Louvain School of Management

A green revolution driven by two wheels: the impact of Dual-credit Policy and Government Subsidies on the sustainability of China's New Energy Electric Vehicle Industry

Author(s): Hui Liu and Chenyi Zhao
Supervisor(s): Prabal Shrestha
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Abstract

This thesis aims to explore the synergistic impacts of China's dual-credit policy and government subsidies on the sustainable development of the new energy vehicle (NEV) industry. Based on the panel data of 29 provincial-level administrative regions in China from 2010 to 2023, we empirically examine the direct impact of the "dual-credit" policy on green technological innovation and carbon emission reduction, then further explore the moderating role of government subsidies. The results show that the "dual-credit" policy, as a market-based tool, significantly increases the output of new energy vehicle patents (by 64.6%) and effectively reduces carbon emissions (by 13.4%). However, government subsidies fail to play a significant role in policy coordination, and even inhibit technological innovation. This study not only enriches the theoretical research on policy synergy and sustainable development, but also provides a reference for the optimization of global new energy vehicle industry policies and the green transformation of developing countries.

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Last but not least, we want to appreciate ourselves. We kept the determination to pursue academic excellence and showed resilience in facing setbacks during the research. After this thesis, we will also maintain enthusiasm for continuously exploring new knowledge.

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1. Introduction

1.1. Context

Since the beginning of the 21st century, global climate change and energy transition have become major challenges shared by human society. According to the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC), the global average temperature from 2011 to 2020 has risen by 1.1°C (IPCC, 2021) compared with the pre-industrial period (1850-1900), and if urgent measures are not taken to reduce emissions, the increase in temperature by 2100 may be more than 3.1°C (UNEP, 2024), which will trigger a series of irreversible ecological crises such as extreme weather, sea level rise. Before this, the "Paris Agreement" had proposed the goal of limiting the global average temperature rise to 2°C above the pre-industrial level and striving to limit the rise to 1.5°C, pushing the world to accelerate the transition to a low-carbon economy (Paris agreement, 2015).

As a major source of carbon emissions, the green transformation of the energy sector (accounting for 73% of global greenhouse gas emissions) has become the core path to achieve the "Carbon Neutrality" goal, while the transport sector, as a key area of energy consumption and carbon emissions, accounts for 24% of global energy related CO_2 emissions (2023), of which road transport accounts for 72% (IEA,2023). It is worth noting that the transport sector is more than 90% dependent on oil. This high level of dependence not only exacerbates the vulnerability of the global energy mix, but also exposes countries to increasing geopolitical risks.

While promoting global economic growth and social progress, the traditional fuel vehicle industry has also brought about multiple problems, such as energy security and environmental pollution. In this context, new energy vehicles, as a green alternative to traditional fuel vehicles, are regarded as a strategic choice to solve the dilemma of energy security and environmental governance. Their level of development has become a core indicator to measure the competitiveness of a country's vehicle industry and its ability of sustainable development.

The revival of NEVs is the key to the energy transformation in the 21st century. Its history can be traced back to 1834, which is more than half a century earlier than internal combustion engine vehicles (IEA, 2023). In recent years, driven by the energy crisis and climate change, new energy vehicle technology has developed rapidly. In 2023, the global stock exceeded 20 million vehicles (Ma, 2024). China has become the absolute dominant force with a 64% market share, while Europe and the United States account for 22% and 9% respectively, presenting a “three-pole dominant” pattern (Tsinghua University, 2024).

From the initial pure electric vehicles to the various types of NEVs we have today, it has become a focal area for policy support in major economies around the world. Globally, the development of the NEV industry has entered an accelerated period, global policies have generally gone through a transition process from financial subsidy support to market-based mechanism guidance, which promote the sustainable development of the new energy vehicle industry.

European Union (EU) policies are mainly driven by regulations, such as the 2035 ban on the sale of fuel vehicles and high subsidies (Germany offers a subsidy of 9,000 euros per vehicle), which have accelerated the expansion of the NEV market. However, battery technology still relies on Asia (EU Regulation, 2023).

Unlike the EU, the United States relies on tax levers to offer up to $7,500 in tax deductions for each electric vehicle through the “Inflation Reduction Act” (IRA, 2022). At the same time, it cooperates with California’s Zero-Emission Vehicle (ZEV) credit trading system, requiring the sale of a certain proportion of zero-emission vehicles in 16 states (Liu et al., 2020).

Whereas, such policies often face the dual challenges of “subsidy dependence” and “insufficient market incentives”. In response to this, China has innovatively adopted a combination of “government subsidies and dual-credit”. Government subsidies started in pilot cities in 2010, stimulated market demand through direct consumer incentives. While dual-credit policy, introduced in 2017, established mandatory NEV production quotas to enforce corporate responsibility. Over the past decade, the total amount of subsidies has exceeded 300 billion yuan (Ministry of Finance, 2023), supplemented by the world’s strictest dual-credit policy (with a NEV credit ratio requirement of 25% by 2025), successfully pushing the sales of NEVs to the top of the world (Yang, 2025).

As the largest market for NEVs, China’s production and sales exceeded 10 million milestone for the first time, reaching 12.888 million and 12.866 million units respectively, with year-on-year growth of 34.4% and 35.5%. These sales accounted for over 70% of the global total by the end of 2024 (EVTank, 2025). Therefore, China’s policy practices have become a “policy laboratory” for the global industry. On the one hand, with a 93% market share of new energy passenger vehicles, policy adjustments directly reshape the global supply chain landscape (Pan, 2025). On the other hand, as the world’s first mandatory credit system covering all vehicle models and nationwide, the innovatively constructed “dual-credit” policy has formed a “government-market” collaborative model, which is being emulated by Southeast Asian countries such as Vietnam and Indonesia (World Bank, 2023), promoting the formation of the “East Asia Policy Demonstration Circle” and providing a sustainable development path for developing countries.

1.2. Objectives

Focusing on China’s new energy vehicle industry, this study examines the synergistic effect between government subsidies and dual-credit policy by analyzing the direct impact of the dual-credit policy, then incorporating the moderating effect of government subsidies. It aims to explore how this policy combination shapes industrial sustainable development, ultimately providing a Chinese solution reference for optimizing global industrial policies.

At first, this paper empirically assesses the direct impact of the dual-credit policy on the sustainable development of the new energy vehicle industry, including the effects on green technology innovation (green patent output) and environmental performance (carbon emission intensity).

Based on this foundation, we then analyze the moderating effect of government subsidies on the sustainable development of NEVs, and clarify the evolutionary paths of government subsidies and dual-credit policies and their functional positioning at different stages of industrial development. Subsequently, reveal the interaction effect (complementarity or conflict) between the two types of policies.

Finally, according to the empirical findings, this study puts forward specific suggestions to optimize the policy mix and promote the sustainable development of the industry, so as to provide a reference for policy makers and enterprises.

1.3. Methods

Literature research method: Systematically combing domestic and international literature on new energy vehicle industrial policy, policy synergies, and sustainable development of the industry, to grasp the current status and cutting-edge dynamics of the research, providing support for the construction of the theoretical framework.

Comparative research method: Compare and analyze the new energy vehicle industrial policy models of major economies such as the European Union, the United States, and China, so as to refine the common rules and individual characteristics of the selection of policy tools, and highlight the uniqueness of China's "subsidy and dual-credit" policy combination.

Econometric Methods: Based on China's provincial-level panel data from 2010-2023, we empirically test the impact of the dual-credit policy and government subsidies on the sustainable development of the industry by using fixed-effects modelling, interaction term model and event-study methods.

1.4. Research contribution

The empirical results of this study show that, as a market-oriented policy tool, the dual-credit policy has a significant direct positive impact on the sustainable development of China's new energy vehicle industry. However, the synergistic effect between government subsidies and the dual-credit policy is not obvious. Government subsidies do not show a significant moderating role in enhancing the dual-credit policy's promotion of green patents or carbon emission reduction, and even show a tendency to suppress patent growth after subsidy withdrawal. Specific contributions are as follows.

1.4.1. Theoretical contribution

At first, this study helps to enrich the application of policy synergy theory in the field of sustainable industrial development. Existing studies have mostly focused on the assessment of the effects of single policy instruments (e.g., the impact of subsidy policy on enterprise innovation, the role of dual-credit policy on market structure), but have paid insufficient attention to the interaction effect of the policy combination of subsidy and dual-credit, which is characteristic of China. By constructing an analytical framework for policy synergy and exploring the complementarities and conflicts between the two types of policies, we can provide new empirical cases for policy combination theory and expand its explanatory power in the fields of environmental regulation and industrial policy.

Secondly, this study can provide a new perspective for the integration of externality theory and Porter's hypothesis. As a green product with positive externalities, the development of NEVs requires government intervention to correct market failures, while the dual-credit policy internalizes environmental externalities through a market-based mechanism, reflecting the synergy between the "invisible hand" and the "visible hand". The study of the impact paths of the two types of policies on technological patent innovation and environmental performance of enterprises can verify the assertion of Porter's hypothesis that appropriate environmental regulation can stimulate the compensatory effect of enterprise innovation, and provide microscopic evidence for the practice of externality theory in industrial policy.

Finally, this study helps to improve the multi-dimensional assessment system of industrial sustainability. Existing studies on the sustainability of the new energy vehicle industry have focused on market size or economic benefits, but have not considered environmental performance like carbon intensity and technological innovations like green patents in a comprehensive manner. This study incorporates environment, economy and technology into the analytical framework, which can provide a more systematic methodological reference for the quantitative assessment of the industry's sustainable development.

1.4.2. Practical contribution

First, it provides a decision-making basis for the optimization of China's new energy vehicle industry policy. Currently, China's new energy vehicle subsidies have entered a stage of full-scale regression, and the dual-credit policy has become a core tool for industry guidance, but there are still problems such as compliance taking precedence over innovation and imbalance in regional development in the implementation of the policy. By evaluating the synergistic effect of the two types of policies and clarifying their actual effects in promoting technological innovation and reducing carbon emissions, we can provide empirical support for policy adjustments.

Second, it provides a reference of China's experience for the global new energy vehicle industry policy. As the largest market for new energy vehicles, China's policy transition path of "subsidy slopes reduction and market mechanism" is of reference significance to other developing countries. By studying the synergy mechanism between the dual-credit policy and government subsidies, a replicable and scalable combination of policy tools can be extracted, which will provide practical samples for global climate governance and energy transition.

Third, it provides guidance for corporate decision-making. In the context of dynamic adjustment of policy portfolios, firms need to balance short-term compliance costs and long-term innovation investment. This study reveals the mechanisms by which policy instruments influence firms' technology choices and production decisions, which can help firms better adapt to the policy environment and formulate sustainable development strategies.

1.5. Thesis structure

The structure of the paper is illustrated in Figure 1 below. Based on the background of global energy transition, this study firstly clarifies the objectives of investigating two policies' impacts on the sustainable development of the new energy vehicle industry, and introduces the research methodology, contributions and the structure of the thesis. Then, we focus on reviewing relevant studies on government subsidies, dual-credit policy and their synergistic effects, pointing out the shortcomings of existing studies and the entry point of this study. Subsequently, the theoretical model is constructed based on the theory of externalities, and the hypothesis of the direct effect of the dual-credit policy, the moderating effect of the government subsidy is put forward. Later, the econometric model is constructed by defining the core variables, describing the source of data and samples, and some statistical analyses are done to test the hypothesis. The empirical part reports the regression results, examining the policy effect and the moderating effect of the subsidy. Finally, we summarize our findings, make suggestions on the insufficiency of the synergy of policies and point out the limitations and future directions of the study.

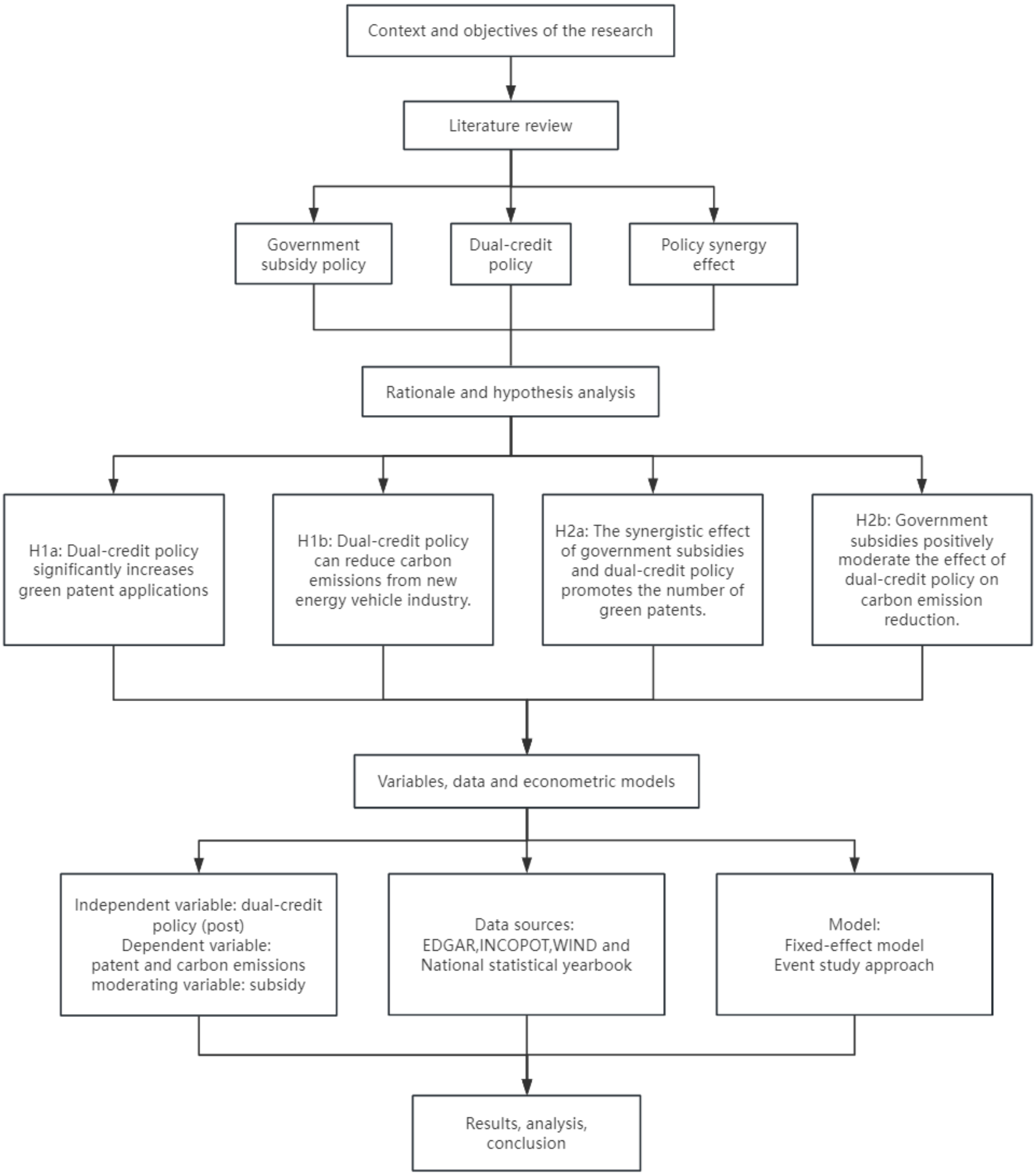

Figure 1. The structure of this research

2. Literature review

The development of the new energy vehicle industry holds strategic significance for global sustainable transformation. Numerous scholars have conducted extensive and in-depth research on these industrial policies. Globally, government subsidies and market-based mechanisms are the core policy tools used by various countries to promote industrial development. China, as the current leader in the new energy vehicle industry, has a policy evolution path that is both typical and of international reference value. This sector will systematically review the development history of China's new energy vehicle policies, focusing on analyzing the actual effects of government subsidy policies and dual-credit policies, as well as the synergistic and interactive mechanisms between them. This will lay a solid theoretical foundation for an in-depth exploration of the impact of the policy combination and its synergy on the sustainable development of the industry.

2.1. Government subsidy policy

In 2009, to break through the market bottlenecks in the early stage of the new energy vehicle industry, the Chinese government launched subsidy pilots (the "Ten Cities, Thousand Vehicles" project), which mainly manifested in direct economic support. It fostered demand through local car purchase subsidies (up to 60,000 yuan per vehicle) and tax reductions (Xie et al., 2025). After 2015, the policy was promoted nationwide, and a subsidy retreat mechanism was established simultaneously.

In recent years, a large amount of literature has explored how to subsidize new energy vehicle firms and assessed the impact of subsidies on the development of NEVs. Research focuses on four areas: a) The necessity of government subsidies; b) The effectiveness of government subsidies and the optimization of the subsidy system; c) Problems with current subsidy policies and whether there are any potential disincentive effects; d) Subsidy degradation and the identification of alternative policies that can be implemented after the subsidies are completely phased out.

a) The necessity of government subsidies

NEVs face problems such as immature technology, low market acceptance and high cost in the early stage of development (Yang, 2024). In order to overcome these obstacles and promote the rapid development of the new energy vehicle industry, government subsidies have become a necessary policy tool. Through the input of financial funds, government subsidies can reduce enterprise costs, promote technological innovation, and accelerate market promotion (Shi et al, 2023).

There are also scholars who analyze the study from the perspective of externality, and they believe that NEVs can save energy, reduce emissions and the use of non-renewable resources such as oil, which are environmentally friendly, with positive externalities. Therefore, in order to compensate for the positive externality of enterprises' research and development of new energy vehicles, it is necessary for the government to provide financial subsidies to improve the enthusiasm of vehicle companies and promote the favorable development of the industry (Zhang et al, 2018).

Some researchers even emphasize that the development of NEV industry is one of the important ways to achieve the global sustainable development goals from the perspective of global sustainable development, and thus promote the economic and social transformation to green and low-carbon.

b) Short-term effects of incentive policies (market creation theory)

First of all, many studies support the key role of subsidies in promoting the development of electric vehicles. On the one hand, Shao et al. (2018) have found that subsidy policies promoted the active participation of enterprises in the upstream and downstream of the new energy vehicle industry chain, attracting a large amount of investment. On the other hand, Hu et al. (2020) showed that subsidies for new energy vehicle production and infrastructure construction can increase the diffusion rate of new energy vehicles in China by up to 60%. Some scholars also agreed that subsidies have increased the sales of new energy vehicles by 62%. However, these subsidies have not improved air quality, as Chinese consumers have not reduced traditional car purchases in the short term (Wang et al., 2025). While Cai et al. (2024) discovered that the subsidies' impact is stronger in cities with advanced NEV innovation, high energy consumption, and higher education levels, reducing a city's carbon emissions by 4.9%.

Based on power system branching theory, the government's subsidy is divided into three types of "R&D subsidies", "market subsidies" and "mixed subsidies", the results show that: the R&D subsidy stimulates the enterprise to invest a large amount of money in product technology R&D, but the excessive investment will affect the stability of the market, the incentive effect of market subsidy on R&D investment is weaker than that of R&D subsidy, and over-investment also affects the stability of the market of new energy vehicles, mixed subsidy will play a certain role in stimulating the R&D investment of the enterprises, but the incentive role of the enterprise profit is not as good as that of the market subsidy(Zhao et al, 2019).

From an international perspective, government subsidies in South Korea can effectively increase the sales of new energy vehicles, and the incentive effect of tax incentives on the expansion of the new energy vehicle market is twice as much as that of the purchase subsidy (Hong et al., 2012). Relevant studies show that government tax incentives are nationally heterogeneous. The incentive effect of tax incentives in Australia, however, is not as competitive as the new energy vehicle market under the purchase subsidy policy (Gass et al,2014).

c) Long-term dependence (potential disincentive effects)

Many researchers pointed out that the potential dampening effect of subsidy programs is gradually emerging. Li et al. (2017) found the impact of government subsidies on the R&D investment of new energy vehicle enterprises and the patent output of enterprises has an "inverted U-shape" distribution, which means that the government subsidies have increased the R&D investment of new energy vehicle enterprises to a certain extent, promoting the development of the industry, but when exceeding a certain threshold, it will inhibit the R&D investment of enterprises, which makes new energy enterprises rely too much on government subsidies, and there is subsidy dependence on industrial technological innovation.

This disincentive effect is mainly reflected in two aspects: First, enterprises may rely excessively on government subsidies, leading to a decline in their own innovation capacity (Liao et al., 2017). This over-reliance is not only damaging to the long-term development of enterprises, but may also have a negative impact on the healthy development of the whole industry. Second, the subsidy policy may trigger rent-seeking behavior of enterprises (e.g., lobbying the government for subsidies) rather than enhancing competitiveness through technological innovation. It was pointed out in the joint document of four national ministries and commissions (2014) that the subsidy policy may also trigger moral risks for enterprises, such as fraudulent subsidies. New energy vehicle subsidy policy can indeed play a role in stimulating enterprise R&D, but its R&D incentives show diminishing marginal utility, and when the subsidy intensity exceeds the critical value, enterprises will completely lose the incentive to R&D, and even have sufficient incentive to carry out “cheating subsidies” (Shao et al., 2018).

d) Impact of subsidy withdrawal

Based on the above research, many scholars have begun to study the impact of government subsidy regression on the new energy vehicle industry. First of all, the gradual withdrawal of government subsidies directly affects the NEV market and bears the burden of the new energy vehicle sales. Li et al. (2023) suggest that the subsidy decline has a significant impact on consumers’ decision-making, and consumers will consider the cost factor more rationally, thus reducing the demand for NEVs, while new energy vehicle producers will adopt the strategy of price increase in order to cope with the cost pressure. However, due to the pressure from the market side, consumers will not buy the increased price. Also, as Cheng et al. (2018) analyzed from the perspective of the automotive supply chain, the government's subsidy withdrawal led to a significant decline in the sales of new energy vehicles.

In addition, the subsidy regression has directly affected the market price of new energy vehicles. After the subsidy regression, the selling price of new energy vehicles generally increases (Li, 2023). At the same time, it has also intensified the competition in the new energy vehicle market. Weaker enterprises may face survival difficulties due to cost pressure, while enterprises with strong technical strength and market competitiveness are able to seize the opportunity to further consolidate their market position, and this process of survival of the fittest helps to promote the healthy development of the new energy vehicle industry (Zhang et al., 2018).

However, there are also scholars who analyze from the perspective of the profitability of enterprises after the subsidy regression, and although the subsidy regression policy may lead to a decline in corporate profitability in the short term, in the long term, it can motivate enterprises to strengthen technological innovation and product R&D, and to improve the quality and performance of their products (Zhao et al., 2019). As Wang et al. (2024) discovered, the withdrawal of subsidies has prompted enterprises to increase their investment in R&D while reducing symbolic innovation activities, as companies no longer seek subsidies merely for reputation. Some researchers find that the impact of subsidy regression policy on innovation performance also decreases year by year, but in the following years, the innovation performance will show a rising trend again (Tu et al., 2024).

2.2. Dual-credit policy

To address the issue of sustainable development after the withdrawal of subsidies, the dual-credit policy was introduced in 2017 (Liu et al., 2023). It has drawn on the Zero Emission Vehicle (ZEV) Program in California of the United States to a certain extent, and the dual-credit policy has formed a new energy vehicle management system with Chinese characteristics through localized adjustments (Liu et al., 2019).

The dual-credit policy establishes a credit trading market through dual assessment of CAFC credits (Corporate Average Fuel Consumption, fuel consumption restrictions) and NEV credits (production requirements for new energy vehicles). For CAFC credits, automakers are incentivized to enhance energy utilization efficiency and reduce emissions. Fuel economy calculations play a key role. Automakers can accumulate CAFC credits if their fleet fuel economy is above a set standard. These credits can then be used to offset deficits in other vehicle models within the company's portfolio or even be sold in the credit trading market. The underlying incentive is that automakers with more efficient vehicle production can profit from their environmentally friendly efforts, either by reducing the costs of compliance for less efficient models or by generating additional revenue through credit sales (Li et al., 2020).

While NEV credits, on the other hand, focus on promoting the production and sales of new energy vehicles. Each automaker is assigned a target proportion of new energy models in its production and sales. If an automaker fails to meet this target, it has two options. The first one is increasing the production of NEVs to achieve compliance or purchasing NEV credits from other companies that have exceeded their targets. This creates a market-based mechanism where companies that are more successful in the new energy vehicle industry can monetize their achievements, while those lagging can still meet regulatory requirements through credit purchases.

The overall trading of both CAFC and NEV credits in the market thus creates a self-regulating environment. Through the market-based adjustment mechanism, automakers are constantly motivated to improve their environmental performance, either through technological innovation to boost energy efficiency (for CAFC credits) or by ramping up new energy vehicle production (for NEV credits). It not only pushes the traditional fuel vehicle sector to accelerate energy efficiency upgrading, but also drives the R&D investment through economic leverage, as it is both economically and environmentally beneficial. The specific operation mechanism is in figure2 (Tian, 2024)

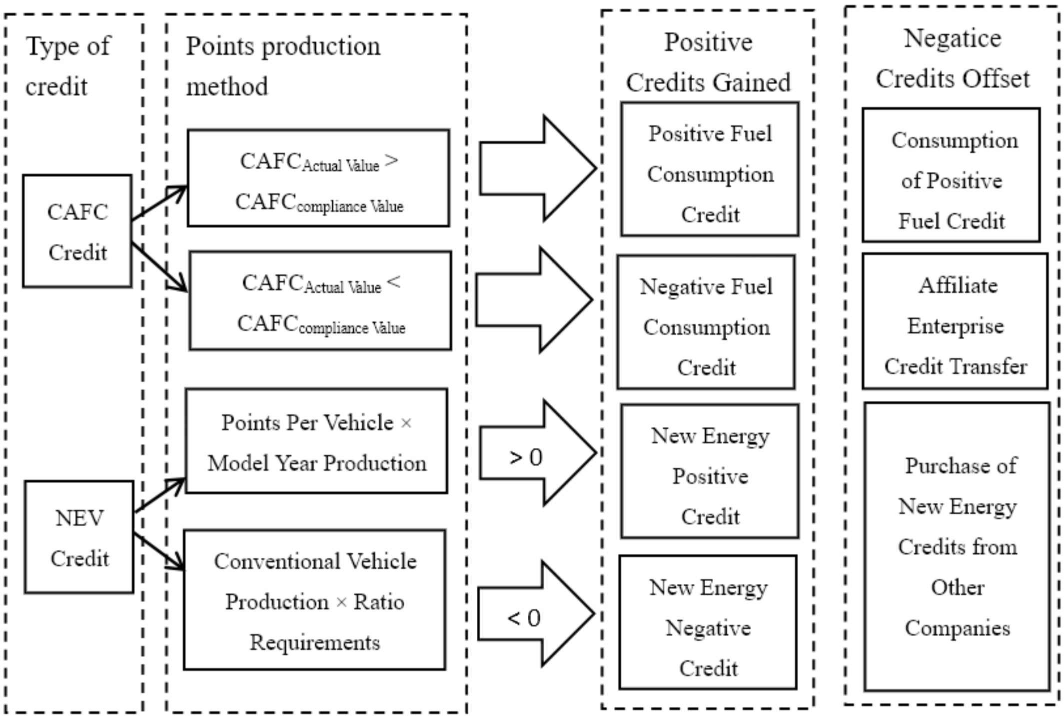

Figure 2: Dual-credit policy operation mechanism

As a core regulatory tool for China's new energy vehicle industry, the dual-credit policy has profoundly guided the sustainable development and driven the transformation of enterprises. At present, the research on its impact mainly focuses on three aspects: a) Technological progress and product upgrading; b) Industrial structure and market competition; c) Infrastructure and business model innovation.

a) Technological progress and product upgrading

The dual-credit policy directly promotes technological iterations throughout the entire industrial chain and makes up for the insufficient incentive of traditional subsidy policies for technological innovation (Zhou et al., 2019). Some scholars have proved that the dual-credit policy is more effective in motivating vehicle manufacturers to upgrade technologies, especially in the field of battery recycling (Li et al., 2020). There are also scholars who adopt Differences-In-Difference (DID) model to further verify that the R&D investment of enterprises grows continuously after the implementation of the policy, and the number of patent applications for core technologies increases significantly (Liu et al., 2023). Empirical research shows that the average range of pure electric vehicles in China has jumped from 250 kilometers in 2017 to over 400 kilometers in 2023, with the power consumption level dropping by 18% (CATARC,2023). In summary, the dual-credit policy not only injects new vitality into technological innovation, but also has a significant long-term effect on promoting the continuous evolution of technological innovation.

b) Industrial structure and market competition

The differentiated assessment mechanism enables the head enterprises that have more resources for R&D and production capacity expansion to form a significant competitive advantage. Under the dual-credit policy, they are more likely to meet the credit requirements for CAFC and NEV. Furthermore, the market concentration of new energy passenger vehicles continues to rise, forcing small and medium-sized car enterprises to shift to OEM or niche markets (Ou et al., 2018).

The trend of vertical integration of supply chain is accelerating, in order to better meet credit requirements and reduce costs, enterprises such as BYD and Geely have increased the self-production rate of core components to over 70% by their self-built battery and electric drive system production bases. This helps them accumulate more NEV credits as they are able to produce more new energy vehicles with reliable components. At the same time, traditional fuel car giants are forced to invest more in electrification under the pressure of the dual-credit policy. They need to invest more resources in R&D to improve the fuel efficiency of their traditional models to earn CAFC credits, and they also need to develop new energy models to earn NEV points (Cheng et al., 2021). The policy forced enterprises to consider more efficient production strategies, like vertical integration or cooperation with other firms, which in turn contributed to the optimization of the industrial structure.

c) Infrastructure and business model innovation

Currently, the charging and switching network construction has entered a period of rapid development. China has become the country with the most complete construction of charging piles, and its recycling rate of battery recycled materials has also significantly increased (Rao et al., 2023). This synergistic evolution of "hard infrastructure and soft services" not only reduces users' anxiety about energy supplementation, but also provides systematic support for the sustainable development of the industry.

However, some structural contradictions and potential risks have been revealed during implementation, posing challenges to the sustainable development of the industry. First, the dual-credit policy may trigger strategic behaviors of enterprises, deviating from the original intention of the policy. When the NEV credits are not met, this policy prompts automakers to increase the production of high fuel consumption models to balance costs (Lou et al., 2020). Second, the strict credit index may also force enterprises to overly rely on the credit trading market and neglect technological innovation and quality improvement, leading to the phenomenon of prioritizing compliance and lagging in innovation (Zheng et al., 2019). Third, some studies have shown that the dual-credit policy may not effectively promote the improvement of vehicle fuel economy in some cases, and may not reduce the production of fuel-intensive vehicles (Ma et al., 2021). Financial constraints in the supply chain can limit the enterprises' R&D capabilities, thus weakening the incentive effect of the dual-credit policy (Meng et al., 2022). Therefore, when manufacturers are facing a shortage of funds, they are more inclined to choose short-term compliance programs rather than long-term technological investment as operational strategies (Ding et al., 2023).

2.3. Policy synergy effect

The interaction between subsidies and the dual-credit policy presents a dual nature of "complementarity and conflict". In terms of synergy and efficiency, during the 2020 to

2022 period when subsidies were being phased down, the simultaneous implementation of stricter dual-credit policy led to a 37.9% growth in new energy vehicle sales against the trend (Tsinghua University, 2024), demonstrating the ability of the policy combination to smooth out market fluctuations. The supply chain optimization effect is significant, as implicit subsidies have reduced the terminal price by 14%, while the credits trading mechanism has curbed traditional automakers from raising prices for arbitrage (Zhao et al., 2025). Schmidt & Sewerin (2019) confirmed through the "policy combination elasticity coefficient" that when the vertical technology spillover rate is > 0.35, R&D subsidies need to be reduced to avoid innovation extrusion. Some scholars also point out that both green subsidies and dual-credit policies can increase the market share of NEVs and enhance the competitiveness of enterprises when the investment cost of green technologies is relatively low. However, subsidies enhance social welfare, while the dual-credit policy undermines it. Both of them can promote the sales of new energy vehicles and corporate profits under different conditions (Xiao et al., 2023).

In terms of conflicts, the mismatch of policy goals triggers strategic predicaments for enterprises: Subsidies encourage low-end models to boost sales volume, while the dual credit system forces high-end models to earn credits, pushing enterprises into a zero-sum game between "maintaining sales volume" and "earning credits" (Zhao et al., 2025). More seriously, policy synergy amplifies regional imbalances, the technology agglomeration effect in the east has widened the gap in per capita industrial added value between the east and the west to 4.2 times (Zhao, 2024).

It is worth noting that some studies have introduced green technological innovation as a mediating variable and found that: although subsidy policies can enhance enterprise performance, they are not achieved through green technological innovation. While the dual-credit policy can enhance enterprise performance through it. Then, as subsidies gradually decrease year by year, the interaction effect between them and the dual-credit policy will weaken (Pei et al., 2023).

To conclude, the existing literature has systematic limitations. The absence of collaborative quantification (Most studies are confined to a single policy effect and lack a quantitative model for dynamic coupling of subsidies and integrals). Then, most literatures focus on subsidies for new energy vehicles, while fewer explore the impact of gradually phasing out subsidies. Last, the fragmentation of sustainable dimensions, most literatures focus on economic benefits and neglect the environmental and social aspects, so that it is impossible to fully measure sustainable development.

In response to the above-mentioned gaps, this paper achieves three innovations:
At the theoretical level, the dimension framework of policy synergy and sustainability was created. At the practical level, provide developing countries with a policy toolkit of “market-driven and gradual subsidy withdrawal”. The Global Governance Initiative incorporates the mutual recognition mechanism of credits into climate agreements to promote the alignment of carbon policies among China, the United States and Europe (Paris Agreement, 2015).

China’s policy on new energy vehicles is a typical example of global climate governance. The subsidy policy resolves early market failures, and the dual-credit policy builds a long-term mechanism. The synergy of the two can resolve the predicaments of “incentive distortion” and “market fluctuations”, but a regional compensation mechanism needs to be established to balance the development gap. Future research should be placed from the perspective of the global value chain, quantifying the net contribution rate of policy mix to the carbon neutrality goal. This is not only the theoretical fulcrum for China to lead the green industrial revolution, but also a key proposition for the reconstruction of the global climate governance system (IEA, 2023).

3. Rationale and hypothesis analysis

This study builds an analytical framework rooted in three core theories. First, the externality theory explains the market failure of NEVs as a positive externality product. Its environmental benefits cannot be fully internalized into enterprise profits, thus leading to insufficient market supply. Government subsidies can correct the positive externality through direct capital injection (Li et al., 2016), while the dual-credit policy internalizes the negative externality of carbon emissions through the credits trading mechanism, forming a complementary policy mix. Second, Porter's hypothesis illustrates how environmental regulation can stimulate innovation compensation effects, with typical examples such as BYD's patent on thermal management system that reduces the energy consumption of the whole vehicle by 17% (Shi et al.,2023). Third, the theory of policy synergy reveals the dynamic relationship between the two types of policies. Zhao Dan et al. (2025) demonstrated that the synergistic mechanism originates from the triple interaction of the demand side, which concerns subsidies lowering thresholds and credits increasing willingness; the supply side, which includes subsidies promoting R&D and credits generating revenue and the regulatory side, which combines the subsidies accelerating iteration and credits ensuring sustainability.

Two sets of hypotheses are proposed based on this:

Direct effect:

Historically, government subsidies have reduced the R&D costs of green technologies, thus accelerating the low-carbon transition (Zhang et al., 2024). However, with the gradual removal of subsidies, there is a need for market-oriented alternative mechanisms. The dual-credit policy is a key tool that directly links automakers' credit compliance to their technological innovation efforts and emissions performance.

Through its credit-trading framework, the policy assigns negative credits to conventional fuel vehicles and positive credits to new energy vehicles, pushing traditional automakers to speed up their electrification transition (Lou et al., 2020).

This creates a direct market incentive for green patents, turning innovation into tradable assets. Also, empirical data shows that after the policy's implementation, the average fuel consumption of vehicles declined by an average of 6 % annually (CAC, 2023).

Consequently, the dual-credit policy constitutes the primary independent variable, with its direct effects on sustainability outcomes being the central analytical focus.

H1a: Dual-credit policy significantly increases green patent applications.

H1b: Dual-credit policy can reduce carbon emissions from new energy vehicle industry.

Synergistic and moderating mechanisms:

The dual-credit policy and government subsidies are regarded as complementary industrial policy tools. The dual-credit policy imposes binding market constraints by linking credit deficits to high-value patents (Yang, 2025), while subsidies send policy support signals, reduce financial institutions' investment risk expectations for green technologies, and attract social capital to invest in R%D (Wang et al., 2024). This signaling effect strengthens manufacturers' response to dual-credit goals, especially in the context of high subsidies. Thus, these policies create synergistic innovation pressures.

However, the drawbacks of subsidies also create conflicting incentives. Subsidies may induce rent-seeking and moral hazard, distort the fairness of the credit market and weaken policy incentives for genuine technological progress (Shao et al., 2018). In addition, during the phase of substantial subsidy withdrawal, when the dual-credit mechanisms are not yet fully mature, firms may exhibit behavioral alienation, such as cutting R&D investment or applying for low-quality patents. This conflicts with the dual-credit policy's requirement for long-term technological investment (Wang et al., 2024), and may even put some firms in operational difficulties during the transition period (Yu, 2022).

Despite these conflicts, subsidies still play a role in reducing the marginal cost of low-carbon R&D and directly stimulate the initial emission reduction investment, which amplify the response of manufacturers to the long-term market constraints imposed by carbon allowance trading (Zhu et al., 2024). This cost conversion mechanism allows subsidies to moderate the strength of the emissions elasticity, higher subsidy levels strengthen the decarbonization effect of unit credit pressures, thus accelerating the transformation of the industrial chain. Based on this, the following hypotheses are proposed:

H2a: The synergistic effect of government subsidies and dual-credit policy promotes the number of green patents.

H2b: Government subsidies positively moderate the effect of dual-credit policy on carbon emission reduction.

4. Variables, data and econometric models

4.1. Variables

When studying the impact of policies on the sustainability of the new energy vehicle industry, most scholars focus on their direct impact on market penetration improvement or short-term financial performance of enterprises. In contrast to existing studies, this study focuses on the environmental and technological innovation dimensions of sustainability, and examines the impacts of dual-credit policy on the sustainable development of the industry from two key perspectives, namely, carbon emission reduction performance and patent output of green technological innovation (H1a, H2b). Further, this study explores the potential synergistic interaction between the two policies in catalyzing green patents (H2a), as well as the moderating mechanism of government subsidy in the process of dual-credit policy's influence on carbon emission reduction (H2b). Therefore, the core independent variable of this study is dual-credit policy (Post), the dependent variables are carbon emission (CE) and green patents (Patent), the moderating variable is government subsidy (Sub). Table 1 details the definitions and measures of each variable.

Table 1. Meanings and names of variables

Type	Variable symbol	Name	Meaning
Independent	Post	Dual-credit policy	Use 0 to indicate that the dual-credit policy has not been implemented, and 1 to indicate that the dual-credit policy has been implemented.
Dependent	CE	Carbon emission (CO_2/KM)	Carbon emissions data for the entire use of new energy sector in each province per kilometer. (From EDGAR)
	Patent	Green patents (piece）	Number of green patents by province. (From INCOPOT)
Moderating	Sub	Government subsidy (million yuan)	Number of subsidies given to enterprises in each province each year on the government side, using its natural logarithm. (From wind)
	Timetrend	Linear time trend	A continuous numerical variable representing the chronological

Control			sequence of years in the panel data. Year of policy implementation = 0, years after policy implementation in order 1, 2, 3..., pre-policy years are -1, -2, -3....
	GDP	Gross domestic product (billion yuan)	The amounts of total regional market value. (From National Statistical Yearbook)
	FDI	Foreign direct investment (billion yuan)	The amounts of investments, using its natural logarithm. (From National Statistical Yearbook)
	IND	Industrialization (%)	Industrial value added as a share of GDP. (From National Statistical Yearbook)
	PD	Population density (persons per square kilometer)	Total population/land area with natural logarithm (ln). (From National Statistical Yearbook)
	EC	Energy consumption (million tons of standard coal)	Total regional energy use levels. (From National Energy Consumption Yearbook)
	Edu	Education level (year)	The average years of education in each province. (From National Statistical Yearbook)

4.2. Research samples and data sources

Considering that 2010 was a key year for the gradual improvement of China's new energy vehicle industry policy, and the NEV subsidy policy began to be implemented, which promoted the rapid development of the new energy vehicle market, 2010 was selected as the starting year for this study. What's more, it ensures sufficient pre-post observations for robust identification of subsequent dual-credit policy implemented nationwide in 2017. At the same time, based on the availability of data, the provincial statistical bureaus have not yet fully published the relevant data for 2024, so as the latest data year, 2010-2023 was selected as the time interval for this study.

In terms of the research sample, this study selects 29 provincial-level administrative regions (including provinces, autonomous regions and municipalities directly under the central government) in mainland China as the research object, and excludes some regions with serious missing data within the research interval, which ultimately results in the panel data of 29 provincial-level administrative regions for the period of 2010-2023.

Data on government subsidies received by companies in each province are sourced from the Wind (Vantage) financial database, and innovation patents are sourced from INCOPOT. Data on carbon emissions of the industry in each province come from the Carbon Public Platform and EDGAR.

4.3. Econometric model construction

Existing literature seldom explores the synergistic effects of government subsidies in moderating the impact of China's dual-credit policy on innovation patents and carbon emission reduction in the new energy automobile industry. Therefore, this study employs a fixed effects model augmented with a linear time trend to address unobserved heterogeneity, analyzing the impact of dual-credit policy on carbon emission and green patent, while using government subsidy as the moderating variable.

$$Y_{i,t} = \beta_0 + \beta_1 Post_t + \beta_2 Timetrend_t + \sum\nolimits_{j=3}^{n} \beta_j Controls_{jit} + \mu_i + \varepsilon_{i,t}$$

$Y_{i,t}$ is explained variable, denoting carbon emission $CE_{i,t}$ and patents $Patent_{i,t}$ granted by province i in year t. $Post_t$ represents the time dummy variable, due to the dual-credit policy is implemented simultaneously in all provinces and is only relevant to the year of implementation, it is 0 before 2017 and 1 after 2017; $Timetrend_t$ denotes a continuous numerical variable, 2017 is 0, and years after 2017 in order 1, 2, 3..., pre-policy years are -1, -2, -3.... to capture secular trends unrelated to dual-credit policy. $Controls_{jit}$ denotes control variables, μ_i is the fixed effect of province, and $\varepsilon_{i,t}$ is the random perturbation term. β_0 is constant term; β_1 is the coefficient of explanatory variables, representing the impact of the dual-credit policy on green patent and carbon emission, which is the parameter of focus in this paper.

The "selectivity bias" is mitigated by the fact that the dual-credit policy is an exogenous policy implemented simultaneously across the country (provinces do not have the right to make their own choices). Endogeneity is further reduced by controlling for province fixed effects to eliminate regional characteristics that do not change over time, and by controlling for time trends to eliminate common shocks.

$$Y_{i,t} = \beta_0 + \beta_1 Post_t \times Sub_{i,t} + \beta_2 Post_t + \beta_3 Sub_{i,t} + \beta_4 Timetrend_t + \sum_{j=5}^{n} \beta_j Controls_{jit} + \varepsilon_{i,t}$$

In order to test the moderating effect of government subsidies on the effectiveness of the dual-credit policy in promoting carbon emission reduction $CE_{i,t}$ (whether government subsidies strengthen or weaken the effect of the policy), we add the government subsidy variable $Sub_{i,t}$ and its interaction term with the post term $Post_t \times Sub_{i,t}$ to the base model. β_1 is the coefficient of interaction variables, $\beta_1>0$ indicates that the subsidy enhances the policy effect, and $\beta_1<0$ indicates that the subsidy weakens the policy effect. The same is true for the synergy effect of the two policies, except that the model is set up similarly to test for moderating effects, but the explained variable is green patent $Patent_{i,t}$, and more attention is paid to the interpretation of the interaction term.

4.4. Descriptive statistics and correlation testing

The descriptive statistics of the main variables of the sample are shown in Table 2. The mean values of the explained variables, which are the number of patents and carbon emission intensity are higher, but the standard deviation is also larger, reflecting that there is a big difference between various provinces in terms of technological innovation ability and carbon emission control in the field of new energy vehicles. Also, the results show a large difference in the amount of explanatory variable, government subsidies (the extreme difference is more than 900 million yuan), which may indicate that the financial support for new energy vehicles in each province is affected by the level of the local economy, the level of industrialization and the strength of policy implementation. For the control variables FDI and GDP, on the other hand, show the stable characteristics of high mean and low standard deviation, indicating that the introduction of foreign investment is balanced with the regional economic development, which provides sustained technical and capital support for the upgrading of the new energy vehicle industry.

Table 2. Descriptive statistics

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
Patent	364	300.973	76	580.619	1	3925
CE	364	9192.473	7005	7127.002	828.4824	37767.41
Sub	364	316.5533	268.757	194.6779	26.88532	985.4856
Post	364	.558	1	.497	0	1
Timetrend	364	0	0	3.924	-7	6
ln FDI	364	23.935	24.3038	1.654	19.625	27.68
ln GDP	364	28.472	28.4886	.753	26.492	30.155
EC	364	16495.409	13360.67	9423.958	799.21	52589.3
PD	364	525.502	312.067	740.86	14.882	3951.476
IND	364	.326	0.330913	.081	.101	.535
Edu	364	9.383	9.2885	.92	7.463	12.782

After implementing the dual-credit policy (Post), we observe a positive association (0.359) with new energy vehicle patent numbers (Patent). It is worth noting that the policy shows a negative correlation (-0.362) with carbon emissions (CE), suggesting its potential contribution to emission reduction, the later test needs to be further verified the significance of the correlation coefficients. It is worth mentioning that the high correlation between Timetrend and Post (r = 0.860) implies that the effect of policy implementation will be compromised if the timetrend is not controlled for. Government subsidies (Sub) demonstrate positive correlations with both patents and carbon emissions. The moderating role of government subsidies needs to be further explored, there may be incentives to expand the scale of production so as to improve carbon emissions.

Table 3. Correlation analysis results

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Patent	1.000										
(2) CE	-0.018	1.000									

(3) Sub	0.163	0.526	1.000								
(4) Post	**0.359**	**-0.362**	-0.093	1.000							
(5) Timetrend	0.379	-0.378	-0.068	**0.860**	1.000						
(6) ln FDI	0.317	0.388	0.268	-0.226	-0.307	1.000					
(7) ln GDP	0.562	0.486	0.443	0.237	0.291	0.567	1.000				
(8) EC	0.271	0.769	0.550	0.070	0.087	0.384	0.705	1.000			
(9) PD	0.220	-0.110	-0.257	-0.049	-0.051	0.383	0.229	-0.033	1.000		
(10) IND	-0.054	0.681	0.394	-0.300	-0.323	0.232	0.276	0.407	-0.102	1.000	
(11) Edu	0.321	-0.373	-0.212	0.242	0.301	0.227	0.170	-0.090	0.585	-0.415	1.000

4.5. Tests for multicollinearity

Prior to formal regression analyses, multicollinearity tests were performed on all variables used in this paper (Table 4). The variance inflation factors of the explanatory variables in the test results show that the variance inflation factors (VIF) of all the variables are much smaller than the critical value of 10 required by the rule of thumb, so it can be considered that the multicollinearity between the variables is low and passes the multicollinearity test.

Table 4. Variance inflation factor

	VIF	1/VIF
Timetrend	4.99	.2
ln GDP	4.922	.203
Post	3.831	.261
ln FDI	3.29	.304
EC	2.479	.403
Edu	2.338	.428
PD	2.172	.46
Sub	1.914	.522
IND	1.803	.555
Mean VIF	3.082	.

5. Empirical results and analysis

5.1. Regression results

(1) Dual-credit policy's impact on patents

We estimate three models before examining the impact of dual-credit policy on the number of patents. As in table 2 (descriptive statistics), patent shows excessive dispersion (Std. Dev = 580.6 > mean = 300.97). We first employ two approaches: a random-effects negative binomial model (RE-NB) addresses unobserved provincial traits, while a fixed-effects version (FE-NB) handles over-dispersion and individual heterogeneity. In addition to that, a Poisson pseudo-likelihood estimation (PPMLHDFE) was used to verify robustness against zero-value issues.

The results of the model selection test for the full sample are known from Table 5, with all key variables significant at least at the 10% level (some up to 1%). The fixed-effect negative binomial model (FE-NB) has a significantly smaller AIC value (3099.767) than the random-effect model (3619.182) and the Hausman test (p-value <0.05) rejects the original hypothesis, confirming FE-NB as the optimal model. Also, although the RE results also show a positive policy effect (β=0.621, p<0.01), the FE approach is used as the baseline model for causal identification due to its ability to eliminate the unobservable province characterization bias associated with policy exposure. Our reporting follows this principle: FE-NB results are primary, PPMLHDFE checks robustness, and RE-NB serves as reference.

Table 5. Regression results——patent

	(1)	(2)	(3)
Patent	RE	**FE**	PPMLHDFE
Post	0.621***	0.646***	0.433***
	(0.121)	(0.123)	(0.12)
Timetrend	0.14***	0.156***	0.037
	(0.022)	(0.022)	(0.101)
ln FDI	0.151***	0.129***	-0.063

	(0.043)	(0.043)	(0.069)
ln GDP	0.396**	0.135	0.806
	(0.167)	(0.177)	(0.777)
EC			***
PD	**	**	0.017***
			(0.005)
IND	***	-2.537***	-3.766
	(0.83)	(0.839)	(2.753)
Edu	-0.428***	-0.442***	-0.161
	(0.101)	(0.108)	(0.424)
Constant	-9.456**	-1.38	-26.928
	(4.545)	(4.7)	(20.862)
N	324	324	324
Chi-square	906.720	850.391	677.339
AIC	3619.182	3099.767	17829.361
Hausman test		P=0.000	

Notes: *, ** and *** indicate significant at 10%, 5% and 1%, respectively; numbers in diagonal brackets indicate the internal consistency coefficients of the scales, and St.Err. are in parentheses.

The fixed-effects coefficient of 0.646 ($p<0.01$) for the dual-credit policy (post), which is the core driver of the growth of new energy patents, suggests that the number of new energy vehicle patents in the provinces increased by 64.6% on average after the implementation of the policy. This estimate is more reliable than the random-effects model (0.621) because the fixed effects model eliminates the bias of inherent provincial characteristics, providing empirical support for the effectiveness of the policy's innovation incentives. Therefore, H1a is supported.

The number of patents decreased by 2.537 ($p<0.01$) for each unit of industrialization, implying that the traditional industrial structure may inhibit new energy innovation. In regions with a high proportion of traditional industries, resources are more inclined to be invested in energy-consuming industries, squeezing funds for new energy research and development and leading to a lack of innovation. The negative coefficient of education investment (-0.442, $p<0.01$) needs to be revisited in conjunction with the skill mismatch theory.

The introduction of the timetrend variable is crucial for the purification of the results. Its coefficient of 0.156 ($p<0.01$) captures non-policy related technological advances, which corresponds to an average annual natural growth rate of patents of 15.6%. Without controlling for this variable, the policy effect would be overestimated, highlighting the need for timetrend control.

(2) Dual-credit policy's impact on carbon emissions

For the continuous dependent variable of carbon emissions, this study uses a high-dimensional fixed-effects linear regression (REGHDFE) for estimation. The model effectively controls for regional heterogeneity that does not vary over time by absorbing fixed effects from 29 provinces and adjusting for standard errors by clustering at the provincial level. The model fit goodness of fit shows that the within R^2 is 0.9899, indicating that the explanatory variables capture 98.99% of the time-series variation in carbon emissions; the F-statistic of 156.13 ($p<0.01$) confirms that the model is highly significant overall. The coefficient of the core policy variable (post) is -0.134 ($p<0.01$), implying that carbon emissions in each province decreased by 13.4% on average after the implementation of the dual-credit policy, providing strong support for hypothesis H1b. Notably, the significant positive effect (0.772, $p<0.05$) of the degree of industrialization (IND), with carbon emissions increasing by 77.2% for each unit of expansion of traditional industry, is a policy dichotomy with the patenting model's conclusion that industrialization inhibits innovation.

To verify the robustness of the results, this study runs a standard panel fixed-effects model (XTREG) in parallel. The model setup, which also controls for province fixed effects and employs heteroskedasticity-robust standard errors, has a within-group R^2 (0.9007) and F-statistic (156.13, $p<0.01$) that are fully consistent with the REGHDFE model. The key findings are highly consistent, the coefficient on the policy variable remains at -0.134 ($p<0.01$), confirming that the abatement effect is stable at 13.4%. The strict consistency of zero difference in the coefficients proves that the result is not affected by differences in the high-dimensional fixed effects algorithm.

Table 6. Regression results——carbon emission

Carbon emission	(1) **REGHDFE**	(2) XTREG
Post	-0.134***	-0.134***
	(0.018)	(0.018)
Timetrend	-0.065***	-0.065***
	(0.008)	(0.008)
ln FDI	0.006	0.006
	(0.011)	(0.011)
ln GDP	0.217**	0.217**
	(0.086)	(0.086)
EC		
PD	-0.001**	-0.001**
IND	0.772**	0.772**
	(0.303)	(0.303)
Edu	0.040*	0.040*
	(0.023)	(0.023)
Constant	2.192	2.192
	(2.320)	(2.320)

N	324	324
R-squared	0.9899	0.901

Economic growth (ln GDP) shows a significant positive effect (0.217, $p<0.05$), suggesting that the expansion of economic scale increases carbon elasticity by 21.7%, highlighting the developmental pressures on low-carbon transition. Since economic expansion has led to an increase in car ownership, and even if the share of new energy vehicles rises, total emissions may still rise due to a widening base. The negative coefficient (-0.001, $p<0.05$) of population density (PD), on the other hand, implies that the agglomeration effect may promote the diffusion of emission reduction technologies.

To conclude, the two models reveal the core purification function of time trend (Timetrend), the coefficient -0.065 ($p<0.01$) reflects a trend of 6.5% annual average emission reductions driven by non-policy factors. Without controlling for this variable, the policy effect will be overestimated. This further confirms that controlling for time trends is necessary to avoid misestimation of policy effects.

5.2. Event study approach

In the baseline regression, the overall effect of the policy as captured by the post dummy variables, while statistically significant, may mask the dynamic heterogeneity and time-series evolutionary mechanism of the policy effect. Therefore, this study further constructs an event study approach (ESA) framework with the policy implementation year (Year0) as the baseline and a set of dummy variables (Year-3 to Year3) set year by year over a seven-year window period of [-3, +3] to test each province for prospective behavior or persistence of policy effects.

Table 7. Event study approach

	(1) Patent	(2) Carbon emission
Year-3	0.091	0.029**
	(0.131)	(0.013)
Year-2	0.458***	0.039**

	(0.104)	(0.017)
Year-1	0.715***	-0.072***
	(0.088)	(0.022)
Year0	0.877***	-0.182***
	(0.072)	(0.023)
Year1	0.59***	-0.078***
	(0.073)	(0.025)
Year2	0.617***	-0.095***
	(0.068)	(0.017)
Year3	0.367***	-0.058***
	(0.064)	(0.014)
Timetrend	0.226***	-0.068***
	(0.017)	(0.015)
ln FDI	0.139***	-0.077***
	(0.037)	(0.007)
ln GDP	0.539***	0.014
	(0.151)	(0.01)
EC	**	0.22**
		(0.089)
PD	***	
IND	-0.241	-0.001**
	(0.749)	
Edu	-0.244**	0.375
	(0.099)	(0.283)
Constant	-15.593***	0.037
	(4.183)	(0.023)
AIC	3702.423	-649.764

Two years before the implementation of the dual-credit policy, patents already showed significant growth (Year-2: coefficient =0.458, $p<0.01$). This phenomenon is closely related to the long-term practice of government subsidies, from the launch of the subsidy pilot in 2010 to the national rollout in 2015, the subsidy system has cultivated the policy sensitivity of enterprises, prompting them to quickly deploy existing subsidy resources into R&D after the release of the policy details, resulting in a significant expected behavioral response, reflected in the Year-1 coefficient jumped to 0.715 (a 25.7% increase from Year-2) and peaked at 0.877 in the policy implementation year (2017/Year 0).

However, with the gradual withdrawal of government subsidies in 2018, the patent incentive intensity decays sharply from the policy year peak to 0.367 in Year 3 (a 51% decrease). This suggests that government subsidies are both an antecedent catalyst for the effect of the dual-credit policy (shortening the policy time lag by fostering corporate responsiveness) and a key constraint for long-term sustainability (the regression leads to diminishing marginal incentives), and the dual-credit policy dividend exhibits a significant time-decaying characteristic.

Unlike the response pattern of patent incentives, we find an interesting phenomenon that carbon emissions rose significantly (coefficient = 0.039, $p<0.05$) in the two years before the implementation of the dual-credit policy (Year -2), which may be related to the synergistic effect of the government subsidy. The purchase subsidy, which was fully implemented in 2015, boosted the new energy vehicle sales significantly. However, the continued expansion of new energy vehicle ownership has led to an increase in emissions that exceeds the emission reduction contribution of new energy substitution, resulting in short-term scale effect-led emissions growth. As the policy implementation approaches (Year-1), the direction of the coefficient is fundamentally reversed (coefficient = -0.072, $p<0.01$), reflecting the drastic adjustment of corporate strategies. After the details of the dual-credit are clarified, companies begin to actively compress the production of high-emission models and accelerate the introduction of low-fuel-consumption models in order to avoid the high compliance costs in the future.

The peak emission reduction intensity is reached in the year of policy implementation (Year 0) (coefficient=-0.182, $p<0.01$). This verifies the effectiveness of the policy's constraints, as companies focus on extreme measures to avoid the risk of production shutdowns due to negative credits. However, this kind of high-intensity emission reduction is obviously not sustainable. By the third year after implementation (Year 3), the reduction effect has decayed to 32% of the peak (coefficient = -0.058), probably because the artificially high emission benchmarks in the early years forced firms to take on the burden of excess emissions reduction in the later years, while the excess supply of credits creates a buyer's market (the coefficient in Year 2 rebounded to -0.095 reflecting firms' short-term purchasing behaviors), and there is a lack of a price signal in the long run to incentivize deeper Emission Reduction. The persistent negative effect of the timetrend (-0.068, $p<0.01$) suggests that the long-term pressure to reduce emissions is objective, but that the policy effectiveness is still partially offset by firms' strategic behavior.

5.3. The role of government subsidy

It is worth noting that government subsidies play a dual role in this process. For patents on technological innovations, subsidies are both an antecedent catalyst for policy effects (accelerating patent growth) and a key constraint on long-term sustainability (subsidy degradation leading to incentive decay). While for carbon emissions, subsidies indirectly interfere with baseline setting through scale effects, exacerbating pre-policy emissions volatility, but their moderating mechanism for long-term emissions reductions is not yet clear.

This leads to a key question: how do government subsidies systematically moderate firms' innovation strategies and emission reduction behaviors under the dual-credit policy? To analyze this mechanism, the following section empirically examines the moderating effect of subsidies, focusing on identifying the impact of their interaction with the dual-credit policy on patent and carbon emissions.

Table 8. The role of government subsidy

	(1) Patent	(2) Carbon emission
Post*ln sub	-0.085	0.004
	(0.279)	(0.034)
Post	0.475***	-0.134***
	(0.13)	(0.18)
ln Sub	-0.868***	-0.015
	(0.125)	(0.030)
Timetrend	0.069	-0.066***
	(0.091)	(0.008)
ln FDI	0.019	0.008
	(0.053)	(0.011)
ln GDP	0.565	0.225**
	(0.896)	(0.085)
EC		
PD	0.02***	-0.001**
	(0.007)	
IND	-2.458	0.807**
	(1.821)	(0.311)
Edu	-0.039	0.043*
	(0.467)	(0.024)
Constant	-8.709	2.183
	(23.23)	(2.274)

PPMLHDFE regression shows that the coefficient of the interaction term (interaction) between government subsidies and dual-credit policy is -0.085 (p = 0.76), which is statistically insignificant. This means that after controlling for other factors, government subsidies and dual-credit policy fail to form a synergistic enhancement of green patents, leading to the rejection of hypothesis H2a.

It is worth noting that the government subsidy itself shows a significant negative effect (coefficient = -0.868, $p<0.01$), implying that the subsidy regression may trigger the alienation of corporate behavior, and the compression of profit margins forces companies to cut their R&D budgets, and turn to filing low-quality patents to fill the gap. At the same time, the structural problem of the flow of funds before the subsidy regression exacerbates this contradiction, as subsidies have long been concentrated in inefficient production capacity (IND=-2.458, reflecting the industrial mismatch), focusing on supporting short-term technological improvements, resulting in the capital break before the completion of the technological iteration.

In stark contrast, the dual-credit policy alone is significantly positive (coefficient=0.475, $p<0.01$), confirming that it is still effective in driving green patent growth on its own. However, the synergistic mechanism of the policy is already broken in practice, when the subsidies are rolled back to reduce the scale of funding, firms are more inclined to buy off-the-shelf technologies to meet their compliance needs through the credit trading market (as shown by the peak effect of table7 year0) than to invest in long-cycle R&D, which is essentially an externalization of the deep conflict between the pace of subsidy withdrawal and the cycle of technological innovation.

The carbon emission regression results show that the dual-credit policy (Post) alone has a significant negative effect on carbon emissions (coefficient = -0.134, $p < 0.01$), indicating that the policy does play a central role in pushing the industry to respond to the policy pressure as soon as possible to achieve emission reductions. Meanwhile, the timetrend coefficient is -0.066 ($p < 0.01$), which further confirms the trend of continuous decrease of carbon emissions over time, suggesting that the policy has produced a long-lasting emission reduction structure. The source of this independent effect lies mainly in the fact that the dual-credit policy achieves short-term apparent compliance with carbon emission reduction measures by forcing firms to respond quickly to institutional pressures through low-cost compliance methods, such as purchasing credits or limiting production. This is consistent with existing research that suggests that the dual-credit policy, as a market-based and mandatory industrial policy, relies on firms' responses to the credit market for its primary emission reduction pathway rather than the short-term embodiment of deeper technological innovation mechanisms (Peng et al., 2021).

In contrast, the government subsidy (Sub) and its interaction with policy are both insignificant ($p > 0.6$), suggesting that the subsidy neither contributes directly to carbon reduction nor plays a moderating role, and hypothesis H2b is rejected.

We argue that after the subsidy rollback and in the face of financial constraints, firms prefer to invest their limited resources in immediate compliance to meet the dual-credit test (purchasing credits or limiting production) rather than in long-term deep decarbonization. This behavioral choice is confirmed by the strong significance of the policy variable (post). At the same time, firms drastically cut back on green R&D and long-term deep decarbonization inputs, echoing the results of the negative effect of subsidies in the patent model. In other words, while subsidies do not significantly impede emissions reductions, they also fail to support firms in investing resources in technological innovation, thus fragmenting the pathways of emissions reductions and innovation.

The industrial structure variable also contributes to this divergence effect. Among them, the IND term coefficient is +0.807 ($p < 0.05$), suggesting that in high-polluting industries, carbon emissions instead increase under policy pressure, revealing the structural lock-in of high-carbon capacity in the context of regression. When subsidies are withdrawn from traditional industries, firms lack the funds to implement radical cleaner upgrades and can only rely on operational level adjustments to maintain compliance, thus intensifying the decoupling of emissions reduction and innovation. In addition, the main effect of energy consumption (EC) is insignificant ($p = 0.377$), while population density (PD) has a weak though slightly negative (-0.001, $p < 0.05$) effect. Together, these results imply that the current macroeconomic policy system has not been effective in breaking the path dependence of high pollution and high emissions, and that subsidies have not been able to form a strong institutional regulation or stimulate a strong incentive for green transformation.

6. Conclusions and policy recommendations

6.1. Conclusions

Taking China's new energy vehicle industry as the research object, this study evaluates the synergistic effect of the dual-credit policy and government subsidies in promoting the sustainable development of the industry. The study constructs a three-layer analytical framework, which combines externality theory, Porter's hypothesis and policy synergy theory. It systematically evaluates the direct impacts and interaction mechanisms of the two types of policies on green technological innovation (patent output) and environmental performance (carbon emission). Based on the panel data of 29 provinces in China from 2010 to 2023, the study empirically examines the implementation effect of the dual-credit policy and the evolution of its effect strength at different time points using the fixed-effect model and Event Study and further explores the moderating role of government subsidies.

The study finds that the dual-credit policy, as a market-oriented tool, has successfully taken over in the context of the subsidy regression, and has continued to promote the green patent output of new-energy vehicle enterprises (about 64.6 % increase) and the reduction of carbon emission (13.4 % reduction on average), which verifies its key role in promoting the green transformation of the industry. This further proves that environmental regulation can be transformed into innovation pressure and motivation for enterprises, reflecting the applicability of the "Strong Porter's Hypothesis".

The results of the event study further reveal that the incentive effect of the policy is most significant in the early stage of implementation, and then decreases year by year, showing the typical characteristics of "time lag of policy incentives" and "marginal effect decay". This suggests that the effectiveness of policy instruments is not constant, but is constrained by multiple factors such as enterprise expectations, institutional inertia and market maturity.

However, regarding the moderating effect of government subsidies, the empirical results show that there is no obvious synergy between these two policies, and there is even a tendency to suppress certain indicators. For example, in terms of technological innovation of patents, the growth rate of patent output slows down significantly after the subsidy is withdrawn, while in terms of carbon emission reduction, the interaction term between government subsidy and dual-credit policy is not significant, indicating that its guiding effect on enterprises' emission reduction behavior is limited. The reason for this may be analyzed as the long-term focus of subsidy funds on inefficient production capacity, with a certain degree of structural mismatch, which has failed to effectively support the deep green transformation of enterprises.

In short, China's new energy vehicle policy has gradually transitioned from finance-driven to market-driven, but it is still in the state of "policy transition" and "market development" intertwined, the institutional coupling has not been completed, the credit market trading mechanism is still immature, the enterprise technology route is still undulating, and market acceptance is still fluctuating. Therefore, this paper calls for while steadily promoting fiscal return and strengthening credit guidance, attention should be paid to the structural coordination and goal consistency between policies to avoid incentive misalignment and form policy synergy.

6.2. Policy recommendations

Based on the theoretical and empirical findings of this paper, the current dual-credit policy has achieved remarkable results in promoting green patent innovation and carbon emission reduction of new energy vehicles, and has become a core institutional support tool after the gradual withdrawal of government subsidy policy. However, the synergistic mechanism between the subsidy and integral policy has shown complexity and stages in practice, and the enterprises' response to the policy has a strategic game and path dependence. Therefore, in order to better promote the high-quality, green and sustainable development of the new energy vehicle industry, it is recommended to optimize the policy in the following four aspects.

First, establishing a linkage mechanism of “subsidy withdrawal and credit undertaking” to prevent incentives from being cut off. From the results of the event study method, it can be seen that the number of green patents for new energy vehicles fluctuates significantly before and after the withdrawal of government subsidies, and the policy incentives have the cyclical characteristics of “lagging-peak-decaying”. In order to avoid the time gap and incentive vacuum between policies, a clear path of “regression-transition-relay” should be formulated. For example, the pace of withdrawal of government subsidies could be synchronized with the increase in credit intensity, and the dual-credit assessment standard can be raised year by year while the subsidies are reduced, so as to ensure a smooth transition between policies. In addition, we should fully absorb the expectation management experience, release the timetable of subsidies and bonus credits in advance, and guide enterprises to reasonably plan their investment and transformation pace, so as to avoid the irrational market volatility of surprise production and sudden cuts in subsidies.

Second, enhance the effectiveness of the dual-credit market and strengthen the incentive function of credit prices. The empirical part shows that the dual-credit policy has been effective in stimulating green patent innovation and reducing carbon emissions, but its policy incentives diminish at the margin from the first to the third year. To some extent, this reflects the immaturity of the trading mechanism in the credit market and the lack of an effective signal transduction mechanism for credit prices.

Therefore, it is recommended to set a price range for credits to prevent incentive distortion caused by excess credits. Improve information disclosure in the trading system by publicly releasing credit prices, trading parties, and flow patterns to enhance market transparency. Promote the joint development and sharing of platforms among small and medium-sized enterprises, enhance their bargaining power, avoid marginalization in credit markets, and ensure stable returns on green investments.

Third, promote coordinated policy to resolve conflicts between “sales-driven” and “compliance-driven” incentives. As shown in the empirical analysis of this paper, the subsidy policy is more inclined to motivate enterprises to prioritize low-cost models for volume growth, while the dual-credit policy drives development of high-efficiency models for credit generation, which may create strategic conflicts between the two, forcing enterprises to fall into the dilemmas between “maintaining sales” and “meeting credit targets.”

To resolve this misalignment, institutional designs should be optimized by adjusting credit weightings to favor technologically advanced models and incorporating lifecycle carbon footprint metrics into credit calculations to prevent credit-gaming through low-cost compliance vehicles. Additionally, local governments should take the credit performance of firms as a reference criterion when granting subsidies, so as to promote the formation of a closed loop of incentives linking subsidies, credit and technology.

Fourth, building a regional coordinated compensation mechanism to narrow the green development gap between regions. After analyzing the data on government subsidies to provinces, we found that the implementation of the policy shows an obvious regional imbalance of “strong in the east and weak in the west”, so we should set up a horizontal fiscal transfer mechanism to provide differentiated subsidy support to the central and western regions, and at the same time, encourage the leading provinces to export their green technologies and management experience, so as to promote the formation of a gradient synergistic pattern of the east leads and the central and western regions follow.

In the technologically developed and production capacity-concentrated eastern coastal cities, we can continue to implement high-standard technical thresholds and strong credit constraints, while in the western resource-based regions, we should focus more on green employment, upstream and downstream integration, infrastructure investment and other support directions. In the transition zone in the central part of the country, we can encourage leading enterprises, universities and institutes to build a “low-carbon pilot zone”.

7. Limitations and next steps

7.1. Limitations

Although this study makes some attempts at innovation in both theoretical and empirical levels, there are still the following research limitations, and it is necessary to expand and revise future research in a broader dimension and at a deeper level.

The first limitation is that the identification of synergistic mechanisms is still simplified. This paper uses a fixed-effects model based on the changes before and after the policy and the interaction term regression method to test the moderating effect of subsidies on the dual-credit policy from the perspective of the multiplication term. However, in reality, policy synergy is often not linear and just one-time effect, it has significant dynamic feedback impact and institutional path dependence. For example, subsidy policy affects enterprises' financing ability and risk appetite, which in turn shapes their response strategies to the dual-credit policy. Therefore, the lack of dynamic mechanism modelling and path-dependence tracking is a structural weakness of this study.

Then, the functional heterogeneity of policies is not sufficiently disaggregated. Subsidies and dual-credit are not single tools. Government subsidies include R&D subsidies and vehicle purchase subsidies, as well as infrastructure construction and tax exemptions, while the dual-credit policy is divided into fuel consumption credits (CAFC) and new energy vehicle credits (NEV), which have different assessment logics and credit generation mechanisms. Modelling policies as a single variable tends to hide the segmented incentive paths of the internal structure of policies on firms' behavior. It is necessary for future research to treat the policy mechanisms separately and identify the marginal effects of each sub-instrument.

Third, this paper neglects local variations in policy implementation. Although the dual-credit policy was formulated by the central government and implemented simultaneously across the country, there are significant differences in the intensity, implementation capacity and environmental regulations in different regions during the specific implementation process. For example, the eastern region is richer in financial resources, and the support for new energy vehicle enterprises is much higher than that in the central and western regions. Some provinces even have a tendency of local protectionism, which affects the policy transmission effect. This paper fails to capture the moderating effect of local government behavioral differences on policy effects. In the future, we can introduce variables such as local financial intensity and local industrial base to explore the real impact of central-local policy tension on industrial transformation.

Fourth, there is a lack of micro-firm level heterogeneity analysis. This study uses the provincial level as the unit of analysis, which captures overall regional trends but ignores heterogeneity at the firm level. In fact, different types of firms (SOEs, private firms, new car manufacturers, etc.) have extremely different response paths to the same policy mix. SOEs may rely more on subsidy orientation, while private enterprises are more active in the credit trading market. Large enterprises tend to build their own R&D system to improve their credit level, while SMEs may choose to buy credits to cope with the policy pressure. In the future, the microheterogeneity of policy effects can be identified, like using multi-layer linear modelling in conjunction with firm-level data (if the data are disclosed).

Last but not least, the sustainability dimensions still focus on economic and environmental aspects, lacking social evaluation. This paper focuses on the sustainability indicators on the number of green patents and carbon emission reduction effects, which represent the two core dimensions of technology-environment, but still fails to capture the far-reaching impacts of the new energy vehicle policy in terms of social equity, employment restructuring, and industry chain redistribution. In particular, some vulnerable groups like low- and middle- income car buyers or small and medium-sized suppliers may be squeezed out of the market in the process of subsidy regression, this kind of social effect has generally been overlooked in existing studies. Subsequent studies can introduce third dimension indicators such as employment, regional equity, and social acceptance with the help of the ESG framework and Social Impact Assessment (SIA) methodology to truly realize the integrated measurement of economy, environment and society.

7.2. Next steps

With the acceleration of the global Carbon-neutral agenda, developing countries are faced with the dual task of "industrial upgrading" and "green transformation". However, most countries lack low path dependency and strong systematic policy combination mechanisms that can be learnt from. China has explored the "government subsidy and dual-credit" as the core incentive tool in the field of new energy vehicles, which provides a replicable and adaptable policy template for these countries. The results of this paper also prove that the combination has formed a delicate balance between short-term incentives and long-term sustainability.

Compared to the EU's strategy, which is dominated by the carbon price, and the US strategy, which is centered on the ZEV credit system. China's path is more systematic and phased. In the early stage, financial subsidies are used to reduce enterprise costs and increase consumer acceptance, thus rapidly opening up the market. In the medium term, mandatory credit is used to promote the evolution of vehicle technologies and the establishment of a credit trading market, so that firms can develop an internal logic of incentives and disincentives, then reduce financial dependence. In the later stage, financial intervention is gradually withdrawn to build a credit-led market mechanism. It is worth mentioning that as a non-price carbon regulatory tool, credit policy is highly operable in countries that have not established a national carbon market. China's experience shows that even in an institutional environment where carbon tax and carbon trading mechanisms are not yet mature, it is possible to mobilize firms to reduce emissions and innovate through structured credit instruments (Yang, 2025). This institutional design is broadly applicable to the low- and middle- income countries that also face fiscal constraints and have a weak industrial base.

In the future, China is expected to promote the transformation of the dual-credit experience into shared resources in the global climate negotiations, South-South cooperation and the “Belt and Road” initiative, exporting the design of the credit point system, credit accounting model, green industry development roadmap and other soft institutional resources to potential countries. In the dual-credit initiative, it will promote the transformation and upgrading from technology transfer to rule co-construction, so that its green influence can really go beyond the country’s borders. China is expected to change from an “industry participant” to a “system shaper” in the transformation of global new energy vehicles, provide practical choices of green development paths, and contribute “Chinese wisdom” to global climate governance.

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Against the background of global energy transition and carbon neutrality, China has taken the lead in exploring a path to support the new energy vehicle industry with a "dual-credit " policy in parallel with government subsidies. This master thesis constructs a policy synergy analysis framework based on the panel data of 29 provincial-level administrative regions in China from 2010 to 2023, and empirically examines the direct impact of the “dual-credit” policy on green technological innovation and carbon emission reduction, then further explores the moderating role of government subsidies. The results show that the “dual-credit” policy, as a market-based tool, significantly increases the output of new energy vehicle patents (by 64.6%) and effectively reduces carbon emissions (by 13.4%). However, government subsidies fail to play a significant role in policy coordination, and even inhibit technological innovation. This study not only enriches the theoretical research on policy synergy and sustainable development, but also provides a reference for the optimization of global new energy vehicle industry policies and the green transformation of developing countries.

UNIVERSITÉ CATHOLIQUE DE LOUVAIN
Louvain School of Management
Place des Doyens, 1 bte L2.01.01, 1348 Louvain-la-Neuve
Boulevard Emile Devreux 6, 6000 Charleroi, Belgique
Chaussée de Binche 151, 7000 Mons, Belgique
www.uclouvain.be/lsm