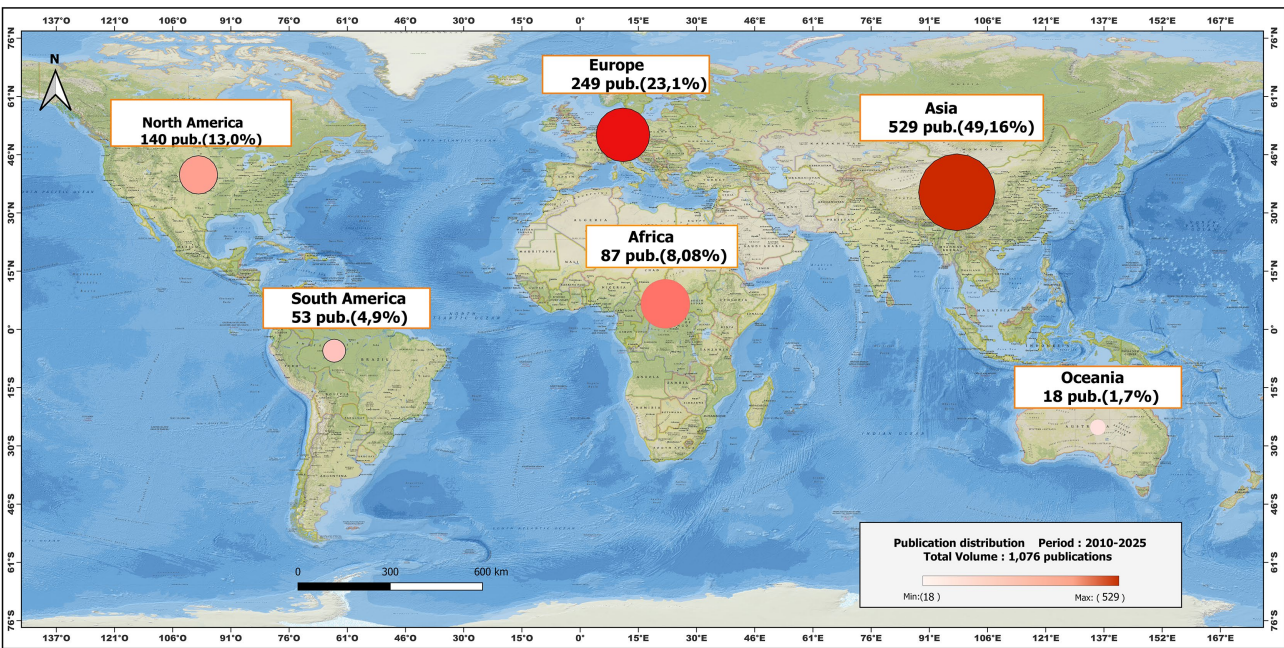
The publications included in this systematic review cover the period from 2010 to 2025 and are geographically distributed across the world, as shown in **Figure 2**.

Figure 2 illustrates the geographical distribution of the publications included in this systematic review. The publications were distributed across Australia (1.67%), Africa (8.08%), the Americas (17.94%), Europe (23.14%), and Asia (49.16%).



Source: Research findings (2026).

Figure 1. PRISMA flow diagram for the selection of publications.

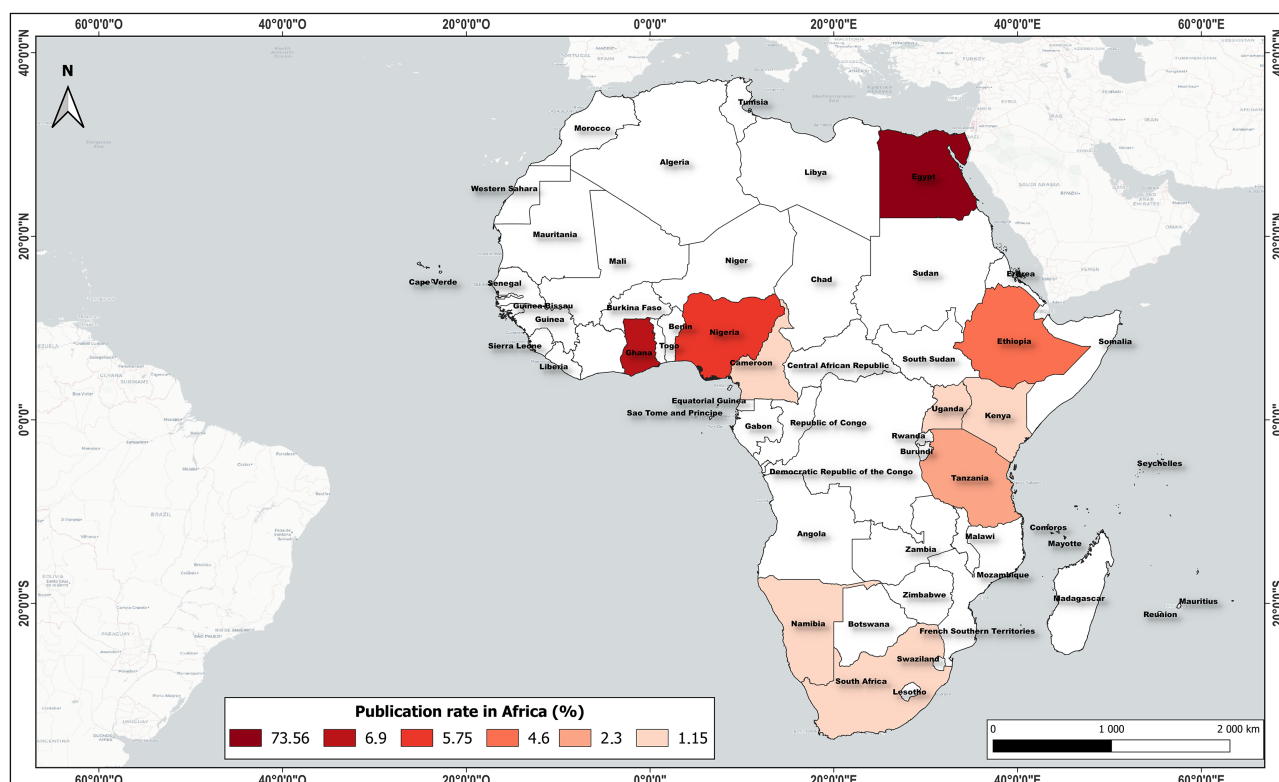


Source: Research findings (2026).

Figure 2. Global geographical distribution of publications on rice residue valorization (2010-2025) included in this systematic review.

3.3. Publication Frequency in Africa

The distribution of publications on rice residue valorization in Africa is presented in Figure 3.



Source: Research findings (2026).

Figure 3. Geographical distribution of publications in Africa between 2010 and 2025 on rice residue valorization included in this systematic review.

The distribution of publications shows a clear dominance of Egypt, which accounts for 73.56% of the African scientific output on rice residue valorization. Ghana (6.90%) and Nigeria (5.75%) rank second and third, respectively, while the other countries, including Benin (1.14%), make only marginal contributions, each accounting for less than 5%. This strong concentration reflects an uneven distribution of research capacity and scientific expertise on this topic across the African continent.

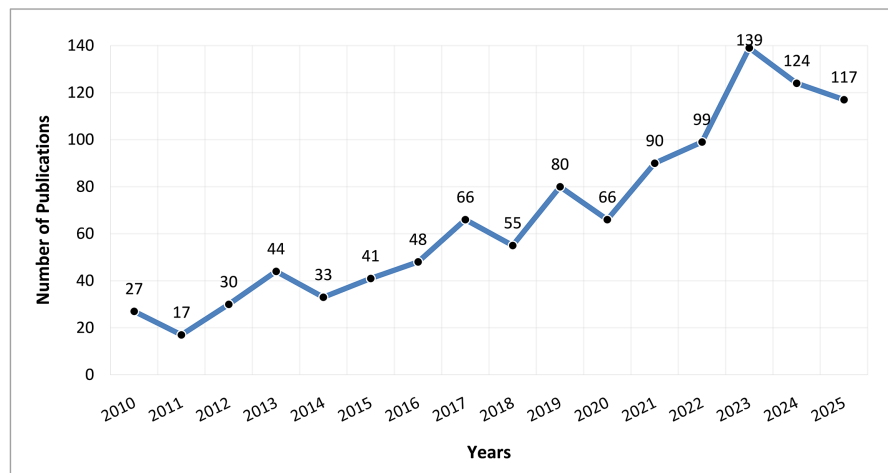
3.4. Publication Trends

Figure 4 and **Figure 5** show, respectively, the trends in publications included in this systematic review worldwide and in Africa between 2010 and 2025.

Figure 4 shows an overall increasing trend in the number of scientific publications on rice residue valorization worldwide between 2010 and 2025, with an average of 72 publications per year over the study period. This gradual increase in the number of publications reflects growing scientific interest in this topic, despite some occasional fluctuations.

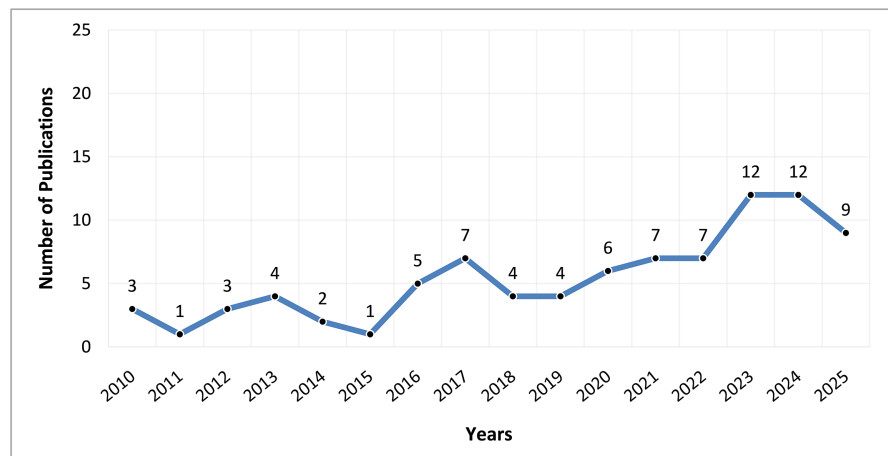
Figure 5 presents the annual evolution in the number of scientific publications on rice residue valorization in Africa between 2010 and 2025. The observed trend indicates that rice residue valorization is gradually becoming an important research area in Africa. Despite the relatively low annual publication output, aver-

aging approximately six publications per year over the study period, the overall trend confirms the growing interest and future potential of this research field across the African continent.



Source: Research findings (2026).

Figure 4. Global publication trends on rice residue valorization between 2010 and 2025.



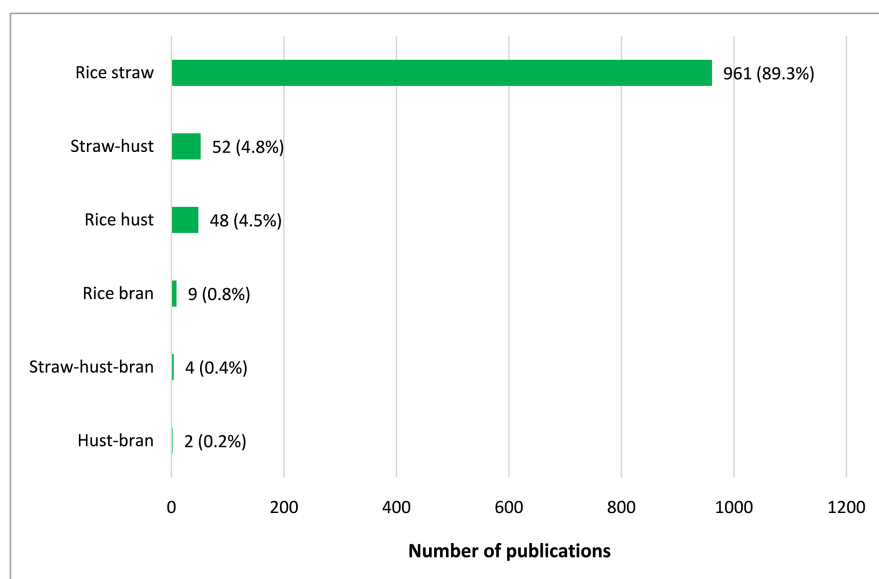
Source: Research findings (2026).

Figure 5. Annual trends in scientific publications on rice residue valorization in Africa between 2010 and 2025.

3.5. Publication Frequency by Type of Rice Residue Studied

Figure 6 and **Figure 7** illustrate the frequency of publications worldwide and in Africa, respectively, according to the type of rice residue studied during the study period.

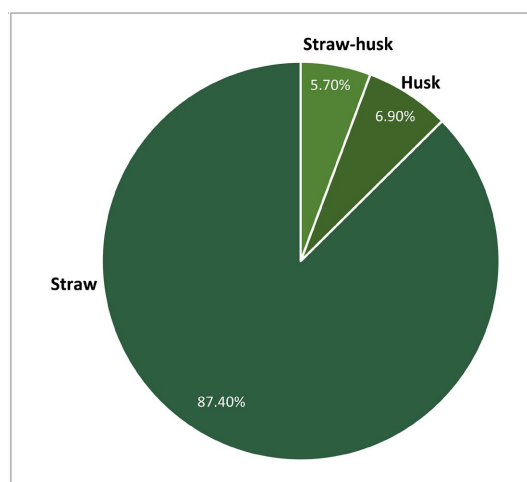
Rice straw accounts for 89.3% of the publications reviewed, while rice husk represents 4.5%. Studies focusing on a combination of rice straw and rice husk account for 4.8%, whereas only 0.8% of the studies focus on rice bran. This distribution highlights the predominance of research on rice straw, while the other rice by-products remain relatively under-studied.



Source: Research findings (2026).

Figure 6. A Global distribution of scientific publications by type of rice residue valorized between 2010 and 2025.

Figure 7 reveals a strong concentration of research on rice straw, which accounts for 87.4% of the publications reviewed. In contrast, the other rice residues receive considerably less attention, with 6.9% of the studies focusing on rice husk and 5.7% examining the combined valorization of rice straw and rice husk. This trend is consistent with the situation observed at the global level.



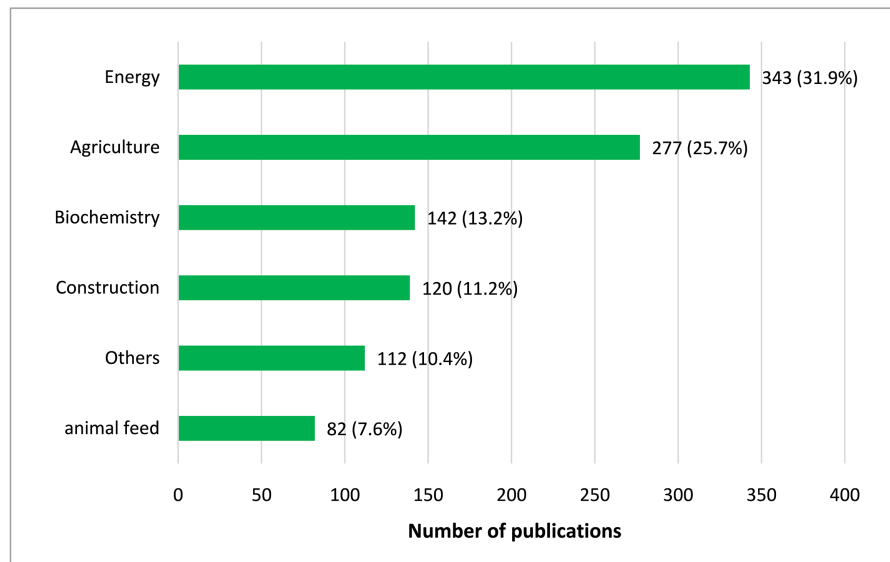
Source: Research findings (2026).

Figure 7. Distribution of scientific publications included in this review by type of rice residue studied in Africa between 2010 and 2025.

3.6. Frequency of Published Articles by Type of Rice Residue Valorization Studied

Figure 8 and **Figure 9** illustrate the trends in scientific publications worldwide

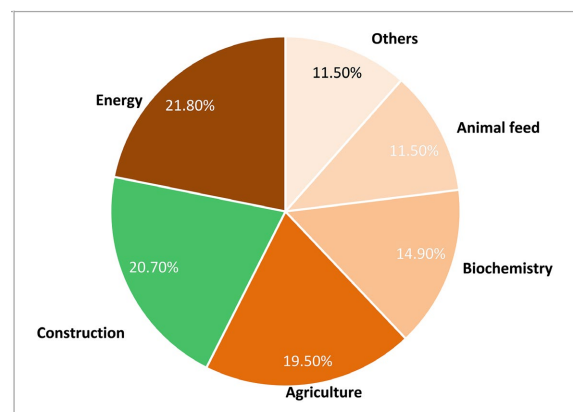
and in Africa, respectively, according to the type of rice residue valorization investigated over the study period.



Source: Research findings (2026).

Figure 8. Distribution of scientific publications included in this review by type of rice residue valorization studied worldwide between 2010 and 2025.

Figure 8 shows the distribution of scientific publications according to the different types of rice residue valorization studied worldwide between 2010 and 2025. The results indicate that the energy sector ranks first, accounting for 31.9% of all studies reviewed. The agricultural sector ranks second, representing 25.7% of the publications. This is followed by biochemistry (13.2%), the construction materials sector (11.2%), the animal feed sector (7.6%), and other areas (10.4%).



Source: Research findings (2026).

Figure 9. Distribution of scientific publications included in this review by type of rice residue valorization studied in Africa between 2010 and 2025.

In Africa, scientific publications show that the energy sector ranks first, ac-

counting for 21.8% of the studies reviewed, followed by the construction materials sector (20.7%) and the agricultural sector (19.5%). Biochemistry accounts for 14.9% of the publications, while the animal feed and other sectors each represent 11.5%.

4. Discussion

The results of this literature review confirm the growing interest in the valorization of rice residues worldwide over the past fifteen years. This increase, particularly pronounced after 2020, reflects the shift in scientific priorities toward more sustainable production models based on the principles of the circular economy and bioeconomy. As highlighted by Zadi *et al.* [4], Kaniapan *et al.* [7], and Harun *et al.* [8], agricultural residues are no longer considered merely as waste, but rather as resources capable of contributing to energy security, greenhouse gas emission reduction, and the development of new value chains. The increase in publications observed in this study is also consistent with the trends reported by Sarkar *et al.* [9] and Alengebawy *et al.* [10], who highlight the intensification of research on lignocellulosic biomass within the framework of the Sustainable Development Goals.

The high concentration of publications in Asia (49.16%) reflects the region's dominant position in global rice production and the substantial availability of rice biomass. It also reflects sustained investment in valorization technologies and the existence of public policies promoting the development of bioenergy and bio-based materials. In contrast, the limited contribution of Africa (8.08%), despite its growing agricultural potential, reveals a gap between available resources and scientific output. This situation may be explained by limited research and development capacities, insufficient access to technological infrastructure, and weak integration among the agricultural, industrial, and academic sectors. The case of Benin (1.14%) particularly illustrates this situation. These observations are consistent with the recommendations made by Alengebawy *et al.* [10], who emphasize the importance of strengthening scientific collaborations and investment in valorization technologies to accelerate innovation in developing countries.

The strong predominance of rice straw among the residues studied (nearly 90% of publications) highlights its central role in current strategies for the valorization of rice by-products. This importance is mainly explained by its abundance and its lignocellulosic composition, which is rich in cellulose, hemicellulose, and lignin, making it a particularly suitable feedstock for the production of bioethanol, biochar, and solid biofuels [7] [8] [10]. This trend has gradually diversified toward higher-value applications. Thus, Mahmood *et al.* [11] and Kim *et al.* [12] demonstrated the potential of cellulose derived from rice straw for the production of functional materials, particularly hydrogels and cellulose microcrystals. Similarly, the studies by Goodman *et al.* [1] and Peralta *et al.* [13] highlight the development of chemical and nanotechnological valorization approaches through the extraction of phenolic compounds and the synthesis of silica nanoparticles. This evolu-

tion is further supported by the more recent studies of Jain *et al.* [14] and Sencan *et al.* [15], which illustrate the growing interest in the production of biodegradable plastics from these residues.

In contrast, rice husk accounts for only approximately 4.5% of the publications reviewed, despite its high silica content, which gives it considerable potential for applications in construction materials, nanomaterials, and water treatment [16] [17]. This imbalance highlights the continued strong orientation of research toward rice straw, at the expense of other promising by-products. It also reveals significant research opportunities, particularly in African countries, where rice husk is produced in large quantities but remains largely underutilized, thereby offering opportunities for the development of local, high-value-added valorization chains.

Furthermore, the small proportion of studies simultaneously integrating several rice residues indicates that current approaches remain largely focused on a single by-product. This specialization is inconsistent with the principles of integrated biorefineries, which aim to valorize all biomass streams in order to optimize economic and environmental performance. As emphasized by Nzereogu *et al.* [18] and Peralta *et al.* [13], integrating rice straw, rice husk, and rice bran within a single valorization chain could diversify the range of products obtained, reduce material losses, and improve the overall profitability of rice-based value chains.

The predominance of energy applications observed in this study (31.9%) reflects the strategic role attributed to rice residues in the energy transition, particularly in countries facing a high dependence on fossil fuels. However, several authors point out that direct conversion into energy is not necessarily the most profitable option. Alengebawy *et al.* [10] and Kaniapan *et al.* [7] recommend a cascading approach in which high-value compounds are first extracted before the remaining fractions are used for energy production. This strategy is fully consistent with the principles of the circular bioeconomy and can improve the economic viability of the processes.

The importance of agricultural applications (25.7%) also confirms the potential role of rice residues in improving soil fertility. The production of compost and biochar can enhance nutrient availability, water retention, and carbon sequestration, thereby contributing to more sustainable agricultural practices [7] [8]. These benefits are particularly relevant to tropical regions, where soil degradation represents a major constraint to agricultural productivity.

Despite the progress observed, several constraints continue to limit the development of rice residue valorization chains. Difficulties associated with residue collection, transportation, and storage, together with their low bulk density, increase production costs and reduce the competitiveness of industrial processes. These challenges are further compounded by variations in biomass composition, technological limitations, and the absence of supportive policies in several rice-producing countries, particularly in Africa. These constraints partly explain the gap between the valorization potential of rice residues and their actual utilization.

Overall, this review shows that rice residues represent a largely underutilized

resource whose potential extends far beyond energy production alone. Future research should focus on integrated approaches combining technological, economic, and environmental dimensions, while prioritizing biorefinery models capable of simultaneously valorizing all by-products of the rice value chain. Such an evolution would contribute to strengthening the sustainability of agro-industrial systems and increasing the added value generated from agricultural biomass.

5. Conclusion

From a sustainable development perspective, the valorization of rice residues represents a major opportunity to reconcile agricultural waste management, economic value creation, greenhouse gas emission reduction, and improved farmers' incomes. The limited contribution of Africa to the scientific literature suggests the need to strengthen research capacities, scientific collaborations, and investment in this field in order to promote sustainable management of agricultural residues and support the development of the circular economy in Africa. Future research should focus on multidisciplinary approaches integrating technical, economic, environmental, and social dimensions to foster the emergence of viable and sustainable valorization value chains.

Declaration of Generative AI and AI-Assisted Technologies in Manuscript Preparation

During manuscript preparation, the authors used Claude (Anthropics) solely for limited language editing of selected sentences in order to revise in order to improve clarity. No AI tool was used to generate research content, analyze data, interpret results, or prepare references, the ideas, argument, and intellectual contribution of the paper are entirely original. All AI-assisted suggestions were reviewed, revised where necessary, and approved by the authors, who take full responsibility for the final manuscript.

Author Contributions

Conceptualization, W.; methodology, W.; formal analysis, W.; investigation, W.; writing-original draft preparation, W.; writing-review and editing, W. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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