Received: 26 July 2024 | Revised: 10 January 2025 | Accepted: 29 April 2025 | Published online: 03 June 2025

Green and Low-Carbon Economy
2025, Vol. 00(00) 1–12
DOI: 10.47852/bonviewGLCE52023971

RESEARCH ARTICLE

Strategies for Achieving Carbon Neutrality in Chinese Metropolitan's Industrial Development: A Case Study of Chongqing in China

Chunyan Dai[1,*], **Jing Zhang**[2], **Shiyan Chang**[3] **and Hao Meng**[4]

[1] *Department of Management Science and Engineering, Chongqing Technology and Business University, China*

[2] *Department of Business Administration, Chongqing Technology and Business University, China*

[3] *Institute of Energy, Environment and Economics, Tsinghua University, China*

[4] *Center for Strategic Research, Chinese Academy of Science and Technology Information, China*

Abstract: Chongqing, the largest industrial city in China's western region and a significant modern manufacturing base, serves as the focus of this paper. This study investigates Chongqing's socioeconomic development, urban and rural spatial patterns, population distribution, industrial structure, energy structure, low-carbon technologies, and policies from multiple dimensions. Utilizing a combination of top-down and bottom-up methodologies, the research establishes the Chongqing Low Emissions Analysis Platform for industrial sectors. The analysis encompasses energy demand and carbon emission trends in Chongqing's industrial sector from 2020 to 2060 across three scenarios: the reference scenario, the positive peak – 2060 near-zero emissions scenario, and the accelerated peak – 2060 net-zero emissions scenario. The study explores potential pathways and breakthroughs for achieving net-zero emissions in Chongqing, with a particular focus on key policy areas during China's "15th Five-Year Plan" period, aiming to achieve a carbon-neutral emission trajectory. Additionally, it summarizes replicable and promotable experiences, providing decision-making guidance for accelerating green and low-carbon transformations and sustainable development in industrial cities.

Keywords: industry, net-zero, carbon emissions, LEAP

1. Introduction

Global climate change has become one of the most pressing challenges facing humanity. Against the backdrop of increasing international calls for emission reductions, China's rapid economic development, urbanization, and industrialization have led to a heavy reliance on fossil fuels within the country's energy structure, resulting in significantly high carbon emissions [1, 2]. According to statistics, China's carbon dioxide emissions have reached 12.6 billion metric tons, accounting for approximately 34% of global CO_2 emissions, maintaining its position as the world's largest emitter. In response to the increasingly severe energy and environmental challenges, China explicitly proposed the goal of "peak carbon emissions before 2030 and carbon neutrality before 2060" in September 2020. Carbon neutrality aims to achieve a balance between carbon dioxide emissions caused by human activities and carbon dioxide absorption within a specified timeframe, requiring zero carbon emissions through emission reductions and enhanced carbon absorption activities [3, 4].

In 2023, the total industrial added value in China reached 39.9 trillion yuan, accounting for 31.7% of the national GDP. The industrial sector is a vital component of the national economy, especially as a core force within the secondary industry [5]. Industrialization has a significant impact on urban carbon emissions, with heavy industry being a primary source of carbon emissions in China, where energy consumption accounts for over 60% of the national total and contributes to more than 80% of carbon emissions [6]. Industrial cities are those that have developed with industrial production as their main function [7]. China has a nearly 150-year history of industrialization, and following the establishment of the People's Republic of China, a relatively complete industrial system has been formed. As the industrialization process has advanced, many industrial bases and cities have been established [8]. These cities typically have a high proportion of industrial electricity, water resources, and land and are heavily reliant on resources, leading to significant environmental pollutants and greenhouse gas emissions [9].

As one of China's six major old industrial bases, Chongqing has a solid traditional industrial foundation, a strong manufacturing base, and a complete industrial system [10]. Among the

---

*Corresponding author: Chunyan Dai, Department of Management Science and Engineering, Chongqing Technology and Business University, China. Email: daichunyan@ctbu.edu.cn

41 industrial categories, Chongqing encompasses 39, making its industrial system relatively complete and representative. Currently, Chongqing is at a critical stage of transformation and development, optimizing its economic structure and achieving a shift in economic momentum. Although national and regional policies have been introduced to reduce greenhouse gas emissions, the ongoing processes of industrialization and urbanization have significantly increased energy demand, leading to a rise in total carbon emissions. The industrial sector contributes nearly 80% of the total emissions in Chongqing. This significant impact is largely driven by key industries, including thermal power generation, chemicals, nonmetallic minerals, ferrous metals, non-ferrous metal smelting, and papermaking. For instance, recent data indicate that the thermal power industry alone accounts for approximately 40% of the region's total carbon emissions, making it the largest single source. Additionally, the chemical sector contributes around 20%, while non-ferrous metal smelting and papermaking each represent significant portions as well. Chongqing's situation mirrors that of many industrial cities across China, where the industrial sector is similarly a major contributor to carbon emissions. These cities often share common challenges, such as low resource utilization efficiency, significant environmental pollution, and a heavy reliance on traditional heavy industries. As in Chongqing, the industrial sectors in these cities are dominated by energy-intensive industries, which exacerbate carbon emissions and hinder progress toward sustainability. Given this context, it is imperative to explore effective strategies for Chongqing to meet its dual-carbon goals. Special attention must be directed toward developing and implementing measures that specifically target emission reductions within the industrial sector. By focusing on innovative technologies, enhancing energy efficiency, and integrating renewable energy sources, Chongqing can not only pave the way for a more sustainable industrial framework but also serve as a model for other industrial cities facing similar challenges. This approach will help minimize its carbon footprint and contribute to broader climate action efforts, fostering a collective response to the pressing environmental issues that affect numerous industrial urban centers.

This study focuses on industrial cities represented by Chongqing, utilizing the Chongqing Low Emissions Analysis Platform (CQ-LEAP) to conduct multi-stage analyses covering various scenarios, including economic scale, urban spatial form, population distribution, industrial structure, energy structure, and energy-saving and emission reduction technologies or policies. The study aims to identify potential pathways for Chongqing to achieve zero carbon emissions and summarize low-carbon development models applicable to other industrial cities. Through forward-looking predictions, we gain an in-depth understanding of Chongqing's zero carbon emission pathways under the "14th Five-Year Plan," and we develop a series of replicable and scalable practices aimed at promoting the green transformation and sustainable development of industrial cities. The contributions of this research mainly lie in three aspects: First, the use of the CQ-LEAP platform for multi-dimensional analysis reveals potential pathways for Chongqing to achieve zero carbon emissions under different economic and industrial scenarios, providing an important reference framework for other industrial cities. Second, a series of low-carbon development models suitable for Chongqing and other industrial cities are summarized, which can provide a scientific basis for policymakers to formulate effective policies and promote the coordinated development of the regional economy and environment. Third, through an in-depth exploration of zero carbon emission pathways under different scenarios in Chongqing, the study proposes a series of replicable practical experiences to assist other industrial cities in achieving green transformation in the context of global climate governance and advancing sustainable development goals.

The literature review is presented in Section 2. Section 3 outlines the methodology and analytical framework employed in this study. The principal findings are detailed in Section 4. Finally, Sections 5 and 6 provide the discussion and conclusion.

2. Literature Review

Global governance has entered a new phase, with various countries worldwide introducing a series of action plans. In March 2020, the European Commission promulgated the "European Climate Law," ensuring the attainment of the European vision of achieving climate neutrality by 2050 through legislation. In April 2020, the French government adopted the revised "National Low-Carbon Strategy" in the form of a decree, proposing the goal of achieving "carbon neutrality" by 2050. In February 2023, the European Commission issued the "Green Deal Industrial Plan," aiming to simplify, accelerate, and adjust incentives to enhance the competitiveness of net-zero industries in Europe. In August 2023, the US Department of Energy released the report "Pathways to 100% Clean Electricity," analyzing the benefits of achieving net-zero carbon emissions in the power sector and recommending 10 actions for achieving this objective.

Since the introduction of the goal of carbon neutrality, a great deal of research has been conducted around the world to address this goal. Panos et al. [11] analyzed the challenges faced by Switzerland's energy transition in various technological, socioeconomic, and geopolitical contexts, exploring pathways for transforming the energy system toward net-zero CO_2 emissions. Shahbaz et al. [12] analyzed the potential impact of economic growth, R&D expenditure, financial development, and energy consumption on carbon dioxide emissions using data from 1870 to 2017. Karlsson et al. [13] examined challenges related to establishing a net-zero emission supply chain for buildings by analyzing a road construction project in Sweden. Tan et al. [14] developed the G-LEAP model to evaluate feasible technical emission reduction potentials within China's cement industry, while providing an analytical framework applicable to other cement industries.

With its flexible data structure and rich technical details, the LEAP model has become an effective tool to explore the possibility of achieving peak time of carbon emissions at the national, provincial, and even industry levels, as well as reaching a neutral level. Lu et al. [15] used the LEAP model to analyze the energy demand and greenhouse gas emissions of ceramic industrial parks and developed three scenario models to simulate the changes and impacts of ceramic industrial park construction. Li et al. [16] set four dynamic scenarios based on the Low Emissions Analysis Platform (LEAP) model to study China's energy demand over the next four decades. Using the case of a state-owned power generation enterprise, Cai et al. [2] explored pathways for the enterprise to reach a carbon emissions peak and carbon neutrality in five scenarios based on the LEAP model.

In summary, this study adopts a regional focus, with 2021 as the base year and 2050 as the target year. It constructs a carbon emission measurement model based on the LEAP framework to analyze Chongqing's future energy demand and carbon emission trends. Specific policy recommendations are provided to assist Chongqing in achieving its "dual-carbon" goals. The findings of this study play a crucial role in guiding Chongqing's low-carbon development and hold significant implications for carbon reduction efforts in other cities.

3. Methodology and Analysis

3.1. Methodology

The LEAP model is a scenario-based energy-environment accounting tool jointly developed by the Stockholm Environment Institute in Sweden and the Tellus Institute in Boston, USA [17]. This bottom-up model adopts an engineering perspective to simulate the energy consumption and production processes of various industries using end-of-pipe technologies [18–20]. There are some research using LEAP to analyze China's provincial carbon emission peaks, such as Shanghai [21], Jiangsu [22], and Zhengzhou [23]. Focusing on Chongqing's industrial sector, we established a low-emission model for the energy industry in Chongqing (CQ-LEAP), which provides a comprehensive depiction of Chongqing's socioeconomic development trends, energy supply and demand potential, and possible carbon emission trajectories at the national scale. The CQ-LEAP model provides a comprehensive analysis of Chongqing's economic structure, industrial composition, and energy landscape. It incorporates China's economic characteristics, categorizing societal economic activities into 21 production sectors and 2 consumption sectors (Table A1). To simulate the carbon-neutral pathway more effectively, the model emphasizes key carbon-neutral technologies such as renewable energy, coal-fired power with Carbon Capture and Storage (CCS), and Bioenergy with Carbon Capture and Storage (BECCS). Additionally, the energy and economic data for Chongqing were refined by integrating the Chongqing Statistical Yearbook with extensive field survey data. Currently, the model exclusively focuses on CO_2 emissions from fossil fuel combustion, omitting other greenhouse gases, pollutant gases, and industrial gas emissions. The estimation of CO_2 emissions is primarily based on the depiction of fossil energy consumption flows within the model. To establish the relationship between energy use and CO_2 emissions, we utilized the latest emission factor data for coal, oil, and gas, as released by the Climate Change Functional Office of China's State Environmental Protection Office (HJ Circular No. 85, 2021)—2.66 tCO_2/tce, 2.73 tCO_2/tce, and 1.56 tCO_2/tce, respectively. Equation (1) is used to calculate the total carbon emissions for each sector.

$$Em_{r,s,t} = En_{r,s,t,coal} \times f_{coal} + En_{r,s,t,roil} \times f_{roil} + En_{r,s,t,gas} \times f_{gas} \tag{1}$$

In this model, *Em* represents the total emissions, *En* represents the energy consumption, and *f* represents the carbon emission factor for energy sources such as coal, refined oil, and natural gas. Meanwhile, *r*, *s*, and *t* represent regions, industries, and years, respectively. In practice, due to variations in coal types and quality as well as differences in oil and natural gas across different regions, their carbon content and heat value also differ. Consequently, their emission factors should be adjusted accordingly. However, for simplicity purposes and under current data availability constraints, an assumption is made that the emission factors remain constant. To address this issue effectively within these limitations of data availability constraints, many *CES* production and consumption functions are employed in this model, requiring calibration of substitution elasticities between various inputs. Substitution elasticity reflects the ease with which input products or factors can be substituted for one another; it is an important parameter affecting the evaluation results of *CGE* models. If substitution elasticity between various inputs in *CES* production functions is high, then adjusting the input structure during the production process becomes easier when responding to external policy shocks, leading to relatively easier reduction of emissions; conversely, if substitution elasticity is low, then adjusting production technology becomes more difficult when implementing emission reduction policies, thereby increasing policy impact on economy as well. The relevant literature has been referred to make appropriate adjustments to Chongqing's energy production and consumption characteristics' substitution elasticity values. Please refer Table A2 for substitution elasticity values pertaining to the main production and consumption sectors. The LEAP model was applied at the bottom-up level to depict the industrial energy consumption situation in Chongqing, covering sub-sectors such as steel, chemical, building materials, non-ferrous metals, automobiles, electronic equipment, and new infrastructure [24]. Each branch of the model's energy demand is calculated by multiplying its activity level by its corresponding energy intensity. Therefore, it is essential for each branch to clarify both its activity level and the energy intensity of various fuels. In our study on emission pathways in key areas of Chongqing, we developed a three-level model framework that includes the industry level (typical industries selected based on output), production process level (different stages within processes), and energy consumption/emission levels (showcasing different types of main energy equipment). Coal, oil, natural gas, and electricity were primarily used as types of involved energies. In this study, the CQ-LEAP model of key industries in Chongqing was constructed to simulate and analyze the energy consumption and emissions under different technology promotion scenarios in the future. The calculation process involved in the model was divided into four categories: activity level of different processes, energy demand, CO_2 emissions, and emission reduction potential between different scenarios.

Formulas (2), (3), (4), (5), and (6) are activity level characterization based on equipment process, energy demand characterization based on equipment process, carbon dioxide emission characterization based on equipment process, energy-saving potential, and carbon emission reduction potential, respectively:

$$P\,\mathrm{m},\ \mathrm{i} = \sum P\,m,\ i,\ j \tag{2}$$

$$E = \sum_{m}\sum_{\mathrm{i}}\sum_{j}\sum_{n} \mathrm{e}n, j, i, m \times Pm, i, j \tag{3}$$

$$CE = \sum_{m}\sum_{\mathrm{i}}\sum_{j}\sum_{n} \mathrm{fn, j, i, m} \times \mathrm{e}n, j, i, m \times Pm, i, j \tag{4}$$

$$ESP = \frac{E_0 - Ea}{E_0} \tag{5}$$

$$CMP = \frac{CE_0 - CEa}{CE_0} \tag{6}$$

where P_m is the typical industry product output; $P_{m,i}$ is the production output of the *i* process within the industry; $P_{m,i,j}$ is the production output of the *j* equipment in the *i* process of industry *m*; *E* is the aggregate energy demand of the representative industry sector; $e_{n,j,i,m}$ is the total energy consumption of type *n* by the *j* type of equipment in the *i* process of industry *m* during production; *CE* is the total CO_2 emissions of the typical industry; $\mathrm{f}_{n,j,i,m}$ is the CO_2 emission factor, which represents the amount of carbon emissions generated by the consumption of the *n* type of energy in the production process of the *j* type of equipment in the *i* stage of the *m* industry; *ESP* represents the potential for energy conservation; E_0 is the total energy consumption in the reference scenario; $E_a$is the total energy consumption for scenario α. CMP represents the potential for carbon mitigation; CE_0 is the total carbon emissions in the reference scenario; and CE_a is the total carbon emissions for scenario a.

This model is based on the year 2020 and targets the year 2060, assuming consistent macroeconomic, energy resource potential, energy infrastructure construction planning, and carbon sequestration potential assumptions. Through mutual calibration and multiple iterations across different sectors and energy types, the two models eventually align in terms of carbon emissions trends, energy supply, and energy consumption structures.

The CQ-LEAP model utilizes economic data primarily sourced from the 2017 Chongqing Input-Output Table. Energy data for each province and department is predominantly derived from the regional energy balance sheet in the China Energy Statistical Yearbook, provincial energy balance sheet in the China Carbon Accounting Data System, and regional electricity generation in the China Electricity Statistical Yearbook. The current version of the model adopts 2017 as its base year and aligns energy economic data to 2020 based on relevant statistics released by China's National Bureau of Statistics. Additionally, we have integrated information from the Chongqing Statistical Yearbook and extensive field survey data to refine Chongqing's energy and economic datasets. The energy structure, intensity, and activity level data for the reference year 2020 are all drawn from the Chongqing Statistical Yearbook 2021. For industries with unavailable energy intensity data directly from this source (e.g., chemical and nonmetallic industries), benchmark or entry levels are established according to those specified in documents such as "National Leading Level and Baseline Level of Energy Consumption Intensity for Key High-Consumption Industries (2021 Edition)" and "Units of Product Energy Consumption Limit Standards," supplemented by expert assessments regarding their leading status nationwide. Data settings for 2030, 2040, 2050, and 2060 refer to various sources including reports like "China Electrification Annual Development Report" (2022) and official plans such as "Opinions on Strictly Imposing Energy Efficiency Constraints" issued by the National Development and Reform Commission (NDRC)'s Industrial Development Department in 2021.

3.2. Scenario

The research is based on the current energy supply, demand, and carbon emissions of industrial sectors in Chongqing. It takes into consideration various policy promotion efforts and the level of technological development. Three scenarios are established in both top-down and bottom-up models: reference scenario (RS), positive peak – 2060 near-zero emissions Scenario (PP-NZES), and accelerated peak – 2060 net-zero emissions scenario (AP-NZES). Given that China's past and recent carbon reduction targets have been expressed in terms of carbon intensity, the national carbon intensity target will be further broken down for each region. To ensure policy comparability over a specific period, this study designs scenarios using the annual reduction rate of carbon intensity as a constraint for carbon emissions.

RS: The carbon reduction efforts in this scenario are designed based on the carbon peak and carbon neutrality targets proposed before their establishment, with China's commitment to carbon reduction at the 2015 Paris Climate Change Conference serving as the foundation. It is assumed that the annual average decrease in carbon emissions per unit of GDP remains around 4% nationwide and approximately 4.25% in Chongqing (Table 1). Moderate adjustments are made to the industrial, energy, transportation, building, and residential sectors based on policy intensity prior to the introduction of dual-carbon targets. This results in a natural reduction of carbon emissions during economic development. The economic structure undergoes moderate adjustments, while heavy industry retains its significance; most high-energy-consumption products are projected to reach peak output around 2035. Following this peak, production levels for crude steel, electrolytic aluminum, cement, synthetic ammonia, caustic soda, methanol, and paper gradually decline steadily thereafter. The energy structure also undergoes moderate adjustments, with coal-fired power generation accelerating its retirement after 2050.

Table 1
The average carbon intensity reduction rate in the three scenarios①

		Chongqing		
Year	NCNS②	RS	PP-NZES	AP-NZES
2021–2025	4.5%	4.25%	4.25%	4.25%
2026–2030	5.0%	4.25%	4.50%	5.00%
2031–2035	6.5%	4.25%	5.00%	6.50%
2036–2040	8.5%	4.25%	7.50%	8.50%
2041–2045	9.5%	4.25%	9.00%	9.50%
2046–2050	12.0%	4.25%	10.75%	12.00%
2051–2055	16.7%	4.25%	14.35%	16.70%
2056–2060	100.0%	4.25%	20.00%	100.00%

Notes: ① Carbon emissions exclude emissions from raw material usage and aviation; ② NCNS: National 2060 Carbon Neutral Scenario.

PP-NZES: The carbon reduction efforts in this scenario are aligned with the national targets of reaching peak carbon emissions before 2030 and achieving carbon neutrality before 2060. The carbon intensity reduction target for Chongqing during the "14th Five-Year Plan" period is established based on the regional decomposition plan of the national "14th Five-Year Plan," aiming for a 19.5% decrease in carbon intensity compared to 2020 by 2025 (equivalent to an annual decrease rate of 4.25% from 2021 to 2025). Furthermore, the carbon intensity reduction target for the period between 2026 and 2050 is determined according to the potential trajectory of nationwide carbon emissions required to achieve carbon neutrality, resulting in a gradual decline in Chongqing's carbon intensity. It is projected that by 2060, energy-related CO_2 emissions in Chongqing will be approximately 24 million tons, leading to near-zero CO_2 emissions. Adhering to the national dual-carbon strategy deployment, there is coordinated optimization across the industrial, energy, transportation, building, and residential sectors within the region, actively reducing carbon emissions during economic adjustments. The economic structure undergoes coordinated optimization and adjustment while witnessing rapid growth in new industries as well as significant advancements in advanced manufacturing and modern services, culminating with most high-energy-consumption products reaching their peak by 2029. Additionally, continuous optimization and adjustment are made within the energy structure, with coal-fired power generation accelerating its retirement after 2040.

AP-NZES: The carbon reduction efforts in this scenario are aligned with the national targets of reaching peak carbon emissions by 2030 and achieving carbon neutrality by 2060. The carbon intensity reduction target for the "Fourteenth Five-Year Plan" period in Chongqing is set at a 19.5% decrease compared to 2020 by 2025 (equivalent to an annual reduction rate of 4.25% from 2021 to 2025). Additionally, the carbon intensity reduction target for the period between 2026 and 2050 is based on the potential trajectory of nationwide carbon emissions required to achieve carbon neutrality, synchronized with the staged national carbon intensity reduction speed, leading to corresponding reductions in Chongqing's carbon intensity. By 2060, it is projected that energy-related CO_2 emissions in Chongqing will be approximately 10 million tons after accounting for raw material consumption and aviation fuel emissions, resulting in net-zero CO_2 emissions. To better demonstrate Chongqing's contribution to the national dual-carbon targets, we will implement mandatory adjustments in key sectors such as industry, energy, transportation, buildings, and residential lifestyles to rapidly reduce carbon emissions amidst a significant economic restructuring. The economic structure is undergoing rapid adjustments, with the strategic emerging industry experiencing significant growth. Outdated capacities are swiftly being phased out, and the peak production of high-energy-consuming products has been advanced. The peak production of crude steel, electrolytic aluminum, cement, synthetic ammonia, caustic soda, methanol, and paper is anticipated to occur around 2026. Additionally, there are swift adjustments within the energy structure as coal-fired power generation accelerates its retirement after 2030.

Utilizing the CQ-LEAP models, the carbon emission pathways of RS, PP-NZES, and AP-NZES were employed as benchmarks. Through adjustments to energy activity levels, energy intensity, and emission factors within various industrial and service sectors based on their respective processes and equipment, along with mutual verification and iterative fitting through multiple iterations, viable pathways to achieve these targets were explored. Subsequently, a multi-stage, multi-scenario analysis was conducted from the perspective of Chongqing's 2060 net-zero emissions target, encompassing dimensions such as economic scale, urban spatial layout, population distribution, industrial composition, energy structure, and technologies for energy conservation and carbon reduction policies.

4. Results

4.1. Analysis of carbon emission

The carbon emission profile of Chongqing Municipality's industrial sectors in 2020 is depicted in Figure 1. Carbon emissions from Chongqing's industrial sector are predominantly concentrated within the other industrial, chemical, building materials, and steel industries, accounting for 28%, 22%, 21%, and 15% of the total emissions, respectively. This distribution can be attributed to Chongqing's status as a typical heavy industrial city, where the chemical industry and other industries serve as a pivotal sector, generating substantial economic benefits alongside high emissions and energy consumption.

Figure 1
Status of carbon emissions from different industries in the industrial sector in Chongqing 2020

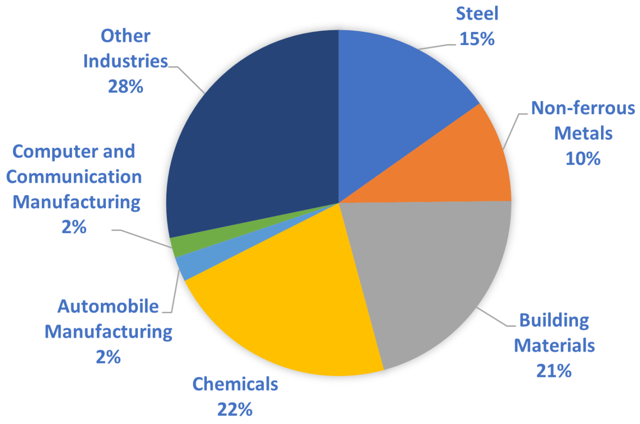


Figure 2 illustrates the trajectory of carbon emissions in Chongqing across various scenarios. The simulation indicates that, under the reference scenario, if Chongqing's unit GDP carbon emissions continue to decrease annually at a rate of 4.25%, industrial-related carbon emissions in Chongqing will reach a peak of approximately 108 million tons of CO_2 in 2033. Subsequently, due to insufficient adjustments in the industrial structure, particularly regarding control over high-energy-consumption and high-emission industrial output, and heavy reliance on natural social and economic development for technological progress and energy structure optimization, this scenario falls short of achieving the "carbon neutrality" goal by 2060. In the PP-NZES, Chongqing increases its utilization of clean energy and enhances terminal electrification rates during the "14th Five-Year Plan" and the "15th Five-Year Plan" period, resulting in industrial carbon emissions peaking at about 105 million tons of CO_2 in 2029—four years earlier than projected—and experiencing a reduction of 2.7% from the peak level seen in the reference scenario. In AP-NZES, Chongqing proactively optimizes and adjusts its industrial structure while rigorously controlling output from high-emission and high-energy consumption industries; as a result, industrial carbon emissions are anticipated to peak at 101 million tons of CO_2 by 2027—a further reduction in the timeframe for reaching maximum levels. Beyond this point (2027), all industries will persist with optimizing their structures related to industry and energy while implementing green initiatives aimed at low-carbon transformation within the sector; consequently, by 2060—without considering Carbon Capture, Utilization and Storage (CCUS)—industrial carbon emissions are expected to diminish to just 3.87 million tons.

In the reference scenario, Chongqing fell short of achieving carbon neutrality. As a result, this study primarily examines the trajectory of industrial development toward net-zero carbon emissions in Chongqing. Consequently, the subsequent analysis focuses on the accelerated peak – 2060 net-zero emission scenario to attain Chongqing's industrial "dual-carbon" target.

4.2. Transformation of the energy structure

The change in the primary energy consumption structure of the industrial sector in Chongqing Municipality is shown in Figure 3. Primary energy demand first increased and then decreased, rising from 37.54 million tons of standard coal in 2020 to 45.49 million tons of standard coal in 2030. The shares of electricity, natural gas, and coal were 29.50%, 24.04%, and 36.15%, respectively, with respective increases of 65.17%, 13.36%, and 4.23% compared to 2020. As the industrial sector phased out outdated capacity and upgraded technologies, demand gradually decreased, reaching 20.67 million tons of standard coal in 2060, a total decrease of 44.93%. While total energy demand decreased, the energy structure became cleaner. Coal and oil consumption in primary energy demand steadily decreased, accounting for 50.16% and 2.37% of the total in 2020, respectively, and dropping to 9.85% and 0.60% in 2050. By 2060, coal and oil would be almost completely phased out, with only a small portion remaining for industrial production. Natural gas is the fossil fuel with the lowest emissions, and its share in the peak stage after the peak would remain relatively slow in its decline compared to coal and oil. Electricity would replace the declining coal and oil in the peak stage as a substitute energy source, reaching a share of 74.57% in 2050. In the carbon-neutral stage, the share of

Figure 2
Trend of overall industrial carbon emissions in Chongqing, 2020–2060

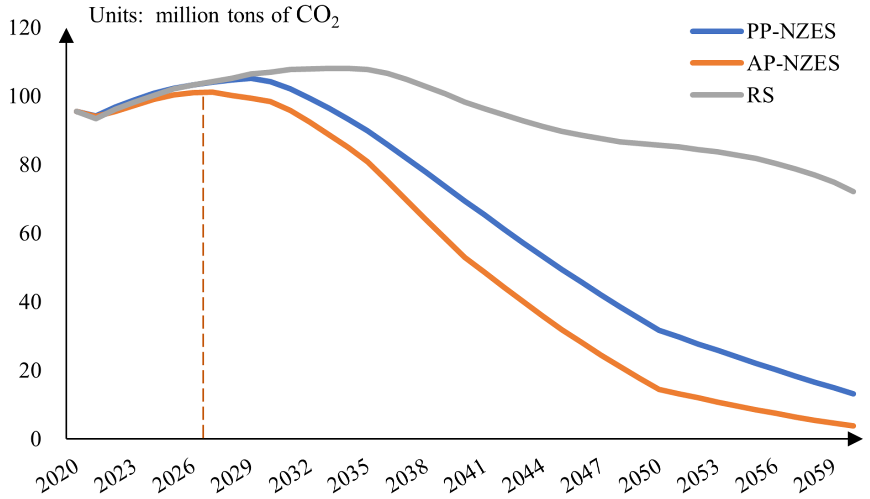
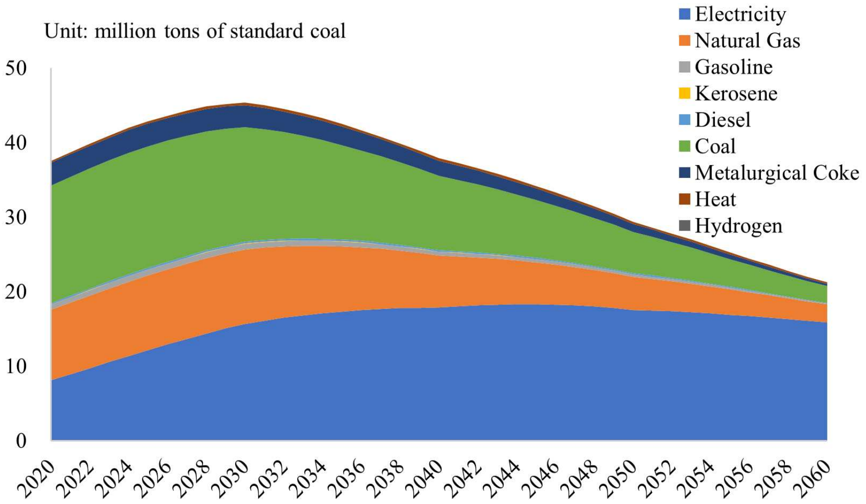


Figure 3
Primary energy consumption structure in Chongqing, 2020–2060



natural gas as a fossil fuel generating emissions would drop below 5%. It can be seen that the accelerated peak and net-zero emissions scenario 2060 shows a reduction in final energy consumption while the energy structure gradually shifts toward clean energy, which means that if the industrial sector in Chongqing takes active measures to reduce energy consumption and improve energy efficiency under the guidance of policy planning, the energy-saving situation in the future will see further improvement.

The energy demand structure by industry is illustrated in Figure 4, with steel, building materials, chemicals, and other industrial sectors serving as the current and future cornerstone industries of Chongqing's industrial sector due to their substantial demand and intricate production processes. This results in a notably higher energy demand compared to the remaining industrial sectors. In 2020 and 2060, these industries, respectively, account for 87.3% and 86.5% of the total energy demand within the industrial sector while also ranking among the top four emitters of carbon emissions. Additionally, three of these industries are highly reliant on energy-intensive resources. Following peak carbon emissions, adjustments will be made to the industrial structure through policy implementation aimed at controlling output from high-emission industries and reinforcing green technologies. Consequently, there will be a significant reduction in both overall and sector-specific energy demands within the industrial sector. Simultaneously with structural adjustments within this sector, Chongqing's overall industry trend is gradually transitioning toward an increased proportion of clean energy usage alongside reduced reliance on fossil fuels. The enhancement of external power supply measures will facilitate Chongqing's gradual progression toward a net-zero carbon emissions development path.

4.3. Carbon emission reduction potential

The term "energy-saving contribution" refers to the disparity between the industrial sector's energy demand in a specific year under a reference scenario and its energy demand in the same year under an alternative scenario, while "carbon reduction potential" denotes the difference between CO_2 emissions from the industrial sector in that same year under both scenarios. A positive value indicates potential for carbon reduction and energy savings.

Figure 4
Structure of energy demand by sector in Chongqing, 2020–2060

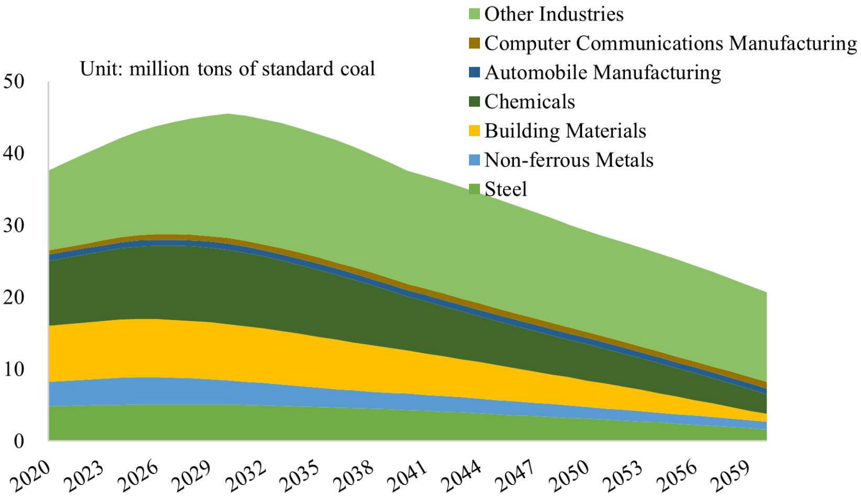
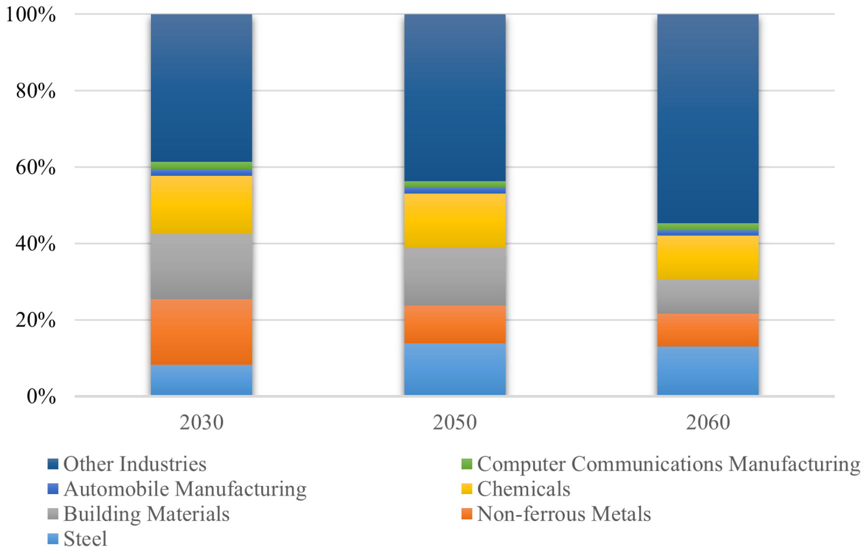


Figure 5
The carbon reduction potential of the industrial sector in Chongqing for the years 2030, 2050, and 2060

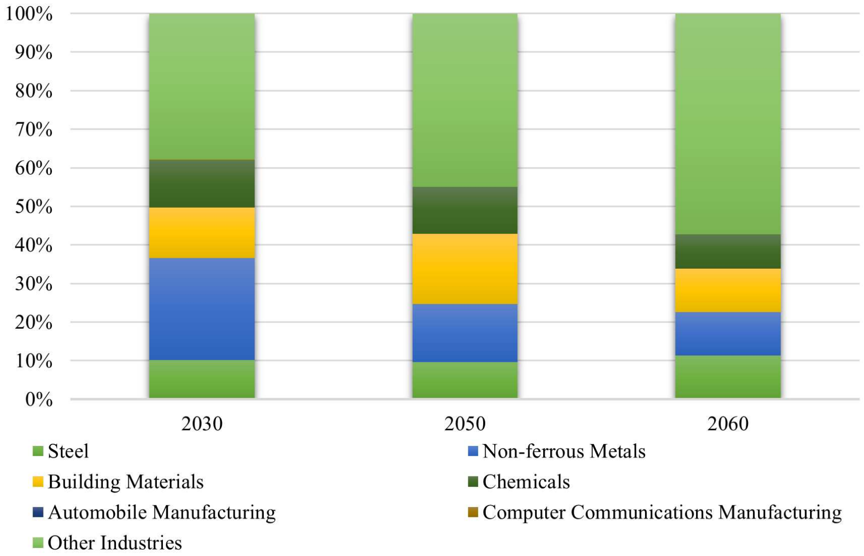


Figures 5 and 6 illustrate the carbon reduction potential and energy-saving contributions of the industrial sector within the accelerated peak and net-zero emissions 2060 scenario for 2030, 2050, and 2060. Overall, as we move toward net-zero carbon emissions, each industrial sector exhibits carbon reduction potential and contributes to energy savings annually, with these contributions increasing over time. In terms of carbon reduction potential, other industries, along with non-ferrous metals, building materials, and chemicals, demonstrate significant potential, accounting for a respective 39%, 17%, and another 17% of total industrial sector reductions by 2030. Conversely, the manufacturing industry's impact on carbon reductions is relatively minor due to its comparatively lower energy demands and carbon emissions within the industrial domain. Compared with different years, in the later period of the carbon peak, the proportion of emission reduction in other industries and steel gradually increased, increasing from 39% and 8% in 2030 to 44% and 14% in 2050, the proportion of emission reduction in non-ferrous metals and building materials slowly declined, and the proportion of chemical and related manufacturing industries changed little.

In terms of energy-saving contribution, the energy-saving contribution of other industries is considerable and shows a significant increase trend, which is due to the adjustment of industrial structures in the later period of emission reduction, the energy-saving contribution of the steel industry has not changed much, and the energy-saving contribution of non-ferrous metals, building materials, and chemical industry has changed significantly, and the trend is not fixed. In 2030, the two industries with the highest energy conservation contributions are other industries and non-ferrous industries; in 2050, the two industries with the highest energy conservation contributions are other industries and building materials; in 2060, the other industries have the highest energy conservation contributions， there is no significant difference in the energy conservation contributions of building materials, non-ferrous industries and steel.

The CQ-CREM-LEAP model is employed in this study to develop an energy and environmental emission model for the

Figure 6
The carbon reduction contribution of the industrial sector in Chongqing for the years 2030, 2050, and 2060



industrial sectors (steel, non-ferrous metals, building materials, chemicals, automobile manufacturing, computer and communication equipment manufacturing, and other industries) in Chongqing City. It simulates energy consumption and CO_2 emissions under various scenarios from 2020 to 2060 while conducting a comparative analysis of each industry's emission reduction potential. The primary findings are as follows:

In AP-NZES, industrial CO_2 emissions are projected to reach their peak in 2027, with an estimated level of approximately 101.15 million tons. By 2060, without considering CCUS, it is anticipated that there will still be 3.87 million tons of emissions. The non-ferrous metals, building materials, steel, and chemical industries are expected to reach their peak emissions before 2027 while maintaining a stable ranking in terms of emissions. The driving forces behind emission growth are undergoing significant changes, with the power generation, chemical manufacturing, nonmetallic mineral products production, ferrous metals production, non-ferrous metals smelting, and paper industries serving as key battlegrounds for CO_2 emission reduction within the industrial sector.

Electricity, natural gas, and coal are the primary energy consumption sources in the industrial sector. In 2020, electricity consumption amounted to 812.5 million standard coal tons, representing 21.6% of total energy consumption. Anticipated improvements in the industrial sector's electrification level and the establishment of a diversified and clean power supply system are expected to lead to a rapid increase in electricity consumption. However, current plans for local power generation and power import channels may not be sufficient to support economic and social development beyond 2035. The continued enhancement of the existing low-emission industrial structure poses a significant challenge within the context of an accelerated peak – 2060 net-zero emission scenario. Additionally, limited technological innovation capacity related to carbon peak and carbon neutrality—particularly in fundamental and original industrial technological innovation—and constrained potential for negative emission technologies within industry make earlier achievement of carbon neutrality difficult.

The emission reduction contributions of the seven industrial sectors, encompassing iron and steel, non-ferrous metals, building materials, chemicals, automobile manufacturing, computer and communication equipment manufacturing, and other industrial sectors were 15.68%, 9.74%, 21.58%, 21.89%, 2.24%, 1.74%, and 27.13% respectively. The three industries that made the most substantial contribution to emission reduction were chemicals, building materials, and other industrial sectors. However, in Chongqing in 2020, the energy consumption of chemicals, building materials, non-ferrous metals, and iron and steel industries accounted for a relatively high proportion of total industrial energy consumption at 66.8%. This is projected to remain at a significant level of 46.2% by the year 2050. Therefore, in the short term, industrial structure adjustment is still the most direct and effective way to reduce carbon emission reduction in Chongqing. At the same time, it is necessary to grasp the opportunity of "plus" (increasing war new industries) and "less" (reducing industries with high energy consumption and high emissions) transformation. In the medium and long term, the focus of carbon emission reduction is to take the lead in capturing and sharing the dividends of cutting-edge and disruptive technologies, promote the adjustment of Chongqing's energy structure, and accelerate the decoupling from fossil energy.

5. Discussion

To achieve the ambitious target of net-zero carbon emissions in Chongqing before 2060, a profound transformation of the industrial sector is imperative during the 15th Five-Year Plan period. This transformation necessitates the systematic and orderly phasing out of obsolete production capacities. Furthermore, it is critical to facilitate the orderly peak of carbon emissions within high-energy-consuming industries while actively fostering the development of strategic emerging sectors. Prioritizing the integration of renewable energy sources and enhancing industrial electrification, particularly the electrification of end-use energy, should be at the forefront of this initiative.

Continuous advancement in the implementation of building-integrated photovoltaics within industrial parks is essential, alongside the promotion of innovative heating and cooling technologies in industrial facilities. The deepening of green manufacturing initiatives and the enhancement of the green manufacturing ecosystem must be prioritized. Additionally, efforts to integrate digitalization, artificial intelligence, and sustainable practices within the industrial sector are crucial. Strengthening technological upgrades in pivotal industries and fields, along with fostering process innovations that yield substantial emissions reductions, is particularly vital for sectors facing significant challenges in emission reduction.

In the steel industry, enhancing the recycling and utilization of scrap steel is imperative. This can be complemented by exploring pilot projects for hydrogen metallurgy and carbon capture and utilization, as well as promoting the utilization of low-grade waste heat. The non-ferrous metal sector should focus on improving the recycling, sorting, and processing frameworks for discarded non-ferrous metals, aiming for consistent reductions in energy consumption per unit of product. The building materials sector must expedite the decommissioning of inefficient production capacities, accelerate the certification and promotion of green building materials, and advance the implementation of energy-saving technologies and equipment. In the petrochemical and chemical industries, optimizing production scale and layout, eradicating outdated capacities, and effectively addressing structural overcapacity are essential steps.

A comprehensive enhancement of resource utilization efficiency is critical for synergistically reducing resource consumption and carbon emissions. This involves promoting the circular development of industrial parks, enhancing the comprehensive utilization of large volumes of solid waste, and establishing a robust resource recycling system. Furthermore, vigorous promotion of waste reduction, resource utilization, and treatment of municipal solid waste is required, alongside raising energy efficiency standards for industrial equipment. Key energy-consuming sectors should focus on energy-saving improvements and efficiency enhancements.

Collaboration among universities, research institutions, and state-owned enterprises should be fostered to drive research and development in low-carbon, zero-carbon, and negative-carbon technologies. Accelerating the exploration and implementation of advanced, applicable technologies is vital, particularly in high-energy-consuming and high-emission industries such as power generation, metallurgy, building materials, and chemicals. Strengthening innovation in green and low-carbon scientific and technological services, as well as implementing the Action Plan for Green Science and Technology Cooperation and Innovation, is essential.

From a policy perspective, enhancing organizational leadership is crucial for successfully attaining carbon neutrality. Effective organization and management of carbon neutrality initiatives in Chongqing should be prioritized, which includes crafting a comprehensive top-level implementation framework, establishing a transparent and effective operational system, and continuously optimizing the management structure for carbon neutrality. Additionally, it is necessary to strengthen foundational capabilities for carbon neutrality by promoting the development of comprehensive carbon emission data, accelerating the collection and utilization of energy big data, and establishing a holistic societal carbon credit certification system.

Guiding key energy-intensive enterprises in adopting carbon asset management practices, enhancing climate change literacy within society, and exploring local legislative measures related to carbon neutrality are also essential. Fiscal and tax policies should be strategically employed to provide both incentives and constraints, concentrating on key areas for support, optimizing fiscal measures and fund allocation, and deepening reforms in environmental and resource taxation.

Furthermore, financial policies should facilitate the establishment of a low-carbon credit system rooted in green finance, invigorate the carbon trading market, accelerate the development of regional carbon financial third-party markets, and promote the formation of carbon financial reform pilot zones. Pricing policies should be designed to incentivize and regulate energy consumption, particularly through the classification and optimization of demand-side time-of-use electricity pricing, enhancing support for renewable energy supply, and aligning market-based reforms of energy and resource pricing. Comprehensive policy integration and synergistic efforts must be emphasized to promote the healthy and sustained rapid development of the new energy vehicle sector, the hydrogen economy, and energy storage technologies.

6. Conclusions

Based on the comprehensive analysis of Chongqing's development trajectory, resource endowments, energy supply and demand characteristics, and industrial structure from 2005 to 2020, this study highlights the significant achievements in carbon emission reduction over the past 15 years. By utilizing the carbon emission inventory for Chongqing, the research evaluates the costs associated with industrial technological advancements and identifies potential pathways and breakthroughs necessary for achieving net-zero emissions. Furthermore, it contextualizes these findings within the framework of the "15th Five-Year Plan," emphasizing the policy priorities that will guide Chongqing toward its net-zero emissions goals.

The primary focus of this study centers on Chongqing's industrial sector, providing insights that can be instrumental for other industrial cities striving for green and low-carbon transitions. The analysis reveals that industrialization has a profound impact on urban carbon emissions, with heavy industry playing a pivotal role in contributing to national carbon emissions in China. In light of the "dual-carbon" objectives, both Chongqing and many industrial cities face formidable challenges that demand significant reforms in their economic and energy structures. For cities dominated by energy-intensive sectors such as coal, steel, power generation, and building materials, achieving carbon peak and carbon neutrality will require more substantial efforts compared to less industrialized regions.

To facilitate meaningful emission reductions, it is crucial for industrial cities to balance environmental sustainability with social and economic development. Emission reduction strategies should be framed within a long-term strategic vision that emphasizes innovation-driven growth, efficient resource allocation, and concentrated development. Moreover, these strategies should leverage market mechanisms while ensuring government oversight, adopting risk-averse practices to safeguard public interests.

In conclusion, this study underscores several essential recommendations for Chongqing's journey toward decarbonization:

1) Diversification of Energy Supply. A strategic shift toward low-carbon and clean energy sources is essential. This encompasses the acceleration of renewable energy and nuclear power development to elevate the proportion of low-carbon/zero-carbon electricity generation while optimizing the energy mix to minimize CO_2 emissions without jeopardizing energy security.
2) Promotion of Advanced Energy Efficiency Technologies. It is imperative to advocate for innovative energy-saving technologies and systematically phase out obsolete production capacities to enhance overall energy efficiency.
3) Enhancement of Energy Efficiency Across the Supply Chain: Improving the efficiency of energy transportation, processing, and utilization is critical for achieving granular emission reductions.

4) Development of a Circular Economy. Establishing a green, low-carbon, circular industrial system is vital for integrating energy conservation and CO_2 emission reduction through comprehensive industrial transformation and upgrading.
5) Structural Optimization of Industries. A strategic emphasis on increasing the tertiary sector's share while regulating the expansion of energy-intensive heavy industries is essential for fostering structural energy savings.
6) Embracing Electrification Trends. Future opportunities for deep electrification in end-use sectors should be harnessed in alignment with ongoing digitalization and smart technologies to facilitate CO_2 neutrality in industrial, construction, and transportation sectors.

The value of this research lies not only in its detailed examination of Chongqing's carbon reduction strategies but also in its provision of a framework that can guide similar industrial cities in their pursuit of sustainable development. Future research should explore several avenues, including (1) the practical effectiveness of various policy measures in real-world applications, (2) successful case studies of industrial transition and carbon reduction across different cities, (3) the specific impacts of diverse energy structures on carbon emissions, and (4) optimal combinations of market mechanisms and governmental interventions to foster low-carbon development. These inquiries will contribute to a more nuanced understanding of the challenges and solutions associated with achieving net-zero emissions in industrial settings.

Acknowledgment

The authors wish to extend sincere appreciation to the editor and anonymous reviewers for their invaluable comments and suggestions.

Funding Support

This work is sponsored by the Major Program of the National Fund of Philosophy and Social Science of China: The triangle dilemma of energy impossibility under the dual-carbon target and China's solution strategy (24AGL003).

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Chunyan Dai: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Jing Zhang**: Software, Validation, Formal analysis, Data curation, Writing – original draft, Visualization. **Shiyan Chang**: Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing – review & editing. **Hao Meng**: Conceptualization, Validation, Writing – review & editing.

References

[1] Wu, W., Zhang, T. T., Xie, X. M., & Huang, Z. (2019). jī yú L E A P mó xíng de qū yù dī tàn fā zhăn lù jìng yán jiū —— yǐ zhè jiāng shěng wéi lì [An analysis of low-carbon development strategies for regional areas using the LEAP model: A case study of Zhejiang Province]. *Ecological Economy*, *35*(12), 19–24.

[2] Cai, L., Duan, J., Lu, X., Luo, J., Yi, B., Wang, Y., ...& Wang, L. Y. (2022). Pathways for electric power industry to achieve carbon emissions peak and carbon neutrality based on LEAP model: A case study of state-owned power generation enterprise in China. *Computers & Industrial Engineering*, *170*, 108334. https://doi.org/10.1016/j.cie.2022.108334

[3] Fankhauser, S., Smith, S. M., Allen, M., Axelsson, K., Hale, T., Hepburn, C., ... & Wetzer, T. (2022). The meaning of net zero and how to get it right. *Nature Climate Change*, *12*(1), 15–21. https://doi.org/10.1038/s41558-021-01245-w

[4] Andersson, J., & Hellsmark, H. (2024). Directionality in transformative policy missions: The case of reaching net zero emissions in the Swedish process industry. *Journal of Cleaner Production*, *437*, 140664. https://doi.org/10.1016/j.jclepro.2024.140664

[5] Chen, N. X. (2021). *Research on energy consumption and carbon emission of industrial sectors in Shanghai based on LEAP model*. Doctoral Dissertation, Donghua University.

[6] Zhao, Y. R., Liu, H. M., Li, W, & Gong, L. D. (2023). shuāng tàn ” mù biāo xià wŏ guó diàn lì bù mén dī tàn zhuăn xíng zhèng cè yán jiū [Research on the low-carbon transition policies of power sector under the "Double Carbon" goal]. *Climate Change Research*, *19*(5), 634–644. https://doi.org/10.12006/j.issn.1673-1719.2023.041

[7] Yang, J. N., & Chen, Y. T. (2023). Chéng shì jí bié duì yú lăo gōng yè chéng shì chăn yè jié gòu yōu huà de yǐng xiăng yán jiū [Study on the influence of administrative level on the optimization of industrial structure in old industrial cities]. *Scientific Decision Making*, *3*(3), 115–127. https://doi.org/10.3773/j.issn.1006-4885.2023.03.115

[8] Meng, X. F., Wang, D. Y., & Li, H. (2018). Analysis on driving forces of construction occupation of arable land in old industrial cities of Northeast China. *Transactions of the Chinese Society of Agricultural Engineering*, *34*(11), 225–233. https://dx.doi.org/10.11975/j.issn.1002-6819.2018.11.029

[9] Tian, J., Shan, Y., Zheng, H., Lin, X., Liang, X., & Guan, D. (2019). Structural patterns of city-level CO_2 emissions in Northwest China. *Journal of Cleaner Production*, *223*, 553–563. https://doi.org/10.1016/j.jclepro.2019.03.146

[10] Tang, Z., Fu, M., Wang, Y., & Zhao, Y. (2023). Spatial characteristics of industrial economic location and its formation in Chongqing, China. *Frontiers in Environmental Science*, *11*, 1115067. https://doi.org/10.3389/fenvs.2023.1115067

[11] Panos, E., Kannan, R., Hirschberg, S., & Kober, T. (2023). An assessment of energy system transformation pathways to achieve net-zero carbon dioxide emissions in Switzerland. *Communications Earth & Environment*, *4*(157), 1–18. https://doi.org/10.1038/s43247-023-00813-6

[12] Shahbaz, M., Nasir, M. A., Hille, E., & Mahalik, M. K. (2020). UK's net-zero carbon emissions target: Investigating the poten-

tial role of economic growth, financial development, and R&D expenditures based on historical data (1870–2017). *Technological Forecasting and Social Change*, *161*, 120255. https://doi.org/10.1016/j.techfore.2020.120255

[13] Karlsson, I., Rootzén, J., & Johnsson, F. (2020). Reaching net-zero carbon emissions in construction supply chains–Analysis of a Swedish road construction project. *Renewable and Sustainable Energy Reviews*, *120*, 109651. https://doi.org/10.1016/j.rser.2019.109651

[14] Tan, C., Yu, X., & Guan, Y. (2022). A technology-driven pathway to net-zero carbon emissions for China's cement industry. *Applied Energy*, *325*, 119804. https://doi.org/10.1016/j.apenergy.2022.119804

[15] Lu, L., Chen, Y., Feng, Q., Li, W., & Chen, D. (2024). Long-range energy demand and greenhouse gas emissions analysis using the LEAP Model: A case study of building ceramic industrial park. *Energy for Sustainable Development*, *83*, 101594. https://doi.org/10.1016/j.esd.2024.101594

[16] Li, S., Kong, W., Wang, Y., & Yuan, L. (2024). Medium and long-term energy demand forecasts by sectors in China under the goal of "carbon peaking & carbon neutrality": Based on the LEAP-China model. *Energy*, *310*, 133017. https://doi.org/10.1016/j.energy.2024.133017

[17] Kumar, A., Bhattacharya, S. C., & Pham, H. L. (2003). Greenhouse gas mitigation potential of biomass energy technologies in Vietnam using the long range energy alternative planning system model. *Energy*, *28*(7), 627–654. https://doi.org/10.1016/S0360-5442(02)00157-3

[18] SEI & TI. (2006). *LEAP: Long range energy alternatives planning system user guide*. Retrieved from: https://tellus.org/tellus/publication/leap-long-range-energy-alternatives-planning-system-user-guide

[19] Cao, Y., Guo, L., Qu, Y., & Wang, L. (2024). Possibility and pathways of China's nonferrous metals industry to achieve its carbon peak target before 2030: A new integrated dynamic forecasting model. *Energy*, *306*, 132386. https://doi.org/10.1016/j.energy.2024.132386

[20] Zhang, X., Yin, S., Lu, X., Liu, Y., Wang, T., Zhang, B., ... & Chen, K. (2025). Establish of air pollutants and greenhouse gases emission inventory and co-benefits of their reduction of transportation sector in Central China. *Journal of Environmental Sciences*, *150*, 604–621. https://doi.org/10.1016/j.jes.2023.12.025

[21] Li, L., Li, J., Peng, L., Wang, X., & Sun, S. (2023). Optimal pathway to urban carbon neutrality based on scenario simulation: A case study of Shanghai, China. *Journal of Cleaner Production*, *416*. 137901.https://doi.org/10.1016/j.jclepro.2023.137901

[22] Miao, A., Yuan, Y., Wu, H., Ma, X., Shao, C., & Xiang, S. (2024). Pathway for China's provincial carbon emission peak: A case study of the Jiangsu Province. *Energy*, *298*, 131417. https://doi.org/10.1016/j.energy.2024.131417

[23] Wen, J., Wang, S., Yu, S., Wang, K., Zhang, R., & Li, W. (2024). Low-carbon transition paths and benefits for the power sector at city level: A case study in Zhengzhou, China. *Journal of Cleaner Production*, *450*, 141852. https://doi.org/10.1016/j.jclepro.2024.141852

[24] Gao, A., Sun, M., & Wen, W. (2024). Uncovering the spillover effects between the new energy industry and eleven economic sectors in China: Evidence based on stock data. *Energy*, *301*, 131671. https://doi.org/10.1016/j.energy.2024.131671

How to Cite: Dai, C., Zhang, J., Chang, S., & Meng, H. (2025). Strategies for Achieving Carbon Neutrality in Chinese Metropolitan's Industrial Development: A Case Study of Chongqing in China. *Green and Low-Carbon Economy*. https://doi.org/10.47852/bonviewGLCE52023971

Appendix

Table A1
Sector classification and description

Industry	Sector	Name	Description
Agriculture	Agriculture	AGR	Agriculture, forestry, animal husbandry, and fisheries
Energy industry	Coal	COL	Coal mining, washing, and coking industries
	Crude oil	OIL	The crude oil extraction industry
	Natural gas	GAS	Natural gas extraction and processing industry
	Oil products	ROI	Refined oil processing industry
	Electricity	ELE	Production and supply of electricity and heat
Energy-intensive industries	Chemical	CRP	Chemical raw materials, chemical products, medicine, and chemical fiber manufacturing
	Metal	ISM	Iron and steel, non-ferrous metal smelting, and rolling processing industry
	Nonmetal	NMM	Manufacture of nonmetallic mineral products
Other industries	Water production supply	WAT	Water production and supply industry
	Mining industry	MIN	Mining and beneficiation of metallic ore, nonmetallic ore, and other ores
	Building industry	CNS	Building industry
	Transportation equipment manufacturing industry	TEQ	Transportation equipment manufacturing and processing industry
	Food manufacturing industry	FOD	Food, tobacco, alcohol, tobacco, and other manufacturing
	Garment manufacturing industry	TWL	Textile industry, leather, fur, and other processing manufacturing industries
	Electronics product manufacturing industry	ELM	Electrical, electronic equipment, and instrumentation manufacturing
	Other manufacturing	OTH	Metal products, scrap, and repair
	Other machinery manufacturing	OME	General, special equipment manufacturing
Service Industry	Transportation industry	TRN	Transportation, warehousing, and postal services
	Other services	SER	Finance, education, and other services
	Property	DWE	Real estate industry
Consuming sectors	Government consumption	GOV	Government consumption
	Household consumption	HHC	Household consumption

Table A2
Main elasticity of substitution values of the model

parameter	Elastic substitution relation	value
σ_{en}	Energy type (excluding electricity)	1
σ_{enoe}	Energy – electricity	0.5
σ_{eva}	Energy/power – value added	0.5
σ_{kl}	Capital-labor	1
σ_{klem}	Capital/labor/energy – factors of production	0.5
σ_{cong}	Power sector coal, oil – natural gas	2
σ_{co}	Coal – oil in the power sector	2
σ_{hn}	Amount of resources in the power sector – other inputs	0.01
σ_{rcol}	Coal power sector resources – other inputs	0.7
σ_{roil}	Oil and power sector resources – other inputs	0.6
σ_{rgas}	Gas and power sector resources – other inputs	1.2
σ_{genoe}	Government sector consumption of energy – other inputs	0.5
σ_{gen}	Government sector consumption between energy	0.1
σ_{gnoe}	Government departments consume between other goods	1
σ_{ct}	Transportation in household consumption sector – non-transportation	0.5
σ_{ce}	Household consumption of medium energy – non-energy	0.3
σ_{c}	Household consumption of non-energy commodities	0.3
σ_{ef}	Household consumption of medium energy commodities	0.5