

# Design and analysis of eco-efficient stoves in latin america: a systematic review of environmental and social impact

*Diseño y análisis de estufas ecoeficientes en américa latina: una revisión sistemática de impacto ambiental y social*

*Projeto e análise de fogões ecoeficientes na América Latina: uma revisão sistemática do impacto ambiental e social.*

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**Received:** May 15<sup>th</sup>, 2025

**Accepted:** August 25<sup>th</sup>, 2025

**Available:** January 13<sup>th</sup>, 2026

#### How to cite this article:

C. J. Jaimes Silva, J. Tovar Quintero, J. E. Arboleda Puerta, and E. S. Gutiérrez, "Design and analysis of eco-efficient stoves in Latin America: A systematic review of environmental and social impact," *Revista Ingeniería Solidaria*, vol. 22, no. 1, 2026. doi: <https://doi.org/10.16925/2357-6014.2026.01.08>

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Review article. <https://doi.org/10.16925/2357-6014.2026.01.08>

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## Abstract

*Introduction:* This review article is the result of research conducted at the Universidad Nacional Abierta y a Distancia (UNAD) in 2024. It analyzes databases and organizations involved in the production of eco-efficient stoves, identifying health aspects, design features, and the use of biofuels between 2017 and 2024 in Latin America.

*Problem:* Traditional wood stoves remain prevalent in rural areas of Latin America, posing serious health and environmental risks due to inefficient combustion and high pollutant emissions.

*Objective:* The objective is to identify diseases and environmental and social impacts associated with traditional stoves, and to analyze the most relevant eco-efficient stove recommendations for rural communities in Latin America.

*Methodology:* A systematic literature review was conducted following PRISMA guidelines, including scientific articles and bibliometric analysis. The topics addressed include combustion systems, particulate matter emissions, biofuel gas production, respiratory illnesses, and improvements in combustion chambers for better eco-efficiency.

*Results:* The review highlights stove models such as Huellas, FN, Lorena, and Patsari, which improve energy use and reduce emissions. The study shows that Norway, the United States, and Chile lead research in this field. However, only 14 of 116 Latin American authors have published more than one article, revealing a gap in consistent regional research. Trends by country and topic were also identified.

*Conclusion:* Bibliometric analysis is essential to understanding the impact of biomass combustion on health and the environment, and to guide future research efforts.

*Originality:* This review presents a comparative view of stove models, health consequences of biomass use, and design features of eco-efficient technologies in Latin America.

*Limitations:* Databases provide information on health and general use, but offer limited detail on specific eco-efficient stove models, resulting in fragmented information.

**Keywords:** Biomass, combustion, eco-efficiency, emissions, wood stoves.

## Resumen

*Introducción:* Este artículo de revisión es resultado de una investigación realizada en la Universidad Nacional Abierta y a Distancia (UNAD) en 2024. Analiza bases de datos y organizaciones involucradas en la producción de estufas ecoeficientes, identificando aspectos de salud, características de diseño y el uso de biocombustibles entre 2017 y 2024 en América Latina.

*Problema:* Las estufas de leña tradicionales siguen siendo prevalentes en las zonas rurales de América Latina, lo que representa graves riesgos para la salud y el medio ambiente debido a la combustión ineficiente y las altas emisiones de contaminantes.

*Objetivo:* El objetivo es identificar enfermedades, impactos ambientales y sociales asociados con las estufas tradicionales y analizar las recomendaciones más relevantes sobre estufas ecoeficientes para las comunidades rurales de América Latina.

*Metodología:* Se realizó una revisión sistemática de la literatura siguiendo las directrices PRISMA, incluyendo artículos científicos y análisis bibliométrico. Los temas abordados incluyen sistemas de combustión, emisión de material particulado, producción de gas biocombustible, enfermedades respiratorias y mejoras en las cámaras de combustión para una mayor ecoeficiencia.

*Resultados:* La revisión destaca modelos de estufas como Huellas, FN, Lorena y Patsari, que mejoran el uso de energía y reducen las emisiones. La investigación muestra que Noruega, Estados Unidos y Chile lideran las

investigaciones en este campo. Sin embargo, solo 14 de 116 autores latinoamericanos han publicado más de un artículo, lo que revela una brecha en la investigación regional consistente. También se identificaron tendencias por país y tema.

*Conclusión:* El análisis bibliométrico es esencial para comprender el impacto de la combustión de biomasa en la salud y el medio ambiente, y para orientar futuras investigaciones.

*Originalidad:* Esta revisión presenta una visión comparativa de los modelos de estufas, las consecuencias del uso de biomasa para la salud y las características de diseño de las tecnologías ecoeficientes en América Latina.

*Limitaciones:* Las bases de datos proporcionan información sobre salud y uso general, pero poco detalle sobre modelos específicos de estufas ecoeficientes, lo que genera información fragmentada.

**Palabras clave:** Biomasa, combustión, ecoeficiencia, emisiones, estufas de leña.

## Resumo

*Introdução:* Este artigo de revisão é resultado de pesquisa realizada na Universidade Nacional Aberta e a Distância (UNAD) em 2024. Analisa bases de dados e organizações envolvidas na produção de fogões ecoeficientes, identificando aspectos de saúde, características de design e o uso de biocombustíveis entre 2017 e 2024 na América Latina.

*Problema:* Os fogões tradicionais a lenha ainda são predominantes em áreas rurais da América Latina, representando sérios riscos à saúde e ao meio ambiente devido à combustão ineficiente e às altas emissões de poluentes. *Objetivo:* O objetivo é identificar doenças, impactos ambientais e sociais associados aos fogões tradicionais e analisar as recomendações mais relevantes sobre fogões ecoeficientes para comunidades rurais na América Latina.

*Metodologia:* Foi realizada uma revisão sistemática da literatura seguindo as diretrizes PRISMA, incluindo artigos científicos e análise bibliométrica. Os tópicos abordados incluem sistemas de combustão, emissões de material particulado, produção de biogás, doenças respiratórias e melhorias nas câmaras de combustão para maior ecoeficiência.

*Resultados:* A revisão destaca modelos de fogões como Huellas, FN, Lorena e Patsari, que melhoram o uso de energia e reduzem as emissões. A pesquisa mostra que Noruega, Estados Unidos e Chile lideram a pesquisa nessa área. No entanto, apenas 14 dos 116 autores latino-americanos publicaram mais de um artigo, revelando uma lacuna na pesquisa regional consistente. Tendências por país e tema também foram identificadas.

*Conclusão:* A análise bibliométrica é essencial para compreender o impacto da combustão de biomassa na saúde e no meio ambiente e para orientar pesquisas futuras.

*Originalidade:* Esta revisão apresenta uma visão comparativa de modelos de fogões, as consequências do uso de biomassa para a saúde e as características de projeto de tecnologias ecoeficientes na América Latina.

*Limitações:* Os bancos de dados fornecem informações sobre saúde e uso geral, mas poucos detalhes sobre modelos específicos de fogões ecoeficientes, resultando em informações fragmentadas.

**Palavras-chave:** Biomassa, combustão, ecoeficiência, emissões, fogões a lenha.

## Introduction

Cooking food with traditional wood stoves remains a deeply rooted practice in many rural communities in Latin America and the Caribbean [1]. Passed down from

generation to generation, this custom responds not only to cultural factors but also to economic conditions and the easy availability of organic materials. However, these stoves have inefficient combustion systems and lack proper oxygen control, generating negative effects on both human health and the environment [2]. Incomplete combustion in conventional stoves is mainly due to the absence of regulation of oxygen supply and poor combustion efficiency, resulting in the release of air pollutants [3]. The main pollutants emitted include particulate matter (PM) and carbon monoxide (CO), as well as carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and volatile organic compounds (VOCs) [4]. These emissions are closely associated with acute respiratory infections (ARI), bronchopulmonary diseases, chronic obstructive pulmonary disease (COPD), cardiovascular conditions, and lung cancer [2]. Indoor air pollution is estimated to be responsible for approximately 1.5 million deaths per year, particularly affecting young children and women, who are commonly near the stove [5]. From an environmental perspective, emissions from inefficient wood combustion contribute significantly to the generation of greenhouse gases (GHG), becoming one of the factors driving global warming and deforestation derived from firewood consumption [2]. Deforestation associated with the excessive use of firewood aggravates the effects of climate change by reducing the capacity of ecosystems to absorb carbon, which increases the concentration of carbon dioxide (CO<sub>2</sub>) and other polluting gases in the atmosphere. In response to these issues, scientific research has developed eco-efficient stove models that optimize the combustion chamber and significantly reduce biomass consumption and pollutant emissions. These models, by integrating local materials and sustainable design principles, represent a transition toward cleaner and socially adapted technologies [6]. In light of the problems identified, new wood stove models have been developed that allow a significant reduction in biomass consumption. The implementation of these technological devices seeks to optimize combustion performance and support the energy transition compared with traditional stoves [7]. In this transition process, combustion chamber design plays a fundamental role, as it directly influences emission levels, generating positive environmental and social impacts [6]. Therefore, this study aims to present the eco-efficient wood stove models developed in Latin America that have shown a greater positive effect on the problems identified, as well as to describe their designs and the improvements incorporated into each model. Additionally, it highlights that, despite technological advances, the literature lacks rigorous comparative syntheses that integrate the technical performance of eco-efficient stoves with their real impact on public health, sociocultural adoption, and environmental sustainability. Gaps persist in the standardization of thermal efficiency and emission indicators, as well as in the evaluation of public policies that

promote their large-scale implementation. This review seeks to integrate both bibliometric and technical approaches to guide future research and environmental policy decisions in the region.

## Materials and methods

The study was developed under the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology, complemented by a bibliometric analysis and a structured review of eco-efficient technologies. A systematic review of various scientific articles obtained from the Scopus database was conducted. The analysis covered issues related to combustion in wood stoves, emission factors, and the release of particulate matter and gases derived from the use of biofuels. Likewise, studies were examined on the incidence of respiratory diseases associated with these emissions, as well as strategies for reducing particulate matter (PM) and volatile organic compounds (VOCs) through reconfiguration of the combustion chamber, considering performance parameters and operating methods. Following this, a search of scientific literature was carried out using keywords, study topics, filters, and specific descriptors such as: (“combustion” OR “combustión”) AND (“wood stoves” OR “estufas de leña”), applying filters (Spanish/English), period (2015–2024), and document type (articles). This initial strategy yielded a total of 289 records, reduced to 80 articles after applying inclusion and exclusion criteria (see Table 1).

### Inclusion and exclusion criteria

**Inclusion:** studies that analyse thermal efficiency, emissions, environmental or social impact of wood stoves and biomass.

**Exclusion:** non-indexed sources (blogs, commercial sites) or without verifiable quantitative data.

### Bibliometric analysis

VOSviewer software was used to process Scopus metadata and generate co-occurrence networks, author analysis and thematic distribution. Variables such as: country of publication, number of authors, frequency of keywords and scientific areas were evaluated.

## Graphical representation

The PRISMA diagram (Table 1) represents the flow of the process of searching, selecting and excluding articles.

**Table 1.** List of Criteria for Choosing Keywords

Search and Choice Criteria	Search Engines/Filters	Quantity
keywords	Combustion; Combustion Wood-burning stoves; wood stoves	
Descriptors	Combustion AND "Wood stoves"	
Databases	Scopus	289
Document Type	Article-Review	230
Publication time	2017-2024	80
Access	Open access, hybrid, bronze	80

**Source:** own work

As a result of the selection of articles, a bibliometric analysis was carried out using the graphic data provided by Scopus and the VOSviewer software, with the aim of identifying and evaluating thematic patterns and significant contributions in this field of study. Likewise, specific information was collected on the most widely used stove models in Latin America, along with the variables and technical parameters that must be met to be considered eco-efficient. The information used in this research came from public and private institutional sources and specialized databases, which are detailed in Table 1.

**Table 1.** Sources of information on eco-efficient items and stoves

Category	Sources
Academic Databases	Scopus
Public Institutions	Ministry of Environment and Sustainable Development of Colombia
Corporations	Regional Autonomous Corporation of the Negro and Nare River Basins CORNARE
Programmes	Energy and Environment Alliance with the Andean Region AEA
Collections	Biocultural Heritage of Northern Sinaloa
Business websites	Metalcof

**Source:** own work

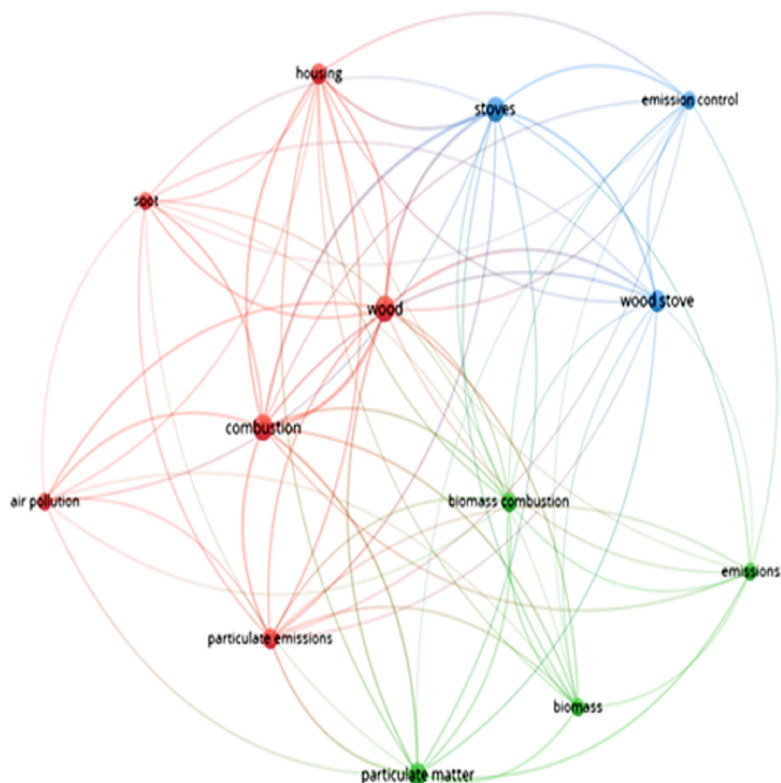
In the PRISMA methodology used for the review, Figure 2 was developed as a graphical representation of the study selection process. This diagram identifies the

initial volume of data found, as well as the stages of selection that allowed the application of inclusion and exclusion criteria until determining the final number of articles considered for analysis. Of the eighty (80) articles related to combustion and wood stoves initially identified, only those that met the requirements established for the systematic review were selected.

## Results

Efficient stove designs have the potential to significantly improve public health indicators at the regional or national level, in addition to promoting the development of new environmental policies aimed at encouraging their adoption by the population. Consequently, an initial review was conducted on the websites of the Regional Autonomous Corporations of Colombia and business platforms related to eco-efficient stoves. This made it possible to identify diverse stove designs, together with their functions, advantages, and disadvantages. Likewise, this review supported the proposal of a new model that integrates Industry 4.0 technologies to enhance eco-efficiency and functionality.

The bibliometric analysis identified 116 active authors, of whom 14 exhibit recurrent production, mainly in Norway, Germany, and Chile. The keywords with the highest incidence were combustion, wood, stove, and particulate matter, which reflects the thematic focus on energy efficiency and emission reduction. These analytical tools made it possible to visualize the data clearly and accurately, facilitating the interpretation of the main research trends in the field and identifying future lines of scientific inquiry. The most represented areas of knowledge were Chemical Engineering (20.3%), Energy and Environment (20.3%), and Environmental Engineering (15.6%), demonstrating the interdisciplinary nature of the topic. In the analysis performed using VOSviewer software, the most frequently used terms in the abstracts of the articles were identified and organized through a term co-occurrence map. Figure 3 presents this map, which displays thirteen (13) selected keywords interconnected through lines that represent thematic relationships between them. The terms with the highest incidence are combustion, wood, stove, and particulate matter. Additionally, the clusters, differentiated by colors, group related words, revealing the main research lines addressed in the literature.



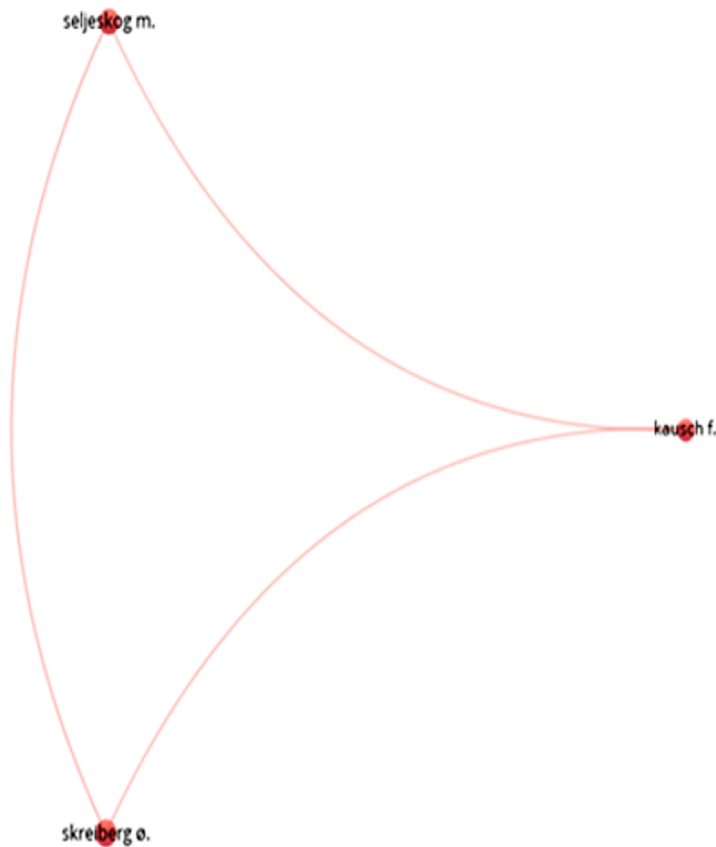
**Figure 3.** Word concurrence map with vosviewer.

Source from: Authors (2024).

This finding is consistent with previous studies that have employed similar methodologies; among them, the study carried out by the National Autonomous University of Mexico stands out, where VOSviewer software was used to construct a keyword co-occurrence network, identifying the central terms in the literature related to sustainability and green technology [8]. Likewise, in a study on transport corridors and sustainable development, a bibliometric approach was used to analyze scientific production in this area, highlighting the importance of terms related to sustainability and energy efficiency [9]. This research highlights the usefulness of bibliometric analyses as a tool for mapping the development of specific areas of knowledge and for identifying patterns and trends in scientific production.

The identification of key terms and the visualization of their interrelationships make it possible to recognize predominant areas of focus and to project possible future research directions. In the field of eco-efficient stoves, the prominence of terms associated with combustion and emissions reflects a sustained focus on improving energy efficiency and mitigating environmental impact. This approach is essential for

designing effective environmental policies and promoting sustainable technologies that contribute both to environmental protection and to public health improvement. On the other hand, in Figure 4, approximately one hundred and sixteen (116) authors were identified, of whom fourteen (14) have published at least two articles related to combustion and the use of wood stoves. Likewise, the analysis showed that the authors with the highest number of publications in this field are Seljeskog, M., Skreiberg, Ø., and Kausch, F.



**Figure 4.** Map of authors with vosviewer.

Source from: Authors (2024).

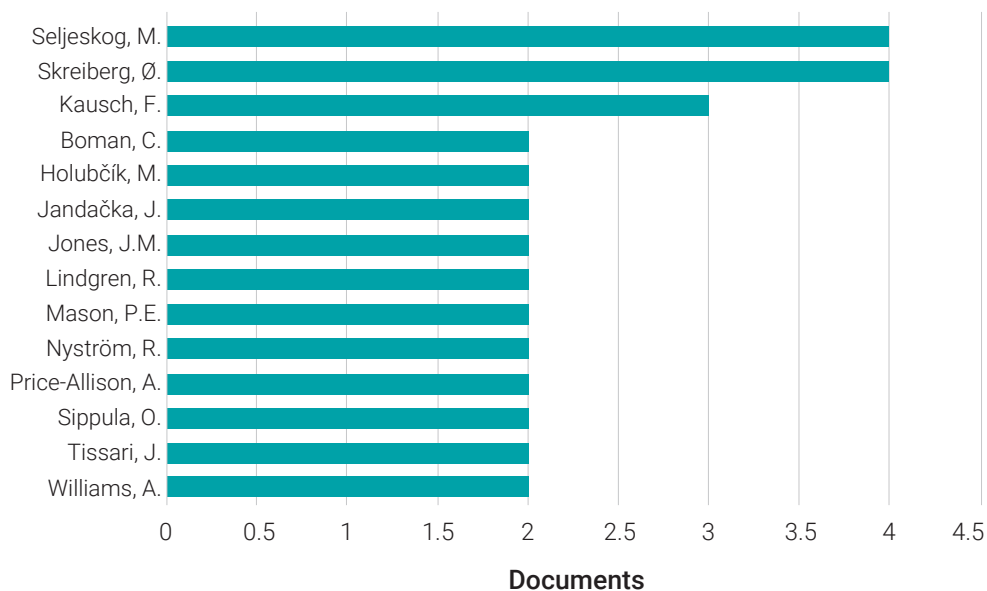
It should be noted that the results presented in Figure 4 are consistent with previous studies on scientific production in the field of combustion and the use of wood stoves. Earlier research has shown that, in this type of subject, a small group of authors concentrates most publications, while a considerable number of researchers contribute only sporadically.

For example, bibliometric studies on biomass combustion have demonstrated that research in this field is dominated by established working groups in regions where the use of wood stoves remains common practice. This phenomenon is particularly evident in European countries such as Norway and Germany, where authors such as Skreiberg, Ø., Seljeskog, M., and Kausch, F. have made significant contributions. These findings are consistent with existing literature, which identifies the improvement of thermal efficiency, the reduction of pollutant emissions, and the optimization of stove design as key areas of research [10].

Similarly, studies in related fields—such as renewable energies and the energy transition—have highlighted the importance of international collaboration networks in strengthening knowledge generation. Previous research has shown that, in disciplines with high environmental and social impact, the most prolific authors tend to be affiliated with research centers specializing in sustainable energy [11]. These results suggest that continuity in scientific production is closely linked to access to funding and the consolidation of research groups, which may explain why, of the 116 authors identified in Figure 4, only 14 have published more than one article on this topic.

These findings also underscore the need to promote greater diversity in scientific output related to combustion and the use of wood stoves. Encouraging the participation of researchers from regions where these devices remain a primary source of energy—for cooking and heating—would broaden the research focus and support the development of solutions better adapted to diverse socioeconomic and climatic contexts. As previous studies have pointed out, greater representation of authors from Latin America, Africa, and Asia would contribute to this goal [12].

Figure 5 also presents the fourteen main authors who have shown sustained interest in the topic of study, together with the number of articles published. In general, these researchers have experience in areas related to the energy efficiency of wood stoves, focusing on improving combustion chamber design and analyzing the emission factors of particles and pollutants derived from biomass combustion.



**Figure 5.** Documents by author of scopus.

Source from: Scopus (2024)

These results are consistent with previous studies that underscore the importance of energy efficiency in the design of biomass stoves. Recent research has shown that the optimization of combustion chambers can significantly increase thermal efficiency and reduce pollutant emissions such as carbon monoxide (CO) and particulate matter (PM) [13].

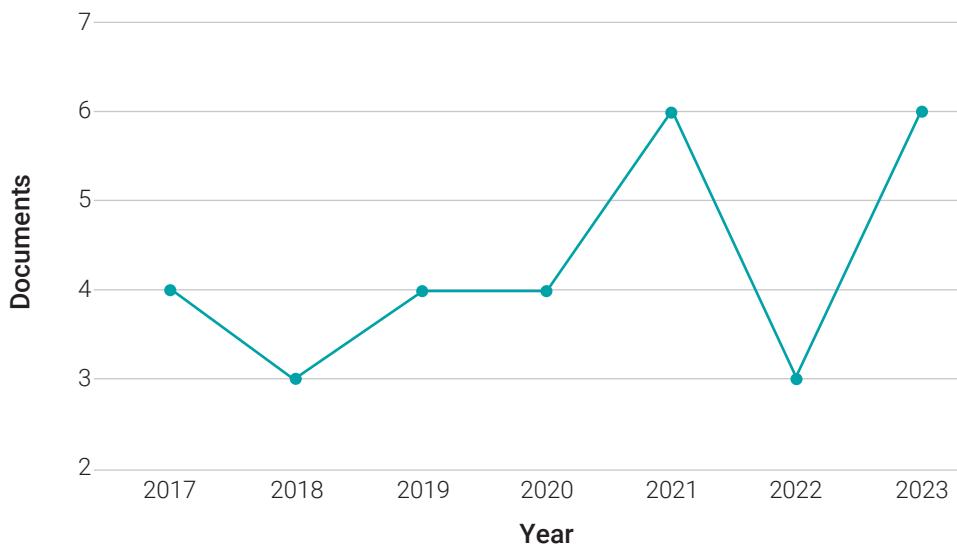
In addition, scientific production related to biomass stoves is dominated by a select group of authors specialized in the improved design of these devices. Research such as that carried out by González, J. A., and Ramírez, L. M. (2024) has shown that the development of more efficient combustion models is a priority within the scientific community due to its direct impact on environmental sustainability and public health, especially in rural communities that depend on biomass as a primary source of energy.

Another relevant aspect is the relationship between the experience of these authors and their affiliation with research centers specialized in renewable energies and clean technologies. Previous studies have shown that the most prolific researchers in this field are often linked to institutions that promote innovative solutions aimed at the energy transition and the mitigation of environmental impact [14].

Figure 6 shows the number of scientific articles published per year. It is observed that, in the last six years, interest in this line of research has not experienced exponential growth but has shown fluctuations. In 2021, there was an increase in the number of publications in the field; however, in 2022 there was a decrease of 5%

compared with the previous year. In 2023, the number of articles returned to levels similar to those observed in 2022.

It should be noted that the most recent studies reflect a growing interest in the promotion of clean air, through the control and optimization of the operation of wood stoves. This indicates that scientific production showed fluctuations between 2018 and 2024, with peaks in 2021 and a subsequent decline associated with funding factors.



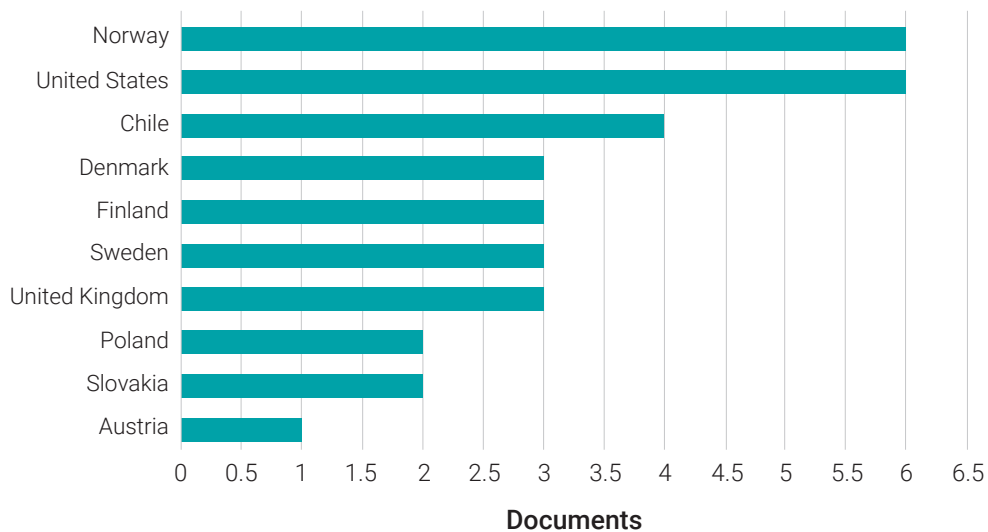
**Figure 6.** Documents per year of scopus.  
 Source from: Scopus (2024).

It should be noted that these findings are consistent with previous research that has also identified fluctuations in the number of scientific publications in areas related to energy efficiency and emission reduction in biomass stoves. Although there is a growing interest in the optimization of these devices, factors such as the availability of funding, the prioritization of other research lines, and global socioeconomic conditions may have influenced the annual variations observed in scientific production [13].

With regard to the most recent articles, there is a clear focus on improving air quality through the control and optimization of wood stove operation. This trend aligns with the growing concern for public health and climate change, as highlighted by recent studies that emphasize the importance of reducing pollutant emissions generated by these energy sources [13].

Likewise, an analysis of the documents recorded and published by country was conducted. Figure 7 presents the geographical distribution of contributions made in

relation to the research topic, with Norway, the United States, and Chile leading scientific production, while participation from Latin America remains limited, despite the region's high dependence on biomass.



**Figure 7.** Documents by country/territory.

Source from: Scopus (2024).

It should be noted that these findings are consistent with previous research that has also identified fluctuations in the number of scientific publications in areas related to energy efficiency and emission reduction in biomass stoves. Although there is a growing interest in the optimization of these devices, factors such as the availability of funding, the prioritization of other research lines, and global socioeconomic conditions may have influenced the annual variations observed in scientific production [13].

In relation to the most recent articles, there is a clear focus on improving air quality by controlling and optimizing the operation of wood stoves. This trend aligns with the growing concern for public health and climate change, as highlighted by recent studies that emphasize the importance of reducing pollutant emissions generated by these energy sources [13].

Likewise, an analysis of the documents registered and published by country was carried out. Figure 7 presents the geographical distribution of contributions made in relation to the research topic. The main countries that have shown the greatest interest in this field of study are Norway, the United States, and Chile.

This pattern is consistent with previous research that has highlighted the critical role of these countries in developing biomass technologies and optimizing wood-burning stoves. In the case of Norway and other European countries, research

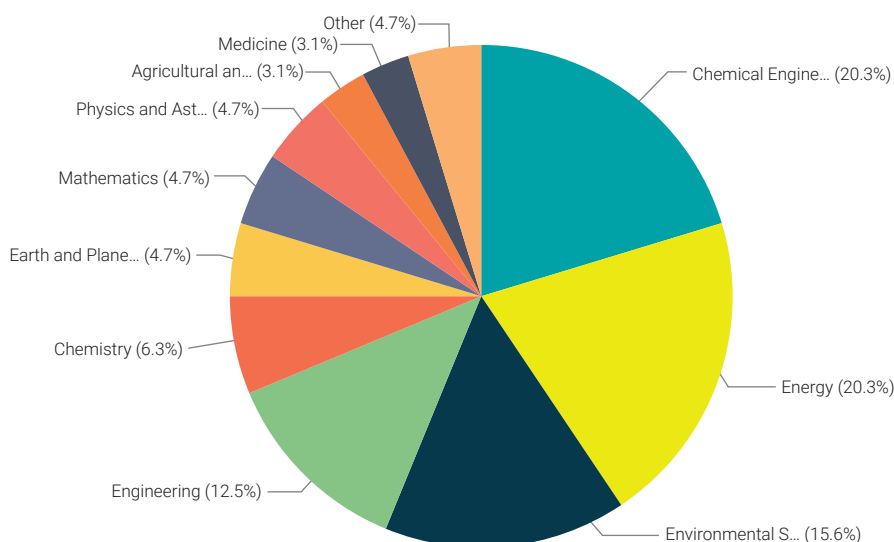
on biomass combustion has focused on improving thermal efficiency and reducing pollutant emissions associated with the use of wood stoves in rural areas [15].

Meanwhile, in the United States, advances in efficient stove design are linked to both academic research and industry-driven initiatives aimed at improving the sustainability and performance of these devices [16].

In Latin America, Chile has established itself as one of the most active countries in wood stove research, largely due to its high dependence on biomass for heating in rural areas. In this context, several studies have emphasized the need to develop solutions that not only optimize energy efficiency but also reduce negative environmental impacts, such as particulate matter emissions [17].

In summary, the findings show that research on biomass combustion is mainly concentrated in Norway, the United States, and Chile, countries that have led the development of more efficient and cleaner stoves. This geographical pattern underscores the need to continue strengthening international collaboration as a key strategy to address the technical and environmental challenges associated with the use of biomass.

In this sense, Figure 8 presents the topics addressed in the articles analyzed, highlighting that the predominant areas are: energy (20.3%), focused on combustion and energy efficiency in wood stoves; chemical engineering (20.3%) and engineering (12.5%), oriented toward the reduction of particulate matter (PM) through airflow configurations in combustion chambers and the implementation of new technologies; and environmental sciences (15.6%), focused on analyzing impacts associated with emissions of particulate matter and polluting gases.



**Figure 8.** Documents by subject area.

Source: Scopus (2024).

In relation to the above, it is important to note that several bibliometric analysis studies have been developed in this area, focused on increasing scientific production and identifying the organizations or universities with the greatest contribution, research areas, and relevant topics in the Web of Science (WoS) and Scopus databases [18]. In the WoS database, two bibliometric analyses carried out in 2016 and 2019 were identified, focused on scientific production related to Life Cycle Assessment (LCA) in Brazil and in the field of conventional and prefabricated construction, using the search algorithm “LCA and bibliometric” in the Title category. In Scopus, fifty-six (56) results were initially obtained by combining the terms “LCA” or “Life and Cycle” and “Assessment” and “Bibliometric” in the categories of title, abstract, and keywords. Subsequently, the abstracts were reviewed to filter those studies corresponding specifically to bibliometric analyses on LCA. From this process, articles were identified in various environmental areas, such as biorefineries, ecosystem services, carbon capture, storage and utilization technologies, photovoltaic solar energy, environmental footprint, bioenergy applied to architecture and construction, as well as scientific bibliometric studies on LCA.

It should be noted that bibliometric analyses—both globally and in specific national contexts—are among the documents with the highest number of citations, which demonstrates the growing interest in this topic. However, Life Cycle Assessment (LCA) is a constantly expanding field in terms of scientific production, which highlights the importance of updating these studies regularly. Continuous updating ensures that the information provided and the topics of interest accurately reflect emerging trends in different areas related to biomass and other environmental topics worldwide [19].

Similarly, the growing interest of environmental sciences in this field reflects a persistent concern about the long-term impacts associated with the use of wood stoves, especially in rural areas where they represent the primary source of energy. Several studies have emphasized the urgent need to reduce people’s exposure to particulate matter (PM) emissions due to their serious effects on public health and the environment [20]. This multidisciplinary approach is essential for addressing challenges related to wood stove use, integrating improved energy efficiency with the mitigation of environmental and health impacts.

## Effects of combustion on wood stoves

The most common emissions in combustion processes correspond to suspended particles, which represent a considerable risk to human health due to their hazardousness when inhaled. The World Health Organization (WHO) has recognized air pollution

as the most significant environmental threat to health, particularly highlighting the impact of suspended particles (PM) for their contribution to increased mortality and morbidity. Particulate matter with aerodynamic diameters smaller than  $2.5 \mu\text{m}$  ( $\text{PM}_{2.5}$  or fine particulate matter) has been associated with numerous respiratory and cardiovascular diseases, in addition to mutagenic effects, immune disorders, decreased cognitive performance, and sick building syndrome [21].

In terms of emissions, standard wood stoves generate approximately 21.6 mg/kg of particulate matter, while those equipped with a dedicated outdoor air intake duct reduce their emissions to 1.4 mg/kg [21]. According to these authors, the daily use of wood stoves for four hours can decrease life expectancy in individuals who are constantly exposed to particles from this activity.

Emissions generated by wood-burning stoves constitute one of the main sources of fine particulate matter ( $\text{PM}_{2.5}$ ), frequently causing daily concentrations of this pollutant to exceed the 24-hour air quality standard established by the NAAQS [22]. In response to this problem, new wood-burning stove designs have been developed to reduce both environmental impact and health risks for people who rely on this resource for home heating or cooking.

From a technical-experimental perspective, emissions from wood stoves—reported in g/kg of fuel—are reduced when the design optimizes the air-fuel mixture, turbulence, and residence time in the combustion chamber. Controlled tests with 22 stoves and six fuel types show that improvements in thermal efficiency do not always translate linearly into lower emissions if combustion efficiency is not controlled; therefore, performance metrics must distinguish between efficiency, specific emissions, and ventilation or smoke evacuation systems [23]. However, comparative laboratory and field studies show that emission factors and variability are typically higher in real use due to heterogeneous fuel loads, humidity, user operation, and aging equipment, underscoring the need to validate performance under real-world conditions [24].

In Latin America, Patsari fireplace griddle models have shown substantial reductions in  $\text{PM}_{2.5}$  and CO in kitchens. Studies in Michoacán report median decreases of 58–71% in indoor  $\text{PM}_{2.5}$  concentrations, despite the continued “combined use” with open stoves during transitions [25], [34]. At the level of personal exposure and biomarkers, significant decreases in urinary CO and PAHs have been observed in rural women after adopting the Patsari stove, although some metabolites remain above external reference values, reinforcing the importance of consistent stove use and proper maintenance [26]. Therefore, in addition to technological availability, adoption and sustained use—monitored with objective instruments—are determinants of real impact on health and the environment [27].

Co-health benefits include respiratory and cardiovascular improvements. Longitudinal trials and interventions in the region show a reduction in respiratory symptoms and a decrease in blood pressure after the introduction of vented stoves with fireplaces, which is consistent with epidemiological evidence on the acute and chronic effects of PM<sub>2.5</sub> and CO [33], [37]. These results emphasize that, even without reaching “clean” levels comparable to LPG or electricity, eco-efficient stoves with adequate evacuation can produce measurable benefits when used exclusively or predominantly [33], [37].

At the socioeconomic level, cost-benefit evaluations in communities estimate B/C ratios of approximately 9:1 to 11:1, driven by savings in firewood, time, and health benefits [28]. However, systematic reviews warn that the scale and sustainability of these benefits depend on enablers such as after-sales service, cultural relevance, durability of components (griddle, chamber, chimney), and financing schemes. Without these elements, adoption barriers may emerge that erode the impact [35], [31]. Programs that incorporate local markets, maintenance strategies, and usage monitoring tend to show more robust results [35], [31].

Regarding climate, the black carbon (BC) fraction of biomass emissions is a positive radiative forcer of relevant magnitude. Its reduction through cleaner stoves provides short-term climate mitigation along with health benefits [29]. Integrated analyses of replacement options show that combining low emissions with effective ventilation (e.g., ventilated iron stoves or forced combustion with evacuation) can bring PM<sub>2.5</sub> exposures closer to intermediate or low bands, while changes focused solely on energy efficiency may fail to reduce exposures if they do not also reduce emissions or adequately evacuate fumes [36]. Additionally, field measurements in Mexico document reductions in GHG and organic/black carbon when open stoves are replaced with improved models, with outcomes sensitive to usage patterns and fuel moisture [32].

Finally, in the regional context, although the proportion of households cooking mainly with solid fuels has decreased globally since 1980, the number of exposed people has remained high due to population growth. In the Americas, the average is lower than in Africa and Asia, but rural pockets with intensive firewood use and indoor exposure persist, reinforcing the relevance of eco-efficient designs and transitions to clean energy [30].

## Analysis of wood stoves in Latin America

The analysis addresses wood stoves, combustion, emission factors and emissions of particulate matter (PM) and volatile organic compounds (VOCs), as well as the

diseases associated with their use. In addition, the process of reconfiguring the combustion chamber is described, which has allowed wood stoves to evolve towards eco-efficient models. Table 2 presents and compares the most representative models of firewood used in Latin America, along with their country of origin.

**Patsari (Mexico):** 67% reduction in  $PM_{2.5}$  and 66% reduction in CO; positive effect on respiratory health.

**La Justa (Central America):** rocket-type chamber and metal chimney; 70% thermal improvement.

**Ecofogón and ONIL (Guatemala):** prefabricated, easy maintenance, reduce firewood consumption by up to 71%.

**Huellas and Ergonauta (Colombia):** local adaptation, use of metallic materials and ventilated chimney.

These technologies have demonstrated environmental and social benefits, although their sustained adoption depends on cultural factors, maintenance, and institutional support.

**Table 2. Wood stoves in Latin America**

Name	Country	Description
Prints	Colombia	Materials: refractory and normal brick, mortar and metal parts. Components: combustion chamber, metal oven, four burners distributed in two metal plates, internal and external chimney. [38]
FN – Fundación Natura	Colombia	Materials: brick, mortar and hardware. Components: combustion chamber, metal furnace, draught regulation register, ash deposit register, internal and external chimney. Developed under the design of the ICA-1791 stove. Combustion chamber based on the Rocket system. . [39]
ICA-1791	Colombia	Materials and components: Huellas and FN stoves.[40]
Lorraine	Mexico	Materials: mud, sand, prickly pear leaves, cow straw, burnt oil, cement, galvanized pipes, comales and rods. Components: wooden table, combustion chamber and external chimney.[41]
Rocket	United States	Materials: metal sheets, clay, sawdust, brick and cement. Components: loading drum, insulated combustion chamber, vertical chimney and grate. Home heating system.[42]

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*(viene)*

Name	Country	Description
Ergoning	Colombia	Materials: mortar, paving stones, aluminum sheet and galvanized sheets. Components: burners, oven with thermometer, grill, water heater, combustion chamber and embedded doors.[43]
Statue	Mexico	Materials: brick, concrete, sand and gravel and barrier. Components: combustion chamber, burners, chimney, comales, galvanized pipes, chacuaco and chimney base. [44]

**Source:** own work

Table 3 summarizes the advantages and disadvantages associated with these technologies

**Table 3. Comparative table of wood stoves in Latin America**

Name	Advantages	Disadvantages
Prints	<ul style="list-style-type: none"> <li>Accessible material.</li> <li>Reduction of GHG emissions (CO<sub>2</sub>, CO, Nox, SO<sub>2</sub>).</li> <li>Reduces MP by 94.2%.</li> </ul>	<ul style="list-style-type: none"> <li>It must be indoors.</li> <li>Fixed stove.</li> </ul>
FN – Fundación Natura		<ul style="list-style-type: none"> <li>It takes time to boil water.</li> <li>Fixed stove.</li> </ul>
ICA-1791	<ul style="list-style-type: none"> <li>Improvement of the Huellas and FN stove.</li> </ul>	<ul style="list-style-type: none"> <li>An average efficiency value of 10% is considered widely accepted for the traditional stove/burner.</li> </ul>
Lorraine	<ul style="list-style-type: none"> <li>Reduce firewood consumption by 50% to 60%.</li> <li>Construction with local materials.</li> <li>Cooking food at the same time.</li> </ul>	<ul style="list-style-type: none"> <li>Control of the inlet of wood combustion.</li> <li>Constant cleaning of griddles and internal space with the oven.</li> </ul>
Rocket	<ul style="list-style-type: none"> <li>Low wood consumption.</li> <li>Reduction of emissions by almost 90%.</li> <li>Construction with local materials. It can cook for a long time without being fed constantly. Structure to create heating system.</li> </ul>	<ul style="list-style-type: none"> <li>Few functions, a single cooking station.</li> </ul>
Ergoning	<ul style="list-style-type: none"> <li>It emits around 10% of CO<sub>2</sub> emissions.</li> <li>Reduces firewood consumption by 70%.</li> <li>Multiple ways of cooking food.</li> <li>It produces electrical energy by means of a thermogenerator.</li> <li>Mobile stove.</li> </ul>	<ul style="list-style-type: none"> <li>It stores a certain amount of energy in the battery.</li> </ul>

*(continúa)*

(viene)

Name	Advantages	Disadvantages
Statue	<ul style="list-style-type: none"> <li>Reduces toxic gas (CO) concentrations by 66%</li> <li>Reduces firewood consumption by 50%.</li> <li>Construction with local materials.</li> </ul>	<ul style="list-style-type: none"> <li>Constant maintenance.</li> <li>The smoke is returned through the entry of the air due to the clogging of tunnels or chimneys.</li> <li>It takes time to heat the pots or eat them.</li> </ul>

**Source:** own work

Wood stoves with an eco-efficient approach have the following characteristics: "Improved stoves can use up to 71.2% less wood than traditional stoves, depending on the technology and the user" [51]. Furthermore, "average concentrations of carbon monoxide (CO) and fine particulate matter (PM<sub>2.5</sub>) over 48 hours were reduced by 66% and 67%, respectively" [45]. This highlights that the new proposals contribute to improving stove designs and the health of people frequently exposed to this type of device.

Among the predominant models are: "In Latin America, designs such as Patsari and La Justa have been developed, as well as prefabricated designs such as Ecofogón and ONIL" [48]. In this region, it has also been recognized that "the use of the Patsari stove significantly reduced women's exposure to CO and PAH" [46], and that it offers health-supporting functions, such as: "actual Patsari stove use reported by women showed a protective effect primarily on the duration of upper and lower respiratory infections" [47]. This is one of the central features sought in eco-efficient stoves for rural families. When the use of these cooking tools is monitored, "significantly lower expression of the MMP-9 gene was observed in induced sputum cells from women who used a fireplace stove" [49].

Another relevant example in this analysis is that "the Justa clean-burning stove is common in Latin America, with a rocket-like combustion chamber, chimney, and metal plate" [50]. These cooking prototypes aim to have a positive impact on both health and the environment. In Colombia, Metalcof's Huellas and Ergonauta are recognized models, already built and currently in use.

## Social impact of wood stoves

The use of wood-burning stoves in rural communities has a significant impact on social welfare, influencing both the health of inhabitants and the environmental conditions in which they reside. In many regions, these stoves are still the main source

of energy for food preparation, which creates substantial effects on daily life. From a public health perspective, prolonged exposure to smoke generated by wood combustion contributes significantly to the development of chronic respiratory diseases. These conditions particularly affect women and children, who spend more time in enclosed spaces where these devices are used. Research has shown that inhalation of particles derived from biomass burning is associated with increased incidence of lung and cardiovascular diseases, posing a considerable challenge to health systems in developing countries.

In the environmental sphere, the indiscriminate use of firewood as a fuel source has intensified deforestation in several regions, threatening biodiversity and contributing to climate change. Excessive logging of trees for firewood not only reduces forest cover but also alters local ecosystems, affecting the availability of natural resources essential for community subsistence. From a social perspective, limited access to clean fuels perpetuates conditions of poverty and inequality, as families dependent on wood stoves must devote significant time and effort to collecting firewood, limiting opportunities for economic and educational development.

The transition to eco-efficient stoves is proposed as a viable alternative to improve the quality of life of these populations by reducing health risks, mitigating environmental impacts, and optimizing the use of energy resources [51].

Therefore, the implementation of programs that promote the adoption of eco-efficient stoves not only generates benefits at the individual level but also strengthens community resilience by fostering awareness of the importance of employing sustainable technologies. This contributes to more equitable and sustainable development, producing a positive impact on health, the environment, and socioeconomic conditions among populations that rely on this type of technology in their daily lives.

Likewise, the results obtained show that various research efforts have contributed significantly to improving efficiency in the use of biomass by transforming it into high-energy materials. Methods such as gasification, briquetting, bioconversion, thermal modification, and fuel synthesis stand out. In this context, pelletization emerges as a notable technological alternative, as it allows the densification of loose materials through pressure and binders, optimizing their energy power, transport, and storage. The variety of techniques and equipment used—from manual pelletization to roller presses—demonstrates the scientific and technological interest in developing adaptable, sustainable, and low-environmental-impact solutions that contribute to the efficient use of biomass resources and to the transition toward cleaner and more sustainable energy systems [52].

# Discussion and conclusions

## Discussion

The analysis reveals that rocket-type models (Justa, Ecofogón) offer greater thermal efficiency; however, their actual performance is affected by the simultaneous use of open stoves and the lack of proper maintenance. Iron-plated models (Patsari, Huellas) contribute to improving indoor air quality, although they face durability challenges due to corrosion.

At the methodological level, regional research lacks standardized protocols for evaluating performance and emissions, which limits comparability among studies. In addition, sociocultural barriers—such as preference for traditional cooking methods, high initial costs, and limited technical assistance—restrict sustainable adoption, underscoring the need to integrate environmental education and technology-subsidy policies.

Compared with Europe, where engineering and energy efficiency approaches predominate, Latin America provides an essential social and health perspective, although with less technical rigor and limited international visibility. Strengthening collaboration and inter-institutional publication networks among Latin American universities is necessary.

On the other hand, the use of eco-efficient stoves has generated a positive impact, as these devices—designed to optimize fuel use—significantly reduce indoor smoke emissions, improve health conditions, and decrease firewood consumption, thereby contributing to environmental conservation. Bibliometric analysis not only validates current research areas but also offers a valuable tool to guide future studies and environmental policies regarding eco-efficient technologies.

However, the results of this analysis show trends similar to those observed in other bibliometric studies on biomass combustion and renewable energies. The identification of the most influential authors, along with the low recurrence of publications among most researchers, highlights the need to strengthen collaboration networks and diversify research lines in this field. The identification of the fourteen lead authors reflects patterns seen in previous studies, where a small group of researchers concentrates leadership in scientific production related to biomass combustion and the design of more efficient stoves. These findings emphasize the importance of fostering international collaboration and promoting diversity in research in order to address environmental and energy challenges from multiple perspectives.

Research gaps remain evident, and scientific research topics can be unified. As observed in this study, the literature analysis enabled the consolidation of information

on eco-efficient stoves in Latin America. An important opportunity was identified to analyze the health impacts of wood stove use alongside the implementation of new eco-efficient models. This opens the possibility of expanding documentary research on health impacts and developing future perspectives such as:

- Standardization of measurements: creation of a Latin American protocol to measure thermal efficiency, emissions, and durability.
- Integration of 4.0 technologies: use of IoT sensors to monitor indoor air temperature, fuel consumption, and air quality.
- Longitudinal evaluation: study of long-term impacts on the health and quality of life of rural families.
- Strengthening of public policies: integration of subsidies, maintenance strategies, and community training into energy transition programs.
- Regional scientific cooperation: establishment of academic networks for innovation and technology transfer on eco-efficient stoves.

## Conclusions

This review integrated bibliometric analysis and a structured review of technologies, showing that research on biomass combustion is led by European countries, while Latin America presents isolated advances. The eco-efficient stoves evaluated significantly reduce  $PM_{2.5}$  and CO emissions, improve respiratory health, and optimize the use of energy resources.

However, their effective adoption depends on socio-technical sustainability and public policies that ensure maintenance, financing, and cultural appropriation. It is concluded that eco-efficient stoves are a key tool for climate mitigation and energy equity, and that strengthening Latin American research in this field will enable the development of more adapted, sustainable, and measurable solutions.

The use of eco-efficient stoves has generated a positive impact, as these devices—designed to optimize fuel use—significantly reduce indoor smoke emissions, improve health conditions, and reduce firewood consumption, thereby contributing to environmental conservation. Bibliometric analysis not only validates current research areas but also offers a valuable tool to guide future studies and policies related to eco-efficient technologies.

The results of this analysis show trends similar to those observed in other bibliometric studies on biomass combustion and renewable energies. The identification of the most influential authors, together with the low recurrence of publications

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## Contribution of the authorship

Jennifer Tovar Quintero: conceptualization, methodology, bibliometric analysis, initial writing.

Catherine Johana Jaimes Silva: documentary research, writing, editing, and revision.

Jorge Enrique Arboleda Puerta: content validation, final review, academic advising.

Edwin Santiago Gutiérrez Perdomo: data systematization, methodological support, review.

## Thanks

We thank the National Open and Distance University (UNAD) and the Cooperative University of Colombia for their institutional support. We also thank the rural communities that shared their experiences with wood stoves. This research would not have been possible without their participation.

## Financing

The funding institutions, both in cash and in kind, are the National Open and Distance University and the Cooperative University of Colombia. The project was endorsed in the Internal 11 call under project code PSIIN0101ECBTI2023.

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