

Cost-Effective Conversion Techniques of Scrap Bicycles into Intelligent Electric Bicycles: A Review

Ravikant Nanvatkar^{1,*}, Anurag Ranaware², Aniket Vakude³, Vedant Sapkal⁴

Abstract

Over the past few years, there has been an overwhelming increase in requirement of sustainable and affordable urban mobility solutions both due to the environmental concerns along with the rising fuel prices and urban traffic jams. Electric bicycles (e-bike) have become an efficient option as a substitute to traditional modes of transport which are similar to conventional tools since they have low emissions and are energy efficient as well as easy to use. Nonetheless, the fact that new e-bikes are relatively expensive has discouraged their adoption, particularly within the developing economies. The paper discusses an affordable way of transforming the readily available but obsolete scrap bikes into intelligent electric bikes utilizing economical electric drive kits, smart control packages, and low-weight power storage options. The conversion process starts by picking up structurally good scrap bikes and assessing the mechanical good condition of the bike. Proper retrofitting would consist of installing a low cost brushless DC (BLDC) hub motor at the front or rear wheel and feeding a lightweight lithium-ion battery pack in strategic position to allow balancing and road feel. They have pedal-assist sensors, speed-monitoring sensors and battery management systems (BMS) sensor equipment that are fitted to the bike to achieve optimal user clarity in using the product to save on energy usage of the EUC bike. Moreover, it has an intelligent control interface, which enables the riders to easily alternate between pedal-assist mode and full-electric mode and get performance data in real-time using a mobile application. Compared to the market price of new commercial e-bikes, it is possible to construct such Upcycled e-bikes at a cost of less than 40 percent and still under no compromise of safety, functionality or even aesthetics. The electrical and mechanical efficiency of the converted e-bikes is then tested in an experimental trial which is aimed at testing their performance during normal urban riding condition (battery range, power output and ergonomic friendliness). The results indicate a huge potential of widespread implementation of the sustainable and scalable conversion approach, particularly in resource-limited environments.

*Author for Correspondence

Ravikant Nanvatkar
E-mail: ravikant.nanvatkar@sinhgad.edu

¹Assistant Professor, Department of Mechanical Engineering, Sinhgad Technical Education Society's NBN Sinhgad Technical Institutes Campus (STES's NBNSTIC) (Affiliated to Savitribai Phule Pune University), Ambegaon, Pune, Maharashtra, India

²⁻⁴UG Student, Department of Mechanical Engineering, Sinhgad Technical Education Society's NBN Sinhgad Technical Institutes Campus (STES's NBNSTIC) (Affiliated to Savitribai Phule Pune University), Ambegaon, Pune, Maharashtra, India

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INTRODUCTION

Sustainable transportation and smart mobility are critical to addressing the growing challenges of urban congestion, air pollution, fossil fuel dependency, and climate change. Traditional transportation systems heavily reliant on internal combustion engines have contributed to environmental degradation and poor urban air quality. As cities become more populated, there is an increasing need for eco-friendly, energy-efficient, and intelligent mobility solutions. Sustainable transportation emphasizes reducing greenhouse gas emissions, optimizing energy use,



Figure 1. Importance of sustainable mobility (Image credits: SLOCAT).

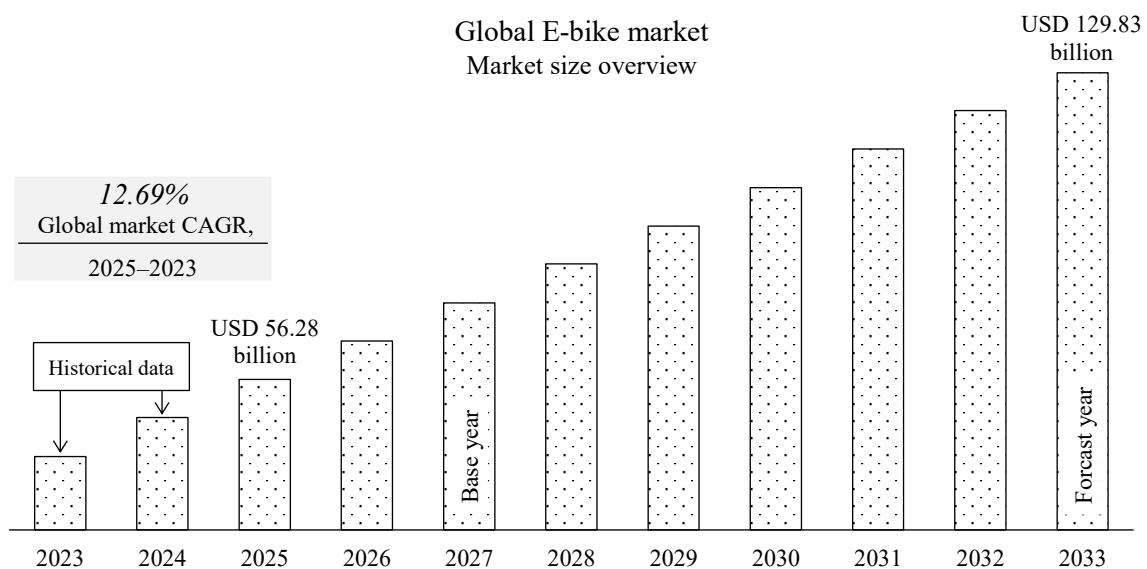


Figure 2. Growth of electric bicycles (E-Bikes) in urban and rural mobility.

and promoting alternative mobility systems such as walking, cycling, and electric vehicles. Smart mobility further integrates technology such as data analytics, IoT, and AI to enhance the efficiency, safety, and connectivity of transport systems. In this context, electric bicycles (e-bikes) present a promising solution by offering clean, efficient, and intelligent mobility options suited for both short- and medium-range commuting needs (Figure 1).

Electric bicycles have witnessed significant growth in recent years as a practical and eco-friendly alternative to conventional transport, especially in both urban and rural settings (Figure 2). In urban areas, e-bikes are increasingly used for last-mile connectivity, reducing traffic congestion, and providing

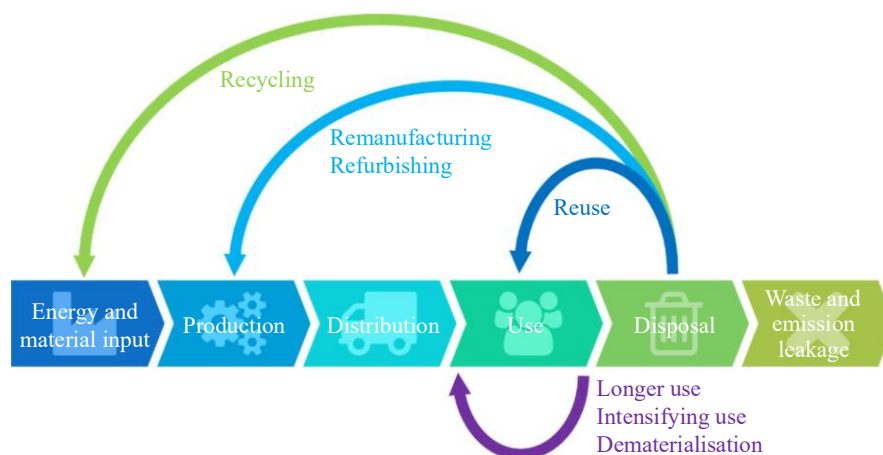


Figure 3. Motivation behind converting scrap bicycles (circular economy, cost-saving, environmental impact).

a convenient mode of travel in densely populated zones. In rural areas, where public transport options are limited or unreliable, e-bikes offer a low-cost and efficient means of transportation for commuting, education, and small-scale logistics. Government incentives, advances in battery technology, and the rising cost of fuel have further accelerated e-bike adoption. The rise of smart mobility solutions and the availability of conversion kits have also made e-bikes more accessible to a wider population. As a result, electric bicycles are becoming an integral part of the sustainable transportation ecosystem, contributing to reduced emissions and improved mobility equity.

The conversion of scrap bicycles into intelligent electric bicycles aligns strongly with the principles of the circular economy, which focuses on extending the life cycle of products and minimizing waste (Figure 3). This approach not only diverts old bicycles from landfills but also transforms them into valuable, functional mobility solutions. The economic motivation is equally compelling, as converting an existing bicycle into an e-bike is significantly more cost-effective than purchasing a new electric bicycle. This affordability opens the door to sustainable transportation for economically disadvantaged populations, particularly in rural and semi-urban regions. Environmentally, the conversion process helps reduce the carbon footprint associated with manufacturing new e-bikes, thereby contributing to resource conservation and lower energy consumption. The initiative also promotes skill development and local entrepreneurship by enabling small workshops and individuals to participate in the upcycling of old bicycles, making it a scalable and impactful sustainability strategy.

Problem Statement

The increasing demand for eco-friendly and affordable mobility options is evident due to rising urbanization, fuel costs, and environmental concerns. However, commercially available electric bicycles (e-bikes) remain expensive for a large segment of the population, especially in developing regions. Simultaneously, a vast number of scrap or unused bicycles lie abandoned, creating waste management challenges. Although there are emerging efforts to retrofit these bicycles with electric components, there is limited structured knowledge or standardized approach to guide such conversions in a cost-effective and technically sound manner. Moreover, the integration of intelligent features such as sensors, battery management systems (BMS), and connectivity remains underexplored in low-cost conversion solutions. This lack of comprehensive knowledge and best practices forms a significant barrier to scalable, affordable, and intelligent e-bike retrofitting efforts.

Scope of the Review

This review focuses on analyzing and compiling existing techniques, tools, components, and systems used in the cost-effective conversion of scrap bicycles into intelligent electric bicycles. The scope includes mechanical retrofitting techniques, motor and battery integration methods, low-cost intelligent

control systems, and DIY and community-based conversion practices. Emphasis is also placed on evaluating different types of motors (hub and mid-drive), battery types (lead-acid and lithium-ion), sensors, controllers, and microcontroller-based smart features such as GPS and Bluetooth connectivity. The study covers both urban and rural applicability, environmental implications, and economic feasibility. It also identifies design and performance challenges and proposes potential directions for research, innovation, and policy support to mainstream such solutions.

Objectives of the Review

The primary objective of this review is to provide a structured and detailed understanding of the existing approaches to converting scrap bicycles into intelligent electric bicycles in a cost-effective manner. Specific objectives include:

- To identify and categorize mechanical and electrical conversion techniques for scrap bicycles.
- To evaluate various low-cost intelligent systems that can be integrated into converted e-bikes.
- To assess the cost-benefit aspects and environmental impacts of such conversions.
- To examine real-world case studies or pilot projects for practical validation.
- To highlight technical challenges, research gaps, and future development opportunities in this domain.

This comprehensive analysis is intended to serve as a reference guide for researchers, engineers, local entrepreneurs, and policymakers working toward low-cost sustainable mobility.

Novelty of the Review

While many studies focus either on e-bike development or battery integration technologies, this review uniquely bridges the gap between sustainability, affordability, and intelligent design by focusing on the upcycling of scrap bicycles into smart e-bikes. The novelty lies in its interdisciplinary approach, combining circular economy principles, low-cost engineering design, and integration of intelligent systems to create accessible and eco-friendly transport solutions. Unlike generic reviews, this work emphasizes hands-on, scalable, and modular techniques suitable for low-resource settings. Furthermore, it explores the potential for IoT-enabled features in retrofitted systems, which is still a nascent area in low-cost e-bike development. By mapping technical, economic, and environmental factors together, the review provides a holistic framework not widely addressed in current literature.

LITERATURE REVIEW

Past studies on electric bicycle (e-bike) conversions have focused on mechanical integration, performance analysis, motor control, and retrofitting kits. Some works designed modular e-bike conversion kits, highlighting performance optimization with BLDC hub motors [1, 2]. Others provided comprehensive reviews of motor types, battery chemistries, and controller architectures used in e-bikes, emphasizing component-level compatibility. Techno-economic assessments of bicycle retrofitting concluded that local fabrication of mounting brackets and frame adjustments can significantly reduce costs [3, 4]. Low-cost conversion systems have been developed and validated for specific road conditions, demonstrating the feasibility of reusing locally available scrap bicycles. Further research explored the integration of IoT modules in converted e-bikes for GPS tracking and theft protection, while other studies investigated low-cost controller designs using open-source hardware like Arduino [5]. Some contributions tested converted e-bikes on a variety of terrains and payloads, validating their utility in semi-urban applications. Together, these studies provide a foundation for developing affordable and intelligent electric mobility solutions by retrofitting existing bicycles rather than producing new ones [6, 7].

Globally, the trend toward low-cost electric vehicle (EV) retrofitting is growing as a response to sustainability goals and urban mobility needs. In regions like Southeast Asia, Africa, and parts of Latin America, converted e-bikes and e-rickshaws are emerging as viable transportation alternatives [8, 9]. According to international agencies, the rise in electric two-wheelers is driven largely by affordability, policy incentives, and declining battery costs. Environmental programs have identified e-bike conversions as a scalable opportunity for clean mobility in developing nations due to minimal infrastructure demands [10–12].

In India, where millions of bicycles are either underutilized or discarded annually, retrofitting offers a dual solution of waste reduction and green mobility. National policy promotes battery-swapping and modular retrofitting for micro-mobility applications, particularly in rural zones. Energy efficiency bodies emphasize the role of local workshops in creating job opportunities through vehicle retrofitting [13–16]. Studies demonstrated effective use of regenerative braking and controller optimization in India-centric low-cost e-bikes. Community-driven innovations and DIY culture documented on various platforms are further accelerating the adoption of budget-friendly e-bike conversions in urban and peri-urban areas [17–20].

Despite significant progress, several critical gaps remain in existing e-bike conversion studies. Cost is still a challenge; while retrofitting is cheaper than purchasing new e-bikes, components like lithium-ion batteries and smart controllers remain expensive or poorly localized. Although many works address cost-cutting methods, comprehensive cost-benefit frameworks for various socioeconomic contexts are lacking [21–23]. Accessibility is another issue; many existing retrofitting kits require technical knowledge, limiting widespread adoption. Instructional resources are fragmented, and standardization of components is minimal. Additionally, modularity — the ability to easily upgrade or replace individual parts — is underrepresented in literature. Most conversion designs are custom fit and do not support flexible architecture for future scalability [24].

Technology integration is another major gap. While a few studies include IoT-enabled features, most focus on basic electrification and overlook the potential of smart systems like GPS tracking, mobile app integration, theft protection, and data analytics [25, 26]. The use of open-source hardware and microcontroller platforms is promising, but there is insufficient validation in field trials and user-centric studies. Overall, a lack of comprehensive frameworks that unify mechanical retrofitting, low-cost smart tech integration, and end-user usability continues to hinder large-scale deployment [27–30].

TYPES AND CONDITIONS OF SCRAP BICYCLES

Scrap bicycles suitable for conversion into intelligent electric bicycles can be classified based on their original design and intended usage (Figure 4). The classification helps in selecting the appropriate frame, wheel size, and mounting compatibility for motors, batteries, and controllers. Mountain and hybrid bikes are generally the best candidates for retrofitting due to their robust frames, standard wheel sizes (26", 27.5", 700C), and flexible geometry for battery/motor mounting (Table 1).

Common Mechanical Issues and Required Refurbishments

Scrap bicycles often exhibit a variety of mechanical issues due to prolonged use, poor maintenance, or exposure to harsh environmental conditions. Common problems include rusted or weakened frames, bent wheel rims, broken or worn-out spokes, corroded chains, damaged cranksets, and malfunctioning



Figure 4. Classifications of scrap bicycles.

Table 1. Classification of usable scrap bicycles (mountain, road, hybrid, etc.).

Type of bicycle	Description	Suitability for conversion
Mountain bikes (MTB)	Sturdy frame, wide tires, and suspension for off-road use.	Highly suitable due to strong frame and space for motor and battery mounting; ideal for rural or mixed-terrain e-bikes.
Road bikes	Lightweight frame with narrow tires for speed and efficiency on paved roads.	Less suitable due to limited frame strength and tight geometry; may require structural reinforcement.
Hybrid bikes	Combines features of road and mountain bikes; moderate frame strength and tire width.	Well-suited for urban commuting conversions; offers balance between comfort and performance.
City/commuter bikes	Designed for daily commuting; often equipped with carriers, mudguards, and comfortable seats.	Very suitable for utility-based e-bike conversions, especially for short-range travel.
Folding bikes	Compact and portable; foldable frame design.	Moderately suitable; limited battery/motor space but good for space-saving e-bike applications.
Cruiser bikes	Comfortable, relaxed riding geometry with wide handlebars and seats.	Suitable for low-speed e-bike conversions focused on comfort and style.
BMX bikes	Small, strong frame for stunts and tricks.	Not ideal for conversion due to small frame size and lack of mounting space.

brakes. Bearings in the bottom bracket, headset, and wheel hubs may seize or wear out, impacting smooth rotation and rider safety. Additionally, saddle damage, handlebar misalignment, and deteriorated tires or inner tubes are frequent in neglected bikes. Before retrofitting, these components must be carefully inspected and either repaired or replaced. Refurbishments typically involve cleaning and sanding rusted areas, re-greasing bearings, replacing brake pads and cables, truing the wheels, changing tires and tubes, and realigning the drivetrain. The goal is to restore the bicycle to a mechanically sound state capable of handling the additional load and stress introduced by electric components such as motors and batteries. Ensuring proper mechanical functionality is essential not only for safety but also for maximizing the efficiency and lifespan of the converted e-bike.

Structural Evaluation Methods for Reusability

Before converting a scrap bicycle into an electric bicycle, it is critical to assess the structural integrity of the frame and key components to ensure safe operation under electric-assist loads. Structural evaluation methods typically begin with a visual inspection to detect signs of frame cracks, deep corrosion, weld fatigue, and deformation, particularly around high-stress zones like the bottom bracket, head tube, seat tube junction, and dropout areas. For more rigorous analysis, non-destructive testing (NDT) techniques such as dye penetrant testing or magnetic particle inspection can be used to reveal micro-cracks that are not visible to the naked eye. Material thickness measurements with ultrasonic gauges help assess the extent of rust-induced thinning, especially in steel frames. In practical settings, static load testing may be performed by applying a known load (often simulating rider and cargo weight) to evaluate the frame’s deflection and recovery response. Additionally, engineers may use basic stress analysis calculations to determine whether the existing geometry and material properties are sufficient to withstand the torque and dynamic loads generated by an electric motor. Bicycles passing these evaluations are considered structurally reusable, and only then should the retrofitting process proceed. This evaluation ensures safety, enhances performance, and prevents premature mechanical failures post-conversion.

CONVERSION METHODOLOGIES

When converting scrap bicycles into electric bicycles, frame reinforcement becomes crucial to ensure the structural integrity of the vehicle under the added weight and torque of the motor and battery. Most conventional bicycle frames are not originally designed to support heavy electrical components or high-speed propulsion forces. Reinforcement may include welding additional support brackets near the bottom bracket, seat stays, and chain stays, as well as installing gussets at stress concentration points. For lighter frames such as those made of aluminum or older steel frames with corrosion, adaptation

techniques like bolting external brackets or clamping reinforcement plates can be used. Additionally, care must be taken to maintain frame alignment and geometry to avoid handling issues. Proper reinforcement not only ensures rider safety but also enhances the longevity of the retrofitted e-bike under real-world conditions.

Secure and vibration-resistant mounting brackets are essential to integrate the motor, battery, and controller onto a scrap bicycle frame. These brackets are typically fabricated from mild steel or aluminum and custom-fitted to the specific frame geometry. For hub motors, minimal external mounting is required, while mid-drive systems necessitate custom brackets near the bottom bracket. Batteries are often mounted on the downtube, rear carrier, or within a central battery box using clamp-on or bolt-on mounts. Controllers are usually positioned near the battery pack or under the seat post for protection and accessibility. All mounting brackets must ensure adequate weight distribution, thermal ventilation, and weather resistance, while also being easy to assemble or remove for maintenance purposes. DIY-friendly designs often use pre-drilled plates and universal clamps for simplified assembly.

Types of Motors (Hub Motor vs. Mid-Drive)

Electric bicycle conversions commonly use two types of motors: hub motors and mid-drive motors. *Hub motors*, integrated into the front or rear wheel, are easier to install, less expensive, and require minimal changes to the existing drivetrain. They are ideal for flat terrains and casual commuting. *Mid-drive motors*, on the other hand, are mounted at the cranksets and provide power directly to the chain drive, offering better torque and hill-climbing performance. Although mid-drive systems are more efficient and better balanced, they are mechanically complex and require modifications to the bottom bracket area. Hub motors are typically preferred for low-cost conversions due to their simplicity, while mid-drives are suitable for high-performance and load-carrying applications.

Battery Types (Li-ion, Lead-Acid) and Specifications

The choice of battery significantly affects the performance, weight, and cost of a retrofitted e-bike. *Lithium-ion (Li-ion)* batteries are widely preferred due to their high energy density, lightweight, long cycle life, and fast charging capabilities. Typical Li-ion packs range from 36V to 48V with capacities between 10Ah and 20Ah, offering ranges from 25 km to 60 km per charge. In contrast, *lead-acid* batteries are more affordable but are heavier, bulkier, and have a shorter lifespan. They are often used in ultra-low-cost conversions despite lower efficiency and depth-of-discharge limitations. Battery selection depends on application, budget, and available space on the bike. Safety features, such as built-in BMS and casing for waterproofing, are critical considerations regardless of battery type.

Power Controllers and Wiring Methods

The power controller regulates voltage and current supplied from the battery to the motor and other electronic components. It determines throttle response, motor efficiency, and safety functions such as overcurrent protection. Modern controllers support features like regenerative braking, pedal assist levels, and thermal cutoff. Wiring methods should follow organized and insulated pathways to prevent short circuits and ensure safety. Use of waterproof connectors, color-coded wires, and flexible cable conduits are recommended for both aesthetics and reliability. Proper layout avoids interference with pedaling or movement and ensures easy troubleshooting or upgrades in the future.

Speed Sensor and Pedal Assist System (PAS)

The Pedal Assist System (PAS) enhances ride experience by activating motor assistance when the rider pedals. A *speed sensor* or cadence sensor, usually mounted on the crank or bottom bracket, detects pedaling motion and sends signals to the controller to deliver proportional motor power. PAS improves energy efficiency and reduces reliance on throttle-only mode, making it ideal for longer rides and regulatory compliance in many regions. Advanced systems can include torque sensors for more responsive power delivery, though cadence-based systems are simpler and cheaper to implement in low-cost conversions.

IoT and Mobile App Integration (Bluetooth Modules, GPS)

Integrating IoT capabilities into retrofitted e-bikes can transform them into smart mobility solutions. *Bluetooth modules* allow wireless communication with smartphones, enabling users to monitor speed, battery level, GPS location, and riding statistics via dedicated apps. *GPS modules* can enhance security through live tracking and anti-theft alerts. These features are often implemented using microcontrollers like Arduino or ESP32, paired with mobile app platforms. Smart integration not only improves user experience but also supports data-driven performance optimization, remote diagnostics, and ride-sharing applications.

Battery Management System (BMS) and Diagnostics

A Battery Management System (BMS) is essential for ensuring the safety, reliability, and longevity of the battery pack. It monitors key parameters such as voltage, current, temperature, and individual cell balance. The BMS prevents overcharging, deep discharge, thermal runaway, and short circuits by isolating faulty cells or disconnecting the battery when unsafe conditions are detected. Advanced BMS units also support diagnostic communication via UART or CAN protocols, enabling real-time battery health monitoring and fault reporting. For retrofitted e-bikes, integrating a robust BMS is critical for both performance and user safety, especially in Li-ion systems.

Use of Microcontrollers (Arduino, Raspberry Pi)

Microcontrollers like *Arduino*, *ESP32*, and *Raspberry Pi* play a vital role in enabling smart functionalities in retrofitted e-bikes. Arduino boards are commonly used for controlling PAS, lights, horn, and speed limiters, while ESP32 adds Bluetooth and Wi-Fi capabilities for IoT integration. Raspberry Pi, being more powerful, is suitable for applications involving GPS tracking, real-time data logging, or touchscreen displays. These platforms are open-source, cost-effective, and widely supported by online communities, making them ideal for DIY smart e-bike projects. They also enable custom automation, remote diagnostics, and user interaction via mobile apps or web dashboards. Table 2 elaborates the retrofitted scrap bicycle versus new E-bike comparison.

Table 2. Retrofitted scrap bicycle vs. New E-Bike comparison table.

Parameter	Retrofitted Scrap Bicycle	New E-Bike
Cost	₹10,000–₹20,000 (depending on components and battery)	₹30,000–₹1,00,000+ (varies by brand and features)
Bill of materials (BoM)	Minimal frame cost (scrap), motor, controller, battery, throttle, wiring	Full-frame, motor, controller, display, battery, frame-mounted sensors
Component sourcing strategies	Locally sourced or refurbished components; reuse of bicycle frames	Factory-assembled with proprietary or imported components
Local manufacturing	High potential—assembly in local garages/workshops	Limited—dependent on OEMs and centralized manufacturing units
DIY kits and assembly	Widely available; enables customization and user involvement	Not user-serviceable; minimal customization allowed
Repair and maintenance cost	Low; easily replaceable standard parts	Higher; proprietary parts often require service center support
Supply chain dependency	Low; uses modular components from multiple suppliers	High; dependent on specific vendors and global supply chain
Affordability for low-income groups	High; ideal for rural and low-income urban users	Low to moderate; price is often prohibitive without subsidies
Environmental sustainability	High; promotes reuse and waste reduction	Moderate; requires raw material extraction and new production
Customization flexibility	High; adaptable for load-carrying, rural roads, smart add-ons	Limited; constrained by brand specifications

PERFORMANCE CONSIDERATIONS AND ENVIRONMENTAL IMPACT

The performance of retrofitted electric bicycles depends largely on motor power and battery capacity, influencing range, speed, and torque. Most low-cost conversions offer a range of 25–50 km per charge, speeds up to 25 km/h, and moderate torque sufficient for urban and semi-urban terrain. Battery life varies based on usage and cell quality, with lithium-ion batteries generally offering longer life cycles and better energy efficiency than lead-acid alternatives. Converted e-bikes must undergo structural evaluation to ensure frame integrity and rider safety under dynamic loads. Since scrap bicycles are reused, it's essential to test for stress, fatigue, and load-bearing capacity, particularly at mounting points for the motor, battery, and controller. Load testing helps prevent failures due to mechanical wear, corrosion, or overloading, ensuring safe operation in varied conditions. Integrating regenerative braking in converted e-bikes can improve energy efficiency by recovering kinetic energy during deceleration. Additionally, electrical protection systems like fuses, circuit breakers, and battery management systems (BMS) safeguard the electronics against overvoltage, overcurrent, and short circuits. These features enhance reliability, extend battery life, and ensure user safety. Converting scrap bicycles into electric ones significantly reduces electronic waste by repurposing existing frames and minimizing the demand for new vehicle production. It also lowers CO₂ emissions by replacing fossil-fuel-based commuting with clean electric propulsion, contributing to both environmental sustainability and circular economy goals. The adoption of e-bike conversion initiatives can generate employment and skill-building opportunities in local communities through small-scale assembly, repair, and maintenance services. Training programs in electrical retrofitting, fabrication, and smart system integration empower youth and technicians, fostering grassroots innovation and economic development.

Retrofitted e-bikes offer an economical mobility option for rural and low-income urban populations, often costing a fraction of commercially available electric two-wheelers. By utilizing locally sourced scrap bicycles and basic electronic components, the overall cost can be minimized, making electric mobility accessible to underprivileged segments. One of the major challenges in retrofitting bicycles into e-bikes is the lack of clear legal frameworks and RTO approval processes. In many regions, electric bicycle regulations are ambiguous, and absence of retrofitting standards leads to enforcement and certification issues, hindering large-scale implementation and policy support. Technical challenges such as compatibility between old bicycle frames and new electrical components can lead to installation difficulties and performance inefficiencies. Improper sizing, weight imbalance, and mismatched components can reduce energy efficiency, ride quality, and overall system reliability, requiring careful design and system integration. Durability is a key concern for retrofitted e-bikes, as reused bicycle frames and low-cost components may not withstand long-term operational stress. Exposure to weather, vibrations, and rough terrain can affect structural integrity and electrical reliability. Ensuring proper assembly, weatherproofing, and component quality is essential for sustained performance.

CONCLUSION

Low-cost e-bike conversions are technically feasible through modular mechanical adaptations and open-source electronic systems, making them an accessible and sustainable transportation solution. Converting scrap bicycles into e-bikes not only reduces emissions but also supports circular economy practices by repurposing existing materials. To scale this innovation, future efforts should focus on standardizing retrofit kits, offering subsidies for essential components, and establishing local training programs. Integrating AI algorithms can further enhance e-bike performance by predicting battery usage, optimizing energy efficiency, and enabling adaptive motor control. Additionally, solar-powered charging systems can improve the self-sufficiency and environmental impact of e-bike conversions, particularly in off-grid rural areas. These smart, converted e-bikes can also be incorporated into Mobility-as-a-Service (MaaS) platforms to improve last-mile connectivity and reduce urban congestion. Open-source tools play a vital role by empowering local communities and innovators to build, customize, and maintain intelligent e-bikes, fostering widespread grassroots adoption.

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