



清華大學  
Tsinghua University

# 2025

## *Global Carbon Neutrality Annual Progress Report*

Institute for Carbon Neutrality (ICON), Tsinghua University  
September 2025







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# • Preface

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As the issue of climate change becomes increasingly severe, with global average temperatures repeatedly setting new records and extreme weather events occurring frequently, the climate crisis has become a major challenge threatening global sustainable development. The year 2025 marks the tenth anniversary of the Paris Agreement. Over the past decade, global climate governance has continuously evolved, and the Nationally Determined Contributions (NDCs) of various countries have been continuously updated and strengthened, demonstrating the global determination and capacity for action in response to climate change.

In this process, scientific, objective, comprehensive, in-depth, systematic, and timely assessment is crucial support for promoting the global achievement of carbon neutrality goals. The Global Carbon Neutrality Annual Progress Report, based on a systematic assessment framework, solid data foundations, and advanced modeling tools, focuses on the latest progress of countries in areas such as target setting, technological innovation, financial support, and international cooperation. It deeply analyzes the gaps and opportunities between commitments and actual actions, aiming to provide data support and a decision-making basis for the adjustment and acceleration of global climate policies. The report brings together diverse global perspectives and condenses international wisdom. After three years of accumula-

tion and refinement, it has gradually developed into an assessment outcome with scientific rigor, forward-looking insights, and international influence.

As the report points out, global carbon neutrality has evolved from a preliminary vision a decade ago into an irreversible structural transformation. An increasing number of countries, cities, and companies are joining the net-zero ranks. The number of countries that have proposed carbon neutrality targets has increased to 165, and 284 cities and thousands of companies have also made commitments, creating a powerful demonstration effect. With the continuous decline in the cost of renewable energy, its market advantage has become more significant. In many economies, the cost of renewable energy is already lower than that of fossil fuels, and the market-driven effect is increasingly strengthening. Diversified and cross-regional cooperation models are constantly emerging, injecting new momentum and resilience into global climate governance. Despite facing multiple uncertainties, the long-term fundamentals of the global carbon neutrality transition remain solid. These trends provide significant confidence for accelerating global climate action in the next decade.

These advancements not only provide strong momentum for achieving carbon neutrality goals but also drive profound economic and social transformations. In the process of carbon neutrality, industrial upgrading and structural adjustment are accelerating, more

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high-quality employment opportunities and social benefits are emerging, and new fields such as green industries, clean technologies, and green finance are becoming important engines of economic growth. Countries should accurately grasp the progress and development trends of global carbon neutrality, seize the key opportunities of the green transition, and promote the deep integration of net-zero targets with high-quality development. This will allow more employment opportunities and industrial dividends to benefit a wider range of people, thereby transforming the grand vision of carbon neutrality into a powerful driving force for social equity, economic prosperity, and global sustainable development.

The realization of global carbon neutrality is inseparable from cooperation and mutual trust among countries. We are pleased to see that the international community is gradually exploring more diversified and pragmatic cooperation models in response to climate change, and multilateral mechanisms such as technology transfer, green investment, and carbon markets are continuously being improved. We are also soberly aware that different countries have differences in development stages, capacity foundations, and interest demands, which requires us to find a balance between pursuing fairness and efficiency. We call on the international community to continue to strengthen communication and dialogue, enhance gover-

nance transparency and execution, and minimize differences to enhance mutual trust. We advocate that all countries adhere to the principle of common but differentiated responsibilities, build an inclusive, open, and mutually beneficial global cooperation network, and work together to address the climate crisis and jointly promote the carbon neutrality process towards a more solid and sustainable future.

Addressing climate change is a long-term battle for all of humanity facing the future, and it is also a relay race that spans generations. We expect this report to always uphold the principles of science, objectivity, and openness, continuously track global carbon neutrality progress, use data and case studies to enhance understanding and mutual trust, and use consensus and action to gather wisdom and strength. We hope it will become a bridge that connects dialogue, stimulates innovation, and catalyzes action, contributing to the acceleration of global carbon neutrality, the promotion of a just transition, and the joint construction of a planetary home where humans and nature coexist in harmony.

**Co-chairs of the Report Advisory Committee:**

**He Kebin & Erik Solheim**

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2025 Global Carbon Neutrality Annual Progress Report

# Executive Summary

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As 2025 marks the tenth anniversary of the Paris Agreement's adoption, the global climate process stands at a critical juncture, faced with both challenges and opportunities. Short-term geopolitical disturbances often arouse worries about the future of global climate cooperation with fragmented evidence and emotional narratives, which frequently fail to capture the full picture of the transition trend. This report, therefore, aims to penetrate these surface signals, presenting an objective assessment of global carbon neutrality progress through a continuous, quantitative, and systematic assessment system.

As the second update in this annual series, this year's assessment deepens its methodological exploration. The analysis is built upon a vertical assessment framework of "Target-Policy-Action-Effectiveness," supported by a comprehensive database encompassing four horizontal themes—"Targets" "Technology" "Finance" and "International Cooperation"—with a total of 217 sub-indicators covering 198 countries and regions, and a suite of 10 proprietary analytical models. The report integrates a vast array of complex information into clear progress signals through this robust quantitative system, thereby revealing long-term, structural transition trends.

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198

Countries and regions



## Global Carbon Neutrality Progress: Overall Trends

Quantitative scoring reveals a complex picture of global carbon neutrality progress, featured as "continued advancement in targets and policies, stagnation in action, and inadequate delivery of effectiveness". In 2025, the median scores for countries in the "Target" and "Policy" dimensions rose from 59 and 36, to 62 and 42, respectively, reflecting a strengthened global consensus and enhanced governance systems. The median score for the "Action" dimension saw a marginal increase from 25 to 26. It is crucial to note that the "Effectiveness" assessment is based on data up to the year 2023 due to the inherent lag in data update, which means that efforts made by countries in policy and action are not yet fully reflected in the effectiveness. The impact of these efforts is expected to become progressively visible in the reports of the next two to three years. Concurrently, national progress patterns are diverging significantly, with widening disparities in policy priorities and implementation. To discern the deep-seated drivers behind these short-term fluctuations—distinguishing fundamental trends from cyclical disturbances—it is necessary not only to observe over a longer time frame but also to conduct an in-depth analysis of the specific performance and drivers within the horizontal dimensions of technology, finance, and international cooperation. This constitutes the pivotal task of the subsequent thematic analysis.



## Global Carbon Neutrality Progress: Thematic Analysis and Core Findings

### 1. What were the core developments of the past year?

Overall, the resilience of target consensus and the completeness of policy systems have been continuously strengthened over the past decade and under the test of recent fluctuations. However, "divergence" at the action level is intensifying—the deployment of mature technologies is accelerating on one hand, but financial support and fossil fuel transition severely stagnated on the other. This stark contrast at the action level has led to a temporary "decoupling" in emission reduction effectiveness—the positive long-term decarbonization trend is not yet reflected in the latest "Effectiveness" data.

Since the adoption of the Paris Agreement in 2015, the global transition towards carbon neutrality has made irreversible structural progress. The number of countries with carbon neutrality targets has increased from 1 in 2015 to 165 by now. The global issuance of green bonds has increased more than tenfold, the share of emissions covered by carbon pricing mechanism has doubled to 24%, and renewable electricity generation capacity has grown 2.4-fold. Against this backdrop, the past year's progress presents a complex picture of both advances and setbacks. Targets remained resilient despite headwinds. Policies saw both progress and retreats. Actions became more polarized, with technology deployment strengthened while climate finance stalled. Effectiveness data, based on 2023 figures, has yet to reflect these recent efforts, highlighting the implementation gap between commitments and outcomes.

## 2. Are updated NDCs sufficient to support medium- and long-term targets?

The world faces a dual "ambition gap." First, the collective ambition of current Nationally Determined Contributions (NDCs) is far from sufficient to meet global temperature goals. Projections show that full implementation of NDCs would lead to a global emission reduction of only 4%–13% by 2035, a figure that falls drastically short of the 21%–35% reduction required by the IPCC for a 2°C pathway. Second, a disalignment exists between most countries' short-term NDC commitments and their long-term carbon neutrality goals, undermining the credibility of the latter.

## 3. Can key technology targets, such as "tripling renewables by 2030" be achieved?

Global technology deployment faces a structural divergence. A significant gap exists: renewable electricity is accelerating—a new forecast based on 2015–2024 growth rates projects that 2030 capacity will reach 2.65 times current levels, approaching the "tripling" target. However, other key technologies including clean hydrogen and CCUS are severely lagging behind, with projections showing they will only achieve 8%–88% of their 2030 targets at current rates. A widening geographical divergence is also apparent. The next five years represent a decisive window to accelerate technology deployment and drive global emissions to their peak.

## 4. To what extent can actions by cities and enterprises fill national policy gaps?

Non-state actors are increasingly indispensable as "twin engines" that drive the global carbon neutrality process. Cities are becoming innovation hubs for locally tailored solutions, while enterprises are phasing from leading proactive initiatives to implementing more pragmatic, robust responses. With 303 cities and over 4,200 companies (via SBTi) committed to carbon neutrality, they provide crucial on-the-ground support for the resilience and depth of global climate action.

**303**

cities

**4200+**

companies



## 5. What are the current implementation gaps around the global carbon neutrality transition?

Insufficient finance and barriers to international cooperation, as two key dis-enablers, are collectively driving up global transition costs. First, the financing gap is widening and structurally imbalanced. Although global climate finance has reached approximately \$1.3 trillion, this is far below the fivefold annual increase needed to achieve the Paris Agreement goals. Funding from developed countries is severely lagging. Under current scale and pace, developed countries will only meet 43% of the new collective quantified goal (NCQG) set at COP29 by 2035. This leaves developing countries, which require an estimated \$470 billion annually, with only about \$35 billion, a fulfillment rate of just 8%. Second, trade protectionism is creating cooperation barriers. Many G20 countries have imposed additional tariffs on key clean energy products such as wind/solar components, EVs, and batteries. These barriers, particularly discriminatory policies from developed nations, are projected to increase investment costs of solar and wind by 6% and 3%, respectively, creating an additional financial burden of approximately \$130 billion to meet renewable energy targets.





## Conclusions and Policy Recommendations

In summary, the global carbon neutrality process is undergoing a profound structural imbalance: "target deepening" and "technological innovation" are the core positive drivers, while the shortage of "climate finance" and "international cooperation" constitute the two key dis-enablers. To bridge the existing gaps and accelerate the interpretation from targets to actions, this report proposes the following policy recommendations:

### 1. Bridge the Ambition Gap:

**Strengthen the ambition and credibility of NDCs.** All countries, particularly developed nations, must significantly enhance their mitigation targets embedded in 2035 NDC that aligns with long-term carbon neutrality strategies.

### 2. Resolve the Implementation Gap:

**Jointly overcome technology and finance bottlenecks to accelerate the transition.** In technology, a differentiated approach is needed for mature technologies (e.g., removing trade barriers) and emerging technologies (e.g., increasing R&D support). In finance, developed countries must translate commitments into action, fully delivering on the NCQG set at COP29 by 2035, while global financial architecture must be reformed to mobilize more capital for developing countries.

### 3. Solidify the Foundation of Mutual Trust:

**Innovate global cooperation models to build a transparent and credible international ecosystem.** This includes supporting diverse cooperation models led by sub-national actors and enterprises, jointly resisting green trade protectionism, and accelerating the development of a public digital platform of global climate action, to foster a virtuous cycle of tracking progress, redirecting investment, and enhancing implementation.

# • Introduction

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On the tenth anniversary of the Paris Agreement, the global journey to address climate change has reached a pivotal, transitional moment. Looking back over the past decade, despite the volatile global geopolitical and economic landscape, a profound and resilient low-carbon transition has taken root and demonstrated formidable vitality worldwide. Today, this transition path is demonstrating increasingly complex and even contradictory signals. Long-term positive structural trends are interwoven with short-term existential "headwinds," making it more critical than ever to objectively and clearly assess the global carbon neutrality progress.

Over the past year, "advances" and "retreats" in global climate action have occurred simultaneously. On one hand, the forward momentum remains strong: the number of countries with carbon neutrality commitments has reached 165; the deployment of clean technologies, led by solar and wind, continues to expand, with their generation costs now below those of fossil fuels in major economies; and the enthusiasm of non-state actors, such as cities and enterprises, is growing, making them a vital force in driving grassroots climate action. On the other hand, the resistance to progress is equally undeniable: policy backsliding in certain countries has cast a shadow over global cooperation; developed countries' financial commitment to developing countries is still unimplemented and inadequate; and the escalation of green trade barriers is slowing the global transition process.

To evaluate carbon neutrality commitments and actions, many internationally renowned research institutions have been continuously tracking on relevant progress, assessing the ambition of net-zero emission commitments across various countries and the transition progress of key sectors. However, the current research publications, when reviewing the progress of carbon neutrality, emphasize goals over actions, lack a systematic and consistent quantitative evaluation index system, pay insufficient attention to domestic policies, practical actions and international cooperation, and cover a relatively small number of countries.

Faced with this complex tapestry of positive and negative impacts, as well as fast and slow paces, this report aims to cut through the noise to identify the key trends and core inflection points of the global low-carbon transition. As the second annual update in this series, the report has accumulated indicators, data and modeling methodologies that have been refined and updated over three years<sup>①</sup>. The indicator system covers over 217 sub-indicators for 198 countries and regions, and the underlying database is

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① Can Wang, Shihui Zhang, Wenjia Cai (2024). Assessment of Global Carbon Neutrality Progress: Indicators, Methods, and Applications. Science Press

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publicly available through the report's official website (<https://www.cntracker.tsinghua.edu.cn/home>). The report's explicit goal is to provide a reliable public dashboard for the global carbon neutrality process. By enhancing transparency, fostering mutual trust among parties, strengthening the implementation of commitments, and promoting a more precise and efficient allocation of valuable resources such as climate finance, technology, and policy, it seeks to collectively address the implementation challenges against decarbonization.

The underlying value of this work is to distinguish the underlying "signal" of structural change from the "noise" of transient disruptions. In a world of fragmented information and emotional narratives, decision-makers risk overreacting to negative headlines, such as a country's policy reversal, while missing the larger and deep-rooted trends. This report's systematic, quantitative evaluation system provides a data-driven anchor, preventing policy overreaction to temporary political and economic turbulence. It aims to demonstrate that the fundamental signal of transition remains strong, even when the surface appears chaotic.



### **Building on this foundation, this year's report aims to answer the following core questions:**

- 01** Amidst the world's complex and varied signals, what were the core developments in carbon neutrality targets, policies, actions, and effectiveness over the past year?
- 02** Are the updated Nationally Determined Contributions (NDCs) sufficient to support their medium- and long-term carbon neutrality targets?
- 03** Are key technology targets, such as "tripling renewable energy by 2030", within reach?
- 04** To what extent can the actions of cities and enterprises fill the gaps left by wavering or insufficient national-level policies?
- 05** What are the current implementation gaps in the global carbon neutrality process?



# 01

## Chapter 1

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# Assessment Methodology and Analytical Framework

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# 1.1 Assessment Framework

To scientifically quantify national progress toward carbon neutrality, this report continues to employ a four-dimensional indicator system of "Target–Policy–Action–Effectiveness." This framework systematically tracks and evaluates the entire process from strategic goal-setting to tangible results (Figure 1.1). This system not only helps to clarify the key stages of each country's carbon neutrality pathway but also reveals the implementation gaps between stated goals and actual outcomes, fostering a dynamic, spiraling process of improvement.

First, countries establish their strategic direction by setting Targets for carbon neutrality, including the type of target, target year, and scope of coverage. This high-level objective provides clear guidance for policymaking. Subsequently, countries formulate and implement Policies aligned with these targets, covering six key areas: technology strategies, climate finance commitments, roadmaps, regulatory systems, and support policies for technology and finance. These policies reflect the institutional response at the national level and create enabling conditions for concrete action.

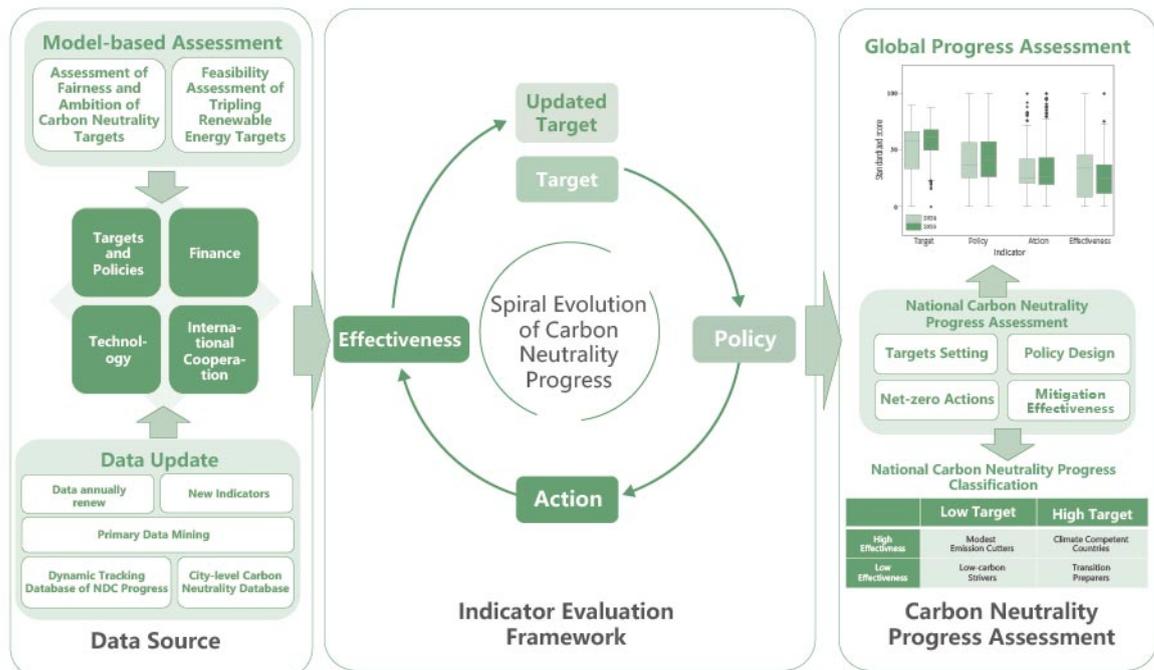
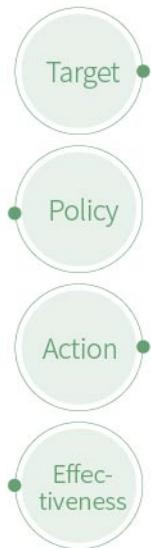


Figure 1.1 The analytical framework of this report.

The implementation of these policies accelerates various Actions at both domestic and international levels. These include the research, development, and deployment of carbon-neutral technologies, contribution and mobilization of climate finance, and the orderly transition of energy systems. Simultaneously, international cooperation drives coordinated global emission reductions.



As actions accumulate, their Effectiveness in reducing carbon emissions becomes apparent. This effectiveness reflects the rigor of policy implementation and, through stocktaking and progress assessment, informs the next cycle of "target enhancement—policy upgrading—action strengthening—effectiveness improvement." This feedback loop ensures that the carbon neutrality process advances in a virtuous cycle (a "ratchet mechanism") of continuous improvement.<sup>②</sup>

The weights for each indicator within this system were determined through a collaborative assessment conducted by multi-disciplinary experts, based on theoretical foundations and practical experience. This ensures the scientific rigor and impartiality of the evaluation method, providing a solid foundation for identifying the strengths, weaknesses, and gaps in national carbon neutrality progress and thus offering an evidence-based rationale for accelerating global climate governance.

## 1.2 Database

To support the aforementioned assessment framework, this report presents a database covering 217 sub-indicators for 198 countries and regions. The database is organized into four thematic areas: Targets, Technology, Climate Finance, and International Cooperation, which are further broken down into 16 primary indicators, 49 secondary indicators, and 217 tertiary

**198**  
countries and  
regions

<sup>②</sup> It should be emphasized that the four dimensions—Target, Policy, Action, and Effectiveness—follow a sequential timeline. For instance, the assessment results for Effectiveness in 2025 primarily reflect the cumulative effects of earlier Target-setting and prior waves of Policies and Actions, rather than the immediate impact of newly introduced measures this year. In interpreting indicators and trends, we pay particular attention to distinguishing between real-time policy updates and lagged outcomes, thereby enabling a more scientifically grounded identification of national-level progress and governance gaps.

indicators. A detailed list of these indicators can be found in Appendix A of this report, and specific data for each indicator are available in the 2025 Global Carbon Neutrality Annual Progress Report Appendix and on the report's official website (<https://www.cntracker.tsinghua.edu.cn/subject>).

The data sources for this database are twofold. One category involves the collection, consolidation, and verification of data from existing public databases to meet the requirements of our assessment indicators. The other category consists of first-hand data generated through proprietary modeling tools developed by the report team (see Section 1.4 for details).

The indicator system is built upon a range of authoritative, public, and transparent international data sources, including major international organizations, leading research institutions, academic databases, and industry initiative platforms. Core data sources include the Climate Action Tracker and Net Zero Tracker, which monitor national climate commitments and actions; the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) provide energy and technology data; official documents published by the United Nations Framework Convention on Climate Change (UNFCCC) secretariat serve as references for accurate official information; and the Web of Science academic database is also used for analyzing research trends. To ensure timeliness, the data in this report are dynamically updated in line with the updates from these sources. At the same time, it is acknowledged that some key effectiveness data, such as official greenhouse gas emission inventories, have an inherent statistical lag. Therefore, to provide the most up-to-date assessment and insights, such data will be uniformly updated to the latest complete year available (i.e., 2023 and 2024) before the report's official release.

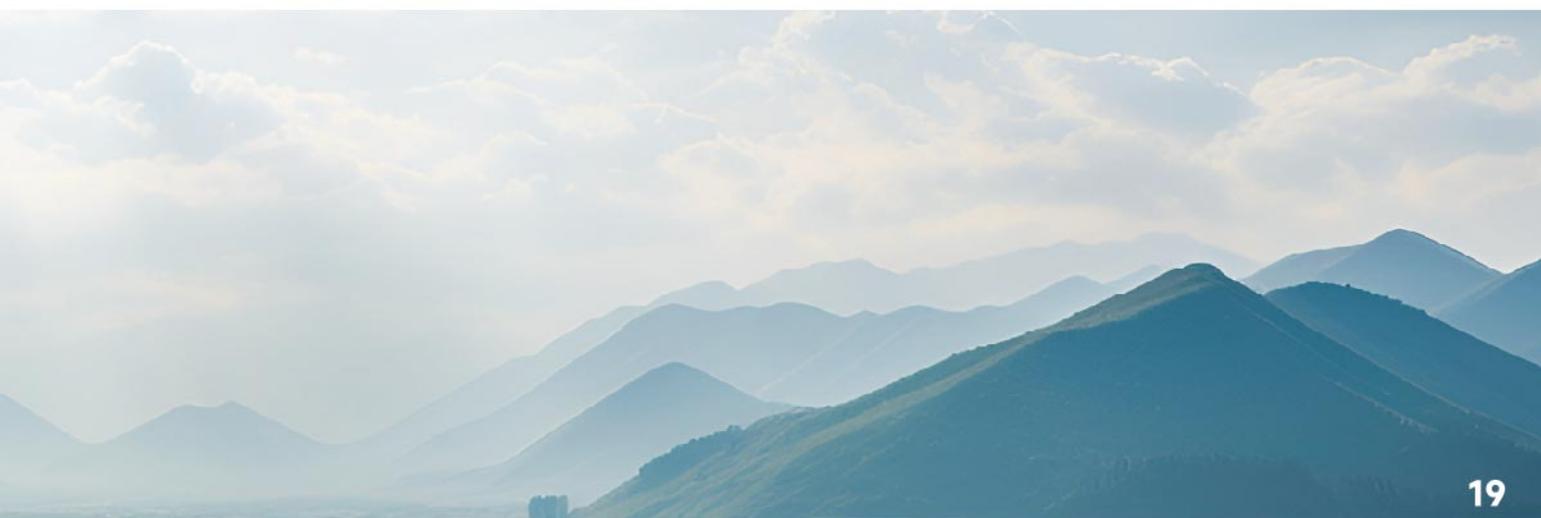
Compared to previous years, the database for this report has been expanded and optimized, primarily with the addition of two new thematic modules: the NDC (Nationally Determined Contribution) Progress Tracking Database and the Urban Carbon Neutrality Thematic Database. The NDC database covers the target years set by countries and includes analysis

**16**

primary indicators

**49**

secondary indicators



based on emission calculations from specific targets. The urban database contains detailed information on the medium- and long-term carbon reduction targets and greenhouse gas emissions coverage of 284 cities. All underlying databases are made publicly available through the project's official website.



## 1.3 Quantitative Assessment Indicator System and Scoring Standards

To scientifically evaluate global carbon neutrality progress, this report establishes a vertical assessment framework of "Target-Policy-Action-Effectiveness." The data for this framework are drawn from the comprehensive database described in Section 1.2, which comprises four horizontal themes ("Target," "Technology," "Finance," and "International Cooperation,") and contains a total of 217 sub-indicators.

# 217

sub-indicators

During the assessment process, the sub-indicators from the database are reorganized and mapped into the four dimensions of the vertical framework. Specifically: The "Target" dimension is primarily assessed based on the "Target" theme from the database; The "Policy" dimension integrates various policy support indicators from the "Technology," "Finance," and "International Cooperation" themes of the database; The "Action" dimension draws on specific deployment and investment indicators from the "Technology," "Finance," and "International Cooperation" themes; The "Effectiveness" dimension independently assesses the final carbon reduction outcomes.

Finally, normalizing and aggregating the indicators with appropriate weights enables quantification of each country's performance in target setting, policy design, action implementation, and emission reduction effectiveness. This provides data-driven support and a reference for decision-making to strengthen global emission reduction actions.<sup>7</sup> The methodological core of this quantitative assessment is detailed in Table 1.1, which clarifies the scoring process and provides a clear understanding of the logic behind the country rankings and progress scores. It shows, for example, that the "Action" score is a weighted average of domestic action (75%) and international cooperation (25%), with domestic action itself being a composite of technology deployment, innovation, finance, and fossil fuel transition. Such detail is essential for the credibility of the report.

Table 1.1 Scoring Standards and Normalization for National Carbon Neutrality Progress

Dimension	Indicator	Weighting Formula	Normalization Process
Target	Carbon neutrality target type	$\text{Target Score} = (\text{Target Type} * 0.3) + (\text{Target Year} * 0.15) + (\text{Target Scope} * 0.35) + (\text{Fairness \& Consistency} * 0.2)$	$\text{Normalized Score} = (\text{Country Score} - \text{Minimum Score}) / (\text{Maximum Score} - \text{Minimum Score})$
	Carbon neutrality target year		
	Carbon neutrality target scope		
	Carbon neutrality target fairness & consistency		
Policy	Carbon neutrality technology strategy target	$\text{Policy Score} = \text{Sum of scores for 6 indicators} / 6$	$\text{Normalized Score} = (\text{Country Score} - \text{Minimum Score}) / (\text{Maximum Score} - \text{Minimum Score})$
	Climate finance commitment declaration		
	Specific roadmap for carbon neutrality target		
	Regulatory system for carbon neutrality target		
	Carbon neutrality technology support policy		
	Climate finance support policy		
Action	Carbon neutrality technology deployment progress	$\text{Action Score} = (\text{Domestic Action} * 0.75) + (\text{International Cooperation Action} * 0.25); \text{Domestic Action} = (\text{Tech Deployment} * 0.4) + (\text{Tech Innovation} * 0.2) + (\text{Climate Finance Action} * 0.3) + (\text{Fossil Fuel Transition} * 0.1)$	$\text{Normalized Score} = (\text{Country Score} - \text{Minimum Score}) / (\text{Maximum Score} - \text{Minimum Score})$
	Carbon neutrality technology innovation capacity		
	Climate finance action progress		
	Fossil fuel transition progress		
	International cooperation action progress		
Effectiveness	Carbon neutrality progress	$\text{Effectiveness Score} = ((\text{Progress} + \text{Trajectory}) / 2) * \text{Adjustment Factor}; \text{Adjustment Factor} = (\text{World average year of peak carbon intensity} / \text{Country's year of peak carbon intensity}). \text{ If } < 1, \text{ factor is } 1. \text{ If } > 1, \text{ factor is mapped to the range } (1, 3).$	$\text{Normalized Score} = \text{Country Score} / \text{Maximum Score}$
	Carbon neutrality trajectory		

Note: The weights for each indicator were determined through a comprehensive assessment conducted by multi-disciplinary experts based on theoretical and practical experience, providing a methodological foundation for the final evaluation results.

Based on the raw indicators in the database, the report systematically constructs a 0-100 scoring system for the four dimensions—Target, Policy, Action, and Effectiveness—to comprehensively evaluate each country's implementation progress and actual outcomes in different areas of climate governance (Table 1.2).

**Table 1.2 Quantitative Benchmarks for Carbon Neutrality Progress Index**

Indicator Type	Score	Meaning and Example
Target	100	Ideal target setting: Carbon neutrality commitment covers all GHG types, and the interval between emissions peak and carbon neutrality is no more than 10 years.
	0	No carbon neutrality commitment.
Policy	100	Best practice: A comprehensive support policy system for all major carbon-neutral technologies is in place, along with a mechanism for climate-related financial risk assessment and disclosure.
	0	No carbon neutrality policies.
Action	100	Best practice: Leading global performance in key actions, such as having the highest number of Carbon Capture, Utilization, and Storage (CCUS) projects or the highest per capita issuance of green bonds.
	0	No carbon neutrality actions.
Effectiveness	100	Best practice, adjusted for national context and challenges: achieving an annual reduction rate that fully aligns with the trajectory required to meet its carbon neutrality target.
	0	Carbon intensity remains unchanged or increases.



## 1.4 A Compendium of Original Models for Analysis and Forecasting

Although many public and transparent data sources are available for assessing global carbon neutrality progress, significant challenges remain. There are severe shortages of first-hand data in critical areas, such as climate finance, non-state actor actions, and less-developed countries. In addition, vast amounts of key information—for instance legal clauses and policy details—are hidden in unstructured, massive texts, making them difficult to extract and utilize. Furthermore, the lack of standardized policy texts across countries makes horizontal comparison and systematic evaluation difficult. These data limitations hinder a truly in-depth and consistent assessment of global carbon neutrality progress.



To address these challenges, the report team has developed and utilized a suite of original modeling tools to generate some of the most crucial first-hand data. The authority of this report stems not just from its conclusions but from this methodological innovation. These models are the very engine of the report's unique insights, allowing it to "penetrate surface signals" and provide analysis that others cannot. These proprietary models (Table 1.3, with details in Appendix B) are what enable the report to provide unique insights, quantify qualitative information, and conduct forward-looking analysis. They can be broadly categorized into two types: tools for text mining and policy quantification, and models for thematic assessment and prediction.



## 1.4.1 Text Mining and Natural Language Processing

These models leverage advancements in AI, particularly large language models, to transform vast, unstructured policy, legal, and project texts into structured, comparable, and quantitative evidence. This allows the report to move beyond simple binary checks (e.g., policy exists/does not exist) to a scaled, repeatable, and systematic assessment of policy strength, legal framework robustness, and financial flows.

### 01 Quantitative Assessment of Policy Strength

The Low-Carbon Policy Intensity ERNIE-CN (LCPI-ERNIE-CN) model systematically quantifies the "intensity" of low-carbon policies rather than just their number. Using natural language processing and ERNIE 3.0 few-shot learning, it has established a comprehensive paradigm for data collection, text classification, and quantitative scoring. This model has been used to assess the policy intensity of China at the national, provincial, and municipal levels since 2007, providing a granular analysis of China's policy evolution for this report.

### 02 Policy Text Mining and Quantification

These models focus on automatically extracting key information from unstructured documents to create original, analyzable datasets.

#### Climate Law Miner (CLAW-Miner) model

Utilizes general-purpose large language models and sophisticated Prompt Engineering to deeply mine and extract structured information—such as covered sectors, responsible agencies, penalty mechanisms, and quantitative targets—from the vast legal texts in the Climate Change Laws of the World (CCLW) database. This model significantly improves data processing efficiency and accuracy, providing a solid data foundation for assessing the evolution and characteristics of global climate legal systems.

#### Multilateral Climate Finance BERT (MLCF-BERT) model

Addresses the challenge of identifying and classifying climate finance projects. Based on the ClimateBERT model, which is fine-tuned on climate-related texts, this two-stage classifier can automatically identify whether a project is climate-related and perform fine-grained multi-label classification. The application of MLCF-BERT has enabled this report to systematically quantify historical multilateral climate finance for the first time, analyzing its scale and trends and filling a critical data gap in the finance action domain.

## 1.4.2 Assessment and Prediction Models

To address the challenge that some key indicators in the global carbon neutrality process lack observable data, the author team has developed structured models. Some of these models provide direct quantitative inputs for the indicator system, while others are used for thematic studies to answer key questions beyond the assessment framework. These original models fall into two main paradigms: bottom-up data-driven models and top-down macro-structural models.

### 01 Data-Driven Prediction and Assessment Models

These models use historical data and structural patterns to assess the current state or predict short-term trends.

<b>Fair Carbon Allocation Model (FairCAM)</b>	To assess the fairness and ambition of national climate targets, this model constructs 1,542 global carbon budget allocation scenarios based on multiple equity principles (e.g., historical responsibility, capacity to pay, per capita convergence). By comparing countries' NDCs and carbon neutrality targets against these scenarios, the model quantifies their ambition level under different fairness principles. This is the core data source for indicator 1.5, "Fairness and Consistency of Carbon Neutrality Targets".
<b>NDC Tracker model</b>	This model resolves the comparability issue arising from the varied formats, scopes, and target types of national NDCs. It uses a consistent and robust methodology to convert different forms of NDC targets (e.g., carbon intensity targets, policy-based reduction targets) into absolute emissions covering the entire economy, enabling a like-for-like comparison of NDC ambition across countries.
<b>Global Renewable Energy Capacity Projection Model (GRECPM)</b>	This model employs the Richards growth model, which characterizes the S-shaped curve of technology diffusion, combined with Bayesian inference to produce probabilistic forecasts of global and regional renewable energy capacity. This allows the report not only to provide point estimates but also to quantify prediction uncertainty, offering a scientific basis for assessing the feasibility of key targets including "tripling renewable energy by 2030".

## 02 Macro Energy-Economic Models

These are large-scale macroeconomic models that simulate the interactions of economic agents (producers, consumers, government) to assess the economy-wide impacts of policies or external shocks.

### Global Hybrid Energy-Economic Research (GHEER) model

As a multi-sector Computable General Equilibrium (CGE) model covering 18 major global regions, GHEER is used to evaluate the macroeconomic impacts of long-term low-carbon strategies. In this report, it quantifies the economic effects of technology spillovers in renewable energy supply chains and the impact of trade barriers on global transition costs and distributional equity.

### China Hybrid Energy-Economic Research/Power (CHEER/Power) model

This is a high-resolution optimization model of China's power sector, capable of simulating the least-cost development pathway for the power system under various constraints, such as carbon reduction targets. The model provides key analytical support for in-depth topics related to China's power system transition and renewable energy integration.

## 03 Trade and Input-Output Models

These models focus on analyzing complex global supply chains and inter-industry linkages, making them particularly adept at assessing the economic impacts of trade policies and overseas investments.

### Global Trade Simulation and Photovoltaic Input-Output (GSIM-PVIO) model

This model couples a global trade simulation model (GSIM) with a detailed input-output model of the photovoltaic industry (PVIO) to assess the cascading effects of PV trade policies (such as tariffs) on global PV trade flows, supply chain employment, and economic welfare.

### China's Overseas Energy Investment Input-Output (COEII) model

Based on a national input-output framework, this model quantifies the economic stimulus effects of China's overseas energy investments (particularly in renewables) on various industrial sectors in host countries, including direct and indirect contributions to output, value-added, and employment.



Table 1.3 Overview of Original Analytical Models

Model Name	Model Type	Core Function	Contribution to This Report
<b>Text Mining &amp; Policy Quantification</b>			
Low-Carbon Policy Intensity ERNIE-CN (LCPI-ERNIE-CN)	Natural Language Processing	Classifies and provides quantitative intensity scores for low-carbon policy texts from various levels in China.	Provides granular Chinese policy intensity data for the "Policy" dimension assessment.
Climate Law Miner (CLAW-Miner)	Large Language Model Application	Extracts structured legal elements from global climate law texts.	Provides first-hand data to assess the completeness of national climate legal frameworks (Policy dimension).
Multilateral Climate Finance BERT (MLCF-BERT)	Machine Learning	Automatically identifies and classifies climate finance projects from multilateral development institutions.	Generates historical multilateral climate finance flow data, supporting the "Action" dimension assessment.
<b>Thematic Assessment &amp; Prediction</b>			
Fair Carbon Allocation Model (FairCAM)	Assessment Model	Assesses the ambition of national climate targets based on multiple equity principles.	Quantifies the "Fairness and Consistency" sub-indicator under the "Target" dimension.
NDC Tracker model	Accounting Model	Converts various forms of national NDC targets into comparable emissions figures.	Enables a like-for-like horizontal comparison of national NDC ambition.
Global Renewable Energy Capacity Projection Model (GRECPM)	Prediction Model	Provides probabilistic forecasts of global renewable energy installed capacity.	Assesses the feasibility of key technology targets including "tripling renewable energy."
Global Hybrid Energy-Economic Research (GHEER) model	CGE Model	Simulates the global macroeconomic impacts of energy transition policies.	Analyzes the economic costs of trade barriers and the economic benefits of technology spillovers.
China Hybrid Energy-Economic Research/Power (CHEER/Power) model	Optimization Model	Simulates the least-cost transition pathway for China's power system under carbon constraints.	Provides in-depth analysis for thematic research on China's energy transition.
Global Trade Simulation and Photovoltaic Input-Output (GSIM-PVIO) model	Trade & Input-Output	Assesses the impact of PV trade policies on global supply chain employment and economies.	Quantifies the specific impacts of trade protectionism on the renewable energy industry.
China's Overseas Energy Investment Input-Output (COEIO) model	Input-Output Model	Assesses the economic stimulus effects of China's overseas energy investments on host countries.	Analyzes the economic co-benefits of international cooperation actions.

Note: For detailed structures and functions of each model, see Appendix B.

# 02

## Chapter 2

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### Global Carbon Neutrality Progress: Overall Trends

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This chapter provides a concise, data-driven "dashboard" of global carbon neutrality progress. Through core scores and a classification of national patterns, it offers readers a rapid overview of the global landscape.

## 2.1 An Overall Assessment of Global Progress

Based on the assessment framework described in Chapter 1, this report scores each country's carbon neutrality targets, policies, actions, and effectiveness through indicator scoring and normalization (where 0 represents no progress and 100 represents best practice). The quantitative results are shown in Figure 2.1. Compared to the assessment results from last year's report, global carbon neutrality progress presents a complex picture: stable ascent in targets and policies, stagnating action, and effectiveness yet to be fully manifested. The global median scores for the "Target" and "Policy" dimensions rose from 59 and 36 to 62 and 42, respectively. The median score for the "Action" dimension saw a marginal increase from 25 to 26, while the median "Effectiveness" score decreased from 34 to 28. Behind these scores lies the reality of coexisting "advances" and "retreats" in global climate action over the past year.

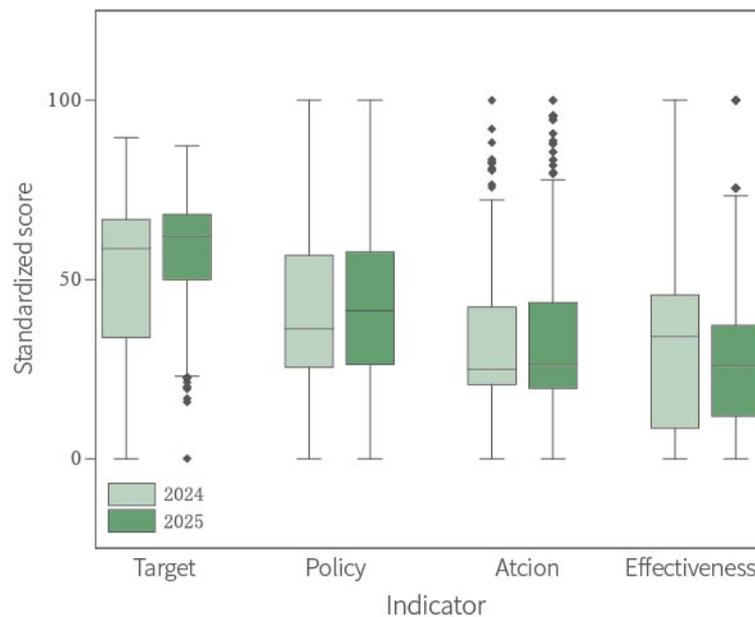


Figure 2.1 Score distribution of global carbon neutrality's goals, policies, actions and performance in 2025 and 2024.



### Target Progress (Median Score 62 vs. 59): Resilient Despite Headwinds.

The steady increase in the target score reflects the strong resilience of the global carbon neutrality consensus amidst a complex international situation. Despite the "headwinds" from policy backsliding in some major countries, the number of nations with carbon neutrality targets still grew from 162 to 165, and more countries have strengthened the legal status of their targets through legislation.



## Policy Progress (Median Score 42 vs. 36): Advancements with Persistent Bottlenecks.

The significant rise in the policy score indicates that national policy frameworks are becoming more comprehensive. The main driver was the substantial increase in the number of countries with complete carbon neutrality policy systems covering three types—mandatory, incentive-based, and supporting policies—has increased significantly from 72 to 103. However, there are underlying concerns: some major economies have regressed on key climate policies, and climate finance policy remains a common bottleneck, with 75 countries still having a policy vacuum in this area.

# 103

the number of countries with complete carbon neutrality policy systems



## Action Progress (Median Score 26 vs. 25): Widening Divergence and Uneven Progress.

The action score remained largely flat, masking a growing internal divergence. On one hand, technology deployment and innovation have steadily advanced, with the number of countries possessing carbon neutrality innovation capabilities rising from 47 to 78. On the other hand, climate finance action has severely stagnated, with 94 countries showing no progress in this area, and some nations are wavering on their fossil fuel phase-out commitments.

# 78

the number of countries possessing carbon neutrality innovation capabilities



### Effectiveness Progress (Median Score 28 vs. 34): Outcomes Not Yet Apparent, Data Lag Exists.

It is crucial to note that the "Effectiveness" indicators assessed in this report are subject to an inherent lag in global data publication, with data available only up to 2023. Therefore, this score primarily reflects past emission reduction performance. The positive developments in policy and action from the last two years have not yet been fully captured in the macroeconomic emission reduction data. Their effects are expected to become gradually visible in future reports. From a data perspective, the direct cause of this year's score decline is that the number of countries with a carbon intensity reduction of less than 25% compared to 2022, increased from 51 to 82. The emphasis on carbon intensity is central to reconciling the development needs of emerging economies with global decarbonization objectives. Given these countries' imperative for economic expansion, strict aggregate emission reductions could impede their growth trajectories. In contrast, the carbon intensity metric offers a more flexible pathway, reflecting progress in industrial and energy structure transformation. Accelerating the deployment of low-carbon technologies and advancing low-carbon restructuring of industries can help curb the growth rate of carbon emissions, ultimately leading to an absolute reduction, thereby fostering a synergistic mechanism between development and carbon mitigation.

# 82

the number of countries with a carbon intensity reduction of less than 25%

## 2.2 A Typology of National Progress Patterns

This report continues to use last year's classification standard, dividing all countries into four camps based on whether their target and effectiveness scores fall within the global top 50%: "Climate Leaders" (both target and effectiveness in the top 50%), "Low-Key Achievers" (target in the bottom 50% but effectiveness in the top 50%), "Transition Challengers" (target in the top 50% but effectiveness in the bottom 50%), and "Emerging Players" (both target and effectiveness in the bottom 50%). Note: These English names are more descriptive than literal translations of the original Chinese terms.

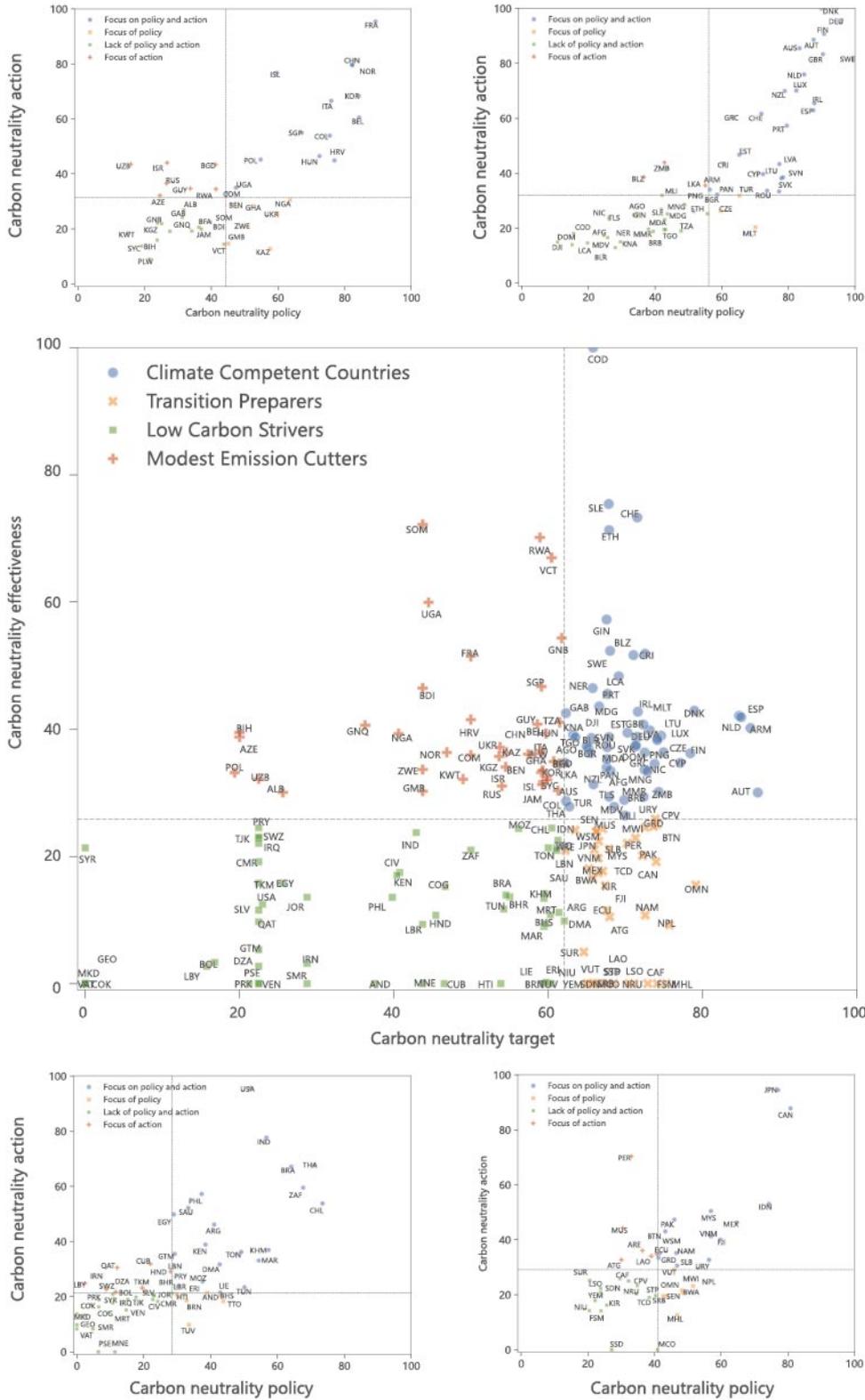


Figure 2.2 Modal categories of carbon neutrality progress by country in 2025.

The "Target-Effectiveness" scores show that countries do not always walk the talk in their carbon neutrality journey; that is, national carbon neutrality targets and effectiveness scores are not perfectly correlated, and decarbonization progress does not always align with stated goals.

**Specifically:**

Thirty-two countries remained in the "Climate Leaders" camp in both last year and this year, continuing to lead the global carbon neutrality process. These countries fall into three main categories: European developed nations such as the UK, Germany, Denmark, and Finland, which maintain their lead through comprehensive policy support, technological innovation, and robust climate finance systems; Eastern European countries such as Latvia, Romania, and Estonia, which are improving their policy frameworks while actively deploying carbon-neutral technologies; and emerging economies such as Costa Rica and Nicaragua, which are achieving their goals through a dual-track approach of policy guidance and technological innovation. This year, 13 developing countries newly joined the "Climate Leaders" camp.

**32**

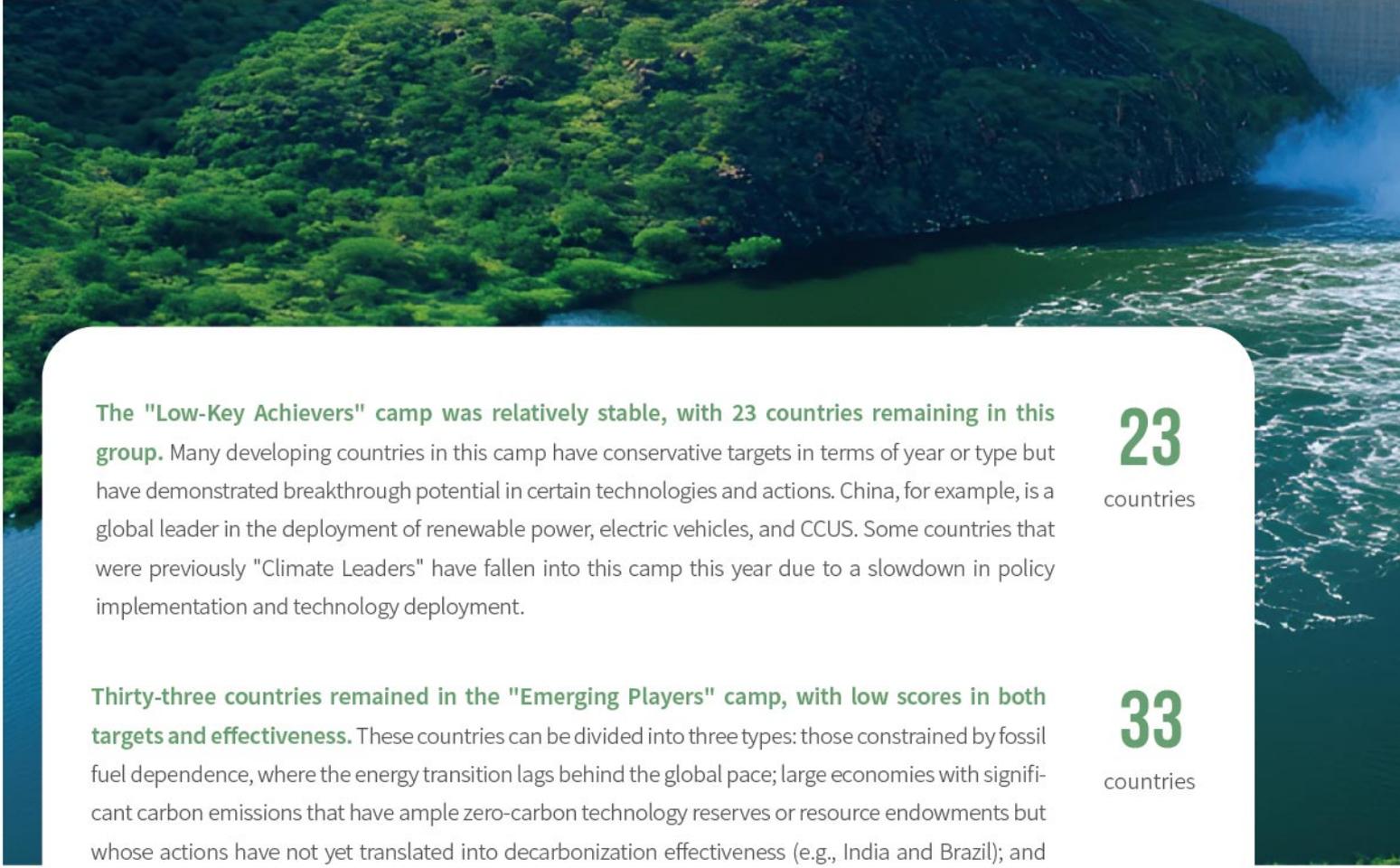
countries

The "Transition Challengers" camp saw significant changes. While 20 countries remained in this group, those that left showed a polarization: 12 countries advanced to "Climate Leaders" due to improved effectiveness, while 8 regressed to "Emerging Players" due to weakened targets. The developed countries in this camp generally have mature policy systems and advanced technology deployment, but these advantages have not yet translated into a structural energy transition, hindering their overall progress. The developing countries that remained in this camp lack robust climate finance systems and have relatively weak technology deployment capabilities, leading to a slower transition.

**20**

countries





The "Low-Key Achievers" camp was relatively stable, with 23 countries remaining in this group. Many developing countries in this camp have conservative targets in terms of year or type but have demonstrated breakthrough potential in certain technologies and actions. China, for example, is a global leader in the deployment of renewable power, electric vehicles, and CCUS. Some countries that were previously "Climate Leaders" have fallen into this camp this year due to a slowdown in policy implementation and technology deployment.

**23**

countries

Thirty-three countries remained in the "Emerging Players" camp, with low scores in both targets and effectiveness. These countries can be divided into three types: those constrained by fossil fuel dependence, where the energy transition lags behind the global pace; large economies with significant carbon emissions that have ample zero-carbon technology reserves or resource endowments but whose actions have not yet translated into decarbonization effectiveness (e.g., India and Brazil); and countries in the early stages of economic development with small economies and emissions, most of which have not yet set carbon neutrality targets.

**33**

countries

**Overall, strengthening targets is often accompanied by improved policy support, while enhanced emission reduction effectiveness primarily stems from progress in action.**

This year, 92 countries changed camps. Notably, 8 countries moved from "Transition Challengers" to "Emerging Players" due to weakened targets, while 12 moved from "Transition Challengers" to "Climate Leaders" due to strengthened targets. Furthermore, 6 countries advanced from "Emerging Players" to "Low-Key Achievers" due to improved effectiveness, while 8 regressed from "Climate Leaders" to "Transition Challengers" due to declining effectiveness. The strengthening of national targets is often coupled with the enhancement of policy systems. For instance, Australia introduced policies for optimized management of forest carbon sinks and set a goal to become a major hydrogen exporter by 2030. Conversely, the improved effectiveness in some countries is linked to concrete actions, such as Kuwait's active deployment of solar and onshore wind power and Ghana's efforts to increase forest carbon sinks through conservation and sustainable management.



## 2.3 Summary: Interpreting the Complex Signals of Annual Progress

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In summary, the macro-assessment results presented in this chapter reveal a picture filled with complex and even contradictory signals: target and policy scores are continuously improving, yet these advancements are not yet fully reflected in the emission reduction effectiveness data; and there are significant differences in the pace and patterns of progress across countries in various dimensions. To accurately understand the true meaning behind these short-term fluctuations and to distinguish fundamental structural trends from temporary cyclical disturbances, it is necessary not only to examine them over a longer time scale but also to delve deeper into the components of each score. This requires a detailed analysis of their specific performance and driving forces across the horizontal dimensions of technology, finance, and international cooperation.

# 03

## Chapter 3

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### Global Carbon Neutrality Progress: Thematic Analysis and Core Findings

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The assessment results in Chapter 2 clearly demonstrate the contradictory signals in global carbon neutrality progress over the past year. To more deeply understand these short-term fluctuations and identify the long-term trends behind them, this chapter—at the special juncture of the tenth anniversary of the Paris Agreement—will not only examine the annual advances and retreats and the national-level diverging pace of progress within the grand "ten-year scale" context, but will also further analyze the components of each score. It will analyze the specific performance and driving forces from the horizontal dimensions of targets and policies, carbon-neutral technologies, and climate finance and international cooperation. Based on this dual analytical perspective, this chapter will answer the following five core questions.

# 3.1 Core Developments of the Past Year: Navigating a Complex Global Landscape

To answer this question, this section analyzes the dual performance of the four dimensions—Target, Policy, Action, and Effectiveness—considering both ten-year structural trends and annual progress fluctuations. The core finding of this section is: over the past decade, the resilience of target consensus and the completeness of policy systems have continuously strengthened, withstanding the test of annual fluctuations. However, divergence at the action level is intensifying—the deployment of mature technologies is accelerating, while financial support and the fossil fuel transition have severely stagnated. This stark contrast at the action level has ultimately led to a temporary decoupling in emission reduction effectiveness—although the long-term decarbonization trend is positive, it has not yet been reflected in the latest reduction outcomes.

## 3.1.1 Targets: A Decade of Consensus Becomes Mainstream, Showing Resilience Amidst Headwinds

- © In the decade since the adoption of the Paris Agreement, global carbon neutrality has evolved from a preliminary vision into a mainstream consensus, deeply integrated into national development plans and the actions of non-state actors. This profound transformation is reflected in the number of countries with carbon neutrality or net-zero emission targets, which has surged from just one in 2015 to 165 today<sup>③</sup>, covering over 80% of global emissions, 86% of the population, and 73% of GDP. This consensus is increasingly being translated into concrete legal and policy commitments: 34 countries have enshrined their carbon neutrality targets in law, 52 have included them in policy documents, 156 have set medium-term emission reduction goals, and 124 have issued national implementation plans. On the technology front, 177 countries have established 618 technology development targets covering seven key areas, including renewable energy and new energy vehicles. This trend has also swept through non-state actors, with 1,195 companies and 284 cities having set carbon neutrality targets.

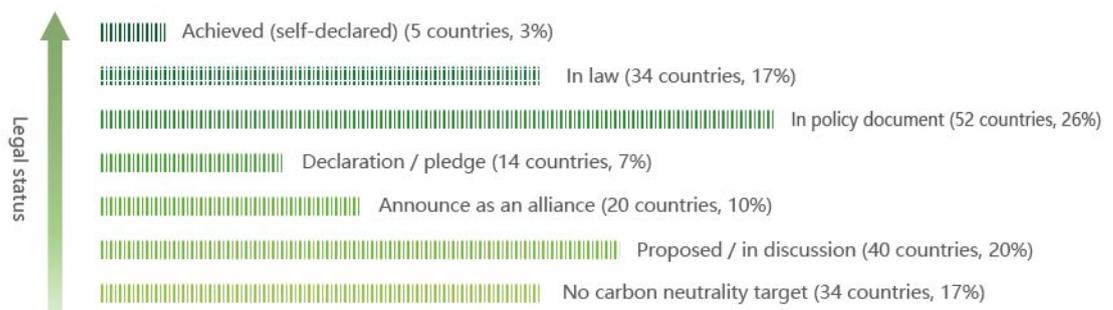


Figure 3.1 Distribution of the legal status of global carbon neutrality targets.

③ As of May 2025

Note: The legal status of national carbon neutrality targets is ranked from highest to lowest: "Achieved (self-declared)" (countries claiming to have achieved carbon neutrality, all through forest carbon sinks); "In law" (target enshrined in legislation); "In policy document" (target included in domestic policy or submitted in a Long-Term Low Greenhouse Gas Emission Development Strategy (LTS) to the UNFCCC); "Declaration / pledge" (e.g., announced by a head of government); "Announce as an alliance" (e.g., Climate Ambition Alliance); "Proposed / in discussion" (target under discussion); "No carbon neutrality target."

- © **The withdrawal of the United States did not trigger a domino effect among other nations; on the contrary, global carbon neutrality targets demonstrated strong resilience during the short-term fluctuations of the past year (June 2024 to May 2025).** Despite the U.S. once again withdrawing from the Paris Agreement and canceling its 2050 net-zero emissions target, which brought uncertainty to the global process, the number of countries with carbon neutrality targets still increased from 162 to 165 during this period. More importantly, the legal status of these targets was strengthened and further integrated into phased and sectoral implementation levels: 4 new countries established carbon neutrality targets in law, 11 new countries set medium-term emission reduction goals, and 28 new countries issued national implementation plans. Among the G20 and EU countries, 9 added new sectoral targets (mainly in methane reduction), while only one country canceled a sectoral target (see Box 1).



Country	Agriculture	Buildings	Industry	Land Use & Forestry	Methane	Power	Transport	Waste
Argentina	✓	✓	✓	×	✓	✓	✓	✓
Australia	✓	✓	✓	✓	✓	✓	✓	✓
Brazil	✓	×	×	✓	✓	✓	✓	×
Canada	✓	✓	✓	✓	✓	✓	✓	✓
China	×	✓	✓	✓	✓	✓	✓	×
European Union	✓	✓	✓	✓	✓	✓	✓	✓
Germany	✓	✓	✓	×	×	✓	✓	✓
India	✓	✓	✓	✓	×	✓	✓	×
Indonesia	✓	✓	✓	✓	×	✓	✓	×
Japan	×	✓	✓	✓	✓	✓	✓	×
Mexico	✓	×	×	✓	×	✓	✓	✓
Russia	×	×	×	×	×	✓	✓	×
Saudi Arabia	×	✓	✓	✓	✓	✓	✓	×
South Africa	✓	✓	✓	✓	×	✓	✓	×
South Korea	×	✓	✓	×	×	✓	✓	×
Turkey	×	×	✓	×	✓	✓	✓	×
United Kingdom	✓	✓	✓	×	✓	✓	✓	×
United States	✓	✓	✓	✓	✓	✓	✓	✓

Note: Blue (✓) indicates maintained, Green (✓) indicates newly added, Purple (×) indicates reduced.

**Table 3.1 Sectoral Emission Reduction Target Status in G20 Countries**



### 3.1.2 Policies: A Decade of Maturing Climate Policy Frameworks, with Coexisting Progress and Adjustments in the Past Year

- © **To implement the long-term vision established by the Paris Agreement, countries have systematically built policy frameworks over the past decade.** This has driven a profound evolution in support for carbon-neutral technologies, moving from non-existence to diversity. It is now widely recognized that no single policy can address the complex challenges of the transition. As a result, countries are actively constructing "policy mixes" that combine mandatory, incentive-based, and enabling policy instruments. Among these, mandatory policies have the widest coverage, with 170 countries having enacted support policies centered on renewable energy portfolio standards, net-zero emission targets, or fossil fuel bans. Building on this, the coverage of market-based incentives including carbon pricing and green certificates has also expanded significantly: 35 countries have implemented a carbon tax, 32 operate emissions trading systems, and 66 participate in the international renewable energy certificate market, collectively promoting the end-use adoption of clean electricity. In contrast, enabling policies are more targeted, mainly used to nurture emerging technologies or optimize management in specific areas. For instance, for technologies including clean hydrogen that still need to overcome cost and scale barriers, policies often combine incentives with enabling measures such as investment support and R&D funding. For forest carbon sinks, the policy focus is on enabling measures including optimizing ecological management and institutional development.
- © **Over the past year (June 2024 to May 2025), progress at the technology policy level has shown a complex picture of "overall advancement" and "localized adjustments." On the positive side, the completeness and sophistication of policy systems continue to improve.** The number of countries with a comprehensive carbon neutrality policy system covering three types—mandatory, incentive-based, and supporting policies—has increased significantly from 72 to 103, and the number of countries with support policies for all seven major low-carbon technologies rose from 8 to 11. The level of policy detail also increased; for example, 9 countries introduced new tax credit policies for renewable power generation, and 10 countries issued laws and regulations related to CCUS technology. However, at the same time, some major economies have made adjustments to key climate policies. The policy vacillation in the United States constitutes the greatest uncertainty, with measures including the cancellation of a \$3 billion climate-smart agriculture program, the repeal of methane leak emission fees for the oil and gas industry, and the dissolution of a

dedicated climate change office. Other countries have exhibited similar trends, such as the UK delaying its ban on the sale of new gasoline and diesel cars. These adjustments in specific areas run counter to the "ratchet mechanism" of the Paris Agreement, which is designed to ensure ever-increasing ambition and prevent backsliding. Such negative developments require close attention from the international community (see Box 1 for a list of negative policy developments).

- © **Overall, national technology policy systems not only exhibit distinct national and regional characteristics but also have varied policy mixes tailored to the development stage of different low-carbon technologies.** For relatively mature technologies such as renewable electricity and electric vehicles, the policy focus is on combining mandatory instruments (e.g., quotas, bans) with incentives (e.g., tax credits) to drive end-use adoption. For emerging technologies such as clean hydrogen and CCUS, which have high costs and rely on infrastructure, enabling policies play a crucial role. Their support is concentrated on R&D funding, pilot projects, supply chain development, and international cooperation to pave the way for commercialization. Similarly, areas including forest carbon sinks, biofuels, and energy efficiency technologies widely use enabling policies focused on optimizing management and setting standards. At the national level, developed countries generally lead in policy coverage and completeness, with the US, Japan, Canada, and Australia having support policies for all seven major low-carbon technologies. European countries tend to prioritize end-use technologies, focusing on promoting electric vehicles, clean hydrogen, and biofuels. Among developing countries, only China and Indonesia currently have comprehensive policy coverage for all seven technologies. Other developing nations tend to focus on their resource endowments, such as Brazil and the Philippines, which favor biofuels and forest carbon sink technologies. In terms of policy instrument choice, China, Japan, Canada, and the EU generally adopt a balanced approach, combining mandatory, incentive-based, and enabling policies, while the US and most developing countries rely more on incentive-based systems centered on subsidies and investment guidance.

		Count of nations						
		Renewable power	Electric vehicles	Energy saving	Clean hydrogen	Biofuel	CCUS	Forest carbon
<b>Compulsory</b>	Standard	20	17	9	1	12	1	7
	Command	11	9	14	3	13	13	7
<b>Incentive</b>	Subsidy	3	6	2	3	3	3	0
	Tax reduction	8	13	1	2	6	2	0
	Investment	0	1	1	10	8	3	0
	Fund	0	1	0	1	7	3	2
	Credit	0	1	1	0	0	0	0
	Pilot project	0	1	0	2	1	5	4
	Market mechanism	13	10	0	0	0	2	1
	NDC inclusion	0	0	1	0	11	8	0
			0	0	0	0	0	0
<b>Auxiliary</b>	Supply chain	0	9	0	1	1	0	6
	Int'l cooperation	0	9	7	5	0	2	5
	Promotion	0	0	1	1	0	1	0
	Optimize managing	0	0	0	1	0	6	13
	R&D support	0	1	1	11	9	2	0

Figure 3.2 Policy support models for different technology categories (example of top 20 GDP countries in 2023, only covering governmental documents directly supporting specific technologies).

- ◎ **Since 2015, policies and market mechanisms supporting climate finance have advanced in parallel, achieving systematic expansion.** On the fiscal policy front, countries have generally increased their focus on climate-related expenditures, with 24% of nations now disclosing their climate budget spending. Meanwhile, climate financial risk management has gradually become mainstream, with 129 countries having initiated climate-related financial risk assessments by 2024. At the market mechanism level, global carbon pricing now covers 24% of global carbon emissions across 50 countries (25% of the global total), which account for 55% of global GDP, 37% of the population, and 57% of carbon emissions. The market regulations and guidelines for innovative financial instruments including green bonds have also become more robust, collectively laying a solid institutional foundation for channeling funds to support carbon neutrality actions.
- ◎ **However, over the past year (June 2024 to May 2025), progress in climate finance policy has shown a divergent trend of "accelerated risk management" and "stagnating market mechanisms." On the positive side, the completeness of policy systems has continued to improve. This is especially evident in the area of climate financial risk management.** The coverage of five key policy tools (mentioning climate finance in NDCs and LT-LEDS, conducting climate financial risk assessments, implementing mandatory climate financial risk disclosure, and establishing carbon pricing mechanisms) has expanded. The number of countries with all five tools increased from 16 in 2023 to 23 in 2024, and these countries account for 42% of global GDP and 49% of carbon emissions. The strengthening of climate financial risk assessment and disclosure mechanisms was particularly prominent. A total of 48 new countries launched climate-related financial risk assessments, 45 of which were developing countries, accounting for 94% of the new additions. Furthermore, the number of countries implementing mandatory climate financial information disclosure rose significantly from 38 in 2023 to 69 in 2024, reflecting a general enhancement of global climate financial regulatory capacity. However, the development of global carbon pricing mechanisms, a core market tool, has been relatively slow. Only two new carbon pricing mechanisms were added globally in 2024, and under Article 6 of the Paris Agreement, only nine countries have established complete authorization and tracking systems, with even fewer submitting initial reports. The actual influence and scale of these policies have yet to be fully realized.



© **The development of global climate finance market mechanisms shows significant regional imbalances. Developed countries continue to lead in the construction of mature market mechanisms.** Carbon pricing mechanisms are still dominated by developed countries: 12 economies have mechanisms covering over 75% of their domestic emissions, all of which are developed nations, while most developing countries remain at the stage of initial design or capacity building. Developing countries, however, have shown strong momentum in improving their policy systems and have become major contributors to progress in some areas over the past year. They were the main group of countries that newly initiated climate financial risk assessments. In fiscal policy, although most countries only disclose budgets at the environmental department level, Small Island Developing States have been particularly active, with 64% of them allocating over 1% of their fiscal budget to climate action. Additionally, in emerging mechanisms including the voluntary carbon market, the participation of developing countries is high, with India and China having the most voluntary carbon market projects globally. It is worth noting, however, that the quality of these projects varies, and there is a need to strengthen the development of high-quality project methodologies and performance monitoring. These efforts indicate that developing countries are working within their means to improve their climate finance policy systems and are gradually increasing their participation and voice in the international climate finance landscape.

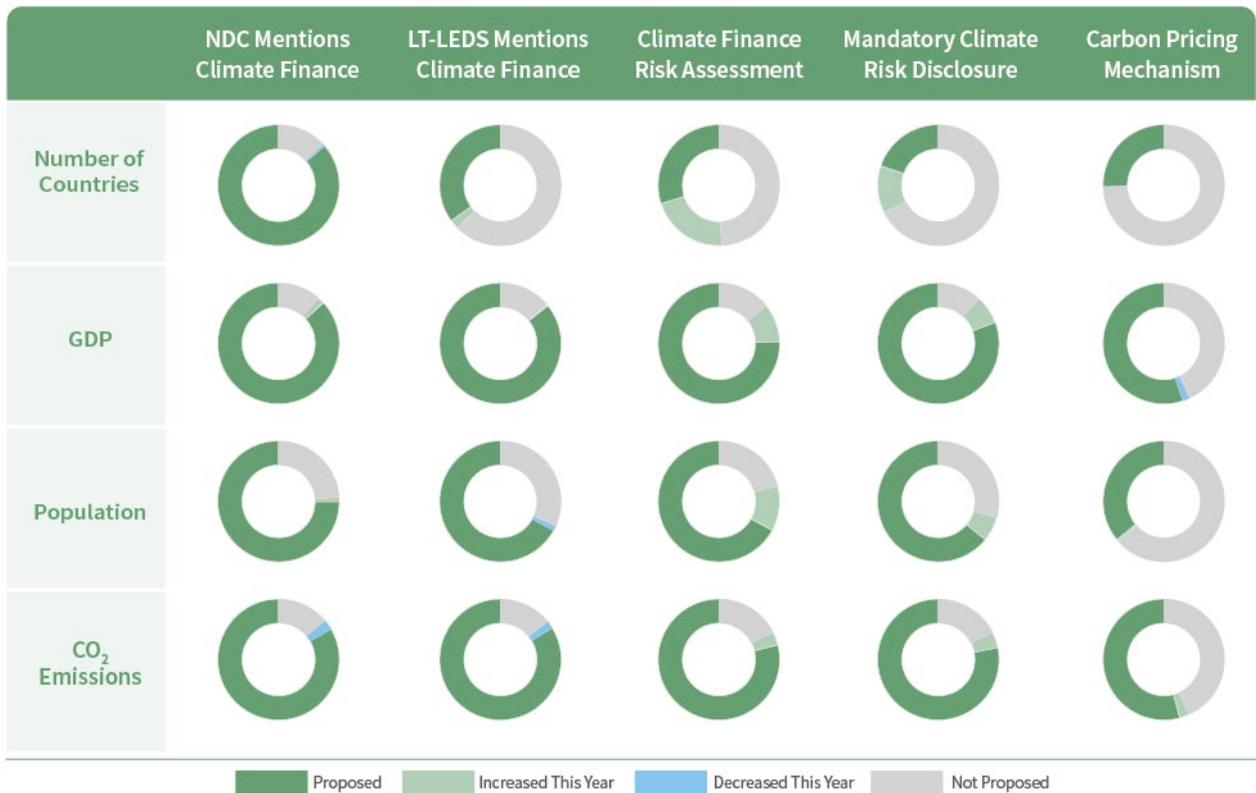


Figure 3.3 Coverage of climate finance policies.

**Box  
1****A Checklist of Negative Developments in  
Low-Carbon Policy in Key Areas****Delaying and  
Potentially  
Weakening  
Medium-Term  
Emission  
Reduction  
Targets**

Sufficiently ambitious medium-term targets (e.g., NDCs) are crucial anchors for the credibility of long-term carbon neutrality goals. However, when these targets are weakened or delayed, it sends a negative policy signal for achieving long-term goals. For example, the EU, a long-standing leader in global climate policy, had planned to amend its climate law in the first quarter of 2025 to set a 90% greenhouse gas reduction target for 2040. However, due to reservations and opposition from several member states (e.g., Poland, Czechia, Slovakia, Hungary), the legislation was postponed, with the European Commission only stating it would proceed "in the near future".

**Weakening  
Sectoral  
Carbon  
Reduction  
Targets**

Sectoral targets are vital components of a carbon neutrality roadmap. Weakening these targets undermines certainty for industries and discourages long-term green investment and production. For example, in Canada, the building sector is a major source of national emissions and a key focus of climate policy. On July 16, 2024, the federal government released the Canada Green Buildings Strategy, aiming for a 40% reduction in the sector's emissions by 2030 compared to 2005 levels. However, a new government report on December 13, 2024, officially lowered this target to a 37% reduction by 2030.



### Prematurely Repealing or Reducing Renewable Energy Production Subsidies

Production subsidies are crucial for supporting the early development of the renewable energy industry and accelerating cost reductions. Rolling back or reducing these subsidies prematurely can slow technological progress, disrupt market expectations, and deter future investment. For example, the United States passed the Inflation Reduction Act in 2022, investing approximately \$370 billion in climate and clean energy through tax credits and other measures. However, in July of this year, the America First Act reversed some of the clean energy support policies, including eliminating the tax credit refunds for renewable energy. The act terminates the electric vehicle tax credit seven years early and completely phases out investment and production tax credits for wind and solar after 2027. As a result, an estimated 4,500 clean energy projects could be halted, and renewable energy capacity may decrease by 72% by 2030.

### Relaxing Fossil Fuel Regulations

Relaxing fossil fuel regulations—such as lifting restrictions on oil and gas leasing, repealing emission standards for coal and gas power plants, and eliminating methane leak fees—encourages further expansion of the fossil fuel industry. These actions will crowd out renewable energy development and lead to more high-emission, inefficient infrastructure. For instance, in January 2025, President Trump issued an executive order declaring a "national energy emergency," which relaxed environmental regulations on oil, gas, and mineral development. In March 2025, the Environmental Protection Agency repealed the Biden-era CO<sub>2</sub> emission limits for fossil fuel power plants. Additionally, the Trump administration pushed Congress to repeal the fee schedule for excess methane emissions from the oil and gas industry set in the Inflation Reduction Act, severely reducing the incentive for companies to manage methane leaks.

### Abolishing the Social Cost of Carbon

The social cost of carbon is a core policy tool for quantifying the long-term economic damages caused by greenhouse gas emissions, guiding both government policy and corporate investment. In 2025, President Trump signed an executive order abolishing the federal government's estimation of the social cost of greenhouse gases, requiring all departments to cease considering carbon pricing in policymaking and canceling related research support for various climate regulations and scientific institutions. As a result, the loss of a carbon price signal is expected to reduce the anticipated returns on low-carbon investments and weaken incentives for companies to pursue emission reductions.

### 3.1.3 Actions: A Decade of Leapfrog Development in Carbon Neutrality Technology, but Limited Progress in Climate Finance and Wavering on Fossil Fuel Transition

Since 2015, the deployment and innovation of global low-carbon technologies have not progressed at the same pace, but have shown significant differences depending on technological maturity. These technologies fall into three categories according to their deployment scale and innovation activity:

**Mature Technologies in the Market Breakout Phase:** Represented primarily by renewable energy and electric vehicles. Over the past decade, global renewable energy generation capacity has more than doubled, growing from 1,985 GW to 4,448 GW. The electric vehicle market has undergone a revolutionary expansion, with annual sales soaring from about 680,000 units to over 17.1 million, a more than 25-fold increase. The common feature of these technologies is that their market deployment has achieved economies of scale and is now driven by cost advantages. As a result, they have entered a self-reinforcing growth trajectory.

**Emerging Technologies with Active Innovation but Nascent Market Deployment:** Represented by CCUS and clean hydrogen. A notable characteristic of these technologies is the stark contrast between their limited deployment scale and the surge in innovation vitality. In terms of deployment, clean hydrogen production capacity has grown from nearly zero in 2015 to 647,000 metric tons per year, while CCUS capture capacity has only increased from 30 million to 51 million metric tons per year, far from achieving large-scale application. However, on the innovation front, annual patent applications for clean hydrogen technology have increased from about 11,000 to 18,000, and the annual number of SCI papers related to CCUS technology has more than tripled, from about 12,000 to nearly 40,000. This indicates that these technologies are on the cusp of a critical transition from "technological breakthrough" to "market breakout".

**Technologies Not Yet in a Breakout Growth Phase, with Some Areas Even Slowing Down:** This category mainly includes energy efficiency technologies and biofuels. Energy efficiency, although the most fundamental means of emission reduction, has made disappointing progress. The global energy efficiency improvement rate slowing from about 1.8% in 2015 to about 1.3% in 2024. The deployment of biofuels has also been sluggish, with production capacity increasing from 131.6 billion liters to 175.6 billion liters per year, a limited increase that is far from showing breakout growth potential.

This is not just a "gap"; it's a structural chasm. The transition is proceeding on two completely different tracks. One is a high-speed rail line powered by market economics and innovation. The other is a stalled freight train weighed down by political inertia, unfulfilled financial commitments, and vested interests in fossil fuels. The core challenge for the next decade is not inventing new technology but bridging this chasm.

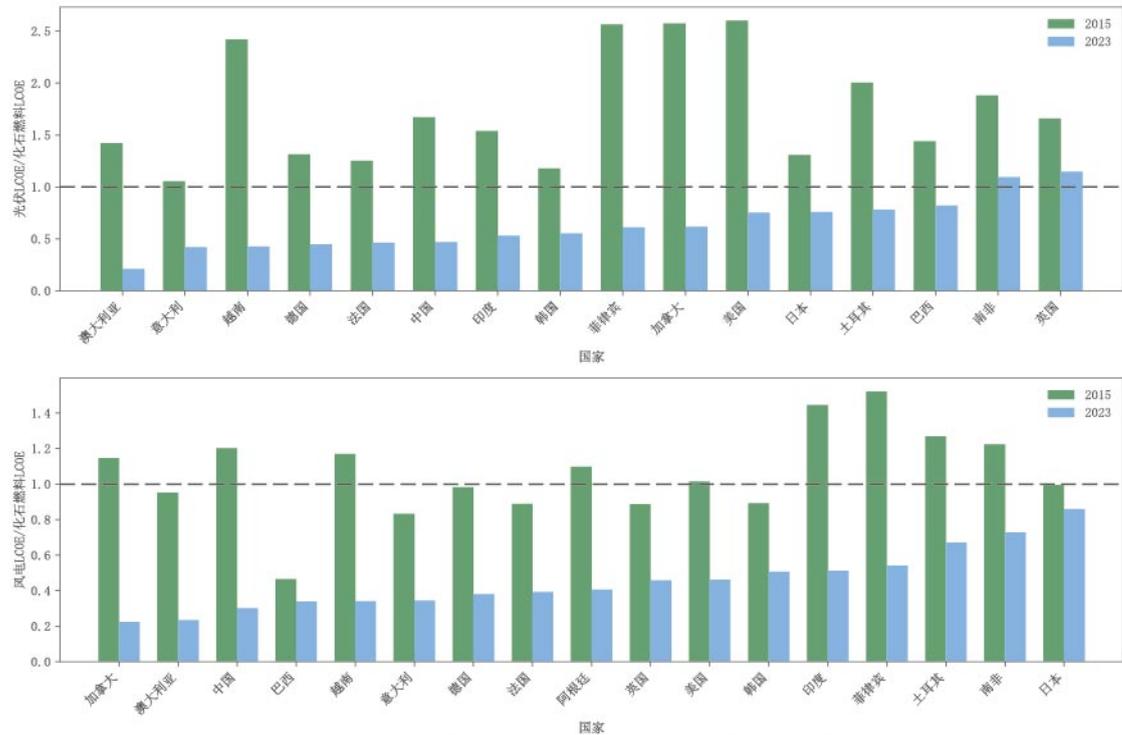


Figure 3.6 Levelized cost of electricity for fossil fuels, solar PV, and wind in major countries in 2023.

Over the past year, the decade-long divergence has not only persisted but has become even more pronounced, with positive momentum accelerating in some areas. The high-speed growth of mature technologies has been particularly significant in the last year, with their fundamental driver—cost advantage—continuing to expand. Global wind and solar power costs have further decreased by 12% and 11% in the past year, solidifying their economic competitiveness. As of 2023, the generation costs of renewable energy in all major countries were already lower than those of fossil fuels (Figure 3.6). In 2024, the global levelized cost of electricity (LCOE) for onshore wind almost maintained at \$0.034/kWh and for solar PV to \$0.043/kWh, far below the \$0.068 to \$0.218/kWh range for fossil fuels. This cost advantage has created an accelerating effect, which is clearly reflected in future expectations (see Section 3.3.2 and Appendix B for details). Based on the latest data up to 2024, the projected renewable energy capacity for 2030 is 2.65 times the 2022 baseline, a

## 2.65

the projected renewable energy capacity for 2030 is 2.65 times the 2022 baseline

significant increase from the 2.15 times projection based on data up to 2023. This indicates that record-breaking annual growth is continuously raising global optimism about the future transition. Similarly, the innovation vitality of emerging technologies remains strong, with the number of countries capable of carbon neutrality technology innovation increasing from 47 to 78 in the past year, showing a continuous diffusion of innovation capacity.

This overall positive momentum is not uniformly distributed globally but is reflected in increasingly divergent national approaches, as countries actively promoting differentiated technology deployment based on their resource endowments and technological advantages. China continues to lead the world in renewable electricity, contributing 64% of the global new installed capacity in 2024. The United States excels in blue hydrogen and CCUS technology, accounting for 154 of the 302 new CCUS projects added globally in the past year. Other developing countries, leveraging their local resource endowments, have a relative advantage in technologies such as hydropower, biodiesel, and forest carbon sinks; for example, Brazil's average annual growth rate of biodiesel production is about 15%. The European Union continues to lead in electrification and energy efficiency improvements, with heat pump sales growing at an average annual rate of 25% over the past three years, far exceeding the global average.

# 78

the number of countries capable of carbon neutrality technology innovation



However, in stark contrast to the positive momentum of technology diffusion, progress in the two key drivers supporting the low-carbon transition—climate finance and the shift away from fossil fuels—has either stalled or become increasingly uncertain over the past year. In climate finance, 94 countries globally have made virtually no progress on climate finance-related actions, indicating near stagnation. In 2024, the total disclosed funding for mitigation projects provided by developed countries to developing countries was \$36.62 billion, which translates to a grant equivalent of \$5.79 billion—a scale insufficient to meet the energy transition and mitigation needs of developing countries. Moreover, some projects focus on social inclusion, capacity building, innovative finance, and green finance, which are not directly related to mitigation and do not fully meet the actual needs of developing countries. In terms of the fossil fuel transition, global actions are uncoordinated, and the wavering or even regression of some countries could drag down the overall process. The world's dependence on fossil fuels remains deeply entrenched; in 2023, 6 countries still relied 100% on fossil fuels for their energy consumption, and in 17 countries, fossil fuels accounted for over 99% of their electricity mix. Even more concerning, many countries are making inconsistent or even regressive moves in their phase-out actions: For example, Germany delayed its decision on new natural gas plants due to energy security concerns, casting doubt on its 2030 coal phase-out target; the UK issued 28 new oil and gas exploration licenses in the North Sea; and Canada, despite having a policy to end fossil fuel subsidies, continues to channel billions of dollars in public funds to the industry under non-transparent conditions.

94

94 countries globally have made virtually no progress on climate finance-related actions

6

in 2023, 6 countries still relied 100% on fossil fuels for their energy consumption

### 3.1.4 Effectiveness: A Positive Ten-Year Decarbonization Trend, with Recent Outcomes Yet to Be Reflected

Since 2015, the global decarbonization process has undergone a structural transformation, with 85% of countries now having achieved a decline in their carbon emission intensity. Notably, 20 countries—including industrial transition leaders such as Sweden and Germany—have seen their carbon intensity drop by more than 75% from their historical peak, and 64 countries have achieved reductions of over 50%. However, over the past year, national decarbonization effectiveness has diverged. The number of countries with a carbon intensity reduction of less than 25% increased from 51 last year to 82 this year, causing the global median effectiveness score to drop from 38 last year to 26 this year. The short-term decline in decarbonization effectiveness reflects that, despite slower growth, economic expansion is still largely driven by fossil fuels. It will take time for the deployed carbon neutrality policies and actions to reveal measurable decarbonization outcomes.

85%

85% of countries now having achieved a decline in their carbon emission intensity.

## 3.2 The NDC Ambition Gap: Are National Pledges Sufficient for Long-Term Goals?

To answer this key question, this section assesses the aggregated ambition of Nationally Determined Contributions (NDCs) from two perspectives. As one of the most important institutional arrangements under the Paris Agreement, NDCs are the critical "medium-term anchors" that countries set to achieve their long-term climate goals. This section first uses the "NDC Tracker" model (see Appendix B) to assess whether the collective mitigation efforts enshrined in NDCs are aligned with global emission trajectory. Second, it uses an "Ambition Index" based on multiple equity principles, derived from the "Fair Carbon Allocation Model" (FairCAM, see Appendix B), to identify whether countries' medium-term NDCs are consistent with their own long-term carbon neutrality goals<sup>④</sup>. The core conclusion of this section is that the world is facing a dual "ambition gap." On one hand, the aggregated ambition of current NDCs is far from sufficient to meet Paris Agreement temperature targets. On the other hand, the medium-term commitments of most countries are inconsistent with their long-term goals, which undermines the credibility of the latter.



### 3.2.1 Existing NDC Ambition is Insufficient to Achieve 2°C/1.5°C Temperature Goals

As of September 25, 2025, 189 parties have communicated their 2030 NDCs, covering 87% of global net greenhouse gas emissions, and 48 countries have communicated their 2035 NDCs, covering 56% of global net greenhouse gas emissions. The submission statues fall far below that of the previous NDC cycle. According to preliminary calculations, if all countries fully implement their NDCs, global emissions could be reduced by -1%-7% by 2030 and 4%-13% by 2035<sup>⑤</sup> (compared to 2019 levels). However, this level of reduction falls far short of the mitigation required by the IPCC to be consistent with the Paris Agreement goals. Countries need to submit their 2035 NDCs as soon as possible and significantly increase their ambition.

**48**  
parties have  
communicat-  
ed their 2035  
NDCs

<sup>④</sup> For Parties with no 2035 NDC, model conservatively assume their 2035 emission as equivalent to 2030 emission. The model will be updated with Parties' communication of latest NDCs in time.

<sup>⑤</sup> For countries that have not submitted 2035 NDCs, their emission levels are assumed to remain unchanged from 2030.

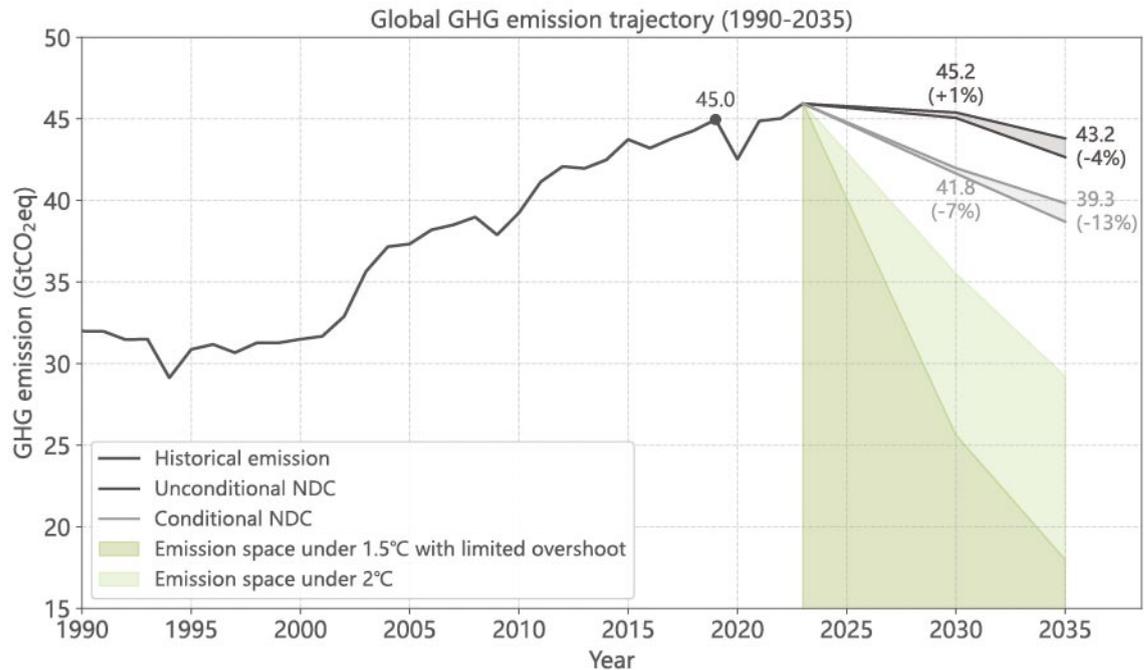


Figure 3.4 Global emission trajectories under the 2030 and 2035 NDCs.

### 3.2.2 Most Countries' NDCs Are Inconsistent with Their Own Carbon Neutrality Targets, Requiring Stronger Medium-Term Ambition

To measure the ambition of a country's climate targets, this report has developed an "Ambition Index" based on equity principles. Using the Fair Carbon Allocation Model (FairCAM, see Appendix B), it separately assesses the stringency of a country's target under four principles: responsibility and capability, per capita convergence, grandfathering, and multi-stage approaches. The assessment shows that the ambition of the active NDCs is generally lower than that of the long-term carbon neutrality targets. Under the four principles, the proportions of countries whose 2030 targets are consistent with their carbon neutrality targets are 22%, 1%, 10%, 1%, respectively. For 2035 targets, the proportions are 20%, 0%, 13%, 0%, respectively. Ensuring consistency between medium-term and long-term targets is crucial for enhancing the credibility of long-term climate ambition.

**20%**  
of 2035 NDCs are consistent with its own carbon neutrality target

Furthermore, 52% of carbon neutrality targets are consistent with the 1.5°C temperature goal under all four equity principles, and 66% are consistent with the 2°C goal under all four principles, showing a slight improvement from last year. Developing countries constitute the vast majority (93%) among the countries whose carbon neutrality targets are consistent with the 1.5°C goal, indicating a more general ambition in carbon neutrality targets. Developing countries generally show greater ambition under the "historical responsibility and capability to mitigate" principle, while developed countries show greater ambition under the "grandfathering" and "multi-stage fairness" principles.

93%

Developing countries constitute the vast majority

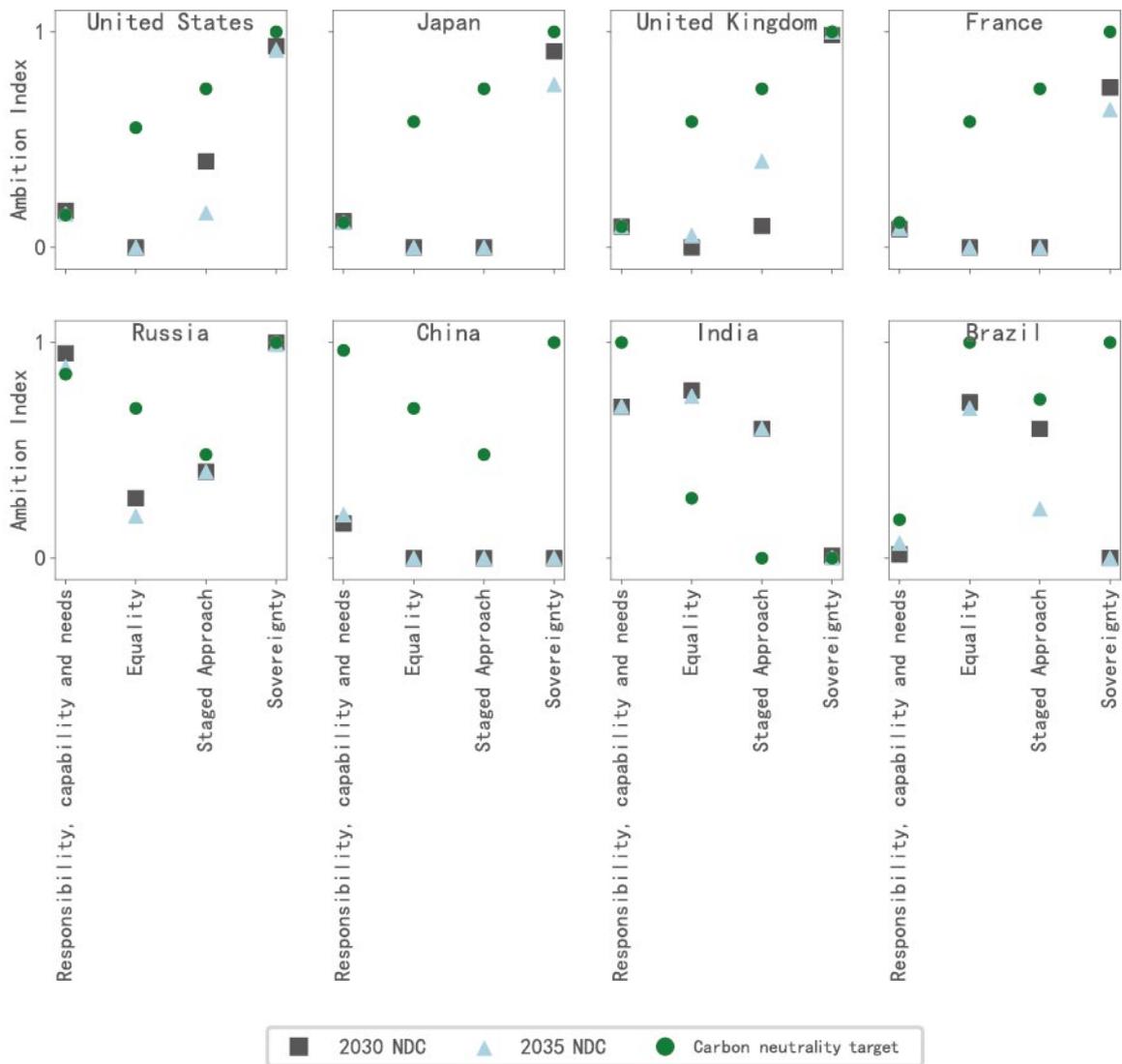


Figure 3.5 Ambition index for the carbon neutrality targets and 2030/2035 NDCs of major countries.



## 3.3 The Technology Deployment Gap: Can Key Targets such as "Tripling Renewables" Be Achieved?

To answer this question, this section assesses the "deployment gap" between the current progress of seven key technologies and the scale required to meet 2030 targets from two perspectives: first, by comparing the deployment stock of the seven technologies in 2024 with their 2030 targets; and second, by comparing their average growth rate from 2015-2024 with the growth rate required to meet the targets. The core conclusion of this section is that despite historical progress in some technologies over the past decade, the world generally faces a huge technology deployment gap. To achieve the 2030 targets, the deployment speed of most technologies needs to be significantly accelerated.



### 3.3.1 Overall Assessment: A Huge Gap Exists Between Current Technology Deployment and 2030 Targets

Since 2015, the deployment of global carbon-neutral technologies has made historic progress. Total global renewable energy installed capacity has increased 2.24-fold, and its share of total capacity has risen from 23% to 32%. The levelized cost of electricity (LCOE) for solar PV and wind has dropped by over 63% and 39%, respectively, completely reshaping the energy system development landscape and further building momentum for the comprehensive replacement of fossil fuel consumption. Annual sales of electric vehicles have also leaped from the hundred-thousand level to the ten-million level. The development of renewable energy generation technology has moved beyond the policy nurturing phase and entered a new stage of sustainable growth led by market forces. The driving force for the development of global carbon-neutral technologies has gradually shifted from policy support to cost advantage, establishing their core position in the global energy system.

Despite these remarkable achievements, the current pace of global carbon-neutral technology deployment is far from sufficient to meet the ambitious goals for 2030. As of 2024, the deployment stock of the seven key carbon-neutral technologies has only reached between 1% and 42% of the scale required for their 2030 targets (Figure 3.7). To close this huge gap, the deployment of almost all technologies must be significantly accelerated in the coming years. According to calculations, if the average growth rate of the past decade is maintained, only electric vehicles and clean hydrogen are expected to exceed their targets by 2030<sup>⑥</sup>. The deployment of other key technologies will lag far behind: renewable energy deployment is expected to reach only 88% of its target, biofuels 53%, energy efficiency technologies 26%, and CCUS a mere 8%. The challenges for energy efficiency, biofuels, and CCUS are particularly severe, requiring their deployment speeds to increase by up to 7, 4, and 8 times, respectively, to meet the 2030 demand.

# 2.24

Total global renewable energy installed capacity has increased 2.24-fold

⑥ The high average growth rates are attributable to their extremely low baseline levels in 2015, making this estimate potentially overoptimistic.

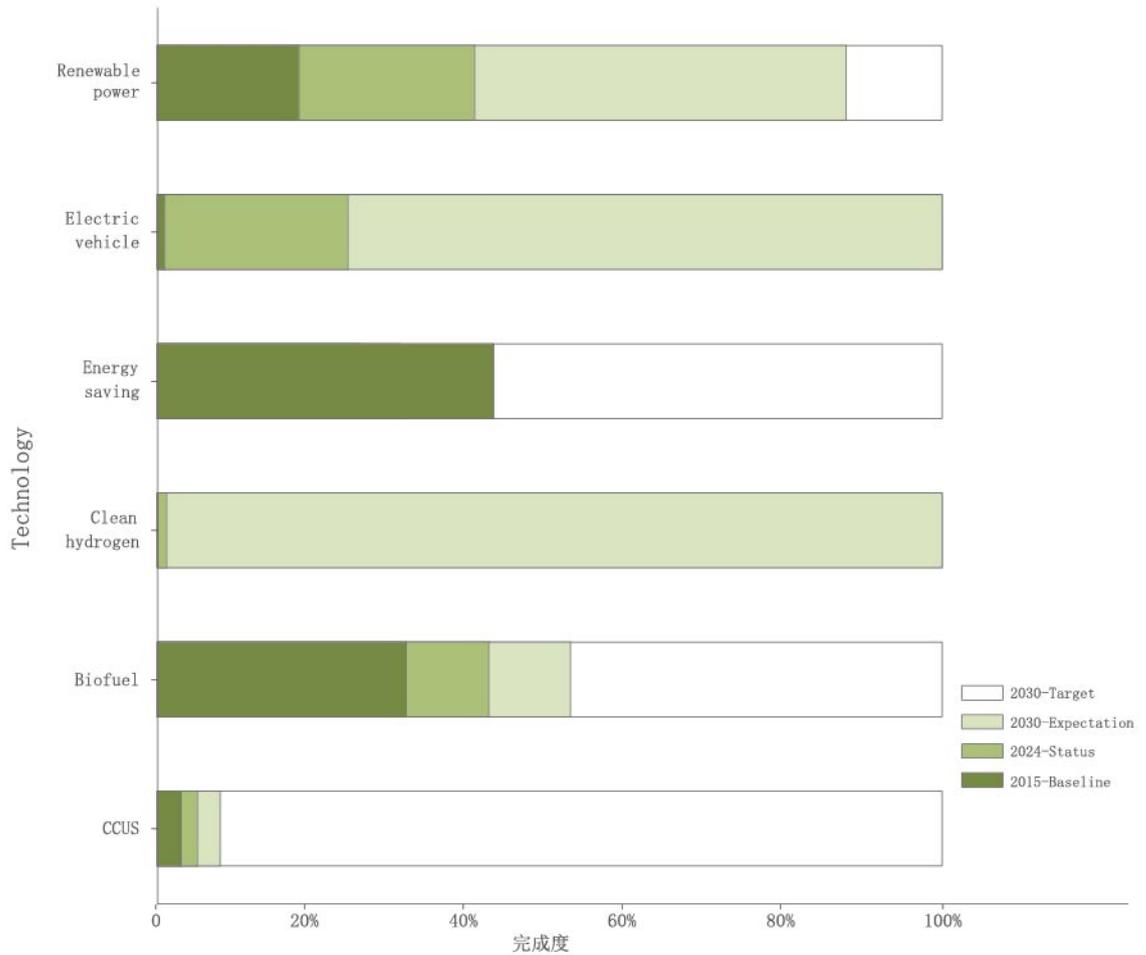


Figure 3.7 The gap between the current deployment of carbon-neutral technologies and their targets. (Note: Forest carbon sink technology deployment is projected to achieve the 2030 zero-deforestation target at the growth rate of the past year.)

### 3.3.2 Thematic Analysis: The "Tripling Renewable Energy" Target is Moving from "Ambition" to "Reality"

Despite the general deployment gap, it is noted that mature technologies, represented by renewable energy, are entering a period of rapid growth (3.1.3). Therefore, the key target of "tripling renewable energy by 2030" is showing an increasing likelihood of being achieved due to recent accelerated growth. In 2024, global renewable energy installed capacity achieved a record annual growth rate of 15.1%, with 585 GW of new capacity added. This strong momentum has significantly increased the probability of achieving the target.

**585**  
585 GW of  
new capacity  
added

This accelerating effect is clearly reflected in future expectations. This is a case study in non-linear change. As technologies such as solar and wind hit cost-competitiveness tipping points, their growth becomes exponential. This "compounding effect" means that linear extrapolations of past trends can be misleading. The success of renewables provides a powerful counter-narrative to general pessimism and a model for how other technologies could scale once they cross similar cost thresholds. Based on this report's GRECPM model forecast (see Appendix B), using the latest data up to 2024, the projected global renewable energy installed capacity for 2030 is approximately 8,948 GW (95% confidence interval: 6,838-10,496 GW), which is 2.65 times the 2022 baseline. In contrast, using data only up to 2023, the forecast was just 2.19 times the baseline (approximately 7,405 GW, 95% confidence interval: 5,883-9,214 GW). This shows that record-breaking annual growth is continuously raising global optimism about the future transition, making the "tripling" target increasingly attainable and moving it from a distant ambition to a tangible reality.

# 8948

the projected global renewable energy installed capacity for 2030 is approximately 8,948 GW

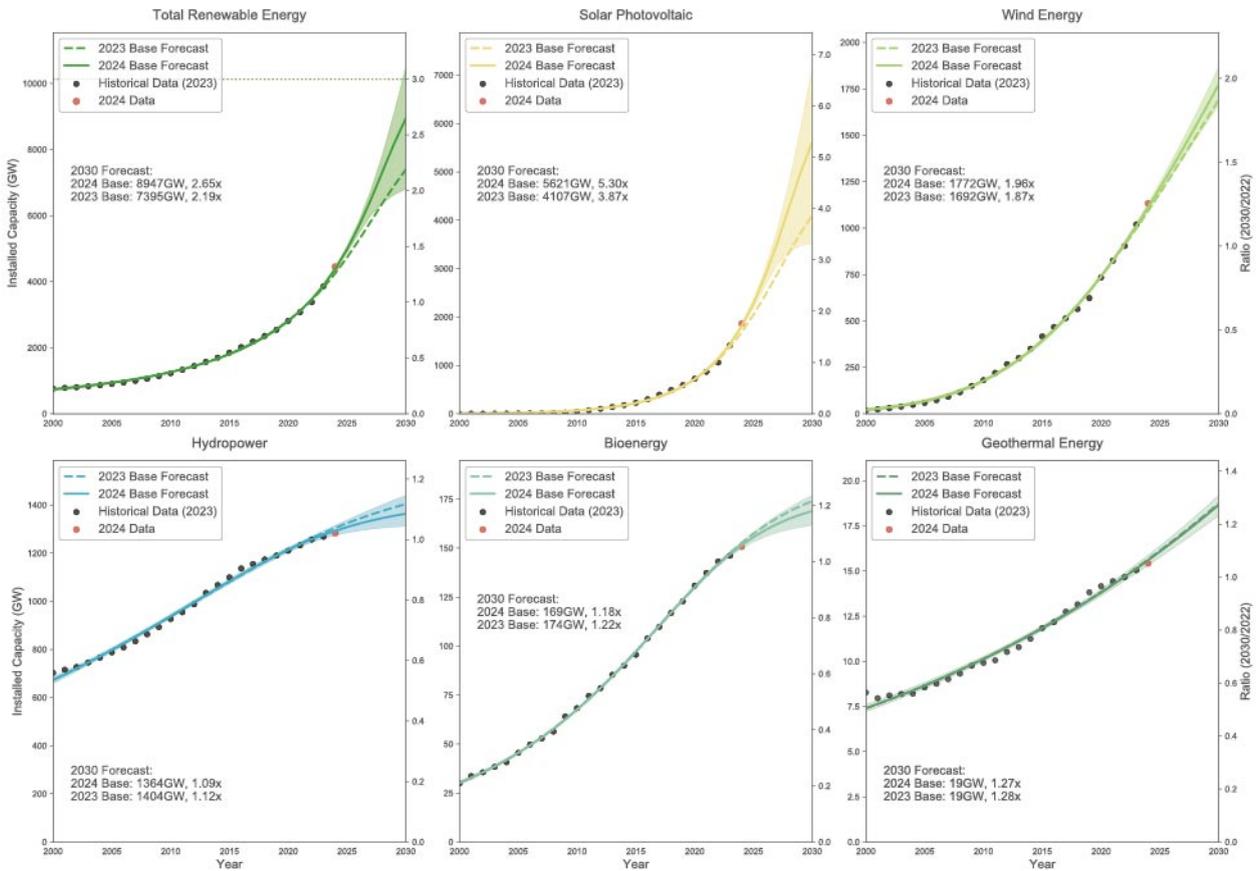


Figure 3.8 Probability of achieving the tripling renewable energy target by 2030 based on historical installed capacity forecasts.

### 3.3.3

#### **National Practices: Some Leading Countries Have Proven the Feasibility of Ambitious Targets**

This positive momentum at the global level is largely due to the pioneering efforts of some leading countries, whose practices have demonstrated that ambitious goals are not just empty talk. For example, for renewable energy, countries including China and Denmark had already met their respective 2030 installed capacity targets by 2024. For electric vehicles, most countries that set 2030 deployment targets, such as Norway, Denmark, Finland, the Netherlands, and Iceland, have also met their short-term goals ahead of schedule and are now advancing at a rapid pace toward their long-term goals of 100% new car sales by 2040-2050. The successful experiences of these pioneers provide valuable confidence and lessons for other countries to accelerate technology deployment and close the action gap.

## 3.4 The Role of Non-State Actors: Can Cities and Corporations Fill National Policy Gaps?

As mentioned earlier, the past year has seen much wavering and uncertainty in global carbon neutrality progress at the national level, especially in key areas such as sectoral emission reduction targets, climate finance policies, and the fossil fuel transition. Against this backdrop, this report also focuses on the progress of two major non-state actors: cities and businesses. The core conclusion of this section is that non-state actors are increasingly becoming indispensable "twin engines" driving the global carbon neutrality process. Cities are becoming "innovation testbeds" for nurturing local, differentiated solutions, while businesses, after a decade of rapid development, are shifting their actions from "proactive initiatives" to a new, pragmatic phase of "robust response." Together, they provide crucial grassroots support for the resilience and depth of global climate action.



### 3.4.1 Cities: An Important Grassroots Force Driving Global Progress

The rapid development of carbon neutrality targets and actions in cities has made them an important grassroots force driving the global carbon neutrality process. To date, 303 cities worldwide have proposed carbon neutrality targets, including 123 cities in developing countries and 180 in developed countries, covering approximately 14% of the global population and 40% of GDP. The largest proportion of these cities (68%) have set their carbon neutrality target for 2050. In addition, many more cities have established emission reduction targets and policies. In the G20, 3,485 cities have proposed carbon reduction targets, including carbon neutrality goals.

However, a simple count of targets masks the vast differences in the transition paths of different cities. This report categorizes these cities into three types based on their development characteristics: emerging, rapidly growing, and established. They represent three distinct transition paradigms (see Box 2 for details on urban carbon neutrality progress and experiences). Emerging cities, such as Cape Town, are exploring how to expand their "low-carbon dividend." Faced with national policy constraints and their own resource limitations, these cities are pioneering "low-starting-point, high-adaptability" transition models through technological innovation and social collaboration. For example, Cape Town has piloted the deployment of distributed solar PV in informal settlements, creating a "low-carbon poverty reduction" model, and has retrofitted diesel buses into electric vehicles to advance its transport transition at a lower cost.

**68** %  
of the cities set carbon neutrality goal for the year 2050

**3485**  
G20 cities have proposed carbon reduction targets, including carbon neutrality goals



Rapidly growing cities, such as Hangzhou, are leading green growth through technological innovation. These cities face the dual pressures of rapid economic growth and energy structure transition. Hangzhou's practices demonstrate a "policy innovation + technological breakthrough + public participation" solution, overcoming land resource constraints with models including "fishery-solar hybrid" and "whole-village PV," and providing a "Hangzhou solution" for large-scale events with the first-ever carbon-neutral Asian Games. Established cities, such as Paris, are focusing on innovative "stock transformation." These cities face challenges such as aging building stock and insufficient energy endowments. The Clichy-Batignolles eco-district in Paris, built on a former railway yard, has transformed an old industrial site into a zero-carbon community through three-dimensional spatial reconstruction and technology integration, proving that carbon neutrality can be a strategic opportunity to reshape urban competitiveness.

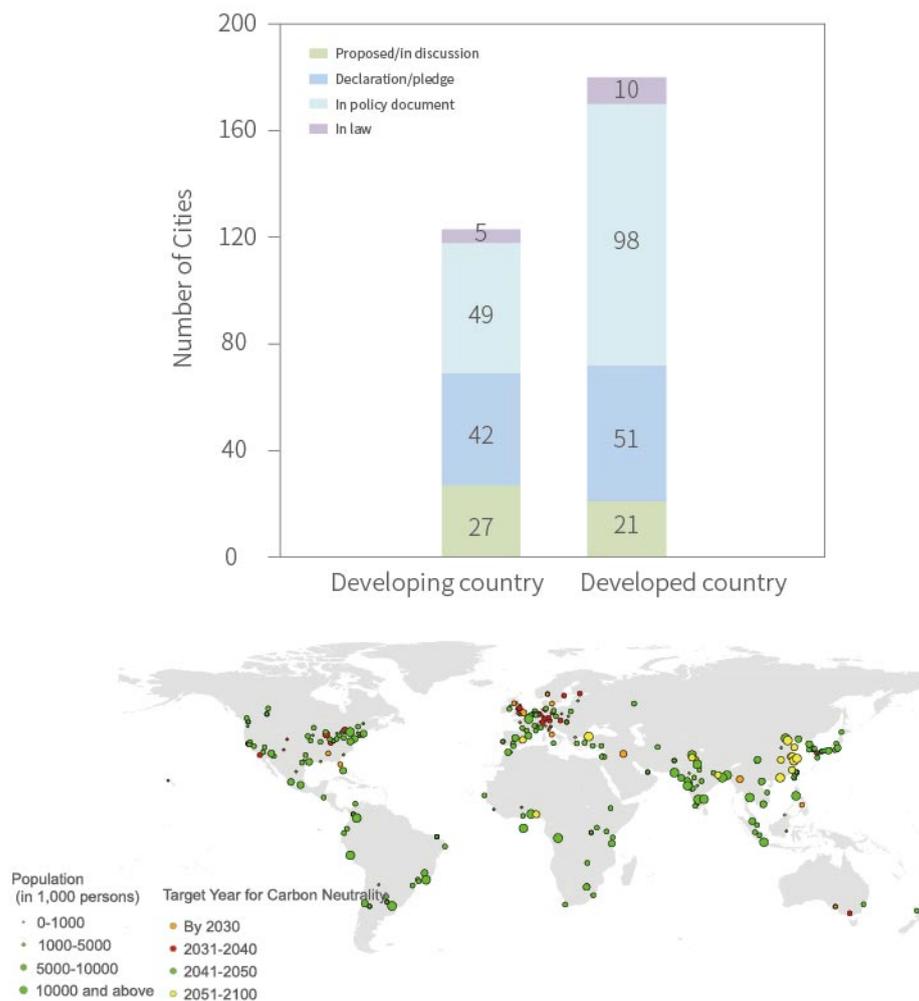


Figure 3.9 Global distribution of cities aiming at carbon neutrality.

**Box  
2****Urban Carbon Neutrality Progress and Experiences**

Different cities have distinct development characteristics and can be broadly classified into three types: emerging, rapidly growing, and established. Using GDP, per capita GDP, and population growth rate to create a city classification index, this report has categorized the 303 cities with carbon neutrality targets into 243 emerging cities, 48 rapidly growing cities, and 12 established cities. Different cities face different opportunities and challenges in achieving carbon neutrality and should adopt differentiated strategies.

**Case 1****Cape Town—An Emerging City Expanding its "Low-Carbon Dividend"**

As the first city in Africa to establish a carbon neutrality target, Cape Town issued its 2050 Carbon Neutral Strategic Framework in 2020, formally committing to achieving carbon neutrality by 2050 and setting a phased reduction path: a 30% reduction in carbon emissions by 2030 from a 2015 baseline, and net-zero emissions by 2050. However, the implementation of its target is constrained by multiple factors. First, there are institutional conflicts between national and local energy policies; South Africa's coal-dominated energy structure limits the development space for renewable energy at the municipal level, resulting in Cape Town's current share of renewable energy capacity falling below 7%, lagging behind the framework's target. Second, transport mitigation faces the barrier of affordability for low-income groups. The high reliance on gasoline and diesel vehicles, which is 58%, leads to a low implementation rate for public electric vehicle retrofitting.

Therefore, Cape Town has explored a transition path suitable for its local context through institutional improvements and technological support. In the energy sector, the city government has begun piloting distributed solar PV systems in informal settlements, covering 5,000 low-income households, reducing their electricity costs by about 30%, and creating 200 local operation and maintenance jobs, forming a "low-carbon poverty reduction" model. In the transport sector, it has adopted a hybrid technology approach, retrofitting decommissioned diesel buses into electric vehicles at a 40% lower cost than new vehicles. Furthermore, carbon neutrality policies in Cape Town have already generated co-benefits, creating about 2,000 jobs in the new energy sector and attracting some international climate finance.

Cape Town's carbon neutrality practice shows that even under institutional and resource constraints, cities can achieve a win-win situation for climate goals and economic development through technological innovation and collaboration. This model has created a "low-starting-point, high-adaptability" transition template, demonstrating that low-carbon development is not limited to economically developed regions.



### Case 2

## Hangzhou—A Rapidly Growing City Leading Green Growth with Technological Innovation

As a dual benchmark city for China's digital economy and ecological civilization, Hangzhou released its Implementation Opinions on Comprehensively and Accurately Implementing the New Development Concept and Doing a Good Job in Carbon Peaking and Carbon Neutrality in 2022. It sets out a three-stage goal: achieving a 24% share of non-fossil fuel energy consumption by 2025, reaching a high-quality carbon peak by 2030 with a 75% reduction in CO<sub>2</sub> emissions per unit of GDP from 2005 levels, and becoming a leading zero-carbon city by 2060. This goal is deeply integrated with its positioning as the "Capital of Ecological Civilization" and aims to achieve high-quality development through green industrial upgrading, digital governance, and public participation. However, Hangzhou's transition faces multiple challenges: a continued reliance on traditional fuels in its energy mix, the dominance of high-energy-consuming industries such as chemical fibers and cement in its industrial carbon emissions, a high dependency on gasoline and diesel vehicles in the transport sector, and limitations on renewable energy promotion due to land resources and generation efficiency.

Facing these challenges, Hangzhou has explored a distinctive path through policy innovation and technological breakthroughs. In the energy sector, the 82 MW "fishery-solar hybrid" project in Qiantang District generates 90 million kWh of electricity annually, saving 715,000 metric tons of standard coal. The "whole-village PV" project in Qunwei Village, Xiaoshan District, has increased the collective economy's income, creating a "green electricity sharing with no land occupation" model. In terms of hydrogen energy, the nation's first hydrogen-electric coupled

**Box  
2****Urban Carbon Neutrality Progress and Experiences****Case 2**

"zero-carbon" park was built in Qiantang District, reducing carbon emissions by 860 metric tons annually and achieving efficient conversion of wind and solar resources through flexible DC technology. In industrial synergy, Yuhang District introduced a "carbon label" system, which increased the brand value of Jingshan tea by 3.569 billion RMB through carbon footprint traceability. Banzhang Town's Banshan Village became the nation's first "zero-carbon village," with a carbon credit mechanism promoting low-carbon tourism and leading to the establishment of dozens of new guesthouses. Furthermore, the Hangzhou Asian Games pioneered "digital fireworks" and a methanol-fueled main torch, achieving the first-ever carbon-neutral Games through green electricity supply and carbon offset, reducing emissions by 882,900 metric tons and attracting 1.1 million metric tons of carbon credits from 47 entities, covering 11 prefecture-level cities nationwide.

Hangzhou's practices have already shown multiple co-benefits: the scale of its green industry is rapidly expanding, with the dual-carbon industry cluster in Binjiang District attracting investments of over 100 billion RMB; in digital governance, the "Yuhang Carbon Eye" platform has integrated 252 data items to achieve precise regional pollution and carbon reduction management; and in terms of international influence, the experience of the Asian Games has been transformed into the Guidelines for Green and Low-Carbon Operation of Large-Scale Sporting Events, providing a "Hangzhou solution" for the world. Through "policy innovation + technological breakthrough + public participation," Hangzhou is creating a transition template for megacities that combines "digital governance, industrial upgrading, and institutional guarantees," proving that ecological protection and economic growth can be deeply integrated and offering a new paradigm for low-carbon development in high-density cities worldwide.



### Case 3

## Paris—An Established City Innovating "Stock Transformation"

As a benchmark city for global climate action, Paris first proposed its goal of achieving carbon neutrality by 2050 in the 2016 Paris Sustainable Development Report Overview. In 2018, its total emissions were approximately 22.7 million metric tons of CO<sub>2</sub> equivalent, an 11.3% decrease from 25.6 million metric tons in 2004.

Paris faces three major challenges in achieving its carbon neutrality goal. First, an aging building stock. 80% of the city's buildings were constructed before 1974, and their old structures pose technical limitations, while fragmented ownership, lack of funding, and inconsistent standards create management difficulties. Second, insufficient energy endowments. Constrained by land area, Paris's local renewable energy sources cannot meet the demands, and technologies including geothermal and hydrogen are still in the experimental stage. Third, high transport pressure. Over 50 million tourists annually contribute to a high carbon footprint from air and road transport, and the electrification of intra-city transport and its supporting infrastructure is urgently needed.

Faced with these dilemmas, many projects have provided innovative, context-specific solutions. The Clichy-Batignolles eco-district, through three-dimensional spatial reconstruction and technology integration, has built 7,500 housing units and a 10-hectare park on a former railway yard. It limits car space, prioritizes pedestrian and public transport networks, and is equipped with four schools, community gardens, and other facilities. The project's overall carbon emissions are 58% lower than traditional models, creating over 3,000 green jobs, increasing surrounding property values by 8-12%, and achieving a resident satisfaction rate of 92%. In 2016, the project won the International Green City Award, providing a global model for the redevelopment of old industrial sites and proving that carbon neutrality can be a strategic opportunity to reshape urban competitiveness.



### 3.4.2 Enterprises: Action Shifts from "Proactive Advancement" to "Robust Response"

In the decade since the adoption of the Paris Agreement, global enterprises have actively responded to the green and low-carbon transition trend, with the scale of their commitments growing exponentially. As of the end of 2023, over 4,200 companies had set emission reduction pathways consistent with the 1.5°C temperature goal under the Science Based Targets initiative (SBTi), whereas in 2015, when the initiative was founded, only a few dozen companies had made similar commitments.

However, over the past year, influenced by changes in the geopolitical, economic, and regulatory environment, corporate action is showing a strategic shift from "proactive advancement" to "robust response." In 2024, global climate finance cooperation initiatives such as the Principles for Responsible Investment (UN PRI) and the Glasgow Financial Alliance for Net Zero (GFANZ) both witnessed a decline in membership. For example, major US financial institutions such as JPMorgan Chase and BlackRock, facing rising domestic political pressure and regulatory uncertainty, chose to exit previously joined initiatives, shifting from formal commitments to voluntary disclosures. This phenomenon is not a simple backslide but reflects a trade-off and adjustment that enterprises are making between long-term sustainability goals and short-term operational pressures in a complex external environment.

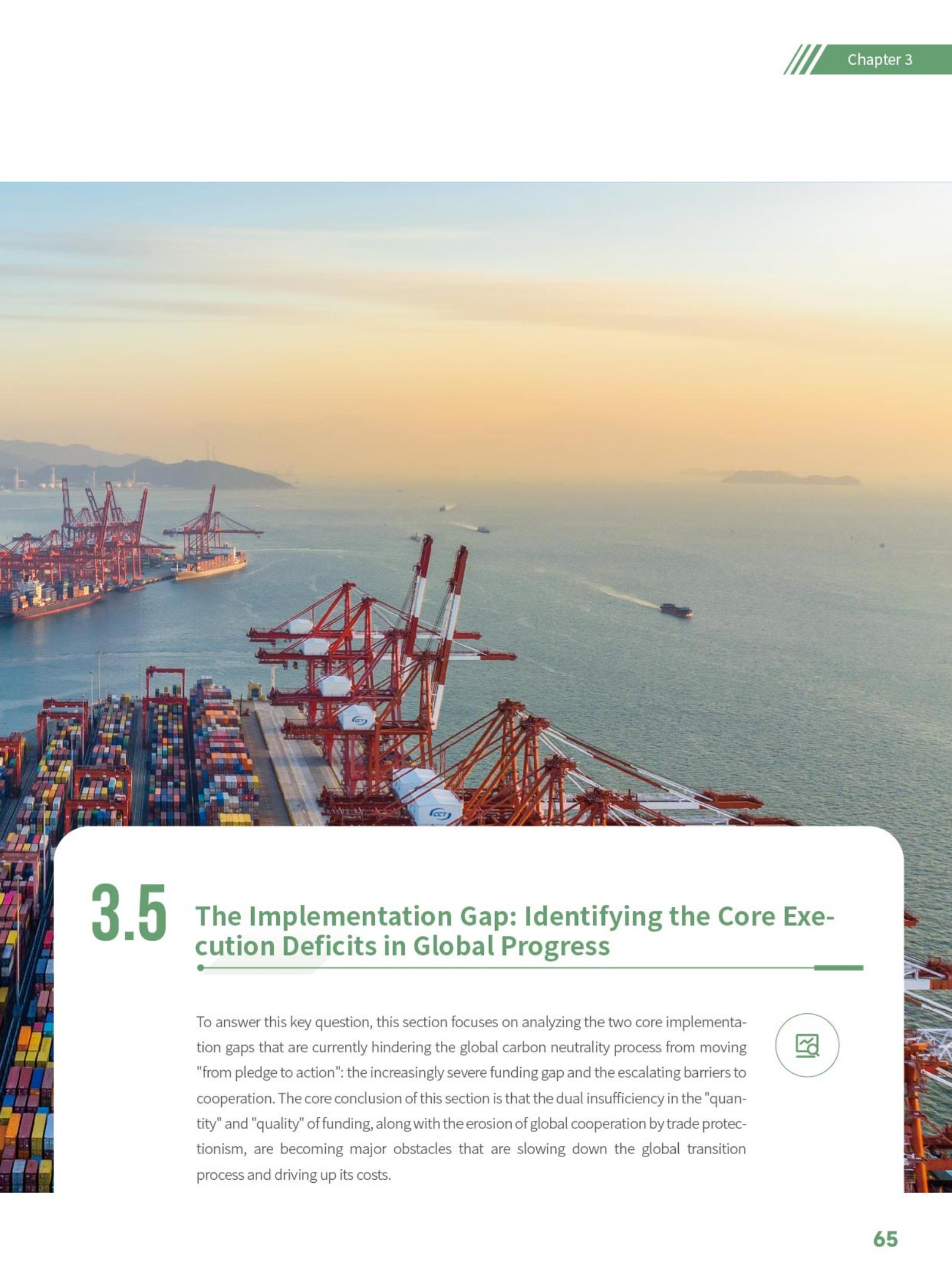
Despite some pullback in corporate action, the participation of companies from developed countries remains high, while the enthusiasm of companies from emerging Asian markets continues to rise, constituting a new driving force of the global climate finance. For example, among the companies that have signed up for SBTi, China is the developing country with the highest number of participants (629), ranking sixth globally, with India following behind.

# 4200

over 4,200 companies had set emission reduction pathways consistent

# 6

China is the developing country with the highest number of participants (629), ranking sixth globally



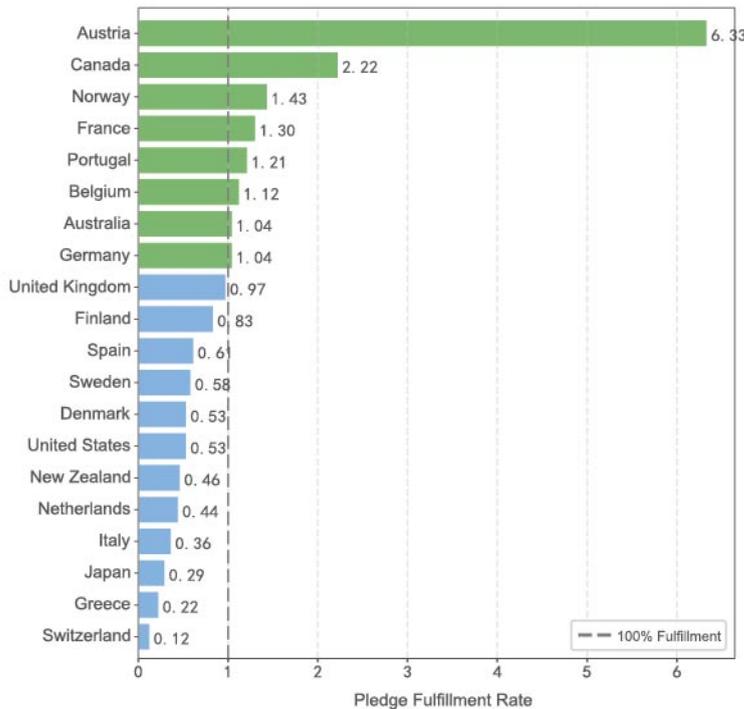
## 3.5 The Implementation Gap: Identifying the Core Execution Deficits in Global Progress

To answer this key question, this section focuses on analyzing the two core implementation gaps that are currently hindering the global carbon neutrality process from moving "from pledge to action": the increasingly severe funding gap and the escalating barriers to cooperation. The core conclusion of this section is that the dual insufficiency in the "quantity" and "quality" of funding, along with the erosion of global cooperation by trade protectionism, are becoming major obstacles that are slowing down the global transition process and driving up its costs.



### 3.5.1 Implementation Gap 1: The Increasingly Severe Funding Gap

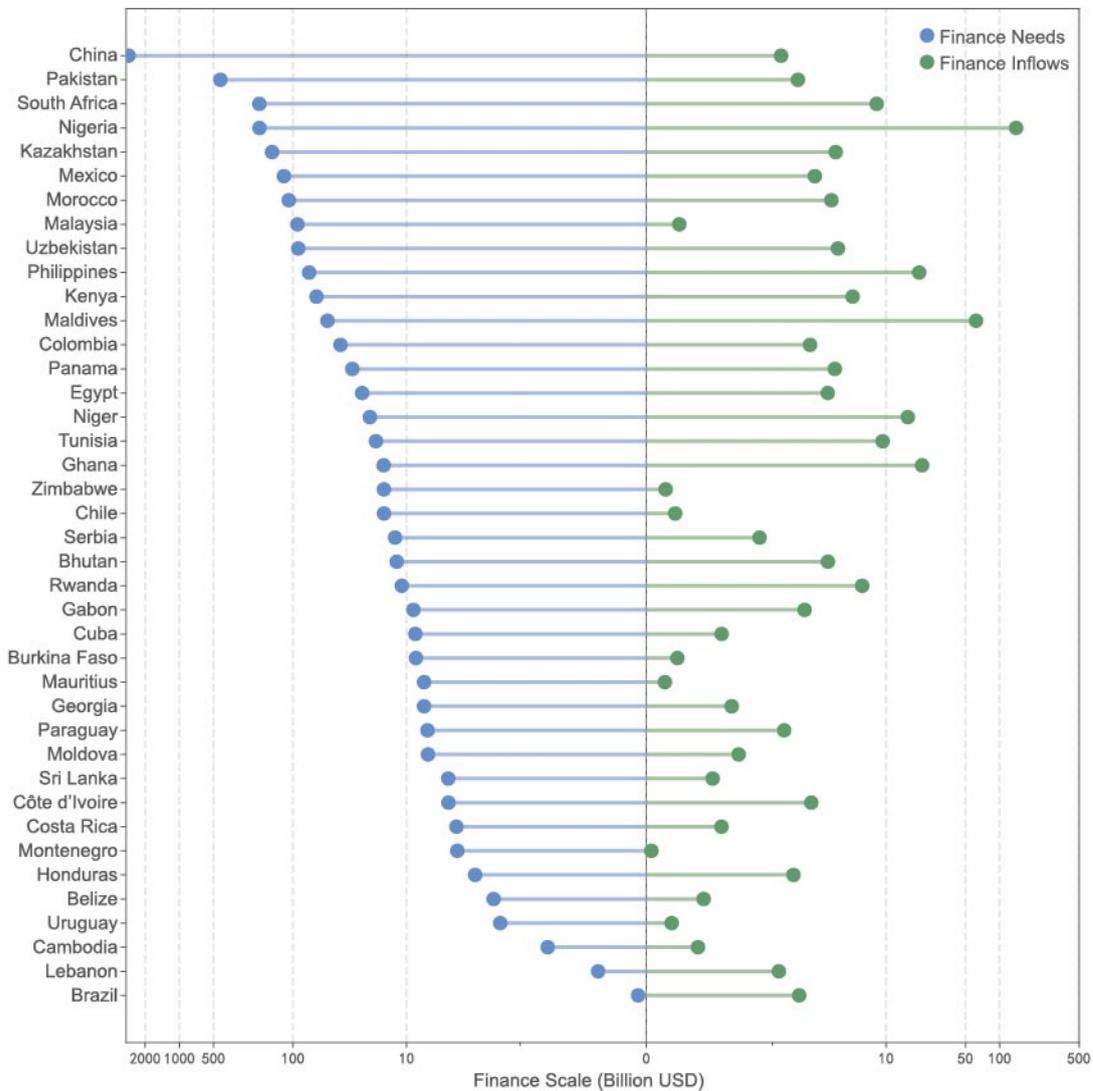
Although the scale of global climate finance has grown rapidly since 2015, the funding gap continues to widen when compared to the huge transition needs and the funding commitments of developed countries. Since 2015, global climate finance flows have nearly tripled to about \$1.3 trillion, and the issuance of green bonds has increased more than tenfold to \$587.6 billion. The scale of international multilateral climate finance has also doubled, reaching \$101.3 billion. However, this growth is far from sufficient to meet the transition needs. To achieve the goals of the Paris Agreement, annual global climate finance needs to increase by five fold from the 2021/2022 levels. Deficiencies in policy frameworks, financing environments, and implementation capacities in some developing countries have constrained the effective mobilization and use of funds, while the delayed fulfillment of funding commitments by developed countries is one of the core reasons for this gap. Based on the funding trend from 2021-2022, the annual contribution by 2035 would only reach 43% of the \$300 billion target set at COP29. To achieve the established goal, an average annual funding growth rate of 16% must be maintained over the next decade (Figure 3.10). Currently, only 8 developed countries have met their 2025 funding commitments, while countries such as Greece and Switzerland have a completion rate of less than 25%. The renewed withdrawal of the United States from the Paris Agreement also puts greater pressure on achieving the overall funding goal.



Note: Data on developed country finance pledges are sourced from the Second biennial communications in accordance with Article 9, paragraph 5, of the Paris Agreement: Compilation and synthesis report by the secretariat (standardized to 2025, with linear extrapolation where data are unavailable), while actual finance contributions are drawn from Parties' first Biennial Transparency Reports.

Figure 3.10 Comparison of international climate finance contributions from developed countries with targets.

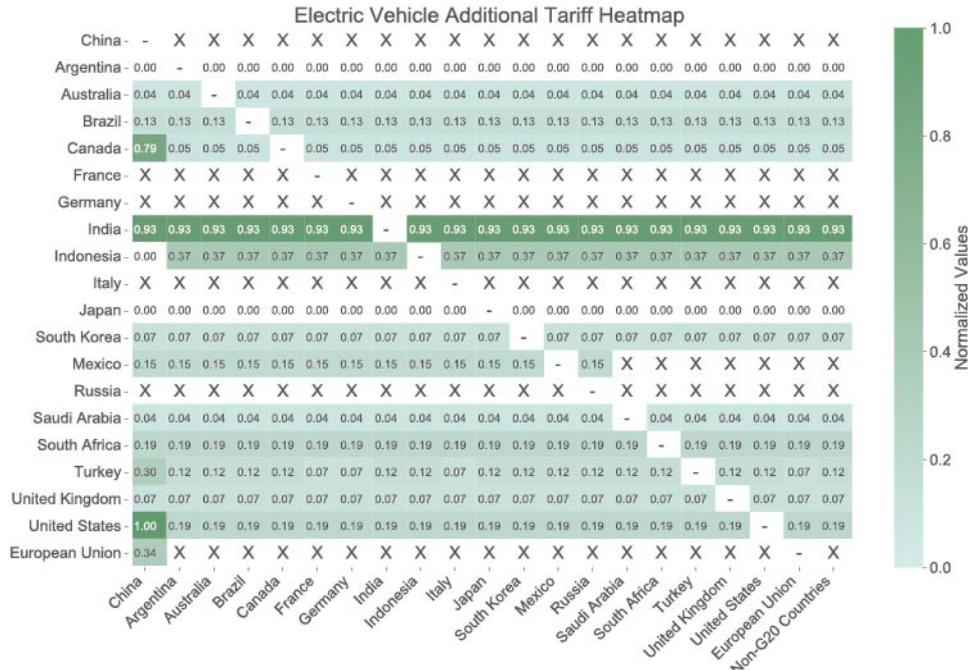
This funding gap directly leads to a significant imbalance in North-South financial flows, severely constraining the climate action capacity of developing countries. According to data disclosed by developing countries in their biennial transparency reports, their total annual funding needs are approximately \$470 billion, but the international climate finance they actually receive is about \$350 billion, meeting only 8% of their needs. The climate actions of the least developed countries and small island developing states are highly dependent on international aid, which is often double-accounted as climate finance, making it imperative to further ensure additionality and expand the scale of international climate finance.



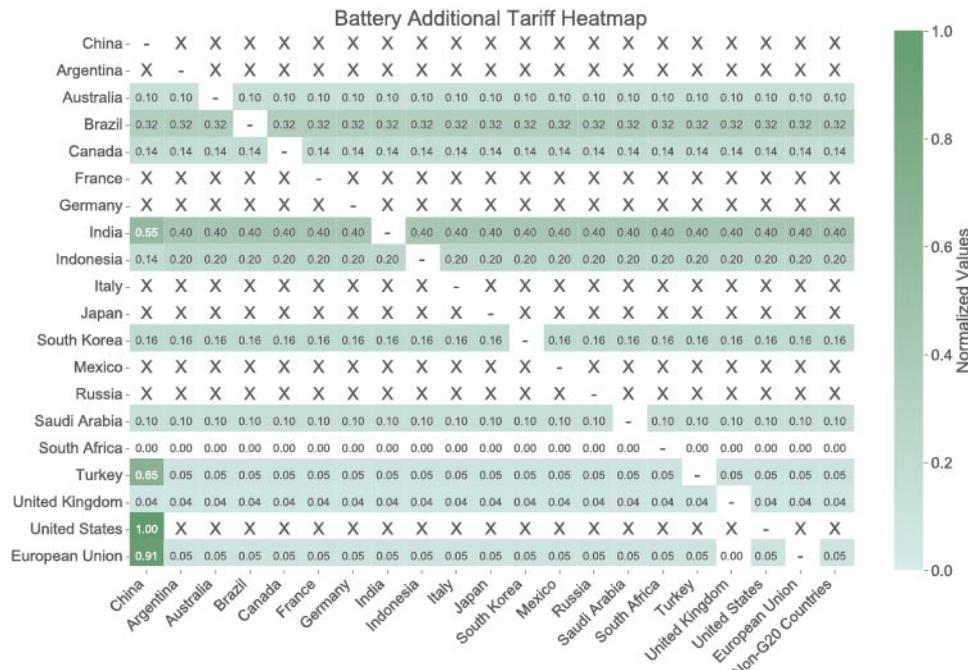
**Figure 3.11 Comparison of annual funding needs and inflows for developing countries.**

Note: Data is from the first biennial transparency reports of developed countries. Brazil's funding needs only include projects from the "Technical Needs Assessment for Brazil's Climate Action Plan (TNA\_BRAZIL)".





(b)



(c)

Figure 3.12 (a) Wind/solar, (b) new energy vehicle, and (c) battery sector additional tariff heatmaps. (data through 2025.5)

Note: The figure shows the additional tariffs imposed by G20 countries on other G20 countries and the rest of the world in three new energy-related industries. The values are the normalized results of the additional tariffs faced by each country in each industry, representing the relative magnitude of the additional tariffs.

# 04

Chapter 4

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## Conclusions and Policy Rec- ommendations

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# 4.1 Key Conclusions: A Structurally Imbalanced Transition

A decade after the Paris Agreement's adoption, the global low-carbon transition has become a central guide for socio-economic development and policymaking in countries worldwide. However, recent short-term geopolitical disturbances have created turbulence in the transition process, leading to fluctuating public perception. This report seeks to penetrate these surface signals through systematic assessment. Based on quantitative models and a comprehensive indicator system, it clearly demonstrates that global carbon neutrality has evolved from a preliminary vision a decade ago into an irreversible structural transition.

The resilience of this transition becomes particularly evident when contrasted with the short-term fluctuations of the past year. On one hand, the consensus on pursuing net-zero has cascaded from the national level down to cities and businesses. Since 2015, the number of countries with carbon neutrality targets has surged from a single nation to 165. Even amidst the "headwinds" of a major country withdrawing from the agreement, this number still saw a net increase over the past year (from 162 to 165). Simultaneously, 303 cities and over 4,200 companies (through SBTi) have made commitments, solidifying the foundation of the transition. The innovation and deployment of low-carbon technologies continue to be the backbone of the global carbon neutrality transition. Renewable energy has crossed the cost "tipping point" against fossil fuels: the global levelized cost of electricity (LCOE) for onshore wind and solar PV has dropped to \$0.033/kWh and \$0.044/kWh, respectively, far below the cost range of fossil fuels. Even as some countries waver on their fossil fuel transition, the

## 165

the number of countries with carbon neutrality targets has surged

## 4200

over 4,200 companies (through SBTi) have made commitments



deployment of renewables continues to accelerate, driven by market forces. An update to the growth rate forecast from 2023 to 2024 caused the projection for 2030 renewable energy capacity to leap from 2.19 times the baseline to 2.65 times. Therefore, while the path of transition will not be smooth, its long-term positive fundamentals are becoming increasingly solid. These data-supported structural advances are the core source of confidence for accelerating global climate action over the next decade.

However, this report also finds that global carbon neutrality progress exhibits a profound structural imbalance. From the horizontal perspective of driving forces, target enhancement and technological innovation constitute the two core forward drivers of the global transition. Conversely, the lagging progress in climate finance and international cooperation forms the two key bottlenecks slowing down the global process. This imbalance is clearly reflected in the vertical chain of "Target-Policy-Action-Effectiveness": the continuous improvement of targets and policies has not been effectively transmitted to the action and effectiveness levels, ultimately leading to a widening implementation gap. Specifically, this gap manifests on three levels :

01

### The Target Ambition Gap

The emission reduction ambition of the currently submitted Nationally Determined Contributions (NDCs) is far from sufficient to achieve the temperature goals of the Paris Agreement. If countries fully implement their NDCs, the global emission reduction by 2035 would only be 4%-13%, and there is a lack of consistency between countries' short-term targets and their own long-term net-zero goals.



02

### The Technology Action Gap

Although the development of renewable electricity is strong, there is a huge deployment gap in other key technology areas. An analysis of seven key technologies shows that as of 2024, the deployment scale of technologies such as clean hydrogen and CCUS has only reached between 1% and 42% of what is needed to meet their 2030 targets, with some technologies requiring an 8-fold increase in deployment speed.

03

### The International Cooperation and Climate Finance Action Gap

At the international cooperation level, increasing trade barriers in the new energy sector are driving up global transition costs, adding an estimated \$130 billion to the cost of achieving the "tripling renewables" target and doubling energy efficiency by 2030. In climate finance, developed countries have failed to effectively deliver on their international climate finance commitments; on current trends, their contributions by 2035 will only reach 43% of the \$300 billion target set at COP29.



## 4.2 Policy Recommendations for Accelerating Global Action

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Based on the above conclusions, to effectively close the implementation gap and advance the global carbon neutrality process from pledges to actions, this report calls for a concerted global effort to amplify the two core forward drivers—target enhancement and technological innovation—while concentrating on unblocking the two key bottlenecks—climate finance and international cooperation. The following are three targeted recommendations:



## 1. Amplify the Forward Drivers: Deepen Target Consensus and Inject New Momentum into the Technology Engine.

### From "Breadth" to "Depth": Deepen Global Target Consensus.

The global coverage of carbon neutrality targets is nearing saturation. The core task ahead is to enhance their "depth" and "credibility." All countries, especially developed nations with greater historical responsibility and capacity, should significantly strengthen the emission reduction ambition of their 2035 NDCs, ensuring their pathways are aligned with the temperature goals of the Paris Agreement. At the same time, it is essential to ensure consistency between medium-term targets (NDCs) and national long-term carbon neutrality strategies (LT-LEDS) to avoid a disconnect where "long-term slogans are loud, but short-term actions are weak." This will transform the macro-consensus into binding and executable action roadmaps.



### A Differentiated Approach to Inject New Momentum into the Technology Engine.

Technology is a core driver, but its development is significantly differentiated, requiring tailored policies. For mature technologies such as renewable energy and electric vehicles, which have entered a market-driven breakout phase, the international community should focus on reducing trade barriers, lowering international cooperation costs, strengthening supply chain coordination, and increasing aid and support to emerging markets to clear the path for their accelerated global adoption. For emerging technologies such as clean hydrogen and CCUS, which are still in the early stages of development, it is necessary to increase R&D support, expand direct investment, and establish pilot projects to create valuable initial markets and application scenarios, helping them cross the critical chasm from "technological breakthrough" to "market breakout."



## 2. Unblock the Lagging Links: Break the Finance Deadlock and Rebuild Mutual Trust in International Cooperation.

### Ensure the Quantity and Quality of Climate Finance to Break the Deadlock.

First, developed countries must translate their commitments into concrete actions. They must not only fulfill their annual financial support commitments to developing countries in full but also focus on improving the quality of funds, such as by increasing the proportion of grants and concessional loans, to ensure that funds flow to areas that can generate the most effective emission reductions. Second, the global financial architecture needs further reform to address the challenges faced by developing countries, such as high financing costs and cumbersome application processes, making financial support more accessible and equitable.



### Innovate Cooperation Models and Enhance Transparency to Strengthen International Mutual Trust.

On one hand, the international community should actively recognize and support the emerging diverse cooperation models to build a more resilient global climate governance network. Encouragingly, new cooperation models are already emerging and showing great potential, such as city-led "green shipping corridors," cross-border industrial chain cooperation driven by corporate investment, and the international carbon market mechanism under Article 6 of the Paris Agreement, which is entering a new phase after COP29 (see Box 3). On the other hand, countries must jointly resist green trade protectionism and oppose "beggar-thy-neighbor" unilateralist thinking.





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### **Establish a Global Transparency Platform and Strengthen Progress-Tracking Infrastructure.**



To fundamentally address the lack of trust and resource misallocation caused by information asymmetry, the international community should encourage and support more independent third-party institutions to conduct broader data collection and sharing, especially for currently lacking action data (such as data on financial needs and actions, and policy action data from less-developed and non-English-speaking countries). This will not only help countries clarify their own needs and send clear signals to the market but also provide solid data support for the Global Stocktake under the Paris Agreement, thereby improving the public governance infrastructure for accelerating the global carbon neutrality process.

**Box  
3****Diverse Cooperation Models Inject New Momentum into Global Climate Governance****Case 1****Shanghai-Los Angeles "Green Shipping Corridor"—Inter-city Cooperation Drives Low-Carbon Transition in the Shipping Supply Chain**

Shanghai plans to achieve carbon neutrality by 2060, and California plans to achieve net-zero emissions by 2045. In January 2022, the ports of Shanghai and Los Angeles jointly initiated the establishment of a "Green Shipping Corridor," with plans to deploy ships with low-carbon/zero-carbon life cycles starting in 2025 and to demonstrate the feasibility of the world's first full life-cycle zero-emission container ship/fleet by 2030. This city-led cooperation is leveraging the entire shipping supply chain to drive systemic emission reductions in global shipping.

In the shipping sector, the ships themselves account for about 60% of emissions, while land-based transport and port operations account for the remaining 40%. Therefore, the "Green Shipping Corridor" initiative requires not only the deployment of electric or green-fueled ships but also the synergy of various clean technologies such as shore power facilities, port electrification, and intelligent systems, effectively driving technological innovation across the entire supply chain. Its implementation also requires the concerted efforts of governments, ports, shipping companies, and cargo owners, providing replicable management experience for other ports worldwide. As of October 2024, there were 62 "Green Shipping Corridors" globally, an increase of 18 from the previous year, with Chinese cities participating in 5 of them.





## Case 2

## Chinese Automakers Investing in Thailand—Cross-border Corporate Action Drives Green Industrial Chain Development in the Host Country

Cross-border corporations, in their pursuit of optimal resource allocation, will also drive cross-border green investment through their own actions, indirectly fostering cross-border low-carbon cooperation. Chinese companies' overseas clean energy investments cover major areas such as wind power, solar PV, and hydropower, helping other countries achieve their emission reduction targets, creating new industries and jobs, and promoting common development and prosperity.

The Thai government, to achieve its goal of "50% electric vehicle sales by 2030," has introduced incentive policies such as EV3.0 and EV3.5. Spurred by these policies, 7 Chinese automakers have already invested in building factories in Thailand, with a planned capacity of over 600,000 vehicles, bringing \$1.44 billion in investment to the local economy. More importantly, the investment of these vehicle manufacturers has driven 153 Chinese supporting companies in auto parts, vehicle batteries, and charging piles to establish a presence in Thailand, building a complete industrial infrastructure ecosystem for Thailand's low-carbon transport transition.



## Case 3

## Implementation of Paris Agreement Article 6 Rules—A Global Unified Carbon Market Mechanism Promotes International Emission Reduction Cooperation

The COP29 conference in Baku finalized the implementation rules for the carbon market under Article 6 of the Paris Agreement, clearing the institutional hurdles for countries to cooperate in a unified carbon market under the agreement, which will inject new momentum into international cooperation on carbon neutrality. As of May 2025, a total of 60 countries have signed 98 bilateral cooperation agreements under Article 6.2 "cooperative approaches," including 56 bilateral memorandums of understanding and 32 bilateral agreements, with more than half of them signed in the last three years.

At the same time, over the past three years, 99 countries have submitted notifications of prior consideration to participate in the Paris Agreement's crediting mechanism (i.e., Article 6.4 mechanism), involving 1,113 cooperative emission reduction projects with an annual reduction scale of 915 million metric tons, accounting for 2% of global emissions in 2023, reflecting the strong willingness of countries to participate in cooperation. It is noteworthy that 89% of these emission reductions occur in low- and lower-middle-income countries, indicating that the international carbon market under the Paris Agreement has the potential to become a new mechanism that not only promotes emission reductions in developing countries but also brings them economic benefits.

# Appendix A

## The CN-Tracker Database Indicator System

Theme	L1 ID	L1 Indicator	L2 ID	L2 Indicator	L3 Indicator
Target	1.1	Target	1.1.1	Carbon Neutrality Target	Target type
Target	1.1	Target	1.1.1	Carbon Neutrality Target	Target year
Target	1.2	Scope	1.2.1	Sectoral Coverage	Covers international aviation
Target	1.2	Scope	1.2.1	Sectoral Coverage	Covers international shipping
Target	1.2	Scope	1.2.2	GHG Coverage	GHG coverage
Target	1.2	Scope	1.2.3	Covers Consumption-side Emissions	Covers consumption-side emissions
Target	1.2	Scope	1.2.4	Covers Full Territorial Emissions	Covers full territorial emissions
Target	1.3	Regulatory System	1.3.1	Legal Completeness	Target legislation status
Target	1.3	Regulatory System	1.3.2	Regulatory Mechanism	Review and reporting system
Target	1.3	Regulatory System	1.3.2	Regulatory Mechanism	Accountability system
Target	1.3	Regulatory System	1.3.3	Legal Action	Number of climate change laws
Target	1.3	Regulatory System	1.3.3	Legal Action	Number of climate change litigation cases
Target	1.3	Regulatory System	1.3.4	Effectiveness/Reliability	Separate carbon removal target
Target	1.3	Regulatory System	1.3.4	Effectiveness/Reliability	Planned use of carbon credits
Target	1.4	Specific Roadmap	1.4.1	Phased Targets	Mid-term target year
Target	1.4	Specific Roadmap	1.4.1	Phased Targets	Mid-term target text
Target	1.4	Specific Roadmap	1.4.1	Phased Targets	Mid-term target type
Target	1.4	Specific Roadmap	1.4.1	Phased Targets	Has mid-term target
Target	1.4	Specific Roadmap	1.4.2	National Planning	Has detailed plan
Target	1.4	Specific Roadmap	1.4.2	National Planning	Overview of detailed plan
Target	1.4	Specific Roadmap	1.4.3	Sectoral Targets	Transport

Theme	L1 ID	L1 Indicator	L2 ID	L2 Indicator	L3 Indicator
Target	1.4	Specific Roadmap	1.4.3	Sectoral Targets	Other
Target	1.4	Specific Roadmap	1.4.3	Sectoral Targets	Agriculture
Target	1.4	Specific Roadmap	1.4.3	Sectoral Targets	Land use and forestry
Target	1.4	Specific Roadmap	1.4.3	Sectoral Targets	Industry
Target	1.4	Specific Roadmap	1.4.3	Sectoral Targets	Waste
Target	1.4	Specific Roadmap	1.4.3	Sectoral Targets	Buildings
Target	1.4	Specific Roadmap	1.4.3	Sectoral Targets	Methane
Target	1.4	Specific Roadmap	1.4.3	Sectoral Targets	Power
Target	1.5	Fairness & Consistency	1.5.1	Fairness	Mentions fairness
Target	1.5	Fairness & Consistency	1.5.1	Fairness	Explains fairness explicitly
Target	1.5	Fairness & Consistency	1.5.2	Consistency	Number of fairness principles met for 1.5°C target
Target	1.5	Fairness & Consistency	1.5.2	Consistency	Number of fairness principles met for 2.0°C target
Technology	2.1	Renewable Energy Power	2.1.1	Target Ambition	Share of renewable energy generation in total generation
Technology	2.1	Renewable Energy Power	2.1.2	Support Policy	Mandatory policy: Mandate
Technology	2.1	Renewable Energy Power	2.1.2	Support Policy	Mandatory policy: Standard
Technology	2.1	Renewable Energy Power	2.1.2	Support Policy	Incentive policy: Market mechanism
Technology	2.1	Renewable Energy Power	2.1.2	Support Policy	Incentive policy: Tax/credit
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of generation by tech: Solar
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of generation by tech: Hydro
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of generation by tech: Biomass
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of generation by tech: Wind
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of capacity by tech: Solar
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of capacity by tech: Hydro
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of capacity by tech: Biomass
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of capacity by tech: Wind
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of renewable energy generation
Technology	2.1	Renewable Energy Power	2.1.3	Deployment Progress	Share of renewable energy capacity
Technology	2.1	Renewable Energy Power	2.1.4	Technology Innovation	Web of Science publications on "renewable energy generation"

Theme	L1 ID	L1 Indicator	L2 ID	L2 Indicator	L3 Indicator
Technology	2.1	Renewable Energy Power	2.1.4	Technology Innovation	IncoPat patents on "renewable energy generation"
Technology	2.1	Renewable Energy Power	2.1.4	Technology Innovation	Solar PV LCOE
Technology	2.1	Renewable Energy Power	2.1.4	Technology Innovation	Total installed cost: Solar PV
Technology	2.1	Renewable Energy Power	2.1.4	Technology Innovation	Total installed cost: Onshore wind
Technology	2.1	Renewable Energy Power	2.1.4	Technology Innovation	Onshore wind LCOE
Technology	2.2	Electric Vehicles	2.2.1	Target Ambition	EV stock share target
Technology	2.2	Electric Vehicles	2.2.1	Target Ambition	EV stock target
Technology	2.2	Electric Vehicles	2.2.1	Target Ambition	EV sales share target
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Mandatory: Mandate
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Mandatory: Standard
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Incentive: Credit
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Incentive: Fund
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Incentive: Market mechanism
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Incentive: Investment
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Incentive: Tax credit
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Incentive: Inclusion in NDC
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Incentive: Subsidy
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Incentive: Pilot project
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Enabling: Supply chain development
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Enabling: Optimized management
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Enabling: International cooperation
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Enabling: R&D support
Technology	2.2	Electric Vehicles	2.2.2	Support Policy	Enabling: Public awareness
Technology	2.2	Electric Vehicles	2.2.3	Deployment Progress	PHEV stock
Technology	2.2	Electric Vehicles	2.2.3	Deployment Progress	PHEV sales
Technology	2.2	Electric Vehicles	2.2.3	Deployment Progress	FCEV stock
Technology	2.2	Electric Vehicles	2.2.3	Deployment Progress	FCEV sales
Technology	2.2	Electric Vehicles	2.2.3	Deployment Progress	EV stock share

Theme	L1 ID	L1 Indicator	L2 ID	L2 Indicator	L3 Indicator
Technology	2.2	Electric Vehicles	2.2.3	Deployment Progress	EV sales share
Technology	2.2	Electric Vehicles	2.2.3	Deployment Progress	BEV sales
Technology	2.2	Electric Vehicles	2.2.3	Deployment Progress	BEV stock
Technology	2.2	Electric Vehicles	2.2.4	Technology Innovation	New patents
Technology	2.2	Electric Vehicles	2.2.4	Technology Innovation	EV patents
Technology	2.2	Electric Vehicles	2.2.4	Technology Innovation	Publications
Technology	2.3	Energy Saving & Efficiency	2.3.1	Target Ambition	Development target in policy documents
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Solar water heater incentive: Subsidy
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump mandatory: Mandate
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump mandatory: Standard
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump incentive: Credit
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump incentive: Market mechanism
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump incentive: Investment
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump incentive: Subsidy
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump enabling: Supply chain development
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump enabling: International cooperation
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump enabling: R&D support
Technology	2.3	Energy Saving & Efficiency	2.3.2	Support Policy	Heat pump enabling: Public awareness
Technology	2.3	Energy Saving & Efficiency	2.3.3	Deployment Progress	Heat pump market share
Technology	2.3	Energy Saving & Efficiency	2.3.3	Deployment Progress	Heat pump sales
Technology	2.3	Energy Saving & Efficiency	2.3.4	Technology Innovation	Patents
Technology	2.3	Energy Saving & Efficiency	2.3.4	Technology Innovation	Solar water heater consumer cost
Technology	2.3	Energy Saving & Efficiency	2.3.4	Technology Innovation	Heat pump capital expenditure
Technology	2.3	Energy Saving & Efficiency	2.3.4	Technology Innovation	Heat pump operational expenditure
Technology	2.3	Energy Saving & Efficiency	2.3.4	Technology Innovation	Publications
Technology	2.4	Biofuels	2.4.1	Target Ambition	Fuel ethanol blending target
Technology	2.4	Biofuels	2.4.1	Target Ambition	Fuel ethanol blending target year
Technology	2.4	Biofuels	2.4.1	Target Ambition	Biodiesel blending target
Technology	2.4	Biofuels	2.4.1	Target Ambition	Biodiesel blending target year
Technology	2.4	Biofuels	2.4.1	Target Ambition	Biodiesel blending target year (achieved)

Theme	L1 ID	L1 Indicator	L2 ID	L2 Indicator	L3 Indicator
Technology	2.4	Biofuels	2.4.1	Target Ambition	Biodiesel blending target (achieved by 2010, no new target)
Technology	2.4	Biofuels	2.4.2	Support Policy	Optimized management
Technology	2.4	Biofuels	2.4.2	Support Policy	Supply chain development
Technology	2.4	Biofuels	2.4.2	Support Policy	Credit
Technology	2.4	Biofuels	2.4.2	Support Policy	Mandate
Technology	2.4	Biofuels	2.4.2	Support Policy	International cooperation
Technology	2.4	Biofuels	2.4.2	Support Policy	Fund
Technology	2.4	Biofuels	2.4.2	Support Policy	Market mechanism
Technology	2.4	Biofuels	2.4.2	Support Policy	Investment
Technology	2.4	Biofuels	2.4.2	Support Policy	Standard
Technology	2.4	Biofuels	2.4.2	Support Policy	Fuel ethanol mandate
Technology	2.4	Biofuels	2.4.2	Support Policy	Biodiesel mandate
Technology	2.4	Biofuels	2.4.2	Support Policy	R&D support
Technology	2.4	Biofuels	2.4.2	Support Policy	Tax credit
Technology	2.4	Biofuels	2.4.2	Support Policy	Inclusion in NDC
Technology	2.4	Biofuels	2.4.2	Support Policy	Subsidy
Technology	2.4	Biofuels	2.4.2	Support Policy	Pilot project
Technology	2.4	Biofuels	2.4.2	Support Policy	Public awareness
Technology	2.4	Biofuels	2.4.3	Deployment Progress	Fuel ethanol consumption
Technology	2.4	Biofuels	2.4.3	Deployment Progress	Fuel ethanol production
Technology	2.4	Biofuels	2.4.3	Deployment Progress	Biodiesel consumption
Technology	2.4	Biofuels	2.4.3	Deployment Progress	Biodiesel production
Technology	2.4	Biofuels	2.4.4	Technology Innovation	Patents
Technology	2.4	Biofuels	2.4.4	Technology Innovation	Fuel ethanol producer price
Technology	2.4	Biofuels	2.4.4	Technology Innovation	Biodiesel producer price
Technology	2.4	Biofuels	2.4.4	Technology Innovation	Publications
Technology	2.5	CCUS	2.5.1	Target Ambition	Technology positioning/development target in policy documents
Technology	2.5	CCUS	2.5.2	Support Policy	Joined Carbon Management Challenge (CMC)

Theme	L1 ID	L1 Indicator	L2 ID	L2 Indicator	L3 Indicator
Technology	2.5	CCUS	2.5.2	Support Policy	Mandatory: Mandate
Technology	2.5	CCUS	2.5.2	Support Policy	Mandatory: Standard
Technology	2.5	CCUS	2.5.2	Support Policy	Government funding support
Technology	2.5	CCUS	2.5.2	Support Policy	Regulatory framework development
Technology	2.5	CCUS	2.5.2	Support Policy	Incentive: Fund
Technology	2.5	CCUS	2.5.2	Support Policy	Incentive: Market mechanism
Technology	2.5	CCUS	2.5.2	Support Policy	Incentive: Investment
Technology	2.5	CCUS	2.5.2	Support Policy	Incentive: Tax credit
Technology	2.5	CCUS	2.5.2	Support Policy	Incentive: Subsidy
Technology	2.5	CCUS	2.5.2	Support Policy	Incentive: Pilot project
Technology	2.5	CCUS	2.5.2	Support Policy	R&D support
Technology	2.5	CCUS	2.5.2	Support Policy	Tax credit/carbon market
Technology	2.5	CCUS	2.5.2	Support Policy	Inclusion in NDC under Paris Agreement
Technology	2.5	CCUS	2.5.2	Support Policy	Pilot project support
Technology	2.5	CCUS	2.5.2	Support Policy	Enabling: Optimized management
Technology	2.5	CCUS	2.5.2	Support Policy	Enabling: International cooperation
Technology	2.5	CCUS	2.5.2	Support Policy	Enabling: Public awareness
Technology	2.5	CCUS	2.5.3	Deployment Progress	Number of planned projects
Technology	2.5	CCUS	2.5.3	Deployment Progress	Number of operational CCS projects
Technology	2.5	CCUS	2.5.4	Technology Innovation	New patents
Technology	2.5	CCUS	2.5.4	Technology Innovation	Publications
Technology	2.6	Clean Hydrogen	2.6.1	Target Ambition	Electrolysis production capacity
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Mandatory: Mandate
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Mandatory: Standard
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Incentive: Fund
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Incentive: Investment
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Incentive: Tax credit
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Incentive: Subsidy
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Incentive: Pilot project
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Enabling: Supply chain development
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Enabling: Optimized management

Theme	L1 ID	L1 Indicator	L2 ID	L2 Indicator	L3 Indicator
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Enabling: International cooperation
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Enabling: R&D support
Technology	2.6	Clean Hydrogen	2.6.2	Support Policy	Enabling: Public awareness
Technology	2.6	Clean Hydrogen	2.6.3	Deployment Progress	Green hydrogen production
Technology	2.6	Clean Hydrogen	2.6.3	Deployment Progress	Number of green hydrogen projects
Technology	2.6	Clean Hydrogen	2.6.3	Deployment Progress	Blue hydrogen production
Technology	2.6	Clean Hydrogen	2.6.3	Deployment Progress	Number of blue hydrogen projects
Technology	2.6	Clean Hydrogen	2.6.4	Technology Innovation	Patents
Technology	2.6	Clean Hydrogen	2.6.4	Technology Innovation	Publications
Technology	2.7	Forest Carbon Sinks	2.7.1	Target Ambition	Target ambition
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Mandatory: Mandate
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Mandatory: Standard
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Incentive: Pilot project
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Incentive: Credit
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Incentive: Fund
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Incentive: Market mechanism
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Incentive: Investment
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Incentive: Tax credit
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Incentive: Subsidy
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Enabling: Optimized management
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Enabling: Supply chain development
Technology	2.7	Forest Carbon Sinks	2.7.2	Support Policy	Enabling: International cooperation
Technology	2.7	Forest Carbon Sink	2.7.3	Market Progress	Forest Carbon Sink Volume
Technology	2.7	Forest Carbon Sink	2.7.4	Technology Innovation	Number of Patents
Technology	2.7	Forest Carbon Sink	2.7.4	Technology Innovation	Number of Papers
Climate Investment and Finance	3.1	Policy Progress	3.1.1	Climate Investment and Finance Commitment Declaration	Whether Countries' LT-LEDS Mention Climate Investment and Finance
Climate Investment and Finance	3.1	Policy Progress	3.1.1	Climate Investment and Finance Commitment Declaration	Whether Countries' NDC Mention Climate Investment and Finance

Theme	L1 ID	L1 Indicator	L2 ID	L2 Indicator	L3 Indicator
Climate Investment and Finance	3.1	Policy Progress	3.1.1	Climate Investment and Finance Commitment Declaration	Latest Release Date of Countries' NDC
Climate Investment and Finance	3.1	Policy Progress	3.1.1	Climate Investment and Finance Commitment Declaration	Latest Release Date of Countries' LT-LEDS
Climate Investment and Finance	3.1	Policy Progress	3.1.2	Climate Investment and Finance Support Policies	Whether Climate-Related Financial Risk Assessment is Conducted
Climate Investment and Finance	3.1	Policy Progress	3.1.2	Climate Investment and Finance Support Policies	Whether Climate-Related Financial Risk Disclosure is Mandatory
Climate Investment and Finance	3.1	Policy Progress	3.1.2	Climate Investment and Finance Support Policies	Domestic Carbon Emission Coverage Rate of Carbon Pricing Mechanism
Climate Investment and Finance	3.1	Policy Progress	3.1.3	Domestic Climate Investment and Finance Action Progress	Scale of Countries' Fiscal Budget for Climate Actions
Climate Investment and Finance	3.2	Action Progress	3.2.1	Domestic Climate Investment and Finance Action Progress	Green Bond Issuance Volume
Climate Investment and Finance	3.2	Action Progress	3.2.2	International Climate Investment and Finance Action Progress	Number of Institutions Joining Climate Action 100 by Countries
Climate Investment and Finance	3.2	Action Progress	3.2.2	International Climate Investment and Finance Action Progress	Number of Institutions Joining GFANZ by Countries
Climate Investment and Finance	3.2	Action Progress	3.2.2	International Climate Investment and Finance Action Progress	Number of Institutions Joining SBTi by Countries
Climate Investment and Finance	3.2	Action Progress	3.2.2	International Climate Investment and Finance Action Progress	Number of Institutions Signing UN PRI by Countries
Climate Investment and Finance	3.2	Action Progress	3.2.2	International Climate Investment and Finance Action Progress	Annual Climate Fund Receipt by Developing Countries
Climate Investment and Finance	3.2	Action Progress	3.2.2	International Climate Investment and Finance Action Progress	Annual Climate Fund Demand by Developing Countries
Climate Investment and Finance	3.2	Action Progress	3.2.2	International Climate Investment and Finance Action Progress	International Climate Fund Contribution Scale by Developed Countries
Climate Investment and Finance	3.2	Action Progress	3.2.2	International Climate Investment and Finance Action Progress	Number of International Carbon Credit Projects
International Cooperation	4.1	Foreign Aid	4.1.1	Foreign Technology Transfer Project Status	Amount of Funding
International Cooperation	4.1	Foreign Aid	4.1.1	Foreign Technology Transfer Project Status	Project Transparency Score
International Cooperation	4.1	Foreign Aid	4.1.1	Foreign Technology Transfer Project Status	Field
International Cooperation	4.2	Trade Barriers	4.2.1	Foreign Additional Tariff Status	PV/Wind Power Industry
International Cooperation	4.2	Trade Barriers	4.2.1	Foreign Additional Tariff Status	New Energy Vehicle Industry
International Cooperation	4.2	Trade Barriers	4.2.1	Foreign Additional Tariff Status	Battery Industry

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# Appendix B

## A Compendium of Original Analytical Models

### Low-Carbon Policy Intensity ERNIE-CN (LCPI-ERNIE-CN) model

The Low-Carbon Policy Intensity ERNIE-CN (LCPI-ERNIE-CN) model was developed by a team led by Professor Wang Can of the School of Environment at Tsinghua University.<sup>1</sup> It provides methodological and data support for the quantitative analysis and formulation of low-carbon policies. The model establishes a new, transparent, and repeatable policy assessment paradigm based on a hybrid method of natural language processing and ERNIE 3.0 few-shot prompt learning. This paradigm covers the entire workflow, including data collection and cleaning, policy text classification, scoring system construction, policy intensity quantification, and model training and validation.

To accommodate different research fields and scales, the LCPI-ERNIE-CN model includes 36 sub-indices across three policy levels (national, provincial, and municipal), four policy objectives (carbon reduction, energy conservation, production capacity, and technology), and three policy instrument types (command-and-control, economic incentive, and comprehensive). Related research has been published in high-level journals such as *Scientific Data* and has been applied in 19 articles across environmental science, public administration, and energy economics.

The Global Carbon Neutrality Annual Progress Report series uses the LCPI-ERNIE-CN model to assess the low-carbon policy intensity of China at the national level, across 31 provinces, and in 334 prefecture-level cities from 2007 to 2022.

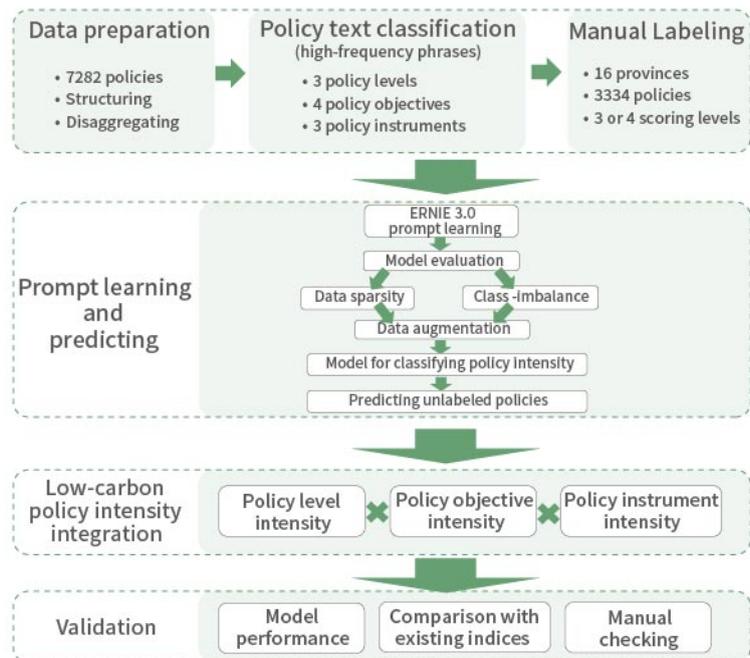


Figure. Core Structure of the Quantitative Assessment Model for China's Low-Carbon Policy Intensity

#### Published Works

- X. Dong, C. Wang, F. Zhang, H. Zhang, and C. Xia, "China's low-carbon policy intensity dataset from national- to prefecture-level over 2007–2022," *Sci Data*, vol. 11, no. 1, p. 213, Feb. 2024, doi: 10.1038/s41597-024-03033-5.

## Climate Law Miner (CLAW-Miner) model

The Climate Law Miner (CLAW-Miner) model is primarily used to extract structured information from large-scale climate law texts, providing reliable data support for subsequent data analysis and empirical research. The model takes climate law texts from the Climate Change Laws of the World (CCLW) database as input. It employs a series of steps, including Prompt Engineering, accuracy testing, and robustness checks, based on a general-purpose large language model to deeply mine and extract key information and corresponding original text content. The basic information that can be output includes covered sectors, responsible agencies, information disclosure requirements, penalty mechanisms, and quantitative targets. Relevant prompts are built into the model and can be flexibly invoked as needed.

Compared to manual information extraction, CLAW-Miner significantly reduces the labor costs of data processing and effectively improves extraction efficiency. Compared to traditional machine learning methods, this model has more prominent advantages in reliability and flexibility. On one hand, by leveraging the semantic understanding and processing capabilities of the general-purpose large language model and testing with a training set, it effectively improves the accuracy of information extraction. Robustness checks further reduce the inconsistency issues that may arise from the probabilistic nature of large language models. On the other hand, in addition to the built-in standardized information extraction functions, researchers can customize and expand the indicator system according to their research needs, with a relatively low barrier to entry.

CLAW-Miner has been applied in the Global Carbon Neutrality Annual Progress Report to analyze the development history of the global climate legal system, assess the main features of typical national climate legal systems, and identify differences in information disclosure requirements, penalty mechanisms, and quantitative targets among climate framework laws, general laws, and administrative regulations. This provides valuable references and data support for the construction of global climate legal systems and policymaking.

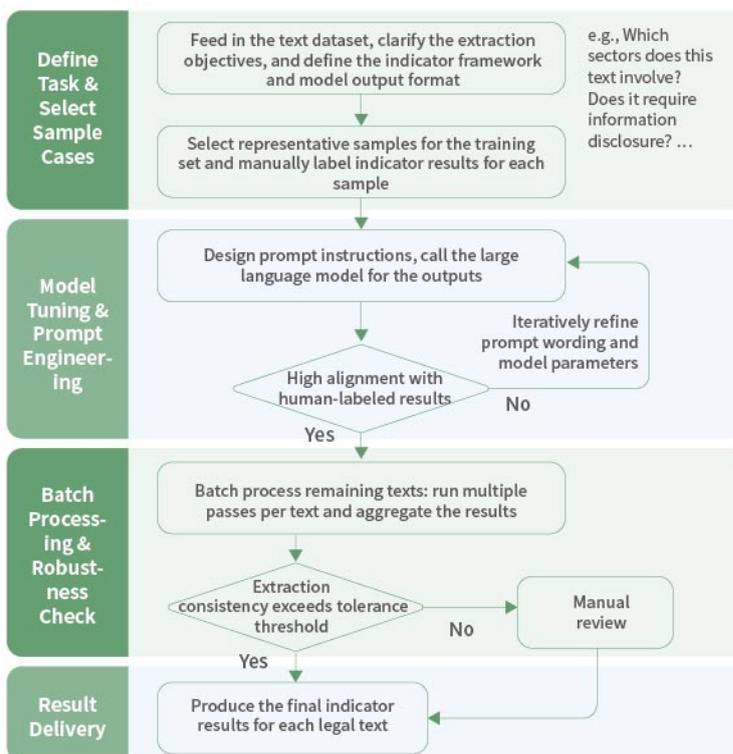


Figure. Operational Flow of the CLAW-Miner Model

**Published Works:**

- Zhang S, Cai W, Zheng X, et al. Global readiness for carbon neutrality: From targets to action[J]. Environmental Science and Ecotechnology, 2025, 25: 100546.

## Multilateral Climate Finance BERT (MLCF-BERT) model

The MLCF-BERT model is designed to automatically identify and classify climate finance projects. To this end, we first performed stratified sampling based on the total number of projects from the project databases of several international institutions, extracting 1,600 projects potentially involving agriculture, energy, electricity, transportation, and environmental protection, and manually annotated their multi-label categories. To enhance the identification capability for categories with fewer samples, an additional 50 projects of this type were added, resulting in a manually annotated corpus of 1,650 entries.

The architecture of MLCF-BERT is based on ClimateBERT, a variant of DistilRoBERTa that has been further pre-trained on a corpus of over two million paragraphs of text from the fields of climate change and the environment.<sup>7</sup> Building on the bidirectional encoder of the original BERT, ClimateBERT's fine-tuning on domain-specific corpora significantly enhances its sensitivity to and understanding of climate-related semantics, providing a solid semantic representation for downstream classification tasks. We divided the task into two stages: first, a relevance classifier to determine whether a project is directly related to climate mitigation, adaptation, or environmental protection; and second, a multi-label classifier to assign the identified relevant projects to the most appropriate climate finance categories. The two-level classifiers were trained and validated separately. For data splitting, the relevance classifier used 85% for training and 7.5% each for validation and testing; the multi-label classifier used 65% for training and 17.5% each for validation and testing, ensuring similar test set sizes for both levels. During training, the AdamW optimizer and cross-entropy loss function were used, with the relevance classifier iterating for 50 epochs and the multi-label classifier for 100 epochs.

Through this design, MLCF-BERT can screen for projects highly relevant to climate issues and achieve efficient, fine-grained multi-label classification. The Global Carbon Neutrality Annual Progress Report series uses the MLCF-BERT model to calculate the global multilateral climate finance amounts for historical years and analyze the historical trends of global multilateral climate finance.

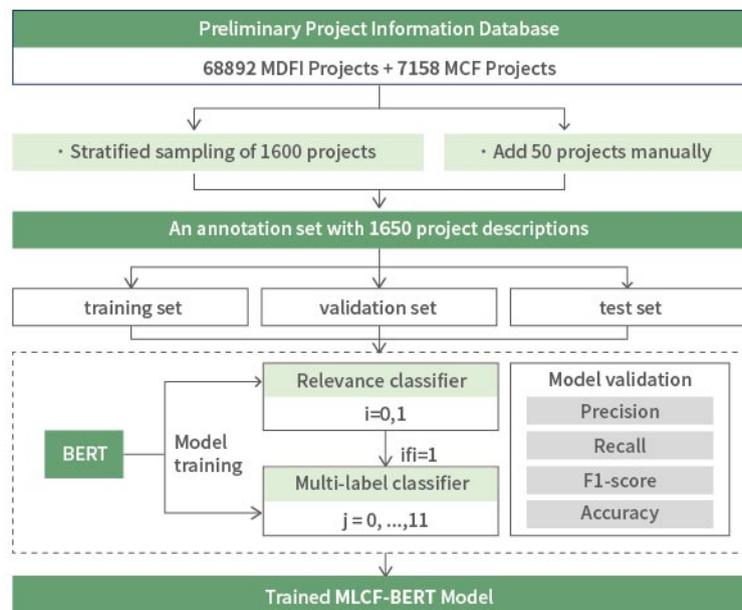


Figure. Schematic of the MLCF-BERT Machine Learning Model for Multilateral Climate Finance

### Published Works

- Fan, S., Wang, C., Zhong, H. et al. International Multilateral Public Climate Finance Dataset from 2000 to 2023. *Sci Data* 12, 952 (2025). <https://doi.org/10.1038/s41597-025-05308-x>.

## Fair Carbon Allocation Model (FairCAM)

The Fair Carbon Allocation Model (FairCAM), developed by a team led by Professor Wang Can of the School of Environment at Tsinghua University, serves the need to quantify fair emission reduction responsibilities for countries, scientifically allocate national remaining carbon budgets, and conduct a multi-dimensional balanced assessment of historical emission responsibilities, economic capabilities, and development rights in the context of global climate governance under the Paris Agreement goals.<sup>8</sup> The model allocates carbon emission rights to 195 parties of the UNFCCC based on a given global warming budget for different climate targets, and outputs the remaining carbon emission space for each country under different allocation principles, providing a comparative reference for target effectiveness assessment. In addition to the overall equality principle, the model incorporates principles such as ability to pay, beneficiary pays, and polluter pays to ensure fairness and feasibility.

The model construction method is based on climate negotiations and international environmental law, comprehensively considering four types of fairness principles: historical responsibility and mitigation capability, per capita convergence, grandfathering, and multi-principle hybrid approaches. This generates a global carbon emission rights allocation model consisting of 1,542 sets of global carbon emission fairness allocation scenarios. The principle of responsibility, capability competence or (and) basic needs refers to the use of national historical emission responsibility, capacity or (and) basic needs as the basis for fair allocation. The principle of equal per-capita (cumulative emissions) is a different form of per capitaism, which requires all countries to approach equal per capita (cumulative) emissions in the current year or in the target year. The principle of current emissions is a different form of statism that distributes based on the status quo. The principle of staged approach is based on multi-stage or blended fairness principles.

The Global Carbon Neutrality Annual Progress Report series, based on this model, has completed the consistency assessment of the carbon neutrality targets of 195 countries with the 1.5°C and 2°C targets (using a "Yes-No-No Target" categorical variable). It also refines the fairness principles into four dimensions: responsibility, capability, and/or basic needs; per capita convergence; grandfathering; and multi-stage fairness, constructing a fairness ambition index for Nationally Determined Contributions (NDCs) and carbon neutrality targets under each fairness principle. The dataset used includes five categories: carbon dioxide emissions, population, GDP, global emission pathways to achieve the Paris temperature control targets, and land area.

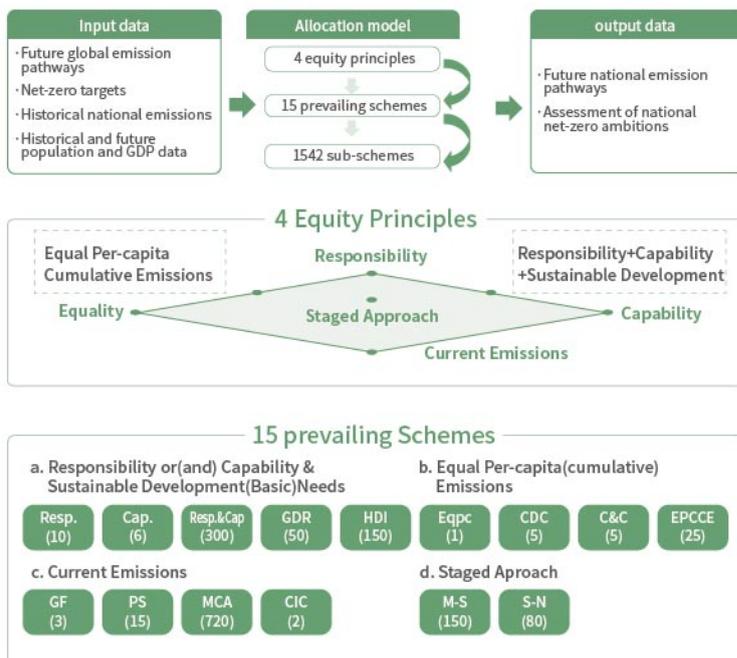


Figure. Core Structure of the Global Carbon Emission Rights Allocation Model

### Published Works

- M. Li et al., "A principle-based framework to determine countries' fair warming contributions to the Paris Agreement," Nat Commun, vol. 16, no. 1, p. 1043, Mar. 2025, doi: 10.1038/s41467-025-56397-6.

## NDC Tracker model

The NDC Tracker compiles all versions of the Nationally Determined Contribution (NDC) documents submitted by all parties to the Paris Agreement. It primarily structures and summarizes information such as the NDC timeframe, covered sectors and greenhouse gases, and target year emissions, based on the "Information to facilitate clarity, transparency and understanding" (ICTU) section.9 For non-direct emission targets such as carbon intensity targets, trajectory targets, and policy-based reduction targets, the NDC Tracker uses consistent and robust parameters and methodologies for estimation. For NDC targets that only cover some sectors and greenhouse gases, the model assumes that the emission structure in the target year is the same as that in the most recent inventory year. It uses the inventory emission structure to proportionally scale the target year NDC target to an economy-wide emission level covering all greenhouse gases 1:

$$NDC_{year,all} = \frac{Emission_{2023,all}}{Emission_{2023,covered}} \cdot NDC_{year,covered} \quad (X)$$

where  $NDC_{year,all}$  is the estimated net emissions for the target year covering the entire economy and all greenhouse gases,  $NDC_{year,covered}$  is the reported limited-coverage emissions for the target year,  $Emission_{2023,all}$  is the net emissions for 2023 covering the entire economy and all greenhouse gases, and  $Emission_{2023,covered}$  is the emissions in 2023 under the NDC's coverage.

From this, the model obtains comparable total NDC emissions for all parties for 2030 and 2035. Based on this, the NDC Tracker further calculates each party's annual emissions, historical cumulative emissions (since 1850), per capita emissions, emissions intensity per unit of GDP, historical cumulative per capita emissions under three different scopes, and the Gini coefficient of population proportion versus per capita emission proportion, to compare greenhouse gas emission fairness under different indicators.

The NDC Tracker uses the best available emissions data, prioritizing inventory data from the Common Reporting Tables (CRT) submitted with countries' Biennial Transparency Reports, followed by the latest data from the PRIMAP inventory. Remaining gaps are filled using the EDGAR and Global Carbon Project databases. Historical GDP and population data are from the World Bank and the UN Department of Economic and Social Affairs, while future GDP and population growth rates are from the IIASA's SSP2 pathway socioeconomic indicators prediction database.

## Global Renewable Energy Capacity Projection Model (GRECPM)

The Global Renewable Energy Capacity Projection Model (GRECPM) is a data-driven probabilistic forecasting tool that uses the Richards growth model combined with Bayesian inference to predict the development trends of global and regional renewable energy installed capacity. The model can fit historical data, forecast future installed capacity, and assess uncertainty. By integrating the forecast results of various renewable energy sources through Monte Carlo sampling, it provides a quantitative basis for evaluating the feasibility of the global goal to triple renewable energy. The model's data is easily accessible, directly using historical data on global and regional renewable energy installed capacity provided by IRENA.

The Richards model is a generalized logistic model, with the formula:

$$l(t) = L \cdot \left(1 + (m - 1) \cdot e^{-k(t-t_0)}\right)^{\frac{1}{1-m}}$$

When  $m$  approaches 1, the model degenerates into the Logistic model; when  $m=0$ , it degenerates into the Gompertz model. The model includes four parameters:

- L** Carrying Capacity → Represents the theoretical maximum potential for installed capacity of a specific renewable energy technology.
- k** Growth Rate → Controls the steepness of the growth curve, reflecting the speed of technology diffusion and market penetration.
- $t_0$**  Inflection Point → The time when the growth rate reaches its peak, marking the transition from accelerated to decelerated growth.
- m** Shape Parameter → Determines the asymmetry and specific shape characteristics of the growth curve

Given the complexity of the four-parameter Richards model, this study uses the advanced Python machine learning package PyMC to implement Bayesian inference. By setting reasonable prior distribution intervals for each parameter and using the Markov Chain Monte Carlo (MCMC) method to obtain the joint posterior distribution of the parameters, probabilistic forecasts of installed capacity for various renewable energy sources are achieved. This method not only provides point predictions but also gives prediction ranges for different confidence intervals and probability assessments for reaching target values in specific years. The total renewable energy installed capacity is obtained by summing the Monte Carlo samples of the forecast results for each technology.

The Global Carbon Neutrality Annual Progress Report series, based on the Richards model, dynamically assesses the progress toward the global goal of tripling renewable energy year by year. It deeply characterizes the development trajectories of renewable energy at the global, regional, and national levels, identifies different development models and stage characteristics, and provides scientific support for policymaking and international cooperation.

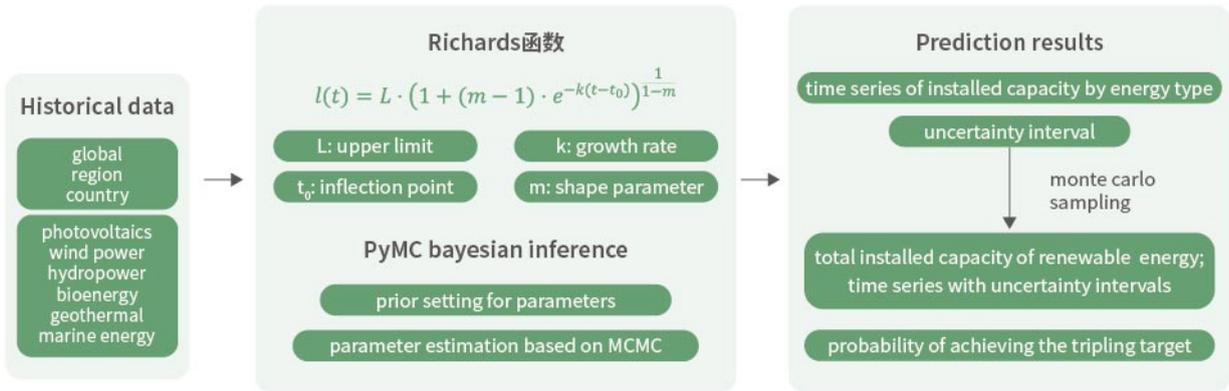


Figure. Core Structure of the Richards Model

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- Wang Can, Cai Wenjia, Zhang Shihui, et al. 2024 Global Carbon Neutrality Annual Progress Report Appendix. Beijing: Institute for Carbon Neutrality, Tsinghua University. <https://www.cntracker.tsinghua.edu.cn/report>.
- Zhang S, Cai W, Zheng X, et al. Global readiness for carbon neutrality: From targets to action[J]. Environmental Science and Ecotechnology, 2025, 25: 100546.
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## Global Hybrid Energy-Economic Research (GHEER) model

The Global Hybrid Energy-Economic Research (GHEER) model was developed by a team led by Professor Wang Can of the School of Environment, Professor Cai Wenjia of the Department of Earth System Science at Tsinghua University, and Assistant Professor Zhang Shihui of the School of Ecology and Environment at Renmin University of China.<sup>14</sup> It aims to address the issues of global long-term low-carbon strategic planning and multi-dimensional impact assessment in the context of carbon peaking and carbon neutrality.<sup>15</sup> The model is a Computable General Equilibrium (CGE) model that divides the world into 18 major regions for modeling, with a primary time frame of 2017-2030. It simulates macroeconomic operations, covering industrial succession, technological updates, energy consumption, and emissions. The model considers four main agents—producers, consumers, government, and investors—and includes 15 industries and 8 electricity sub-sectors. It achieves cost minimization through nested CES production functions, integrates energy demand from various industries, establishes an international trade system for commodity markets, and matches savings and investments of urban and rural residents and the government. The model uses the open-source Julia framework, providing strong support for related research and academic exchange.

The Global Carbon Neutrality Annual Progress Report series couples the GHEER model with a learning curve model to quantify how technology spillover effects in renewable supply chains affect economic efficiency and distributional justice in the decarbonization process. The research results show that transnational spillover effects can save nearly \$1 trillion in investment for achieving the goal of tripling renewable energy—an implicit economic subsidy for climate ambition. Conversely, supply chain decoupling disproportionately harms energy access and household welfare in vulnerable regions. Maintaining multilateral renewable energy technology flows is not only a cost-optimization mechanism but also a pillar of global just transition governance.

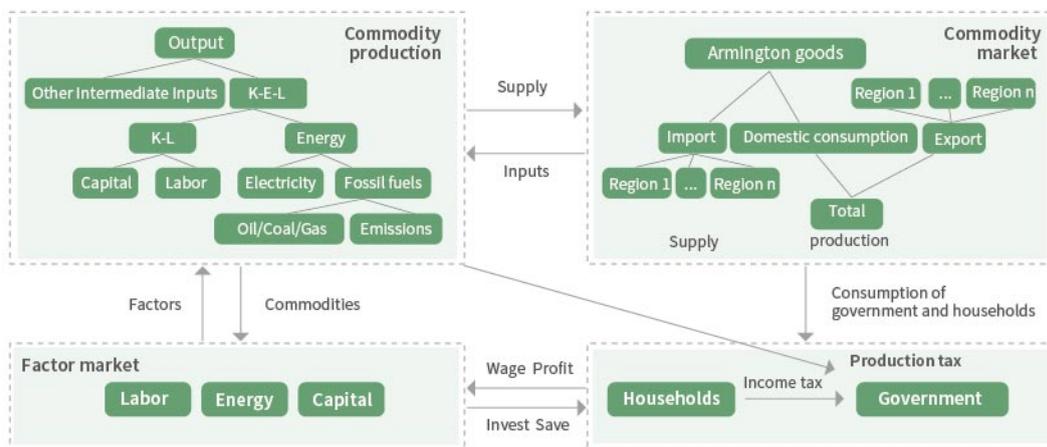


Figure. Core Structure of the GHEER Model

### References & Published Works:

- Institute for Carbon Neutrality, Tsinghua University, 2024 Global Carbon Neutrality Annual Progress Report Appendix. <https://www.cn-tracker.tsinghua.edu.cn/report>.
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- Y. Guan, K. An, S. Zhang, and C. Wang. "Trade Barriers Impede Solar and Wind Technological Spillovers, Increasing Global Low-Carbon Transition Costs and Inequity" (under preparation).

## China Hybrid Energy-Economic Research/Power (CHEER/Power) model

The China Hybrid Energy Economic Research Model for Power system (CHEER/Power) was developed by a team led by Professor Wang Can of the School of Environment and Professor Cai Wenjia of the Department of Earth System Science at Tsinghua University. It serves the needs of simulating long-term low-carbon transition pathways, policy analysis, and impact assessment for China's power sector in the context of carbon peaking and carbon neutrality.<sup>16</sup> The model forms a systematic modeling framework that includes two parts: a resource potential assessment of multiple renewable energy generation technologies at a spatial grid scale, and a provincial-scale, hourly-level power system optimization of the entire generation-storage-transmission-use chain based on mixed-integer linear programming.

With 2020 as the base year and in 5-year intervals, the model optimizes the investment scale and economic dispatch of power generation units, energy storage technologies, Carbon Capture and Storage (CCS) technologies, and inter-provincial transmission lines to minimize total system costs. This is done for 32 provinces, 14 generation and storage technologies, and 12 typical days, under constraints such as installed capacity, power supply-demand balance at each time point in each province, operating conditions of each generator unit, and energy planning and carbon reduction policy targets. The generation technologies included in the model are coal, gas, nuclear, conventional hydro, onshore wind, offshore wind, centralized solar PV, distributed solar PV, and biomass, allowing for CCS retrofitting of coal, gas, and biomass power plants. It also considers two types of energy storage technologies: battery storage and pumped hydro storage. Related research has been published in high-level journals such as Nature Communications and Scientific Data, and has served multiple national and local carbon neutrality consulting projects.

The Global Carbon Neutrality Annual Progress Report series, based on the power system optimization model from the CHEER series, has assessed key issues such as the pathway to achieving China's goal of tripling renewable energy.

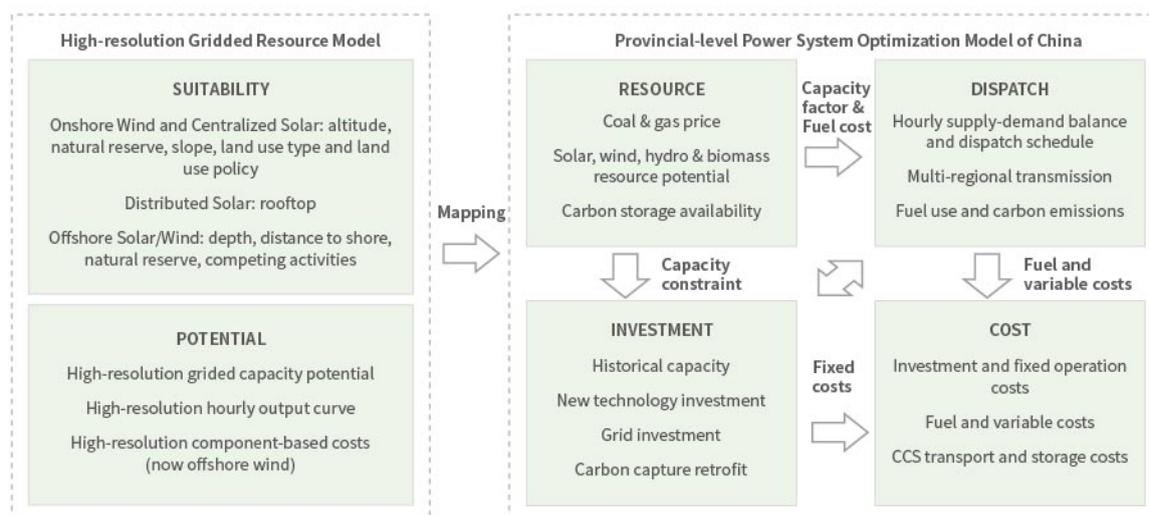


Figure 3. Core Structure of the CHEER/Power Model

### References & Published Works:

- Official model website: [www.cheer.org.cn](http://www.cheer.org.cn)
- K. An et al., "Repositioning coal power to accelerate net-zero transition of China's power system," *Nat Commun*, vol. 16, no. 1, p. 2311, Mar. 2025, doi: 10.1038/s41467-025-57559-2.
- K. An, W. Cai, X. Lu, and C. Wang, "High-resolution gridded dataset of China's offshore wind potential and costs under technical change," *Sci Data*, vol. 12, no. 1, p. 69, Jan. 2025, doi: 10.1038/s41597-025-04428-8.

## Global Trade Simulation and Photovoltaic Input-Output (GSIM-PVIO) model

The GSIM-PVIO model, developed by a team led by Professor Wang Can of the School of Environment at Tsinghua University and Professor Zheng Xinzhu of the School of Economics and Management at China University of Petroleum-Beijing 17, serves to assess the impact of photovoltaic (PV) trade policies on supply chain employment and the economy. The model is centered around the Global industry-level trade policy SIMulation model (GSIM) and a detailed Photovoltaic industry Input-Output model (PVIO). The GSIM model solves for price changes resulting from trade policy shifts based on global market-clearing conditions, thereby calculating changes in trade flows, tariff revenues, and welfare. Its output of PV product trade flow changes is then input into the PVIO model to assess broader supply chain linkages and their impacts. Based on this model, the team has assessed the economic and employment impacts of historical trade policies in the PV industry, identified hotspot industries or regions directly or indirectly affected by policies, and predicted future trends in economic and employment changes under new trade policy shifts.

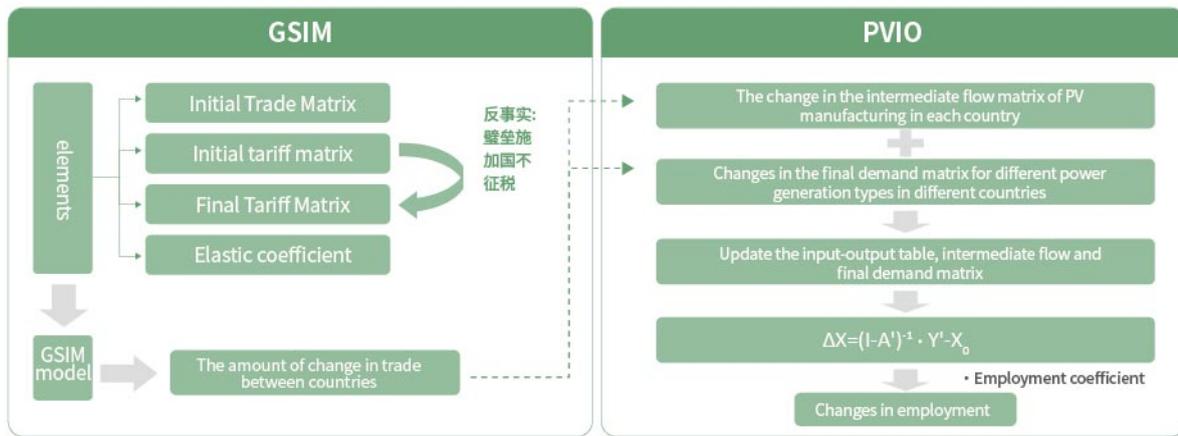


Figure. Core Structure of the Coupled Trade and Input-Output Model

The Global Carbon Neutrality Annual Progress Report series, using the GSIM-PVIO model, assessed the economic and employment impacts of a counterfactual scenario where no PV trade barriers are imposed globally. It found that breaking down PV trade barriers not only directly promotes global PV industry economic and employment growth but also brings more significant scale benefits through industrial linkages.

### Published Works

- Wang Can, Cai Wenjia, Zhang Shihui, et al. 2024 Global Carbon Neutrality Annual Progress Report Appendix. Beijing: Institute for Carbon Neutrality, Tsinghua University. <https://www.cntracker.tsinghua.edu.cn/report>.
- Gao Yiyang, Zheng Xinzhu. The Economic Welfare Impact of PV Trade Barriers Against China and Countermeasure Research. *Coal Economy Research*. 2025, 45(4): 17-28.

## China's Overseas Energy Investment Input-Output (COEIO) model

The China Overseas Energy Investment Input-Output (COEIO) model is a quantitative assessment tool based on a national input-output framework. The model selects country-specific input-output tables, disaggregates the power sector into coal, gas, hydro, nuclear, solar, and wind power, and focuses on the renewable energy sector and its upstream and downstream related industries to calculate the economic stimulus effect of China's overseas energy investments on different sectors in different countries.

In terms of model mechanism, it first constructs a technology coefficient matrix  $A$  based on each country's intermediate input matrix, and then calculates the Leontief inverse matrix  $L=(I-A)^{-1}$ . China's annual investment in a single country's renewable energy sector is treated as a final demand shock vector  $\Delta Y$ , and the output increment for each industry is calculated through  $\Delta X=L\Delta Y$ . This step includes both the direct stimulus of the investment within the sector and the indirect effects throughout the entire supply chain. To measure broader economic effects, the model further introduces sectoral value-added coefficients ( $v_i$ ) and employment coefficients ( $e_i$ ). The total value-added is calculated by  $\Delta VA=v \cdot \Delta X$ , and the total employment increment is derived from  $\Delta EMP=e \cdot \Delta X$ . Output and value-added multipliers can also be calculated to assess the investment stimulus effect in different countries.

The Global Carbon Neutrality Annual Progress Report series, using the COEIO model, systematically assessed the direct and indirect stimulus effects of China's renewable energy investments in ten countries along the "Belt and Road" on local output, value-added, and employment.



Figure. Schematic of China's Overseas Energy Investment Input-Output Model



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