TOWARDS SUSTAINABLE DEVELOPMENT: EXPLORING THE OPTIMAL STRATEGY FOR PROMOTING NEW ENERGY VEHICLES WITHIN THE 2030 CARBON EMISSION REDUCTION TARGET IN CHINA

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ABSTRACT

China has set itself the goal of peaking carbon dioxide emissions before 2030 and becoming carbon neutral by 2060. New energy vehicles (NEVs) have become the centrepiece of carbon reduction in the transportation sector due to their efficient use of energy. Under the 'dual carbon' target, China has set electric vehicle sales at around 20% of total new vehicle sales in 2025, and this figure is expected to reach 35%–55% by 2030. However, there are still scare studies about the optimal strategy of promoting electric vehicles to help to achieve the 2030 carbon reduction target. To achieve this goal, this study applied a multi-objective optimization analysis with the NSGA-II genetic algorithm to formulate an effective strategy to promote NEVs in China. The research shows that the five provinces with the largest economic volume need to promote 42% of NEVs. This research provides the framework for assigning tasks to reduce carbon emissions in the transportation industry. The optimal strategy is beneficial for evaluating the regional NEV promotion potential and put forward a cost-effective and highly efficient promotion strategy. The results are relevant for coordinating regional interests and guiding governments to implement sustainable energy policies

Keywords: carbon reduction goal, multi-objective optimization, new energy vehicles.

1 INTRODUCTION

Given the challenges posed by climate change, most countries are actively striving to achieve ambitious carbon emission reduction targets by 2030 [1]–[4]. With the transportation sector contributing a quarter of global carbon emissions, it emerges as a pivotal area for carbon mitigation efforts. Transitioning from gasoline-powered vehicles to low-carbon and sustainable energy sources is imperative to reduce energy consumption and associated carbon emissions [5]. One potential strategy entails the gradual replacement of gasoline-powered vehicles with new energy vehicles (NEVs). NEVs encompass vehicles utilizing alternative energy sources instead of fossil fuels, including battery-only electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel-cell vehicles (FCVs) [6]. Recognized as a promising solution to energy and environmental challenges, NEVs hold strategic significance and receive substantial government support as a burgeoning industry. In China, NEVs play an important role in advancing the sustainable development agenda, aiding the country in meeting climate change targets, addressing energy complexities, and bolstering transportation sectors through diversified energy resources. Consequently, a suite of interconnected policy measures has been taken at national and local levels over the past decade to incentivize NEV adoption. Furthermore, NEV promotion has emerged as a focal point for the central government. In 2020, the Chinese central government unveiled the Development Plan for the NEV Industry (2021–2035), setting forth an objective for NEV sales to comprise approximately 20% of total new vehicle sales by 2025 [7].

However, the conflict between the external effects of the national NEV promotion and the internal effects of the promotion costs has always existed. The goal of the national NEV

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promotion is to maintain sustainable development and the well-being of people throughout the country, with anticipated social and public impacts. However, local governments tasked with promoting NEVs often bear the brunt of promotion costs, without clear and immediate benefits. In practice, some provinces prioritize emission reduction, emphasizing NEVs development to trade economic costs for environmental benefits through emission reduction initiatives. Conversely, other provinces prioritize economic growth and thus adopt a slower pace in promoting NEVs. This disparity in the design and execution of energy policies to promote NEVs across different regions impedes progress toward carbon reduction targets within the transportation sector. On the one hand, local government face the challenge of maintaining a stable increase of vehicles, and rapid NEV development could exacerbate financial burdens. Simultaneously, solely prioritizing the economic costs of NEV promotion creates obstacles in reducing carbon emissions in the transportation sector. Therefore, it is urgent to find an effective way to promote NEVs tailored to the situation of each province, focusing on the carbon emission reduction plan proposed by the central government by 2030.

On this basis, this article aims to strike a balance between the economic costs and environmental benefits of promoting NEVs. At the same time, this study provides an efficient answer to the question of 'how to coordinate the promotion targets for NEVs across provinces within the framework of the 2030 goal of reducing carbon emissions'. The main contribution of this article is to deconstruct the policy coordination mechanism between the central government and local government in promoting NEVs and to construct emission reduction tasks and optimization methods for emerging industries at the inter-provincial decomposition level under the theory of sustainable development. Based on this approach, the carbon peaks and emission reduction tasks of the transportation industry are allocated. The allocation plan identified by the research helps to evaluate the promotion potential of NEVs in the region. Overall, the research results are of great significance for guiding governments in formulating efficient industrial policies and promoting the integration of national development plans and local development plans.

2 LITERATURE REVIEW

The attainment of the national goal of NEV promotion hinges significantly on the active involvement of local governments in promoting NEVs. In China, the central government enforces political centralization alongside economic decentralization, while local governments are internally driven to maximize their interests. Within the sphere of developing a sustainable transportation industry, China operates under a hierarchical territorial administrative system for NEV promotion. Firstly, local governments operate autonomously and cooperate to meet the national NEV sales target amidst the background of the 2030 carbon peak. Secondly, both the central and local governments influence decision-making variables for NEV promotion, constantly striving to strike a balance between their respective interests. Finally, local governments set forth targets for NEV promotion and track progress toward the central government's national targets by aggregating total sales volumes (as depicted in Fig. 1).

The central government promotes NEVs to pursue their environmental benefits, which are also the focus of the academic community. Most studies analyse the ecological benefits of NEV using the life cycle assessment model. For example, Qiao et al. [8] estimate the CO_2 emissions from the production phase and compare the results with the Internal Combustion Engine Vehicles (ICEVs) level. Their results revealed that battery electric vehicles emit 50% more greenhouse gases than ICEVs, mainly due to the production of power batteries. Additionally, Shafique and Luo [9] presented a comparative cradle-to-grave life cycle

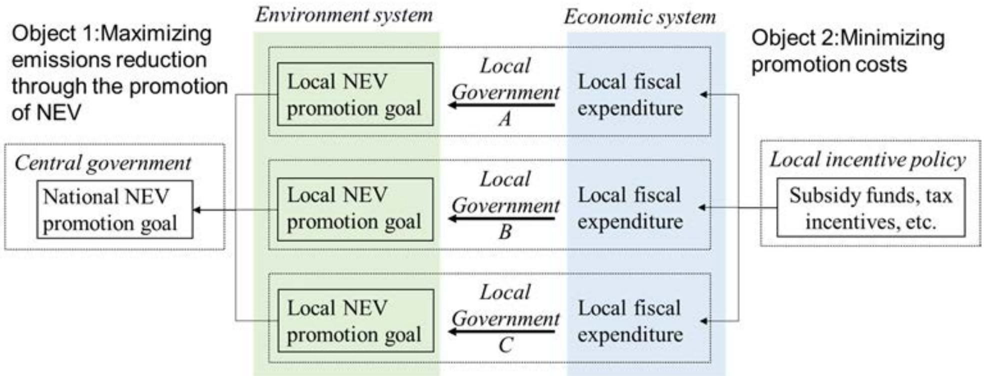

Figure 1: Multi-objective decision-making for promoting NEV.

analysis of BEVs in ten selected countries, accounting for current and projected electricity mix scenarios. Their findings underscored the 2030 Norway electricity mix as optimal for BEVs, noting its minimal environmental impact across various categories. While debates persist regarding the environmental friendliness of NEVs, a common consensus emerges: with optimized electric structures, NEVs can substantially reduce emissions. Furthermore, NEVs, boasting zero tailpipe emissions, play a pivotal role in mitigating localized pollution, a critical concern in densely populated urban areas [10].

Although it has been demonstrated that transitioning to NEVs presents a sustainable option, the positive impacts can vary significantly depending on the policies implemented by local governments and regions. Such a situation requires the central government to disaggregate the national NEV promotion target to the provincial level, considering the provincial disparities in energy systems, carbon emissions, and cost-effectiveness. Previous studies usually discuss this question in carbon quota allocation. For instance, Zhou et al. [11] proposed a disaggregation model from the viewpoint of emission reduction pathways, revealing that certain provinces would shoulder larger emission reduction responsibilities while adhering to the principle of minimizing total emission reduction costs. However, limited studies have explored the optimal strategy for NEV promotion under the national target, except for the study of Zhang and Hanaoka [12] and Zhang and Han [13]. Specifically, Zhang and Hanaoka [12] explored the impacts on energy consumption and emissions following EV adoption at the provincial level in China. Their economic analysis indicated relatively low economic feasibility in northeast China, alongside lower emission reduction potential compared to the national average. Besides, Zhang and Han [13] conducted a regional optimization study, balancing cost and environmental benefits and highlighting the suitability of EVs over hybrid vehicles in developed regions for promotion. These outcomes are instrumental in devising an effective NEV promoting strategy for the government. Nevertheless, further optimization studies focusing on disaggregating the national NEV promotion target to the regional level are imperative.

3 RESEARCH METHODOLOGY AND ANALYSIS

Suppose there are several sub-regions of NEVs in the country (i), each region has some types of power system (j), and each type of power system is applied to a type of vehicle (there are k type of vehicle). Part of the combined data is determined by three attributes: the sub-region where the NEV is located, the power system technology and the vehicle type, and is referred as $x_{i,j,k}$. All the combined data form the national NEV ownership structure [14]. The purpose of studying the national NEV ownership structure is to find an optimal ratio of NEV ownership structure under the conditions of economic development. The so-called optimal means that the ownership structure must meet two objectives: one is to minimize the economic cost of promotion, and the other is to maximize the direct greenhouse gas emission reduction. The boundary conditions mainly consider the analysis model created by Peng et al. [15] for the analysis model for energy demand and greenhouse gas emissions in Chinese interprovincial road transportation (CPREG model).

$$EM_t = \sum_j \sum_k (VP_{t,j} \times FC_{t,j,k} \times L_{t,j} \times SH_{t,j,k} \times EF_k) \quad (1)$$

EM_t represents the total greenhouse gas emissions in year t (the well-to-wheel method is used), where k denotes the fuel type, $VP_{t,j}$ represents the number of vehicles of type j in year t, $FC_{t,j,k}$ denotes the fuel consumption rate of fuel k in vehicles of type j in year t, $L_{t,j}$ represents the mileage of vehicles of type j using fuel k in year t, and $SH_{t,j,k}$ represents the proportion of fuel k used by vehicles of type j in year t, EF_k represents the direct greenhouse gas emission density of various fuel types. It is assumed that 91% of the fuel type of internal combustion engine vehicles is gasoline and 9% of the fuel type is diesel [16].

In summary, this study proposes the objectives of the multi-objective optimization model for NEVs in the province:

$$\min C = \sum_{i\in I} \sum_{j\in J} \sum_{k\in K_j} w^C_{i,j,k} \times x_{i,j,k} \quad (2)$$

$$\max L = \sum_{i\in I} \sum_{k\in k_j} Z_{i,j,k} \times x_{i,j,k} \quad (3)$$

The objective function C represents the total government support costs (such as subsidies, infrastructure support, etc.) of the interprovincial car ownership structure. $w^C_{i,j,k}$ represents the subsidy cost of type vehicles k using the power grid j in the province i. $x_{i,j,k}$ represents the number of types k vehicles using the electricity grid j in province i. L represents the greenhouse gas emissions reduced by the structure of car ownership between provinces in a given year. $Z_{i,j,k}$ represents the greenhouse gas emissions reduced by promoting type vehicle k with new energy and the electricity system j in province i, i.e. the greenhouse gas emissions of type vehicle k with new energy and an internal combustion engine drive system.

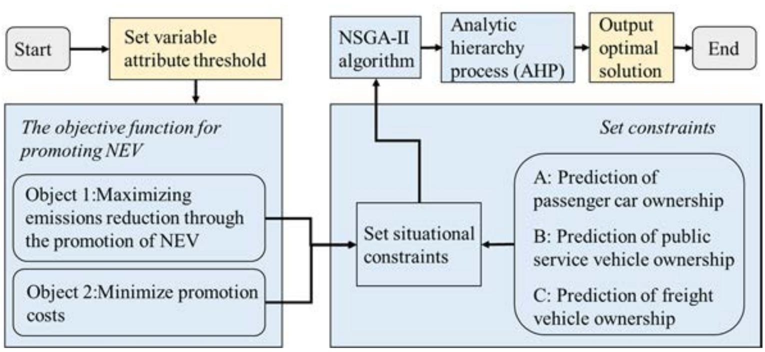

Figure 2: The framework of exploring the optimal strategy of promoting NEVs within 2030 peak carbon dioxide emission.

4 RESEARCH METHODOLOGY AND ANALYSIS

Using the NSGA-II algorithm program provided by Python, the Pareto solution set for the optimized model is determined. The concept of Pareto front or set of optimal solutions in the space of objective functions in multi-objective optimization problems stands for a set of solutions that are non-dominated to each other but are superior to the rest of solutions in the search space, which means the solutions are not unique. As seen in Fig. 3, the initial solution is randomly determined from the 0th generation and the iterative optimization is performed up to the 10000th generation. The optimization continues until the 10000th generation, stopping when the average change in the Pareto solution set is less than the set value. From the perspective of the optimization process, the NSGA-II algorithm exhibits fast convergence speed and has essentially converged to the final Pareto set by the 8000th generation. The number of unknown variables solved in this study is large, and the Pareto frontier has a wide distribution range. Evolutionary algorithms can effectively handle such problems.

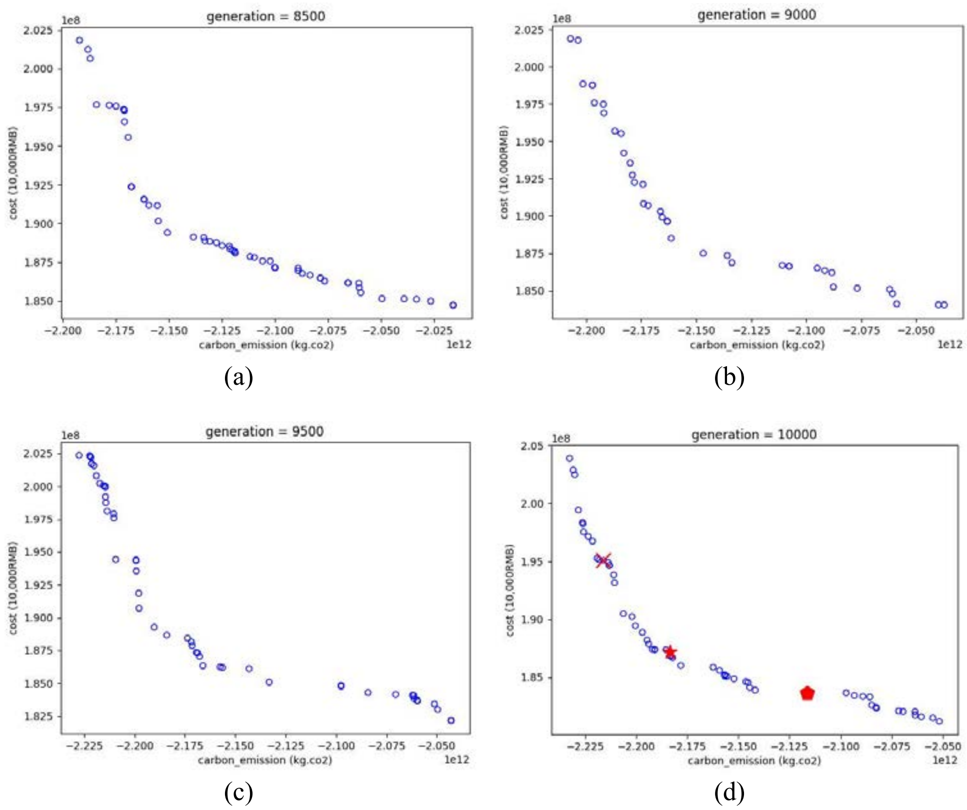

Figure 3: Pareto front-end under different iteration times. (a) 8500 generations; (b) 9000 generations; (c) 9500 generations; and (d) 10000 generations. All x and y axes represent variables obtained from Eqns (3) and (2), respectively. Note: In the 9000th generation Pareto front-end, the positions corresponding to three preference scenarios are marked: environmental benefit scenario (pentagon), balance scenario (pentagram), and emission reduction cost scenario (cross shape).

The determination of objective function weights holds paramount importance for searching the most suitable solution from pareto solution set, with two primary methods commonly employed: subjective weighting and objective weighting. The subjective weighting method uses the preferences of the decision makers and mathematical methods to determine the target weights. Conversely, in the absence of decision maker preferences, the objective weighting method can be used to determine the target weight using mathematical rules. This study aligns with the decision preferences of the government, where five experts from the Development and Reform Commission of Beijing, Shanghai, Guangdong, Sichuan and Chongqing Province provided evaluations. Based on pairwise comparison, an evaluation matrix was created, and a consistency test was carried out to determine the target weights for the three preference scenarios. The results show that the weighting of the environmental benefit type is (0.17, 0.83), the weighting of balance type is (0.5, 0.5) and the weighting of the emission reduction costs type is (0.83, 0.17). These weightings correspond to the target values. Subsequently, the objective function is weighted and summed, with the maximum sum value corresponds to the Pareto solution, delineating the inter-provincial NEV subsidy target in China amidst the carbon peak background across the three preference scenarios. The position of the Pareto solutions in the front range for three preference scenarios, as depicted in Fig. 3 for the 10000th generation of Pareto. Specifically, the environmental benefit scenario corresponds to a carbon reduction of 2.217×10^{12} kg CO_2 with an economic cost of 1950 billion (CNY). Conversely, the balanced and emission reduction cost scenario correspond to carbon reduction of 2.183×10^{12} kg CO_2 and 2.117×10^{12} kg CO_2, with economic costs of 1875 billion (CNY) and 1833.3 billion (CNY) respectively.

The study assessed the results of three scenarios based on the average production volume of NEVs in 21 provinces. It identifies the NEV promotion proportion target of the top five provinces with the biggest economic volume, as shown in Fig. 4. In Fig. 4, there are four concentric circles, with each level representing the total national economic output, the total target of NEV promotion, the total target of electric vehicle promotion, and the total target of fuel cell vehicle promotion. The GDP of the five provinces with the highest economic strength constitutes 46.1% and 42% of the NEV promotion target. Specifically, Henan, Jiangsu, Shandong, Zhejiang, and Guangdong account for 9.1%, 9.0%, 8.8%, 8.3%, and 7.1% respectively to the total number of promotion tasks. The promotion targets for BEVs in these five provinces represent 41% of the whole national aim, whereas the promotion targets for FCVs represent 77% of the overall national target. FCVs offer benefits such as a short

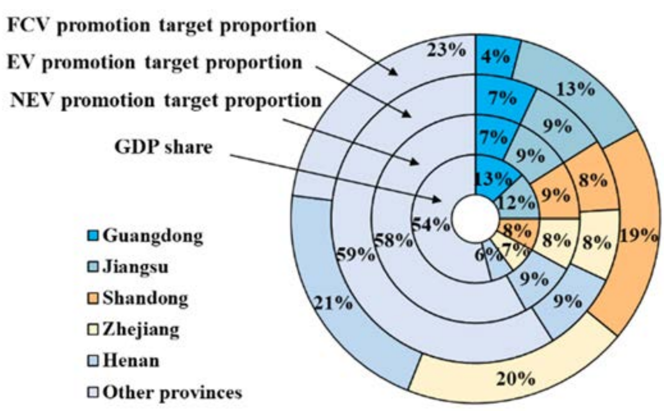

Figure 4: The optimal allocated NEV promotion target of top five province in China.

hydrogenation time and an extensive driving range, but also necessitate a great level of innovation. The higher proportion of FCVs promotion in these five provinces compared to BEVs indicates that developed regions possess greater capability and dedication in promoting NEVs and advancing the hydrogen industry and technology. The results of this study support previous research findings. For example, Burke et al. [17] pointed out that FCVs are projected to achieve a substantial market share by 2040, given strong governmental backing. Overall, the promotion of NEVs in China is closely linked to factors such as the strength of regional economic development, the regional population, the population's education level, and the climate. Promoting NEVs in China is still mainly concentrated in provinces with a large economic volume. Provinces with large economic volumes have greater potential for expanding the market for NEVs and should take on the obligation of driving innovation in the fuel cell vehicle sector.

5 CONCLUSION

The promotion of NEVs is intricately tied to market competition and the development of local economies. This study delves into the medium-term development objectives of national NEV markets and observes that the economic framework supporting NEV promotion has remained steadfast despite constraints posed by emission reduction goals and economic development. The predominant support model, primarily oriented towards meeting emission reduction targets, is observed to have a limited impact on local economic growth. Therefore, it is advisable for China to prioritize environmental benefits in its NEV promotion efforts, particularly in provinces and cities with vehicles purchase restrictions, such as Beijing and Shanghai. For the reason that the promotion of NEVs could actively contribute to alleviating air pollution, cities with vehicles purchase restrictions are poised to experience substantial development opportunities in the upcoming years and align with the 2025 industrial plan. It is projected that by 2030, China's NEV fleet will reach 60 million units. The future trajectory of the industry hinges significantly on the development of charging infrastructure, private sector investment, and the formulation of coherent central and local policies. These measures will gradually lessen the industry's reliance on fiscal resources, ultimately achieving the dual objectives of enhancing environmental quality through NEV promotion and fostering industrial economic development. Such measures are not only consistent with China's objectives, but also useful in the context of goals and targets defined by Agenda 2030. As a new government sustainable energy policy research field, it has realistic and practical value.

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