A Bibliometric Analysis of Wireless Power Transfer Technology Applications: Cross-Domain Insights from Emerging Fields

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Research paper

A bibliometric analysis of wireless power transfer technology applications: Cross-domain insights from emerging fields

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ABSTRACT

Wireless power transfer (WPT) technology, as a representative power solution in the new energy revolution, has attracted increasing research and attention. Owing to its inherent advantages-such as freedom, flexibility, and safety-WPT has expanded beyond traditional applications into emerging fields with broad potential. This study conducts a bibliometric analysis of WPT research across six emerging fields: electric vehicles, sensors, unmanned aerial vehicle, wearable devices, underwater devices, and rail transit. By systematically examining leading countries/regions, institutions, journals, authors, highly cited publications, and keyword trends, the study delineates the current research landscape and application scenarios for each field. Furthermore, cross-domain analyses reveal shared technical challenges and interdisciplinary synergies. The findings provide researchers with a comprehensive reference to navigate WPT advancements, identify innovation opportunities, and prioritize future investigations in both domain-specific and integrated frameworks.

1. Introduction

Wireless Power Transfer (WPT) is a disruptive technology enabling contactless energy delivery across diverse applications, thereby eliminating the need for battery replacements and physical connectors in energy-constrained systems [1,2]. The concept of inductive charging traced back over a century to the work of Nikola Tesla, laying the foundation for wireless power transfer (WPT) systems. The earliest literature dates back to the 1970s [3]. A transformative milestone occurred in 2007 when MIT researchers demonstrated magnetically coupled resonance technology in SCIENCE, which significantly accelerated global WPT innovation [4]. Propelled by advancing electrification and intelligentization across industries-from transportation [5,6] and healthcare [7] to smart infrastructure [8], even down to room-scale magnetoquasistatic [9]-WPT has evolved into a cornerstone technology for sustainable energy ecosystems. In 2017, Sid Assawaworrarit innovatively proposed nonlinear parity-time-symmetric circuit, which significantly improved the robustness and transmission efficiency of the system [10]. Along this line of thought, researchers have carried out a series of research works on nonlinear parity-time-symmetric circuits in the aspects of efficiency optimization [11], constant current and constant voltage control [12], bound state in the continuum [13], etc. The development of WPT technology to another peak. Its growing prominence is further validated by NATURE ELECTRONICS, which recently recognized WPT as one of the most impactful research topics of the past five years [14], underscoring its critical role in addressing energy autonomy challenges in an increasingly wireless world. Milestone breakthroughs in WPT technology as shown in Fig. 1.

This study focuses on six emerging domains where WPT holds transformative potential: electric vehicles (EVs), sensors, unmanned aerial vehicles (UAVs), wearable, underwater and rail. Each domain has garnered dedicated scholarly attention, with existing reviews addressing domain-specific challenges. Driven by the expanding EV industry and advancements in vehicle-to-grid (V2G) technology, research in the EV field has broadened considerably [15–19], with current efforts spanning dynamic charging topologies and control strategies [20–22], coupler design optimization [23–25], system robustness under misalignment conditions [26,27], distance adaptation [28,29] and grid integration challenges and opportunities [30–32]. The advancement of Internet of Things (IoT) technology has propelled significant attention toward WPT applications in sensor-related domains, particularly in microsystem sensors [33,34], flexible sensors [35], and sensor networks

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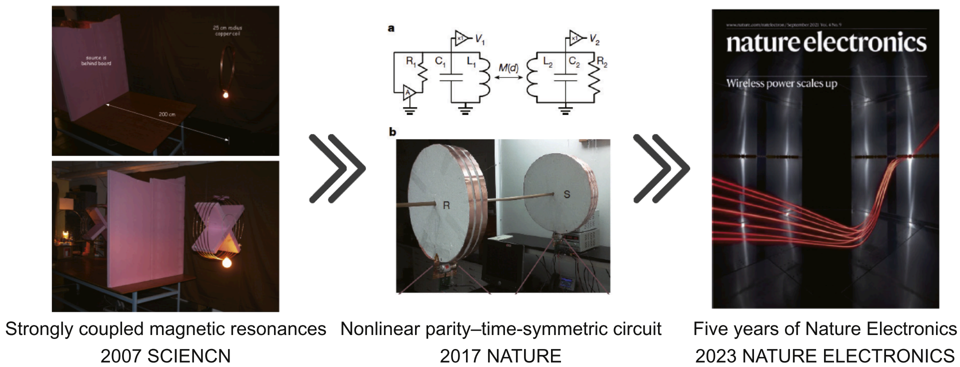

Fig. 1. Milestone breakthroughs in WPT technology.

[36], driven by the demand for autonomous and maintenance-free sensing solutions. Emerging application domains of WPT technology-UAVs [37–39], wearable devices [40–44], underwater systems [45–47], and rail transit [48–50]-have spurred growing research discussions, particularly in dynamic alignment [51], interoperability [52,53], standardization [54], and energy harvesting [55,56], security issues [57,58], laying the groundwork for scalable and adaptive power delivery solutions.

Despite these advancements, the current literature remains siloed, predominantly examining innovations within isolated applications rather than identifying cross-domain technical convergences. This fragmented approach obscures opportunities to leverage shared breakthroughs. A critical gap persists in understanding how WPT research priorities and innovation pathways diverge across emerging domains and in identifying cross-domain technical synergies to accelerate advancements. Addressing these questions remains pivotal to unlocking the full potential of WPT within heterogeneous technological ecosystems.

Bibliometric analysis, validated by extensive prior studies, offers a robust methodology to map technological landscapes and identify research frontiers [59,60]. By applying this approach to six emerging WPT domains, the study systematically delineates current research priorities, technological disparities, and shared challenges, while critically assessing limitations in existing methodologies. This analysis reveals domain-specific innovation patterns and establishes a cross-domain knowledge transfer framework, highlighting synergistic opportunities in materials, control systems, and energy architectures. The findings provide actionable insights for researchers to address critical gaps, prioritize fundamental breakthroughs, and foster international collaboration-ultimately accelerating evolution of WPT from isolated applications toward interoperable, ecosystem-scale solutions.

2. Data and methodology

2.1. Data collection

This paper's research source is from the online version of the SCI-Expanded database in the Web of Science Core Collection, which has advantages in the citation counts of publications [61], tracking early literature [62], more precise journal categorization [63], lower error rate in document type tagging [64]. In order to encompass as many papers as possible related to "Wireless Power Transfer Technology", the query used for searching the data is "TS =("wireless charg*" OR "wireless power trans*" OR "Inductive power trans*" OR "Inductive charg*")". The publication date is set as "all years", and the dataset is retrieved on April 10, 2025. The publication language is set as "English". At the same time, duplicate data was removed and preliminary correlation processing was carried out. A total of 10,286 result are obtained after screening. The results cover many types of research results, each type and proportion is shown in the Fig. 2. As can be seen from the search results, the document types of "Article" and "Review" rank first and second, which are the concerns of bibliometric analysis.

The document types of "Article" and "Review" are refined in the further process, 10,158 records are collected. Define different application objects for further search. ① AND TS = ("electric vehicle*" OR "electric car*" OR "electric automobile*" OR "electromobile*"). 1456 articles and 127 reviews are collected. ② AND TS =("sensor*"). 1439 articles and 75 reviews are collected. ③ AND TS =("unmanned aerial vehicle*"). 318 articles and 19 reviews are collected. ④ AND TS =("wearable*"). 234 articles and 28 reviews are collected. ⑤ AND TS =("underwater*"). 183 articles and 10 reviews are collected. ⑥ AND TS =("railway*" OR "rail"). 99 articles and 6 reviews are collected. The overall step of literature screening is summarized as shown in the Fig. 3 (1). The search results are summarized in a bar chart as shown in Fig. 3 (2). As listed in Fig. 3 (2), the research field with more publications studied are "electric vehicle" and "sensor". In Section 3, a detailed bibliometric analysis is conducted for each field.

2.2. Bibliometric methods

Bibliometrics is defined as a cross-disciplinary field that employs statistical techniques to systematically measure and evaluate information-bearing entities. This analytical approach synthesizes mathematical principles, data analysis, and systematic documentation to map the intellectual landscape of specialized domains. Practitioners utilize this methodology to examine, categorize, and assess scholarly publications, enabling academics to systematically discover, assess, and critically examine targeted academic domains for generating substantive research conclusions [65,66]. Bibliometric techniques establish a structured framework for evaluating the existing conditions, scientific influence, scholarly merit, and evolutionary patterns in academic inquiry by employing computational examination of published works [67]. Thus, bibliometric analysis is an appropriate method and tool for gaining a thorough understanding of the current scope and comprehensive knowledge of global carbon-neutral research [68].

Core bibliometric instruments encompass established platforms like CitNetExplorer, VOSviewer, SciMAT, BibExcel, CiteSpace, and VantagePoint. Amidst contemporary methodological progressions in measurement science, open-source R-based frameworks have become progressively integrated into analytical workflows. These computational bibliometric frameworks have garnered global academic endorsement, catalyzing the proliferation of rigorous cross-disciplinary investigations through enhanced analytical reproducibility and methodological transparency [69].

Furthermore, the graphical output of the R-tool is aesthetically pleasing and aligns with mainstream quantitative research presentations, It bridges the communication gap between qualitative and quantitative studies and facilitates dialogue. In light of these advantages, the Bibliometric package in R-tool (version 4.3.3) is selected as a bibliometric

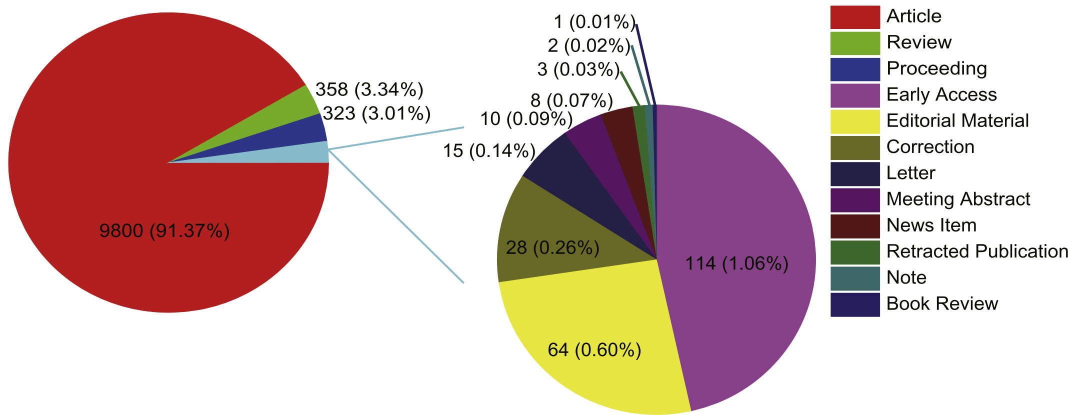

Fig. 2. Type and proportion of research results.

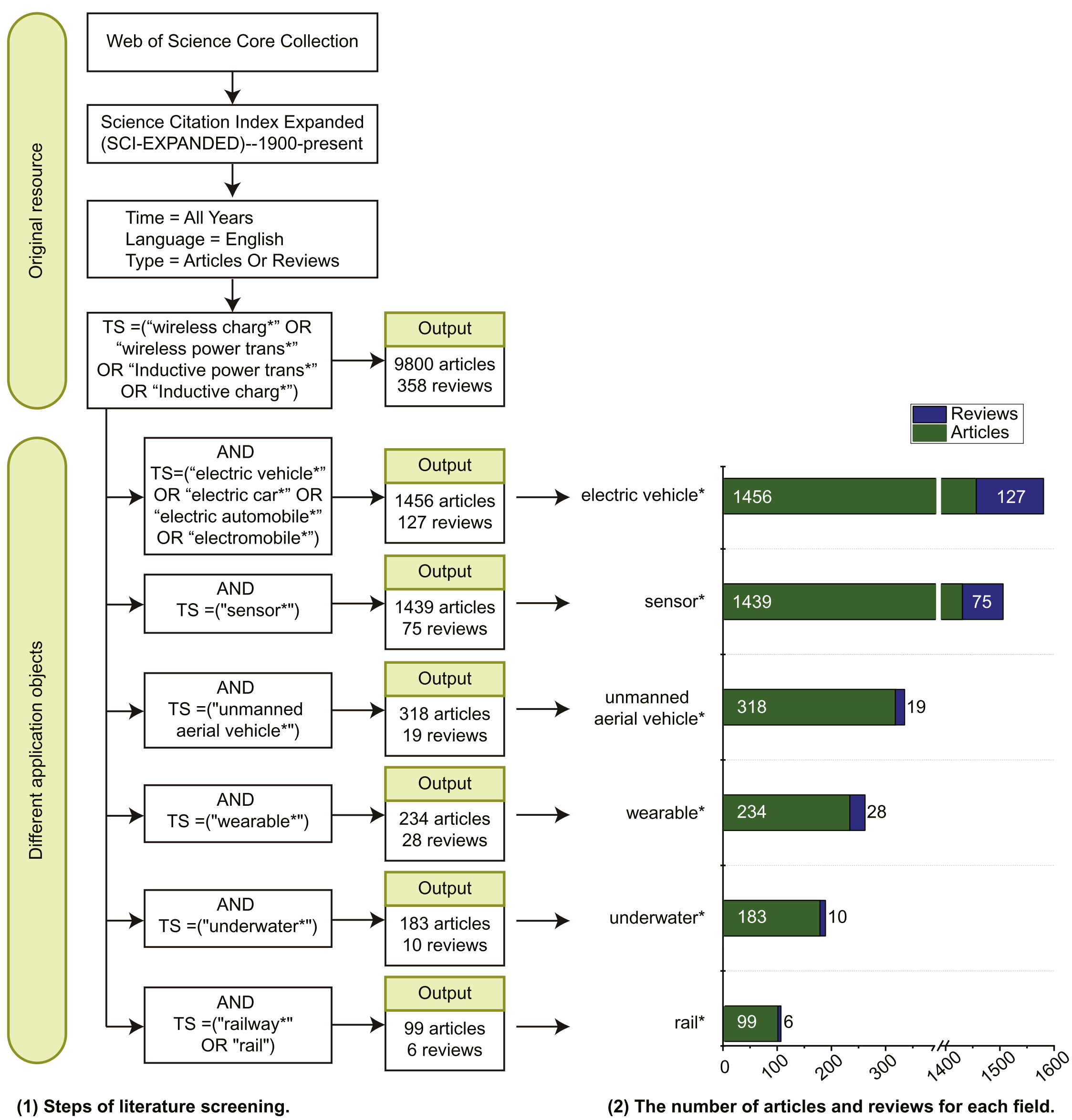

Fig. 3. Steps and results of literature screening. (Data updated on April 10, 2025).

analysis tool to summarize the development of wireless power transfer technology research in various field.

2.3. Analytical dimensions and terminology

The methodology of bibliometric analysis used in this work sorts out the publications by distribution per year, distribution by countries/regions, source journals, institutions, authors, keywords and most cited publications.

To perform quantitative analysis, this study considers several bibliometric measures, including total citations (TC), total number of publications (TNP), average publication year (APY), first publication year (FPY), average article citation(AAC), H-index.

A steady increase in TC and TNP indicates that the chosen field of research has gained significant importance. The AAC is a country-wise metric used to calculate the average citations of articles authored by a specific country. H-index is defined as the number of published paper (h) that have been cited h or more than h times.

Bibliometric analysis based on R-tool introduces the concept of Thematic map, which categorizes the research themes into four quadrants based on their development [70]. The conceptual framework partitions research domains into four distinct analytical dimensions based on thematic prominence. Quadrant I “motor theme” constitutes core developmental clusters characterized by elevated centrality and density metrics, representing methodologically mature investigation for that have sustained prolonged scholarly engagement. These constitute the epistemological foundation driving disciplinary advancement.Quadrant II “niche theme” delineates specialized innovation nodes demonstrating concentrated centrality with dispersed density profiles, encapsulating cutting-edge conceptual territories primed for intensified academic exploration. These domains exhibit high potential for catalyzing paradigm shifts through novel research trajectories.Quadrant III “emerging or declining theme” encompasses transient developmental phases marked by diminished centrality and density indices, reflecting either nascent theoretical constructs requiring validation or obsolescent knowledge structures undergoing epistemological marginalization. These transitional states manifest the dynamic evolution of scientific discourse.Quadrant IV “basic theme” comprises fundamental conceptual scaffolding exhibiting robust density with limited centrality, constituting persistent theoretical pillars that maintain enduring relevance despite not occupying current investigative priorities. These elements provide essential referential frameworks for disciplinary coherence. In the subsequent Thematic Map analysis of this article, based on the classic Bibliometric algorithm in the R-tool, the top 250 most frequently occurring keywords were selected, with the minimum occurrence frequency being 5.

3. Results

3.1. Electric vehicles (EVs)

As a field with the largest number of literatures in the search results, the developing EV market reveals the importance and significance of this topic. Driven by carbon neutrality, the transportation sector is undergoing significant electrification [71]. Electric car sales keep rising and could reach around 17 million in 2024, accounting for more than one in five cars sold worldwide [72]. The annual distribution and corresponding cumulative results are shown in Fig. 4 (1). The first article on this topic was published in 1998 from USA researchers, which investigated the design criteria of the high-power converter for a 120-kW inductive battery charger [73]. In the first few years (1998–2012), the number of articles on this topic did not exceed five each year. Since 2013, the exponential growth of publications means that the number of researchers, institutions and source journals is constantly increasing. Dynamic wireless charging, where vehicles are charged wirelessly, as they are driven, via charging pads buried beneath the surface of the road, could provide a solution [74]. And the related research will keep developing vigorously in the next decades.

3.1.1. Top countries

According to the collected data, all the articles are from 71 countries or regions around the world. As listed in Table S1, the countries with more publications studied are China (585 articles) and USA (251 articles). In 2024, China’s EV sales accounted for over 60% of the global market share [72]. The scaled-up electric vehicle industry and continuous advancements in battery technology have collectively driven the imperative for charging infrastructure upgrades. China has the highest number of papers, while USA ranks in the first place in total citations and New Zealand has the highest average citations per paper. It is worth noting that the average publishing year in the United States is 2019.11, and in China it is 2021.11. China dominates patenting activity in the majority of WPT in EVs field in the last five years.

3.1.2. Key institutions

The top 10 productive institutions are shown in Table S7. The University of Auckland from New Zealand ranks first. Combined with the Table S1, New Zealand has the highest AAC, which can indicate that University of Auckland has the theoretical authority of WPT technology in EVs field. It has a strong strength in the field of coils design. Zhejiang University followed with 47 papers and it is famous for its control of dynamic wireless power transfer. The third most prolific is Fuzhou University (41 papers) and it is focus on the control of Constant Current (CC) and Constant Voltage (CV) output. It is worth noting that Egyptian Knowledge Bank ranks seventh with 26 publications. Egypt, as a participant in the EU’s ’Mediterranean Electric Vehicle Corridor’ initiative, must align its domestic research outcomes with EU standards through the EKB framework.

3.1.3. Leading journals

Information about the journals in which worldwide authors most frequently published their articles is presented in Table S13. As the leading journal, the IEEE TRANSACTIONS ON POWER ELECTRONICS published 182 articles (12.5 %), followed by the ENERGIES and the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, with 117 (8 %) and 96 articles (6.6 %), respectively. Among them, the TC of IEEE TRANSACTIONS ON POWER ELECTRONICS and IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS is the top two, and the H-index also certifies their authority in the WPT technology in EVs field.

3.1.4. Prolific authors

With the vigorous development of WPT technology in EVs, more and more researchers have joined in the exploration. The top 10 prolific authors with more published articles are presented in Table S19. Of the 10 authors, 4 are from China, 4 are from New Zealand, 1 is from USA, 1 is from India. The most prolific author is Covic, Grant, who is a professor at University of Auckland. Meanwhile, Boys, John is also a professor at University of Auckland. These two scholars have worked together for a long time, and collaboration produced 19 articles. Covic and Boys have pioneered foundational research in electric vehicle wireless charging, revolutionizing magnetic coupler design, compensation topologies, and system stability analysis, thereby bridging theoretical principles with practical static and dynamic charging applications. The second ranked prolific author is Zhang, Yiming from Fuzhou University, and the third ranked is Mi, Chunting C from UNIVERSITY OF MICHIGAN.

3.1.5. Most cited publications

The most cited publications in the EV field reflect a concerted effort to solve core engineering challenges. The top 10 most cited publications are displayed in Table A1. The most cited publication reviews the current status and implementation of battery chargers, charging power levels, and infrastructure for plug-in electric vehicles and hybrids [75].

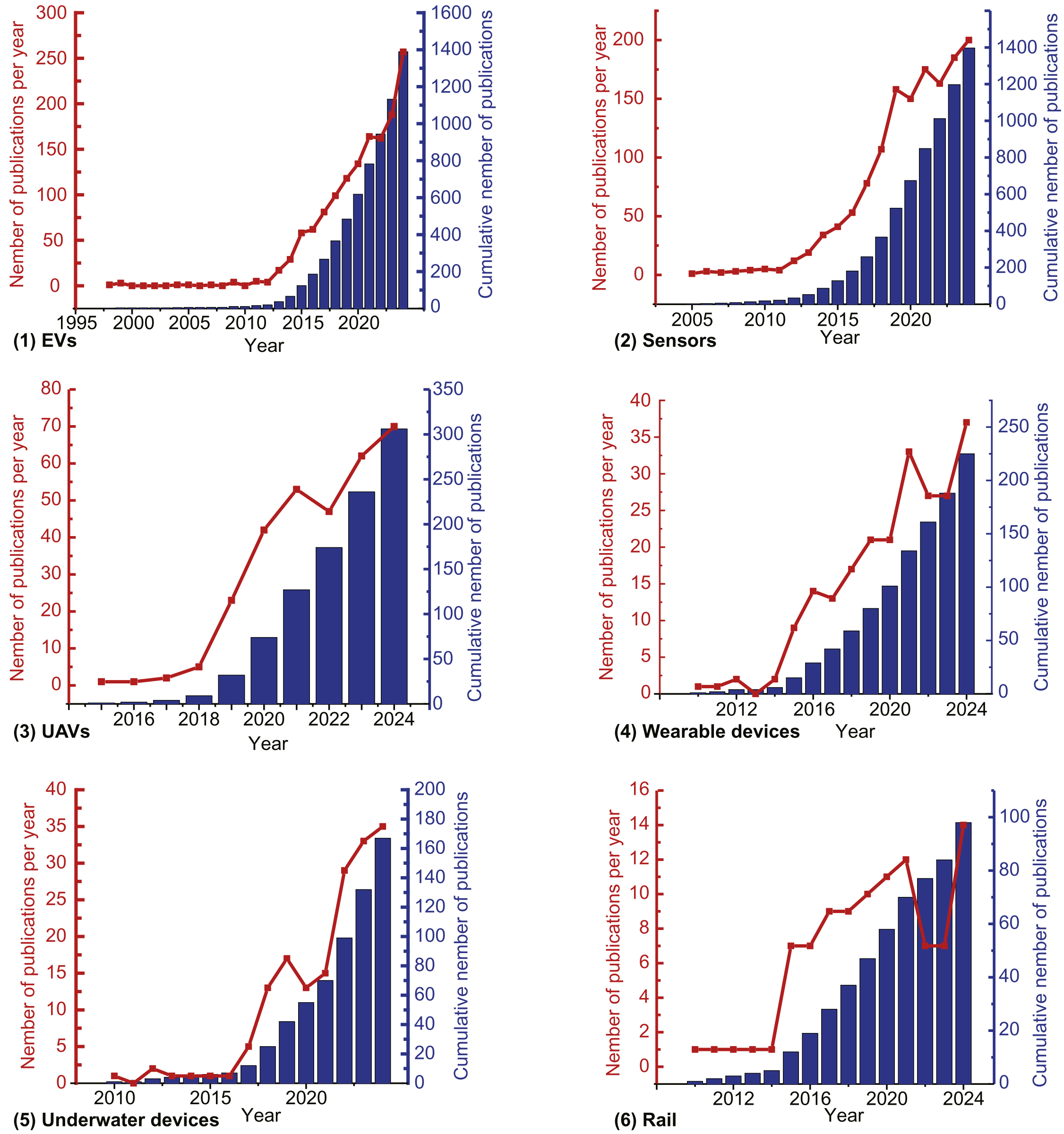

Fig. 4. Annual distribution of WPT technology in each field publications. The statistics are as of 12/31/2024.

Design and optimization [76,77], bifurcation phenomena [78], Single-Sided flux magnetic coupler [79], compensation network [80] and modern trends [81–84] are the topics of these articles.

3.1.6. Terms

Terms analyze the frequency of occurrence, and provide insights into main themes and research trends [85]. In order to identify hot topics of WPT technology LIBs in EVs field, the collected paper title and abstract information are extracted. The top ten most occurrences keywords is shown in Table S25. The topic words, i.e. “wireless charging”, “electric vehicle”, etc., and related words with the same meaning are excluded. Fig. 5 (1) show trending keywords for the last five year. It can be seen that “voltage”, “coils”, “topology” are get more attention in the research. The thematic map is shown as Fig. 6 (1). The thematic map divides the keywords of WPT technology in EVs field into four themes, and decomposes into quadrants 2 and 4. The size of the circle indicates the number of keywords in the cluster, and the keywords that appear most frequently are listed on the circle. Within quadrant 4, Basic Themes are in the high central density region and represent the fundamental themes of WPT technology in EVs field. Although not the primary focus of current global researchers, these Basic Themes encompass a substantial amount of foundational knowledge in research and serve as building blocks for the field. Within quadrant 2, Niche Themes are situated in the high centricity low density region and represent themes that are likely to garner future attention from WPT technology in EVs field researchers. The results show that under the premise of ensuring electromagnetic compatibility and electromagnetic safety, enhancing the coupling effect and improving the energy transmission capacity are the main research directions in the future.

3.2. Sensors

The current application domains of the Internet of Things (IoT) have permeated virtually all industries, with ’passive operation’ and ’self-sustainability’ emerging as key evolutionary trends. While IoT systems increasingly integrate AI chips to enable edge autonomous decision-making, energy supply remains one of their foremost challenges. Breakthroughs in wireless charging technologies offer promising pathways to

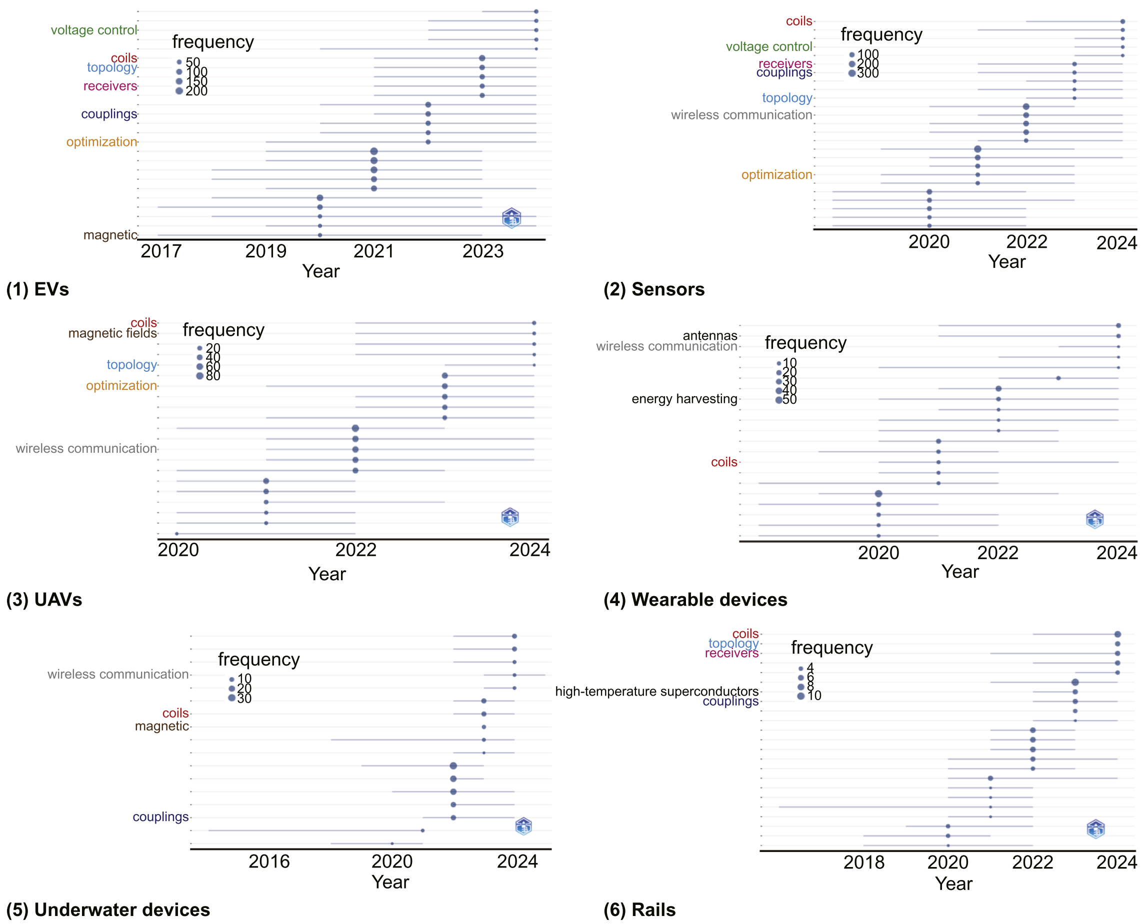

Fig. 5. Trendtopics of WPT technology in each field, 2020–2024.

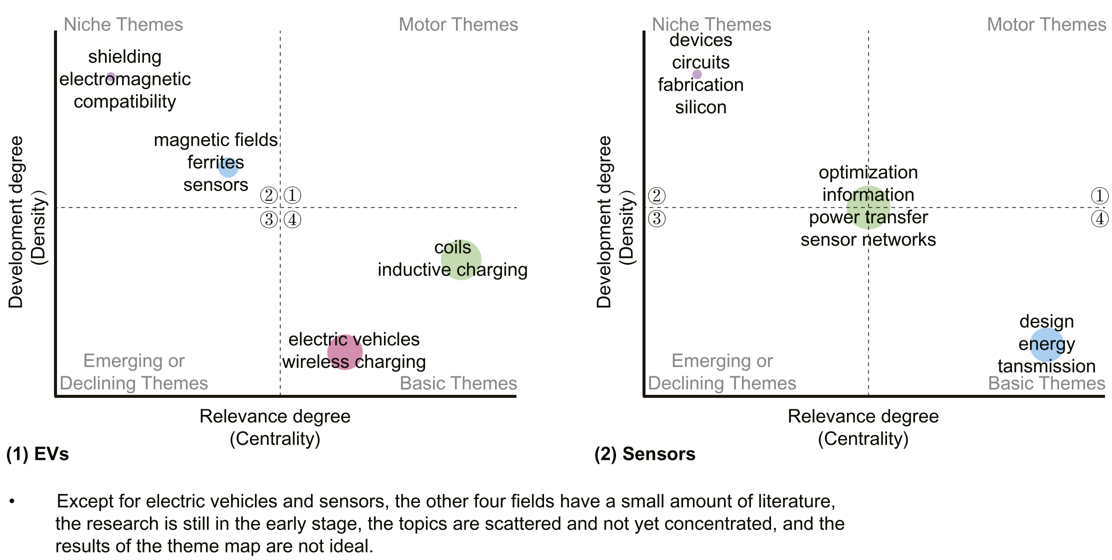

Fig. 6. Thematic Map of WPT technology in EVs and Sensors field.

address this critical bottleneck. The annual distribution and corresponding cumulative results are shown in Fig. 4 (2). The first article on this topic was published in 2005 from USA researchers, which propose a circularly polarized (CP) microstrip patch antenna that can function as a WLAN antenna in the 5.15-5.35 GHz and as a rectenna at 5.5 GHz [86]. However, the focus of the research is not WPT technology. In the first few years (2005–2011), the number of articles on this topic did not exceed five each year. Since 2012, WPT technology in sensors field is also gained more attention, and will have broad prospects in the future.

3.2.1. Top countries

According to the collected data, all the articles are from 77 countries or regions around the world. As listed in Table S2, the countries with more publications studied are China (632 articles) and USA (282 articles). China has the highest number of papers and total citations, Singapore has the highest average citations per paper. Based on the APY, Singapore started research of WPT technology in sensors field earlier. China and India have done more research in this field in recent years.

3.2.2. Key institutions

The top 10 productive institutions are shown in Table S8. The top three prolific institutions are all from China. Of the top 10 institutions, 6 are from China, 2 are from USA, 1 is from South Korean and 1 is from India. Chinese Academy of science ranks the first with 43 papers, and almost focuses on WPT technology used in various devices, such as hybridized electromagneticn triboelectric nanogenerator [87] and flexible microsystem capable [33]. The second is Nanjing University with 39 papers, which almost concentrates on constrained scheduling [88] and dynamic programming of task [89].

3.2.3. Leading journals

Information about the journals in which worldwide authors most frequently published their articles is presented in Table S14. As the leading journal, the SENSORS published 104 articles (7.2 %), followed by the IEEE ACCESS and the IEEE INTERNET OF THINGS JOURNAL, with 88 (6.1 %) and 77 articles (5.4 %), respectively. Among them, the TC of IEEE INTERNET OF THINGS JOURNAL and IEEE TRANSACTIONS ON MOBILE COMPUTING is the top two. IEEE INTERNET OF THINGS JOURNAL, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES ranks in the first group with more than 20 H-index.

3.2.4. Prolific authors

The top 10 prolific authors with more published articles are presented in Table S20. The countries/regions of the top 10 authors are diverse. The top three authors are all from china, and co-published several articles. Their research focuses on algorithmic breakthroughs for wirelessly charged sensor networks, pioneering radiation-constrained scheduling and dynamic mobile charger deployment to achieve sustainable network operation. Kim, Dong In from South Korea has the most TC, whose research centers on optimizing resource allocation and communication protocols for wirelessly powered sensor networks, with a focus on simultaneous wireless information and power transfer (SWIPT) to enhance network throughput and energy efficiency. The research of France and Portugal illustrate the European interest in research of WPT technology in sensors field.

3.2.5. Most cited publications

In the sensor domain, highly cited works have been pivotal in bridging WPT with communication and computation paradigms. The top 10 most cited publications are displayed in Table A2. WPT technology in the sensors field is mainly aimed at protocol [90], mobile edge computing [91,92], synchronous transmission of information and energy [93,94], and applications on smart devices [36,95]. As the low power WPT technology Low-power wireless charging technology has attained a high degree of technological maturity, with standardized implementations now prevalent across commercial and industrial applications. There are few researches on wireless charging technology [96].

3.2.6. Terms

The top ten most occurrences keywords is shown in Table S26. The topic words, i.e. “wireless charging”, “sensors”, etc., and related words with the same meaning are excluded. Fig. 5 (2) show trending keywords for the last five year. It can be seen that “coils”, “voltage control”, “receivers” are get more attention in the research. The thematic map is shown as Fig. 6 (2). The thematic map divides the keywords of WPT technology in sensors field into three themes, and decomposes into quadrant 2, quadrant 4, and center. The size of the circle indicates the number of keywords in the cluster, and the keywords that appear most frequently are listed on the circle. It can be seen from the map, technical problem like “design” and “transmission” is foundational knowledge in research and serve as building blocks for the field. It is worth noting that the green cluster is located at the center, which means extensive co-occurrences with other topics, indicating its role as a Knowledge Hub. In the future, sensors will develop towards the trend of lighter weight and miniaturization. Combined with the future concerns of quadrant 2, how to achieve higher energy density and more stable transmission is the future development direction of WPT technology in sensors field.

3.3. Unmanned aerial vehicles (UAVs)

Under the robust impetus of low altitude economy policy frameworks, UAVs, as strategic emerging industries, are exhibiting a dual trajectory characterized by strengthened safety governance regimes and expanding application scenario liberalization. Concurrently, the development of WPT technology in UAVs field is navigating a critical juncture marked by the simultaneous advancement of core technical breakthroughs and exploratory commercial deployment. The annual distribution and corresponding cumulative results are shown in Fig. 4 (3). The first article on this topic was published in 2015 from USA researchers, which evaluates the method of using UAVs to charge sensor networks for increasing network life [97]. In the first few years (2015–2018), the number of articles on this topic did not exceed five each year. Since 2019, WPT technology in UAVs field is also gained more attention, and will have broad prospects in the future.

3.3.1. Top countries

According to the collected data, all the articles are from 48 countries or regions around the world. As listed in Table S3, China has the highest number of papers and total citations, Australia has the highest AAC. The APY of the top 10 countries/regions has all been in the past five years, indicating that WPT technology in the UAVs field as an emerging technology has broad prospects for future development.

3.3.2. Key institutions

The top 10 productive institutions are shown in Table S9. The top 8 prolific institutions are all from China. UNIVERSITY OF LONDON ranks ninth, and RWTH AACHEN UNIVERSITY ranks tenth. China dominates the field of research.

3.3.3. Leading journals

Information about the journals in which worldwide authors most frequently published their articles is presented in Table S15. As the leading journal, the IEEE INTERNET OF THINGS JOURNAL published 29 articles (9.1 %), followed by the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY and the IEEE ACCESS, with 24 (7.5 %) and 17 articles (5.3 %), respectively. Among them, the TC of IEEE INTERNET OF THINGS JOURNAL and IEEE ACCESS is the top two. IEEE INTERNET OF THINGS JOURNAL, IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY ranks in the first group with more than 10 H-index.

3.3.4. Prolific authors

The top 10 prolific authors with more published articles are presented in Table S21. The countries/regions of the top 10 authors are almost China. It also reflects China’s leadership of WPT technology in UAVs field.

3.3.5. Most cited publications

The research focus for UAVs is clearly on system-level optimization, as evidenced by the most cited papers. The top 10 most cited publications are displayed in Table A3. At present, the research of WPT technology in UAVs field mainly focuses on time and space optimization under different optimization objectives [98–101]. Edge computing is also an important concern [102–104].

3.3.6. Terms

The top ten most occurrences keywords is shown in Table S27. The topic words, i.e. “wireless charging”, “UAV”, etc., and related words with the same meaning are excluded. Fig. 5 (3) show trending keywords for the last five year. It can be seen that “coils”, “optimization”, “resource-allocation” are get more attention in the research. Due to the small amount of literature, the clustering distribution of thematic map is very loose, and it is difficult to explain the problem. As a result, thematic map is no longer rendered in subsequent application fields. In the application of WPT technology in UAVs field, the optimization of time and space charging task and path is the main research direction. The technical development of WPT technology in the UAVs field is stable energy transmission under the changing external environment.

3.4. Wearable devices

Transferring power between devices on a person, for wearable technologies or electronic medical devices for example, is challenging [14]. Inductive approaches typically work over short distances, while far-field radio frequency methods require line of sight between devices. Additionally, body movement can detune coupled circuits that need to remain in fixed positions [105]. The annual distribution and corresponding cumulative results are shown in Fig. 4 (4). The first article on this topic was published in 2010 from South Korea researchers, in which a self-configured body sensor network controller and a high efficiency wirelessly powered sensor are presented for a wearable, continuous health monitoring system [106]. In the first few years (2010–2014), the number of articles on this topic did not exceed two each year. Since 2015, WPT technology in wearable devices field is also gained more attention.

3.4.1. Top countries

According to the collected data, all the articles are from 43 countries or regions around the world. As listed in Table S4, USA has the highest number of papers and China has the highest TC and South Korea has the highest AAC. The number of articles published by China and USA is roughly equal. Combined with APY, South Korea’s research in this field started earlier.

3.4.2. Key institutions

The top 10 productive institutions are shown in Table S10. Of the top 10 institutions, 3 are from USA, 3 are from China, 2 are from China, 1 is from England and 1 is from India. STATE UNIVERSITY SYSTEM OF FLORIDA and UNIVERSITY OF SOUTHAMPTON are the top two and have more than ten articles.

3.4.3. Leading journals

Information about the journals in which worldwide authors most frequently published their articles is presented in Table S16. Among them, the TC of IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES is the highest, and also has the highest proportion of high cited articles.

3.4.4. Prolific authors

The top 10 prolific authors with more published articles are presented in Table S22. Wagih, Mahmoud from England has the highest TC and H-index, whose research specializes in developing high-sensitivity rectennas and textile-based antennas for RF energy harvesting, enabling batteryless operation of wearable electronics through ambient wireless power capture. Researchers have not published more than 10 papers, so there have not yet formed an authoritative author group of WPT technology in the wearable devices field.

3.4.5. Most cited publications

Achievements in the wearable field are marked by material innovation and successful system integration. The top 10 most cited publications are displayed in Table A4. Among them, WPT technology is applied to different wearable devices, for example, contact lenses [95], flexible integrated system [107], continuous health monitoring system [106], Biomedical Capsule Endoscope [108][109]. achieves efficiency breakthroughs based on metasurface, [110,111] focuses on material innovation, [112] focuses on structural innovation.

3.4.6. Terms

The top ten most occurrences keywords is shown in Table S28. The topic words, i.e. “wireless charging”, “wearable”, etc., and related words with the same meaning are excluded. Fig. 5 (4) show trending keywords for the last five year. It can be seen that “energy harvesting”, “rectenna” are get more attention in the research. Technologically, the WPT technology in wearable devices field are poised to achieve breakthroughs in ultra-thin flexible architectures and electromagnetic safety enhancements. From an application perspective, cross system interoperability and stringent cost control measures emerge as critical determinants for market dominance in this rapidly evolving sector.

3.5. Underwater devices

Underwater devices are increasingly used for undersea exploration. The endurance is limited by the onboard energy storage among which the battery systems dominate. Currently, contact-based underwater recharging utilizes the wet-mate connector technology that requires a high-precision AUV docking, and is prone to electrical safety issues. To overcome these limitations, underwater wireless recharging techniques have been explored in recent years [46]. The annual distribution and corresponding cumulative results are shown in Fig. 4 (5). The first article on this topic was published in 2010 from USA researchers, in which a ocean-observing smart sensor web presented is composed of both mobile and fixed underwater in situ ocean sensing assets and Earth Observing System satellite sensors providing larger-scale sensing [113]. In the first few years (2010–2017), the number of articles on this topic did not exceed five each year. Since 2018, WPT technology in wearable devices field is also gained more attention.

3.5.1. Top countries

According to the collected data, all the articles are from 25 countries or regions around the world. As listed in Table S5, China has the highest number of papers and the highest TC, Singapore has the highest AAC. Combined with APY, South Korea’s research in this field started earlier. In terms of TNP, China is absolutely dominant.It’s worth noting that Norway and Scotland are listed in top ten, which may be related to the geographical environment and strategic needs of the regions.

3.5.2. Key institutions

The top 10 productive institutions are shown in Table S11. Of the top 10 institutions, 7 are from China, 2 are from USA, 2 are from China, 1 is from Japan. NORTHWESTERN POLYTECHNICAL UNIVERSITY, HARBIN INSTITUTE OF TECHNOLOGY and ZHEJIANG UNIVERSITY are the top three and have more than ten articles.

3.5.3. Leading journals

Information about the journals in which worldwide authors most frequently published their articles is presented in Table S17. Among them, the IEEE TRANSACTIONS ON POWER ELECTRONICS has the highest TNP, TC and H-index.

3.5.4. Prolific authors

The top 10 prolific authors with more published articles are presented in Table S23. Chinese researchers have the highest TC and H-index. Eight research or the top 10 are all from China. The top four researchers are all from Northwestern Polytechnical University and have co-published several articles. Their research focuses on developing rotation-resilient and pressure-tolerant wireless charging systems for autonomous underwater vehicles, optimizing magnetic coupling and compensation networks to achieve stable power transfer in dynamic marine environments.

3.5.5. Most cited publications

The top-cited literature in underwater applications directly tackles the unique challenges of the marine environment. The top 10 most cited publications are displayed in Table A5. Kim et al. [114] is the most cited article, which presents a comprehensive review of near-field magnetic wireless power transfer (WPT) and communication technologies in a variety of applications from general free-space systems, to implantable biomedical devices. Three-phase [115], rotation-free [116,117], frequency optimization [118], loss [119], fault tolerant [120] are the main technical breakthrough direction of highly cited literature.

3.5.6. Terms

The top ten most occurrences keywords is shown in Table S29. The topic words, i.e. “wireless charging”, “underwater”, etc., and related words with the same meaning are excluded. Fig. 5 (5) show trending keywords for the last five year. It can be seen that “wireless communication”, “inductance” is research points of concern in recent years. WPT technology provides an effective solution for the endurance of underwater equipment, but there are also many challenges, like, alignment and retention, pressure-tolerant, communication and data transfer. WPT technology for underwater applications needs more advancement before it becomes a reliable replacement for the contact charging or battery swapping approaches.

3.6. Rail transit

With continuous breakthroughs in the field of electric vehicles, the WPT technology has achieved higher power and more stable performance, making its application in railway transportation possible. The annual distribution and corresponding cumulative results are shown in Fig. 4 (6). The first article on this topic was published in 2010 from Malaysia researchers, in which the nature and characteristics of radio frequency identification (RFID) antennas for wireless communication and the real world, such as railway vehicle identification, are studied [121]. Currently, research on this topic is still limited and mostly in the experimental stage. However, as railway transportation develops toward greener and more intelligent solutions, large-scale research and application of WPT technology are expected in the future.

3.6.1. Top countries

According to the collected data, all the articles are from 17 countries or regions around the world. As listed in Table S6, China has the highest number of papers and South Korea with the highest TC, Canada has the highest AAC. Combined with APY, South Korea’s research in this field started earlier. In 2015, researchers at KAIST developed and fabricated a 1-MW WPT system supplying power to the vehicles in real time without battery for high-speed trains. The train could successfully run at the speed of 10 km/h [122]. It is the earliest demonstration case of WPT technology applied to high-speed railway.

3.6.2. Key institutions

The top 10 productive institutions are shown in Table S12. Of the top 10 institutions, 6 are from China, 2 are from South Korea, 2 are from Japan. HARBIN INSTITUTE OF TECHNOLOGY are the top 1 with more than ten articles. KOREA ADVANCED INSTITUTE OF SCIENCE TECHNOLOGY KOREA RAILROAD RESEARCH INSTITUTE are collaborating institutions, working together on project work and paper output.

3.6.3. Leading journals

Information about the journals in which worldwide authors most frequently published their articles is presented in Table S18. Among them, the IEEE TRANSACTIONS ON POWER ELECTRONICS has the highest TNP, TC and H-index, and it is much higher than the second place, occupying an absolutely dominant position.

3.6.4. Prolific authors

The top 10 prolific authors with more published articles are presented in Table S24. The top authors are all from China, Japan, Korea South, East Asian countries. The sample size of the literature in rails field is small, it is still in the initial stage of development.

3.6.5. Most cited publications

The most influential publications in rail transit are characterized by breakthroughs in high-power dynamic charging. The top 10 most cited publications are displayed in Table A6. The realization of high power and dynamic charging [123,124] are the main research themes. Modular is a issue to address the problem [125]. In order to achieve operational stability, different forms of rails such as cross-segmented [126], I-type [127] and S-Type [128] are also proposed.

3.6.6. Terms

The top ten most occurrences keywords is shown in Table S30. The topic words, i.e. “wireless charging”, “rail”, etc., and related words with the same meaning are excluded. Fig. 5 (6) show trending keywords for the last five year. It can be seen that “coils”, “high-temperature superconductors” is research points of concern in recent years. For rail transit, there are stringent demands for power level and energy stability. Achieving stable power transmission at high power levels is the core focus of WPT technology development in the rail field.

4. Discussion

4.1. Cross-domain collaboration

The literature retrieved through keywords in each field contains cross-field duplicate literature. The heat map of duplicate publications is shown in the Fig. 7.

The results presents there is a high-overlap field pairs {EV, Rail}, which indicates that the application of WPT technology in EVs and rail transit vehicles may share common technical requirements, such as high-power transmission [129,130], dynamic charging [131–133], and electromagnetic compatibility (EMC) [134,135], reflecting the universality of medium-to-high power WPT systems. Furthermore, technologies developed for static and dynamic charging scenarios are transferable between these two fields, enabling cross-domain knowledge exchange and synergistic advancements. In contrast, there are low-overlap field pairs {UAV, Underwater}, {UAV, Rail}, {Wearable, Rail}. The results clarify the technical barriers among some fields. For instance, wearable devices focus on low-power, high-frequency and miniaturized designs [136,137], while underwater devices need to address issues such as sealing [138], corrosion resistance [139] and long-distance transmission [140]. UAVs, on the other hand, pay attention to lightweight designs [141,142] and dynamic alignment [143–145].

These overlapping patterns profoundly reveal the similarities and differences in technological paradigms and research ecosystems across different application fields. High-overlap field pairs indicate a strong underlying technological commonality and knowledge flow. The high degree of overlap between the sensor field and multiple others stems from its role as a universal enabling technology, where the power supply requirement is a core, cross-cutting challenge. Whether for EV battery management, UAV onboard sensing, or physiological monitoring in wearable devices, all rely on stable, self-sufficient, low-power wireless energy solutions. Consequently, research on WPT for sensors forms a

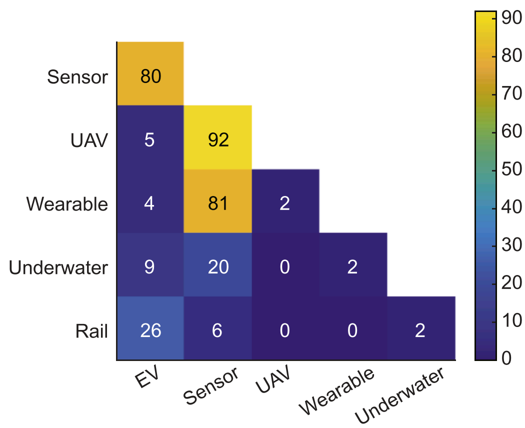

Fig. 7. Field research relevance based on publication duplication.

cross-domain knowledge hub, whose breakthroughs can benefit numerous downstream applications.

Conversely, low-overlap field pairs highlight unique technical barriers and relatively isolated research communities. Taking the underwater field as an example, its minimal overlap primarily originates from: 1) Extreme environmental specificity: Challenges such as electromagnetic propagation attenuation due to seawater, sealing and pressure resistance requirements, and anti-corrosion demands constitute a distinct set of technical problems compared to other fields; 2) Dedicated research infrastructure: Studies in this domain often rely on large-scale water tank experiments, marine engineering platforms, and specialized simulation tools, creating a high entry barrier; 3) A focused academic circle: The research community is predominantly led by specialized groups in ocean engineering and underwater robotics, with relatively limited academic exchange with other fields. This combination of technological uniqueness and community isolation jointly leads to the lower cross-citation of its literature.

In summary, high-overlap regions represent the mainstream trajectory for technological maturation and commercialization, where reinforcing synergistic ecosystems should remain a priority. Conversely, low-overlap regions constitute potential blue oceans of original innovation and paradigm shifts, warranting intentional investment in exploratory "bridging" research. The conscious identification and resourcing of such seemingly unrelated technological combinations could be key to unlocking the next breakthrough growth point in WPT technology.

4.2. Geographical patterns

Based on the results of the top 10 countries/regions in each research fields Table S1–S6, summarize FPY and APY of top 10 countries/regions in each research field to obtain Fig. 8. Fig. 8 shows that there are 4 countries/regions ranking in the top 10 for each research field, namely China, USA, South Korea and England.

China's WPT development is a central pillar of its national strategic energy plans, with a pronounced emphasis on transportation electrification, including electric vehicles and high-speed rail systems. This strategic focus, backed by substantial public and private investment, indicates that the country's WPT sector is rapidly transitioning from the technical demonstration phase to early commercial deployment, particularly in the realm of large-scale infrastructure applications.

The United States has demonstrated a strong focus on pioneering long-distance and cutting-edge WPT solutions, often driven by defense and space applications. These efforts highlight the U.S. strategy of exploring the limits of WPT for specialized, high-impact applications, with its development stage characterized by fundamental breakthroughs and proof-of-concept demonstrations in long-range energy delivery.

South Korea has distinguished itself through targeted development of WPT for public transportation and consumer electronics, with a clear path toward commercialization. Leading this effort is the Korea Advanced Institute of Science and Technology (KAIST), which developed the Online Electric Vehicle (OLEV) system. KAIST has continuously improved the power transfer density and reduced the cost and size of the system components, demonstrating a clear focus on practical implementation and market readiness . This positions South Korea's WPT development at an advanced stage of real-world testing and early adoption, particularly in the realm of dynamic charging for public transport.

Japan ranks in the top 10 across five of the six examined research fields (excluding UAVs), Canada in those excluding underwater devices, and Singapore in all fields except Electric Vehicle research. It should be noted that Germany and Saudi Arabia rank in the top ten exclusively within the UAVs field, while Norway and Scotland are listed among the top performers solely in the underwater field. This phenomenon is intrinsically tied to the convergence of geopolitical resources, sectoral imperatives, and state-level strategic prioritization.

The prioritization of WPT research in EVs and sensors by nations globally stems from the convergence of four interdependent factors: market demand-driven imperatives, manageable technological risks, policy-driven resource allocation, and mature industrial ecosystems. This strategic alignment adheres to the techno-economic "principle of least resistance," while simultaneously laying the groundwork for future expansion into the other four more technologically demanding fields. Moving forward, accelerated breakthroughs in core technologies and cross-disciplinary convergence are anticipated to drive WPT research toward diversified application scenarios. Nevertheless, EVs and sensors are projected to persist as foundational fields for sustained technological innovation, serving as critical platforms for iterative advancement.

4.3. Institutional & journal preferences

According to the results of the top 10 institutions (Table S7–S12) and top 10 Journal (Table S13–S18) in each research fields, four institutions are ranked among the top 10 in publication output across more than three research fields, while five journals achieve comparable prominence in over four distinct research domains, as shown in Fig. 9. In this analytical framework, NaN (Not a Number) signifies that the publication output in the specified field did not meet the threshold for inclusion in the top ten rankings, rather than denoting a complete absence of scholarly contributions.

Among research institutions demonstrating cross-domain research prominence, three are based in China and one in South Korea. The observed multi-field productivity of these four institutions fundamentally stems from their integrated strengths in foundational theoretical innovation, modular technological versatility, and systemic resource integration capabilities. Among multidisciplinary journals, IEEE TRANSACTIONS ON POWER ELECTRONICS and IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS are recognized as premier engineering technology journals with substantial academic influence. In contrast, ENERGIES (energy science and technology), SENSORS (instrumentation), and IEEE ACCESS (multidisciplinary)-all three being open-access journals-exhibit high publication volumes, though their broad scope and accessibility-driven models may raise concerns regarding academic selectivity and perceived prestige in specialized fields.

4.4. Future trajectories of research and applications

This section identifies cross-disciplinary challenges in WPT technology and outlines field-specific research trajectories through systematic analysis of high-frequency keyword distributions (Table S19–S24), temporal keyword evolution trends (2020–2025, Fig. 5) and high cited publications (Table A1–A6).

Beyond merely mapping the research landscape across the six domains, the bibliometric analysis has identified two fundamental

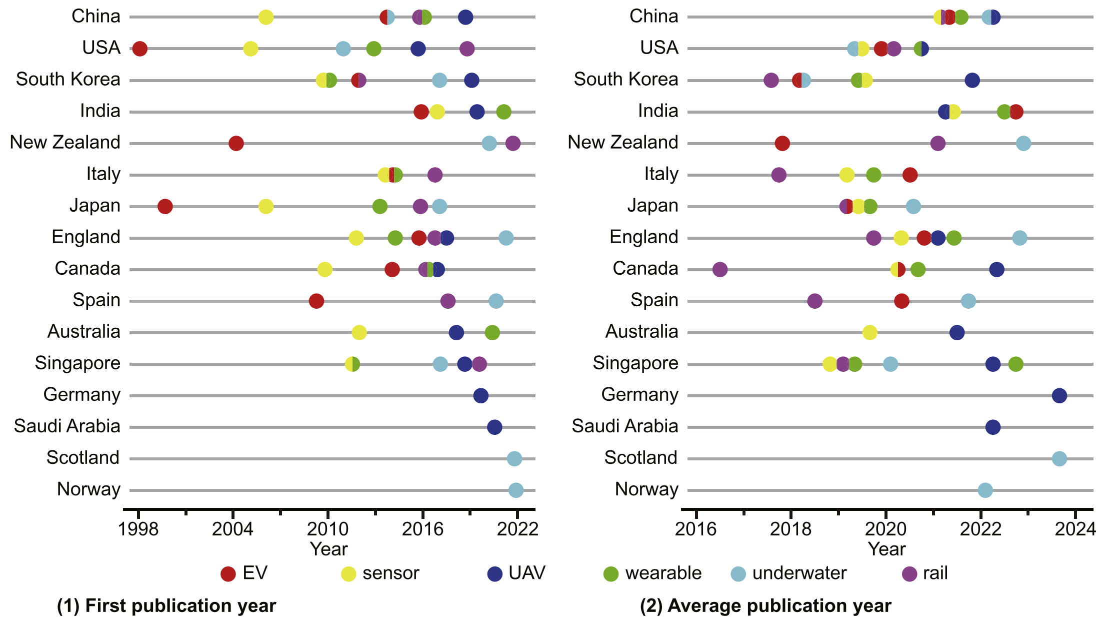

Fig. 8. First publication year and Average publication year of top 10 countries/regions in each research field.

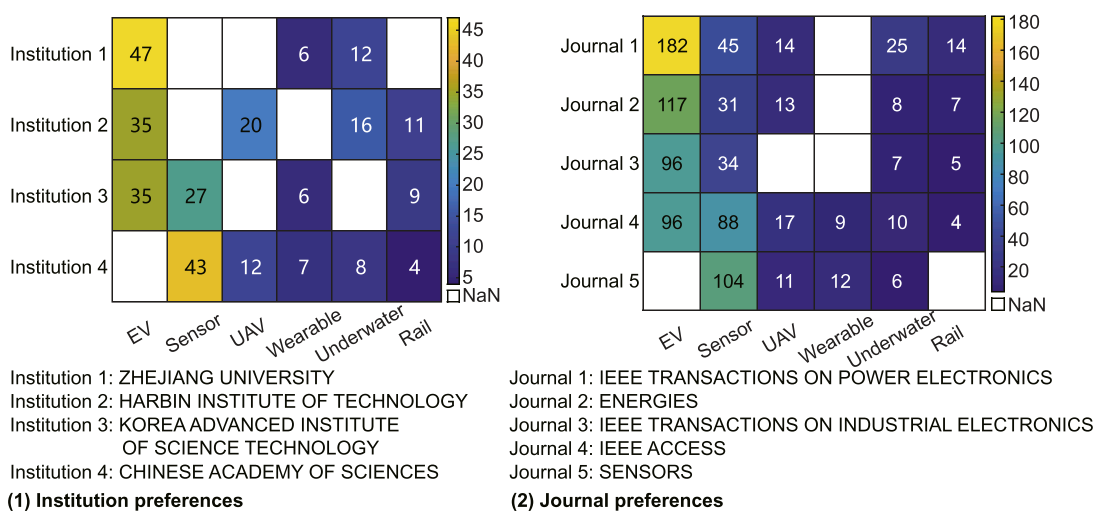

Fig. 9. Institutional & journal preferences; (1) Institutions with more than three fields of research in the top ten; (2) Journals in the top ten covering research in more than four fields.

bottlenecks that impede the widespread adoption of WPT technology. First, “Coils” as a cross-domain high-frequency keyword reflects both the universal nature of WPT technology (all scenarios rely on electromagnetic coupling) and exposes the current technical fragmentation under differentiated demands. These findings suggest that breakthroughs in coil technology may serve as a critical nexus for cross-domain collaborative development of WPT, with its progress directly impacting the commercialization process across 6 major application scenarios. Second, despite decades of research, WPT struggles to achieve large-scale commercialization, trapped by the intractable ‘impossible triangle’ of efficiency, size, and cost. Strategically navigating these trade-offs is essential for market success, which in turn can fuel a virtuous cycle of reinvestment and further technological advancement.

In terms of differentiated innovation pathways, future research should prioritize dynamic charging capabilities and system robustness for applications like electric vehicles and rail transit, given their requirements for high operational flexibility and power levels. For UAVs and underwater devices, where mobility is constrained by energy, the pivotal challenge lies in the co-optimization of mission trajectory and energy transfer. Meanwhile, the development for sensors and wearable devices must primarily address the imperative for miniaturization and system-level integration.

In addition to the cross-domain technological synergies discussed above, the bibliometric analysis reveals several pervasive and enabling trends. First, the increasing integration of Artificial Intelligence (AI) addresses core WPT challenges; its data-driven paradigm is particularly well-suited for tackling the nonlinear, dynamic, and multivariate optimization problems inherent in WPT systems. Undoubtedly, future WPT research will rely more heavily on AI to create genuinely adaptive, resilient, and autonomous wireless power ecosystems. Next, leveraging Digital Twin technology, the construction of virtual simulation models enables real-time monitoring, performance prediction, and fault diagnosis of WPT systems, making it especially applicable in complex environments such as dynamic charging and underwater

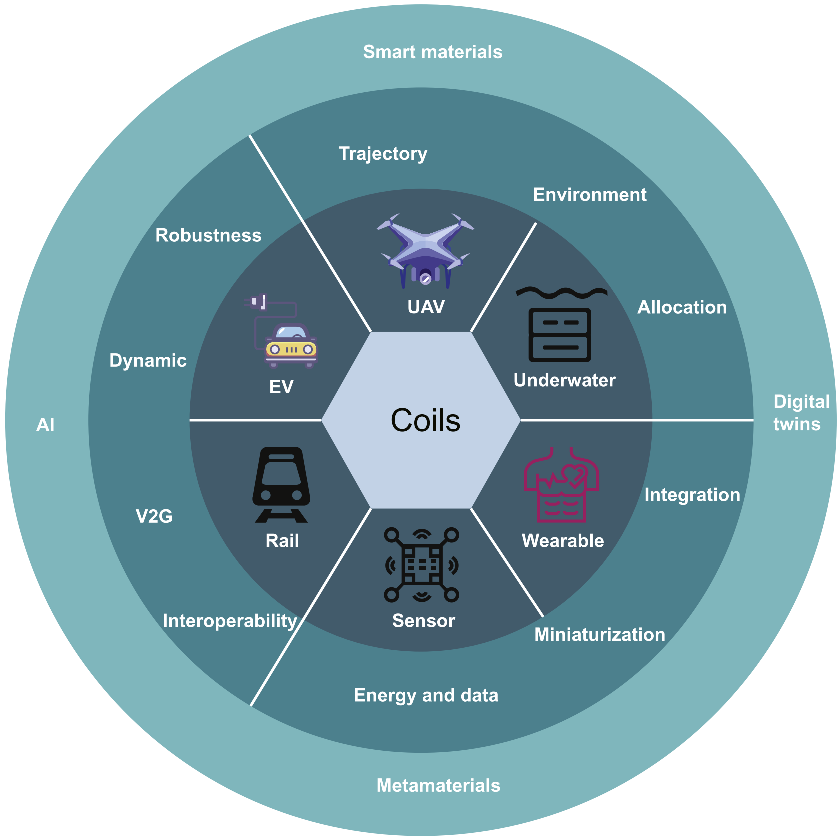

Fig. 10. Current, short and long term research directions of WPT technology.

operations. Furthermore, metamaterials can manipulate electromagnetic field distributions, significantly enhancing coupling efficiency and transmission distance, with notable potential in miniaturized and high-frequency scenarios. Smart materials, such as shape-memory alloys and piezoelectric materials, provide novel pathways for adaptive coil structures and environment-responsive energy harvesting. The convergence of these technologies will further propel WPT toward greater intelligence, efficiency, and integration. The current, short-term, and long-term research directions of WPT technology are reflected by concentric circles as shown in Fig. 10.

5. Conclusion

A bibliometric analysis of WPT technology research is performed using literature data from the Web of Science Core Collection SCI-Expanded database (1998 to April 10, 2025), focusing on six emerging fields: EV (1456 articles), Sensor (1439 articles), UAV (318 articles), Wearable (234 articles), Underwater (183 articles) and Rail (99 articles). The study examined top countries/regions, key institutions, leading journals, prolific authors, most cited publications, high-frequency keywords and trend topics to delineate domain-specific research characteristics. Cross-domain comparisons further uncovered technological synergies and distinct innovation pathways.

The bibliometric analysis reveals an upward trajectory in research across all domains. Studies on EV and Sensor originated earlier, currently in a mature phase with substantial accumulated literature. The remaining four fields, initiated more recently, remain in nascent stages with relatively limited publications. China has established a predominant presence in all fields, while the USA and South Korea have also played significant roles. Journal analysis identifies IEEE TRANSACTIONS ON POWER ELECTRONICS and IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS as leading platforms for WPT research.

5.1. Contributions

This research provides three primary contributions to WPT research. First, it delivers a concise yet comprehensive reference for researchers to rapidly grasp the current developmental landscape of WPT technologies. Second, by delineating domain-specific trends and cross-domain synergies, the study fosters interdisciplinary conceptual frameworks and guides innovation pathways for diverse research communities. Third, the integration of bibliometric mapping with keyword evolution analysis offers actionable insights for prioritizing fundamental challenges, that transcend application boundaries. This framework moves beyond qualitative discussion by providing a systematic tool for evaluating the readiness, adaptation needs, and synergy potential of WPT technologies across different domains, thus offering a actionable roadmap for future interdisciplinary research and development.

5.2. Limitations

The research findings have certain limitations in the following aspects. Firstly, the data in this study were obtained from the CC database, excluding potential sources such as patents and technical reports, which may result in the current analysis being more inclined towards theoretical research and lacking a practical engineering perspective. In the follow-up, Derwent Innovation or IEEE Xplore for technical reports can be added to further improve the research. Secondly, to enhance the accuracy of the bibliometric analysis, this study focused exclusively on research articles, excluding review papers. However, inconsistencies in article classification across journals may have led to the inadvertent inclusion of certain review articles as research articles, potentially introducing biases into the findings. Subsequently, this study primarily ranked countries, journals, and researchers based on the number of published papers as a comparative metric. A high number of publications for an author may not necessarily represent a strong influence in the field, and it's possible that outstanding researchers with lower publication numbers may have been overlooked. Therefore, some highly cited papers may not have been considered in these rankings. To address these limitations, future work will implement critical literature screening to refine database completeness and classification accuracy, complemented by meta-analysis to quantitatively capture research characteristics. Additionally, comprehensive evaluations of WPT advancements will integrate content-based and methodological dimensions, transcending mere publication metrics.

CRediT authorship contribution statement

Wenmei Hao: Writing - review & editing, Writing - original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization; **Cai Sun:** Writing - original draft, Visualization, Resources, Formal analysis, Data curation; **Zhifu Wang:** Writing - review & editing, Supervision, Project administration, Investigation; **Paolo Guglielmi:** Writing - review & editing, Supervision, Methodology; **Yi Hao:** Writing - review & editing, Project administration.

Data availability

The data and materials used to support the findings of this study are available from the corresponding author upon reasonable request. Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary material

Supplementary material associated with this article can be found in the online version at 10.1016/j.rineng.2026.110695.

Appendix A. Top 10 cited publications in each field

TC: Total citation;
TNP: Total number of publications;
APY: Average publication year;
FPY: First publication year;
AAC: Average article citation.

Table A1
Top 10 cited publications of WPT technology in EVs field ranked by number of citations.

Rank	Title	Year	TC
1	Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles [75]	2013	1960
2	Wireless Power Transfer for Electric Vehicle Applications [81]	2015	1429
3	Design Considerations for a Contactless Electric Vehicle Battery Charger [76]	2005	1118
4	Power Transfer Capability and Bifurcation Phenomena of Loosely Coupled Inductive Power Transfer Systems [78]	2004	928
5	Modern Trends in Inductive Power Transfer for Transportation Applications [82]	2013	923
6	Development of a Single-Sided Flux Magnetic Coupler for Electric Vehicle IPT Charging Systems [79]	2013	875
7	Inductive Power Transfer [83]	2013	790
8	A Double-Sided LCC Compensation Network and Its Tuning Method for Wireless Power Transfer [80]	2015	780
9	Design and Optimization of Circular Magnetic Structures for Lumped Inductive Power Transfer Systems [77]	2011	740
10	Modern Advances in Wireless Power Transfer Systems for Roadway Powered Electric Vehicles [84]	2016	592

Table A2
Top 10 cited publications of WPT technology in sensors field ranked by number of citations.

Rank	Title	Year	TC
1	Relaying Protocols for Wireless Energy Harvesting and Information Processing [90]	2013	1527
2	Deep Reinforcement Learning for Online Computation Offloading in Wireless Powered Mobile-Edge Computing Networks [91]	2020	717
3	Wireless Charging Technologies: Fundamentals, Standards, and Network Applications [93]	2016	713
4	Computation Rate Maximization for Wireless Powered Mobile-Edge Computing With Binary Computation Offloading [146]	2018	667
5	Simultaneous Wireless Information and Power Transfer (SWIPT): Recent Advances and Future Challenges [94]	2018	639
6	Soft, smart contact lenses with integrations of wireless circuits, glucose sensors, and displays [95]	2018	492
7	Opportunistic Wireless Energy Harvesting in Cognitive Radio Networks [147]	2013	481
8	Energy Efficient Mobile Cloud Computing Powered by Wireless Energy Transfer [92]	2016	393
9	Wireless body sensor networks based on metamaterial textiles [36]	2019	311
10	Making Sensor Networks Immortal: An Energy-Renewal Approach With Wireless Power Transfer [96]	2012	309

Table A3
Top 10 cited publications of WPT technology in UAVs field ranked by number of citations.

Rank	Title	Year	TC
1	Computation Rate Maximization in UAV-Enabled Wireless-Powered Mobile-Edge Computing Systems [102]	2018	636
2	A Survey of Multi-Access Edge Computing in 5G and Beyond: Fundamentals, Technology Integration, and State-of-the-Art [103]	2020	463
3	UAV-Enabled Wireless Power Transfer: Trajectory Design and Energy Optimization [98]	2018	431
4	Throughput Maximization for UAV-Enabled Wireless Powered Communication Networks [104]	2019	276
5	UAV-Assisted Wireless Powered Cooperative Mobile Edge Computing: Joint Offloading, CPU Control, and Trajectory Optimization [99]	2020	240
6	Joint Resources and Workflow Scheduling in UAV-Enabled Wirelessly-Powered MEC for IoT Systems [100]	2019	179
7	Wireless Charging Techniques for UAVs: A Review, Reconceptualization, and Extension [148]	2018	161
8	Softwarization of UAV Networks: A Survey of Applications and Future Trends [149]	2020	132
9	Transfer Systems Demonstrated With Batteryless Drones [150]	2019	124
10	Multi-Objective Optimization for UAV-Assisted Wireless Powered IoT Networks Based on Extended DDPG Algorithm [101]	2021	116

Table A4
Top 10 cited publications of WPT technology in wearable devices field ranked by number of citations.

Rank	Title	Year	TC
1	Soft, smart contact lenses with integrations of wireless circuits, glucose sensors, and displays [95]	2018	492
2	Energy Efficient Mobile Cloud Computing Powered by Wireless Energy Transfer [92]	2016	393
3	A Flexible Integrated System Containing a Microsupercapacitor, a Photo detector, and a Wireless Charging Coil [107]	2016	164
4	A 5.2 mW Self-Configured Wearable Body Sensor Network Controller and a 12 μ W Wirelessly Powered Sensor for a Continuous Health Monitoring System [106]	2010	156
5	An Improved Wearable Resonant Wireless Power Transfer System for Biomedical Capsule Endoscope [108]	2018	148
6	Efficient Wireless Power Transfer System Integrating With Metasurface for Biological Applications [109]	2018	132
7	Wireless Power Transmission: R&D Activities Within Europe [151]	2014	130
8	Ni-GaIn Amalgams Enabled Rapid and Customizable Fabrication of Wearable and Wireless Healthcare Electronics [110]	2018	125
9	Stretchable Electrode Based on Laterally Combed Carbon Nanotubes for Wearable Energy Harvesting and Storage Devices [111]	2017	124
10	Highly Stretchable Microsupercapacitor Arrays with Honeycomb Structures for Integrated Wearable Electronic Systems [112]	2016	117

Table A5
Top 10 cited publications of WPT technology in underwater devices field ranked by number of citations.

Rank	Title	Year	TC
1	Review of Near-Field Wireless Power and Communication for Biomedical Applications [114]	2017	182
2	Design and Analysis of a Three-Phase Wireless Charging System for Lightweight Autonomous Underwater Vehicles [115]	2018	172
3	A Rotation-Free Wireless Power Transfer System With Stable Output Power and Efficiency for Autonomous Underwater Vehicles [116]	2019	171
4	Frequency Optimization of a Loosely Coupled Underwater Wireless Power Transfer System Considering Eddy Current Loss [118]	2019	131
5	Design and Loss Analysis of Loosely Coupled Transformer for an Underwater High-Power Inductive Power Transfer System [119]	2015	116
6	Agile and Resilient Insect-Scale Robot [152]	2019	105
7	A Rotation-Resilient Wireless Charging System for Lightweight Autonomous Underwater Vehicles [117]	2018	78
8	Design of a Capacitive Wireless Power Transfer System for Operation in Fresh Water [153]	2018	64
9	Fault-Tolerant Wireless Power Transfer System With a Dual-Coupled LCC-S Topology [120]	2019	63
10	Design and analysis of an underwater inductive coupling power transfer system for autonomous underwater vehicle docking applications [154]	2014	63

Table A6
Top 10 cited publications of WPT technology in rail field ranked by number of citations.

Rank	Title	Year	TC
1	Narrow-Width Inductive Power Transfer System for Online Electrical Vehicles [155]	2011	536
2	Development of 1-MW Inductive Power Transfer System for a High-Speed Train [122]	2015	353
3	Modular Multilevel Converters for Transportation Electrification: Challenges and Opportunities [125]	2018	238
4	Wireless Power Transfer by Electric Field Resonance and Its Application in Dynamic Charging [118]	2016	178
5	New Cross-Segmented Power Supply Rails for Roadway-Powered Electric Vehicles [126]	2013	158
6	Generalized Active EMF Cancel Methods for Wireless Electric Vehicles [156]	2014	139
7	Ultraslim S-Type Power Supply Rails for Roadway-Powered Electric Vehicles [128]	2015	128
8	Uniform Power I-Type Inductive Power Transfer System With DQ-Power Supply Rails for On-Line Electric Vehicles [127]	2015	118
9	Analysis and Design of Inductive and Capacitive Hybrid Wireless Power Transfer System for Railway Application [157]	2020	84
10	Analysis and Design of Multiphase Receiver With Reduction of Output Fluctuation for EV Dynamic Wireless Charging System [124]	2019	71

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