

Assessment of the carbon peaking status

----- an international perspective

Meiyue Sang^{1,2}, Liyin Shen^{3,1,2*}

¹School of Management Science and Real Estate, Chongqing University, Chongqing, 400044, China

²International Research Centre for Sustainable Built Environment, Chongqing University, Chongqing, 400044, China

³School of Spatial Planning, Hangzhou City University, Hangzhou, 310015, China

Corresponding author's E-mail: shenliyincqu@163.com

Abstract

The majority of countries in the international context have set the timing of carbon peak, which is crucial for assisting countries in progressing towards the final goal of carbon neutrality. This paper reports the different carbon peak statuses between a sample of 154 countries in terms of carbon intensity. The data used in the analysis were gathered from 1990 to 2020. Peaking statuses are classified into three categories: true peaked, false peaked, and under peaked. The analysis reveals that most sample countries have attained the true peaked status in terms of carbon intensity. Higher-income countries reached true peaked status sooner. Those with false peaked status are primarily influenced by various economic, social, and political factors.

Keywords: Carbon emissions, Carbon peak status, Carbon intensity, International perspective.

* Corresponding author: Liyin Shen

E-mail addresses: 20190313028t@cqu.edu.cn (Meiyue Sang), shenliyincqu@163.com (Liyin Shen).

1. INTRODUCTION

Reducing carbon emissions is widely acknowledged as the most vital approach to addressing climate change, which has precipitated a range of social, economic, and environmental issues, such as extreme weather, species extinction, and food scarcity. Research demonstrates that carbon dioxide emissions resulting from human activities are the primary contributors to climate change (Chen et al., 2019). Data from the World Bank indicate that global carbon emissions increased by more than 50% from 1990 to 2020, rising from 212.8 GT to 335.7 GT. In reaction to this trend, governments and global organizations have escalated their initiatives in recent decades to confront the critical issue of climate change. Notably, in 2015, almost 200 nations endorsed the Paris Agreement, which seeks to cap the increase in global average temperatures to 2°C within this century, while ideally limiting it to 1.5°C to achieve more favorable outcomes. Under the terms of the Paris Agreement, the governments of 138 countries have set timelines to achieve carbon peaking and carbon neutrality. Significantly, developing countries such as China have committed to reaching peak carbon emissions by 2030 and aim to attain carbon neutrality by 2060 (Fang et al., 2022). Norway and Uruguay have established ambitious goals to attain carbon neutrality by 2030. Moreover, in 2020, the United Arab Emirates committed to achieving carbon neutrality by 2050 (Safi et al., 2021). Identifying a carbon peak is a critical milestone on the path to achieving carbon neutrality. Consequently, evaluating whether a country has reached its carbon peak is essential for developing an effective strategy to attain carbon neutrality.

Identifying a carbon peak is a critical milestone on the path to achieving carbon neutrality. Consequently, evaluating whether a country has reached its carbon peak is essential for developing an effective strategy to attain carbon neutrality. Carbon intensity (CI) serves as a fundamental metric for assessing the effectiveness of carbon reduction initiatives and the achievement of carbon peaking. This paper undertakes an examination of the carbon peaking status of 154 countries by analyzing their carbon intensity. The findings will offer a comprehensive overview of carbon emission patterns across different nations and provide valuable insights for the formulation of effective carbon reduction strategies. The results of this study are anticipated to promote international cooperation and dialogue, thereby establishing a foundation for coordinated global efforts to reduce carbon emissions.

2. LITERATURE REVIEW

Previous research on carbon peaking has predominantly focused on analyzing and predicting the timing of carbon peaks. Studies have explored the CKC hypothesis across various groups of nations, including BRICS and G7 countries, OECD member states, as well as countries in Latin America and the Caribbean (Chang, 2015, Cho et al., 2014, Al-mulali et al., 2015). Some researchers have utilized the CKC model to investigate whether carbon emissions have reached their peak at both the provincial and city levels (Fang et al., 2019, Wang et al., 2019). Bersalli et al. (2023) evaluated the carbon peaking timelines of 45 countries and determined that 28 of

them have already reached their carbon peaks. The study identified economic crises as a significant factor influencing the achievement of carbon peaking. Cai and Wu (2022) conducted a forecast and analysis of carbon emissions for 30 provinces in China. Their findings suggest that 8 of these provinces are projected to reach their carbon emission peaks by 2030. Huo et al. (2024) evaluated the current carbon peaking status of residential buildings across thirty provinces in China, identifying that Heilongjiang and Shanghai have already achieved carbon peaking. Liu et al. (2024) examined the carbon peaking status of 192 small and medium-sized cities in China, finding that cities with emerging dynamic industries tend to reach carbon peaking more rapidly, while resource-based cities encounter significant challenges in achieving this goal. Tang et al. (2024) predicted the carbon peaking trajectory for Hunan Province in China, concluding that the province is likely to reach carbon peaking by 2030, with the industrial sector expected to play a pivotal role in reducing carbon emissions.

The World Resources Institute (WRI) defines carbon peaking as the point at which CO₂ emissions in a country or region reach their highest level before beginning to gradually decline (WRI, 2014). Following the peak, carbon emissions typically enter a plateau phase, during which they fluctuate within a specific range, before eventually transitioning into a phase of sustained reduction (Li et al., 2023). With this understanding, carbon peaking is considered not as a singular moment but as an extended process. From this perspective, numerous studies have applied the Mann-Kendall (MK) trend test method to analyze historical emission trends. For example, Li et al. (2023) utilized the MK trend test to assess the historical carbon peaking status of the building sectors across different provinces in China.

The previous literature review highlights a gap in the examination of carbon peaking status from a global perspective. This lack of a comprehensive global outlook impedes efforts to coordinate international actions toward achieving global carbon reduction targets. In response to this gap, the present study aims to evaluate carbon peaking status in terms of carbon intensity (CI) on a global scale. By employing the MK trend test and the Tapio decoupling model, the carbon peaking status is classified into three categories: under peaked (UP), false peaked (FP), and true peaked (TP) (Sang and Shen, 2024).

3. RESEARCH METHOD

As previously outlined, this study seeks to assess the carbon emission status of various countries based on carbon intensity (CI). The status can be classified into three categories: under peaked (UP), false peaked (FP), and true peaked (TP). To accurately determine a country's carbon peaking status, a two-stage assessment approach is employed. The first stage evaluates whether a country's carbon emissions are under peaked (UP). In the second stage, the analysis distinguishes between true peaked (TP) and false peaked (FP) statuses.

To determine whether carbon emissions are under peaked, the method proposed by the United Nations Environment Program and the World Resources Institute (WRI) suggests that emissions must have reached their peak within the last five years, followed by a plateau phase,

and then transitioned into a stable downward trend (WRI, 2014). Carbon emissions are classified as under peaked (UP) under two conditions: (1) if the period including and following the peak value is less than 5 years ($N < 5$); or (2) if the peak occurred 5 or more years ago ($N \geq 5$) but the subsequent decline is not statistically significant (Li et al., 2023). In the second scenario, the Mann-Kendall (MK) trend test is used to assess the significance of the downtrend. The main objective of the MK test is to identify whether a time series exhibits a monotonic trend, meaning whether the values consistently increase or decrease over time. The test relies on two critical statistics: the Z value and the P value. The Z value reveals the direction of the trend in the time series: $Z > 0$ signifies an upward trend, while $Z < 0$ indicates a downward trend. The P value measures the statistical significance of the trend, with a P value of ≤ 0.05 being considered statistically significant. Therefore, to confirm that the carbon emission trend is significantly decreasing, two conditions must be satisfied: $Z < 0$ and $P \leq 0.05$. This study employs R language tools to compute both the Z value and the P value.

To determine whether the status is false peaked (FP) or true peaked (TP), the Tapio decoupling method is applied (Sang and Shen, 2024). According to this method, a strong decoupling between carbon emissions and economic growth occurs only when the economic growth rate is positive, while the carbon emission growth rate is negative. When using the decoupling method, if a strong decoupling relationship is observed between carbon emissions and economic development, the status is classified as true peaked (TP). Conversely, if this relationship is not present, the status is considered false peaked (FP).

4. RESEARCH DATA

To carry out the research analysis, data on carbon intensity (CI) and GDP were required. These datasets, spanning the years 1990 to 2020 for 154 countries, were obtained from the World Bank Database. For instance, Table 1 presents the data for China. Due to space constraints, the original data for other countries are not included in this paper.

Table 1. Research data for the country of China.

Year	CI	GDP	Year	CI	GDP	Year	CI	GDP
1990	2.12	1027.38	2000	1.21	2770.11	2010	1.12	7554.11
1991	2.05	1122.54	2001	1.18	3001.02	2011	1.12	8275.59
1992	1.89	1282.22	2002	1.16	3275.12	2012	1.07	8926.36
1993	1.81	1460.24	2003	1.23	3603.88	2013	1.04	9619.60
1994	1.68	1650.61	2004	1.29	3968.37	2014	0.97	10333.93
1995	1.69	1831.42	2005	1.32	4420.54	2015	0.89	11061.57
1996	1.53	2013.14	2006	1.29	4982.88	2016	0.83	11819.15
1997	1.43	2199.09	2007	1.23	5691.99	2017	0.80	12640.25
1998	1.36	2371.63	2008	1.15	6241.30	2018	0.78	13493.44
1999	1.24	2553.33	2009	1.13	6827.91	2019	0.75	14296.37
						2020	0.75	14616.41

Note: the units of CI and GDP are Kg/USD and billion USD respectively.

5. ANALYSIS RESULTS

To conduct the research analysis, data on carbon intensity (CI) and GDP were essential. These datasets, covering the years 1990 to 2020 for 154 countries, were sourced from the World Bank Database. As an example, Table 1 provides the data for China. However, due to space limitations, the original data for other countries are not included in this paper.

Upon completing the calculations and analysis, the countries identified as having TP, UP, and FP status are listed in Table 2.

Table 2. The peaking status in terms of CI among the 154 sample countries

Country Code	CI	Country Code	CI	Country Code	CI
HI					
Andorra	TP	Denmark	TP	Norway	TP
United Arab Emirates	TP	Spain	TP	New Zealand	TP
Antigua and Barbuda	TP	Finland	TP	Oman	UP
Australia	TP	France	TP	Panama	TP
Austria	TP	United Kingdom	TP	Poland	TP
Belgium	TP	Greece	TP	Portugal	TP
Bahrain	TP	Guyana	TP	Romania	TP
Barbados	FP	Ireland	TP	Saudi Arabia	TP
Brunei Darussalam	UP	Italy	TP	Singapore	TP
Canada	TP	Japan	TP	Sweden	TP
Switzerland	TP	St. Kitts and Nevis	TP	Seychelles	UP
Chile	UP	Korea, Rep.	TP	Trinidad and Tobago	TP
Cyprus	TP	Luxembourg	TP	Uruguay	TP
Czechia	TP	Malta	TP	United States	TP
Germany	TP	Netherlands	TP		
UMI					
Albania	TP	Ecuador	TP	Mauritius	TP
Argentina	TP	Fiji	UP	Malaysia	TP
Armenia	TP	Gabon	TP	Peru	TP
Azerbaijan	TP	Georgia	UP	Paraguay	UP
Bulgaria	TP	Equatorial Guinea	TP	Russian Federation	TP
Belarus	TP	Grenada	UP	El Salvador	TP
Belize	TP	Guatemala	UP	Suriname	UP
Brazil	FP	Indonesia	TP	Thailand	TP
Botswana	TP	Iraq	TP	Turkmenistan	TP
China	TP	Jamaica	FP	Tonga	UP
Colombia	TP	Kazakhstan	TP	Turkey	TP
Costa Rica	TP	St. Lucia	UP	Tuvalu	TP
Cuba	TP	Mexico	TP	St. Vincent and the Grenadines	TP

Dominica	UP	North Macedonia	TP	South Africa	TP
Dominican Republic	TP				
LMI					
Angola	TP	Iran, Islamic Rep.	UP	Pakistan	TP
Benin	UP	Jordan	TP	Philippines	TP
Bangladesh	UP	Kenya	UP	Papua New Guinea	TP
Bolivia	UP	Kyrgyz Republic	TP	Senegal	UP
Bhutan	UP	Kiribati	UP	Solomon Islands	TP
Cote d'Ivoire	UP	Lao PDR	UP	Eswatini	TP
Cameroon	TP	Lebanon	UP	Tajikistan	TP
Congo, Rep.	UP	Sri Lanka	UP	Tunisia	TP
Comoros	UP	Lesotho	TP	Tanzania	UP
Cabo Verde	TP	Morocco	TP	Ukraine	TP
Algeria	UP	Myanmar	TP	Uzbekistan	TP
Egypt, Arab Rep.	TP	Mongolia	TP	Vietnam	UP
Ghana	UP	Mauritania	UP	Vanuatu	UP
Guinea	UP	Nigeria	TP	Samoa	UP
Honduras	TP	Nicaragua	TP	Zambia	UP
Haiti	UP	Nepal	UP	Zimbabwe	TP
India	TP				
LI					
Burundi	UP	The Republic of Madagascar	UP	Sudan	UP
Burkina Faso	UP	Mali	UP	Sierra Leone	UP
Central African Republic	TP	Mozambique	UP	Syrian Arab Republic	TP
Ethiopia	UP	Malawi	TP	Chad	UP
Gambia, The	TP	Niger	TP	Togo	TP
Guinea-Bissau	UP	Rwanda	TP	Uganda	UP

6. DISCUSSION

In the analysis of carbon intensity (CI), the sample countries were classified into three categories: 31.82% were identified as under peaked (UP), 1.95% as false peaked (FP), and 66.23% as true peaked (TP). Figure 1 presents the geographical distribution of the 154 countries based on these peaking statuses (UP, FP, TP). Countries with a true peaked (TP) status are distributed across various regions globally, whereas those classified as under peaked (UP) are predominantly concentrated in Africa, the Middle East, South Asia, and South America.

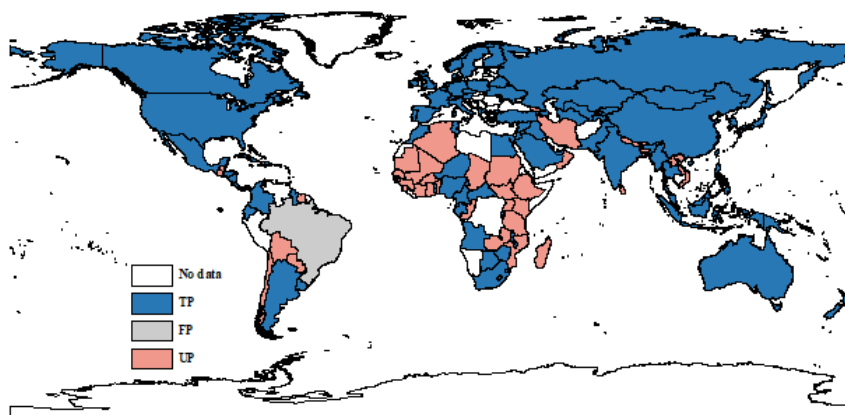


Figure 1. Geographical distribution of CI peaking statuses in sample countries.

It is evident that TP status is predominantly observed in developed nations or regions, as highlighted by Shuai et al. (2017). The reduction in carbon intensity in many developed countries surpasses that in developing nations. This disparity can be attributed to the numerous advantages enjoyed by developed countries, including higher energy efficiency, optimized industrial and energy consumption structures, and advanced renewable energy technologies, all of which contribute to reducing their carbon emission intensity. For example, over the past few decades, developed countries have transitioned from manufacturing-based economies to those driven by service and high-tech industries, leading to lower carbon emissions in these sectors (Shuai et al., 2017). Additionally, these nations were among the first to adopt clean energy sources such as nuclear, wind, and solar power, gradually decreasing their dependence on fossil fuels and thereby reducing carbon emissions. Moreover, they have implemented stringent environmental regulations, including emission trading systems and carbon taxes, employing mandatory measures to curb carbon emissions (Duan et al., 2022). These combined factors have enabled developed countries to achieve carbon peaking earlier.

In less developed countries, carbon intensity remains closely tied to economic growth, and these nations continue to encounter significant challenges in improving their carbon intensity. Many countries in this group are still in the developmental stage and heavily depend on high-carbon energy sources (Hu et al., 2018). These economically less developed nations rely on low-cost fossil fuels to drive economic growth and alleviate poverty (Hu et al., 2018). The economies of many developing countries are still heavily reliant on high-carbon industries such as manufacturing, heavy industry, and traditional agriculture, which presents substantial obstacles to transitioning to low-carbon practices. Furthermore, these less developed countries struggle to secure sufficient funding and advanced low-carbon technologies needed to implement renewable energy projects (Weko and Goldthau, 2022). Due to economic limitations, developing nations invest less in research and innovation, which hinders their capacity to independently develop clean energy and efficient energy utilization technologies. Although some developing countries have established environmental protection and emission reduction policies, they face considerable challenges in actual implementation, resulting in limited effectiveness.

In conclusion, the findings of this study reveal varying carbon intensity (CI) statuses—under peaked (UP), false peaked (FP), and true peaked (TP)—across 154 countries. These outcomes are influenced by a range of socio-economic factors, including a country's level of economic development, industrial structure, urbanization, innovation capacity, government policies, and population density. Therefore, reducing carbon emissions requires strategies that are specifically tailored to the unique circumstances of each country, rather than a one-size-fits-all approach. For countries that have not yet reached a peak in carbon intensity, a comprehensive approach is essential. First, these nations should work closely with developed countries and international organizations to integrate advanced clean energy technologies and enhance energy efficiency, thereby expediting the transition in their energy structures. Additionally, they should pursue greater international financial assistance and support to develop clean energy initiatives and implement effective emission reduction strategies. Secondly, these countries should capitalize on their natural resources by actively promoting and expanding renewable energy sources, such as wind, solar, and hydro power, to decrease their reliance on fossil fuels. Moreover, it is vital to design and rigorously enforce stricter environmental protection and emission reduction policies, including the establishment of carbon emission trading systems and the implementation of carbon taxes. Additionally, increasing investment in research and development for carbon reduction technologies is essential, as it fosters local innovation and technological advancement. By adopting these comprehensive strategies, countries can more effectively address the challenges of carbon emissions and progressively achieve carbon peaking in terms of carbon intensity.

7. CONCLUSION

This study examines the carbon emission peaking status of 154 countries from 1990 to 2020. The findings reveal that while most developed nations have achieved true peaked (TP) status in terms of carbon intensity (CI), some less developed countries have also reached TP status. The results indicate that countries with TP status are predominantly located in Europe and North America, whereas those with under peaked (UP) status are mainly found in Africa and South America. The status of false peaked (FP) countries is influenced by a combination of economic, social, and political factors.

The innovation of this study lies in its unprecedented and comprehensive analysis of the carbon peaking status of 154 countries worldwide through the lens of carbon intensity. This perspective not only enhances the depth and scope of the theoretical framework surrounding carbon peaking but also introduces a novel analytical approach and methodology. Theoretically, this study addresses gaps in the existing literature on carbon peaking, offering new insights and understanding. Practically, it provides essential theoretical support and policy recommendations for countries to develop tailored strategies for reducing carbon intensity and achieving carbon peaking. This research offers significant reference and guidance for global efforts to tackle the challenges of climate change, highlighting its substantial theoretical and practical value.

The limitations of this study are primarily related to its exclusive focus on the analysis of carbon intensity peaking statuses across various countries. Future research should consider evaluating carbon peaking performance using additional indicators to provide a more comprehensive assessment. Furthermore, this study only examines the current carbon peaking status of 154 countries without delving into the underlying mechanisms driving these statuses. Future research could expand upon this by exploring the factors that influence carbon peaking in different countries.

Reference

- AL-MULALI, U., TANG, C. F. & OZTURK, I. 2015. Estimating the environment Kuznets curve hypothesis: Evidence from Latin America and the Caribbean countries. *Renewable & Sustainable Energy Reviews*, 50, 918-924.
- BERSALLI, G., TRONDLE, T. & LILLIESTAM, J. 2023. Most industrialised countries have peaked carbon dioxide emissions during economic crises through strengthened structural change. *Communications Earth & Environment*, 4, 11.
- CAI, K. & WU, L. 2022. Using grey Gompertz model to explore the carbon emission and its peak in 16 provinces of China. *Energy and Buildings*, 277.
- CHANG, M. C. 2015. Room for improvement in low carbon economies of G7 and BRICS countries based on the analysis of energy efficiency and environmental Kuznets curves. *Journal of Cleaner Production*, 99, 140-151.
- CHEN, J. D., SHEN, L. Y., SHI, Q., HONG, J. K. & OCHOA, J. J. 2019. The effect of production structure on the total CO₂ emissions intensity in the Chinese construction industry. *Journal of Cleaner Production*, 213, 1087-1095.
- CHO, C. H., CHU, Y. P. & YANG, H. Y. 2014. An environment Kuznets curve for ghg emissions: A panel cointegration analysis. *Energy Sources Part B-Economics Planning and Policy*, 9, 120-129.
- DUAN, H., SUN, X., SONG, J., XING, J. & YANG, W. 2022. Peaking carbon emissions under a coupled socioeconomic-energy system: Evidence from typical developed countries. *Resources Conservation and Recycling*, 187.
- FANG, K., LI, C. L., TANG, Y. Q., HE, J. J. & SONG, J. N. 2022. China's pathways to peak carbon emissions: New insights from various industrial sectors. *Applied Energy*, 306, 10.
- FANG, K., TANG, Y. Q., ZHANG, Q. F., SONG, J. N., WEN, Q., SUN, H. P., JI, C. Y. & XU, A. Q. 2019. Will China peak its energy-related carbon emissions by 2030? Lessons from 30 Chinese provinces. *Applied Energy*, 255, 12.
- HU, H., XIE, N., FANG, D. & ZHANG, X. 2018. The role of renewable energy consumption and commercial services trade in carbon dioxide reduction: Evidence from 25 developing countries. *Applied Energy*, 211, 1229-1244.
- HUO, T., DU, Q., YUAN, T., CAI, W. & ZHANG, W. 2024. Has the provincial-level residential building sector reached the carbon peak? An integrated assessment model. *Environmental Impact Assessment Review*, 105.
- LI, R., YU, Y., CAI, W., LIU, Q., LIU, Y. & ZHOU, H. 2023. Interprovincial differences in the historical peak situation of building carbon emissions in China: Causes

- and enlightenments. *Journal of Environmental Management*, 332.
- LIU, H., PANG, S., SUN, M., LIU, J. & LI, Q. 2024. How can small and medium-sized cities differentiate their carbon peaks? *Ecological Indicators*, 158.
- SAFI, A., CHEN, Y. Y., WAHAB, S., ZHENG, L. Y. & RJOUB, H. 2021. Does environmental taxes achieve the carbon neutrality target of G7 economies? Evaluating the importance of environmental R&D. *Journal of Environmental Management*, 293, 8.
- SANG, M. & SHEN, L. 2024. An international perspective on carbon peaking status between a sample of 154 countries. *Applied Energy*, 369, 123580.
- SHUAI, C. Y., SHEN, L. Y., JIAO, L. D., WU, Y. & TAN, Y. T. 2017. Identifying key impact factors on carbon emission: Evidences from panel and time-series data of 125 countries from 1990 to 2011. *Applied Energy*, 187, 310-325.
- TANG, L., LUO, M., LI, K. & ZHANG, F. 2024. Driving factors and peaking of CO₂ emissions: An empirical analysis of Hunan Province. *Energy*, 289.
- WANG, H. K., LU, X., DENG, Y., SUN, Y. G., NIELSENS, C. P., LI, Y. F., ZHU, G., BU, M. L., BI, J. & MCELROY, M. B. 2019. China's CO₂ peak before 2030 implied from characteristics and growth of cities. *Nature Sustainability*, 2, 748-754.
- WEKO, S. & GOLDTHAU, A. 2022. Bridging the low-carbon technology gap? Assessing energy initiatives for the Global South. *Energy Policy*, 169.
- WRI 2014. Mitigation goal standard.