Electric Vehicles Facilitating the Coordinated Advancement of China' s Energy Security and Carbon Peaking and Carbon Neutrality (Postprint)

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Abstract

The current international landscape is complex and volatile, and China is at a critical juncture of economic ascension, confronting the dual challenges of energy security and the objectives of "carbon peak and carbon neutrality" (hereinafter referred to as "dual carbon"). While energy security constitutes a fundamental cornerstone for achieving the "dual carbon" objectives, certain emission reduction pathways impose constraints on elements directly related to energy security, such as energy supply and power grid load, making it difficult to achieve simultaneous optimization of both targets. Consequently, rationalizing and optimizing the relationship between energy security and "dual carbon" objectives and advancing their synergistic development has become an imperative challenge for China. Electric vehicles (EVs) deliver multifaceted benefits in energy conservation, energy storage, and emission reduction, representing one of the effective instruments for ensuring the coordinated development of energy security and "dual carbon" objectives. This article proposes, with the aim of mitigating policy conflicts, the establishment of a bilateral integrated coordination system underpinned by policy networks as a safeguard and energy storage technology as a foundation, leveraging the electric vehicle industry' s role in constructing compatible policy networks, strengthening the energy storage function of electric vehicles at the current stage, and jointly establishing a bilateral integrated coordination system through policy-technology integration.

Full Text

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Title and Authors

Electric Vehicles Contribute to China' s Energy Security and Carbon Peaking and Carbon Neutrality

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Abstract

The current international landscape is complex and volatile, and China is at a critical stage of economic transformation, facing the dual challenges of energy security and carbon peaking and carbon neutrality (hereinafter referred to as "dual carbon goals"). While energy security constitutes an important foundation for achieving dual carbon objectives, certain emission reduction pathways impose constraints on elements directly related to energy security, such as energy supply and grid load, making it difficult to simultaneously optimize both sets of goals. Therefore, reconciling and optimizing the relationship between energy security and dual carbon goals to promote their coordinated development has become an imperative challenge for China. Electric vehicles offer multiple benefits in energy conservation, energy storage, and emission reduction, making them a powerful instrument for coordinating energy security and dual carbon goals. This article proposes establishing a bilateral integration and coordination system anchored in energy storage technology and safeguarded by policy networks, with the aim of mitigating policy conflicts. The paper argues for leveraging the electric vehicle industry' s role in constructing compatible policy networks, strengthening the energy storage function of electric vehicles at the current stage, and building a bilateral integration and coordination system through the joint efforts of policy and technology.

Keywords: energy security, dual carbon goals, electric vehicles, coordinated development

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Constrained by global resources and the environment, the energy situation is becoming increasingly severe, the energy structure urgently needs transformation, and energy security is deeply affected. To address the energy and environmental problems brought about by rapid economic development, China has repeatedly formulated national, regional, and sectoral energy strategies and environmental protection strategies, such as the "Four Revolutions and One Cooperation" new energy security strategy and the "carbon peaking and carbon neutrality" (hereinafter referred to as "dual carbon") goals. However, in the process of jointly promoting energy security and dual carbon goals, rapid emission reduction strategies have also introduced certain energy security risks. The 20th Party Congress report further pointed out that based on China's energy resource endowment, we must adhere to the principle of establishing before breaking, and implement carbon peaking actions in a planned and step-by-step manner. These major strategic decisions and deployments all demonstrate that China is actively seeking to maximize the synchronization of energy security and dual carbon goals at different stages.

As a high-pollution and high-energy-consumption industry, the continuously expanding scale of the automotive sector has led to rapid increases in oil demand and exhaust emissions, becoming one of the main factors limiting energy security and increasing carbon emissions. As the transformation of replacing fuel vehicles with electric vehicles unfolds on a large scale, the automotive industry will inevitably undergo tremendous changes for a considerable period, which will have positive effects on safeguarding China's energy security and reducing carbon emissions. Electric vehicles can promote diversified energy development, reduce the transportation sector's dependence on traditional fossil energy, and lower national energy risks. Simultaneously, the zero-emission characteristic of electric vehicles helps reduce greenhouse gas emissions and contributes to achieving dual carbon goals. Supportive policies introduced by governments worldwide have injected vitality into the electric vehicle market, with global sales showing exponential growth trends. In 2022, global pure electric vehicle sales reached 7.8 million units, a year-on-year increase of 68%; China's pure electric vehicle sales reached 5.365 million units, a year-on-year increase of 81.6%, with the market share of electric vehicles continuing to grow [1]. Therefore, paying attention to the development trajectory of electric vehicles is significant for coordinating energy security and dual carbon goals.

Current research focuses on describing the status quo, development directions, and contradictions between energy security work and dual carbon goal implementation, but lacks analysis of the impact mechanisms through which products like electric vehicles can contribute to their coordinated development. This article clarifies the relationship between China's energy security and dual carbon goals, constructs a dual-triangle theory centered on the high efficiency and zero-emission characteristics of electric vehicles, and analyzes their influence mechanism on coordinating energy security and dual carbon goals. From the perspectives of stability and coordination, this paper examines the driving role of electric vehicles in energy security and dual carbon goals, covering three aspects: policy synergy, technology synergy, and integrated synergy. To continuously amplify these driving effects, it is necessary to build a bilateral integration and coordination system safeguarded by policy networks and anchored in energy storage technology, thereby enhancing the synchronization and coordination of electric vehicles in supporting energy security and dual carbon goals, and guiding the future development focus and direction of the electric vehicle industry.

1 The Relationship Between Energy Security and Dual Carbon Goals

At present, China' s energy security work is no longer simply about ensuring energy supply security, but also concerns ecological environment and sustainable development issues. As the new concept of energy security takes root, sustainable development strategies such as energy conservation, emission reduction, low-carbon economy, and dual carbon goals have gradually been incorporated into energy security work. In the process of coordinating energy security and dual carbon goals, since their objectives and positioning differ, complete synchronization cannot be achieved. Therefore, it is particularly important to rationalize the complex relationship between them.

1.1 Energy Security as a Critical Foundation for Dual Carbon Goals

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C analyzes that global carbon neutrality will be achieved around 2050, and green low-carbon development has become an irreversible trend and consensus worldwide. Carbon emissions mainly originate from the combustion of fossil fuels. To achieve dual carbon goals, China must inevitably embark on an energy transformation path from fossil energy to renewable energy. China' s resource endowment determines that at the current stage, both energy supply and consumption are dominated by coal . To ensure social stability and long-term national security, the coal-dominated energy structure cannot be changed temporarily. The dual carbon goals do not mean abandoning coal, but continuously developing efficient technologies to promote the efficient, scientific, and green use of coal, thereby consolidating coal' s foundational role.

To ensure coal' s foundational position and energy supply security, achieving dual carbon goals must still be based on energy security, with proper utilization of coal as the main approach. There are two models for clean and efficient coal utilization: (1) Clean coal utilization. Efficient and clean coal utilization runs through the entire pathway of dual carbon goals—carbon substitution, carbon reduction, carbon sequestration, and carbon cycling—involving the safe, efficient, and green mining and utilization of coal. It is projected that by 2050, coal substitution will account for 47% of global carbon neutrality contributions, while carbon reduction, carbon sequestration, and carbon cycling will contribute 21%, 15%, and 17% respectively [2]. (2) Substitutive coal applications. Vigorously developing products that use clean energy, such as electric vehicles, reduces the proportion of fossil energy use and increases the proportion of clean energy use. This fully demonstrates that green low-carbon development and coal' s foundational role are not contradictory. Energy security work is also the cornerstone for steadily advancing dual carbon goals.

1.2 Risks to Energy Security Under Dual Carbon Goals

The relationship between ensuring energy security and achieving dual carbon goals is complex. China faces many challenges on the road to dual carbon goals, including a late start, heavy tasks, and a short window period, which further increase the pressure on China' s energy security work regarding expected goals and supply stability. First, expected goals cannot be simultaneously optimized. Dual carbon goal implementation focuses on environmental sustainability, while energy security work emphasizes providing stable energy supply support for national stability. Under the constraint of resource limitations, it is difficult for both to achieve optimal goals simultaneously. Second, energy supply stability. To complete dual carbon goals on schedule, immediate changes to the coal-dominated energy consumption structure are required. However, the clean and substitutive use of coal also requires substantial capital, technology, and time, all of which threaten energy supply stability.

Through reviewing existing literature, this study finds that the focus of China' s energy security work and dual carbon goal implementation paths differs at different stages , and rapid promotion of dual carbon goals intensifies the risks and challenges to energy security. First, traditional energy security risks. Government emphasis on emission reduction policies affects and suppresses fossil energy production and investment demand, leading to decreased production capacity and surging prices of fossil energy products, resulting in traditional energy supply security risks for China. Second, power system security risks. The low-carbon energy transformation shifts the focus of energy security work to the power system, and energy security issues characterized by fossil energy will evolve into power system security issues. China possesses 60%-70% of the global photovoltaic industry chain and 40% of the wind power industry chain resources. However, the current volatility and non-dispatchability of renewable energy during power generation have not been properly resolved. Large-scale application and grid connection increase the likelihood of instability in the current power system operation, raising energy supply security risks.

Traditional fuel vehicles depend on oil resources, and the extraction, transportation, and use of oil resources generate substantial carbon emissions and environmental pollution. Therefore, fuel vehicles cannot simultaneously ensure energy security and achieve dual carbon goals. To solve this dilemma, the Chinese government is promoting the transformation of replacing fuel vehicles with electric vehicles. On the one hand, as clean products, electric vehicles use electricity instead of fossil fuel combustion, resulting in lower carbon emissions. On the other hand, electric vehicles use batteries to store energy, reducing fuel dependence and thereby improving energy supply security. Consequently, electric vehicles are expected to become an important means of achieving dual carbon goals and ensuring energy security.

2 Theoretical Mechanism for Electric Vehicles to Coordinate Energy Security and Dual Carbon Goals

The future market space for electric vehicles is enormous, and in-depth analysis of their theoretical mechanism for coordinating energy security and dual carbon goals is of great significance for planning the market diffusion focus, technological improvement, and risk reduction of electric vehicles. The dual-triangle theory consists of the "Sustainable Development Triangle" and the "Energy Impossible Triangle," describing sustainable development from three dimensions: "Energy-Economy-Environment" [3] (hereinafter referred to as the " '3E' system") and three dimensions: "Energy Price-Energy Supply-Energy Ecology" [4] (hereinafter referred to as the "energy subsystem"). The impact of electric vehicles on the coordinated development of energy security and dual carbon goals runs through both the "3E" system and the energy subsystem, involving three levels: implementation path, current status, and long-term goals. Based on this, this article constructs a "two-system, three-level" theoretical analysis framework [Figure 1: see original paper].

2.1 Stability Thrust of Electric Vehicles in the "3E" System

During the process of adjusting social and economic development rates, the dynamic correlation changes between the energy system and the environmental system are referred to as the internal stability challenges of the "3E" system. The "Sustainable Development Triangle" theory posits that in the context of rapid economic development, problems such as energy consumption and environmental pollution are inevitable. To alleviate environmental issues, governments should implement dual carbon policies. These emission reduction strategies primarily target the energy sector and seize transformation opportunities, meaning that environmental and energy issues are often closely related. Nevertheless, energy transformation should also prioritize maintaining energy security. However, achieving dual carbon goals requires technology, capital, and time costs for efficient and clean coal utilization, and considering energy security, energy structure adjustment is difficult to complete in the short term. These factors threaten the stability of energy supply and power systems.

In the "3E" system, electric vehicles exert a thrust effect on ensuring energy security and achieving dual carbon goals, mainly by enabling the electric vehicle industry to overcome defects at the current status and path levels, and maintain stability in energy supply and power systems. First, regarding energy supply stability, electric vehicles use electricity instead of fuel for power, and electricity is supplied by multiple sources including fossil fuels, hydropower, wind power, nuclear power, and solar power, ensuring diversified energy supply, reducing dependence on single energy sources, lowering energy system risks, and improving sustainability and stability. Second, regarding power system stability, achieving dual carbon goals requires widespread use of clean products and clean energy across society, further focusing energy consumption pressure on the power system. However, electric vehicles, with their own energy storage devices, have diverse charging times and methods, and supporting infrastructure such as charging piles can provide energy storage support when grid pressure is high, ensuring stable grid operation.

2.2 Coordination Thrust of Electric Vehicles in the Energy Subsystem

Achieving secure, clean, low-carbon, and affordable energy supply is the ultimate goal of global energy transformation. Under current technological conditions, the coordinated development of these three major goals is known in the industry as the "energy impossible triangle" problem, representing the impossible triangle contradiction in the energy subsystem. Under the premise of affordable energy prices, energy supply and energy ecology cannot be simultaneously optimized, and nations or governments must comprehensively balance and coordinate these energy system objectives. Ensuring national energy supply stability is the main goal of energy security, while maintaining energy ecological stability inevitably requires implementing dual carbon policies. Therefore, under technological and resource constraints, ensuring energy security and achieving dual carbon goals also face the same impossible dilemma.

The thrust effect of electric vehicles on the coordinated development of energy security and dual carbon goals in the energy subsystem is mainly manifested in the synchronized development of both in terms of expected goals in the long run. As a transportation tool powered by clean energy, electric vehicles can reduce the dependence of traditional fuel vehicles on fossil fuels, thereby reducing China' s energy dependence on the international crude oil market and ensuring energy security. At the same time, promoting electric vehicles can facilitate the use of clean energy, as the electricity source for electric vehicles can be solar, wind, and other clean energy sources, further promoting the marketization, industrialization, and technological innovation of clean energy, reducing exhaust emissions from vehicles, and providing tremendous potential for achieving dual carbon goals.

3 Electric Vehicles as an Effective Path for Coordinated Development

Electric vehicles are an important driver for ensuring energy security and achieving dual carbon goals. Based on the above theoretical mechanism analysis of how electric vehicles contribute to their coordinated development, it is necessary to accurately identify the focal points of electric vehicles' synergistic effects to clarify their implementation path. These synergistic effects can be categorized into three aspects: policy synergy, technology synergy, and integrated synergy.

3.1 Policy Synergy

Policy synergy refers to the flexible coordination of policies and macroeconomic policy coordination under electric vehicle promotion. China' s dual carbon goal advancement affects the stability of energy supply security, and electric vehicle development provides possibilities for mitigating conflicts from the source [Figure 2: see original paper]. First, flexible policy coordination. Electric vehicle promotion can directly reduce non-renewable energy consumption, providing broader options for policy formulation. By shifting transportation power from highly polluting fossil energy to clean energy dominated by electricity, electric vehicles reduce the consumption of fossil energy such as petroleum and extend the exploitable lifespan of energy reserves. With sufficient energy reserves and stable energy supply, the government' s work focus can shift to other areas of energy security, such as climate change or environmental security, thereby promoting dual carbon goal progress. Second, macroeconomic policy coordination. Large-scale application of electric vehicles can indirectly affect energy prices, giving full play to government macroeconomic regulation. Under dual carbon policies, emission reduction strategies increase fossil energy costs, suppress traditional energy production and investment demand, reduce supply elasticity, cause energy prices to soar, and exacerbate energy supply risks. Large-scale application of electric vehicles reduces demand for traditional energy. According to market supply and demand principles, demand changes cause equilibrium prices and quantities to move in the same direction, so market equilibrium prices and quantities will decrease, weakening energy security risks.

During electric vehicle promotion, policy synergy consistency among different local governments is relatively low. Local governments formulate and implement electric vehicle incentive policies with different standards, and the scale of electric vehicle industries varies across regions, which may cause market imbalances and resource waste, leading to unsatisfactory coordinated development effects. In addition, the synergistic effect between different policies is not strong. During policy adjustment, it is difficult for governments to formulate appropriate policies based on the level of contradiction between energy security work and dual carbon goal implementation in their jurisdictions, which may also adversely affect electric vehicle promotion and energy structure transformation.

3.2 Technology Synergy

Technology synergy refers to energy storage technology upgrades and charging/discharging technology optimization under the coordinated operation of electric vehicles and grid systems. The "Vehicle-to-Grid" (V2G) mode allows electric vehicles to release electricity stored in their batteries into the grid to stabilize the balance between power supply and demand and respond to market changes. Following the "cost-benefit calculation method" for electric vehicles participating in grid services under V2G mode [5], this article constructs six scenarios with peak-valley electricity price differences (Pgap) of 0.3, 0.4, 0.5, 0.6, 0.7, and 0.8 yuan to analyze the total revenue and net income of single-vehicle electricity regulation under V2G mode . The results show that both total revenue and net income from energy accumulation-storage increase with larger peak-valley electricity price differences. In regions with large peak-valley electricity price differences, deploying electric vehicles can regulate grid peak and valley electricity usage and generate higher returns. Empirical data support that introducing V2G mode electric vehicles has positive effects on the grid.

The coordinated development of electric vehicles and grid systems mainly relies on the close integration of energy storage technology and charging/discharging technology under V2G mode to achieve efficient energy utilization and optimized grid dispatch. First, realizing bidirectional energy flow. When electric vehicles are parked and charging, batteries can serve as grid energy storage devices to store excess electricity; when vehicles need to travel, batteries can act as mobile energy storage devices to release stored electricity for vehicle use. Energy storage technology can position electric vehicle batteries as mobile energy storage devices on the generation side, grid side, and user side to interact with the grid system. This bidirectional energy flow based on energy storage technology can achieve coordinated development between electric vehicles and grid systems. Second, optimizing grid load management. Through charging/discharging technology, intelligent control of electric vehicle charging can be implemented to avoid the impact of concentrated charging on the grid. Meanwhile, the grid can balance peak and valley electricity through charging/discharging technology to achieve optimized load dispatching.

3.3 Integrated Synergy

Integrated synergy refers to the effective thrust of electric vehicles in optimizing the achievement of both energy security and dual carbon goals, specifically manifested as the coordinated development of dual utility of energy conservation and emission reduction driven by policy and technology. Electric vehicles possess both excellent energy-saving and emission-reduction benefits, which facilitate the synchronized development of energy security and dual carbon goals. Using an energy consumption and carbon emission calculation model [6] and constructing scenarios with different market share ratios between electric vehicles (EV) and fuel vehicles (FV) on the road—EV proportions of 0%, 20%, 40%, 60%, 80%, and 100% corresponding to FV proportions of 100%, 80%, 60%, 40%, 20%, and 0%—this article analyzes the energy consumption and carbon emissions of electric vehicles from 2015 to 2022 [Figure 3: see original paper]. The results show that as the proportion of electric vehicles increases, both energy consumption and carbon emissions of road vehicles decrease, demonstrating clear dual effects of energy conservation and emission reduction. With technological upgrades, energy consumption peaked in 2018 and gradually declined thereafter. Over time, the marginal effect of increasing electric vehicle market share on emission reduction gradually weakens, but overall vehicle carbon emissions still show a year-by-year decreasing trend. Empirical evidence shows that electric vehicles have excellent energy-saving and emission-reduction benefits, and with continuous technological progress and policy optimization, electric vehicles will become an important force in promoting sustainable energy development and ecological environmental protection.

Electric vehicles can rely on policy and technology to drive the coordinated development of dual utility in energy conservation and emission reduction. At the policy level, governments can formulate purchase subsidies, vehicle purchase tax exemptions, and emission standards to stimulate market demand and corporate technological upgrades, expand electric vehicle market share, and improve energy utilization efficiency and emission reduction benefits. At the technology level, energy conservation and emission reduction technologies have multi-stage and diverse characteristics throughout the entire lifecycle from production to recycling. These technologies include lightweight body technology, efficient drive system technology, intelligent charging and management technology, and energy recovery technology. For example, using lightweight aluminum alloy bodies and carbon fiber reinforced materials can reduce vehicle weight and improve energy utilization efficiency and driving range; using permanent magnet synchronous motors and continuously variable transmission technology can enhance electric vehicle performance. These technologies can avoid energy waste and reduce carbon emissions, providing support for the coordinated development of dual utility. However, electric vehicle promotion also faces challenges such as difficult technological bottlenecks, frequent safety accidents, and insufficient supporting facilities, which affect development and pose obstacles to the coordinated development of energy security and dual carbon goals, requiring further research and solutions.

4 Policy Recommendations

Currently, the Chinese government should establish a bilateral integration and coordination system safeguarded by policy networks and anchored in energy storage technology to mitigate potential contradictions between energy security work and dual carbon goal implementation. Based on this, three recommendations are proposed.

4.1 Maximizing the Role of EV Industry in Building Compatible Policy Networks

Large-scale electric vehicle development can mitigate conflicts between energy security policies and dual carbon policies, but resolving contradictions between them at the source of policy formulation is more important.

First, prevent policy conflicts. Policies should be formulated with a focus on electric vehicle industry development as the starting point, optimizing policy objectives by time and stage, integrating conflict points between energy and environmental policies, and enriching the policy toolbox for top-level planning.

Second, construct hierarchical networks. Using the electric vehicle industry as a bridge, prioritize formulating policies compatible with both energy security and dual carbon goals, such as accelerating the scaling, electrification, and energy storage of the electric vehicle industry. By improving the top-down policy system within the electric vehicle industry and establishing policy network mechanisms from the supply side, technology side, and recycling side, and constructing policy network structures through external synergistic development from government and enterprise perspectives, the space for policy options can be expanded.

Third, local adaptation. Local governments should address the actual conditions of their local environment and energy systems, use electric vehicle industry development as one of their policy tools, and dynamically adjust policy directions by absorbing experience and adapting measures to local conditions in target setting, policy implementation, and feedback.

4.2 Strengthening Energy Storage Capabilities through Technical Means

The low stability of grid systems is a common pain point for energy security work and dual carbon goal implementation. However, electric vehicles with V2G mode, as important energy storage tools, have attracted high government attention. Therefore, comprehensive planning from design to recycling stages is needed to reduce electric vehicle energy storage device costs, improve energy storage capacity and levels, and expand the energy storage layout of electric vehicles.

First, design stage. By improving components such as batteries, motors, and control systems, different efficient energy storage systems should be designed. Taking actual application scenario demands as reference standards, detailed analysis, design, and selection of appropriate energy storage systems should be conducted based on specific scenarios, battery charging/discharging capabilities, maximum power of storage units, and electricity usage periods of loads to improve electric vehicle energy storage capacity.

Second, production stage. Focus on using lightweight technology to manufacture electric vehicle body components, equip electric vehicle energy storage systems with energy generated through different methods, reduce fragmented management in each equipment 环节, and reduce energy storage system equipment costs through collaborative optimization and integration to avoid energy waste.

Third, usage stage. Adopt efficient drive system technologies such as high-efficiency motors, transmissions, and electronic control systems to improve energy utilization efficiency, store remaining energy to ensure self-sufficiency during subsequent driving, and use advanced battery management systems to monitor battery status and performance, reducing battery life loss and improving energy storage effectiveness.

Fourth, recycling stage. Apply environmentally friendly recycling technologies to systematically and hierarchically utilize retired power batteries, improve the full lifecycle utilization value of batteries, reduce energy storage device costs, and save capital for the next stage of energy storage technology upgrades.

4.3 Establishing a Joint Policy-Technology Bilateral Integration System

The dual benefits of energy conservation and emission reduction make electric vehicles one of the important driving forces for the coordinated development of energy security and dual carbon goals. Policy and technology are the main pathways, and constructing a joint policy-technology bilateral integration and synergy system is conducive to parallel advancement of energy system and environmental system protection.

First, policy integration. Jointly formulate unified emission reduction targets and unified vehicle charging standards with governments of various countries to promote international market interoperability and expand the electric vehicle market scale.

Second, technology integration. Enterprises and research institutions should jointly conduct electric vehicle technology research and development to solve technical challenges, particularly those related to energy conservation and emission reduction such as battery technology, charging technology, and intelligent transportation systems, thereby improving the energy-saving utility and emission reduction benefits of electric vehicles.

Third, resource sharing. Governments at all levels should share electric vehicle-related resources and talent exchange pools, encourage enterprises to disclose manufacturing details and methods of battery materials, electric vehicle components, and charging facilities to reduce manufacturing costs, and exchange experts and engineers for technical exchanges and training to promote common progress in electric vehicle technology, jointly solve safety hazard issues, and build shared supporting facilities.

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Note: Figure translations are in progress. See original paper for figures.