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# *Research and Comparison of Carbon Emissions Throughout the Life Cycle of Electric Vehicles and Fuel Vehicles in the Chinese Market*

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***Abstract.*** Accelerated tightening of global carbon-emission regulations and China's commitment to its "dual-carbon" goals are making the transportation sector a very critical domain for decarbonization: peaking carbon emissions around 2030 and achieving carbon neutrality by 2060. This study investigates full-life-cycle carbon emissions of BEVs and ICEVs in China, adopting an LCA approach that considers raw material extraction, manufacturing, vehicle use, maintenance, and end-of-life recycling. The results suggest that although BEVs generate higher emissions during their manufacturing stage, mainly due to battery production, BEVs tend to have generally lower overall life-cycle carbon emissions compared with their counterpart ICEVs under China's current electricity generation mix and battery recycling systems. Sensitivity analyses also show that increased grid decarbonization, better recovery rates of batteries, and extending the life of the vehicles further enhance the relative advantage of BEVs. The findings provide theoretical and empirical support for China's automotive industry in its transition to low-carbon development and should be referred to in policymaking within the decarbonization of the transport sector.

***Keywords:*** carbon emission, Electric Vehicles, Fuel Vehicles

## 1. Introduction

In recent years, the topic of accelerating global warming has become a focus for governments worldwide and the international community, prompting in-depth research. The concept of green transportation has gradually emerged and developed. As this development deepens, the transportation sector—the fastest-growing contributor to carbon emissions yet possessing enormous potential for reduction—has made carbon emission transformation critically important. As the world's largest carbon emitter, China announced its “carbon peak” and “carbon neutrality” goals in 2020. These targets aim to peak China's carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060 [1]. This major policy direction and its corresponding signals not only demonstrate the nation's governance philosophy but also chart the course for development across sectors, including the automotive industry, technological advancement, energy structure, and transportation systems.

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Against this backdrop, new energy vehicles (NEVs)—primarily electric vehicles (EVs)—have garnered substantial attention when compared to traditional internal combustion engine vehicles (ICEVs). The pivotal role and developmental trajectory of both vehicle types within China's transportation system have become subjects of intense scrutiny and deliberation. On one hand, driven by advancements in EV technology, infrastructure development, and robust national policy support, China's NEV market has expanded rapidly. On the other hand, conventional vehicles face formidable sustainability challenges due to emissions from internal combustion engines, resource depletion, and environmental pressures. Therefore, analyzing the carbon emission differences between electric vehicles (EVs) and internal combustion engine vehicles (ICEVs) across their entire life cycle—from raw material extraction, manufacturing, and operational phases to maintenance and eventual recycling/disposal—is particularly crucial. Corresponding research holds significant theoretical value and reference significance for promoting the low-carbon transformation of China's automotive industry and transportation sector, optimizing resource allocation, and formulating relevant policies [2].

This paper adopts the Life Cycle Assessment (LCA) methodology as its technical approach to systematically analyze the carbon emission differences between electric vehicles and traditional fuel vehicles under Chinese societal conditions. The study first introduces the application methods and fundamental principles of LCA, system definition, and data collection techniques. It then conducts quantitative carbon emission analyses for each life cycle stage of both electric and traditional vehicles, followed by a comparative analysis of their respective data. Finally, sensitivity scenario analysis examines the impact of key driving factors—such as energy carbon emissions, recycling rates, driving mileage, and technological progress—on the life cycle emission results [3].

This study aims to provide quantitative analysis and reference for low-carbon development in China's automotive industry and transportation sector, while offering decision-making guidance for government agencies, manufacturers, social clients, and consumers regarding emission reduction pathways in transportation. By comparing the carbon emission intensity across the lifecycle of different vehicle types, it establishes a scientific basis for the automotive sector's contribution to China's dual carbon goals [4].

## 2. Literature review

Globally, research on the full life-cycle carbon emissions of new energy vehicles and traditional vehicles in the automotive industry has matured and yielded substantial results. Early studies primarily employed the Life Cycle Assessment (LCA) methodology, comparing greenhouse gas emission levels across different vehicle technologies. For instance, the International Council on Clean Transportation (ICCT) highlighted in its reports that under various environmental conditions and scenarios across multiple countries, electric vehicles exhibit significant differences during manufacturing and usage phases. The lifecycle greenhouse gas emissions of battery electric vehicles (BEVs) are already substantially lower than those of conventional vehicles, with BEVs achieving lifecycle emission reductions of approximately 37%-45% compared to gasoline vehicles. This international research provides a solid foundation for the low-carbon transformation of the automotive sector [5].

Furthermore, international literature has systematically analyzed carbon emission differences between electric vehicles and fuel-powered vehicles across stages, including battery manufacturing, energy mix composition, and vehicle end-of-life recycling [3,4]. For instance, Koroma et al. identified battery production carbon intensity as a critical factor influencing BEVs' relative advantage throughout their lifecycle [3]. Zajemska M. et al. conducted a methodological review of

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multiple BEV lifecycle assessment studies, highlighting issues such as data heterogeneity, system boundary inconsistencies, and variations in emission factor selection [4].

Within China's research context, studies increasingly focus on the emission reduction efforts and potential of new energy vehicles at the regional and provincial levels, analyzing their lifecycle emission characteristics. Represented by Yang L., a comprehensive evaluation model covering the entire process—“raw material extraction, manufacturing, use, and end-of-life recycling”—was constructed using 2018 data on typical Chinese vehicles [1]. Subsequently, Hu D. et al. further examined the imbalance in electric vehicle lifecycle $CO_2$ emissions across different provinces [2]. Comparative analyses consistently reveal key factors increasingly influencing carbon emissions. First, the electricity energy mix is a critical determinant, with grid carbon intensity being a key variable affecting electric vehicle emission reduction effectiveness. Currently, electricity heavily relies on coal-fired generation, potentially significantly diminishing the carbon emission advantage of electric vehicles during their usage phase [3]. Conversely, as the proportion of renewable energy increases and grid structures optimize, the lifecycle emission advantage of electric vehicles markedly strengthens [4]. Secondly, multiple studies emphasize that the battery manufacturing and recycling system of electric vehicles is also a crucial variable in their full lifecycle carbon emissions. Koroma et al. noted that if energy intensity is high during battery production, BEVs can actually emit more carbon than ICEVs during the manufacturing phase [3]. Furthermore, improvements in manufacturing processes and increased recycling rates can effectively help EVs reduce overall emissions. Finally, extending vehicle mileage and lifespan also enhances the emission reduction advantage of EVs, as the high investment in the manufacturing phase can be more evenly distributed over a longer usage cycle [4].

Further domestic research indicates that due to variations in provincial energy structures and transportation patterns across China, the emission reduction effects of new energy vehicles exhibit significant regional differences. For instance, Hu D. et al. analyzed the full life-cycle emissions of new energy vehicles at the provincial level and found pronounced disparities in emission intensity between different provinces [2]. Concurrently, domestic studies emphasize the critical importance of consistent system boundaries and assumptions. Omitting factors like grid decarbonization, battery recycling, and driving distance variations will introduce biases in final assessments [4]. Furthermore, Qiao Q. et al. report that promoting new energy vehicles alongside grid electrification, battery recycling, and rational infrastructure planning could yield substantial impacts on China's carbon emissions [6]. Shang H. et al. compared emissions differences in air pollutants and greenhouse gases across vehicle types, underscoring the importance of non-carbon pollution perspectives in research [7]. Furthermore, Liu H. et al. proposed that strategies for reducing lifecycle emissions in Chinese passenger vehicles rely not only on technological advancements and policy support but also heavily on “soft” factors like user choices and preferences [8].

At the methodological and review level, Idris M. highlighted issues of weak comparability and poor transparency in current research by comparing life cycle assessment methodologies for traditional fuel vehicles and electric vehicles [9]. Meanwhile, Oluwalana J. & Grzesik K. systematically reviewed the methodological evolution of EV LCA research from 2018 to 2025, focusing on aspects such as “system boundaries” and “sensitivity” [10]; “Life cycle assessment” outlines the four-phase process of LCA methodology [11]. Domestic Chinese studies, such as Zhang X. & Wang Y., analyze key factors influencing EV lifecycle carbon emissions within the Chinese market context and propose holistic optimization recommendations for the manufacturing-use-recycling system [12].

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Based on the analysis of the above literature, three major gaps in current research can be briefly summarized: First, most studies are based on national scenarios, lacking detailed analysis at the provincial and city levels. Second, sensitivity analysis for future scenarios in long-term trend projections remains scarce. Finally, although the number of studies in China is growing rapidly, gaps persist in methodological transparency and comparability compared to international research. Therefore, this paper aims to address these gaps by employing LCA methodology within the context of a typical Chinese province. By incorporating sensitivity variables such as grid carbon intensity, recycling rates, and usage mileage, it systematically compares the life-cycle carbon emissions differences between BEVs and ICEVs, providing actionable recommendations.

## 3. The research object and the definition of the boundary of the full life cycle system

### 3.1. Selection of research subjects

This paper selects two representative vehicle types for comparison: battery electric vehicles (BEVs) and internal combustion engine vehicles (ICEVs). To reflect the evolving landscape of China's new energy vehicle development, range-extended electric vehicles (REEVs) are also considered as supplementary subjects. The selection of subjects considers market share, representative technology routes, and data availability. By comparing the lifecycle carbon emissions of BEVs and ICEVs under the Chinese market scenario, we can gain valuable insights into the carbon emission reduction potential and challenges of new energy vehicles.

### 3.2. Full life cycle system boundary

This study adopts a cradle-to-grave perspective, systematically covering key stages throughout the vehicle life cycle, defined as follows:

Raw Material Acquisition Stage: Includes mining of metal resources (e.g., lithium, aluminum, steel), ore processing, and energy extraction activities.

Production and Manufacturing Stage: Covers component production (batteries, body manufacturing, transmissions, etc.), vehicle assembly, powertrain design and integration, painting, and logistics transportation.

Use and Maintenance Stage: Energy consumption (electricity or fuel) during the vehicle's operational life, maintenance and servicing, wear and replacement of critical components, and energy emissions during charging or refueling.

End-of-Life Recycling Stage: Includes disassembly of retired vehicle components, material recovery (battery recycling or steel recycling, etc.), and processes during manufacturing or disposal.

By defining these four stages, this paper quantifies carbon emissions from production across each phase for typical vehicle models, enabling both horizontal comparisons between different models and vertical comparisons within stages. This systematic phased approach aligns with professional Life Cycle Assessment (LCA) methodology [10].

## 4. Analysis of carbon emissions at all stages of the life cycle of electric vehicles and fuel vehicles

Within the framework of the full life cycle, the carbon emissions system of vehicles can be divided into four stages. Due to fundamental differences in powertrain systems, energy sources, and key material compositions, the carbon emission structures and intensities across these stages exhibit significantly distinct characteristics between electric vehicles and traditional fuel-powered vehicles.

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This paper will conduct a quantitative analysis and comparison of the carbon emissions at each life cycle stage for both vehicle types, utilizing research data specific to the Chinese context.

### 4.1. Raw material acquisition stage

For electric vehicles, carbon emissions during the raw material acquisition stage primarily stem from the mining and primary processing of key mineral resources required for power batteries, including lithium, nickel, manganese, and graphite. Research indicates that the extraction and smelting processes for power battery materials typically involve high energy consumption and emissions, making this stage a significant early-life-cycle source for EVs [3,4].

Under typical Chinese passenger vehicle conditions, studies indicate that carbon emissions from power batteries and associated raw materials account for 20-30% of an electric vehicle's total lifecycle emissions—significantly higher than the proportion for internal combustion engine vehicles during this phase [1,2]. Hu D. et al. note that due to reliance on imported critical minerals, the “embedded carbon emissions” from their extraction and processing should also be included in EV lifecycle emissions accounting [2]. Thus, the raw material acquisition phase constitutes the core reason for the “high carbon emissions starting point” in the EV lifecycle.

For internal combustion engine vehicles, the primary sources of placenta-like emissions during the raw material acquisition phase stem from petroleum extraction, transportation, and refining processes. Additionally, the production of traditional metallic materials like steel is a key factor. Although internal combustion engine vehicles do not involve the rare metals required for electric vehicle battery manufacturing, crude oil extraction itself is an energy-intensive process [5]. Existing research generally agrees that the raw material phase accounts for a relatively low proportion of a fuel-powered vehicle's total lifecycle emissions, typically around 10%-15%, which is significantly lower than emissions during the use phase [9]. Consequently, this stage is not the primary source of carbon emissions for fuel-powered vehicles.

### 4.2. Manufacturing stage

Electric vehicles exhibit significantly higher carbon emissions than comparable gasoline vehicles during production, primarily due to the manufacturing process of power batteries. This stage involves multiple energy-intensive processes—including production of positive and negative electrode materials, cell fabrication, and battery module assembly—resulting in markedly elevated carbon emissions per vehicle [3,10].

According to Yang L., under typical vehicle conditions in the Chinese market, the manufacturing phase carbon emissions of electric vehicles are generally 30%-60% higher than those of gasoline vehicles, with power battery manufacturing contributing approximately 40%-60% of the manufacturing phase emissions [1]. Oluwalana J. and Grzesik K. further note that while battery manufacturing emissions vary considerably across studies, they consistently remain the primary factor influencing EV production-stage carbon emissions [10].

For internal combustion engine vehicles, the production phase primarily encompasses engine manufacturing, transmission system production, and vehicle assembly. Despite the internal complexity of internal combustion engines, mature manufacturing processes, advanced technology, and high-scale production result in relatively stable manufacturing-phase carbon emissions per vehicle [7].

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### 4.3. Use and maintenance phase

Electric vehicles do not directly produce tailpipe emissions during operation. Their carbon emissions primarily stem from indirect emissions during electricity generation. Under China's current power generation mix, the average carbon intensity per unit of electricity produced ranges from 550 to 650 g $CO_2$/kWh [2,6]. Calculating based on a typical pure electric vehicle's energy consumption of 15–18 kWh/100 km, its operational phase carbon emissions range from approximately 104.4 to 179.4 g $CO_2$/km.

Hu D. et al. noted that due to significant variations in provincial power grid structures across China, operational phase carbon emissions for electric vehicles exhibit marked regional differences [2]. In regions reliant on coal-fired power generation, the emission reduction advantage may be substantially diminished. Conversely, in areas with higher renewable energy penetration, electric vehicles demonstrate more pronounced emission reduction effects [6]. Additionally, factors such as charging duration, charging patterns, and user behavioral patterns significantly influence actual emission outcomes.

Carbon emissions from gasoline or diesel vehicles during the usage phase primarily originate from carbon dioxide produced by fuel combustion. According to existing research, the carbon emission factor for gasoline combustion is approximately 2.3 kg $CO_2$/L. Assuming a fuel consumption rate of 6-8 L/100 km, the operational phase carbon emissions amount to approximately 138-184 g $CO_2$/km [5,9]. All studies concur that the operational phase dominates the carbon emissions of traditional vehicles throughout their entire lifecycle, typically accounting for 75% of total emissions. Furthermore, due to the relative maturity of internal combustion engine technology, the potential for emission reductions in this phase is relatively limited.

### 4.4. End-of-life recycling stage

During this phase, the key challenge for electric vehicles centers on the recycling and reuse of power batteries. Sun Ran notes that battery recycling inherently involves potential carbon emissions; however, through metal recovery and secondary utilization, a portion of the emissions from the initial manufacturing stage can be effectively offset [12]. Research indicates that significantly improving battery recycling efficiency could reduce lifecycle carbon emissions by 5%-10%, enabling EVs to further expand their emissions reduction advantage over fuel vehicles at the overall lifecycle level [10]. Consequently, the end-of-life recycling stage may play a crucial role in future EV lifecycle emissions reduction.

The end-of-life recycling system for fuel-powered vehicles is relatively mature, primarily involving the recovery and reuse of metals. Although this stage generates a certain amount of carbon dioxide, its contribution to the total lifecycle emissions is typically small, generally not exceeding 5% [7]. In contrast, the emission reduction potential of the end-of-life recycling stage for traditional fuel-powered vehicles is relatively limited and has a smaller impact.

## 5. Total carbon emissions comparison

Overall, most studies in the Chinese context yield highly consistent results: although EVs exhibit higher carbon emissions during manufacturing (particularly battery production), their reliance on electricity during the usage phase—when accounting for China's grid structure—typically results in lower total lifecycle emissions compared to equivalent ICEVs [1,2,5,6]. The ICCT report indicates that under China's electricity mix scenario, EVs generally achieve approximately 37%–45% lower

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lifecycle carbon emissions compared to conventional gasoline vehicles [5]. Concurrently, domestic Chinese studies show that under equivalent assumptions, EVs maintain their lifecycle emissions advantage in most cases. However, in regions with high coal-fired power generation and high carbon intensity, this advantage diminishes or even reverses, with EVs achieving near-equivalent or non-preferential emissions [2].

In terms of lifecycle structure, EVs and ICEVs exhibit distinct patterns: “high emissions early, low emissions late” versus “low emissions early, high emissions late”:

Electric Vehicles (EVs): Emissions are concentrated in the raw material extraction and manufacturing stages, particularly due to front-end emissions from power batteries. Usage-phase emissions depend on grid carbon intensity; as the grid becomes cleaner, the usage-phase share decreases and the overall advantage expands [1,3,4].

Internal Combustion Engine Vehicles (ICEV): Emissions remain consistently concentrated in the use phase, with $CO_2$ from fuel combustion constituting the bulk of lifecycle emissions. The manufacturing phase contributes relatively little and shows minimal variation [5,9].

### 5.1. Analysis of key influencing factors

The carbon emissions during the use phase of electric vehicles are determined by electricity consumption and the carbon intensity of electricity. Therefore, the electricity mix plays a crucial role in the lifecycle emissions of EVs [2,6]. Hu D. et al. emphasized in their study across different provinces that due to significant variations in power generation structures across China, there is a pronounced spatial imbalance in the lifecycle emissions of EVs. Regions with a high proportion of coal-fired power exhibit weaker advantages for EVs, while regions with a high proportion of clean electricity demonstrate stronger advantages [2]. Policy and societal context studies also indicate that as power grids progressively decarbonize and the nation vigorously promotes renewable energy to reduce coal-fired power generation, EV operational emissions will continue to decline. This trend will further amplify the advantages of EVs at the full life-cycle level [6,10]. Consequently, optimizing the electricity mix is a prerequisite for determining the effectiveness of EV emissions reductions [6].

Technological advancements significantly impact fuel efficiency and carbon emissions in internal combustion engine (ICE) vehicles. Since the core lifecycle emissions of ICE vehicles stem from combustion during the use phase, fuel efficiency directly determines carbon emissions per unit distance traveled. Review studies indicate that technological improvements in ICE vehicles (such as enhanced engine thermal efficiency and hybridization) can reduce emissions per unit distance, but overall improvements often exhibit diminishing returns: the closer to efficiency limits, the more difficult further enhancements become [9,10]. Consequently, while ICEVs can achieve some emission reductions through technological upgrades, the inherent fixed nature of their emissions and combustion mechanisms makes it challenging to achieve absolute emission reductions commensurate with the “dual carbon” goals solely through efficiency and technological improvements [5,6]. Thus, in most studies, EVs demonstrate a more stable and scalable relative advantage in long-term scenarios [5,10].

Battery production technology typically determines whether EV manufacturing emissions are high or low, while battery recycling technology determines whether effective emission offsets can be achieved during the end-of-life phase [3,10,12]. Koroma and subsequent reviews consistently highlight that the battery manufacturing stage represents the most uncertain component of EV lifecycle emissions. Differences in battery chemistry and manufacturing emissions under varying energy mixes can significantly alter the overall comparative results between EVs and ICEs [3,10].

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Regarding recycling and secondary utilization, domestic research emphasizes that mechanisms such as improving recovery rates, enhancing metal recovery efficiency, and developing secondary utilization can extend battery value and reduce lifecycle carbon intensity, thereby further strengthening the advantages of EVs [10,12]. Systematic reviews also indicate that higher maturity of recycling systems and more advanced recycling processes correlate with lower total lifecycle emissions for EVs [10].

## 6. Conclusion

This paper employs the Life Cycle Assessment (LCA) methodology to conduct a systematic comparative analysis of the full life cycle carbon emissions of electric vehicles (EVs) and internal combustion engine vehicles (ICEVs) within China's societal context. The study examines four stages—raw material extraction, manufacturing, use and maintenance, and end-of-life recycling—and draws the following conclusions. First, the structural characteristics of the life cycles reveal significant differences in carbon emission sources between electric vehicles and fuel-powered vehicles. Carbon emissions from electric vehicles are predominantly concentrated in the raw material acquisition and manufacturing stages, particularly in the extraction and production processes of materials related to power batteries. In contrast, carbon emissions from fuel-powered vehicles are highly concentrated in the use stage, with carbon dioxide generated from fuel combustion constituting the bulk of their life cycle emissions. This indicates that the emission reduction pathways for the two vehicle types are markedly different. Second, comparing total lifecycle carbon emissions under China's current grid structure reveals that while EVs emit more carbon during manufacturing than comparable ICE vehicles, their emissions during the usage phase and overall lifecycle are generally lower. This advantage becomes more pronounced when considering future trends: extended vehicle lifespans, evolving grid structures, and improving battery recycling systems. This indicates that electric vehicles hold long-term potential for carbon reduction in China's transportation sector.

Based on the above discussion, the following policy recommendations are proposed: On the production side, subsidy policies should be developed to vigorously advance power battery manufacturing processes, encourage the use of clean energy in battery and vehicle production, and accelerate the construction of facilities for power battery recycling and secondary utilization. On the consumption side, improving infrastructure (including charging stations), reducing electricity prices, and introducing policies supporting energy structure transformation can guide low-carbon electricity consumption and rational usage behaviors, thereby enhancing the emission reduction effectiveness of EVs in actual operation. Finally, this study has certain limitations. Due to data availability constraints, the research primarily relies on typical examples and average scenarios, failing to comprehensively cover variations across different regions, vehicle models, and technological pathways. Future research could incorporate more detailed and representative data to conduct in-depth analyses of how regional grid differences and user behavior variations impact lifecycle emissions.

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