

Research on the Green Innovation Development and Environmental Protection Value of Transportation Vehicles

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Abstract. During the Industrial Revolution, steam-powered vehicles caused severe air pollution, as seen with early London Underground trains filling tunnels with harmful smoke. The invention of electric motors later enabled cleaner subways. Early trams had high infrastructure costs, leading to engine-driven buses that polluted more than trams, but battery technology was too primitive to offer a solution. This article focuses on the green innovation process and environmental protection value of transportation vehicles as its core research topic, and systematically reviews the technological iterations and development changes of various types of vehicles. The research finds that technological innovation is the core driving force for the green development of transportation. Advances in rechargeable batteries have allowed electric buses to replace traditional ones; a single city switching to electric buses can save a lot of carbon emissions annually. Converting cars to electric power would largely eliminate CO₂ emissions, though range limits have spurred the development of extended-range and hybrid vehicles, which cut emissions by about half compared to pure internal-combustion cars. Electric trains have improved as well, moving from DC to AC motors, which save more energy. Public transport use is rising while bus fleets shrink, and subways are more environmentally friendly due to high capacity. Future innovations such as regenerative braking and improvements in hydrogen safety could further reduce emissions and even enable resource recovery, thereby helping to slow greenhouse gas emissions and conserve natural resources.

Keywords: Green Transportation, Technological Innovation, Electrification Transformation, Traffic Emission Reduction, Sustainable Development

1. Introduction

During the Industrial Revolution, steam-powered vehicles caused severe air pollution—early London Underground trains famously filled tunnels with harmful smoke. Electric motors later enabled cleaner subways, but early trams faced high infrastructure costs, leading to the adoption of engine-driven buses that actually polluted more than trams, as battery technology remained too primitive to offer a better alternative. These historical trade-offs reveal a central theme: the path to green transportation has been shaped by the constant struggle between operational demands and environmental costs. This article takes the green innovation process and environmental protection value of transport vehicles as its core research focus, systematically reviewing technological

iterations across different vehicle types. Our findings show that technological innovation is the key driver of sustainable development in transport. Advances in rechargeable batteries have allowed electric buses to replace traditional ones; a single city that switches to electric buses can reduce substantial carbon emissions annually. Widespread car electrification would largely eliminate CO₂ emissions, though range limits have spurred extended-range and hybrid vehicles, which cut emissions by half compared to pure internal-combustion cars. Electric trains have also improved, moving from DC to AC motors for greater energy savings. Public transport ridership is rising while bus fleets are shrinking, and subways are more environmentally friendly because of their high passenger capacity. Future innovations like regenerative braking and hydrogen safety could further reduce emissions and even recover resources, helping slow greenhouse gas production and conserve natural resources.

2. Development and green transformation of modern transportation vehicles

2.1. Urban traffic pattern and fuel pollution dilemma in the early 20th century

At the beginning of the 20th century, trams (streetcars) were widely used in cities around the world. They offered clean, efficient urban transport powered by electricity from overhead lines or ground-level conduits. However, installing and maintaining the necessary power lines and tracks required a very high initial investment, making tram networks expensive to build and difficult to reroute. To solve this problem—especially the need to serve rural areas where laying tram tracks was not cost-effective—motor buses appeared. Because rechargeable battery technology at the time was still primitive (lead-acid batteries were heavy, had low energy density, and short lifespans), all early buses used internal combustion engines that ran on gasoline or diesel. Compared with trams, which produced zero tailpipe emissions, engine-powered buses caused significantly more air pollution, releasing carbon monoxide, nitrogen oxides, and particulate matter. However, due to the technological limitations of that era—no alternative power sources existed—this pollution problem could not be adequately solved, and buses became the dominant mode of road transport for much of the 20th century.

2.2. Large-scale development of public transport and emission reduction application of electric buses

Vehicle development has been driven by several factors, including the development of computers, the Internet, shared data, and artificial intelligence [1]. The global transportation sector stands at a crossroads, facing a critical juncture that demands immediate attention and transformative action. Conventional fossil fuel-powered transportation, responsible for a staggering 29% of global greenhouse gas emissions, has an impact on climate change and air quality that cannot be overstated [2]. The technology of vehicles must be developed to reduce emissions. Nowadays, with the continuous development of public transportation systems, more and more people are choosing to take buses, subways, trams, and trains. At the same time, the variety and number of public transport vehicles have increased substantially. Consequently, the total environmental impact of public transportation is gradually increasing—not because each vehicle is dirtier, but because the overall volume of public transport has grown. It is important to note, however, that on a per-passenger-kilometer basis, public transport remains far cleaner than private cars. Since the 2000s, with the technological advancement of rechargeable batteries, an increasing number of cities have been choosing to replace traditional buses with electric ones. From the supercapacitor buses

piloted in Shanghai around 2010 to the battery and hybrid buses with increasingly longer range after 2015, the adoption of electric buses in just one city can reduce 690,000 tons of carbon emissions annually, offering significant protection for urban air quality and the natural environment.

2.3. Technological iteration and carbon emission optimization of new energy passenger cars

In addition to buses, in recent years, with the continuous increase in the energy density of batteries, a large number of electric cars have also emerged. Compared with buses, passenger cars are much more numerous. If converted from internal combustion to electric power, these vehicles could reduce carbon emissions substantially. If a car travels 20,000 kilometers a year, it will release approximately 2 tons of carbon emissions in a year. At present, there are over 300 million small cars in China alone, which means they emit more than 600 million tons of carbon annually. If these cars are converted to electric vehicles, most of their emissions will disappear. As many electric cars currently have batteries that can only travel less than 500 kilometers when fully charged, to address this issue, many manufacturers have developed a type of car that enhances its range through a power generator. In this kind of car, there is an engine specifically designed to generate extra power. Since the engine does not directly drive the wheels, it can always operate at optimal combustion efficiency, thereby providing additional power to the motor and reducing overall emissions compared with conventional vehicles. Another type is the hybrid vehicle. This type of vehicle is equipped with both an electric motor and an engine as its driving force. Compared with pure electric and extended-range electric vehicles, its battery capacity is smaller. When fully charged, it can run for about 200 to 300 kilometers. Even after the battery runs out, the engine can still be used to continue driving. Although the carbon emissions are higher than those of the other two types of vehicles, they can still be reduced by half compared with pure engine vehicles. Fuel cells have also been tested in recent years. The most popular fuel cell type is hydrogen. One of the main advantages of hydrogen energy is its environmental benefits; when used as a fuel, hydrogen only produces water vapor as a byproduct, making it a zero-emission energy source [3]. This is particularly important in sectors such as transportation, where hydrogen fuel cells can be used to power electric vehicles, offering long driving ranges and fast refueling times [4].

2.4. Motor technology upgrade and energy-saving development of rail transit

At the same time, the technology of electric trains has also improved significantly in the past few years. In order to enhance efficiency, around the late 1990s, the motors of trains were converted from DC motors to AC motors. The earliest AC traction converters used GTO power transistors, whose efficiency and switching frequency were not very high. With the subsequent advent of IGBT power transistors, the switching frequency was several times higher than that of GTO. Not only was the efficiency higher, but the system also consumed less electricity. With the emergence of permanent magnet synchronous motors in recent years, not only has the noise during train operation been reduced, but it is also about 30% more energy-efficient than traditional asynchronous AC motors. Although the cost of permanent magnet motors (PMSM) is high, considering their vast potential for future development and the electricity savings over the long term, such motors will become the main traction systems for trains and even for all types of vehicles. Nowadays a lot of underground trains are based on connected-vehicle signal systems. This technology allows trains on the same line to maintain a restricted gap, thereby avoiding accidental collisions. This system will have a profound impact on the long range planning and land-use models used today. It will provide

planners with a greater insight into each step than ever before leading possibly to more precise models and providing enhanced information for better decision making [5, 6].

2.5. Traffic structure optimization and overall environmental efficiency improvement

Meanwhile, with the rapid construction of subways (metros) and regional railways (commuter and intercity lines), the ridership of traditional city buses has declined in many developed regions. The number of buses scrapped each year now far exceeds the number of new buses purchased, as transit agencies shift investment toward rail-based systems. At the same time, the fares for many public transportation modes have been decreasing thanks to government subsidies, encouraging large numbers of people to switch from private cars to public transit. Clearly, public transport is far more environmentally friendly than private cars, because a single bus or train can carry dozens or even hundreds of passengers, resulting in a much smaller number of vehicles on the road and far lower emissions per passenger-kilometer. Compared with previous decades, these changes have led to a significant reduction in transportation-related carbon emissions in various regions around the world.

2.6. Cutting-edge green transportation technology and sustainable development prospects

Finally, emerging technologies promise even greater environmental benefits. One example is motor kinetic energy recovery, commonly known as regenerative braking. When an electric vehicle slows down, the electric motor reverses its role to become a generator, converting kinetic energy back into electricity and storing it in the battery. This reduces energy waste and extends range. Another promising field is hydrogen fuel cell vehicles. Although safety concerns (high-pressure hydrogen storage) have historically hindered their adoption, continuous improvements in tank materials and leak detection have made hydrogen vehicles much safer. Fuel cell vehicles emit only water vapor as "waste"—no carbon dioxide at all. That water can even be collected and reused for purposes such as cleaning or irrigation. In the future, people will not only be able to curb transportation-related carbon emissions, but also obtain valuable resources (e.g., clean water) through these means of transport, thereby reducing the consumption of limited natural resources. With ongoing innovation, the transportation sector is on a clear path toward sustainability.

3. Conclusion

At the beginning of the 20th century, trams were widely used for their clean and efficient electric operation. However, the high cost of installing and maintaining overhead lines and tracks made them expensive and inflexible, leading to the introduction of motor buses that ran on gasoline or diesel. Because rechargeable batteries at that time were heavy, had low energy density, and had short lifespans, these buses produced significant air pollution. Nevertheless, they became the dominant road transport for much of the century. Since the 2000s, advances in battery technology have allowed many cities to replace conventional buses with electric models, reducing hundreds of thousands of tons of carbon emissions annually. The same trend has expanded to electric cars, which—if widely adopted—could cut billions of tons of CO₂. Meanwhile, range-extender and hybrid vehicles offer practical compromises with lower emissions than pure internal-combustion cars, and hydrogen fuel cells provide a zero-emission option with long driving ranges and quick refueling. In rail transport, train motors evolved from DC to AC in the late 1990s, with IGBT transistors improving switching frequency and efficiency, and more recently permanent magnet synchronous motors have achieved about 30% energy savings over older asynchronous types, though at higher

cost, while connected-vehicle signal systems now allow subways to operate with safe, close gaps, enhancing both safety and planning. At the same time, the rapid construction of subways and regional railways has reduced the demand for traditional buses in many developed regions, with more buses scrapped than purchased. Government subsidies have lowered fares, encouraging a shift from private cars to public transit. Public transit remains far more environmentally friendly per passenger-kilometer and this shift has contributed to a significant decline in transport-related emissions globally. Looking ahead, regenerative braking recovers kinetic energy during deceleration and stores it in batteries, reducing waste. Hydrogen fuel cells, made safer by better tank materials and leak detection, emit only water vapor that can be collected and reused. These examples illustrate that continued innovation not only cuts greenhouse gases but also can provide valuable resources, steering the transportation sector clearly toward sustainability.

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