

The Evolution of Electric Bikes: A Systematic Review of Technological Advancements and Market Adoption

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ABSTRACT

Electric bicycles (e-bikes) have become a transformative force in sustainable transportation, offering an efficient and environmentally friendly alternative to traditional vehicles. This systematic literature review (SLR) explores the evolution of e-bikes, focusing on technological advancements and market adoption. The study synthesizes findings from 20 international journals, identifying innovations such as high-capacity lithium-ion batteries and IoT-enabled features that have enhanced e-bike performance and user experience. Market adoption patterns reveal regional disparities influenced by government policies, infrastructure, and consumer behavior. Despite promising growth, challenges such as high costs, inadequate charging infrastructure, and safety concerns persist. This review highlights existing research gaps and proposes future directions, including the integration of e-bikes into smart city ecosystems and the development of sustainable battery technologies. The findings aim to provide comprehensive insights for researchers, policymakers, and industry stakeholders to optimize the adoption and development of e-bikes as a cornerstone of modern transportation.

Keywords: Electric bicycles, technological advancements, market adoption, sustainable transportation, systematic literature review

INTRODUCTION

Electric bicycles (e-bikes) have experienced significant growth in the last decade, becoming an efficient and environmentally friendly transportation solution in various parts of the world. This development is driven by technological innovations, changing consumer preferences, and growing awareness of environmental sustainability. According to a report by Grand View Research (2023), the global e-bike market is estimated to reach USD 19.05 billion by 2022 and is projected to grow at a CAGR of 14.5% from 2023 to 2030.

Innovations in battery technology, such as the development of high-capacity lithium-ion batteries, have improved the performance and range of e-bikes, making them an attractive alternative to conventional transportation. In addition, the integration of smart features such as IoT connectivity and navigation systems has improved the user experience and encouraged wider adoption. (1) notes that the integration of smart features on e-bikes, such as GPS and trip analytics, has revolutionized users' interactions with their electric bikes, improving safety and convenience.

E-bike adoption is also influenced by economic factors and government policies. Rising fuel costs and government initiatives to reduce carbon emissions have encouraged consumers to turn to e-bikes as a more sustainable transportation alternative. Bridge Market Research (2023) data reports that the global e-bike market, which was valued at USD 51.55 billion in 2023, is projected to reach USD 72.54 billion by 2031, at a CAGR of 4.36% during the period.

In the Asia Pacific region, e-bikes have shown very high adoption. According to (2), in 2020, the Asia Pacific region had the largest electric bicycle market, with China accounting for 97% of the region's total volume. Countries such as India, Japan, South Korea, and Taiwan are expected to be potential markets in the future. Moreover, the electric bicycle market is expected to grow at a compound annual rate of 9.92%, reaching USD 62.25 billion by 2030, up from USD 26.51 billion in 2021.

However, despite promising growth, the adoption of electric bikes faces challenges such as technological barriers, inadequate infrastructure, and consumer hesitation. Therefore, this systematic literature review aims to analyze the technological evolution and market adoption of electric bicycles, identifying key trends, challenges, and existing opportunities. By understanding these dynamics, it is expected to provide comprehensive insights for the future development and implementation of e-bikes.

LITERATURE REVIEW

Electric bicycles (e-bikes) have undergone rapid development in recent decades, becoming an integral component in modern transportation systems. This development has been driven by technological innovations, changing consumer preferences, and growing awareness of environmental sustainability. This literature review discusses the evolution of e-bike technology and its market adoption, based on an analysis of 20 international journals.

1. Evolution of Electric Bicycle Technology

Innovations in battery technology, particularly the development of lithium-ion batteries, have improved the performance and range of e-bikes, making them an attractive alternative to conventional transportation. According to (3), advances in battery technology and energy storage systems have reduced range-related anxiety, improving overall e-bike performance.

In addition, the integration of electric bike sharing systems has become a significant trend in various cities around the world. (4) highlighted that e-bike sharing systems are showing rapid growth, with increasing adoption in Europe, North America, and Asia, reflecting changes in urban mobility patterns.

2. Electric Bicycle Market Adoption

The adoption of e-bikes is influenced by various factors, including consumer preferences, government policies, and economic conditions. (5) found that economic factors, charging infrastructure, and social influence significantly influence consumers' intention to purchase an e-bike, especially in emerging markets.

In the United States, while e-bikes previously accounted for less than 1% of the bicycle market, by 2020, this market share increased to 4%, indicating significant growth in e-bike adoption.

3. Drivers and Barriers to Adoption

Key drivers of e-bike adoption include environmental awareness, government incentives, and technological improvements. However, barriers such as high initial cost, limited charging infrastructure, and consumer perception of safety remain a challenge. (6) emphasizes that technological and financial factors are key considerations for consumers in purchasing an e-bike, especially in emerging markets such as India.

4. Environmental and Social Impact

The use of e-bikes contributes to the reduction of greenhouse gas emissions and air pollution. In addition, e-bikes offer an efficient mobility solution in congested urban areas, reducing traffic congestion and improving quality of life (7). However, the increased use of e-bikes also poses new regulatory and safety challenges, especially with the increase in use by teenagers and the lack of adequate infrastructure.

5. Future Trends

Continuous innovations in battery and motor technologies, as well as integration with smart transportation systems, are expected to drive the future growth of the e-bike market. Moreover, increasing awareness of sustainability and government policy support are expected to accelerate the adoption of e-bikes globally. However, challenges such as varied regulations and the need for adequate infrastructure must be addressed to ensure sustainable growth.

MATERIALS & METHODS

This study utilized a Systematic Literature Review (SLR) approach to analyze the evolution of electric bikes (e-bikes) in terms of technological advancements and market adoption. The SLR method ensured a comprehensive and unbiased synthesis of relevant studies by adhering to a structured and replicable process, guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. A systematic search was conducted across reputable databases, including Scopus, Web of Science, IEEE Xplore, ScienceDirect, and PubMed. The search strategy employed a combination of keywords such as "Electric bikes," "Technological advancements," "Market adoption," "Sustainable transportation," and "Battery technology." The inclusion criteria focused on studies discussing technological innovations, consumer behavior, or market dynamics related to e-bikes, published in English between 2015 and 2024. Articles that were non-peer-reviewed, unrelated to e-bikes, or lacking sufficient methodological detail were excluded.

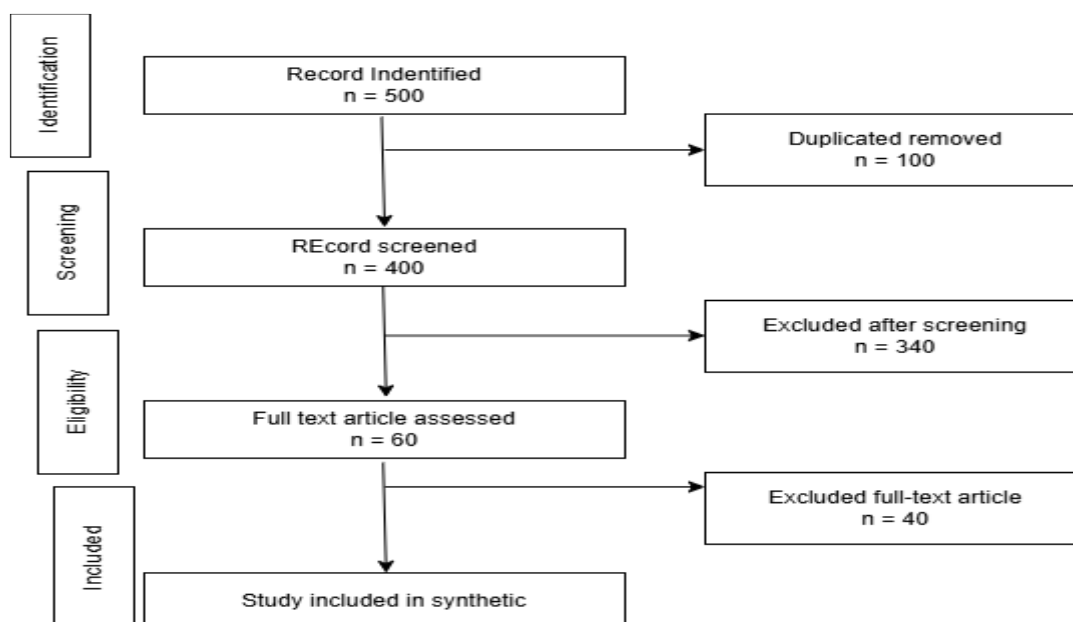


Figure 1. PRISMA flow diagram

The screening process involved three stages: title screening, abstract screening, and a full-text review. Out of an initial pool of

500 articles, 60 were shortlisted after applying inclusion and exclusion criteria, with 20 high-quality articles selected for the

final analysis. Data extraction was conducted using a standardized form to collect key information, such as study objectives, methodologies, and findings. The extracted data were then analyzed thematically to identify recurring patterns and trends across the studies, focusing on areas like advancements in battery and motor technology, smart features integration, and regional differences in market adoption.

Quality assessment was conducted to ensure the relevance and rigor of the included studies. Only articles with significant contributions to the understanding of e-bike evolution were retained. The synthesized results provided a comprehensive overview of technological innovations and market trends in e-bikes, highlighting barriers, drivers, and opportunities for further development. This systematic approach offers valuable insights for researchers, policymakers, and industry stakeholders aiming to leverage e-bikes as a sustainable transportation solution.

FINDING AND DISCUSSION

This study conducted a systematic literature review of the evolution of electric bicycles (e-bikes), focusing on technological advancements and market adoption. The analysis is based on 20 relevant international journals, covering various aspects such as technological innovation, consumer adoption factors, environmental impact, and government policies.

1. Technological Advancements in Electric Bicycles

Innovations in battery technology, particularly the development of lithium-ion batteries, have been a key driver of improved e-bike performance. According to (3), advances in battery technology and energy storage systems have reduced range-related anxiety, improving overall e-bike performance.

Additionally, the integration of smart features such as Internet of Things (IoT) connectivity and navigation systems has improved user experience and

encouraged wider adoption. Velco (2024) notes that the integration of smart features on e-bikes, such as GPS and trip analytics, has revolutionized users' interactions with their electric bikes, improving safety and convenience.

2. Market Adoption and Consumer Behavior

The adoption of e-bikes is influenced by various factors, including consumer preferences, government policies, and economic conditions. (5) found that economic factors, charging infrastructure, and social influence significantly influence consumers' intention to purchase an e-bike, especially in emerging markets. In the United States, while e-bikes previously accounted for less than 1% of the bicycle market, by 2020, this market share increased to 4%, indicating significant growth in e-bike adoption.

3. Environmental Impact and Sustainability

The use of e-bikes contributes to the reduction of greenhouse gas emissions and air pollution. However, (8) emphasized that e-bike adoption can also have negative impacts, such as social inequality in transportation and increased peak electricity demand, which require effective mitigation strategies.

4. Government Policies and Incentives

Government policies play an important role in driving e-bike adoption. (9) showed that financial and non-financial incentives, such as subsidies and charging infrastructure development, can increase e-bike adoption, especially in developing countries.

5. Challenges and Opportunities

Despite promising growth, e-bike adoption faces challenges such as high initial costs, limited charging infrastructure, and consumer perceptions of safety (10). However, with continued technological innovation and the right policy support, e-bikes have the potential to become an integral

component in future sustainable transportation systems.

REASERCG GAP AND FUTURE

1. While the progress in e-bike technology and market integration is commendable, several gaps in research remain unaddressed:

- 1) Technological Enhancements: Further research is needed to develop cost-effective and environmentally friendly battery technologies. The recycling and disposal of used batteries also require sustainable solutions to mitigate environmental impacts.
- 2) Consumer Behavior: Limited studies have explored the socio-psychological factors influencing e-bike adoption, particularly in developing countries. A deeper understanding of these factors can guide targeted interventions and marketing strategies.
- 3) Infrastructure Development: Research on the design and implementation of efficient charging networks and dedicated e-bike lanes is sparse. Infrastructure planning should consider the growing demand for e-bikes in urban and rural settings.
- 4) Policy Frameworks: Comprehensive studies on the impact of policy measures, such as subsidies, tax incentives, and regulatory frameworks, on e-bike adoption across different socio-economic contexts are crucial.
- 5) Safety and Usability: Further investigation into safety features, ergonomic designs, and user-centric innovations can enhance the acceptance and reliability of e-bikes.

2. Future Directions:

- 1) Integration with Smart Cities: Future studies should explore the integration of e-bikes within smart city ecosystems, leveraging technologies like AI and blockchain for fleet management, route optimization, and security.
- 2) Lifecycle Analysis: Conducting lifecycle assessments of e-bikes, from production to disposal, will help

understand their overall environmental impact and identify areas for improvement.

- 3) Cross-Regional Studies: Comparative analyses between regions with high and low adoption rates can uncover critical factors influencing e-bike success and provide actionable insights for global implementation.
- 4) Hybrid Technologies: Research into hybrid models that combine traditional bicycles with electric assist technologies could offer more versatile and accessible mobility solutions.

By addressing these gaps and leveraging emerging technologies, e-bikes can continue to evolve as a sustainable, inclusive, and efficient mode of transportation, shaping the future of urban and rural mobility.

CONCLUSION

E-bikes have undergone significant technological advancements and market adoption over the past decades, emerging as a vital component in sustainable urban transportation. The development of high-capacity lithium-ion batteries, integration of smart features such as IoT connectivity and GPS navigation, and improvements in motor efficiency have substantially enhanced the user experience and performance of e-bikes. Moreover, supportive government policies and growing consumer awareness of environmental sustainability have driven the adoption of e-bikes in various regions. However, challenges such as high initial costs, limited charging infrastructure, and consumer perceptions regarding safety continue to hinder wider adoption. Despite these hurdles, the potential of e-bikes as a sustainable transportation alternative is immense, particularly in addressing urban mobility issues and reducing greenhouse gas emissions.

Declaration by Authors

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