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SYSTEMATIC REVIEW

Determining the Predominant Materials for Triboelectric Nanogenerator Fabrication: A Bibliometric and a Systematic Analysis

Determinación de los Materiales Predominantes para la Fabricación de Nanogeneradores Triboeléctricos: Un Análisis Bibliométrico y Sistemático

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ABSTRACT

Introduction: Triboelectric Nanogenerators (TENGs) have gained considerable attention as efficient energy-harvesting devices based on the triboelectric effect and electrostatic induction. Their performance is highly dependent on the materials used, which influence charged generation efficiency, durability, and application potential. Despite significant advancements in material design, a comprehensive analysis of the most frequently used materials and their impact on output performance remains limited.
Method: a bibliometric and systematic review was conducted to identify the predominant materials in TENG fabrication. Data was collected from Scopus and Web of Science, analyzing publication trends, material co-occurrence, and performance metrics. A co-occurrence network analysis was performed using VOSviewer, and experimental studies were systematically reviewed to evaluate the correlation between material selection and output voltage (Voc).
Results: the analysis revealed that PTFE, FEP, PVDF, PDMS, and carbon-based nanomaterials are the most frequently utilized materials due to their high triboelectric polarity and electrical stability. The highest reported Voc values exceeded 400 V, with hybrid materials, nanostructured interfaces, and electrode engineering significantly enhancing TENG performance. Additionally, China, the United States, and South Korea were identified as the leading contributors to TENG research.
Conclusions: this study quantitatively assesses TENG material trends and their impact on electrical performance. The findings offer valuable insights for researchers and engineers working on next-generation TENGs, facilitating the optimization of material selection for self-powered devices and large-scale energy harvesting applications.

Keywords: Triboelectric Nanogenerator; Material Selection; Bibliometric Analysis; Energy Harvesting; Co-Occurrence Network.

RESUMEN

Introducción: los nanogeneradores triboeléctricos (TENGs) han despertado un gran interés como dispositivos eficientes de recolección de energía basados en el efecto triboeléctrico y la inducción electrostática. Su rendimiento depende en gran medida de los materiales utilizados, los cuales influyen en la eficiencia de generación de carga, la durabilidad y la aplicabilidad. A pesar de los avances en el diseño de materiales, aún es limitada una evaluación integral sobre los materiales más utilizados y su impacto en el desempeño eléctrico.

Método: se realizó una revisión bibliométrica y sistemática para identificar los materiales predominantes en la fabricación de TENGs. Se recopilaron datos de Scopus y Web of Science, analizando tendencias de publicación, co-ocurrencia de materiales y métricas de desempeño. Se llevó a cabo un análisis de redes de co-ocurrencia con VOSviewer, y se revisaron estudios experimentales para evaluar la correlación entre la selección de materiales y el voltaje de salida (Voc).
Resultados: el análisis reveló que PTFE, FEP, PVDF, PDMS y nanomateriales basados en carbono son los más utilizados debido a su alta polaridad triboeléctrica y estabilidad eléctrica. Se encontraron valores de Voc superiores a 400 V, donde el uso de materiales híbridos, interfaces nanoestructuradas y optimización de electrodos mejoró significativamente el desempeño de los TENGs. Además, China, Estados Unidos y Corea del Sur fueron identificados como los principales países productores de investigación en TENGs.
Conclusiones: este estudio proporciona una evaluación cuantitativa de las tendencias en el uso de materiales para TENGs y su impacto en el rendimiento eléctrico. Los hallazgos ofrecen información valiosa para investigadores e ingenieros, facilitando la optimización de la selección de materiales para dispositivos autoalimentados y aplicaciones de recolección de energía a gran escala.

Palabras clave: Nanogenerador Triboeléctrico; Selección de Materiales; Análisis Bibliométrico; Recolección de Energía; Redes de Co-Ocurrencia.

INTRODUCTION

The triboelectric effect is a fundamental electrostatic phenomenon in which electrical charges are generated when two materials come into contact and then separate.[1] This charge transfer mechanism is widely observed in nature and has been extensively studied for its potential in energy harvesting applications.[2] Based on this principle, Triboelectric Nanogenerators (TENGs) have emerged as innovative self-powered energy harvesting devices[3], converting mechanical energy into electricity through triboelectrification and electrostatic induction. Since their first demonstration, TENGs have gained significant attention for their high energy conversion efficiency, cost-effectiveness, and broad applicability in areas such as wearable electronics, biomedical devices, and large-scale environmental energy harvesting.

TENGs operate through four primary working modes, each tailored to specific mechanical interactions: vertical contact-separation mode, lateral sliding mode, single-electrode mode, and freestanding triboelectric-layer mode. These modes can be categorized into contact-driven and friction-driven mechanisms, where the former relies on periodic physical contact between materials. At the same time, the latter involves surface friction or lateral displacement to generate charge transfer. The effectiveness of a TENG depends on several factors, including the choice of triboelectric materials, surface modifications, and device architecture, which collectively influence the output voltage, current density, and power generation capacity.[4]

As TENG research continues to expand, it is necessary to identify the most effective materials that enhance energy harvesting efficiency. Numerous studies have explored dielectric polymers, metal electrodes, carbon-based nanomaterials, and hybrid composites to improve triboelectric charge generation.[4] However, despite the rapid advancements in material design, a comprehensive analysis of the most frequently used materials and their performance impact remains limited.

This study aims to bridge this gap by conducting a systematic and bibliometric analysis of materials employed in TENGs, identifying the predominant material choices, their structural configurations, and their role in enhancing charge transfer efficiency. Through an in-depth co-occurrence analysis using Scopus and Web of Science databases, this research quantitatively assesses publication trends, highlighting the most researched materials and their frequency of use in high-performance TENGs. Furthermore, a systematic review of experimental studies is conducted to evaluate the correlation between material selection and electrical output, mainly focusing on the highest open-circuit voltages (Voc) reported in recent literature.

By combining bibliometric insights with material-based performance analysis, this study offers a comprehensive reference for researchers in nanogenerators and sustainable energy harvesting. The findings provide a scientifically grounded foundation for optimizing TENG designs and accelerating their commercialization in self-powered electronic systems and large-scale renewable energy applications.

METHOD

Bibliometric Analysis Approach

To investigate the predominant materials used in the fabrication of triboelectric nanogenerators (TENGs), a bibliometric study was conducted using Scopus and Web of Science (WoS), two of the most comprehensive scientific databases. The analysis focused on identifying global publication trends, leading countries in research output, and key material-related terms through co-occurrence analysis.

Search Strategy and Data Collection

The search query was formulated to retrieve publications on the materials used in TENG fabrication. The following Boolean search string was applied in both databases: (“triboelectric nanogenerator*” OR “TENG”) AND (“material*” OR “fabrication” OR “synthesis” OR “construction”).

This query was applied to the Title, Abstract, and Keywords (ATK) fields to ensure the inclusion of the most relevant publications. The search was restricted to 2014–2024 to focus on recent advancements in TENG material research (table 1).

Table 1. Data Collection

Filtering Criteria	Scopus	Web of Science
Initial results	4478	3490
Filtered between 2014-2024	4097	3318
Open Access publications	1027	873
Abstract screening	627	485

Data Processing and Bibliometric Indicators

The collected data were analyzed using quantitative bibliometric indicators, including annual publication trends. The number of publications per year was analyzed in Scopus and WoS to determine research growth over the past decade. Geographical distribution of research output by analyzing the number of publications per country was extracted to identify leading contributors to TENG material research and the co-occurrence analysis where keywords and material-related terms were analyzed using VOSviewer to determine the most frequently occurring words associated with TENG fabrication materials.

The keyword datasets were processed as follows: i) Scopus with 7439 extracted words and 207 words appearing at least 10 times. ii) Web of Science: with 2875 extracted words and 219 words appearing at least 5 times.

Systematic Analysis Methodology

To ensure a rigorous and reproducible review of the materials used in the fabrication of triboelectric nanogenerators (TENGs), a systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology. This approach allows for identifying, screening, and selecting relevant studies based on predefined inclusion and exclusion criteria.

The same Boolean search query used in the bibliometric analysis was applied to the Scopus and Web of Science (WoS) databases to retrieve relevant scientific publications.

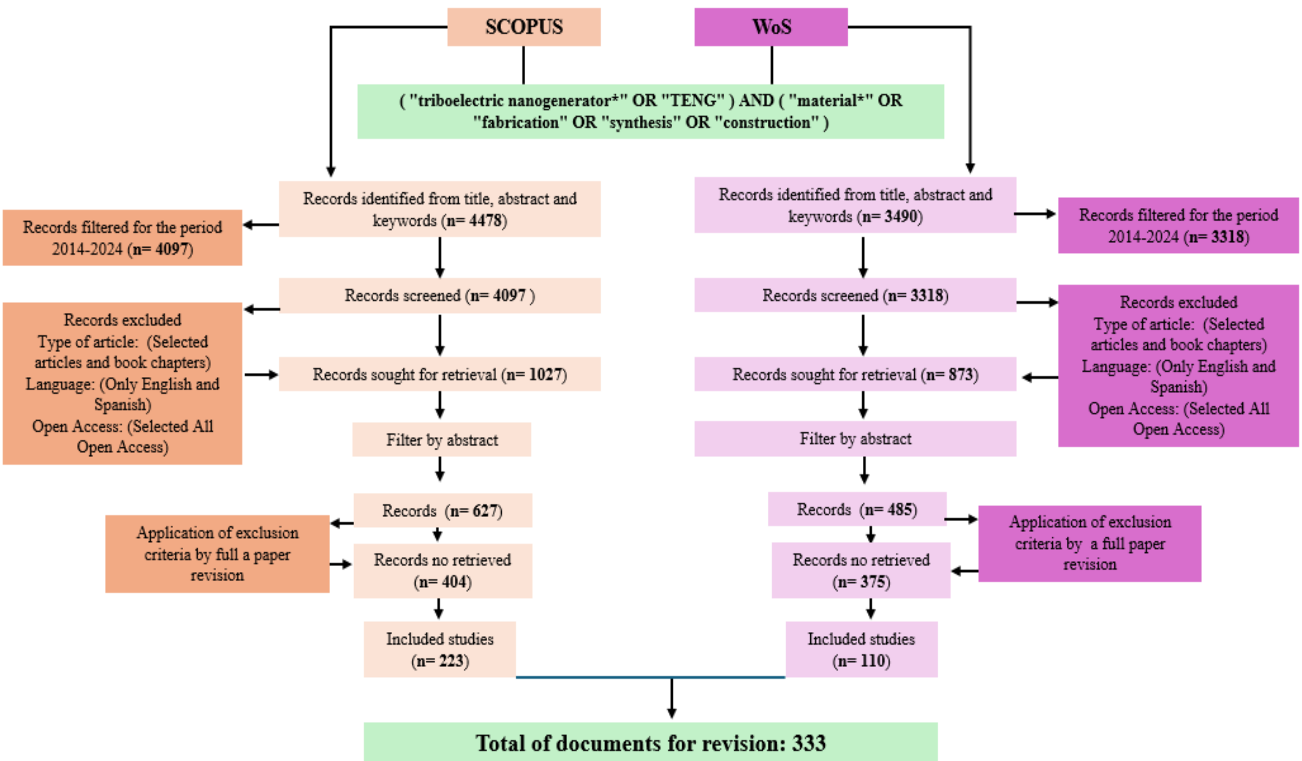

Figure 1. Prisma Framework

Following the PRISMA framework, the study selection was conducted in four stages. In the identification stage, 4 478 records were retrieved from Scopus and 3 490 from Web of Science (WoS). After filtering for the publication period (2014–2024), the dataset was reduced to 4 097 records in Scopus and 3 318 in WoS. During the screening stage, records were evaluated based on their title, abstract, and keywords (ATK), resulting in 1 027 potentially relevant records from Scopus and 873 from WoS. In the eligibility stage, the abstracts of these records were manually reviewed to exclude irrelevant studies, retaining 627 articles from Scopus and 485 from WoS. Finally, in the inclusion stage, a full-text review was conducted, applying additional exclusion criteria. This led to a final dataset of 223 studies from Scopus and 110 from WoS, totaling 333 documents for systematic analysis. A visual representation of the PRISMA flow diagram used in this study is provided in figure 1.

RESULTS

Annual Scientific Production in Web of Science and Scopus

The analysis of the number of publications related to Triboelectric Nanogenerators (TENGs) and their fabrication materials in Web of Science (WoS) and Scopus from 2014 to 2024 reveals a continuous increase in research output over the past decade. The publication count in both databases shows a steady upward trend, indicating the growing interest and development in this research field.

From 2014 to 2018, the number of publications in both databases remained relatively low, with fewer than 50 articles per year. However, a notable increase is observed after 2018, with an accelerated rise in publication output, particularly from 2020 onwards. In 2020, publications in WoS reached 66, while Scopus reported 88, showing a 33,3 % higher publication rate in Scopus. This trend continued, with a sharp increase between 2021 and 2024 when the number of publications almost doubled. By 2024, the total number of publications reached 222 in WoS and 236 in Scopus, highlighting a peak in research activity.

Linear regression models were fitted to the data to understand the growth trajectory better. These regression equations suggest that the annual growth rate (slope) of publications is slightly higher in Scopus (25 573) than in WoS (22 564), indicating a faster expansion of research publications in Scopus. The coefficient of determination (R^2) for both models is above 0,89, demonstrating a strong correlation between the publication count and the years, affirming the reliability of the observed trend (figure 2).

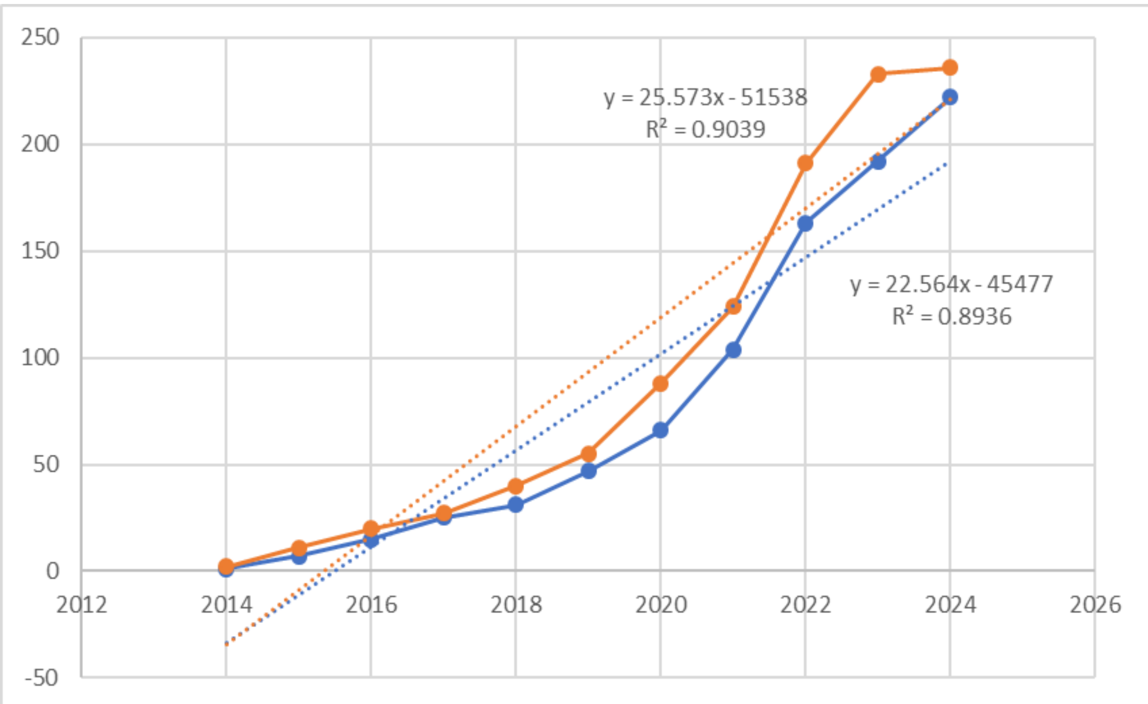

Figure 2. Scientific Production in Web of Science and Scopus

The continuous increase in publications suggests that the field of TENG fabrication materials is becoming a mature research area, with significant advancements in material development, device efficiency, and real-world applications. The steep incline in recent years (2020–2024) indicates that researchers are actively exploring novel materials and fabrication techniques to enhance TENG performance. The sustained publication growth also suggests that TENGs are progressing towards commercialization, making them a viable alternative for low-

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power energy harvesting solutions.

Comparative Analysis of Publications by Country in Web of Science and Scopus

The distribution of research publications related to Triboelectric Nanogenerators (TENGs) and their fabrication materials was analyzed across Web of Science (WoS)(figure 4) and Scopus (figure 3). The results highlight key trends in global research contributions and allow for a direct comparison between the two databases. In both databases, China has the highest number of publications, followed by the United States and South Korea. The top five contributing countries in each database are shown in table 2.

Table 2. Top five contributing countries contributions

Rank	WoS	Record Count	Scopus	Record Count
1	China	465	China	519
2	USA	136	USA	165
3	South Korea	126	South Korea	145
4	England	71	England	108
5	India	52	India	71

The distribution of research publications related to Triboelectric Nanogenerators (TENGs) and their fabrication across Scopus is shown in figure 3.

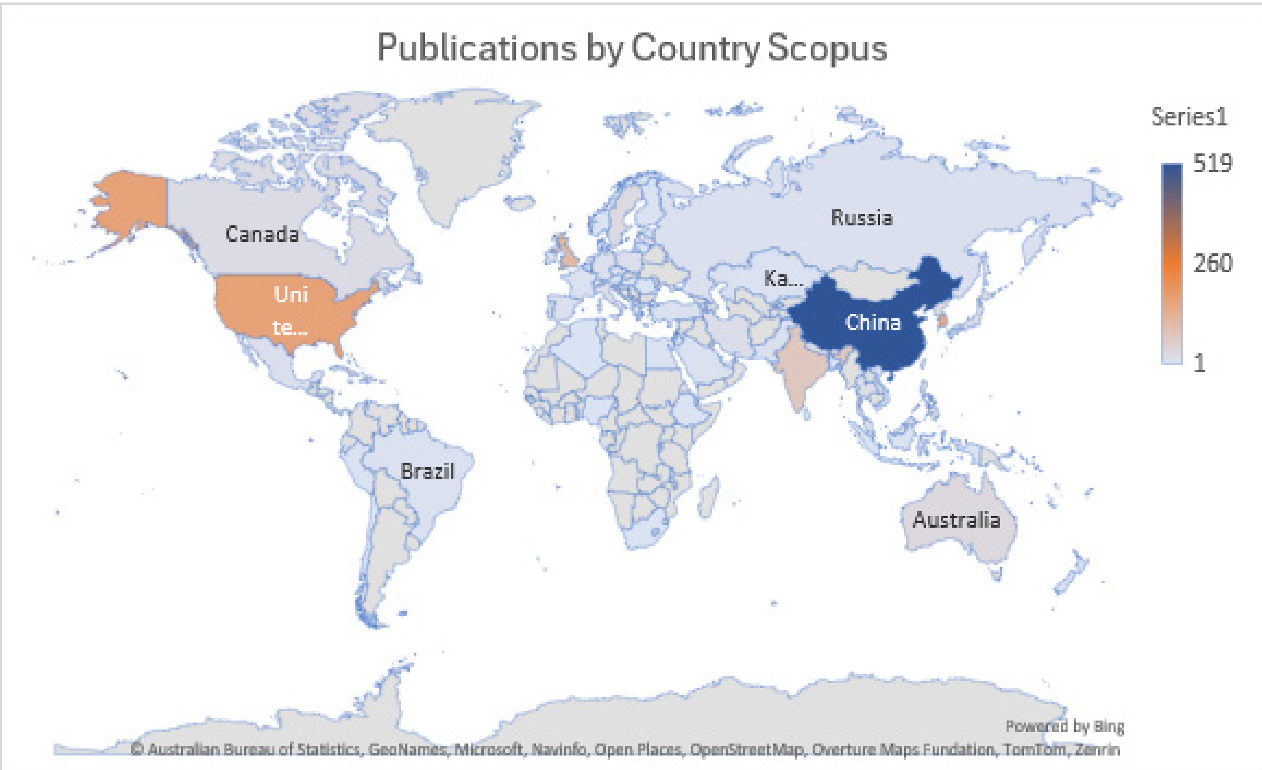

Figure 3. Publications by Country Scopus

The distribution of research publications related to Triboelectric Nanogenerators (TENGs) and their fabrication across Web of Science (WoS) is shown in figure 4.

China dominates both databases, with 519 publications in Scopus and 465 in Web of Science (WoS). This can be attributed to the country's extensive research funding in nanotechnology and sustainable energy harvesting, strong institutional support, and industrial applications. The United States consistently ranks second, with a slightly higher number of publications in Scopus (165) compared to WoS (136), reflecting its strong focus on applied and experimental research. South Korea ranks third, showing similar numbers in both databases, with 126 in WoS and 145 in Scopus.

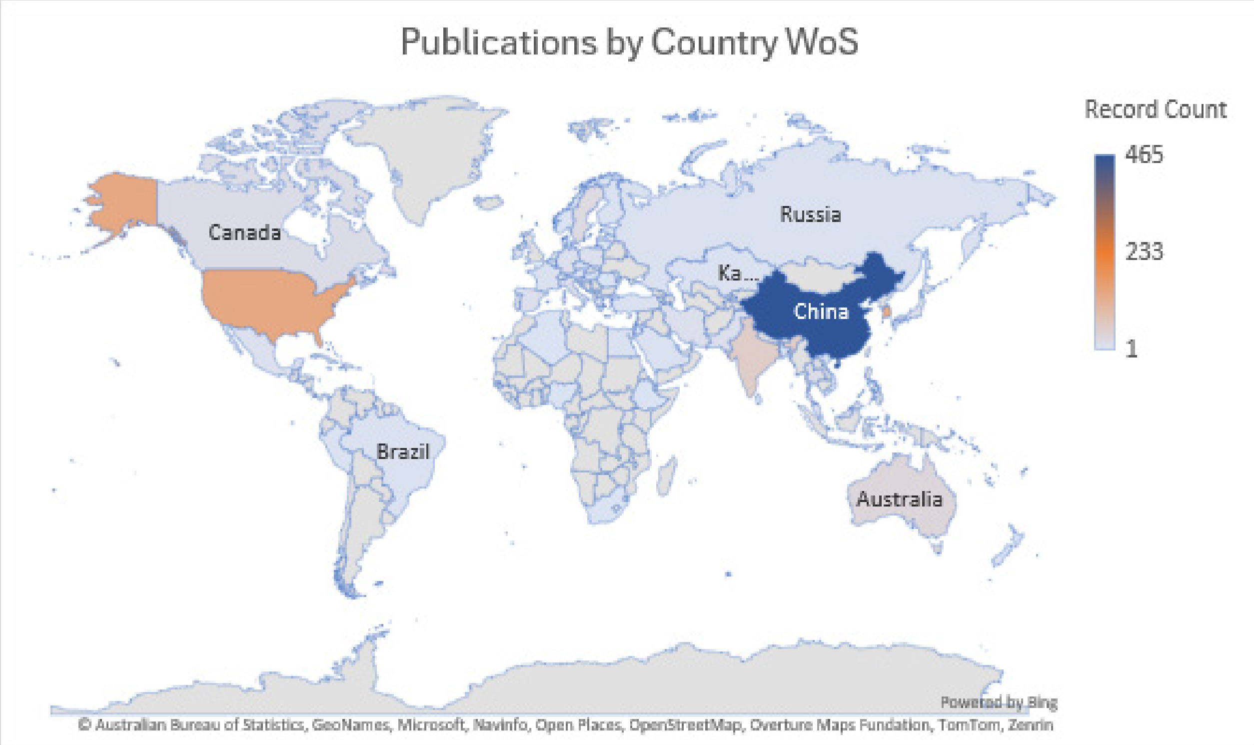

Figure 4. Publications by Country Scopus

In fourth place, England (WoS) and the United Kingdom (Scopus) highlight Europe's significant contribution to the field, demonstrating a strong presence in theoretical advancements and material innovations for TENG technology. India, emerging as a key player, exhibits steady research growth and appears in the top five for both databases, reflecting the country's increasing focus on nanotechnology and renewable energy research.

The regional distribution of research activity underscores the dominance of Asia in triboelectric nanogenerator (TENG) research, with countries such as China, South Korea, India, Taiwan, Hong Kong, Singapore, and Japan leading the field. European countries contribute significantly, including the United Kingdom, Germany, Sweden, the Netherlands, Spain, France, Italy, Portugal, Switzerland, Poland, and Latvia. However, their overall publication counts remain lower than those of Asia. The United States and Canada show consistent contributions in North America, with Canada ranking 12th in both databases. Additionally, emerging contributors such as Brazil, Mexico, Iran, Thailand, and Malaysia indicate a growing research presence in TENG-related studies, signaling increased global interest in this technology.

A comparative analysis between Web of Science and Scopus reveals notable differences in coverage. China has 11,6 % more publications in Scopus (519) than in WoS (465), suggesting that Scopus indexes a slightly broader range of Chinese research articles. Similarly, the United States has 21 % more publications in Scopus (165) than in WoS (136), indicating that Scopus includes more applied and multidisciplinary journals in this field. Scopus also captures more research output from emerging regions such as Hong Kong (50), Singapore (38), and Taiwan (27). In contrast, WoS places a slightly higher emphasis on traditional research hubs like England and Sweden.

Despite these differences, both databases show strong alignment in the top three research-producing countries, confirming China, the United States, and South Korea as the global leaders in TENG technology. Among more minor contributors (countries with fewer than 10 publications), both databases exhibit similar numbers, indicating a balanced representation of lower-output nations in the field.

Co-Occurrence Analysis of Materials Used in Triboelectric Nanogenerators (TENGs)

The co-occurrence analysis, performed using VOSviewer, provided a comprehensive overview of the materials most frequently associated with triboelectric nanogenerators (TENGs) based on publications indexed in Scopus (figure 6) and Web of Science (WoS) (figure 7). These analyses allow us to identify key trends in material usage and understand how different materials are interconnected in TENG fabrication.

The co-occurrence network generated from Scopus data highlights the following key materials used in TENG fabrication.

Polymers: The dominant category shows materials like polydimethylsiloxane (PDMS), polyvinylidene fluoride (PVDF), polyfluoro compounds, polytetrafluoroethylene (PTFE), polyurethane (PU), and polyamides being the most common. These materials are preferred due to their high triboelectric properties, flexibility, and ease of processing.

Carbon-Based Materials: Graphene, carbon nanotubes, carbon nanocomposites, and MXene appear frequently, indicating their growing use in enhancing electrical conductivity and improving charge transfer efficiency.

Nanocomposites and Nanostructured Materials: The analysis shows significant connections to nanoparticles, nanowires, and nano clay, which are widely used for enhancing surface roughness and increasing charge generation.

Biodegradable and Natural Materials: Terms like cellulose, nanocellulose, and chitosan appear, showing an increased interest in sustainable and eco-friendly TENGs.

Metal Oxides and Inorganic Materials: Titanium dioxide (TiO_2), zinc oxide (ZnO), perovskites, and barium titanate were detected, suggesting their role in high-performance TENGs with piezoelectric and triboelectric hybrid properties.

The Scopus co-occurrence network reveals strong interconnections between polymers, carbon-based materials, and metal oxides, highlighting a focus on flexible, high-performance, and hybrid materials for TENG development.

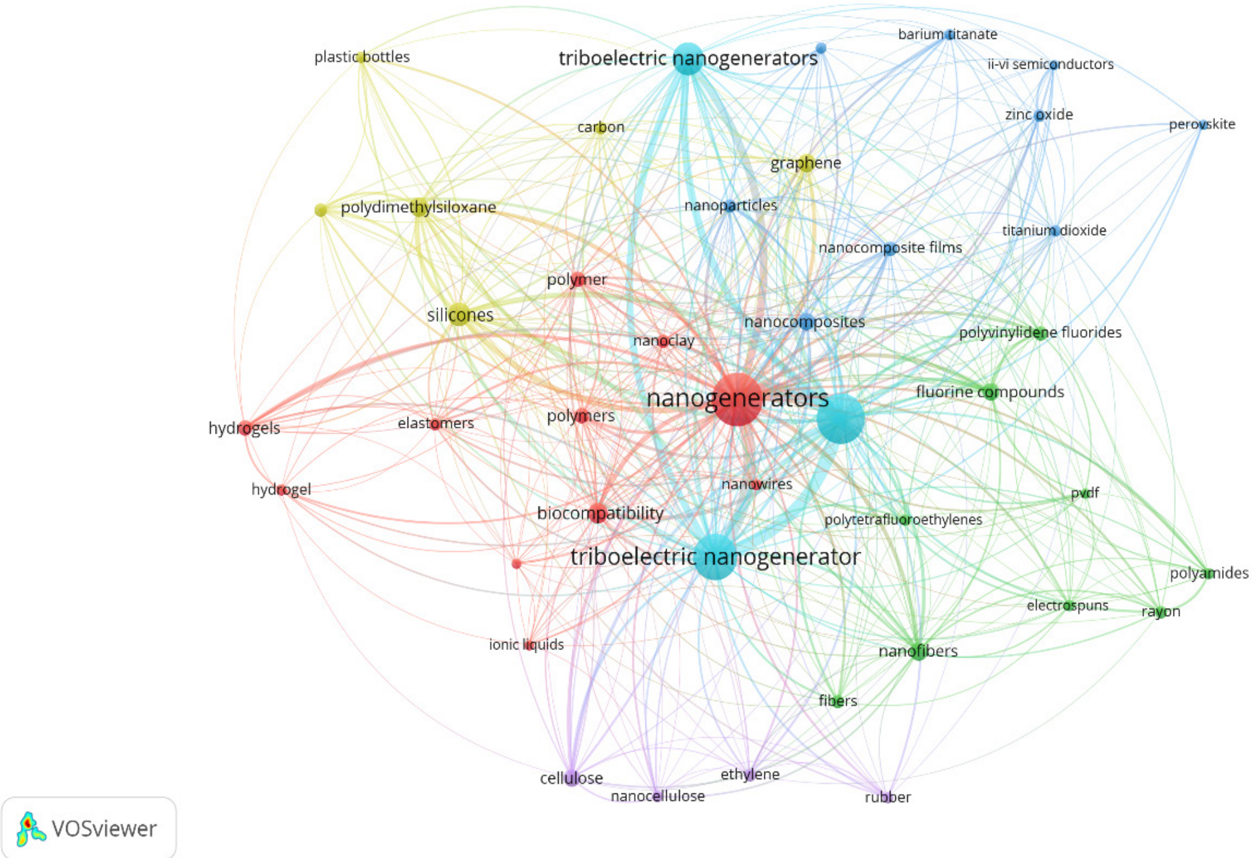

Figure 6. co-occurrence network generated from Scopus

The co-occurrence analysis from Web of Science (WoS) provides similar but slightly distinct trends.

Polymers: As in Scopus, polymers dominate, with polyvinylidene fluoride (PVDF), polytetrafluoroethylene (PTFE), polyurethane (PU), and polydimethylsiloxane (PDMS) being the most referenced. This confirms that synthetic polymers remain the primary material category for TENG fabrication.

Carbon-Based Materials: Graphene, graphene oxide, carbon nanotubes (CNTs), and carbon nanocomposites are prevalent, confirming their role in enhancing conductivity and mechanical strength.

Nanomaterials: The WoS analysis highlights MoS_2 (molybdenum disulfide), nanosheets, and nanocomposites, indicating an increased focus on 2D materials and hybrid structures.

Sustainable and Bio-Based Materials: The presence of starch, bacterial cellulose, nanocellulose, and chitin suggests that researchers are actively exploring eco-friendly TENG materials.

Triboelectricity-Enhancing Materials: PVDF, PTFE, and polytetrafluoroethylenes appear frequently, confirming their use in high-performance triboelectric layers.

The WoS co-occurrence network shows strong clusters around polymeric, carbon-based, and biocompatible/eco-friendly materials, suggesting an increasing shift towards flexible and biodegradable TENG devices.

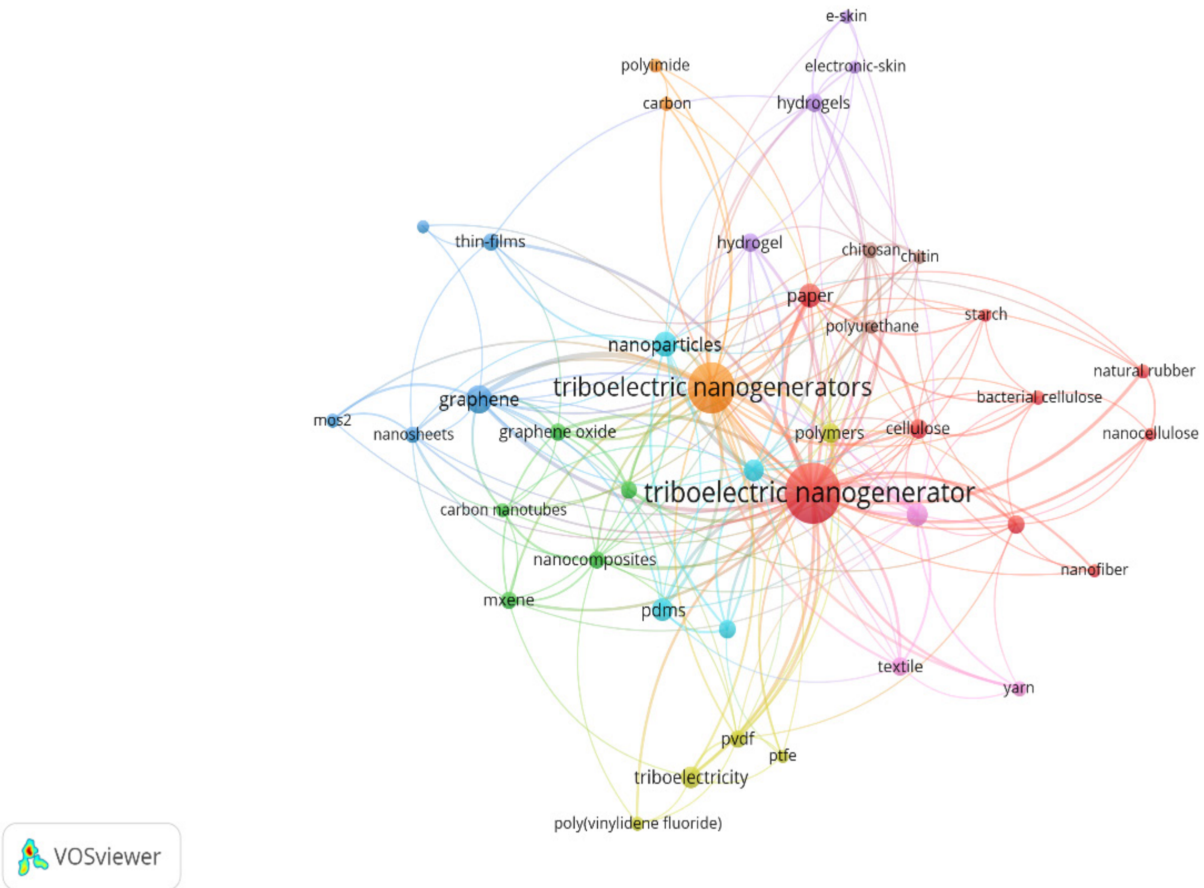

Figure 7. co-occurrence network generated from WoS

Systematic Review Results

The field of Triboelectric Nanogenerators (TENGs) has experienced remarkable growth, particularly in the exploration of new materials and designs to enhance energy conversion efficiency. Research articles focus on optimizing different generation modes, utilizing novel materials, and improving power output for practical applications such as wearable electronics, self-powered sensors, and renewable energy harvesting.

One key area of research is the development of hybrid structures to maximize charge transfer efficiency. For example, a study on hydrodynamic and energy captures properties of a TENG system designed for marine energy harvesting demonstrates how PTFE, nylon, and copper are effectively utilized to generate electricity in oceanic environments.[5] These findings highlight the increasing focus on sustainable energy solutions, leveraging triboelectricity for large-scale applications.

Material innovation remains a cornerstone of TENG research, with many studies exploring traditional dielectric polymers and emerging hybrid nanocomposites. For instance, a photoelectric-enhanced triboelectric nanogenerator incorporates Polydimethylsiloxane (PDMS) and Cobalt (Co) powder, achieving a high open-circuit voltage of 124,2 V.[6] The integration of photoelectric enhancement suggests that multi-functional TENGs are being developed to maximize power output under diverse environmental conditions.

Similarly, aluminum oxide (Al_2O_3) has been investigated as an electron-blocking layer to improve charge retention in vertical contact-separation mode TENGs.[7] These studies indicate that researchers are actively modifying surface properties and electron transport mechanisms to push the boundaries of energy conversion efficiency.

Apart from materials, the structural design of TENGs plays an important role in performance optimization. A study on rotating freestanding triboelectric nanogenerators utilizes Interdigital ITO electrodes on quartz substrates, demonstrating how alternative electrode architectures can improve output voltage and current levels.[8] This research underscores the importance of micro-patterned electrode designs to enhance distribution of charge and maintain long-term stability.

Another notable approach involves using iodine-doped polyvinylidene fluoride (PVDF), which improves dielectric properties and increases overall power output.[9] These findings confirm that surface modification and chemical doping are standard techniques for improving TENG efficiency.

TENG applications are expanding rapidly across multiple fields. The reviewed studies indicate that TENGs

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are being integrated into wearable devices, environmental energy harvesting, and biomedical applications. One article presents a TENG-based system for marine energy harvesting, showcasing how fluid-induced motion can be converted into electrical energy, paving the way for large-scale ocean energy solutions.[10]

Additionally, TENGs are being adapted for wearable electronics, as seen in a study investigating a flexible, self-powered TENG system designed for real-time health monitoring.[11] This trend suggests that self-powered sensor systems will play a critical role in the future of biomedical engineering and smart wearables.

Material Selection in TENGs

The selection of materials in Triboelectric Nanogenerators (TENGs) is crucial in determining their energy conversion efficiency, durability, and application versatility. Based on systematic review, the most frequently used materials can be categorized into key base materials, often paired with complementary layers or substrates to optimize charge transfer, mechanical properties, and environmental stability.

This study reveals that metals (Aluminum, Copper), fluoropolymers (PTFE, FEP, PVDF), carbon-based materials (Graphene, Carbon Nanotubes, MXene), and elastomers (PDMS, Nylon, Polyurethane) are the dominant materials in TENG fabrication. The high recurrence of these materials is attributed to their high triboelectric polarity, mechanical flexibility, conductivity, and processability.

The following table 3 presents the most frequently occurring materials, common combinations.

Table 3. Most frequently occurring materials and common combinations

Based Materials	Combinations
Aluminum	Aluminum oxide (Al_2O_3) as an electron-blocking layer,Polydimethylsiloxane (PDMS),Indium tin oxide (ITO) glass Aluminum (structured with micro- and nanoscale patterns), Fluorinated Ethylene Propylene (FEP). [12]
	Aluminum electrodes, PTFE (Polytetrafluoroethylene) with nanowire array, copper coils, magnets, acrylic substrate. [13]
	Aluminum-doped zinc oxide (AZO) on cellulose nanofibril (CNF) paper, with plasma and TiCl4 treatments to enhance triboelectric properties. [14]
	Aluminum (Al) film, polydimethylsiloxane (PDMS) layer, plastic resin (PR) sheet, polymethyl methacrylate (PMMA) sheet. [15]
	Aluminum (Al) and Kapton, polyethylene terephthalate (PET), and polytetrafluoroethylene (PTFE). [16,17]
PTFE	PTFE, nylon, copper. [18]
	Polyurethane (positively charged material), PTFE (negatively charged material), and P(VDF-TrFE) in the casing. [19]
	(PTFE), (PET) and aluminum. [20]
	Acrylic sheet, PTFE film for Module A; Acrylic sheet, FEP film, and copper electrodes for Module B. [21]
	PTFE film, Aluminum (Al) electrode, Copper (Cu) electrode, PVC and Kapton films as substrates. [22]
	Polytetrafluoroethylene (PTFE) film with a copper (Cu) electrode Kapton film with copper (Cu) deposition Secondary structure with PDMS and ZnO nanowires for cantilever TENG. [23]
	Polytetrafluoroethylene (PTFE) layer, electrode layers. [24]
	Hoja de bambú y película de Politetrafluoroetileno (PTFE), con cobre como electrodo conductor. [25]
	Polytetrafluoroethylene (PTFE) film on fluorine-doped tin oxide (FTO) glass substrate. [26]
	Polytetrafluoroethylene (PTFE) film, indium tin oxide (ITO), polyethylene terephthalate (PET) layer. [27]
	Ionized-PTFE (I-PTFE) and fully charged fluorinated ethylene propylene (FEP) film. [28]
	Kapton, Aluminum (Al), Polyethylene Terephthalate (PET), Polytetrafluoroethylene (PTFE). [29]
	Polytetrafluoroethylene (PTFE), aluminum tape, soft PVC, and paper components. [30]
	Polytetrafluoroethylene (PTFE) as the triboelectric material, paper, and PVC for the origami spring structure, transparent hemispherical shell for waterproofing. [31]
	Polytetrafluoroethylene (PTFE) with soft polyvinyl chloride (PVC) as triboelectric materials, along with aluminum tape, transparent hemispherical shell, and spring origami structure. [30]
	PTFE (polytetrafluoroethylene) disc, Copper electrodes,Blood as a conductive medium Polymethyl methacrylate (PMMA) elements. [32]
	PTFE film on rotor blades combined with PET, and aluminum sheets on the stator. [33]

Carbon	Collagen/PVA/Ag nanowires as triboelectric positive layer, PVDF as triboelectric negative layer, aluminum foil as electrodes. (34)
	Graphene-Polylactic Acid (gPLA) nanocomposite for the bottom electrode, Teflon as the top electrode. (35)
	Cellulose nanofibrils (CNF) paired with fluorinated ethylene propylene (FEP), integrated into recycled fiberboard; 20 %. (36)
	Graphene-coated Polyethylene Terephthalate (PET) Polydimethylsiloxane (PDMS) Screen-printed electrodes. (37)
	Graphene oxide (GO), Aluminum (Al), Kapton, Latex. (38)
	MXene (Ti3C2Tx) as the primary material for both piezo-resistive and triboelectric functions. Polydimethylsiloxane (PDMS) layers for encapsulation. (39)
	Graphene oxide (GO) and aluminum (Al) foils. (40)
	CoC@FeNiG-F nanocomposite derived from metal-organic frameworks (MOFs) combined with perfluorinated epoxy matrix. (41)
	Carbon nanotube (CNT)-polydimethylsiloxane (PDMS) composite foam. (42)
Copper	Copper coated with silk protein, Silver electrode (80 nm) on FEP (12,5 μm thick film) as lower electrode, Acrylic as substrate. (43)
	Copper and aluminum as electrode materials, with spherical silicon rubber as the dielectric. (44)
	Copper pick-up coil, copper impact sheet, polydimethylsiloxane (PDMS) blocks, acrylic cantilever beam, polytetrafluoroethylene (PTFE)/carbon black (CB) film, circular permanent NdFeB magnet. (45)
	Copper electrodes, acrylic plates, silicone rubber dielectric, Rhenium tungsten needles in an argon atmosphere. (46)
	Copper (Cu), Polytetrafluoroethylene (PTFE) film, and a ferroelectric material (barium titanate, BT) - 20 %. (47)
	Copper-coated ethylene vinyl acetate (EVA) tubing (electrode); Polydimethylsiloxane (PDMS) for triboelectric layer. (48)
	Cu, Al, Pt with Kapton, PTFE, FEP, ETFE. (49)
	Copper nanowires (CuNWs) as the electrode. Ecoflex as the triboelectric layer. (50)
	Copper electrodes, polyvinylidene fluoride (PVDF) membrane, seawater as the liquid dielectric, permanent magnets. (51)
	Copper (upper electrode), Aluminum (lower electrode), Acetal dielectric material. (52)
	Copper as the electrode and PTFE (polytetrafluoroethylene) as the dielectric material. (53)
FEP	Fluorinated Ethylene Propylene (FEP), Polycarbonate, Aluminum (Al), and Copper (Cu). (54)
	Fluorinated ethylene propylene (FEP) as the triboelectric layer Kapton film as the membrane material Acrylic sheet with Au layer (gold) coating as the upper electrode. (55)
	FEP (fluorinated ethylene propylene) polymer film with nanowire surface structure; Au nanoparticles were used as a mask for etching. (56)
	Fluorinated ethylene propylene (FEP) film, cylindrical steel rods (conductor) and dielectric rods (dielectric-to-dielectric type). (57)
	Fluorinated ethylene propylene (FEP) film, copper (Cu) electrodes. (58)
	Fluorinated Ethylene Propylene (FEP) for the triboelectric layer. Aluminum as the electrode material. Polyurethane foam used as the stress ball base. (59)
	Fluorinated ethylene propylene (FEP) film as the, Indium tin oxide (ITO)-coated glass substrate triboelectrification layer, SU-8 photoresist mold for creating air gaps. (60)
Nylon	Nylon-coated copper wire, PTFE-coated enameled copper wire, rubber fiber core. (61)
	Nylon, politetrafluoroetileno (PTFE), electrodos de cobre Nylon-11 nanowires (self-poled) fabricated using gas-flow assisted template wetting in anodised aluminium oxide (AAO) templates Gold-coated Teflon film as counterpart. (62)
	Nylon fabric with gold (Au) coating and polytetrafluoroethylene (PTFE) film; 20 %. (63)
PDMS	PDMS and glass for tribo-materials, and Ni adhesive tape. (64)
	PDMS and crumpled gold (Au) electrode. (65)

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	PDMS (polydimethylsiloxane) film patterned with leaf-inspired microstructures and long silver nanowires as a high-transparency electrode. (66)
	PDMS (Polydimethylsiloxane) and CNT (Carbon Nanotube) composite, with fluorocarbon plasma etching. (67)
	PDMS (Polydimethylsiloxane) thin film with rough surface, Cu foil as electrode. (68)
	PDMS (Polydimethylsiloxane) Kapton film SiO2 (Silicon Dioxide) Aluminum (Al). (69)
	PDMS (Polydimethylsiloxane) ITO (Indium Tin Oxide) electrodes PET (Polyethylene Terephthalate). (70)
	PDMS (polydimethylsiloxane) and MXene (used in a composite form). (71)
	PDMS (polydimethylsiloxane) paired with copper as the tribo-positive material. (72)
PVDF	Polyvinylidene fluoride (PVDF) and polyamide 6 (PA) fibers, in various combinations (e.g., stratified three-layer structure and intertwined). (73)
	Polyvinylidene difluoride (PVDF) asPolyimide (PI) asKapton tape f. (74)
	Polyvinylidene fluoride (PVDF) composite with BaTiO3 particles for the piezoelectric unit, Polydimethylsiloxane (PDMS) with carbon nanotubes (CNT) and graphite for the triboelectric unit. (75)
	PVDF-TrFE/Ag nanowire (piezoelectric layer) and PDMS/graphite nanocomposite (triboelectric layer). (76)
	Polyvinylidene fluoride (PVDF) blended with second-generation silane-based hyperbranched polymer (Si-HBP-G2). (77)
	Polyvinylidene fluoride (PVDF) and poly(methyl methacrylate) (PMMA) in a porous matrix, with Nylon-6 as a tribo-positive layer. (78)
	PVDF, PHBV, graphene oxide. (79)
	Polyvinylidene fluoride (PVDF) and polydimethylsiloxane (PDMS) layers. (80)
	Polyvinylidene fluoride (PVDF) nanofibers as the triboelectric layer, copper foil as the electrode, assembled using a kirigami structure. (81)
	Polyvinylidene fluoride (PVDF) nanofibers. Polypropylene (PP) film. Copper electrodes. (82)
	PVDF (Polyvinylidene fluoride), $BaTiO_3$ (Barium titanate) composite with ITO-coated PET substrate. (83)

In table 4, the results of the generators with the highest output are presented. The selection was based exclusively on articles where the methodology for measuring voltage and current is replicable.

Table 4. Most frequently occurring materials and common combinations

Title	Reference	Output voltage. (Voc)	Short-circuit current/ short-circuit current density	Generation mode	Materials used in the nanogenerator's design
A high-efficiency bioinspired photoelectric-electromechanical integrated nanogenerator	(6)	Maximal open-circuit voltage of 124,2 V.	Maximal short-circuit current density of 221,6 μA/cm²	Solid-liquid contact electrification using tidal waves and sunlight.	Polydimethylsiloxane (PDMS),Cobalt (Co) powder,Titanium dioxide (TiO_2),Polyaniline (PANI) for constructing a P-N heterojunction
Facile growth of aluminum oxide thin film by chemical liquid deposition and its application in devices	(1)	Approximately 200 V	Around 9 μA	Vertical contact-separation mode	Aluminum oxide (Al_2O_3) as an electron-blocking layer,Polydimethylsiloxane (PDMS),Indium tin oxide (ITO) glass
Textile Manufacturing Compatible Triboelectric Nanogenerator with Alternating Positive and NegativeWoven Structure	(84)	62,9 V (RMS peak voltage)	1,77 μA (RMS peak current)	Sliding mode with independent triboelectric layer	Positive triboelectric material: Nylon fabric. Negative triboelectric material: PTFE coated glass fiber fabric. Electrodes: Silver (Ag) ink on PVC coated polyester fabric

Surfactant-free GO-PLA nanocomposite with honeycomb patterned surface for high power antagonistic bio-triboelectric nanogenerator	(85)	~170 V	~56 μA	Vertical contact-gap mode, antagonistic friction surfaces	Positive triboelectric material: Honeycomb-patterned graphene oxide/polylactic acid (GO/PLA) nanocomposite. Negative triboelectric material: Convex-patterned polydimethylsiloxane (PDMS)
Energy Storage Triboelectric Nanogenerator Based on Ratchet Mechanism for Random Ocean Energy Harvesting	(86)	495 V	19 μA	Ratchet mechanism with stored energy released centrally	Rotor: Polylactic acid with fluorinated ethylene propylene (FEP) films. Stator: Copper films
A Self-Powered Sport Sensor Based on Triboelectric Nanogenerator for Fosbury Flop Training	(87)	420 V	54 μA	Vertical touch separating mode	Triboelectric Material: Carbon oil (CO) coated on cotton fabric (CF). Counter Electrode: Polytetrafluoroethylene (PTFE) film
Fabric-rebound triboelectric nanogenerators with loops and layered structures for energy harvesting and intelligent wireless monitoring of human motions	(88)	Up to 466,61 V (under 600 N force and 3 Hz frequency)	12,61 μA (under the same conditions as above)	Contact-separation mode (based on biomechanical force)	* Conductive Fabric: Copper-Nickel fabric (CNF) * Dielectric Layer: Polydimethylsiloxane (PDMS) doped with Barium Titanate ($BaTiO_3$) nanoparticles
Development of the triboelectric nanogenerator using a metal-to-metal imprinting process for improved electrical output	(13)	200 V	60 μA	Finger tapping motion	Aluminum (structured with micro- and nanoscale patterns), Fluorinated Ethylene Propylene (FEP)

CONCLUSIONS

This study provides a comprehensive bibliometric and systematic review of the predominant materials used in Triboelectric Nanogenerators (TENGs), analyzing publication trends, material compositions, and their influence on device performance. The results reveal that fluorinated polymers, metal electrodes, carbon-based nanomaterials, and engineered elastomers constitute the core materials driving advancements in TENG technology. The co-occurrence analysis from Scopus and Web of Science confirmed that PTFE, FEP, PVDF, PDMS, and graphene derivatives are among the most frequently utilized materials, emphasizing their superior triboelectric properties, durability, and flexibility.

The bibliometric analysis highlights China as the leading contributor to TENG research, followed by the United States and South Korea. This dominance is largely attributed to substantial governmental funding, large-scale research initiatives, and industry collaborations fostering nanogenerator development for wearable electronics, energy harvesting, and self-powered sensors. The systematic review further demonstrated that hybrid material systems, particularly polymer-ceramic composites and carbon-based conductive nanostructures, are increasingly employed to enhance charge transfer efficiency and overall electrical output.

A critical evaluation of high-performance TENGs revealed that voltage output (Voc) is influenced by material selection, surface engineering, and structural design. Among the highest-performing devices, FEP, PTFE, $BaTiO_3$-doped PDMS, and MXene composites exhibited outstanding triboelectric behavior, often surpassing 400 V in output voltage under controlled conditions. Integrating nanostructured interfaces and doping techniques, such as using barium titanate ($BaTiO_3$), graphene oxide (GO), and cobalt nanoparticles, demonstrated substantial improvements in charge retention and power density.

The findings also underscore the importance of advanced electrode configurations in optimizing TENG performance. ITO-coated glass, silver nanowires, and aluminum micro-patterned films were frequently employed to enhance electron transport and minimize resistance losses. The increasing trend of incorporating biodegradable and eco-friendly materials, including cellulose, chitosan, and starch-based substrates, suggests a growing interest in sustainable energy harvesting solutions.

The results of this study confirm that TENG technology is evolving toward higher efficiency, multifunctionality, and broader application potential. Future research should focus on scalability, material stability, and integration with hybrid energy systems to facilitate the commercialization of TENG-based self-powered devices. Moreover, emerging material trends, such as MXenes, 2D nanomaterials, and bio-inspired structures, offer promising avenues for further improving triboelectric charge generation and durability.

This work provides a valuable reference for researchers and engineers working on next-generation nanogenerators, offering insights into the most effective material choices and their corresponding performance metrics. By bridging bibliometric insights with systematic material analysis, this study paves the way for the rational design of high-efficiency TENGs for applications in wearable electronics, biomedical sensors, and large-scale energy harvesting.

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