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Application of thermoelectric generators for the green hydrogen production: A systematic review

Aplicación de generadores termoeléctricos para la producción de hidrógeno verde: Una revisión sistemática

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Resumen

Objetivo: Analizar la evolución y las dinámicas de investigación relacionadas con el uso de generadores termoeléctricos (TEG) para la producción de hidrógeno verde con el fin de identificar a los principales contribuyentes, las áreas temáticas y las oportunidades tecnológicas dentro de este campo. **Metodología:** Se presenta una revisión sistemática basada en el enfoque PRISMA 2020 para identificar redes de coocurrencia y evaluar el impacto de la integración de TEG en sistemas de energía solar, procesos de recuperación de calor y aplicaciones de energía geotérmica. Un total de 119 documentos científicos fueron indexados en las bases de datos de Scopus y Web of Science entre 2012 y 2026. **Resultados:** Los resultados revelan un aumento exponencial en la producción científica, alcanzando un máximo histórico de 27 documentos en 2025. Esta tendencia destaca la consolidación de TEG como un componente clave en las estrategias globales de descarbonización y transición energética. **Discusiones:** Las tendencias actuales de investigación posicionan a los TEG como un componente fundamental en la sostenibilidad de los sistemas de generación de energía. Su integración con fuentes de energía renovable y residual ha demostrado ser tanto técnicamente viable como ambientalmente ventajosa, facilitando la generación dual de electricidad e hidrógeno. **Conclusiones:** El análisis concluye que la investigación sobre la tecnología de TEG para la producción de hidrógeno verde experimentó un crecimiento de 250% entre 2020 y 2025, con Asia representando el 74% de las contribuciones. Los TEG demuestran una clara viabilidad para la generación dual de electricidad e hidrógeno.

Palabras claves: revisión sistemática, generador termoeléctrico, hidrógeno verde, recuperación de calor residual, transición energética.

Abstract

Objective: To analyze the evolution and research dynamics related to the use of thermoelectric generators (TEG) for green hydrogen production to identify the main contributors, thematic areas, and technological opportunities within this field. **Methodology:** A systematic review based on the PRISMA 2020 approach is presented to identify co-occurrence networks and assess the current impact of TEG integration on solar energy systems, heat recovery processes, and geothermal energy applications. A total of 119 scientific documents were filtered in the Scopus and Web of Science databases between 2012 and 2025. **Results:** The results reveal an exponential increase in scientific production, reaching a historic peak of 27 documents in 2025. This trend highlights the consolidation of TEG as a key component in global decarbonization and energy transition strategies. **Discussions:** Current research trends position TEG as a fundamental component in the sustainability of energy generation systems. Their integration with renewable and residual energy sources has been shown to be both technically viable and environmentally advantageous, facilitating the dual production of electricity and hydrogen. **Conclusions:** The analysis concludes that research on TEG technology for green hydrogen production experienced a 250% growth between 2020 and 2024, with Asia accounting for 74% of the contributions. TEG demonstrates clear feasibility for dual generation of electricity and hydrogen.

Keywords: systematic review, thermoelectric generator, green hydrogen, waste heat recovery, energy transition.

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1. Introduction

The growing energy demand, coupled with the depletion of fossil fuels reserves and the consequent rise in pollutant emissions, has precipitated a severe environmental crisis and intensified the urgency for sustainable energy alternatives [1]. In response, there is a growing need for alternative energy sources to supply energy demand across multiple end-use sectors including transport, residential/commercial buildings, and industry [2].

A systematic plan is required to gradually reduce the use of fossil fuels. With this context, hydrogen has emerged as a key vector for achieving decarbonization goals across multiple sectors of the economy [3]. Hydrogen is characterized by its high energy density, versatility for use in diverse applications, and clean combustion, which makes it a promising energy source in the pursuit of sustainability [4].

Hydrogen can be produced primarily through two main types of processes: electrochemical processes (proton exchange membrane electrolysis cells and microbial electrolysis cells) and thermochemical processes (biomass gasification, steam reforming, partial oxidation, supercritical water gasification, aqueous-phase reforming, and biomass pyrolysis) [5]. Depending on the production pathway, hydrogen is classified into five categories, commonly referred to as colors: turquoise, gray, brown, blue, and green [6].

The generation of green hydrogen involves the use of energy derived from sustainable resources. Currently, green hydrogen is more expensive to produce than hydrogen generated from hydrocarbon-based fuels or through natural gas reforming. Therefore, green hydrogen requires supportive policies and regulations, as well as the development of alternative production methods that enable it to become cost competitive [7].

Green hydrogen is an emerging fuel for the transition toward cleaner and more sustainable energy systems. This type of hydrogen is produced through the chemical process of electrolysis, in which water is converted into hydrogen and oxygen [8]. Energy derived from sustainable resources is used to power the electrolyzer. The hydrogen produced can be stored for various applications, such as aviation, maritime transport, and the chemical industry [9]. This alternative method of hydrogen production is gaining traction as a promising strategy to mitigate environmental impacts and reduce emissions.

Another technology associated with renewable energy is the TEG [10]. These devices have the capability to generate electricity from a thermal source, which can subsequently be used for hydrogen production through water electrolysis. The operating principle of TEG is based on the Seebeck thermoelectric effect, whereby a temperature difference generates an electric current [11]. The thermal energy required by TEG can originate from various sources, such as combustion exhaust gases, industrial waste heat, and renewable sources (solar and geothermal) [12]. The reliability and adaptability of TEG make them a promising technology for integration into green hydrogen generation and storage systems.

The analysis of the literature reveals that green hydrogen is a key fuel for achieving a carbon-free energy transition. Furthermore, TEG are identified as devices with the potential to harness various thermal sources for electricity generation. Given the importance of green hydrogen, TEG may represent a promising solution for the simultaneous production of electricity and hydrogen.

Therefore, this study performs a bibliometric analysis focused on the use of TEG for green hydrogen production. In addition, it evaluates the potential applications of TEG in the utilization of renewable energy sources and waste heat recovery. The research aims to identify the main contributors, thematic areas, and technological opportunities, as well as to assess the overall potential of TEG.

2. Methodology

This section describes the methodology of the systematic review and meta-analysis of the PRISMA 2020 approach to identify relevant trends, reduce biases and delete irrelevant and low-quality studies in scientific production [13]. The Scopus and Web of Science databases were used as primary information resources to generate the dataset from experimental and computational studies that describe the main technological applications of TEG in green hydrogen production systems and heat recovery processes [14].

The systematic review and meta-analysis followed a series of structured steps. First, the appropriate formulation of the query equation was determined. Second, filtering procedures were applied based on inclusion and exclusion criteria, in accordance with the PRISMA 2020 guidelines [13].

Relational patterns were identified among countries, research topics, fields of study and institutions. Finally, a literature search was conducted to assess the potential of TEG technology for green hydrogen production and waste heat recovery applications across transport, commercial and residential buildings, and industrial systems [15].

The query equation used in the Scopus and Web of Science databases to identify documents related to TEG technologies is presented in equation 1. The ScienceDirect Topics engine was employed to identify keywords commonly applied in scientific vocabulary to select the keywords for the search equation. This query equation was conducted in the Scopus and Web of Science databases on November 4, 2025, yielding a total of 298 documents from 2012 to 2026.

("green hydrogen" OR "hydrogen production") AND ("thermoelectric generator" OR "thermoelectric device" OR "thermoelectric conversion" OR "thermoelectric power generation" OR "thermoelectric equipment"). (1)

The methodology provides a standardized framework documenting systematic reviews and meta-analyses from the bibliometric data. This review process ensures bias reduction and strengthens the validity of results during the identification, selection and evaluation stages of scientific publications related to the application of TEG for green hydrogen production and waste heat recovery systems.

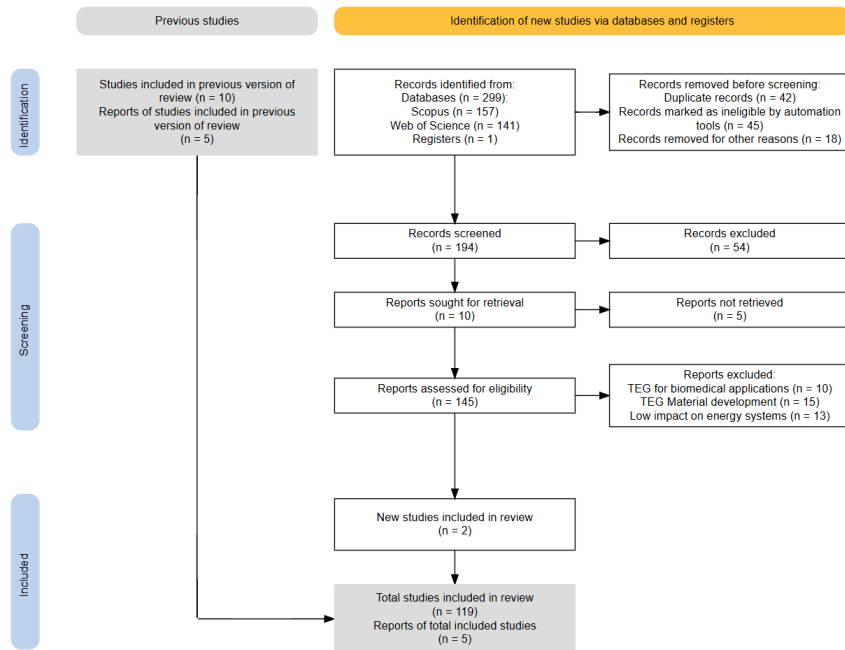
Figure 1 presents the methodology of systematic analysis based on PRISMA 2020 approach [13]. In the identification phase, a total of 299 records were retrieved from the Scopus and Web of Science scientific databases. This dataset was subjected to a refinement and selection process under the PRISMA 2020 framework, applying exclusion criteria such as the removal of duplicates, automated exclusion of irrelevant documents, and inclusion only of publications in the form of peer-reviewed scientific articles.

Subsequently, during the screening stage, 194 unique documents were filtered, selecting only those studies that directly addressed TEG applications within the energy context. Articles related to biomedical applications (n = 10), material development for TEGs without energy integration (n = 15), and studies with low impact on green hydrogen production and heat recovery systems (n = 13) were excluded.

Finally, 119 studies were included in the systematic review, consolidating a specific dataset that represents the current state of knowledge on the use of TEG for green hydrogen production and heat recovery systems. The PRISMA 2020 framework enhanced the traceability of data analysis, enabling replicability in future similar studies.

Furthermore, the set of metadata from the Scopus and Web of Science databases were also exported to represent the co-occurrence networks from the application of VOSviewer software and describe the main results of the meta-analysis based on the application of TEG in the production of green hydrogen and the integration of renewable energy resources for waste heat recovery applications in energy generation systems.

Figure 1. Systematic analysis methodology.



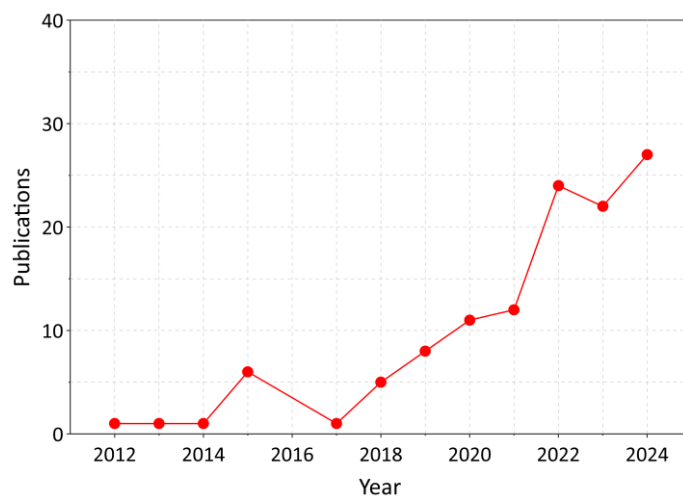
Source: Own elaboration.

3. Results

3.1. Number of documents per year

The results show an exponential increase in the number of published documents. Between 2012 and 2020, a total of 34 publications were reported, while between 2021 and 2024 the number rose to 85. This represents a 250% increase in research on hydrogen production through TEG, reflecting significant growth within the scientific community in this field of study. Between 2021 and 2024, an average of 21 publications per year was observed, reaching a maximum in 2024 with 27 documents. The increase in scientific production may be associated with energy transition objectives aimed at decarbonization, where hydrogen and the use of residual energy sources represent key solutions for reducing and substituting fossil fuel consumption. Figure 2 shows the variation in the number of documents published between 2012 and 2024.

Figure 2. Annual publications on research in hydrogen production through TEG.

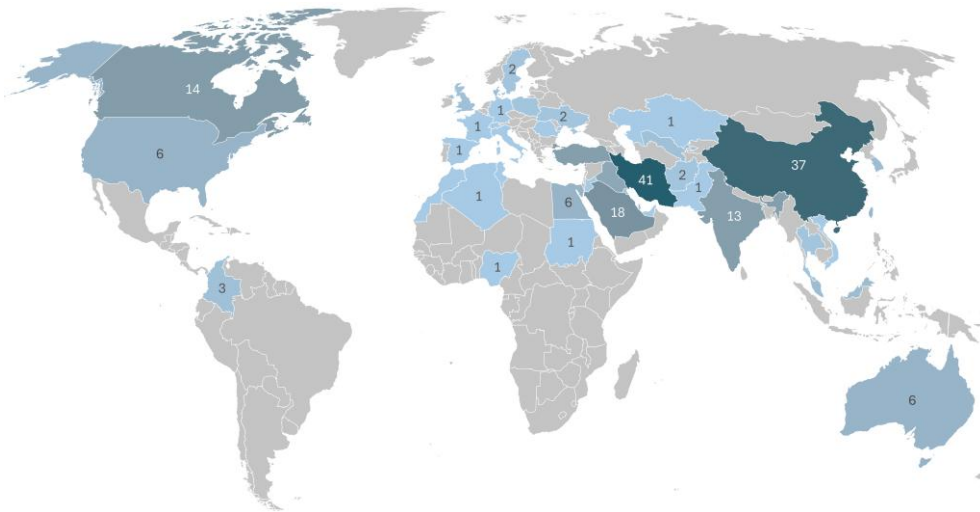


Source: Own elaboration.

3.2. Geographic distribution analysis

The documents published between 2012 and 2024, 74% were concentrated in Asia. The remaining percentages were distributed as follows: 10.1% in the Americas, 8.4% in Europe, 4.8% in Africa, and 2.6% in Oceania. The seven countries with the highest scientific output on hydrogen generation from TEG were Iran (41), China (37), Saudi Arabia (18), Canada (14), India (13), Turkey (13), and Iraq (10). In general, the results indicate that research on hydrogen production from TEG is not uniformly distributed; instead, it reflects national energy priorities, policies, sustainability strategies, and resource availability. In countries such as Iran and Saudi Arabia, research on hydrogen production technologies is promoted to foster energy diversification. Similarly, countries such as China, India, and Turkey have invested significantly in decarbonization and clean energy. Finally, industrialized countries such as Canada show interest in hydrogen as a means of reducing greenhouse gas emissions. In Figure 3, the global distribution of publications by country on the research topic, prepared using Microsoft Excel, is shown.

Figure 3. Geographical distribution of publications.



Source: Own elaboration.

3.3. Institutions

Based on the metadata, 160 institutions were identified as contributors to this field between 2012 and 2024. The three institutions with the highest number of publications were the University of Tehran, with 14 documents, followed by Ontario Tech University (8) and Prince Sattam Bin Abdulaziz University (7).

The participation analysis revealed that only 17.5% (28/160) of the institutions published more than three documents. A total of 61.3% (98/160) published between two and three documents, while the remaining 21.3% contributed only one document. In Table 1, the ten institutions with the highest global productivity in the selected research topic are shown.

Table 1. Top 10 of the most productive institutions in the subject.

Nº	Institution	Country	Documents
1	University of Tehran	Iran	14
2	Ontario Tech University	Canada	8
3	Prince Sattam Bin Abdulaziz University	Saudi Arabia	7
4	GLA University, Mathura	India	7
5	Isparta University of Applied Sciences	Turkey	7
6	King Khalid University	Saudi Arabia	6

7	Urmia University	Iran	5
8	Iran University of Science and Technology	Iran	5
9	King Saud University	Saudi Arabia	5
10	University of Guilan	Iran	5

Source: Own elaboration.

3.4. Journals

45 journals published documents on this research topic. The International Journal of Hydrogen Energy ranked first with 20 publications. The second, third, and fourth positions were occupied by Energy, Renewable Energy, and Sustainable Energy Technologies and Assessments, each with 7 publications. In Table 2, the main journals specializing in hydrogen production through TEG are shown.

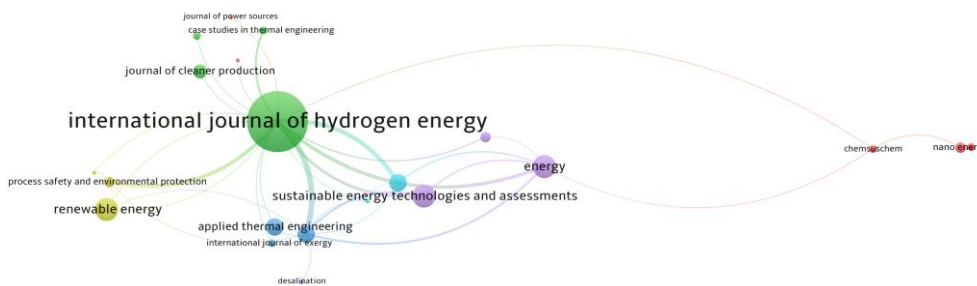
Table 2. Top 10 journals ranked by number of documents published.

Nº	Journal	Documents	Percent. (%)
1	International Journal of Hydrogen Energy	20	18.3
2	Energy	7	6.4
3	Renewable Energy	7	6.4
4	Sustainable Energy Technologies and Assessments	7	6.4
5	Applied Energy	5	4.6
6	Applied Thermal Engineering	5	4.6
7	Energy Conversion and Management	5	4.6
8	Journal of Cleaner Production	4	3.7
9	Nano Energy	3	2.8
10	Process Safety and Environmental Protection	3	2.8

Source: Own elaboration.

Percentage analysis indicates that the International Journal of Hydrogen Energy accounted for 18.3% of the total publications. To better visualize the relationships among journals publishing on the research topic, a network visualization was generated with VOSviewer, as shown in Figure 4.

Figure 4. Correlation network between journals during the period 2012 – 2024.



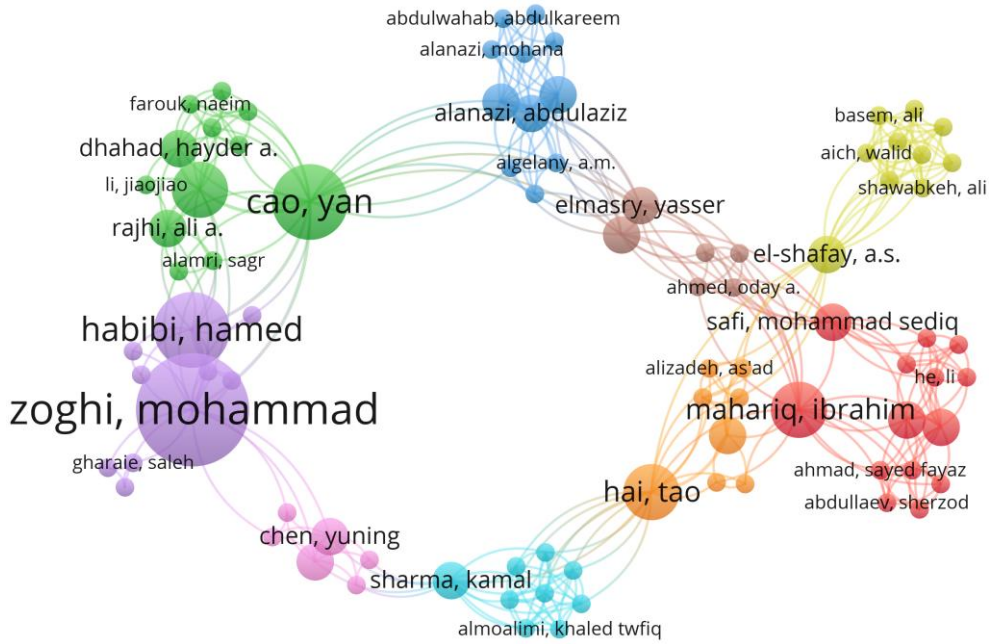
Source: Own elaboration.

Based on the VOSviewer data, 8 clusters (groups of strongly interrelated journals) were identified, with 38 links and a total link strength of 70. The connections among journals derive from co-authorship, keyword co-occurrence, and co-citation. The largest node (circle) corresponds to the International Journal of Hydrogen Energy, which indicates a higher number of global citations.

3.5. Keywords

A total of 1218 keywords were identified in research on green hydrogen production through TEG. The most frequent keywords include “hydrogen

Figure 6. Network co-authorship between the authors.



Source: Own elaboration.

Table 3. Top 10 of the most productive authors publishing on the subject.

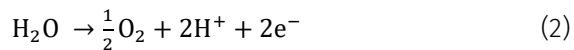
Nº	Author	Documents	Citations
1	Zoghi Mohammad	6	322
2	Ahmadi Pouria	5	631
3	Mehrpooya Mehdi	5	241
4	Ozturk Murat	5	82
5	Cao Yan	4	192
6	Assareh Ehsanolah	4	356
7	Habibi Hamed	4	282
8	Khanmohammadi Shoaib	4	112
9	Dincer Ibrahim	4	198
10	Yilmaz Fatih	4	62

Source: Own elaboration.

3.7. Applications for green hydrogen production using TEG

Green hydrogen production occurs through the electrolysis process, which uses electric current to dissociate water. Among the technologies used for green hydrogen generation are alkaline electrolyzers. These devices separate hydrogen and oxygen through the reaction shown below:

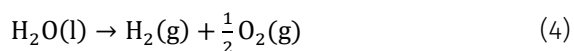
Anode (water oxidation):



Cathode (proton reduction):



Overall equation:



The electrical energy required for water electrolysis can be supplied by TEG. The versatility of TEG enables their use in various applications, as described below.

3.8. Solar Energy

Solar energy is one of the primary renewable energy sources worldwide [16]. Due to its intermittent nature, solar energy systems are often coupled with energy storage technologies [17]. Hydrogen production serves as a form of energy storage, enabling the utilization of excess energy in these systems [18]. In this context, TEG can recover heat dissipated during electrolysis and convert it into electricity, thereby improving overall system efficiency [19]. Additionally, TEG can generate electricity from the temperature difference between solar panels and the surrounding air. This electricity can be used to power the electrolyzer.

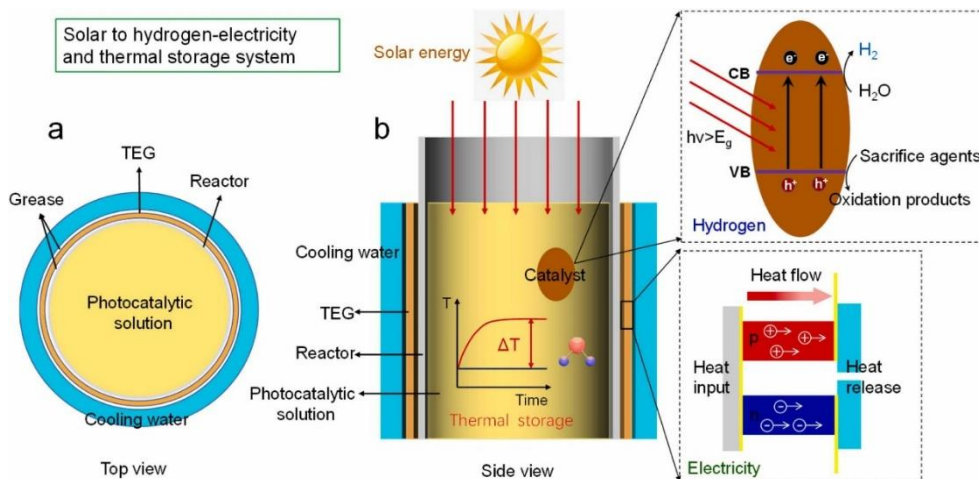
The advancement and widespread adoption of solar technologies have become a viable alternative in response to the progressive depletion of fossil fuels. Broadly speaking, the utilization of energy from the sun is classified into three major areas: photovoltaic conversion, solar thermal energy, and biofuel-derived technologies [20]. Among these options, the production of solar fuels through the photolysis of water to generate hydrogen has emerged as one of the most prominent pathways for transforming solar radiation into renewable energy sources [21].

Hydrogen has been extensively studied due to its high energy content, clean nature, and minimal contribution to carbon emissions [22]. Typically, the photochemical processes involved in photolysis occur at temperatures below 100 °C. On the other hand, TEG devices capable of converting temperature differences into electrical energy have found widespread use across multiple fields [23].

They are employed in hybrid photothermal electric systems, configurations integrating photovoltaic and thermoelectric modules, applications in small hydropower plants, photoelectrochemical systems coupled with thermoelectric modules, waste-heat recovery processes, as well as in devices designed to harness body heat, among other technological developments [24].

In recent years, more advanced architectures integrating thermal storage with solar-driven conversion for hydrogen production have been proposed (see Figure 7). These systems are generally divided into two main components: a photothermal catalytic module responsible for generating hydrogen, and a TEG designed to recover low-grade waste heat and convert it into electricity.

Figure 7. The schematic diagram of solar to hydrogen electricity and thermal storage system: (a) top view and (b) side view.



Source: Adapted from Zhang et al. [25].

Table 4 presents studies on the integration of TEG with solar energy systems.

Table 4. TEG applications with solar energy.

Author	Methodology	Results
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[26]	Proposed a system for solar thermoelectric electrolysis (STEG) of water using iron sulfide nanosheet arrays.	A hydrogen yield of 10.4 $\mu\text{mol/h}$ and an overall conversion efficiency of 2.0% were obtained.
[25]	Proposed a solar thermal hydrogen energy storage (STHET) system. This system integrates photothermal catalytic processes with TEG and liquid-phase thermal storage.	The results show a 22.7% improvement in hydrogen production compared to conventional methods, which is attributed to efficient solar energy recycling and optimal TEG utilization. Furthermore, the TEG demonstrated significant utilization of waste heat, achieving a maximum output power of 1578.13 μW .
[27]	Proposed an integrated control strategy combining maximum power point tracking (MPS) with dual-axis solar tracking (DAST), improving the actual performance of the photovoltaic-thermoelectric generator (PV-TEG).	The average power output increased by 71.73%, and the photovoltaic conversion efficiency improved by 10.01%.

Source: Own elaboration.

3.9. Waste heat recovery

In recent years, energy efficiency and the reduction of industrial emissions have become global challenges, driven by the increasing scarcity of energy resources and worsening environmental degradation [28]. One key approach to addressing this issue is the utilization of waste heat, which represents an abundant energy source in various industrial processes.

TEG technology makes it possible to directly convert low- and medium-temperature heat into electricity through the Seebeck effect. TEG are notable for their simple design, lack of moving parts, silent operation, zero emissions, and long service life. Owing to these characteristics, TEG technology has emerged as a promising alternative for generating energy from waste heat.

The transportation and industrial sectors are among the largest energy consumers worldwide, and both rely primarily on fossil fuels, which results in a significant release of waste heat into the environment [29]. Recovering and harnessing this wasted energy can reduce the use of non-renewable fuels, lower CO₂ emissions, and mitigate the effects of climate change.

Moreover, because waste heat is an energy source available at no cost, the limited efficiency of TEG becomes less critical; on the contrary, characteristics such as their compact design, scalability, and high reliability make them particularly suitable for this type of energy recovery application. Table 5 summarizes various waste heat sources that can be used for hydrogen production via TEG.

Table 5. Sources of waste heat with recovery potential using TEG.

Source	Type	Description
Industrial waste heat	Flue gas waste heat recovery	Combustion gases constitute one of the most readily exploitable waste-heat sources in various systems. Although they exhibit a relatively low heat transfer coefficient, their recovery is less complex than that of other gaseous streams. Although TEG are typically classified as low-power devices, in industrial waste-

		heat recovery applications they can reach power outputs on the order of tens of kilowatts.
	Waste heat recovery from products of an industrial process	Another source of wasted thermal energy is the heat released by products generated in various processes, which are often underutilized. Recovering this heat poses several technical challenges, including limited space availability, the transient nature of the heat source, and the predominance of radiative heat transfer. In this context, the ability of TEG to operate in compact, scalable configurations makes them a suitable alternative for capturing this form of residual energy.
Vehicle exhaust waste heat	Automobiles	In vehicles, it is estimated that nearly two-thirds of the energy released during combustion is dissipated as wasteful heat, and approximately 40% of this thermal energy is associated with exhaust gases. It has been estimated that if only 6% of this available heat were converted into electricity, fuel consumption could be reduced by approximately 10%. With this goal in mind, automotive manufacturers, together with research centers and universities, are developing various configurations of TEG aimed at improving engine energy efficiency.

Source: Own elaboration.

Table 6 presents recent studies focused on the use of TEG for waste heat recovery aimed at green hydrogen production.

Table 6. Application of TEG with waste heat recovery.

Author	Methodology	Results
[30]	Evaluated the efficiency of heat pipes with flat plates integrated with TEG for power generation from waste heat.	The results indicate that TEG can produce a maximum output power of 4115 W and achieve a conversion efficiency of 4.4% at a heat source temperature of 100 °C.
[31]	Presented a study of an integrated system focused on hydrogen production through the recovery of exhaust waste heat using a TEG.	An 8.6% increase in engine efficiency and a 4.9% reduction in fuel consumption were observed. Furthermore, the system reduces HC, CO ₂ , and CO emissions.
[32]	Investigated the use of TEG for recovering waste heat from a smelting process resulting from the thermochemical generation of hydrogen.	The results indicate a maximum energy conversion efficiency of 7.1% and a maximum rated power output of 37.9 W at a mass flow rate of 0.0196 kg/s.
[33]	Studied the use of a TEG to recover thermal energy from the exhaust gases of a proton exchange membrane fuel cell.	The incorporation of the TEG resulted in maximum increases of 34.5%, 31.5%, and 39.4% in hydrogen production, efficiency, and output power, respectively.

Source: Own elaboration.

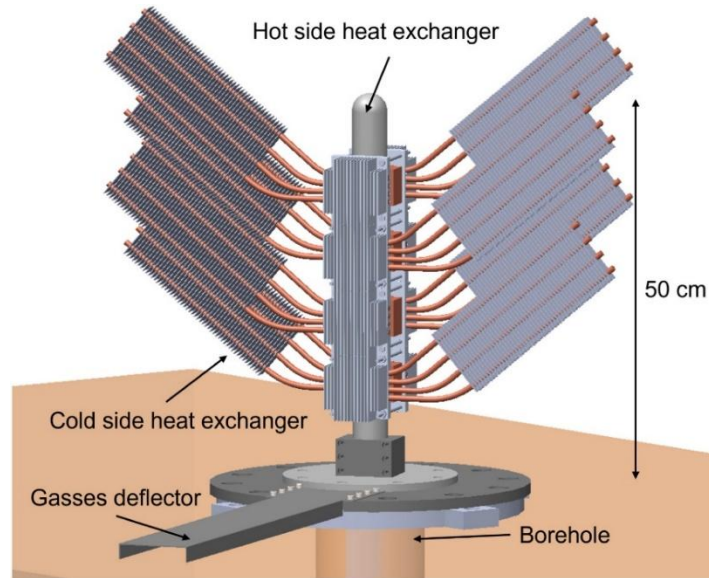
3.10. Geothermal energy

Despite its potential, geothermal energy is not commonly utilized for electricity generation [34]. Currently, the use of this energy source remains limited due to

disadvantages such as a lack of scalability, high initial investment, and potential environmental impacts. In this context, TEG have demonstrated potential as a suitable solution for the sustainable utilization of geothermal energy, owing to advantages such as scalability and the absence of moving parts.

A geothermal TEG is a system that directly converts subsurface thermal energy into electricity by means of a thermoelectric module. These modules, being solid state devices, generate electric current from the heat flow established between their faces when a temperature difference exists a phenomenon known as the Seebeck effect. Their performance increases as the thermal gradient increases. For this reason, heat exchangers play a crucial role, as they determine the thermal conditions achieved on both sides of the thermoelectric module. These exchangers enable the transfer of heat from the geothermal source to the hot side of the module and the removal of heat from the cold side to the sink. [Figure 8](#) shows a design of TEG for geothermal applications.

Figure 8. The schematic diagram of geothermal TEG.



Source: Adapted from Alegria et al. [35].

[Table 7](#) presents various studies focused on the application of TEG in geothermal energy systems.

Table 7. TEG applications with geothermal energy.

Author	Methodology	Results
[36]	Conducted a comparative analysis of the energy-economic performance of three cogeneration systems based on three organic cycles: the Organic Rankine Cycle (ORC), the Trilateral Cycle (TLC), and the Organic Flash Cycle (OFC). Hydrogen is another product of these systems, produced via a proton exchange membrane electrolyzer. The electrolyzer is powered by electricity generated from a TEG.	The comparative analysis demonstrated that the newly proposed systems can generate both electricity and hydrogen at a substantially lower cost than conventional systems.
[37]	Evaluated an optimized thermoelectric power generation system for low to medium temperature geothermal	The results showed that the optimal design of a TEG module enables the generation of 1 kW of

	energy, focusing on maximizing power output and overall system efficiency.	power using a total of 600 thermoelectric modules.
[38]	Assessed a geothermal thermoelectric generator (GTEG) equipped with passive phase change heat exchangers and operating without moving parts or auxiliary electrical power consumption in a hot dry rock (HDR) field with air temperature anomalies of 173 °C.	The study prototype using 10 thermoelectric modules generated a maximum of 20.9 W with a temperature difference of 158 °C between sources, while the prototype with 6 thermoelectric modules produced 16.67 W under the same conditions.

Source: Own elaboration.

3.11. Technical limitations of TEG

Although TEG are employed in multiple applications related to the energy transition, they still exhibit significant limitations that hinder their large-scale implementation. One of the main barriers is their low energy conversion capacity, which is closely linked to the intrinsic properties of the materials used in thermoelectric modules. Currently, the typical efficiency of TEG is only around 5%, which considerably restricts the usable power that can be extracted from available temperature gradients [39].

Nevertheless, recent advances in the field have focused on the development of materials with improved thermoelectric properties and the optimization of new design configurations capable of overcoming thermal and electrical constraints. The rise of nanotechnology has spurred renewed interest in these devices, as reflected in the accelerated growth of scientific publications on the subject.

Another relevant challenge in the performance of TEG is the gradual or sudden loss of their functional characteristics due to thermal fatigue [40]. During normal operation, the materials undergo continuous heating and cooling cycles that generate differential thermal expansion. These differences in expansion lead to the accumulation of stresses at contact interfaces, which often constitute the primary cause of failures and the reduced lifespan and efficiency of the device [41].

4. Conclusions

In this study, a systematic review was conducted based on 119 scientific documents indexed in the Scopus database between 2012 and 2024, with the objective of providing an overview of the evolution and research dynamics on TEG applied to green hydrogen production. The results reveal a steady and exponential growth of scientific activity, with a 250% increase in the number of publications between 2020 and 2024. In 2024, a historical maximum of 27 documents was reached, confirming the consolidation of TEG as a promising technology within the framework of global decarbonization and energy transition efforts.

From a geographical perspective, Asia accounts for 74% of global research output, led by Iran (41 documents), China (37), and Saudi Arabia (18). The Americas contributed 10.1%, Europe 8.4%, Africa 4.8%, and Oceania 2.6%. This uneven distribution reflects regional energy policies and research priorities: while Middle Eastern countries focus on diversifying fossil fuel-based economies, nations such as China, India, and Turkey prioritize technological innovation for emissions reduction. Conversely, Canada (14 documents) leads in the Americas, underscoring its commitment to sustainable hydrogen production.

At the institutional level, 160 entities were identified, of which only 17.5% published more than three documents. The University of Tehran (14 publications), Ontario Tech University (8), and Prince Sattam Bin Abdulaziz University (7) lead global productivity. Regarding publication channels, 45 journals contributed to the topic, with the International Journal of Hydrogen Energy representing 18.3% of total

publications, followed by Energy, Renewable Energy, and Sustainable Energy Technologies and Assessments (each with 6.4%).

The co-authorship analysis revealed 437 active researchers distributed across nine collaboration groups, led by authors such as Zoghi Mohammad (6 publications, 322 citations) and Ahmadi Pouria (5 publications, 631 citations), indicating an increasing trend in international cooperation.

The keyword analysis identified 1,218 unique terms, with “hydrogen production” (106 occurrences), “thermoelectric devices” (86), and “waste heat” (51) being the most representative, evidencing a strong correlation between TEG technology and hydrogen generation through renewable and residual energy recovery. From a technological standpoint, bibliometric results and literature review highlight three main areas of application: solar energy systems, waste heat recovery and geothermal applications.

In general, the integration of TEG with renewable and residual energy sources has proven technically feasible and environmentally advantageous, enabling dual generation of electricity and hydrogen while minimizing greenhouse gas emissions.

Nevertheless, the analysis identifies the need for further research on high-performance thermoelectric materials, scalability strategies, and cost-benefit optimization to ensure industrial viability. Strengthening international collaboration networks and fostering interdisciplinary approaches among materials science, thermal engineering, and hydrogen technologies will be crucial to accelerate innovation.

TEG represents an emerging field at the intersection of energy recovery and clean hydrogen production. Their growing scientific visibility, reflected in both publication volume and diversity, positions TEG-based systems as a cornerstone for next-generation energy transition technologies capable of contributing substantially to global carbon neutrality goals by 2050.

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