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Scenario of carbon dioxide (CO₂) emission peaking and reduction path implication in five northwestern provinces of China by the low emissions analysis platform (LEAP) model

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Achieving global peaking of carbon dioxide (CO₂) emissions as early as possible is a common goal for all countries. However, CO₂ emissions in the northwest China still show a rapid growth trend. Thus, we used the Low Emissions Analysis Platform (LEAP) model to build three scenarios to investigate the peak of CO₂ emissions and reduction pathways in five northwestern provinces of China. The results show that: 1) the CO₂ emissions of five northwestern provinces under the baseline, the policy, and the green scenarios will peak in 2035 (1663.46 × 10⁶ tonnes), 2031 (1405.00 × 10⁶ tonnes), and 2027 (1273.96 × 10⁶ tonnes), respectively. 2) The CO₂ emissions of all provinces, except Qinghai, will not peak before 2030 in the baseline scenario. Under the policy and green scenarios, each province will achieve the peak of CO₂ emissions by 2030. 3) The CO₂ emissions from agriculture, transportation, and other sectors will peak before 2030 under the baseline scenario. The CO₂ emissions from construction will peak before 2030 in policy scenario. The industry and commerce will peak before 2030 in green scenario. 4) The emission reduction effect indicates that CO₂ emissions from 2020 to 2040 will be reduced by 4137.70 × 10⁶ tonnes in the policy scenario and 7201.46 × 10⁶ tonnes in the green scenario. The industrial coal and thermal power are the sectors with the greatest potential to reduce CO₂ emissions. Accelerating the restructuring of industries and energy structures and improving technologies to reduce energy intensity can promote the achievement of the peak in CO₂ emissions by 2030.

KEYWORDS

five northwestern provinces of China, CO₂, LEAP, scenario, reduction path

1 Introduction

Global warming caused by CO₂ emissions has become a serious threat to human survival and development. In 2015, the Paris Agreement clearly states that the global average temperature cannot be more than 1.5–2°C above pre-industrial levels, with parties aiming to reach a global peak in greenhouse gas emissions as soon as possible ([The United Nations Framework Convention on Climate Change, 2015](#)). As the world's largest carbon emitter, China has also made a series of emission reduction measures and pledged to achieve the peaking of CO₂ emissions by 2030 ([Intended Nationally Determined Contributions, 2015](#)). However, it will require the joint efforts of all provinces to achieve these ambitious goals.

The five northwestern provinces of China, which contain Shaanxi, Gansu, Ningxia, Qinghai and Xinjiang (See [Supplementary Material](#)), are deeply inland and are not conducive to attracting investment compared with the eastern coastal regions. In addition, the implementation of open-door policy has accelerated the outflow of talent and technology from the region, resulting in a lagging economic and technological level in the region ([Fu et al., 2015](#); [Zeng et al., 2019](#)). However, abundant fossil energy is an inherent advantage of the region ([Chen et al., 2010](#)). In recent years, with its advantages and the support of policies such as “One Belt, One Road” and Western Development, the economy of the region is expected to maintain a rapid growth trend. Economic development will inevitably lead to the massive consumption of fossil energy, thus producing more greenhouse gases. This will have a negative impact on achieving the target of the peaking of CO₂ emissions by 2030. Therefore, the scenario analysis of CO₂ emission peaks and emission reduction pathways in northwest China is of great practical importance.

The methods of estimating energy demand and CO₂ emissions are mainly divided into three categories: top-down, bottom-up, and hybrid models. Top-down models, such as the computable general equilibrium model, can simulate the response of sectors to policy shocks ([Krook-Riekkola et al., 2017](#)). However, they cannot explain the specific pathway of the peak in CO₂ emissions ([Yu et al., 2014](#); [Yan et al., 2021](#)). Hybrid models, such as the global change assessment model, are fully functional, but their structures are complex ([Zhang et al., 2019](#)). The Low Emissions Analysis Platform (LEAP) model is a typical bottom-up model that includes energy supply, energy conversion, and final energy demand. It can forecast the energy demand of a country or region and calculate the greenhouse-gas emissions ([Heaps, 2022](#); [Sun et al., 2022](#)). The policy analyst can create and evaluate different scenarios by comparing the indicators to be achieved. Therefore, many scholars have studied CO₂ emissions from different sectors using the LEAP model. For example, using LEAP model, [Duan et al. \(2019\)](#) analyzed the peak of CO₂ emissions from the construction sector in Jilin Province of China, and their results indicate that the construction sector will peak in 2030. [Masoomi et al. \(2021\)](#)

projected CO₂ emissions from the power sector in Iran, and the results indicate that the CO₂ emissions from the power sector will reach 429 Mt by 2035. [Liu et al. \(2021\)](#) investigated the peak of CO₂ emissions from the tourism sector of China, and their research suggests that the tourism sector will peak in 2033. [Zhao et al. \(2021\)](#) analyzed the peak of carbon emissions from the transportation sector in Guangdong Province of China, and the results indicate that the peak will be reached in 2027 under the low-carbon scenario. [Duan et al. \(2022\)](#) analyzed the peak of CO₂ emissions from the industrial sector of China, and the results indicate that the industrial sector will peak in 2030 under the energy-saving and low-carbon scenario. All the above scholars have studied the peak of CO₂ emissions from a single sector. However, the achievement of a region's peak target for CO₂ emissions requires the combined efforts of multiple sectors. Therefore, we created three CO₂ emission scenarios for six major sectors and analyzed the reduction potential of each sector in the lagging northwestern region of China. This study can specifically analyze the peak pathways and emission reduction measures of CO₂ for each sector in the region.

2 Data sources and methodology

2.1 Data sources

The data of energy consumption and value added by sector are obtained from the China Energy Statistical Yearbook, Provincial Statistical Yearbooks, and the official website from the National Bureau of Statistics. Various types of energy are classified into coal, oil products, natural gas, and electricity. Furthermore, to eliminate the effect of price changes, the value added by each sector in past years was converted to constant 2010 prices.

2.2 Methodology

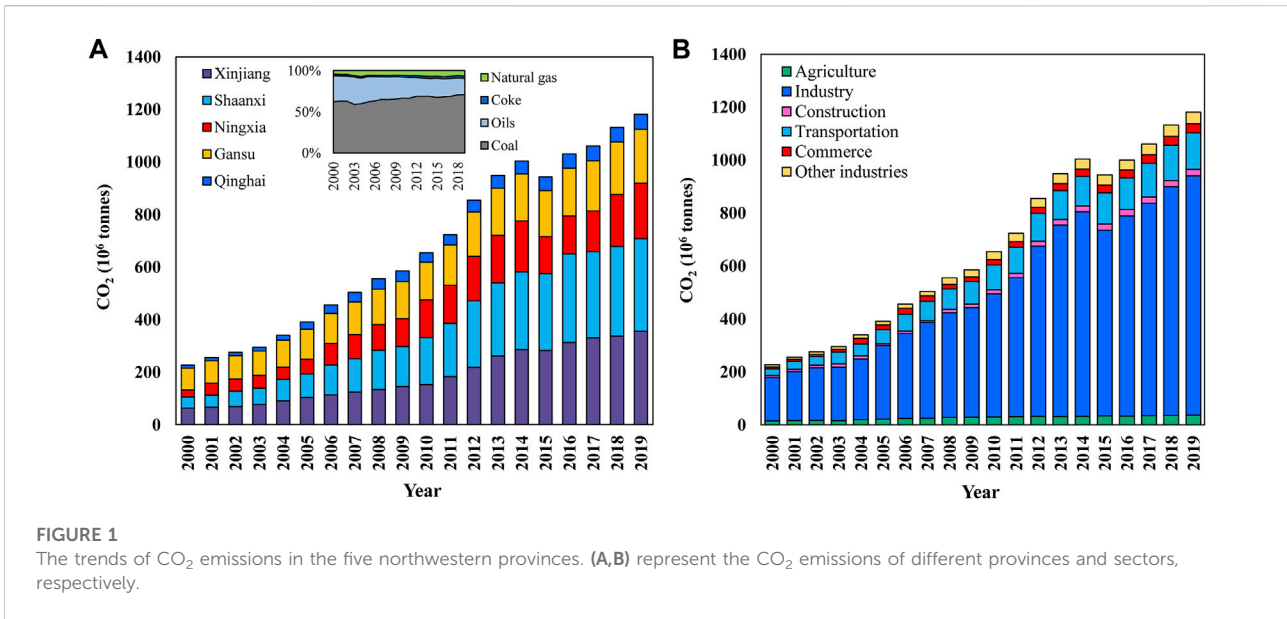
According to the LEAP model, total CO₂ emissions are from terminal energy consumption and energy conversion processes. The formula is as follows:

$$C_{tot} = TE_{tot} + CE_{tot} \quad (1)$$

where, C_{tot} denotes the total CO₂ emissions, TE_{tot} and CE_{tot} denote the total CO₂ emissions from terminal energy consumption and energy conversion processes, respectively.

$$TE_{tot} = \sum_i \sum_j AL_i \times EI_i \times \theta_{i,j} \times EF_j \quad (2)$$

where, AL_i is the activity data for value added of industry i , EI_i is the energy intensity of industry i , $\theta_{i,j}$ is the ratio of energy consumption j in industry i to total energy consumption in industry i , EF_j is the CO₂ emission factor of energy j . CO₂ emission factors are obtained from the 2006 Intergovernmental



Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

$$CE_{tot} = \sum_p \sum_t \sum_j (ETP_{p,t,j} / f_{p,t,j}) \times EF_j \quad (3)$$

where, $ETP_{p,t,j}$ is the secondary energy p produced by the primary energy j through the conversion device t , $f_{p,t,j}$ is the dynamic energy conversion efficiency of the primary energy j to secondary energy p through the device t .

2.3 Scenario setting

To achieve the goal of CO₂ emissions' peak and energy savings, three scenarios are designed: the baseline scenario, the policy scenario and the green scenario. The specific scenario and parameter settings are described in the supplementary material (Supplementary Tables S1–S6).

3 Results and discussion

3.1 Historical CO₂ emissions

Five northwestern provinces showed a fluctuating growth trend in CO₂ emissions from 2000 to 2019 (Figure 1). The CO₂ emissions increased from 226.74×10^6 tonnes in 2000 to 1181.51×10^6 tonnes in 2019. The CO₂ emissions of Shaanxi, Gansu, Ningxia, Qinghai and Xinjiang from 2000 to 2019 increased by 310.48×10^6 tonnes, 122.92×10^6 tonnes, 184.69×10^6 tonnes, 45.14×10^6 tonnes and 291.52×10^6 tonnes, respectively (Figure 1A). The contribution of Shaanxi and Xinjiang is the largest; their average annual growth rate is

11.83 and 9.48%, respectively. The smallest is Qinghai with an average annual growth rate of 4.93%.

The CO₂ emissions from agriculture, industry, construction, transportation, commerce, and other sectors from 2000 to 2019 increased by 21.43×10^6 tonnes, 740.56×10^6 tonnes, 17.41×10^6 tonnes, 111.58×10^6 tonnes, 28.63×10^6 tonnes, and 35.16×10^6 tonnes, respectively (Figure 1B). Among them, the industrial and transportation sectors are the main sectors of CO₂ emissions, and they account for more than 70% of the total CO₂ emissions. Another, it can be easily seen that the energy consumption in northwest China since 2000 has been dominated by coal (59%–71%). Then, the consumption of oil products (20%–32%) followed it (Figure 1A). The main reasons are as follows. Firstly, the Western Development Policy has promoted the development of industrialization and the establishment of energy-reserve bases, which in turn has led to a rapid increase in CO₂ emissions. Secondly, the limitation of resource endowment of “less gas and more coal” and the less-developed energy utilization technologies still exist in China, especially in the five northwestern provinces.

3.2 CO₂ emissions peaking under different scenarios

3.2.1 CO₂ emissions' peak of different provinces

The total and peak of CO₂ emissions in the five northwestern provinces are shown in Figure 2A. The CO₂ emissions in the baseline scenario will peak in 2035 (1663.46×10^6 tonnes), 5 years later than the national target of 2030. The policy scenario will peak in 2031 (1405.00×10^6 tonnes). The green scenario will peak in 2027 (1273.96×10^6 tonnes), 3 years ahead of the national

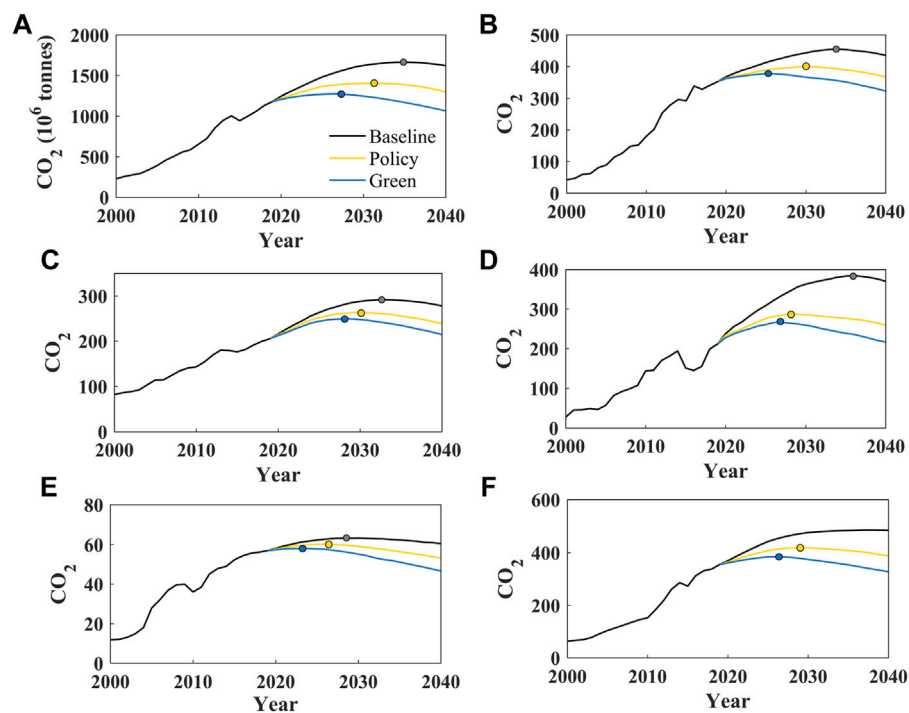


FIGURE 2

The CO₂ emissions and peaks of each province under the three scenarios. (A) represents the total CO₂ emissions. (B–F) represent the CO₂ emissions of Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang, respectively.

target. This indicates that CO₂ emissions in the region cannot be maintained in the baseline scenario and need to be advanced in the policy and green scenarios.

The CO₂ emissions of Shaanxi (Figure 2B) will peak in 2034 (454.87×10^6 tonnes) under the baseline scenario. The policy and green scenarios will peak in 2030 (399.15×10^6 tonnes) and 2025 (377.52×10^6 tonnes), respectively. Shaanxi Province has a relatively developed economy in the five northwestern provinces, and its economic contribution accounts for 40% of the region. However, the province's energy structure is relatively single, with coal consumption accounting for 75%. In addition, relative to the eastern region, the technology level of Shaanxi Province is still backward, with a surplus of low-end products and a lack of high value-added products. This has led to its reliance on large-scale energy-intensive and low-end industries to drive economic growth, which in turn leads to CO₂ emissions not peaking by 2030. Therefore, the future development of Shaanxi Province needs to be improved technology and propelled energy-use efficiency.

In the baseline scenario, the CO₂ emissions of Gansu (Figure 2C) and Ningxia (Figure 2D) will peak in 2033 (291.53×10^6 tonnes) and 2036 (384.42×10^6 tonnes), respectively. Xinjiang (Figure 2F) does not show a peak under the baseline scenario. Under the policy and green scenarios, all three provinces will peak prior to 2030. The industrialization of

these three provinces started later, and the main problems at present are as follows. 1) Energy structure urgently needs to be adjusted, coal accounts for more than 60% of its energy consumption. 2) Low level of technology, except for a few backbone enterprises, there is generally a low level of the production process, resulting in a large energy consumption per unit of output value. Its unit output value is 3–5 times higher than the domestic average. 3) Due to the abundant resources of coal and oil, a heavy industrial structure has formed with non-ferrous, metallurgical, petroleum, chemical and coal industries. These reasons lead to the economic growth of the three provinces accompanied by huge energy consumption, and thus their CO₂ emissions are difficult to peak in 2030 under the baseline scenario. Therefore, the restructuring of industrial and energy structures and the introduction of advanced equipment to improve production technology are the main directions for the three provinces.

The CO₂ emissions of Qinghai (Figure 2E) will peak in 2028 (63.15×10^6 tonnes) under the baseline scenario. The policy and green scenarios will peak in 2026 (60.15×10^6 tonnes) and 2023 (57.96×10^6 tonnes), respectively. Qinghai Province is sparsely populated and is dominated by animal husbandry and tourism. In addition, the province has abundant clean energy and a relatively reasonable energy structure. In 2019, the proportion

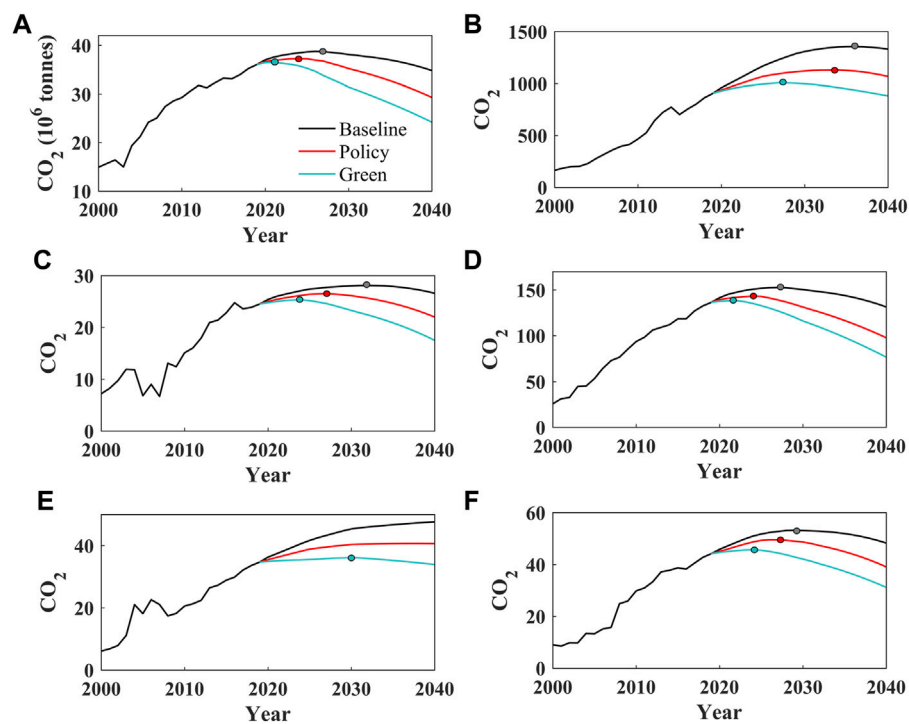


FIGURE 3

The CO₂ emissions and peaks for each sector under three scenarios. (A–F) denote agriculture, industry, construction, transportation, commerce, and other industries, respectively.

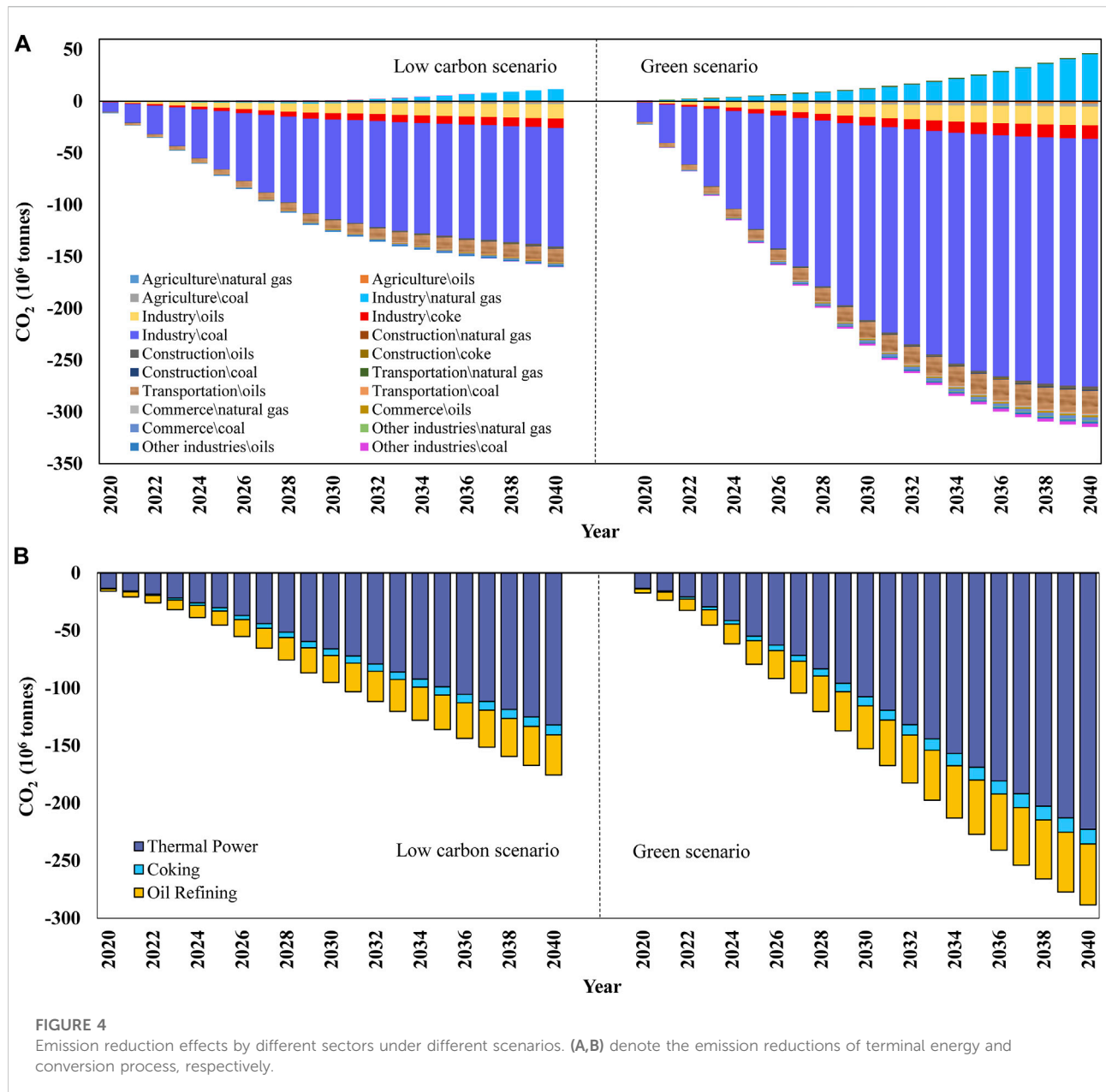
of coal, oil, natural gas, and renewable-energy consumption in the province was 29.15%, 10.87%, 16.83% and 43.6% (China Statistical Yearbook, 2019). Therefore, the CO₂ emissions in Qinghai Province are increasing slowly and will be able to reach the peak by 2030.

3.2.2 CO₂ emissions' peak of different sectors

To further explore emission reduction pathways from a sectoral perspective, we estimated the peak of CO₂ emissions for six sectors in the region. The CO₂ emissions of the agriculture sector (Figure 3A) will peak in 2027 (38.73×10^6 tonnes) under the baseline scenario, 3 years ahead of the national target. The policy and green scenarios will peak in 2024 (37.24×10^6 tonnes) and 2021 (36.51×10^6 tonnes), respectively. Chen et al. (2019) predicted that the CO₂ emissions of the agricultural sector in China will peak in 2026. This is similar to our findings in the baseline scenario. Industrialization has contributed to the increase in the level of mechanization of agricultural production and the improvement of water, electricity, roads and infrastructure in the agricultural sector, which has created conditions for the modernization and scaling up of agricultural development. This will inevitably lead to an increase in CO₂ emissions from the agricultural sector. However, the five northwest provincial governments have formulated relevant

policies for the agricultural sector, such as promoting low-carbon agricultural technologies, strengthening agricultural water and fertilizer management, upgrading agricultural machinery, and developing biogas digesters (National Development and Reform Commission of the People's Republic of China, 2021). These measures have also curbed the growth of CO₂ emissions. In addition, the demand and scope of activities in the agricultural sector are relatively stable. And in recent years, the implementation of afforestation and the establishment of modern ecological pastures and farmland in the northwest China have led to a rationalization of the agricultural structure. Therefore, the CO₂ emissions from agricultural sector can peak prior to 2030 in the baseline scenario.

The CO₂ emissions of the industrial sector (Figure 3B) will peak in 2036 (1356.68×10^6 tonnes) under the baseline scenario, 6 years later than the national target. Under the policy scenario, the industrial sector will peak in 2034 (1130.99×10^6 tonnes). Under the green scenario, the industrial sector will peak in 2027 (1008.24×10^6 tonnes), 3 years ahead of the national target. In addition, the CO₂ emission trend of the industrial sector is largely consistent with the overall trend of CO₂ emissions, which indicates that the industrial sector is the key sector for peaking CO₂ emissions. This is consistent with the findings of



Li et al. (2018) for China and Zhang et al. (2019) for Beijing, both of which suggest that industry is the main sector that delays the peaking of CO₂ emissions. China is a developing country, and industry is the dominant sector of the national economy. Since the implementation of the Western Development Policy in 2000, the region has invested and built a large number of heavy chemical industries and nationally important energy production and processing bases, such as coal production and coal chemical bases, large oil and gas extraction and processing bases, and other industries. This fact inevitably leads to the result that the peak times of the industrial CO₂ emissions affect the overall peak times. Considering that the industrial base in the

region is solid relatively and is continuing to advance. To ensure sustained economic growth in the region, CO₂ emissions from the industrial sector cannot only consider peaking by 2030, but needs to combine policy scenarios and green scenarios to achieve a gradual peaking of CO₂ emissions. Namely, it should be ensured that the average annual growth rate of the economy of the industrial sector does not exceed 4.3% until 2030, and the share of secondary industry decreases to 29.09%. Meanwhile, energy intensity should be reduced to 1.45 tonnes/10⁴ China Yuan (CNY) in 2030.

The CO₂ emissions of the construction sector (Figure 3C) will peak in 2032 (28.08 × 10⁶ tonnes) in the baseline scenario,

2 years later than the national target. The policy and green scenarios will peak in 2027 (26.50×10^6 tonnes) and 2024 (25.31×10^6 tonnes), respectively. Chen et al. (2019) investigated the peak of carbon emissions from the construction sector in China, and the results showed that China's construction-industry carbon emissions will peak in 2035. This is similar to our results from the baseline scenario. At present, the urbanization process of China is accelerating (Liang et al., 2019). Meanwhile, the construction sector is also advancing rapidly. The housing construction area in the five northwestern provinces has increased by $49,280.94 \times 10^4$ square meters from 2000 to 2019. This leads to the massive consumption of steel and cement and generates great CO₂. According to the seventh population census, 63.89% of China's population lives in urban and 36.11% in rural (National Bureau of Statistics, 2021). However, the urban population in the five northwestern provinces is 59.80% and the rural population is 40.20%, which is lower than the national average. As urbanization progresses in the region, the building area will also increase, which in turn will generate more CO₂ emissions. Therefore, to ensure the stable economic growth and achieve the peak of CO₂ emissions by 2030, the construction sector needs to advance in a policy scenario.

The CO₂ emissions of the transportation sector (Figure 3D) will peak in 2027 (152.66×10^6 tonnes) under the baseline scenario. The policy and green scenarios will peak in 2024 (143.30×10^6 tonnes) and 2022 (138.50×10^6 tonnes), respectively. Transportation is the second-largest source of CO₂ emissions after industry and is expected to peak prior to 2030 in the baseline scenario, which will undoubtedly play an important role in achieving the peak of CO₂ emissions on time. Continued economic growth has improved the transportation conditions and increased the willingness of people to travel in the Northwest. This has led to an increase in energy consumption and CO₂ emissions in the region. However, the northwest region is sparsely populated with a more dispersed population. This has led to higher costs for people in the region to use private cars to travel. Therefore, there is a lower level of car ownership in the region. In addition, the northwestern region is rich in clean energy sources such as solar, wind and natural gas. This has led to a decrease in oil consumption and an increase in the proportion of electricity and natural gas, and the popularity of electric vehicles has further curbed the growth of CO₂ emissions. At present, there is a lower density of both rail and road in the northwest, and CO₂ emissions are growing slowly. If the government takes strong measures in the transportation sector, such as improving fuel economy and promoting the optimization and upgrading of transportation modes and equipment. It should be ensured that the economic growth rate does not exceed 5.57% annually until 2030, and that the energy intensity decreases to 0.71 tonnes/10⁴ CNY and the share of oil to 59.68% by 2030. In this pattern, the CO₂ emissions from transportation will be further slowed and hopefully reach the peak by 2030 in the baseline scenario.

Under the green scenario, the CO₂ emissions from the commerce sector will start to slow down after 2030 (Figure 3E). With the promotion of the Belt and Road policy, the level of service industry has also improved significantly in the region. The CO₂ emissions have increased because of the development of tourism resources and the improvement of supporting facilities related to the commerce sector in the western region. Although commerce generates some CO₂ and shows a growing trend, its growth rate exceeds the growth rate of CO₂ emissions. For example, the average annual growth rate of commerce CO₂ emissions from 2020 to 2040 is 1.34% in the baseline scenario, while its economic growth rate is 3.91%. Li et al. (2018) showed that the share of energy in the commerce sector will grow significantly in the China, reaching 82% of energy use by 2050. The tertiary sector has the characteristic of low energy consumption and high output. This is the main reason that China is vigorously developing the tertiary sector to ensure high-quality economic growth. Therefore, the commerce sector can be advanced in the baseline scenario.

The CO₂ emissions from other industries (Figure 3F) will peak in 2029 (53.17×10^6 tonnes) in the baseline scenario. The policy and green scenarios will peak in 2027 (49.50×10^6 tonnes) and 2024 (45.70×10^6 tonnes), respectively. Other industries have the same attributes as commerce. Therefore, it is feasible for the other industries to advance in the baseline scenario.

3.3 Emission reduction effect

3.3.1 Emission reduction effect of terminal energy consumption

As shown in Figure 4A, compared to the baseline scenario, the terminal consumption module in the policy scenario will cumulatively reduce 2183.00×10^6 tonnes CO₂ from 2020 to 2040. Among them, industrial coal will have the largest emission reduction effect, with a cumulative reduction of 1687.65 tonnes CO₂, accounting for 77.3% of the total emission reduction effect.

Compared to the baseline scenario, the terminal consumption module in the green scenario will cumulatively reduce 4020.36×10^6 tonnes CO₂. Among them, the CO₂ emissions from the industrial coal will be reduced by 3444.49×10^6 tonnes, accounting for 85.6% of the total emission reduction effect. In addition, natural gas will increase CO₂ emissions in both scenarios. This is because the share of natural gas will increase significantly in the future.

3.3.2 Emission reduction effect of energy conversion

As shown in Figure 4B, compared to the baseline scenario, the energy conversion process under the policy scenario will cumulatively reduce 1954.70×10^6 tonnes CO₂ from 2020 to 2040. Among them, the CO₂ emissions from thermal power will

be reduced by 3444.49×10^6 tonnes, accounting for 71.9% of the total emission reduction effect.

Compared to the baseline scenario, the energy conversion process in the green scenario will cumulatively reduce 3181.09×10^6 tonnes CO₂. The CO₂ emissions from thermal power will be reduced by 2329.54×10^6 tonnes, accounting for 73.2% of the total emission reduction effect.

In summary, the CO₂ emissions from 2020 to 2040 will be reduced by 4137.70×10^6 tonnes in the policy scenario and by 7201.46×10^6 tonnes in the green scenario. This is equivalent to 41.72% and 72.64% of the industrial CO₂ emissions from 2000 to 2019, respectively.

4 Conclusion and policy recommendation

4.1 Conclusion

Total CO₂ emissions in the five northwestern provinces will peak in 2035 under the baseline scenario, and that of the policy and green scenarios will peak in 2031 and 2027, respectively.

In the analysis of the provinces, the CO₂ emissions of all provinces except Qinghai are unable to reach the peak before 2030 in the baseline scenario. Under the policy and the green scenarios, all provinces are able to peak by 2030.

In the sector analysis, the CO₂ emissions from agriculture, transportation, and other sectors in the region will peak before 2030 under the baseline scenario. The CO₂ emissions from industry, construction and commerce will peak before 2030 in policy and green scenarios. Compared to the baseline scenario, the CO₂ emissions from 2020 to 2040 will be reduced by 4137.70×10^6 tonnes under the policy scenario and 7201.46×10^6 tonnes under the green scenario. Among the end-consumption module, industrial coal is the sector with the greatest potential for reducing CO₂ emissions. In the energy conversion module, thermal power is the sector with the largest emission reduction, followed by oil refining and coking.

4.2 Policy recommendation

Firstly, the five northwestern provinces should adjust the industrial structure. The five northwestern provinces commonly have the problem of over-weighting of secondary industries. Therefore, the region should transform the deformed industrial structure which is based on the development of natural resources. This includes strictly controlling and regulating the growth of these energy-intensive sectors, as well as upgrading traditional

sectors through technological innovation and developing emerging sectors that consume less energy. In addition, the government should establish a strict monitoring and control mechanism to keep the industry structure within a reasonable range. It should be ensured that the share of the secondary industry will decrease to 37.43% by 2030, and the commerce and other industries increase to 47.86%. Meanwhile, the share of the agricultural and transport sectors should be maintained at no more than 9.14% and 5.46%, respectively, by 2030.

Secondly, the energy intensity should further be reduced. Thus, the government should encourage technological innovation and give financial and policy support to enterprise sectors with higher energy-saving and energy conversion efficiency. In addition, the government should further strengthen the technical exchange with the eastern of China and introduce advanced talents and equipment to eliminate that equipment with high-energy consumption. It should be ensured that the energy intensity of agriculture, industry, construction, transportation, commerce, and other sectors will be reduced to 0.13 tonnes/10⁴ CNY, 1.45 tonnes/10⁴ CNY, 0.08 tonnes/10⁴ CNY, 0.71 tonnes/10⁴ CNY, 0.24 tonnes/10⁴ CNY, and 0.047 tonnes/10⁴ CNY, respectively, by 2030. In addition, the thermal power efficiency should also be improved, such as accelerating the closure of small thermal power plants and integrating and recycling waste power plants. It should be ensured that the thermal power efficiency will increase to 49.3% by 2030.

Finally, the northwest of China is rich in clean energy sources such as solar, wind and natural gas. Therefore, the full utilization of the region's solar and wind energy to reduce the use of coal energy should be a long-term strategy that needs to be maintained. It should be ensured that the share of coal in end consumption will not exceed 43.3% by 2030, while the share of natural gas and non-fossil energy will increase to 25.42%. With the above policy implementation efforts, the five northwestern provinces will hopefully achieve the peak of CO₂ emissions by 2030.

4.3 Limitations and the future research directions

The limitations of this article deserve further research. Firstly, we did not consider the impact of biomass energy on CO₂ emissions peaking, which is an issue that needs to be addressed in the future. Secondly, we only consider measuring the peak of CO₂ emissions. However, we do not consider the cost effects required under three scenarios. Therefore, the trade-off between the implementation of emission reduction measures and the required costs deserves further in-depth study.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary Material](#), further inquiries can be directed to the corresponding author.

Author contributions

ZZ and JJ conceived and designed the research. ZZ collected and analysed the data. ZZ and JJ wrote and revised the paper. YG, BW, and CC contributed to progress of research idea and provide a critical review for this study. All authors have read and agreed to publish the current version of the manuscript.

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Conflict of interest

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenrg.2022.983751/full#supplementary-material>

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