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Environmental and Health Benefits of Promoting New Energy Vehicles: A Case Study Based on Chongqing City

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Abstract: The transportation industry plays a key role in reducing urban emissions of air pollutants and energy consumption. The transition from traditional fossil fuel-based vehicles (TFFBVs) to new energy vehicles (NEVs) is critical to China's strategic goal of reaching peak carbon dioxide (CO_2) emissions before 2030 and achieving carbon neutrality before 2060. On the basis of the environmental status and development of NEVs in Chongqing in 2020, we designed scenarios for replacing TFFBVs in Chongqing with NEVs according to targets such as the number of proposed NEVs in China's 14th Five-Year Plan. Following this, we evaluated the environmental and health benefits of NEVs and their monetary value using exposure–response and disease–cost methods. Replacing 18%, 35%, and 50% of TFFBVs with NEVs can create health benefits of approximately CNY 11.391 billion, CNY 21.696 billion, and CNY 30.443 billion, accounting for 4.56%, 8.68%, and 12.18%, respectively, of Chongqing's GDP in 2020. These amounts exceed the cost of government subsidies. Greater health benefits were derived from reducing the toxic emissions of nitrogen dioxide (NO_2); the reduction in deaths caused by cardiovascular diseases created the best benefits for health endpoints, exceeding a 59% reduction in all three scenarios. Our study provides empirical support for promoting NEVs.

Keywords: new energy vehicles; air quality; impacts on the environment; health benefits; valuation

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Citation: Pan, R.; Liang, Y.; Li, Y.; Zhou, K.; Miao, J. Environmental and Health Benefits of Promoting New Energy Vehicles: A Case Study Based on Chongqing City. *Sustainability* **2023**, *15*, 9257. https://doi.org/10.3390/su15129257

Academic Editor: Elena Cristina Rada

Received: 24 April 2023
Revised: 5 June 2023
Accepted: 6 June 2023
Published: 8 June 2023

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1. Introduction

In recent years, the growing number of traditional fossil fuel-based vehicles (TFFBVs) has posed a severe impact on air quality. Car exhausts are a major source of air pollutants and greenhouse gases (GHGs) in Chongqing. In 2020, China set its strategic goal to reach peak carbon dioxide (CO_2) emissions before 2030 and achieve carbon neutrality before 2060 ("Goal 3060"). Studies have proven that increasing the use of renewable energy is important for countries to achieve sustainable development and maintain good environmental performance. Additionally, a study found that there is a possibility of using different mobility options under sustainable mobility, which can counter the tensest environmental and socio-economic restrictions on transportation [1,2]. The transportation industry plays a key role in reducing energy consumption and GHG emissions, and the transport sector is facing the demanding challenges of transition and upgrade. By replacing traditional fossil fuels with new and renewable energy, we can not only alleviate the problems of fossil energy depletion and increasingly severe air pollution, but also supplement the energy supply and adjust the energy structure. Therefore, replacement through supporting the technological advances in new energy vehicles (NEVs) and devoting additional efforts to the development of the NEV industry is a strategic focus of China's future energy development and a key strategy to achieve "Goal 3060".

Various countries are taking active measures to promote NEVs. European countries, led by the Netherlands, have joined the International Zero-Emission Vehicle Alliance and

promised to increase the share of electric vehicles (EVs) in new vehicle sales to 100% by 2050 [3]. The United States is accelerating the electrification and intelligentization of its automotive industry through innovative technologies. The Japanese government has issued its Strategic Roadmap for Hydrogen and Fuel Cells, proposing a "three-step" strategy and providing preferential policies for their research and development, demonstration, and subsidies [4]. China's NEV industry has been developing rapidly since 2014, and the number of NEVs is growing. By the end of 2021, China saw 7.84 million NEVs on the road, which accounted for 2.60% of the total vehicle population (302 million units) and represented an increase of 59.25% compared to that in the previous year. Specifically, 6.4 million pure EVs were recorded, accounting for 81.63% of the total NEVs [5]. NEVs and the NEV industry have been examined from different perspectives, including investigations into the impact of NEVs on the improvement in air quality [6,7], whether or not NEVs are conducive to the transformation of energy [8], and the promotion of NEV industry [9–11].

NEVs can bring about environmental benefits. As an alternative to TFFBVs, NEVs can save energy and have an advantage due to their lack of toxic emissions when running on the road. Their popularization can effectively reduce the emissions of atmospheric pollutants from the transport industry and thereby mitigate the health damage caused by atmospheric degradation. Studies carried out with NEVs from the perspective of different regions, pollutants, and health outcomes [12–14] showed that in the entire life cycle of manufacturing, use, and recycling, the emissions of NEVs were less than those of TFFBVs. Many scholars are interested in the characteristics of NEVs and have developed models to study their fuel consumption, charging characteristics and impact on the urban environment [15–17]. Compared with TFFBVs, NEVs significantly reduce emissions by 13–68% [18] and demonstrate a 46% higher energy efficiency. By comparing the exhaust pollution from pure EVs and TFFBVs, Guo et al. [19] found that the pollution from pure EVs mainly occurred in power plants. Cao et al. [20] compared hybrid EVs and fuel cell vehicles (FCVs) in Shanghai and found that NEVs produced significant fuel-saving and substitution effects. Jiang analyzed the pollution caused by the structure of power generation, energy, vehicle types, and urban transportation conditions [21]. Yang et al. [22] established a model for reducing pollutant emissions to explore the impact of NEVs on reducing pollutant emission. In addition, numerous studies have used life cycle analysis to compare NEVs and TFFBVs based on the structure of power generation, vehicle fuel types, the driving efficiency of hybrid EVs [23], and the power supply chains of coal-fired power technology [24]. Their different impacts on pollutant emissions were also identified in the production, use, and power/fuel supply stages. Muhammad et al. [25] conducted a life cycle assessment of EVs in 10 representative countries from the perspective of energy and power structures and analyzed their environmental footprint in the phases of production, transportation, and use.

NEVs can bring about health benefits. In recent years, attention has been focused on the impact of the development of the NEV industry on population health and its economic value has been monetized. Based on the environmental impacts of NEVs, their impact on human health is being evaluated using quantitative monetary tools to determine the economic value of their environmental and health benefits [26]. Assessments of the health benefits of promoting NEVs based on the assessment of environmental benefits can support industrial policies regarding NEVs from an economic perspective. The monetization of the economic value of these health benefits can enable us to compare the results of promoting NEVs in different regions and ranges.

The health costs incurred due to air pollution can be measured using assessments of the environmental value, for example, the costs of the damage caused by $PM_{2.5}$ [27], CO [28], SO_2 [29], and NO_x [30] have been explored. Assessments of the environmental values have adopted the dose–response method to establish the relationship between the degree of pollution and the effects on health, and then the relevant environmental values have been compared. Many methods have been developed to monetize the effects on health, such as the human capital approach [31], evaluations of the willingness to pay [32], and

the disease–cost method [33]. By assuming the contribution of PM_{10} from motor vehicle emissions to air pollution, Deng [34] calculated the cost of health effects caused by air pollution from road traffic by using the human capital and willingness to pay methods. The health costs caused by air pollution from TFFBVs in Beijing in 2000 were obtained accordingly. Zhou et al. [35] used the disease–cost method to assess the external costs of air pollution from TFFBVs in Beijing in 2014.

The environmental damage caused by air pollution and the related effects on health have been explored for EVs and NEVs. Gai et al. [36] developed an integrated model to evaluate the environmental and health impacts of deploying EVs in the Greater Toronto Area and Hamilton in Canada. Pan et al. [37] explored the impact of future mobility (i.e., vehicle electrification, automation, and shared mobility) on air quality and health in the United States, using a technical–economic mobility model, a chemical transport model, and a health impact assessment tool. Erika et al. [38] evaluated the adoption of zero-emission vehicles (i.e., battery electric, plug-in hybrid, and hydrogen FCVs) on the relationship between air quality and asthma in California. Kouridis et al. [39] estimated the environmental and social benefits of electrifying the vehicle fleet in urban areas of Greece and found that the electrification of the vehicle fleet contributed to avoiding premature mortality attributed to particulate pollution. This study helped to evaluate the cost efficiency of energy and transportation policies aimed at promoting the electrification of vehicle fleets in urban areas. Chen et al. [40] investigated future sustainable transport in Malaysia and compared its health impacts among several scenarios of the projected growth of electric vehicles and energy generation combinations.

Studies on the promotion of NEVs have mainly focused on environmental impacts, such as reduced emissions. However, a comprehensive evaluation of the environmental and health benefits of NEVs, including various health outcomes, is lacking. Moreover, regarding the environmental impact of NEVs, current research has often focused on particulate matter, and most case studies in China have been conducted in the regions of Beijing, Tianjin, and Hebei. Assessments of the economic value of the environmental and health benefits of NEVs remain preliminary. The present study analyzed Chongqing, an important pilot city for the promotion of NEVs in the southwestern part of China. Policy scenarios where TFFBVs were replaced with NEVs were designed on the basis of car parks and gradually evolving policies regarding the NEV industry. The emissions of CO, NOx, SO_2, and $PM_{2.5}$ were included as our indicators of pollution. Additionally, multiple methods of assessment were utilized to comprehensively explore the environmental and health benefits created by promoting NEVs. In addition, the economic value of the environmental and health benefits under different policy scenarios and objectives were estimated. The cost effectiveness of promoting NEVs was also analyzed on the basis of the monetized value. Chongqing is among the first batch of provinces and cities to launch a pilot project of being a low-carbon city as determined by the National Development and Reform Commission of China. Thus, the city faces the challenges of controlling the growth of energy consumption and total carbon emissions. Car exhausts contribute greatly to the major atmospheric pollutants in Chongqing. According to Chongqing's 14th Five-Year Plan for the Development of Charging Infrastructure, the number of cars in Chongqing reached 5.037 million in 2021, ranking third in China only after Beijing and Chengdu, but with only approximately 137,000 NEVs. Chongqing has enormous potential to replace TFFBVs with NEVs. To achieve "Goal 3060", Chongqing must take on the arduous task of promoting the transition from TFFBVs to NEVs.

In line with the latest policy scenario for the NEV industry during the period of the 14th Five-Year Plan, we assumed that different proportions of TFFBVs are being replaced with NEVs in Chongqing. Following this, we evaluated and monetized their environmental and health benefits. Our study made the following marginal contributions. The scientific methods used in this study included the use of different policy scenarios and substitution rates for assessing the environmental benefits, and the exposure–response function method, the statistical life value method and disease cost method for assessing the health benefits.

This study was based on the number of existing NEVs and the latest industrial policies and analyzed from the perspectives of the internalized benefits and external environmental costs. Thus, it provides a basis for a cost–benefit analysis of NEV policies. Our focus on Chongqing can provide the necessary empirical support for the study of the environmental and health benefits of promoting NEVs at the urban level, especially in the pilot cities. It is noteworthy that in Chongqing, the promotion of NEVs is highly important and has potential.

2. Materials and Methods

2.1. Materials

Since the release of China's Energy-Saving and New Energy Vehicle Industry Development Plan (2012–2020) in 2012, Chongqing has been actively promoting NEVs. This move has continuously enhanced investments, efforts towards introduction, and policy incentives in the NEV industry. During the 14th Five-Year Plan period, China's environment entered a critical period with CO_2 reduction as a key strategic direction. Civil construction has aimed to promote synergistic interaction between mitigating pollution and reducing carbon emissions as well as a comprehensive green transition for economic and social development. Chongqing has also included the NEV industry as a strategic emerging industry. In the future, it will make additional efforts to promote and adopt NEVs, increasingly replacing TFFBVs with NEVs.

The ecological environment of Chongqing is as follows. According to the Report on the State of the Ecology and Environment in Chongqing, 2020, the city's average annual concentrations of PM_{10}, $PM_{2.5}$, SO_2, and NO_2 were 53, 33, 8, and 39 $\mu g/m^3$, respectively. The 95th percentile of the daily average CO concentration was 1.1 mg/m^3, and the 90th percentile daily maximum 8 h average O_3 concentration was 150 $\mu g/m^3$. The concentrations of these six main pollutants all met the secondary standards of the National Ambient Air Quality Standards for the first time. According to Chongqing's statistical yearbook on the environment for 2021, the NO_x emissions from motor vehicle pollution sources in Chongqing amounted to 88,484 tons, accounting for 52.97% of the total emissions. Emission monitoring by Huang et al. [41] indicated that the contribution of transport sources in the main urban area of Chongqing has significantly increased year by year from 2013 to 2019, reaching 48% in 2019. Wu et al. [42] found that SO_2 from motor vehicle sources contributed only 6.2% of the total emissions. According to Yang et al. [43], motor vehicle exhausts contributed 80.0% of the CO emissions in Chongqing. According to the abovementioned databases and literature, the contributions of motor vehicle exhausts to total NO_2, $PM_{2.5}$, SO_2, and CO emissions in Chongqing were set at 52.97%, 48%, 6.2%, and 80.0%, respectively.

2.2. Methodology

2.2.1. Assessment of the Health Benefits of Promoting NEVs

The core of the quantitative evaluation of the health benefits of reducing emissions of atmospheric pollutants was establishing an exposure–response relationship between population-level health endpoints and atmospheric pollutants. The exposure–response relationship refers to the relationship between levels of environmental exposure and the occurrence of adverse reactions in the human body. In epidemiological studies on air pollution, this relationship refers to the change in the proportion of individuals suffering from certain health problems in the population caused by the concentration of air pollutants [44]. Compared to the incidence of a certain health impact in the population, the incidence of disease and death is extremely low, conforming to the Poisson distribution in statistics. Most current health risk assessments for air pollutants are based on the Poisson regression model for determining the relative risk. Through evaluations of the health costs caused by each unit of increase in the major pollutants, the resulting impact on human health can be characterized quantitatively [45]. The following calculation model was used:

$$I_0 = I \times e^{\beta(C_0 - C)} \quad (1)$$

$$\Delta I = I - I_0 = I \times \left[1 - e^{\beta(C_0 - C)}\right] \quad (2)$$

$$E_i = \Delta I \times P = P \times I_i \left[1 - e^{\beta(C_0 - C)}\right] \quad (3)$$

where I_0 and I are the probability of health benefits at the baseline concentration and the actual concentration of atmospheric pollutants, respectively; β is the exposure–response coefficient between a specific pollutant and a health endpoint; C and C_0 are the average concentrations of atmospheric pollutants in 2020 and after the replacement of TFFBVs with NEVs, respectively; E represents the health benefits of reduced emissions of atmospheric pollutants (i.e., the change in the number of deaths or hospital admissions); and P is the exposed population in the study area. Chongqing has a large flowing population and many incoming migrants; thus, the registered household population is not a good indicator of the exposed population. Therefore, the population of permanent residents was used to indicate the exposed population. According to Chongqing's statistical yearbook for 2021, Chongqing had a permanent resident population of 32.089 million in 2020.

2.2.2. Assessment of the Economic Value of Environmental and Health Effects

The value of a statistical life (VSL) method is used to evaluate the economic benefits of fatal outcomes' endpoints. The VSL is the measured monetary value of the cost that people are willing to pay for a unit of decrease in the risk of death in a statistical sense [46]. Wang and Mullahy [47] investigated the willingness of residents in Chongqing to pay for reductions in air pollution and health issues in 1998 using the contingent valuation method and obtained a VSL value of CNY 285,300. This result was adopted as the economic value of a death in our study. To consider social and economic development and the changes in the per capita income of residents in Chongqing, this VSL was adjusted according to the disposable per capita income and income elasticity coefficients of 1998 and 2020 (our benchmark year). Finally, the VSL for Chongqing in the year 2020 was calculated as follows:

$$VSL_{2020} = VSL_{1998} \times \left(\frac{Y_{2020}}{Y_{1998}}\right)^{\beta} \quad (4)$$

$$EB = N \times VSL_{2020} \quad (5)$$

where VSL_{2020} is the VSL of the population in Chongqing in 2020; β is the income elasticity, usually set at 0.8; Y represents the per capita disposable income in Chongqing for different years; N is the estimated number of deaths from diseases; and EB is the estimated economic benefits of a death due to disease. According to Chongqing's statistical yearbook for 2021, the per capita disposable income in Chongqing for 2020 and 1998 was CNY 30,800 and CNY 5896, respectively. Therefore, the average VSL in Chongqing for 2020 was CNY 1.07 million.

2.2.3. Inpatient, Outpatient, and Patient Endpoints

The disease–cost method was used to evaluate the economic benefits created by promoting NEVs as a result of reducing the number of inpatients, outpatients, and patients. The disease cost refers to the economic losses of the patients, families, and society due to illness, disability, or premature death and the health resources consumed for preventing and controlling disease [48]. Our evaluation mainly consisted of two parts, estimating the reduced medical expenses and estimating the increased patient income, both being due to the improved environmental quality. The reduction in medical expenses was equal to the reduction in the number of patients multiplied by the medical expenses per patient, and the increase in patient income was equal to the reduction in the number of patients multiplied by the affected time and the average daily income of patients. The specific formulae are as follows:

$$EC_i = EC_{i,p} + perGDP_p \times T_i \quad (6)$$

$$EB = N \times EC_i \quad (7)$$

where EC_i is the economic cost incurred by the health endpoint, i, due to atmospheric pollutants; $EC_{i,p}$ is the per capita medical expenses, including direct and indirect costs; $perGDP_P$ is the daily per capita cost of lost work, that is, the daily per capita GDP in Chongqing for 2020 (CNY 219.25); T_i is the time lost due to medical treatment, that is, the duration of outpatient and inpatient treatment; and N is the change in endpoint i caused by improved air quality.

3. The Analysis of the Benefits of Promoting NEVs

3.1. The Results of the Environmental Benefit Assessment

According to Chongqing's 14th Five-Year Plan for the Development of Charging Infrastructure, by the end of 2020, Chongqing had 137,000 NEVs, accounting for 2.72% of the total number of vehicles in the city. Policy documents related to the development of the NEV industry at the national and city levels were collected. These, included China's NEV Industrial Development Plan (2021–2035) and Chongqing's Action Plan to Accelerate the Construction of an Improved Intelligent NEV Industrial Ecology (Draft for Comments), which set the respective targets of 18% and 35% of the TFFBVs being replaced with NEVs. These targets were based on the sales targets (with sales of NEVs accounting for 20% of the national total vehicle sales by 2025) and production targets (with the production of NEVs' accounting for 40% of Chongqing's total vehicle production by 2025). Furthermore, a higher replacement ratio of 50% was added, considering the technological progress of future NEVs and their potential for reducing pollution and providing environmental and health benefits after their large-scale adoption. Table 1 shows scenarios with different proportions of TFFBVs being replaced with NEVs after rounding.

Table 1. Targets for different replacement percentages of NEVs.

Goals for NEV Promotion	Policy Document
To reach 20% of the national sales by 2025	China's NEV Industrial Development Plan (2021–2035)
To reach 40% of the total production in Chongqing by 2025	Chongqing's Action Plan to Accelerate the Construction of an Improved Intelligent NEV Industrial Ecology (Draft for Comments)
To reach 40% of national sales by 2030	China's NEV Industrial Development Plan (2021–2035)

The concentration and content of atmospheric pollutants are extremely low. Pure EVs can achieve a zero-emission and pollution-free status. Therefore, we considered the gap in emissions between TFFBVs and NEVs when driving, and calculated the reduction in emissions of atmospheric pollutants as a percentage, according to the proportion of TFFBVs being replaced with NEVs. The emissions and concentration of atmospheric pollutants showed a strong and direct linear relationship. According to Chen's work [49], the proportion of TFFBVs being replaced (*replacement percentage*), the contribution of motor vehicles to the emission of atmospheric pollutants (*emission contribution*), and the concentration of atmospheric pollutants after the replacement of TFFBVs with NEVs (*ex-post pollutant concentration*) have the following relationships:

Ex-post pollutant concentration (baseline concentration) = concentration of specific pollutants in base year × (1 − emission contribution of the specific pollutant × replacement percentage).

Figure 1 illustrates the reductions in the concentrations of four atmospheric pollutants as a result of promoting NEVs under different replacement percentages. The concentrations of the four major atmospheric pollutants decrease with an increase in the replacement percentage. Due to the contributions of motor vehicles to emissions, reductions in CO, NO_2, and $PM_{2.5}$ concentrations were greater when the replacement percentage increased.

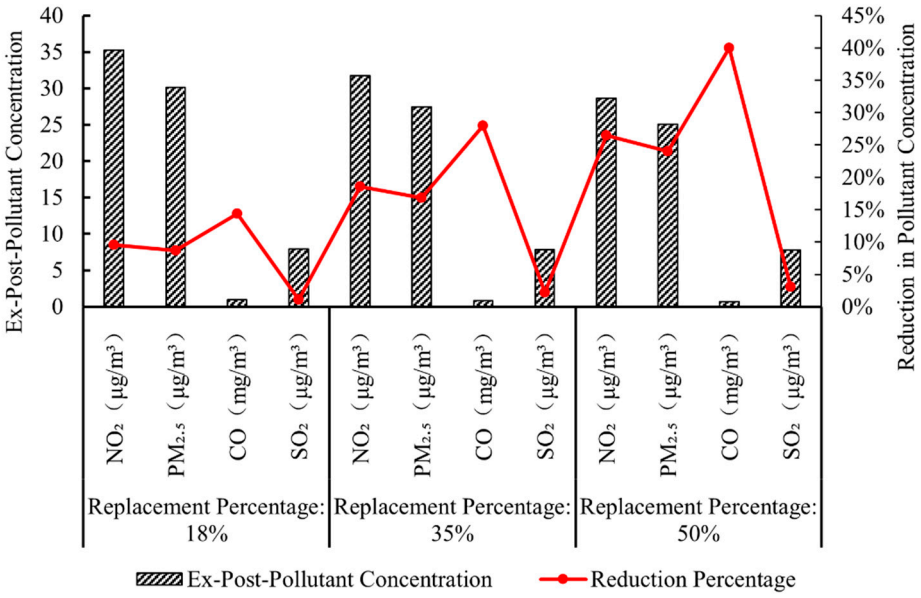


Figure 1. Environmental benefits of promoting NEVs under different replacement percentages.

3.2. Health Benefit Assessment for Promoting NEVs

The health endpoints were selected according to basic selection principles and the International Classification of Diseases, 10th Revision (ICD-10). The existing research on the health impacts of atmospheric pollutants in China was also considered. The health benefit endpoints were the number of deaths caused by respiratory diseases or cardiovascular diseases (CVDs); the number of inpatients presenting with respiratory diseases or CVDs; the number of outpatients presenting with respiratory diseases and CVD; and the number of patients with chronic bronchitis, acute bronchitis, or asthma.

3.2.1. Parameter Selection

The baseline incidence refers to health data to be studied, including the population's incidence or mortality rates without the specific factors. The baseline incidence rate in Chongqing in 2020 was derived from the relevant statistical yearbooks and literature, including Chongqing's statistical yearbook on health for 2021 and China's statistical yearbook on health for 2018. The exposure–response coefficient, β, which established the relationship between the health endpoints and pollutants, was determined by referring to the relevant literature, particularly studies on Chinese scenarios. Table 2 shows the baseline incidence rates of different health endpoints and the exposure–response coefficients corresponding to various pollutants.

Table 2. Baseline incidence rates and exposure–response coefficients for different health endpoints.

Health Endpoints		Baseline Incidence (‰)	Pollutant	Mean β
Deaths	Respiratory diseases	1.063	NO_2	0.0162 [50]
			$PM_{2.5}$	0.00143 [51]
			SO_2	0.001 [52]
	Cardiovascular diseases (CVDs)	3.153	NO_2	0.0146 [50]
			$PM_{2.5}$	0.00053 [51]
			CO	0.0477 [50]
			SO_2	0.004 [52]

Table 2. *Cont.*

Health Endpoints		Baseline Incidence (‰)	Pollutant	Mean β
Inpatients	Respiratory diseases	21.9	NO_2	0.0004 [35]
			$PM_{2.5}$	0.00109 [53]
			SO_2	0.0015 [52]
	CVDs	10.2	NO_2	0.00123 [35]
			$PM_{2.5}$	0.00068 [53]
			SO_2	0.0019 [52]
Outpatients	Respiratory diseases	58.2	$PM_{2.5}$	0.001006 [54]
Patients	Chronic bronchitis	6.9	$PM_{2.5}$	0.01009 [55]
	Acute bronchitis	38	$PM_{2.5}$	0.0079 [53]
	Asthma	9.4	$PM_{2.5}$	0.0021 [51]

3.2.2. The Results of Assessing the Health Benefits

Figure 2 shows the calculated health benefits under different replacement percentages in Chongqing. As the replacement percentage increased, all four health endpoints (death, inpatients, outpatients, and respiratory patients) showed gradually increasing health benefits. For the endpoints of death and inpatients, the health costs of CVDs were significantly greater than those of respiratory diseases. Among them, the reduction in NO_2 emissions resulted in 5346, 10,136, and 14,164 fewer cases at replacement percentages of 18%, 35%, and 50%, respectively. From the perspective of the endpoints of outpatients and respiratory patients, decreases in the $PM_{2.5}$ concentration due to the promotion of NEVs result in significant health benefits, particularly for chronic bronchitis (at replacement percentages of 18%, 35%, and 50% with 6279, 12,046, and 17,005 fewer cases, respectively) and acute bronchitis (at replacement percentages of 18%, 35%, and 50%, with 27,157, 52,254, and 73,957 fewer cases, respectively).

3.3. The Results of Assessing the Economic Value of Environmental and Health Effects

The average length of hospital stay and of medical expenses for respiratory diseases were replaced by those for important diseases, such as invasive pulmonary tuberculosis, bacterial pneumonia, pediatric bronchitis, and chronic pulmonary heart disease. Similarly, the length of hospital stay and medical costs per patient for CVDs were replaced by those for important diseases, such as acute myocardial infarction, congestive heart failure, myocardial infarction, and hypertension. The duration of chronic bronchitis is difficult to define; therefore, the disease–cost method did not apply. According to Viscusi et al. [56], we assumed that the economic cost of chronic bronchitis is 32% of the VSL. Following Huang et al. [57], we converted the economic cost of acute bronchitis and asthma by considering the difference in income between cities based on differences in disposable per capita income among regions at different times and with different elasticity coefficients of the willingness to pay. The economic cost of acute bronchitis and asthma thus obtained was CNY 2874.8 and CNY 1968.9, respectively. Table 3 presents the parameters of the evaluation of economic value for each health endpoint derived from China's statistical yearbook on health for 2021 and other sources.

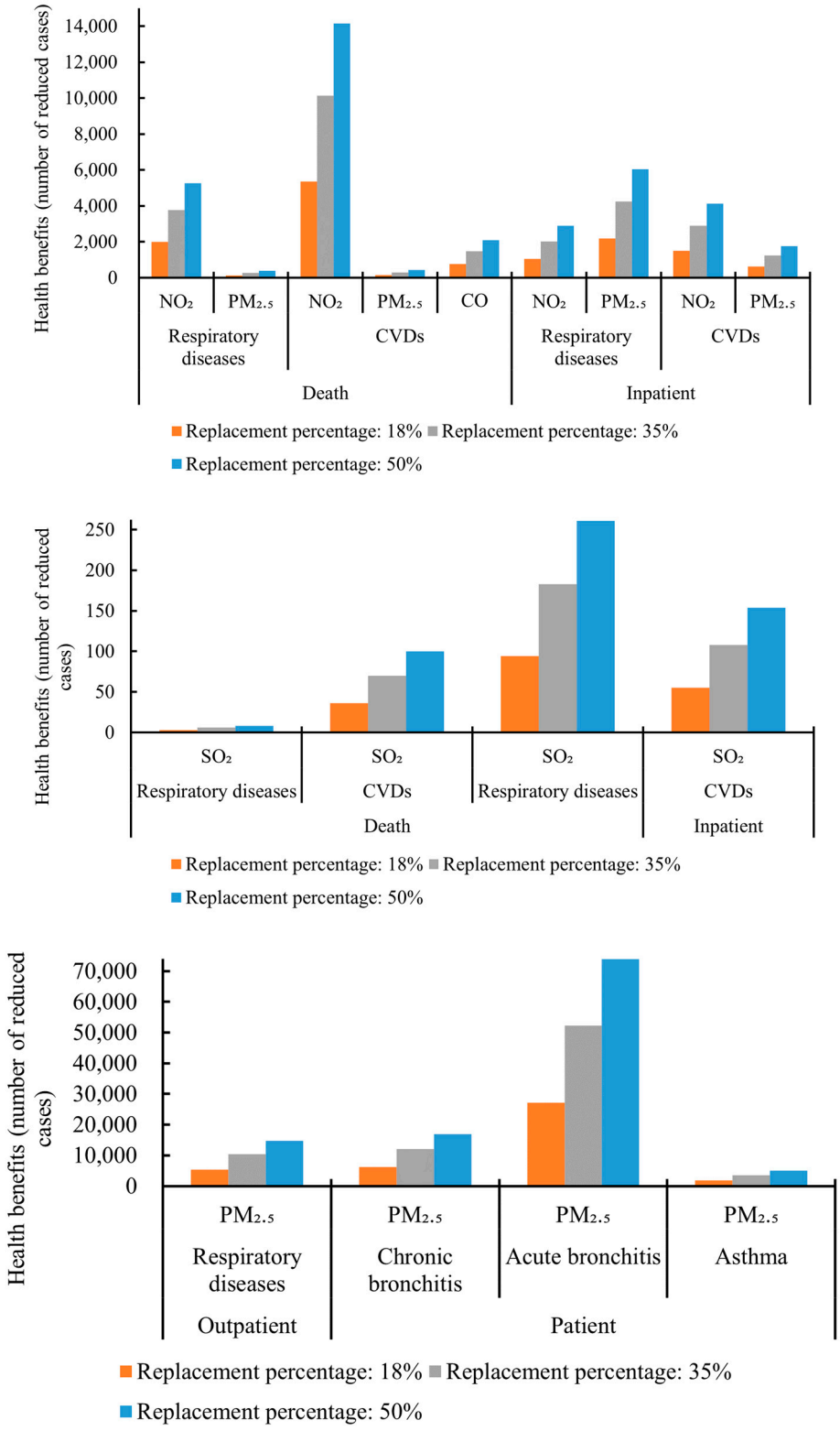


Figure 2. Health benefits of different health endpoints under different replacement percentages.

Table 3. Parameters of the evaluation of economic value for each health endpoint.

	Hospital Stay		Outpatient
	Respiratory Diseases	**CVDs**	**Respiratory Diseases**
Medical expenses per patient (CNY)	13,521.6	37,455.9	344.1
Number of workdays lost	9.3	9.2	0.5 [49]

Figure 3 illustrates the economic values of the environmental and health benefits of promoting NEVs in Chongqing under different replacement percentages. These values were determined according to the monetization method and the related parameter settings. As determined in this study, the total economic values of the environmental and health benefits created by replacing 18%, 35%, and 50% of TFFBVs with NEVs in Chongqing in 2025 were CNY 11.391 billion, CNY 21.696 billion, and CNY 30.443 billion, respectively.

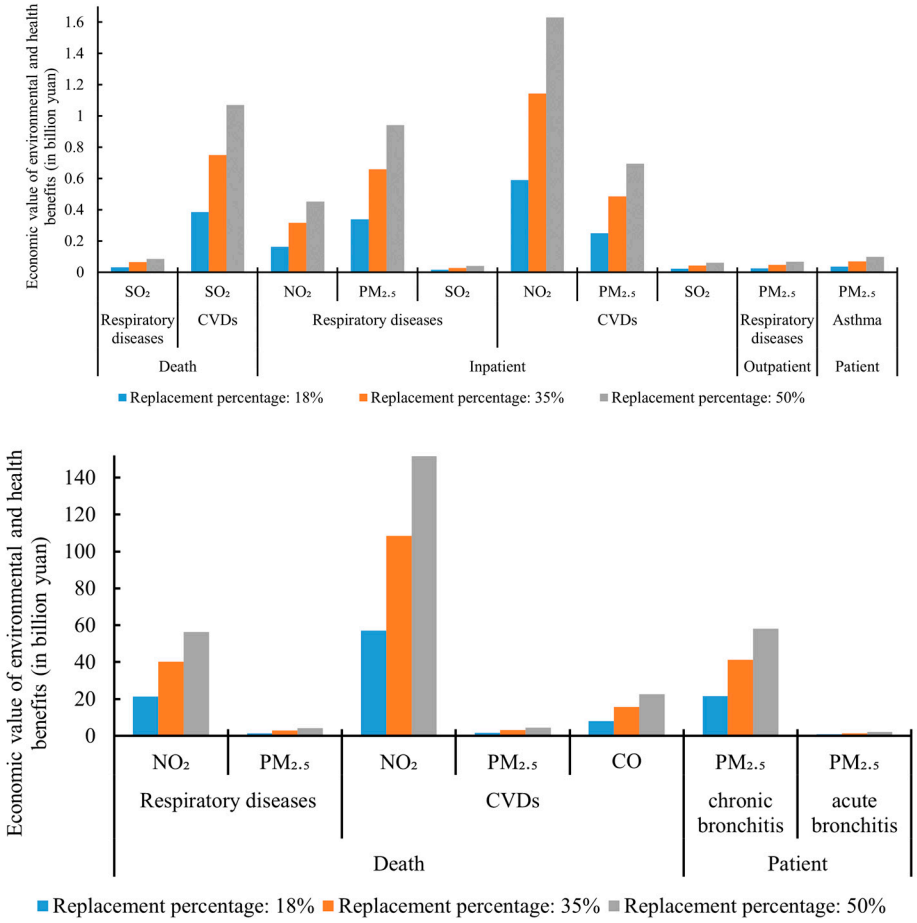


Figure 3. Economic values of the environmental and health benefits of promoting NEVs.

4. Discussion

4.1. Atmospheric Pollutants

The contributions of the health benefits generated by reducing different atmospheric pollutants to the total health benefits were roughly the same at different replacement percentages. Figure 4 shows the health benefits of such reductions when the replacement percentage was 35%. The highest level of health benefits, at 69.26%, was generated by reducing the NO_2 from motor vehicles, which causes significant harm to the exposed population. Reductions in $PM_{2.5}$ contributed 23.08% of the total health benefits, due to its widespread impact on the health of the exposed population, while reducing CO emissions

accounted for only 7.26% of the total health benefits. Nevertheless, as only one of the health endpoints selected in our study involves CO, the health benefits of reducing CO emissions can directly reflect the extensive contribution of motor vehicles and the highly toxic nature of the pollutant. As TFFBVs are not the main sources of SO_2 emissions, reductions in this pollutant accounted for the lowest contribution to the total health benefits, with only 0.40%.

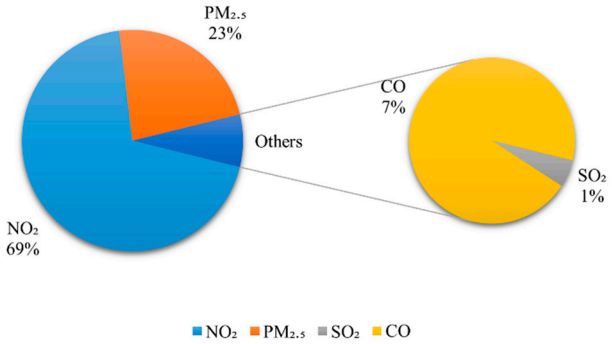


Figure 4. Contribution to the environmental and health benefits of reducing the emissions of different air pollutants with 35% replacement of TFFBVs with NEVs.

4.2. Health Endpoints

Under the three NEV replacement scenarios, the health benefits of different endpoints accounted for the same proportion of the total. Figure 5 shows the proportions of the health benefits of different endpoints in a 35% replacement scenario. Among all the selected health endpoints, the health benefits of the reduction in deaths caused by CVDs had the highest proportion, exceeding 59%. The reduction in deaths caused by respiratory diseases followed, reaching approximately 20%. Atmospheric pollutants are much more harmful to the cardiovascular system than to the respiratory system of the exposed population. The health benefits of reduced deaths accounted for approximately 79% of the total, whereas the health benefits of reduced inpatients, outpatients, and respiratory patients accounted for 1.2%, 0.02%, and 20%, respectively, which are much lower than those of reduced deaths. Specifically, the health benefits of the reduction in the number of patients with chronic bronchitis accounted for approximately 90% of the benefits due to improvements in respiratory patients.

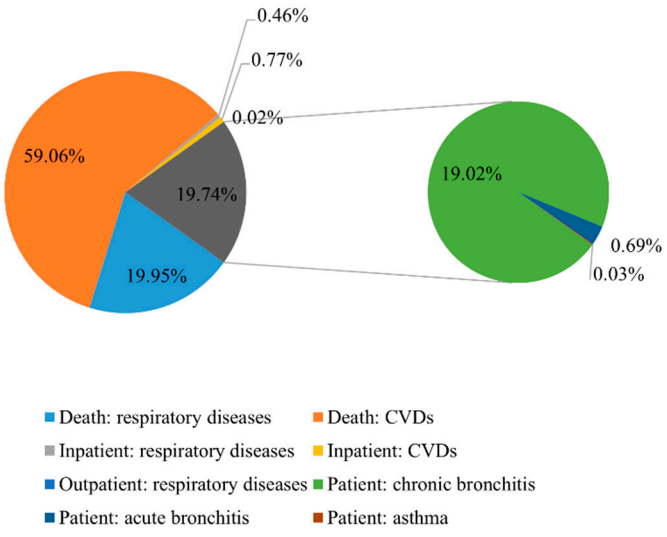


Figure 5. Proportions of the health benefits of the different endpoints at 35% replacement.

4.3. Cost–Benefit Analysis

Chongqing invested approximately CNY 5.4 billion in the NEV industry during the period of the 13th Five-Year Plan and approximately CNY 1 billion in 2021. According to the health benefits shown in our study, during the period of the 14th Five-Year Plan, Chongqing's full achievement or over achievement of the goals of promoting NEVs will create health benefits far exceeding the government's current investment costs. In terms of providing various subsidies and grants for NEVs, the government should fully consider the environmental and health benefits of NEVs and increase financial investments towards this effort.

4.4. A Comparative Analysis of Cases

Existing studies have analyzed the environmental and health benefits of promoting NEVs. Nevertheless, due to the differences in the research objectives, policy scenarios assumed, research methods, and other aspects, there are also differences in the research results. However, comparisons between the studies remain valid and can provide a reference for other countries and regions to further investigate the environmental health benefits of NEVs. Liang et al. [58] studied the impact of automobile electrification on air quality, climate, and health benefits in China. These authors found that electrifying 27% of private cars and a larger proportion of the commercial fleet would lead to significant reductions in $PM_{2.5}$, NO_2, and summer ozone concentrations (O_3) by 2030. Such reductions would decrease the number of premature deaths in China by 17,456 per year. Compared to the results calculated in this study under the three policy scenarios, those of the effects of health benefits of promoting NEVs on the decrease in the number of premature deaths in Chongqing showed decreases of 8430 cases, 16,024 cases, and 22,439 cases, respectively, for the 18%, 35%, and 50% replacement percentages. The results of the studies were comparable, showing that widespread adoption of electric vehicles can help mitigate air pollution and has positive health effects. Wang et al. [59] evaluated the economic benefits of promoting NEVs in Beijing from 2016 to 2019 using the exposure–response model and the disease–cost method, and concluded that the monetized value of the environmental health benefits of promoting NEVs in Beijing in 2019 was CNY 33.71 billion or about 0.95% of Beijing's GDP in the same period. In this study, the monetized value of environmental health benefits in Chongqing was CNY 11.391 billion, CNY 21.696 billion, and CNY 30.443 billion under the three policy scenarios. This value was slightly lower than Beijing's. However, considering that the total GDP of Chongqing in the base year (2020) was CNY 25,279 billion, the proportion of monetized environmental health benefits from NEVs of the GDP was about 0.46%, 0.87% and 1.22%. That is, the economic benefits of promoting NEVs accounted for a similar proportion of GDP in the corresponding provinces, and the research of this can be extended to other cities.

5. Conclusions

This study calculated the environmental health benefits of the promotion of NEVs in Chongqing. On the basis of the economic, social, and ecological environmental conditions of Chongqing, we designed scenarios for replacing TFFBVs in Chongqing with NEVs according to the targets regarding the number of proposed NEVs set out in China's 14th Five-Year Plan.

This study investigated the environmental and health benefits of NEVs under different replacement scenarios using different evaluation methods. Accordingly, we drew the following conclusions:

(1) When NEVs were actively promoted and had replaced 18%, 35%, and 50% of the TFFBVs in Chongqing by 2025, reductions in the CO emissions (80.0% from motor vehicle sources) were highest, followed by emissions of NO_2 and $PM_{2.5}$ with SO_2 showing the smallest decrease (only 6.2% from motor vehicle sources). This result is due to the different contributions of motor vehicles to emissions of air pollutants;

(2) When 18%, 35%, and 50% of TFFBVs in Chongqing were replaced with NEVs, the economic value of the environmental and health benefits created by the decrease in the concentration of atmospheric pollutants was CNY 11.3913 billion, CNY 21.6963 billion, and CNY 30.443 billion, accounting for 4.56%, 8.68%, and 12.18%, respectively, of Chongqing's GDP in 2020;
(3) For a 35% replacement rate, the economic value of the reductions in the atmospheric pollutants NO_2, $PM_{2.5}$, CO, and SO_2, in terms of the total environmental and health benefits, was 69.26%, 23.28%, 7.26%, and 0.4%, respectively. These contributions were related to emissions from motor vehicles, their harmful effects on the exposed population, and the selection of health endpoints. Greater health benefits were associated with higher contributions of NEVS to motor vehicle sources, fewer harmful effects on the exposed population, and more health endpoints being involved;
(4) In terms of the types of health endpoints, the reduction in deaths caused by CVDs accounted for the highest proportion of the total economic value of the environmental and health benefits, exceeding 59% at all three replacement percentages, followed by the reduction in deaths caused by respiratory diseases. The sum of the two endpoints accounted for 79% of the total economic value of the environmental and health benefits. The economic value of the environmental and health benefits of the inpatient, outpatient, and respiratory patient endpoints accounted for 1.2%, 0.02%, and 20%, respectively, all of which were lower than those of the reductions in deaths. Specifically, among the patient endpoints, the reduction in the number of patients with chronic bronchitis accounted for 90% of the total economic value of the environmental health benefits;
(5) During the period of the 14th Five-Year Plan, the environmental health benefits obtained by Chongqing for achieving its goal of promoting NEVs will exceed its current investment costs. Therefore, the government should fully consider the environmental and health benefits of promoting NEVs and continue to increase its financial investment in the industry, thus helping to achieve "Goal 3060" in the future.

Due to data availability limitations, this study assumed that the emissions of NEVs in the road operation stage were zero, and did not consider the emissions of NEVs during the process of production. This may have led to an overestimation of the environmental health benefits. Future research could incorporate the full life cycle parameters of NEVs for a more refined analysis. The present study provides important reference values, and the adopted parameters and emission factors are authoritative and provided results that were compared with similar studies. Furthermore, the study prompts the relevant authorities to pay attention to the huge health benefits created by NEVs and introduce policies to encourage green consumption in transportation.

Author Contributions: Conceptualization, R.P. and K.Z.; methodology, R.P. and Y.L. (Yifei Li); software, R.P. and Y.L. (Yiping Liang); validation, Y.L. (Yifei Li), K.Z. and J.M.; formal analysis, R.P.; investigation, Y.L. (Yiping Liang); data curation, Y.L. (Yiping Liang); writing—original draft preparation, R.P.; writing—review and editing, Y.L. (Yifei Li); visualization, Y.L. (Yiping Liang); supervision, K.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The main data and parameters used in this paper are shown in the main text and tables.

Conflicts of Interest: The authors declare no conflict of interest.

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