Designs 2026 Conference

The 1st International Online Conference on Designs

9–10 February 2026 | Online

MDPI

Hybrid Solar–Biomass Energy Systems for Rural Agro-Industrial Applications: A Technical and Bibliometric Review.

Jhon Javier Espitia[1], Edwin Villagran[1], Fabian Velasquez[1], Andres Sarmiento[1], Jader Rodriguez[1].

[1]Colombian Corporation for Agricultural Research—Agrosavia, Central Headquarters, Km 14, Mosquera–Bogotá, Mosquera 250040, Colombia.

INTRODUCTION & AIM

The demand for thermal energy in industrial applications continues to rise, particularly in agro-processing, where postharvest drying is essential to ensure storage stability, product quality, and food safety [1]. Drying operations not only reduce microbial activity and extend shelf life but also support market competitiveness across agricultural value chains. However, industrial drying accounts for nearly 15% of the sector's global energy consumption and remains strongly dependent on fossil-based resources, raising concerns regarding operating costs and environmental sustainability [2]. In response, solar drying technologies have gained increasing attention as cost-effective and low-emission alternatives. Nevertheless, conventional solar dryers often exhibit limited performance due to the intermittency of solar radiation, prolonged drying times, and non-uniform product quality, with studies reporting lower efficiencies compared with hybrid configurations that incorporate auxiliary heat sources [3]. In this context, the integration of solar and biomass energy emerges as a promising strategy to enhance reliability, improve thermal efficiency, and enable continuous operation in decentralized agro-industrial settings. Therefore, the objective of this study is to conduct a comprehensive technical and bibliometric review of hybrid solar–biomass drying systems applied to the agricultural and food sectors, with the aim of identifying research trends, leading contributors, collaboration patterns, and existing knowledge gaps that may guide future technological development and sustainable rural energy transition.

METHOD

A combined technical and bibliometric approach was adopted to systematically evaluate the development of hybrid solar–biomass drying systems for agricultural and food-processing applications. The Scopus database was selected as the primary source due to its broad coverage of peer-reviewed scientific literature. The search was conducted for the 2005–2025 period using the query TITLE-ABS-KEY(("hybrid" W/2 (solar AND biomass)) AND (dryer OR drying OR "process heat") AND (agricultur OR food OR agroindustrial)), and only articles, reviews, and conference papers written in English were considered. Retrieved records were screened to remove duplicates and irrelevant documents, resulting in a final dataset of 22 publications. Bibliometric indicators including annual scientific production, collaboration networks, leading countries and institutions were analyzed to characterize the structure and evolution of the research field. Additionally, a thematic co-occurrence analysis of keywords was performed to identify dominant research clusters, emerging topics, and knowledge gaps.

RESULTS & DISCUSSION

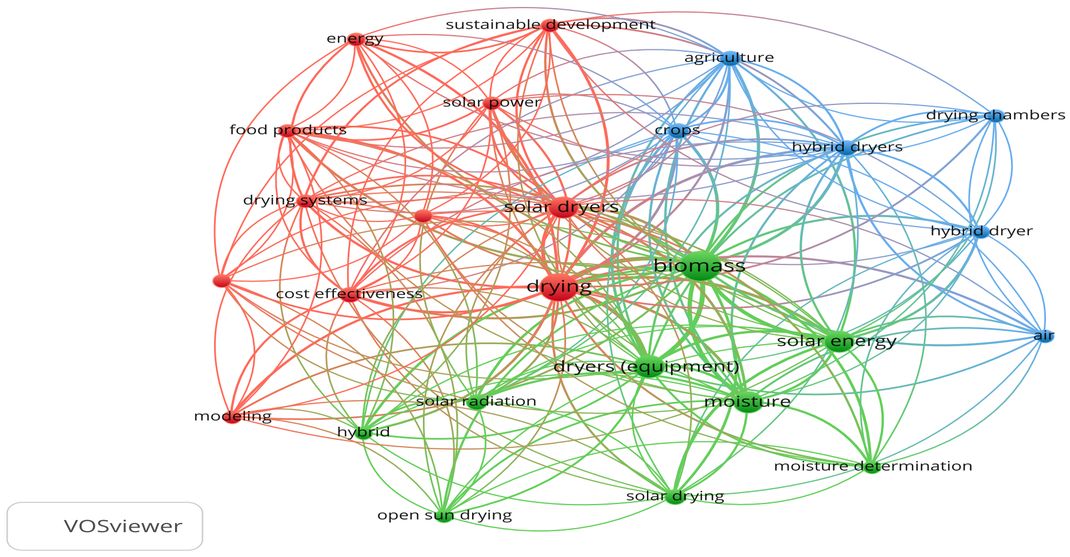
Bibliometric results – document and collaboration structure.

The bibliographic dataset comprised 24 publications distributed across 23 scientific sources during the 2005–2025 period, reflecting the still emerging nature of research on hybrid solar–biomass drying technologies. Journal articles represented the dominant document type (16 papers), followed by review articles (4), conference papers (3), and one conference review, indicating that the field is primarily driven by original experimental and technical contributions rather than synthesis studies. A total of 129 authors participated in the selected publications, with no single-authored documents, highlighting the collaborative and interdisciplinary character of this research area. The average number of co-authors per document was 7.17, while the international co-authorship rate reached 25%, suggesting moderate but increasing global cooperation. The corpus included 91 author keywords and 195 references, with an average document age of seven years and 23.83 citations per publication, indicating both conceptual consolidation and growing scholarly impact.

Timespan 2005:2025	Sources 23	Documents 24	Annual Growth Rate 7.18 %
Authors 129	Authors of single-authore 0	International Co-Authorsh 25 %	Co-Authors per Doc 7.17
Author's Keywords (DE) 91	References 195	Document Average Age 7	Average citations per doc 23.83

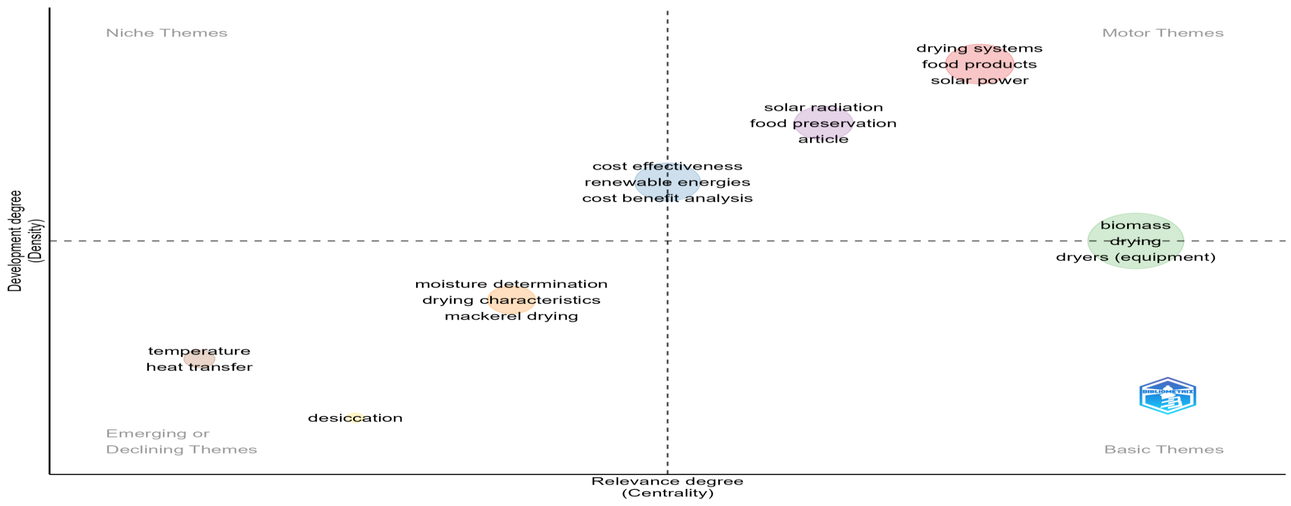
Geographic and temporal distribution of publications

The geographical distribution reveals a strong concentration of research activity in developing and emerging economies where agro-industrial drying plays a critical socio-economic role. India leads scientific production with 12 documents, followed by Nigeria (3), and Indonesia, Malaysia, and Thailand with two publications each. This regional pattern underscores the relevance of hybrid renewable drying systems for rural energy access and agricultural value addition in tropical and subtropical contexts. Temporally, scientific output shows intermittent early activity between 2005 and 2018, followed by a clearer upward trend after 2020, with the highest productivity recorded in 2025 (4 documents). This recent acceleration suggests growing academic and technological interest in hybrid solar–biomass solutions as sustainable alternatives for process heat and decentralized thermal applications.



The keyword co-occurrence

Network reveals the conceptual structure and thematic organization of research on hybrid solar–biomass drying technologies. Four main clusters can be identified according to the strength of keyword associations. The first cluster (red) is centered on terms such as *solar dryers*, *drying*, *energy*, *solar power*, and *sustainable development*, indicating that the core of the literature focuses on the design and performance improvement of solar-based drying systems within broader energy and sustainability frameworks. The high connectivity of these terms suggests that solar drying remains the foundational technological approach upon which subsequent hybridization strategies are developed. Additionally, the presence of keywords related to *cost effectiveness*, *food products*, and *modeling* highlights an increasing interest in techno-economic evaluation and system optimization. The second cluster (green) groups terms such as *biomass*, *solar energy*, *dryers (equipment)*, *moisture*, *moisture determination*, and *solar drying*, reflecting research oriented toward thermal performance, moisture removal mechanisms, and equipment configuration. Meanwhile, the third cluster (blue), including *agriculture*, *crops*, *hybrid dryers*, *drying chambers*, and *air*, emphasizes practical applications and system integration for agro-industrial processes. The strong interconnections between these clusters indicate a progressive transition from conventional solar drying toward hybrid solar–biomass solutions aimed at improving reliability and process control. Overall, the network structure demonstrates that biomass integration, hybrid system design, and process optimization constitute emerging and increasingly interconnected research directions within the field.



Thematic map

The thematic map indicates that, although *drying systems*, *solar power*, and *food products* are well-established motor themes, several critical gaps persist. Techno-economic aspects such as *cost effectiveness* and *cost–benefit analysis* remain only moderately developed, while fundamental process variables, including *temperature*, *heat transfer*, and *desiccation* appear as emerging topics, revealing limited modeling and mechanistic understanding. Moreover, despite the central relevance of *biomass* and drying equipment, their low density suggests insufficient integration strategies, control methods, and long-term performance validation, highlighting the need for deeper technical, economic, and experimental studies to advance hybrid solar–biomass drying technologies.

CONCLUSION AND FUTURE WORK

Overall, the results indicate that hybrid solar–biomass drying systems are gaining relevance as sustainable solutions for decentralized agro-industrial heat generation; however, the field remains fragmented and technically immature. Future research should prioritize deeper thermo-fluid modeling, standardized performance metrics, integrated techno-economic assessments, and long-term experimental validation to enhance system reliability, scalability, and real-world deployment.

REFERENCES

1. Review of Optimization Strategies for Solar-Biomass Dryers. *Sustain. Energy Technol. Assessments* **2025**, *83*, 104672.
2. Kong, D.; Wang, Y.; Li, M.; Liang, J. A Comprehensive Review of Hybrid Solar Dryers Integrated with Auxiliary Energy and Units for Agricultural Products. *Energy* **2024**, *293*, 130640.
3. López-Vidaña, E.C.; Méndez-Lagunas, L.L.; Rodríguez-Ramírez, J. Efficiency of a Hybrid Solar–Gas Dryer. *Sol. energy* **2013**, *93*, 23–31.