# 中国综合经济区碳达峰实现的时空差异研究

# Research on Time–Space Differences in the Prediction of Carbon Peaking of China's Comprehensive Economic Zones

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**摘要**

实现碳达峰、碳中和目标已成为各国参与全球气候变化治理的关键一环，中国碳达峰研究对于“中国于2030年前实现碳达峰”承诺的达成和路径的执行具有重要影响和现实支撑。本文构建了STIRPAT碳达峰时间预测模型，结合情景设置方法，对中国八大综合经济区碳达峰时间进行预测，并在全国层面分析碳达峰实现的可能路径。研究结果显示：各大经济区实现碳达峰时间差异较大，分为基准情景可达峰地区、条件约束下可达峰地区和条件约束下仍无法达峰地区。基准情景可达峰地区基于区域社会经济发展特征，具有主动达峰（大西南、东部沿海经济区）和被动达峰（东北经济区）的内部差异；条件约束下可达峰地区包括两大经济发达沿海经济区（北部沿海、南部沿海经济区）和主要能源输出经济区（黄河中游经济区）；条件约束下仍无法达峰地区为发展起步较晚的两大经济区（长江中游、大西北经济区）。本文结合各区域实际经济、人口、产业和能源等特征，提出保障区域发展公平均衡的全国协调的碳达峰路径倡议，并指出，不同区域采取差异化的达峰策略可能比所有区域同时采取单一产业或能源约束策略对碳排放增长更具约束力。

**关键词**

碳达峰；STIRPAT模型；情景分析；区域差异；八大综合经济区；碳排放强度

**ABSTRACT**

Carbon peaking and carbon neutrality have become key agendas for countries to participate in global climate change governance. Research on China's carbon peaking has a guidance significance for the actions to achieve a nationwide carbon peaking by 2030. This paper builds a STIRPAT model which, in combination with a scenario -setting method, predicts the carbon peaking time of eight comprehensive economic zones in China, and analyzes the possible path of achieving carbon peaking at national level. The result shows a disparity in carbon peaking time among the zones—there are zones that can achieve carbon peaking under baseline scenario; zones that can achieve carbon peaking under conditional scenarios; and zones that cannot achieve carbon peaking under any scenario. In the first group, the zones can achieve carbon emission through both active path (southwest and eastern coastal comprehensive economic zones) and passive path (northeast comprehensive economic zones) according to characteristics of regional socio-economic development. The second group includes two economic anchors (northern coastal and southern coastal comprehensive economic zones) and an energy-exporting center (the middle reaches of Yellow River comprehensive economic zone). Zones in the third group generally witness a late development (the middle reaches of Yangtze River and northwest comprehensive zones). Based on characteristics of regional economy, population, industry, and energy of each zone, this paper proposes an initiative that the achievement of a nationwide carbon peaking should take regional development equity into consideration, and presumes that making each zone adopts differentiated peaking strategies may have a stronger effectiveness in controlling carbon emission growth than making all zones adopt strategies constraining on single factors on industry or energy.

**KEYWORDS**

Carbon Peaking; STIRPAT Model; Scenario Analysis; Regional Difference; Eight Comprehensive Economic Zones; Carbon Emission Intensity

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## 1 研究背景

自工业革命以来，以二氧化碳为主的温室气体的排放量急剧增加[1]，至2020年，全球二氧化碳浓度已达413.2ppm，是工业化前水平的149%[2]。IPCC报告显示，全球平均气温在1880~2012年间已上升0.85℃，而人为温室气体排放与其他人为强迫是发生全球变暖的主要原因[3]。当前，气候变暖导致人类面临海平面上升[4][5]、极端天气[6][7]、生物多样性减少[8]~[10]等诸多问题，并为社会经济发展和人们生命财产安全带来巨大挑战[11]。作为一个负责任大国，中国积极参与全球气候变化治理体系——2020年9月，中国政府承诺将通过更有力的政策措施，力争在2030年和2060年前分别实现碳达峰和碳中和[12]。

与西方发达国家研究碳排放与经济增长间的环境库兹涅茨曲线假设（Environmental Kuznets Curve，简称EKC）的是否存在和EKC拐点的出现[13]~[19]等的研究不同，中国等发展中国家的学者的碳达峰研究多聚焦于分析碳排放影响因素，并对未来碳排放路径及其拐点时间进行预测[20]。当前，中国此类既有研究路径大致分为三种：1）判断未来碳排放是否存在EKC拐点及出现拐点时间[21]~[23]；2）对碳排放影响因素独立分析，并结合情景分析利用模型（IPAT模型[24]、STIRPAT模型[20]、KAYA恒等式[25]、LEAP模型[26]等）对未来碳达峰时间进行预测；3）创建系统模型（如灰色预测模型[27]、自回归移动平均模型[28]、向量自回归模型[29]等）对碳排放进行直接预测。其中，STIRPAT模型是研究二氧化碳排放达峰领域广泛认可并应用的情景分析利用模型[30]，此模型不仅可预测某地区中长期碳排放量，还可反映该地区对应碳排放路径中最需关注的影响因素。

许多中国学者从国家尺度[31]~[33]、区域尺度[34]~[36]、省份尺度[20][37][38]和重点城市尺度[26][39]展开碳达峰研究。但整体而言，现有研究主要集中在国家或省市级尺度层面——前者常存在局部地区易受忽视、研究范围过大及政策制定易显粗糙等缺陷；后者虽然能够清晰反映出单一省市碳达峰的时间特征，但难以基于此制定全国碳达峰政策，易出现政策制定成本升高、地区间协调难度增加、政策有效性降低[40]等问题。对于区域尺度的碳达峰研究，当前主要集中在东北三省[34]、长三角[41]、珠三角[42]等特定区域，研究视角较为局限，还有部分集中在“四大区域”[35]、“五大区域”[43][36]等传统的大尺度视角，易忽视区域内部各地

## 1 Research Background

Since the Industrial Revolution, the sharp increase in greenhouse gas emission dominated by carbon dioxide has become one of the causalities to global warming[1]. Concentration of carbon dioxide has reached 413.2 ppm in 2020 which is 149% of the pre-industrial level[2]. According to the IPCC report, the global average temperature has increased by 0.85°C from 1880 and 2012, which was mainly caused by the increase of anthropogenic greenhouse gas emissions and other anthropogenic forcing[3]. Climate warming has brought not only serious risks such as sea level rise[4][5], extreme weather events[6][7], and biodiversity loss[8]~[10], but also huge challenges to socio-economic development and the safety of life and property[11]. As a responsible world power, China has proactively participated in mitigating the impact of global climate change—in September 2020, Chinese government pledged to adopt stronger policy measures to achieve carbon peaking and carbon neutrality by 2030 and 2060, respectively[12].

Different from the research on the EKC (Environmental Kuznets Curve) hypotheses on carbon emission and economic growth, as well as whether there is an inflection point of EKC[13]~[19], in western developed countries, scholars from China and other developing countries mostly focus on analyzing the influencing factors of carbon emission and forecasting future carbon emission path and the occurrence time of inflection point[20]. At present, such research in China can be roughly divided into three categories: 1) determining whether there is an EKC inflection point and obtaining the time of the inflection point[21]~[23]; 2) independently deconstructing the influencing factors of carbon emission to predict future carbon peaking by using models (IPAT model[24], STIRPAT model[20], KAYA identity[25], LEAP model[26], etc.) with scenario analysis; and 3) building system models (gray prediction model[27], autoregressive integrated moving average model[28], vector autoregression model[29], etc.) to directly predict carbon emissions. STIRPAT model is the most commonly recognized and used model for the research on carbon peaking[30], which could not only predict medium- and long-term carbon emissions, but also reflect the critical influencing factors to the corresponding carbon emission path of a region.

A large number of Chinese scholars have carried out research on carbon peaking at varied scales, from national[31]~[33], regional[34]~[36] to provincial[20][37][38] or municipal[26][39], most of which concentrates on the national and provincial/municipal scale—the former often has defects such as neglect in locality difference, excessive research coverage, and rough policy formulation; the latter though explores the specific trajectory of carbon peaking of a given province/city, it would increase the cost of the making of national policies, and the difficulty in coordination among regions and policy implementation[40]. Currently, studies on carbon peaking at regional scale focus more on limited regions such as the Three Northeastern Provinces[34], Yangtze River Delta[41], and Pearl River Delta[42], or are conducted from traditional large-scale perspectives such as “four major regions”[35] or “five major regions”[43][36], which often ignore the disparity and agglomeration of different areas within the region and therefore little inform in-depth analysis of

区的差异性与集聚性，不利于深入分析区域间差异并制定区域政策[44]。

此外，还有研究聚焦于行业层面（如工业[45]、交通[46]和建筑[47]等），但相关研究难以揭示全国总体碳排放水平。为弥补既有研究的局限，本文依据国务院发展研究中心发布的《区域协调发展战略与政策》，根据地理位置、资源禀赋、经济发展水平及相互联系、社会结构，以及区域规模等因素将中国划分为八大综合经济区[48][49]，更符合当今经济社会实际发展需求，可操作性更强[50]，且较传统区域划分更具区域微观应用价值[51]。基于此，本文将以八大经济区为主体进行碳达峰年份预测，以期为中国各区域碳减排目标及实施路径的制订提供参考。

## 2 研究模型与数据来源

### 2.1 STIRPAT预测模型

STIRPAT模型是由托马斯·迭特滋和尤金·A·罗莎在IPAT模型的基础上提出的模型[52]。STIRPAT模型消除了IPAT模型默认不同因素对环境压力的贡献相同的局限性影响[53][54]，增加了随机性，便于实证分析[38]，且具有较高的灵活性和一定的拓展空间[55]。在只把人口规模、经济增长、技术水平作为环境影响的决定因素的传统STIRPAT模型基础上[30]，STIRPAT扩展模型引入城镇化率、产业结构和能源结构等碳排放重要影响因素[56]，被广泛应用于对碳排放与各影响因素间的关系的定量分析中[57]，是得到学术界认可的碳排放研究模型。

现有对于碳排放驱动因素的研究证明，人口规模、人均GDP、城镇化率、产业结构、能源强度和能源结构均可对二氧化碳排放产生显著影响[58]~[60]，也是当前碳排放预测研究中最为常见的影响因素[20][32][38][61]。因此，本研究以STIRPAT扩展模型为基础，将上述6种影响因素作为相关变量，进行碳达峰时间预测及路径实现分析研究。

本文建立的STIRPAT模型如下：

$$\ln I = \ln a + b\ln P + c\ln A + d(\ln A)^2 + f\ln U + g\ln IS + h\ln EI + j\ln ES + \ln e \quad (1)$$

其中，$I$表示二氧化碳排放总量，$a$表示模型系数，$P$表示人口规模，$A$表示人均GDP，$U$表示城镇化率，$IS$表示产业结构，$EI$表示能源强度，$ES$表示能源结构，$e$表示随机误差项，$b$、$c$、$d$、$f$、$g$、$h$、$j$表示各变量的弹性系数。模型中各变量的解释说明如表1所示。本文还加入了人均GDP的二次项，以保障碳排放与经济增长存在非线性“倒U型”关系[62]的省市的预测拟合的准确性。本文采用岭回归模型避免回归的多重共线性问题。

### 2.2 数据来源与处理

#### 2.2.1 数据来源

本文中涉及的各省市人口规模数据、国内生产总值数据和第二产业增加值数据来自2005~2019年《中国统计年鉴》及各省市统计年鉴，城镇化率数据来自2005~2019年《中国人口和就业统计年鉴》，能源消

regional differences and related policy making[44].

Besides, some studies are made from perspective of industrial sectors (industry[45], transportation[46], construction[47], etc.), but difficult to reveal the overall national carbon emission. Regarding this research gap, this paper adopts the division of comprehensive economic zones of China, according to the Strategy and Policy for Coordinated Regional Development issued by the Development Research Center of the State Council. Eight zones are designated by geographical location, resource endowment, economic development and interconnection, social structure, regional scale, and other factors[48][49]. This division is more in line with the actual current development needs of China’s economy and society, and has greater realistic significance[50] and higher guidance value in local application[51]. This paper predicts the carbon peaking of the eight comprehensive economic zones in hope to provide references for the carbon emission reduction targets of each zone at national level.

## 2 Research Methods and Data Sources

### 2.1 STIRPAT Prediction Model

STIRPAT model is proposed by Thomas Dietz and Eugene A. Rosa based on the IPAT model[52]. It eliminates the limitation of the IPAT model that different factors have the same contribution to environmental pressure[53][54], increases randomness, facilitates empirical analysis[38], and has high flexibility that supports research initiative[55]. Based on the traditional STIRPAT model which only takes population, economic growth, and technological level as the determinants of environmental impact[30], extended versions of STIRPAT model introduce more influencing factors to carbon emission such as urbanization rate, industrial structure, and energy structure[56], and has been recognized as a carbon emission research model that supports quantitative analysis on the correlations with various influencing factors[57].

In current research on carbon emission, population, GDP per capita, urbanization rate, industrial structure, energy intensity, and energy structure are verified as main driving factors to carbon dioxide emission[58]~[60], which are also the most common influencing factors in current carbon emission prediction research[20][32][38][61]. Based on the extended STIRPAT model, this study adopts the above six factors as variables to predict the carbon peaking time and analyze the realization paths accordingly.

The STIRPAT model established in this paper is as follows:

$$\ln I = \ln a + b\ln P + c\ln A + d(\ln A)^2 + f\ln U + g\ln IS + h\ln EI + j\ln ES + \ln e \quad (1)$$

where $I$ represents the total amount of carbon dioxide emission, $a$ represents the model coefficient, $P$ represents population, $A$ represents GDP per capita, $U$ represents urbanization rate, $IS$ represents industrial structure, $EI$ represents

表1：模型变量说明
Table 1: Definition of variables in the model

| 变量<br>Variable | 解释或说明<br>Definition | 单位<br>Unit |
| --- | --- | --- |
| 二氧化碳排放（*I*）<br>Carbon Dioxide emission | 能源相关二氧化碳排放量<br>Energy-related carbon dioxide emission | $10^6$ t |
| 人口规模（*P*）<br>Population | 年末常住人口<br>Permanent resident population by the end of the year | 10 000人<br>10,000 people |
| 人均GDP（*A*）<br>GDP per capita | 国内生产总值/年末常住人口<br>GDP/resident population by the end of the year | 10 000元/人<br>10,000 yuan/people |
| 城镇化率（*U*）<br>Urbanization rate | 城镇居民人口占总人口比重<br>Ratio of urban residents to the total population | — |
| 产业结构（*IS*）<br>Industrial structure | 第二产业占国内生产总值比重<br>Ratio of secondary industry to the total GDP | — |
| 能源强度（*EI*）<br>Energy intensity | 单位GDP消耗的能源量<br>Energy consumption per unit of GDP | t标准煤/10 000元<br>ton of standard coal/10,000 yuan |
| 能源结构（*ES*）<br>Energy structure | 煤炭消费量占能源消费总量的比重<br>Ratio of coal consumption to the total energy consumption | — |

费数据来自2005~2019年《中国能源统计年鉴》及各省市统计年鉴，碳排放数据来自中国碳核算数据库中的碳排放数据省级清单。由于能源与碳排放数据库暂不包含西藏自治区、香港和澳门特别行政区，以及台湾省能源统计数据，故本研究中大西北综合经济区暂不包括西藏，且此四个地区暂不列入计算范围（表2）。

2.2.2 数据处理与情景设置

本文首先需要对各省市的六大碳排放影响因素变化率进行设置。考虑到碳达峰显示结果的滞后性，为探究各区域于2030年前是否能实现碳达峰，故将预测研究时间截止时间设置为2040年。

在现状值设置方面，鉴于六大影响因素的相关最新数据统计时间存在不一致性，除采纳人口规模、人均GDP、产业结构的最新相关数据（均已更新至2020年）外，本研究对于统计数据稍滞后的城镇化率依据相关规划文件五年平均变化速率设置，能源强度的变化率参照各省市《国民经济和社会发展第十三个五年规划纲要》进行设置，能源结构依据历史变化率设置。

在中值设置方面，人口规模与城镇化率变化率参照各省市《国民经济和社会发展第十四个五年规划和2035年远景目标纲要》（以下简称“十四五”规划）、《人口发展规划（2016—2030年）》等相关规划文件设置——北京市参照《北京市城市总体规划（2016—2035年）》、上

energy intensity, *ES* represents energy structure, *e* represents random error term, and *b*, *c*, *d*, *f*, *g*, *h*, and *j* represent the coefficient of elasticity of each variable. The variables in the model are defined as Table 1. This paper also adopts the quadratic term of GDP per capita to ensure the accuracy of prediction fitting of each province/city where there is a nonlinear inverted-U- shape correlation[62] between carbon emission and economic growth. Besides, ridge regression model is used to avoid the multi-collinearity of regression.

### 2.2 Data Sources and Processing

2.2.1 Data Sources

The data of population, GDP, and added value of secondary industry of all provinces/cities required in this paper are from China Statistical Yearbooks (2005 to 2019) and Statistical Yearbooks of each province/city; the data of urbanization rate are from China Population & Employment Statistical Yearbooks (2005 to 2019); the data of energy consumption are from China Energy Statistical Yearbooks and Energy Statistical Yearbooks of each province/city (2005 to 2019); and the data of carbon emission are from the provincial inventory of carbon emission in Carbon Emission Accounts & Datasets of China (CEADs). Since the energy and carbon emission database does not contain the statistics of Tibet, Hong Kong, Macao, and Taiwan, these four provinces/cities are not studied in the research (the carbon emission of Tibet is not included in the prediction for the northwest comprehensive economic zone) (Table 2).

2.2.2 Data Processing and Scenario Setting

At first, the research needs to postulate the change rates of the six influencing factors for each province/city. Considering the lag in carbon peaking reporting and the goal of examining whether each zone can achieve carbon peaking before 2030, the study time period is set from the year of 2020 to 2040.

As there is a difference in statistics time span about the six influencing factors, in the benchmark rate setting of this prediction, data in population, GDP per capita, and industrial structure are updated to 2020; data in urbanization rate are set as the five-year average change rates in related planning documents; the benchmark rate of energy intensity is set according to the Outline of the 13th Five-Year Plan for the Economic and Social Development of China; and data in energy structure are determined according to historical change rates.

The medium change rates of population and urbanization are set in line with the Outline of the 14th Five-Year Plan (2021–2025) for Economic and Social Development and Vision 2035 of China (the 14th Five-Year Plan), and Population and Development Plan (2016–2030) of each province/city—those of Beijing, Shanghai, and Tianjin are consistent with Beijing Urban Master Plan (2016–2035), Shanghai Urban Master Plan (2017–2035), and Tianjin Urban Master Plan (2015–2030), respectively. As the national birth rate keep dropping over recent years, the estimated population growth rate of some provinces/cities is lowered appropriately. As for GDP per capita, the medium rates are set

表2：中国八大综合经济区划分
**Table 2: Eight comprehensive economic zones of China**

| 区域<br>Zone | 所含省份及直辖市<br>Provinces/cities included |
|---|---|
| 东北综合经济区<br>Northeast comprehensive economic zone | 辽宁、黑龙江、吉林<br>Liaoning, Heilongjiang, and Jilin |
| 北部沿海综合经济区<br>Northern coastal comprehensive economic zone | 北京、天津、山东、河北<br>Beijing, Tianjin, Shandong, and Hebei |
| 东部沿海综合经济区<br>Eastern coastal comprehensive economic zone | 上海、江苏、浙江<br>Shanghai, Jiangsu, and Zhejiang |
| 南部沿海综合经济区<br>Southern coastal comprehensive economic zone | 福建、海南、广东<br>Fujian, Hainan, and Guangdong |
| 黄河中游综合经济区<br>The middle reaches of Yellow River comprehensive economic zone | 陕西、山西、河南、内蒙古<br>Shaanxi, Shanxi, Henan, and Inner Mongolia |
| 长江中游综合经济区<br>The middle reaches of Yangtze River comprehensive economic zone | 湖北、湖南、江西、安徽<br>Hubei, Hunan, Jiangxi, and Anhui |
| 大西南综合经济区<br>Southwest comprehensive economic zone | 云南、贵州、四川、重庆、广西<br>Yunnan, Guizhou, Sichuan, Chongqing, and Guangxi |
| 大西北综合经济区<br>Northwest comprehensive economic zone | 甘肃、青海、宁夏、新疆<br>Gansu, Qinghai, Ningxia, and Xinjiang |

**注**
西藏、香港、澳门和台湾暂不列入计算范围。

**NOTE**
The carbon emission of Tibet, Hong Kong, Macau, and Taiwan are not predicted in this study.

海市参照《上海市城市总体规划（2017—2035年）》、天津市参照《天津市城市总体规划（2015—2030年）》设置。由于近年来全国人口出生率大幅降低，因此参照近年人口实际变化速率对部分省市人口预计增长率适当下调。对于人均GDP，参照各省市“十四五”规划进行人均GDP变化率设置，并结合人口变化率计算得出。对于能源强度，2021~2025年的数据则参照各省市“十四五”规划进行设置。其中部分未有规划数据根据影响因素实际变化率情况进行设置。

与产业结构和能源结构变化率相关的数据在各省市规划文件中未见设置。对于产业结构，本文根据各省市实际产业结构变化情况，并结合发达国家产业结构变化特征[63]~[65]，设置各时段产业结构变化率，使各省市产业结构（第二产业占比）在2030年不低于20%，部分省市低于此比例，包括经济发达的两大直辖市北京市、上海市和以第三产业为主的海南省。

对于能源结构，中国能源研究会发布的《中国能源展望2030》预计2030年煤炭、非化石能源占比分别达到49%和22%[66]，郝宁等人预测在能源“新常态”背景下，预计2030年煤炭、非化石能源占比约为50%和21%[67]，而国务院印发的《2030年前碳达峰行动方案》中要求到2030

according to the 14th Five-Year Plan and the corresponding population medium rate.

The medium rate of energy intensity for 2020 to 2025 is set according to the 14th Five-Year Plan—Data of actual change rates are used when no date can be sourced there.

Relevant data about industrial structure and energy structure change rates are not involved in official planning schemes. In the research, as for industrial structure, the medium rates for each period of time are made in consideration of the actual change rate of each province/city, with reference from the change characteristics of industrial structure in developed countries[63]~[65], to ensure the industrial structure (the proportion of industrial sectors) of most provinces/cities will not be less than 20% by 2030—The provinces/cities lowering than this proportion include Beijing and Shanghai (the two economic centers in China), as well as Hainan (service sectors as its pillar industry).

For the energy structure, China Energy Outlook 2030 released by China Energy Research Society predicts that the proportion of coal and non-fossil energy will reach 49% and 22% respectively by 2030[66]. Hao Ning et al. predicted that under the “energy new normal” policy of China, the proportion of coal and non-fossil energy will account for approximately 50% and 21% by 2030[67]. The Action Plan for Carbon Dioxide Peaking Before 2030 issued by the State Council requires that China’s non-fossil energy should account for about 25% of primary energy

年我国非化石能源占一次能源消费比例需达25%左右[68]，基于此，本文将至2030年时煤炭占比控制在45%左右，并由此设定中值变化率，部分发达省市（北京市、上海市、天津市、广东省）、第三产业主导省份（海南省）、重工业大省（黑龙江省、吉林省）、能源大省（山西省、内蒙古自治区、陕西省、宁夏自治区、新疆自治区）根据该省/市实际能源结构进行适当调整。

研究在现状值和中值的基础上对各影响因素变化率的低值与高值进行设置。鉴于贵州省正处于巩固脱贫成果实现乡村振兴、向以高质量发展统揽全局转变的关键时期，其发展方向与国家“十四五”政策导向一致[69]，故此处以贵州省为例展示各影响因素变化率数据设置具体情况（表3）。

依据影响因素变化率的高、中、低值的不同组合，研究选择了5种代表性的碳排放情景（表4）。

1）基准情景：各影响因素变化率的设置均为中值，旨在探索政策规划下未来的碳排放变化趋势；

2）产业结构优化情景：产业结构变化率设为低值，其他影响因素设为中值，为在基准情景基础上进一步探索产业结构转型升级时的碳排放趋势；

consumption by 2030[68]. Based on this, the research controls the proportion of coal energy at about 45% by 2030, and sets the medium rates accordingly—The provinces/cities that are estimated with adjusted medium rates according to their actual energy structure include Beijing, Shanghai, Tianjin, and Guangdong (developed provinces/cities); Hainan (service sector pillaring province); Heilongjiang and Jilin (heavy industry provinces); and Shanxi, Inner Mongolia, Shaanxi, Ningxia, and Xinjiang (energy production provinces).

Based on the determining of benchmark and medium rates, the study sets the low and high change rates of each influencing factor. Guizhou Province, as a region in a critical transition towards an overcome of poverty and backwardness and rural revitalization, needs to guarantee a high-quality provincial development, which is consistent with the national policy guidance of the 14th Five-Year Plan[69]. Here the research takes Guizhou as an example to show the specific setting of change rates of each influencing factor (Table 3).

Five typical carbon emission scenarios are selected that are defined by different combinations of high, medium, and low change rates of influencing factors (Table 4).

1) Baseline scenario: with medium change rate of each influencing factor, this scenario simulates the future carbon emission trajectory of each zone based on the existing carbon emission and under current polices.

2) Industrial structure optimization scenario: with low change rate of industrial structure and medium change rate of other influencing factors, this scenario estimates the carbon emission trend when further promotion and upgrades in industrial structure transformation are adopted upon the baseline scenario.

**表3：碳排放影响因素变化率设置（以贵州省为例）**
**Table 3: Change rate setting of factors on carbon emission (Guizhou Province)**

| 变化率 Change rate | 时间 Time frame | 影响因素变化率设置 Value setting | | | | | |
|---|---|---|---|---|---|---|---|
| | | P | A | U | IS | EI | ES |
| 现状值 Benchmark | 2020 | 0.26% | 6.03% | 3.54% | -3.55% | -3.20% | -2.00% |
| 低值 Low | 2021 ~ 2025 | 0.37% | 5.50% | 2.61% | -1.60% | -3.26% | -2.20% |
| | 2026 ~ 2030 | 0.32% | 5.00% | 2.41% | -1.40% | -3.06% | -2.00% |
| | 2031 ~ 2040 | 0.27% | 4.50% | 2.21% | -0.12% | -2.86% | -1.80% |
| 中值 Medium | 2021 ~ 2025 | 0.47% | 6.50% | 3.01% | -1.20% | -2.86% | -0.18% |
| | 2026 ~ 2030 | 0.42% | 6.00% | 2.81% | -1.00% | -2.66% | -0.16% |
| | 2031 ~ 2040 | 0.37% | 5.50% | 2.61% | -0.80% | -2.46% | -0.14% |
| 高值 High | 2021 ~ 2025 | 0.57% | 7.50% | 3.41% | -0.80% | -2.46% | -1.40% |
| | 2026 ~ 2030 | 0.52% | 7.00% | 3.21% | -0.60% | -2.26% | -1.20% |
| | 2031 ~ 2040 | 0.47% | 6.50% | 3.01% | -0.40% | -2.06% | -1.00% |

**表4：碳排放情景设置**
**Table 4: Scenario setting of carbon emission**

| 情景 Scenario | 影响因素变化率设置 Value setting | | | | | |
|---|---|---|---|---|---|---|
| | P | A | U | IS | EI | ES |
| 基准情景（S1）Baseline | 中值 Medium | 中值 Medium | 中值 Medium | 中值 Medium | 中值 Medium | 中值 Medium |
| 产业结构优化情景（S2）Industrial structure optimization | 中值 Medium | 中值 Medium | 中值 Medium | 低值 Low | 中值 Medium | 中值 Medium |
| 节能情景（S3）Energy saving | 中值 Medium | 中值 Medium | 中值 Medium | 中值 Medium | 低值 Low | 低值 Low |
| 绿色发展情景（S4）Green development | 低值 Low | 低值 Low | 低值 Low | 低值 Low | 低值 Low | 低值 Low |
| 粗放发展情景（S5）Extensive development | 高值 High | 高值 High | 高值 High | 高值 High | 高值 High | 高值 High |

3）节能情景：能源强度和能源结构变化率设为低值，其他影响因素设为中值，以研究在加大能源相关约束力度、提升能源利用效率、提高清洁能源比例时的碳排放变化；

4）绿色发展情景：各影响因素变化率设置均为低值，探索将低碳发展而非经济增长作为主要发展目标时的碳排放趋势；

5）粗放发展情景：各影响因素变化率设置均为高值，探索将经济发展作为主要目标时的碳排放趋势。

## 3 结果与分析

### 3.1 各经济区未来碳排放趋势情况

各省市碳排放回归拟合结果见表5，除个别省市外，回归方程决定系数$R^2$均在90%及以上，整体拟合度较好。

3) Energy saving scenario: with low change rates of energy intensity and energy structure and medium change rates of other influencing factors, this scenario studies the carbon emission trend when reinforcing energy-related constraints, improving energy efficiency, and increasing the proportion of clean energy in energy consumption.

4) Green development scenario: with low change rate of each influencing factor, this scenario examines the future carbon emission by assuming that instead of economic growth, low-carbon development is prioritized.

And 5) extensive development scenario: with high change rate of each influencing factor, this scenario explores future carbon emission all for economic growth.

## 3 Research Results and Analysis

### 3.1 Future Carbon Emission of Each Comprehensive Economic Zone

The carbon emission regression fitting results of each province/city (Table 5) show that, with the exception of a few provinces/cities, the determination coefficient $R^2$ of regression is 90% or above, performing a high goodness of fit.

表5：八大区域各省市碳排放回归拟合结果

Table 5: Carbon emission regression fitting results of provinces/cities in each zone

| 区域 Zone | 省份 Province/city | Cons | ln(P) | ln(A) | (ln(A))$^2$ | ln(U) | ln(IS) | ln(EI) | ln(ES) | k | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 东北综合经济区 Northeast comprehensive economic zone | 辽宁 Liaoning | -22.424* | 3.442** | 0.140*** | 0.005 | 0.963*** | -0.011 | 0.022 | 0.008 | 0.100 | 0.918 |
| | 黑龙江 Heilongjiang | -81.128** | 10.665** | 0.184*** | 0.100*** | 1.162** | 0.078 | -0.070 | 0.848** | 0.100 | 0.939 |
| | 吉林 Jilin | -73.782*** | 10.130*** | 0.150*** | 0.008 | 1.071*** | 0.405 | 0.014 | 0.397 | 0.080 | 0.955 |
| 北部沿海综合经济区 Northern coastal comprehensive economic zone | 北京 Beijing | 4.282** | 0.127 | 0.062* | -0.012* | 3.339*** | 0.050 | 0.006 | 0.119*** | 0.050 | 0.829 |
| | 天津 Tianjin | 2.144** | 0.431*** | 0.112*** | 0.027*** | 2.159*** | 0.23 | -0.004 | 0.124 | 0.080 | 0.941 |
| | 山东 Shandong | -25.571*** | 3.630*** | 0.252*** | 0.057*** | 1.000*** | 1.140*** | 0.185** | -0.029 | 0.150 | 0.973 |
| | 河北 Hebei | -6.218** | 1.476*** | 0.219*** | 0.032* | 0.261** | 1.032*** | -0.077 | -0.041 | 0.060 | 0.966 |
| 东部沿海综合经济区 Eastern coastal comprehensive economic zone | 上海 Shanghai | 0.038 | 0.703*** | 0.068*** | 0.008 | 0.849** | 0.161 | -0.074** | 0.242** | 0.050 | 0.925 |
| | 江苏 Jiangsu | -34.915*** | 4.724*** | 0.157*** | 0.025*** | 0.733*** | 0.924*** | -0.052** | 0.565** | 0.100 | 0.989 |
| | 浙江 Zhejiang | -10.392*** | 2.116*** | 0.260*** | 0.015 | 1.576*** | 1.505*** | 0.073 | 0.483 | 0.080 | 0.950 |

续表见下页 / Continued

表5：八大区域各省市碳排放回归拟合结果
Table 5: Carbon emission regression fitting results of provinces/cities in each zone

| 区域<br>Zone | 省份<br>Province/city | Cons | ln(P) | ln(A) | (ln(A))$^2$ | ln(U) | ln(IS) | ln(EI) | ln(ES) | k | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 南部沿海综合经济区<br>Southern coastal comprehensive economic zone | 福建<br>Fujian | -13.556*** | 2.561*** | 0.180*** | 0.041*** | 0.997*** | 2.374*** | 0.014 | 0.272 | 0.100 | 0.989 |
| | 海南<br>Hainan | -18.745*** | 3.778*** | 0.333*** | 0.095 | 1.490** | 1.868*** | -0.879** | -0.494 | 0.150 | 0.899 |
| | 广东<br>Guangdong | -2.480*** | 1.046*** | 0.158*** | 0.033*** | 1.344*** | 0.466** | -0.152*** | 0.458** | 0.150 | 0.988 |
| 黄河中游综合经济区<br>The middle reaches of Yellow River comprehensive economic zone | 陕西<br>Shaanxi | -61.941*** | 8.445*** | 0.171*** | -0.004 | 0.717*** | 1.532*** | -0.218*** | 0.698*** | 0.140 | 0.975 |
| | 山西<br>Shanxi | -38.382* | 5.678** | 0.312*** | -0.055 | 2.801*** | -0.292 | 0.083 | -0.571 | 0.050 | 0.938 |
| | 河南<br>Henan | 34.129 | -2.848 | 0.232*** | 0.032* | 0.767*** | 1.603*** | -0.136 | 0.601 | 0.050 | 0.955 |
| | 内蒙古<br>Inner Mongolia | -57.074*** | 8.205*** | 0.255*** | 0.062*** | 1.510*** | 0.639*** | 0.007 | -0.15 | 0.100 | 0.985 |
| 长江中游综合经济区<br>The middle reaches of Yangtze River comprehensive economic zone | 湖北<br>Hubei | 0.787 | 0.590 | 0.178*** | 0.003 | 0.595*** | 0.107 | -0.009 | 0.163 | 0.300 | 0.751 |
| | 湖南<br>Hunan | 30.937*** | -2.664*** | 0.211*** | 0.030* | 0.985*** | 1.415*** | -0.019 | 0.345 | 0.150 | 0.969 |
| | 江西<br>Jiangxi | -14.872*** | 2.416*** | 0.117*** | 0.035** | 0.412*** | 0.866*** | -0.112*** | -0.203 | 0.080 | 0.991 |
| | 安徽<br>Anhui | 7.605 | -0.078 | 0.150*** | 0.025 | 0.673*** | 0.756*** | -0.224*** | 0.568* | 0.050 | 0.994 |
| 大西南综合经济区<br>Southwest comprehensive economic zone | 云南<br>Yunnan | -27.671*** | 4.010*** | 0.211*** | -0.174*** | 0.652*** | -0.048 | -0.177** | 0.514** | 0.150 | 0.923 |
| | 贵州<br>Guizhou | 22.592*** | -1.798** | 0.179*** | -0.117*** | 0.660*** | 0.890 | -0.206*** | 1.340*** | 0.150 | 0.975 |
| | 四川<br>Sichuan | 24.551 | -1.975 | 0.206*** | -0.050 | 0.692*** | 0.934*** | -0.095** | 0.064 | 0.150 | 0.921 |
| | 重庆<br>Chongqing | 2.494 | 0.373 | 0.184*** | -0.002 | 0.308** | 1.698*** | -0.020 | -0.441 | 0.100 | 0.939 |
| | 广西<br>Guangxi | 12.019 | -0.671 | 0.305*** | 0.074* | 0.647*** | 0.486* | -0.391*** | 0.702** | 0.100 | 0.978 |
| 大西北综合经济区<br>Northwest comprehensive economic zone | 甘肃<br>Gansu | -18.307*** | 3.136*** | 0.159*** | -0.052* | 0.425*** | 0.273** | -0.226*** | 0.652** | 0.130 | 0.985 |
| | 青海<br>Qinghai | -7.670** | 2.105*** | 0.160*** | 0.096** | 0.799*** | 1.562*** | -0.254** | 0.256* | 0.080 | 0.982 |
| | 宁夏<br>Ningxia | -31.819*** | 7.147*** | 0.435*** | -0.277 | 3.879*** | 8.825*** | 0.017 | 0.949 | 0.200 | 0.895 |
| | 新疆<br>Xinjiang | -2.330** | 1.162*** | 0.201*** | 0.095*** | 0.770*** | 0.138 | -0.424*** | 0.421*** | 0.200 | 0.989 |

**注**
*代表$p < 0.1$；**代表$p < 0.05$；***代表$p < 0.01$。

**NOTE**
* means $p < 0.1$; ** means $p < 0.05$; *** means $p < 0.01$.

研究发现，各影响因素对各省市碳排放量影响的显著程度不同，且对不同省市碳排放影响最显著的因素也不尽相同。例如，就辽宁省而言，人口规模因素的影响最为显著，即当地人口每增加1%，碳排放可能增长3.442%；而就重庆市而言，产业结构因素的影响最为显著，即当地产业结构每减少1%，碳排放可能减少1.689%。就所有省市而言，人口规模、城镇化率和产业结构这三个因素对碳排放总量的影响较为显著。

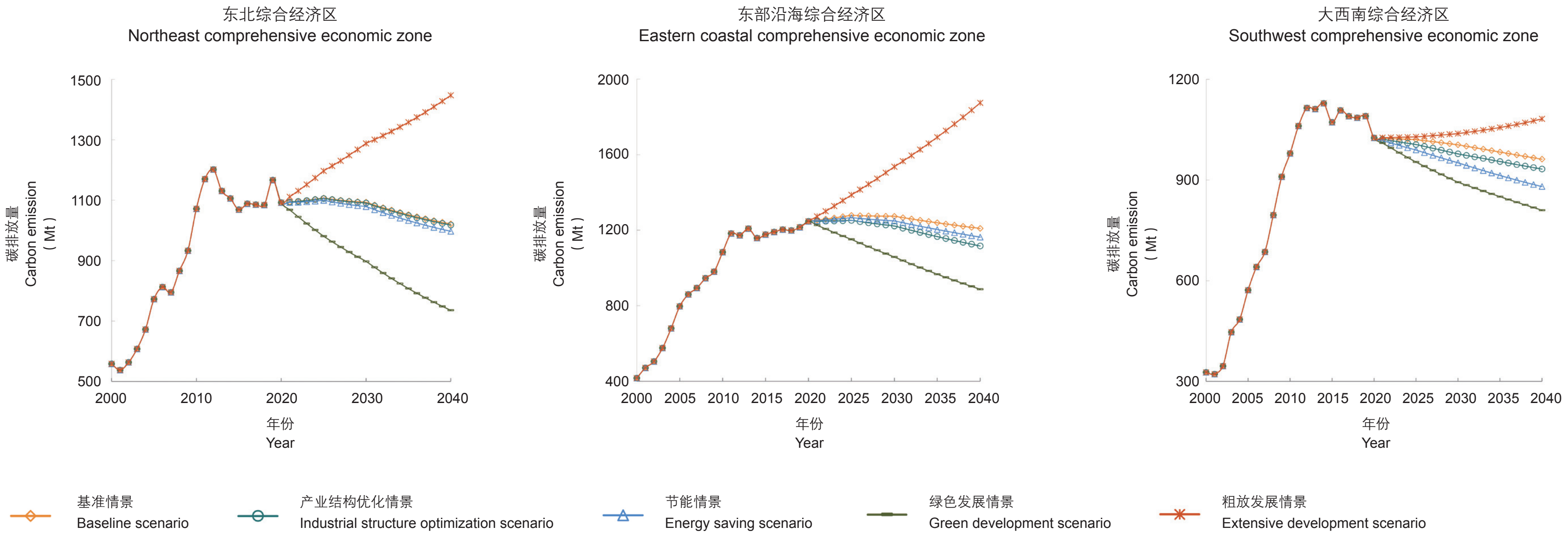
通过岭回归方程得到各省市碳排放回归方程相关参数后，将各影响因素变化率的预测值输入STIRPAT模型，计算得出各省碳排放预测结果。在此过程中，涉及到的各经济区碳排放量为所包含省市计算结果的总和，碳排放峰值则基于整体碳排放量判断。研究结果显示（表6），东北、东部沿海和大西南综合经济区在基准情景、产业结构优化情景和节能情景下，可于2030年前实现碳达峰；在绿色发展情景下，除以上三个经济区外，北部沿海、南部沿海和黄河中游综合经济区也可实现碳达峰目标；而长江中游和大西北综合经济区在任何情景下均无法于2030年前达峰。根据各区域的碳达峰时间与情景，研究将八大经济区划分为基

The study found that the significance level of each influencing factor on carbon emission differs. For example, for Liaoning Province, the impact of population is the most significant, where for every 1% increase in population, carbon emission may increase by 3.442%. However, for Chongqing City, industrial structure is the most significant factor, where for every 1% reduction in industrial structure, carbon emission may be reduced by 1.689%. Overall, factors of population, urbanization rate, and industrial structure have a relatively significant impact on carbon dioxide emission of Chinese provinces/cities.

After obtaining relevant parameters of the carbon emission regression for each province/city through ridge regression analysis, the research puts the values of change rates of each influencing factor into STIRPAT model, and obtains the carbon emission prediction result of each province/city. In the process, the carbon emission of each zone is estimated as the sum of the calculation results of every province/city included, and the carbon emission peak is approximated upon the overall carbon emissions. As shown in Table 6, three of China's eight comprehensive economic zones (northeast, southwest, and eastern coastal) can achieve carbon peaking before 2030 under baseline, industrial structure optimization, and energy saving scenarios. Under green development scenario, in addition to the above three economic zones, the northern coastal, southern coastal, and the middle reaches of Yellow River comprehensive economic zones can also achieve carbon peaking by 2030; the middle reaches of Yangtze River and northwest comprehensive economic zones cannot achieve carbon peaking by 2030 under any scenario. According to the peaking time under each scenario, the eight zones can be classified into three types,

**表6：不同情景下各区域碳达峰时间预测**
**Table 6: Carbon peaking prediction of each zone under different scenarios**

| 区域<br>Zone | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|
| 东北综合经济区<br>Northeast comprehensive economic zone | 2012 | 2012 | 2012 | 2012 | — |
| 北部沿海综合经济区<br>Northern coastal comprehensive economic zone | — | — | — | 2019 | — |
| 东部沿海综合经济区<br>Eastern coastal comprehensive economic zone | 2025 | 2025 | 2025 | 2020 | — |
| 南部沿海综合经济区<br>Southern coastal comprehensive economic zone | — | — | — | 2020 | — |
| 黄河中游综合经济区<br>The middle reaches of Yellow River comprehensive economic zone | — | — | — | 2030 | — |
| 长江中游综合经济区<br>The middle reaches of Yangtze River comprehensive economic zone | — | — | — | — | — |
| 大西南综合经济区<br>Southwest comprehensive economic zone | 2014 | 2014 | 2014 | 2014 | — |
| 大西北综合经济区<br>Northwest comprehensive economic zone | — | — | — | — | — |

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准情景可达峰地区、条件约束下可达峰地区和条件约束下仍无法达峰地区三类。

### 3.2 基准情景可达峰地区

基准情景下，东北、东部沿海和大西南综合经济区均能于2030年前达峰（图1），但达峰模式存在差别：由于东北综合经济区社会经济发展相对缓慢甚至停滞，人口呈现负增长态势，该区域的碳达峰模式为社会经济衰退导致的被动达峰结果，不利于地区的长期可持续发展；而东部沿海与大西南综合经济区社会经济活力较高，加之正在进行的产业结构与能源强度、结构的绿色转型，使其得以于2030年前实现碳达峰，属于保障社会经济发展下的主动达峰过程。

（1）被动达峰的东北综合经济区

在除粗放发展情景外的其余情景下，东北综合经济区均于2012年实现碳达峰。当前，东北地区人均GDP与东部地区差距不断拉大，与中、西部地区差距逐渐缩小，区域人口自2014年起便出现负增长，近年来人口流失尤为严重[70]；由于区域工业化进程较早且已达较高水平，城镇化率增长速度缓慢[71]；自然、劳动、资本、技术等生产要素不断流出[70]，以第二产业为主的产业结构已成为制约地区发展的主要

1. 东北、东部沿海与大西南综合经济区碳排放预测
1. Carbon emission predictions of northeast, eastern coastal, and southwest comprehensive economic zones.

namely zones that can achieve carbon peaking under baseline scenario, zones that can achieve carbon peaking under conditional scenarios, and zones that cannot achieve carbon peaking under any scenario.

### 3.2 Zones That Can Achieve Carbon Peaking Under Baseline Scenario

The northeast, eastern coastal, and southwest comprehensive economic zones can achieve carbon peaking under baseline scenario (Fig. 1), while the corresponding peaking paths vary. As the northeast comprehensive economic zone has been lagging or even stagnant in its socio-economic development and seen a decreasing population growth, it can achieve a passive carbon peaking resulted from socio-economic recession, which is not conducive to its long-term sustainable development. In contrast, the eastern coastal and southwest comprehensive economic zones have a relatively high social and economic vitality, coupled with the ongoing green-oriented transformation in industrial structure, energy intensity, and energy structure, enabling them to actively achieve carbon peaking by 2030 while guaranteeing the sustainability of socio-economic development.

(1) The passive peaking path of northeast comprehensive economic zone

Except for extensive development scenario, the northeast comprehensive economic zone should have achieved carbon peaking by 2012 under all other scenarios. At present, the GDP per capita gap between the northeast and eastern regions has continued to widen, and that gap with the central and western regions has gradually narrowed; Population in the zone has witnessed a negative growth since 2014 and an accelerated loss of residents in recent years[70]; Since it has an early and developed industrialization, the growth rate of urbanization in this zone is also slowing down[71] in recent years. The outflows of natural, labor, capital, and technological resources and other production factors[70], and the industrial structure pillared by industrial sectors have principally obstructed the provincial

短板因素[72]，东北综合经济区经济优势逐渐丧失，陷入“区域塌陷”的现实困境[70]。

预测结果显示，虽然辽宁省仍呈现碳排放增长趋势，但由于黑龙江和吉林两省碳排放降幅更大，东北综合经济区整体表现为可于2012年实现碳达峰的格局。这一时间早于部分预测研究[34]结果，本文认为经济的严重下滑和人口的加速流失[70][73]导致研究应用数据的不同可能是造成预测结果差异的主要原因。

（2）主动达峰的东部沿海与大西南综合经济区

在除粗放发展情景外的其余情景下，大西南综合经济区均可于2014年实现碳达峰；东部沿海综合经济区在基准情景、产业结构优化情景和节能情景下的碳达峰时间为2025年，在绿色发展情景下为2020年，结论与岳书敬预测在基准及优化情景下，长三角城市群（即东部沿海综合经济区）能够在2030年前实现碳达峰的结论相一致[41]。

2013~2019年，根据《中国统计年鉴》《中国人口和就业统计年鉴》及各省市统计年鉴中的相关数据，大西南综合经济区人均GDP、城镇化率和人口增速的年均复合增长率分别为8.31%、2.53%和0.56%，高于全国平均水平，对碳排放量的增长有较强的驱动作用；产业结构、能源强度和能源结构的年均复合增长率分别为−3.83%、−6.62%和−4.28%，降幅远超全国平均水平，产业与能源的绿色转型在一定程度上促进了区域的高质量发展[74]，并抑制了碳排放。与之类似，东部沿海综合经济区的社会经济发展水平始终处于全国领先地位[75]，其人口与人均GDP增长较为迅速，在一定程度上驱动了碳排放。由于东部沿海综合经济区技术应用较其他地区发达，且能源碳排放效率最高[76]，基于此，此区域可在基准情景下于2025年实现碳达峰。

### 3.3 条件约束下可达峰地区

在条件约束下，北部沿海、南部沿海和黄河中游综合经济区均只可在绿色发展情景下于2030年前实现碳达峰，时间分别为2019年、2020年和2030年。前二者是中国改革开放以来便作为经济重心的沿海地区[77]，人口流入较集中[78]，区域社会经济活力充沛，较难实现碳达峰；而后者作为中国能源输出的主要区域，难以实现碳达峰主要受制于由其资源禀赋特征决定的发展模式，需考虑区域分工合作和隐含的碳排放转移[79]等因素对碳排放峰值的影响，其达峰路径需结合全国碳排放情景，与全国碳达峰路径进行协调，避免为实现达峰目标而制定对区域经济发展不利的苛刻目标。

（1）北部沿海综合经济区

北部沿海综合经济区的北京市与河北省在基准情景下可分别于2010年、2013年实现碳达峰，本文预测达峰时间与CEADs中两地碳排放峰值显示时间一致。山东省只在绿色发展情景下可于2019年实现碳达峰，天津市在任何情景下均无法达峰，综合计算得出北部沿海综合经济区无法在基准情景下于2030年前达峰（图2）。

其中，天津市在任何情境下均无法达峰的预测结果，与其在CEADs中碳排放实际变化趋势和学者预测结果[39]均不一致，推测产生这一误差的原因是由于本研究中参照天津市规划文件中城镇化率和人口规模所设

development[72]. On the whole, the zone is losing its economic strength and suffering from the dilemma of “regional collapse”[70].

The prediction results show that the carbon emission of Liaoning Province will keep growing, but that of Heilongjiang and Jilin Provinces will sharply decline, leading to an estimated carbon peaking of the northeast comprehensive economic zone by 2012. This prediction is earlier than other forecast results[34], which might result from the difference of data sourcing in the economic downturn and accelerated population loss[70][73].

(2) The active peaking path of eastern coastal and southwest comprehensive economic zones

It is estimated that the southwest comprehensive economic zone should have achieved carbon peaking by 2014 in any scenario except for extensive development. The carbon peaking time of the eastern coastal comprehensive economic zone is predicted to be 2025 under baseline, industrial structure optimization, and energy saving scenarios, and 2020 under green development scenario—This is consistent with the prediction by Yue Shujing[41] that under baseline and optimization scenarios, the Yangtze River Delta city constellation (the eastern coastal comprehensive economic zone in this study) can achieve carbon peaking before 2030.

According to China Statistical Yearbooks, China Population & Employment Statistical Yearbooks, and relevant statistics documents of each province/city, the compound annual growth rate of the southwest comprehensive economic zone in GDP per capita, urbanization rate, and population was 8.31%, 2.53%, and 0.56%, respectively, from 2013 to 2019, which were higher than the national average, suggesting that these factors had a strong driving effect on the provincial carbon emission; the compound annual growth rate in industrial structure, energy intensity, and energy structure in that period was 3.83%, -6.62% and -4.28%, respectively, which were largely lower than the national average rates. The green transformation of industry and energy has facilitated the promotion of high-quality provincial development[74] and reduction in carbon emission. Similarly, the development of the eastern coastal comprehensive economic zone in recent years has always been leading nationwide[75], and the rapid growth in population and GDP per capita has propelled the increase of its carbon emission. Since the zone sees advance in technology development and has the highest energy carbon emission efficiency in comparison to other zones[76], it can achieve carbon peaking by 2025 under baseline scenario.

### 3.3 Zones That Can Achieve Carbon Peaking Under Conditional Scenarios

Among conditional scenarios, the northern coastal, southern coastal, and the middle reaches of Yellow River comprehensive economic zones should have achieved carbon peaking under green development scenario in 2019, 2020, and 2030, respectively. The former two zones are coastal regions and national economic anchors since China’s reform and opening up[77], with more concentrated population inflow[78] and higher socio-economic demands, making it difficult to

置的预测数据相对较高（《天津市城市总体规划（2015—2030）》中2030年对城镇化率和人口规模的设置目标分别为91%和2 150万人），使预测结果中碳排放增长的驱动作用较强，而天津市的实际碳排放总量可能将小于预测值，导致本研究中碳达峰预测时间与事实偏差较大。

根据碳排放回归拟合结果，影响山东省碳排放的三个最主要因素依此为人口规模、产业结构和城镇化率。鉴于通常不以牺牲人口、城镇化率或人均GDP的增长换取碳减排[37]，因此，在基准情景的基础上，对山东省产业结构控制并优化可能将加快山东省的碳达峰时间。

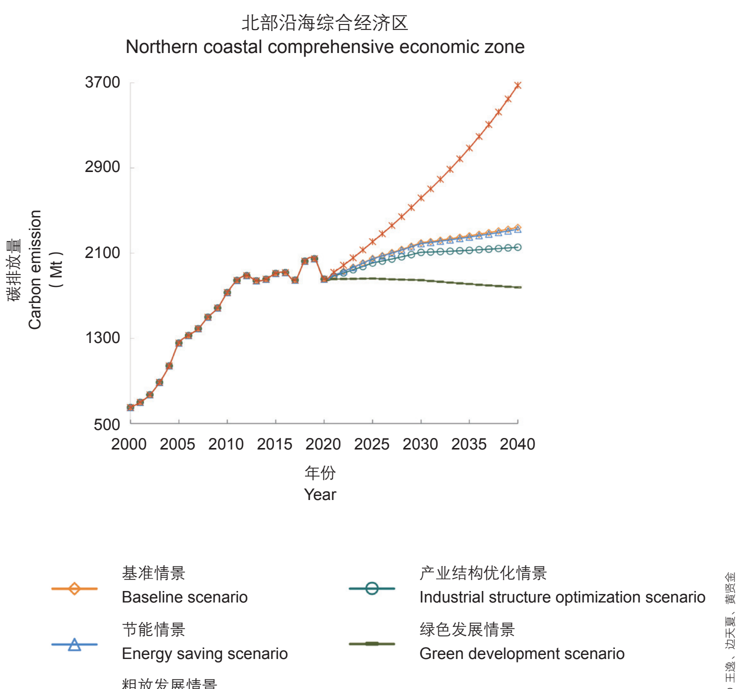
（2）南部沿海综合经济区

在南部沿海综合经济区中（图3），福建省在基准情景、产业结构优化情景、节能和绿色发展情景下于2020年实现碳达峰；广东省仅可在绿色发展情景下于2025年实现碳达峰；而海南省在任何情景下均无法实现碳达峰。因此，南部沿海综合经济区碳达峰时间主要受制于广东省与海南省。

具体而言，驱动广东省碳排放增长的主要两大因素分别为城镇化率和人口规模；此外，广东省高碳产业具有高度集中性，其中电力、蒸汽和热水的生产和供应业等的碳排放量均较大[80]，优化广东省产业结构、提高产业技术水平可能将有效抑制碳排放总量。海南省是中国第五个经济特区，旅游业作为全省支柱产业在国家政策的支持下一直稳居高位，

2. 北部沿海综合经济区碳排放预测

2. Carbon emission prediction of northern coastal comprehensive economic zone



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achieve carbon peaking. For the latter, the difficulty in achieving carbon peaking is resulted from the region's energy-exporting development mode determined by its resource endowment. In future it is necessary to consider the impact on carbon emission by regional inter-cooperation and possible carbon emission transfer[79], and its peaking path needs to be coordinated with the national carbon peaking vision while avoiding harsh targets unfavorable to regional economic development.

(1) Northern coastal comprehensive economic zone

It is predicted that under baseline scenario Beijing City and Hebei Province in the northern coastal comprehensive economic zone should have achieved carbon peaking in 2010 and 2013, respectively, which is consistent with the reported carbon peaking time in CEADs. Shandong Province can only achieve carbon peaking under green development scenario (in 2019), and Tianjin City will fail achieving carbon peaking under any scenario. Overall, northern coastal comprehensive economic zone cannot achieve carbon peaking by 2030 under baseline scenario (Fig. 2).

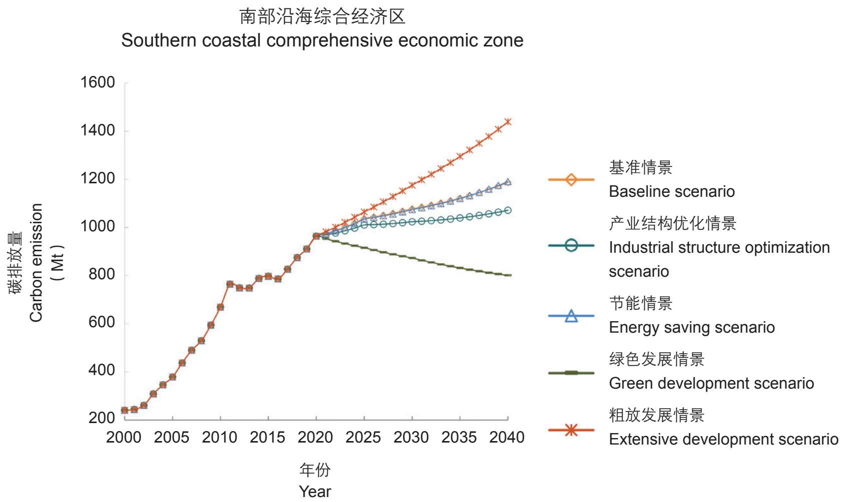
Notably, the prediction that Tianjin cannot achieve carbon peaking under any scenario is inconsistent with the reported carbon emission or other prediction results[39]. A possible reason for this deviation is that the data in carbon emission driving factors such as urbanization rate and population used in this study are sourced from Tianjin Urban Master Plan (2015–2030), according to which the both factors will reach 91% and 21.5 million in 2030, respectively. The figures are relatively high, leading to that the estimated carbon emission growth may be higher than the actual increase.

According to the result of carbon emission regression fitting, the most significant factors affecting the carbon emission of Shandong Province are population, industrial structure, and urbanization rate. Since generally it is not encouraged to decrease the growth in population, urbanization rate, and GDP per capita for the reduction of carbon emission[38], the control and optimization of industrial structure may speed up the carbon peaking of Shandong.

(2) Southern coastal comprehensive economic zone

For the southern coastal comprehensive economic zone, Fujian Province should have achieved its carbon peaking in 2020 under baseline, industrial structure optimization, energy saving, and green development scenarios. Guangdong Province can only achieve carbon peaking under green development scenario (in 2025), while Hainan Province cannot achieve carbon peaking in any case. Therefore, the delay in peaking time of the zone is subject to the heavy carbon emission of Guangdong and Hainan Provinces (Fig. 3).

Specifically, the two driving factors to the growth of carbon emission in Guangdong Province are urbanization rate and population. Besides, Guangdong accommodates a number of concentrated high carbon industries, the production and supply of electric power, steam, and hot water industries all bring about high carbon emissions[80]. Optimizing industrial structure and improving the technological level of industries may effectively curb the total carbon emission of the province. Hainan is the fifth special economic zone in China, with tourism as its pillar industry that

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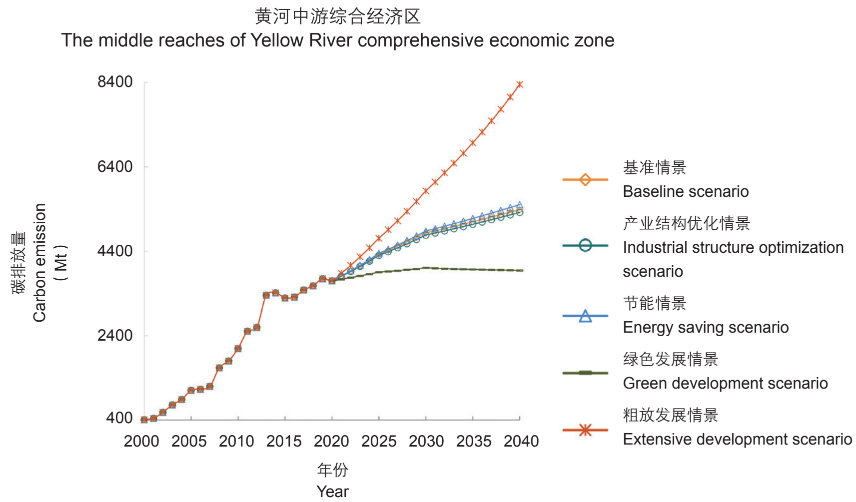


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自由贸易港的成立更进一步促进地区经济发展[81]，且总体发展趋势持续向上，短期内可能较难实现碳达峰。由于海南省产业结构以第三产业为主，第二产业占比不高，开发省内海洋的蓝碳潜力[82]是海南省未来重要发展方向。

（3）黄河中游综合经济区

黄河中游综合经济区预测结果显示（图4），陕西省与河南省在基准情景下可分别于2017年和2011年实现碳达峰，内蒙古自治区仅可在绿色发展情景下于2019年实现碳达峰，而山西省在任何情景下均无法实现碳达峰。

山西省和内蒙古自治区作为中国前两大能源输出省[83][84]，均较难实现2030年前碳达峰目标。特别是山西省，至2015年仍有约64%的能源产量被输送出省，且电力出省占比不断增加，导致其碳排放量仍快速上升[85]。吴青龙等人通过开放与封闭STIRPAT模型（开放STIRPAT模型从山西和全国两个层面选择山西碳排放量的影响因素，封闭STIRPAT模型仅从山西省层面选择山西碳排放量的影响因素）预测山西省2016~2040年间的碳达峰时间。研究结果显示，在封闭模型中山西省在所有情景组合下预测时段内均无法达到峰值，表明山西省对自身碳排放峰值缺乏完全可控性；而在开放模型中山西省则能在预测时间段内出现碳排放峰值，表明山西省碳排放峰值在预测时段内是否出现主要由全国层面发展

3. 南部沿海综合经济区碳排放预测
4. 黄河中游综合经济区碳排放预测

3. Carbon emission prediction of southern coastal comprehensive economic zone
4. Carbon emission prediction of the middle reaches of Yellow River comprehensive economic zone

is greatly supported by national policies; besides, the establishment of Free Trade Port has further promoted its economic development[81]. In the near future, it may be difficult for Hainan to achieve carbon peaking in an upward economy. Since the provincial industrial structure is dominated by service sectors, developing blue-carbon industries based on the rich marine resources[82] in Hainan needs to be considered in its future development.

(3) The middle reaches of Yellow River comprehensive economic zone

The forecast results (Fig. 4) of the middle reaches of Yellow River comprehensive economic zone show that Shaanxi and Henan Provinces should have achieved carbon peaking in 2017 and 2011 respectively under baseline scenario, Inner Mongolia would only achieve carbon peaking under green development scenario (in 2019), and Shanxi cannot achieve carbon peaking under any scenario.

Shanxi and Inner Mongolia, as the top two energy-exporting provinces in China[83][84], both have difficulty in achieving carbon peaking by 2030. For Shanxi Province in particular, by 2015, approximately 64% of its energy production was still transported out of the province, and its proportion of power generation keeps climbing, which has resulted in a rapid increase in the provincial carbon emission[85]. Wu Qinglong et al. studied the carbon peaking time of Shanxi during the period from 2016 to 2040 through the open and closed STIRPAT models—The influencing factors on carbon emission for the open model were selected from both provincial and national perspectives, and the ones for the closed model were selected from provincial perspective only. The research findings in the closed model shows that Shanxi could not achieve carbon peaking under any scenario, revealing that Shanxi lacks a complete control over its carbon emission peak. However, in the open model, a peak in carbon emission can be found during the studied period of time, indicating that whether its carbon emission peak occurs within the forecast period would be largely determined by the national visions on carbon

策略选择决定[85]。对于内蒙古自治区，在其他研究中，内蒙古自治区实现碳达峰的预测时间也较晚[84]，原因在于其终端消费主要集中于电力、化工等部门[86]，碳排放量随经济增长而增加。

总体而言，黄河中游综合经济区由于自身资源禀赋、能源技术水平及能源配置和以煤炭为主的能源结构等因素，决定了其以牺牲环境为代价发展经济的模式[83]，使该区域较难达峰。因此，此区域为在2030年前实现碳达峰的目标，除了要提升区域内的节能减排能力，还要结合其他区域低碳减排趋势，制定适合区域发展的碳排放达峰政策。此外，若提升能源利用效率并加大可再生能源的投入，可能会加快实现碳达峰目标。

### 3.4 条件约束下仍无法达峰地区

条件约束下仍无法实现碳达峰的区域是长江中游与大西北综合经济区（图5）。这两大经济区均属于内陆地区，在中部崛起和西部大开发战略等政策的影响下得以快速发展。但由于发展起步较晚，生产方式仍较为粗放，短期内难以实现碳达峰。

长江中游综合经济区除湖南省可在基准情景、产业结构优化情景、节能情景及绿色发展情景下于2012年实现碳达峰外，其余湖北、江西、安徽三省在任何情景下均无法实现碳达峰。其中，本研究对湖北省的预测结果与当前对于湖北省将在2021~2025年实现碳达峰[20][87]的普遍预测存在差异，推测造成此差异的原因可能在于为解决多重共线性问

5. 长江中游与大西北综合经济区碳排放预测

5. Carbon emission predictions of the middle reaches of Yangtze River and northeast comprehensive economic zones

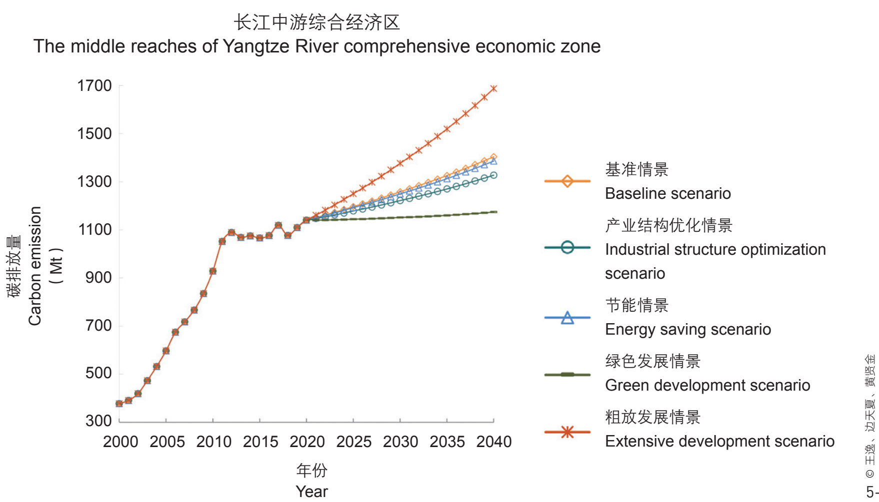
emission[85]. The predicted carbon peaking time of Inner Mongolia is also later than other studies[84]. This may be because its end-use consumption is mainly in power and chemical sectors[86], so its carbon emission will increase along with economic growth.

On the whole, the economic development mode of the middle reaches of Yellow River comprehensive economic zone—determined by factors of resource endowment, energy technology level, energy allocation, and coal-dominated energy structure—has compromised its environmental quality[83], making it difficult to achieve carbon peaking by 2030. Therefore, this zone should not only improve its capacity in energy saving and carbon emission reduction, but also formulate related policies favorable for regional development and conforming to the low-carbon emission visions of other allied regions. In addition, enhancing energy efficiency and renewable energy inputs may accelerate the achieving of carbon peaking.

### 3.4 Zones That Cannot Achieve Carbon Peaking Under Any Scenario

The middle reaches of Yangtze River and northwest comprehensive economic zones cannot achieve carbon peaking under any scenario (Fig. 5). These two inland zones witness a rapid development under the national policies such as Rise of Central China and Develop the West Campaign. However, due to the late development and current extensive production mode, it is difficult for the two zones to achieve carbon peaking in short term.

For the middle reaches of Yangtze River comprehensive economic zone, the estimated carbon peaking time of Hunan Province under baseline, industrial structure optimization, energy saving, and green development scenarios is 2012; Hubei, Jiangxi, and Anhui Provinces cannot achieve carbon peaking under any scenario. The prediction result for Hubei is different from current board outlook that the province can achieve carbon peaking during 2021 to 2025[20][87]. A reason for this disparity may be that the k value selected in the ridge regression is relatively



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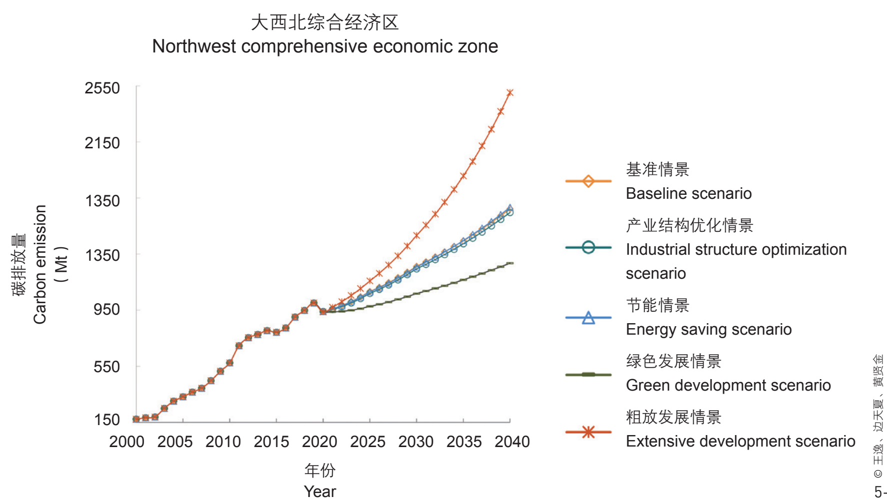


5-2

题，湖北省岭回归岭迹曲线趋于稳定时所选k值较大，导致STIRPAT模型对湖北省碳排放预测的回归拟合度不高（$R^2$值仅为0.751），预测精度降低。安徽省和江西省则分别受产业结构和能源结构的影响较大，故若两省增加技术资金投入、鼓励技术创新、优化产业结构、提升清洁能源占比，也可将提供更多的碳减排空间。

对于大西北综合经济区而言，青海和宁夏两省可在基准情景、产业结构优化情景、节能情景和绿色发展情景下分别于2013和2019年实现碳达峰，而甘肃省和新疆自治区在任何情景下均无法实现碳达峰。近年来，在西部大开发的战略支持下，大西北综合经济区经历了人口规模、经济和城镇化率的强劲增长。此外，根据各省实际统计数据，该地区第二产业占比普遍较高、能源利用效率较低，煤炭消费比重下降缓慢甚至出现上升趋势，使得难以实现碳达峰目标。回归拟合结果显示，产业结构、能源结构均对大西北综合经济区各省具有较大影响。因此，优化产业结构、改善能源结构将可能显著约束碳排放增长，提升能源利用效率并对现有高新技术进行推广利用也将促进该区域尽早实现碳达峰。

尽管从预测结果上看，长江中游和大西北综合经济区在任何情景下都无法实现碳达峰，但考虑到两区域发展起步较晚，且应坚持共同富裕的发展理念，不能以实现碳达峰目标为由阻碍区域经济发展。这两大区域应逐步促进产业升级、淘汰落后产能，实现区域社会经济高质量发展，从而早日实现碳达峰目标。

### 3.5 全国碳达峰预测

针对上述研究结果，本文提出七种全国碳达峰发展策略（表7）。

1）基准情景达峰策略：各区域均采取基准情景，参照各省市规划文件设置目标，延续当前发展趋势。

2）产业结构优化情景达峰策略：各区域均采取产业结构优化情景，在基准情景的基础上进一步降低第二产业占比，推动产业转型升级，并基于此制订未来政策标准。

3）节能情景达峰策略：各区域均采取节能情景，在基准情景的基础上进一步提升能源利用效率，优化能源结构，减少煤炭能源占比，大力发展清洁能源。

large, which leads to the low goodness of regression fit in STIRPAT model for carbon emission prediction ($R^2 = 0.751$) and thus a low prediction accuracy. Anhui and Jiangxi are more likely to be affected by factors of industrial structure and energy structure, respectively. Solutions such as increasing capital investment in technological development, encouraging technological innovation, optimizing industrial structure, and promoting the proportion of clean energy help reduce carbon emission reduction in the two provinces.

For the northwest comprehensive economic zone, the forecast results show that Qinghai and Ningxia should have achieved carbon peaking in 2013 and 2019 under baseline, industrial structure optimization, energy saving, and green development scenarios, while Gansu and Xinjiang cannot achieve carbon peaking under any scenario. In recent years, under the Develop the West Campaign, the northwest comprehensive economic zone has experienced vibrant growth in economy, population, and urbanization rate. According to the reported statistics of each province in the zone, the zone has a large proportion in industrial sectors, a low energy utilization efficiency, and a hardly decreasing (or even slightly growing) proportion of coal consumption, making it difficult to achieve carbon peaking. The regression fitting analysis shows that factors of industrial structure and energy structure have a significant impact on the carbon emission of each province in the zone. Thus, optimizing industrial and energy structure may reverse the growth of carbon emission, and the improvement of energy utilization efficiency and the promotion of new technologies may also shorten the time till carbon peaking.

Although the prediction tells that the middle reaches of Yangtze River and northwest comprehensive economic zones cannot achieve carbon peaking under any scenario, the economic development of the two zones should not be compromised simply for carbon peaking. Considering the late development and adhering to the national policy of Common Prosperity, the two zones should gradually promote industrial upgrades and shut down backward production capacities, so as to achieve carbon peaking as early as possible and to boost high-quality regional socio-economic development.

### 3.5 Simulation of Carbon Peaking of China's Comprehensive Economic Zones

Based on the prediction above, this paper proposes seven carbon peaking path strategies for China's comprehensive economic zones (Table 7).

1) Baseline strategy: each zone adopts baseline scenario and sets development targets according to corresponding provincial/municipal planning documents.

2) Industrial structure optimization strategy: each zone adopts industrial structure optimization scenario, further reduces the proportion of industrial sectors, promote industrial transformation and upgrading, and formulates future policy standards based on those under baseline scenario.

3) Energy saving strategy: each zone adopts energy saving scenario, further improves energy efficiency, optimizes energy structure, reduces coal use, and promotes the use of clean energy.

表7：中国碳达峰策略情景设置
Table 7: China's carbon peaking strategy scenario setting

| 策略类型<br>Strategy | 策略情景设置<br>Strategy setting | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 东北综合经济区<br>Northeast comprehensive economic zone | 北部沿海综合经济区<br>Northern coastal comprehensive economic zone | 东部沿海综合经济区<br>Eastern coastal comprehensive economic zone | 南部沿海综合经济区<br>Southern coastal comprehensive economic zone | 黄河中游综合经济区<br>The middle reaches of Yellow River comprehensive economic zone | 长江中游综合经济区<br>The middle reaches of Yangtze River comprehensive economic zone | 大西南综合经济区<br>Southwest comprehensive economic zone | 大西北综合经济区<br>Northwest comprehensive economic zone |
| 基准情景达峰策略<br>Baseline strategy | S1 | S1 | S1 | S1 | S1 | S1 | S1 | S1 |
| 产业结构优化情景达峰策略<br>Industrial structure optimization strategy | S2 | S2 | S2 | S2 | S2 | S2 | S2 | S2 |
| 节能情景达峰策略<br>Energy saving strategy | S3 | S3 | S3 | S3 | S3 | S3 | S3 | S3 |
| 绿色发展情景达峰策略<br>Green development strategy | S4 | S4 | S4 | S4 | S4 | S4 | S4 | S4 |
| 粗放发展情景达峰策略<br>Extensive development strategy | S5 | S5 | S5 | S5 | S5 | S5 | S5 | S5 |
| 达峰协同策略<br>Synergic peaking strategy | S1 | S4 | S1 | S4 | S4 | S4 | S1 | S4 |
| 发展协同策略<br>Synergic development strategy | S1 | S4 | S4 | S4 | S2 | S2 | S2 | S2 |

4）绿色发展情景达峰策略：各区域均采取绿色发展情景，坚持低碳发展，加大相关绿色产业的投入力度，制订政策进行强约束，以实现全国层面的绿色发展目标。

5）粗放发展情景达峰策略：各区域均采取粗放发展情景，将主要目标集中于发展经济，对产业转型、能效提升、清洁能源发展的政策约束力低。

6）达峰协同策略：易实现碳达峰的东北、东部沿海和大西南综合经济区采取约束性最弱的基准情景，较难实现碳达峰的北部沿海、南部沿海、黄河中游、长江中游和大西北综合经济区采取约束效果最强的绿色发展情景。此策略旨在既保证碳达峰易实现地区的经济发展，也促进全国碳达峰目标的早日实现。

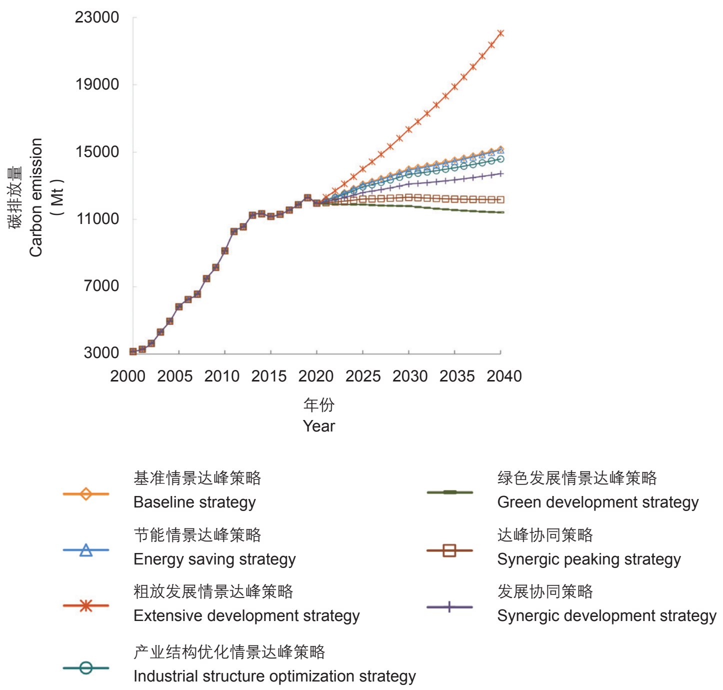
7）发展协同策略：经济相对发达[38]的东部沿海、南部沿海和北部沿海综合经济区采取绿色发展情景，经济相对欠发达的黄河中游、长江中游、大西南和大西北综合经济区均采取约束效果次强的产业结构优化情景，而已处于经济衰退的东北综合经济区采取基准情景。此策略旨在减少碳排放的同时尽可能保障欠发达与经济衰退地区的发展空间。

4) Green development strategy: each zone adopts green development scenario, promotes low-carbon development, increases investment in green industries, and imposes policy constraints to guarantee national green development.

5) Extensive development strategy: each zone adopts extensive development scenario for a rapid economic growth, with less policy support on industrial transformation, energy efficiency improvement, and clean energy development.

6) Synergic peaking strategy: the northeast, eastern coastal, and southwest comprehensive economic zones that can easily achieve carbon peaking adopt baseline scenario, and the others take green development scenario; this strategy aims not only to promote the economic development in the former three zones, but also to accelerate the national carbon peaking progress.

7) Synergic development strategy: the eastern, southern, and northern coastal comprehensive economic zones that are economically developed[38] adopt green development scenario, the northeast comprehensive economic zone that witnesses an economic recession adopts baseline scenario, and the others take industrial structure optimization scenario; this strategy aims to reduce carbon emission while minimizing constraints on the less developed and recession affected zones.






6. 在七种碳达峰策略下中国碳排放预测
6. China's nationwide carbon emission prediction with seven strategies

图6显示，若采用基准情景策略，在当前政策规划的约束下，中国无法在2030年前实现碳达峰，但碳排放速度与粗放发展策略相比明显减缓；若仅降低能源强度和优化能源结构（即采用节能情景策略），预测碳排放趋势与基准策略相近，说明节能策略对碳排放的约束力有限；若仅调整产业结构（即采用产业结构优化情景策略），尽管碳排放量增幅放缓，但在2030年后中国碳排放量仍持续增长，依然无法实现碳达峰目标。综上所述，在当前政策规划下，仅仅通过约束能源或产业等单一因子的措施只能使碳排放速度放缓，但无法使中国于2030年前实现碳达峰。

在达峰协同策略下，预测中国将在2030年实现碳达峰。但此策略可能会制约部分地区的经济发展，无益于解决“人民日益增长的美好生活需要和不平衡不充分的发展之间的矛盾”[88]。如果综合考虑各地区均衡发展以及碳达峰目标（即采用发展协同策略），仅仅较采用单一因子约束策略进一步放缓了碳排放增长速度，依然无法实现2030年达峰目标。而在绿色发展策略下，全国于2019年便可达到碳排放量峰值，但这与实际情况不符。可以说，上述7种碳达峰策略均无法在保障各区域均衡发展的基础上实现全国碳达峰目标。

## 4 结论

研究结果表明，中国八大经济区碳达峰时间存在差异，且可以将其分为基准情景可达峰区、条件约束下可达峰区和条件约束下仍无法达峰

Figure 6 shows that adopting the baseline strategy will not lead to a nationwide carbon peaking by 2030 if each zone implement current planning schemes. Meanwhile, carbon emission will be significantly slower compared with adopting the extensive development strategy. The carbon emission simulation of adopting energy saving and baseline strategies are similar, suggesting that simply lowering energy intensity and optimizing energy structure would little reduce carbon emission. If exclusively adjusting industrial structure (i.e., adopting the industry structure optimization strategy), China's carbon emission will continue to grow beyond 2030 but at a slower rate. In conclusion, if implementing current planning schemes, constraining single factors on energy and industry can only slow down the growth of carbon emission but cannot ensure a national carbon peaking by 2030.

With the synergic peaking strategy, it is estimated that China will successfully achieve carbon peaking by 2030. However, this strategy will constrain the economic development of some zones, and might exacerbate the principal contradiction "between unbalanced and inadequate development and the people's ever-growing needs for a better life"[88]. Considering a balanced nationwide development and the goal of achieving carbon peaking, adopting the synergic development strategy can reduce the growth rate of carbon emission compared with the strategies constraining single factors, but still fail to achieve carbon peaking by 2030. With the green development scenario strategy, the estimated results show that China should have achieved carbon peeking in 2019, which is inconsistent with the actual carbon emission. It can be concluded that none of the above seven carbon peaking strategies can achieve a nationwide carbon peaking while guaranteeing a balanced development.

## 4 Conclusions

The estimation results show that there are differences in achieving carbon peaking time among China's eight comprehensive economic zones. Accordingly, the zones can be classified into three groups.

1) Zones that can achieve carbon peaking under baseline scenario: the northeast, eastern coastal, and southwest comprehensive economic zones, through passive or active achieving paths.

2) Zones that can achieve carbon emission under conditional scenarios: the northern and southern coastal comprehensive economic zones as China's economic centers, and the middle reaches of Yellow River comprehensive economic zone as China's energy-exporting center; among the covered provinces/municipalities, Tianjin, Shandong, Guangdong, Hainan, Shanxi, and Inner Mongolia see difficulty in achieving carbon peaking under any scenario.

And 3) zones that cannot achieve carbon peaking under any scenario: the middle reaches of Yangtze River and northwest comprehensive economic zones, among the covered provinces, only Hunan, Qinghai, and Ningxia can achieve carbon peaking by 2030.

区三类。东北、东部沿海与大西南综合经济区为基准情景可达峰区，且存在被动达峰与主动达峰的差异。条件约束下可达峰地区为经济相对发达的北部沿海和南部沿海综合经济区，以及重要能源输出基地黄河中游综合经济区，其中天津市、山东省、广东省、海南省、山西省和内蒙古自治区是这三大区域中的难达峰省市／自治区。条件约束下仍无法达峰地区主要为长江中游和大西北综合经济区，只有湖南省、青海省和宁夏自治区能于2030年前实现碳达峰。

当前，欠发达经济区的碳排放增长趋势较强，仅靠单一因子约束难以抑制其持续增长。由于中国各大经济区资源禀赋、发展程度不同，各区域碳排放的主要影响因素亦存在区别，故在进行碳达峰政策制定时要结合区域实际发展情况，不能为实现碳达峰目标而实行一刀切政策，阻碍部分欠发达地区的社会经济发展。同样地，研究结果表明，仅次于绿色发展情景达峰策略，不同经济区采取差异化的达峰策略（达峰协同策略、发展协同策略）是比所有经济区同时采取单一因子约束情景（产业结构优化情景策略、节能情景策略）的策略形式对碳排放增长更具约束力。因此，加强欠发达地区长期低碳化发展，并使各经济区采取差异化达峰路径，可能是一种实现全国碳达峰较优的策略选择。

整体而言，本文研究预测结果与地区实际碳排放变化趋势或相关研究结果基本吻合，而部分地区的碳达峰时间预测结果存在差异。导致这一现象的原因可能在于研究中采用的碳排放影响因素变化率参照各省市相关规划文件进行设置，但可能存在规划的发展目标与当地发展现状不符的情况。以人口为例，大量研究表明中国人口增长逐渐放缓，甚至在5~10年内将迎来负增长的转折点[89]~[91]，然而多个地区现有规划文件中依然设置了较高的未来人口规划目标。尽管本研究已参照近年人口实际变化速率适当下调部分省市人口的预计增长率，使人口变化速率更贴近于实际变化情况，一定程度上降低了预测偏差，但不排除仍存在系统性偏差的可能性。

由于规划文件对于人口规模、人均GDP、城镇化率指标的设定多为预期性指标，且部分文件的预测时段较长，可能会出现规划与实际发展状况不一致的情况。因此，对于未来碳达峰的相关研究，建议结合最新权威预测研究和短期规划文件，或将提高预测的准确性。此外，有必要将能源输送和碳排放转移等事件的影响纳入考虑；跳出封闭视角的单一区域研究，仅靠单一区域自身的努力无法实现全国碳达峰目标；更要考虑各区域的分工合作和协调配合，保障全国各区域公平且均衡的发展。**LAF**

At present, the growth momentum of carbon emission in less developed zones continues, which is difficult to be curbed through constraining single factors. Each comprehensive economic zone is different in resource endowment and development level, causing a disparity in the significant influencing factors to carbon emission. Carbon peaking policies should be tailored to suit the actual development situation of each zone, avoiding hindering the socio-economic development of some less developed zones through a unified peaking path. According to the estimation, second only to the green development strategy, zones adopting customized peaking strategies (i.e. synergic peaking strategy, synergic development strategy) yield better results in curbing carbon emission growth, compared with adopting scenarios that constrain single factors (i.e. industry structure optimization strategy, energy saving strategy). Therefore, adopting customized strategy for each comprehensive economic zone while emphasizing the long-term low-carbon development in less developed ones could be more appropriate to achieving a nationwide carbon peaking.

On the whole, the study results are largely consistent to the growth momentum of observed carbon emissions or relevant research results. The differences between the observed and estimated carbon peaking time in some zones may be due to the inconsistency between the actual and assumed change rates of influencing factors on carbon emission. Taking the factor of population as an example, a large number of studies show that China's population growth is slowing down, and even will usher in a turning point in 5 to 10 years[89]~[91]; however, the predicted population in many existing local planning schemes are still high. In this study, some of the estimated local population growth rates were lowered reference to the reported data in recent years to reduce estimation deviation. However, the possibility of systematic deviation cannot be easily ruled out.

In this study, the indicators of population, GDP per capita, and urbanization rate collected from local planning schemes are mostly expected indicators, and the long prediction period in some planning schemes may cause data inconsistency with the reality. For future research, it is suggested to combine the latest authoritative prediction studies and short-term planning schemes to improve estimation accuracy. In addition, it is necessary to take impact of energy transmission and carbon emission transfer into account, to think beyond from a single perspective—Carbon peaking cannot be achieved only through regional efforts, but through regional cooperation and coordination to ensure an equitable and balanced national development of the nation. **LAF**

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