A Comparison of International Carbon Neutrality Pathways

Likely Changes in China's External Energy Dependence

Edited by

Guangyue Xu

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Preface

The frequent occurrence of extreme weather events and the disruption of ecosystems caused by global warming have become common challenges to sustainable development worldwide. In response, transforming energy systems and achieving carbon neutrality by mid-century have become a broadly shared goal. By 2025, over 130 countries and regions had pledged to reach carbon neutrality. However, each country's pathway reflects its unique resource endowments, industrial structure, technological capabilities, and policy frameworks. Carbon neutrality strategies therefore exhibit distinct national characteristics. As a major energy consumer and carbon emitter, China's own low-carbon transition and changes in external energy dependence will not only shape its sustainable development but also influence the global carbon neutrality process. It is thus essential for China to examine international experiences and derive targeted insights for its domestic strategy.

From the perspective of international practice, different economies have explored diverse carbon neutrality paths based on their specific conditions. For example, in North America the United States combines federal and state climate initiatives, emphasizing absolute emission targets and leveraging market-driven shifts such as the shale gas revolution and carbon capture technologies. Canada, after peaking its emissions in 2007, has implemented nationwide carbon pricing and a comprehensive hydrogen energy strategy to steadily drive down emissions while maintaining economic growth. In Europe, the European Union has used its integrated policy framework—centered on a robust carbon emissions trading system and extensive renewable energy deployment—to construct a dual transformation model of "policy-driven + technological innovation." Major European economies each chart distinct routes under this umbrella: Germany is achieving deep industrial decarbonization through expanding offshore wind power and pioneering hydrogen-based steelmaking; France benefits from a predominantly nuclear-powered electricity mix and is accelerating renewable energy expansion; the United Kingdom's "Green Industrial Revolution" emphasizes offshore wind, electric vehicles, and hydrogen technology to spur green growth and job creation; and Italy, a representative of Southern Europe's transition, leverages abundant solar resources and clusters of small and medium enterprises to promote distributed generation and energy efficiency. Across the Asia-Pacific, Japan is constrained by an extreme scarcity of domestic energy resources and thus, alongside boosting solar and wind power, it prioritizes the development of hydrogen energy and next-generation nuclear technology – forming a transition path that "pays equal attention to opening new sources and reducing consumption." New Zealand, endowed with rich hydropower and geothermal resources, has developed unique expertise in distributed energy use and building energy efficiency; through innovations in agricultural emissions control, it pursues an "ecological priority + industrial adaptation" pathway to carbon neutrality. Australia, for its part, is rich in coal and natural gas and is gradually adjusting its energy structure by increasing the share of renewables; at the same time, it faces the difficult task of balancing the phase-out of traditional fossil-fuel industries with employment and economic stability. The practices of all these countries – from the U.S. and Canada to the EU and its member states, and on to Japan, New Zealand, and Australia – provide a multitude of reference cases for global carbon neutrality efforts. Their varied experiences offer important lessons for China as it explores a carbon neutrality route suited to its own national circumstances.

The significance of comparing carbon neutrality pathways across different countries lies in several dimensions, encompassing strategic planning, technological innovation, industrial policy, and global governance. In particular, such comparative analysis allows us to:

Inform domestic policy with differentiated international insights. Because of differing natural resources, economic structures, and technologies, each country's carbon neutrality path is unique. Comparative study provides a nuanced reference framework that helps countries design policies suited to their conditions rather than copying others blindly. For instance, the European Union has adopted a governance model that combines legally binding emissions targets with market-based carbon trading – a "legal constraint + market regulation" approach – whereas China has pursued a strategy of "reducing coal without reducing energy," aiming to balance energy security with low-carbon transformation. By examining these contrasts, policymakers can identify their own country's strengths and weaknesses and calibrate the pace of energy transition, the mix of regulatory mandates and market incentives, and the level of industrial support in a way that best fits their national context.

Stimulate innovation in clean energy and carbon-negative technologies. Technological choices are at the core of different carbon neutrality pathways. International comparison highlights various technology strategies and can accelerate knowledge sharing and innovation. Germany, for example, is decarbonizing heavy industry with a combination of offshore wind power and green hydrogen (e.g. hydrogen-based steel production), while the United States has leveraged its shale gas revolution to reduce coal use and is investing in carbon capture, utilization and storage (CCUS) technologies. China has rapidly advanced solar photovoltaic efficiency through programs like the "Top Runner" initiative, pushing new N-type solar cell efficiency above 26%. By comparing such advances, countries can identify critical technological bottlenecks and potential breakthroughs. This process guides global collaboration and healthy competition in clean tech development, helping to drive down the costs of renewable energy and carbon-removal solutions. For developing countries, learning from the technological trajectories of more advanced economies – for instance, China's large-scale solar manufacturing or Europe's offshore wind deployment – can facilitate technology transfer and localized innovation, enabling them to leapfrog to cleaner energy systems.

Establish fair and effective international climate governance rules. Divergent carbon neutrality pathways lead to different national interests and policy stances in climate negotiations. Developed economies with early mover advantages often advocate for stringent emission cuts and may implement mechanisms like carbon tariffs, while developing countries emphasize principles of historical responsibility, equity, and the need for financial and technological support. Through comparisons, it becomes easier to design differentiated yet cooperative climate governance frameworks under the principle of "common but differentiated responsibilities." For example, the European Union's Carbon Border Adjustment Mechanism (CBAM) is intended to prevent carbon leakage by applying carbon costs to imports – but comparative analysis underscores that such measures must account for the capabilities and circumstances of trading partners to avoid veering into protectionism. International pathway comparison can thus inform more balanced rule-making, encouraging industrialized countries to consider the developmental needs of others. At the same time, it can promote convergence in technical standards (for instance, common reporting metrics or clean technology certifications), thereby reducing barriers to international trade in low-carbon goods and services and enhancing the overall fairness and effectiveness of the global climate governance regime.

Optimize industrial transition strategies and employment policies. Achieving carbon neutrality necessitates profound industrial transformation, which poses challenges to economic structure and labor markets. By examining how different countries manage this transition, we can identify strategies to mitigate risks such as the decline of carbon-intensive industries or regional job losses. The United Kingdom, through its Ten Point Plan for a Green Industrial Revolution, is fostering new industries like offshore wind, hydrogen production, and electric mobility, with an expectation of generating hundreds of thousands of green jobs to offset losses in traditional sectors. Japan, for its part, has designated numerous clean technologies and industries as strategic and seeks to reduce costs via standardization and innovation, in order to maintain its industrial competitiveness. Comparing such approaches helps reveal potential pitfalls and effective measures. Countries can learn to implement supporting policies – for example, workforce retraining programs, social safety nets, and regional redevelopment funds – to ensure a just transition for affected workers and communities. Sharing lessons on industrial policy design thus aids each country in formulating more comprehensive transition plans that align economic restructuring with social stability.

Reduce the overall cost of global climate action through coordination. Uncoordinated climate actions can lead to problems like "carbon leakage," where emissions-intensive production shifts to countries with looser regulations, undermining the environmental effort. International comparison of pathways highlights these misalignments and can foster cooperation to harmonize policies. By understanding each other's trajectories, countries can work towards establishing global mechanisms such as linked carbon markets or a unified carbon pricing system, which help synchronize emission reduction efforts. For example, as the EU implements its CBAM and China develops its national carbon trading market (now the world's largest by volume of emissions covered), dialogue informed by comparative analysis can ensure these initiatives complement rather than conflict with each other. Coordinating timelines—for instance, aligning the peaking and neutrality targets of different countries—and sharing best practices in regulation can minimize competitive distortions. Moreover, comparing pathways strengthens international cooperation in climate finance and technology transfer: developed countries can better appreciate the needs of developing nations and collectively mobilize resources to support emissions reduction globally. Such coordination, guided by mutual understanding of each country's path, ultimately lowers the aggregate cost of cutting emissions and accelerates the world's progress toward carbon neutrality.

Enhance public engagement and social consensus on climate action. The success of carbon neutrality strategies hinges on broad public support and participation, as these transformations affect lifestyles and require behavioral change. Different countries have adopted various methods to build societal consensus, and comparing these can yield valuable insights. The European Union, for instance, launched extensive public consultations and awareness campaigns under its Green Deal to ensure citizens are informed and involved in the transition. Germany has convened forums such as the Bürgerdialog (Citizens' Forum for Energy Transition) to solicit public input and address concerns about its energy roadmap. China has integrated climate goals into its social narrative by promoting the concept of "dual carbon" (carbon peaking and neutrality) and experimenting with personal carbon credit systems to incentivize low-carbon choices among the public. By examining these experiences, countries can learn how to design more effective communication strategies, educational programs, and participatory decision-making processes. Effective public engagement, informed by international examples, increases policy transparency and credibility, reduces resistance to new measures (such as changes in energy prices or infrastructure projects), and mobilizes society-wide efforts towards achieving carbon neutrality.

Anticipate geopolitical shifts and energy security implications. The transition to carbon neutrality is reshaping the global geopolitical and energy landscape. Comparative analysis helps countries foresee and prepare for these changes. For example, the European Union's drive to reduce reliance on fossil fuel imports has significantly lessened its dependence on Russian natural gas, altering geopolitical alliances and energy trade flows. The United States, through the shale revolution, not only cut its domestic emissions by replacing coal with natural gas, but also became a major energy exporter, influencing global energy markets and diplomatic leverage. As nations decarbonize at varying paces, new interdependencies (such as critical mineral supply for clean technologies) and potential conflicts could arise. By studying each other's pathways, countries can better assess how the global transition might affect access to energy resources and the balance of power. This understanding enables the development of strategies to mitigate risks – such as diversifying energy import sources, investing in strategic stockpiles of critical materials, or cooperating on transnational energy projects – thereby safeguarding national energy security during the low-carbon transition.

In summary, comparing different countries' carbon neutrality pathways is valuable not only for policy benchmarking, but also for advancing a more equitable and efficient global climate governance system. Countries can use such analysis to strengthen cooperation in technology, finance, and rule-making, and to build broader social and political support for climate action, thereby jointly working toward the goals of the Paris Agreement.

Under the impetus of the global carbon neutrality movement, the pace of energy transformation is accelerating worldwide. This raises important questions about energy security alongside decarbonization. Energy external dependence – the degree to which a country relies on imported energy – is a core indicator of national energy security, and its trajectory is influenced by policy shifts, changes in trade patterns, and technological breakthroughs during the low-carbon transition. As an integral player in the world energy market, China faces considerable stakes in this arena: how China's external energy dependence evolves in the course of pursuing carbon neutrality will have significant implications both domestically and globally. It is against this backdrop that the present volume examines international carbon neutrality pathways and their relevance to energy security. By systematically analyzing the carbon neutrality strategies of key countries and regions – including the European Union, Germany, France, the United Kingdom, Japan, Italy, New Zealand, Australia, the United States, and Canada – this study dissects the internal logic and outcomes of various transition approaches. These international case studies provide a crucial reference point for anticipating and guiding changes in China's own energy dependence and security as it moves toward its carbon neutrality target.

Accordingly, the book is structured into four parts. Part I (North America) reviews the carbon neutrality pathways of the United States and Canada, highlighting their policy frameworks and emission trends as leading examples from North America. Part II (Europe) focuses on the European Union's supranational approach and delves into individual analyses of major European economies – Germany, France, the United Kingdom, and Italy – to illustrate the diversity within Europe's decarbonization efforts. Part III extends the comparative lens to the Asia-Pacific region, examining how Japan, New Zealand, and Australia are navigating the route to carbon neutrality amid their distinct resource and economic contexts. Finally, Part IV (Energy Dependence and Security) evaluates the critical interplay between carbon neutrality and energy security. This concluding section uses the insights from previous chapters to assess changes in China's external energy dependence, with a detailed exploration of overall energy import reliance and a case study on natural gas supply security. By bridging the international pathway analysis with China's energy security outlook, Part IV provides a coherent link that underscores the practical significance of global experiences: it ensures that the lessons drawn from other countries' low-carbon transitions directly inform strategies to safeguard energy supply and security in the course of China's own journey toward carbon neutrality. Through this integrated structure, the book as a whole offers a comprehensive and multi-dimensional understanding of how different nations are striving for carbon neutrality and what these efforts mean for the balance between climate ambition and energy stability.

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Author Contributions

This book is the result of a collaborative effort by researchers affiliated primarily with the Institute of Ecological Civilization Economy, Henan University. Under the general editorship of Guangyue Xu, each chapter was jointly developed through coordinated work in research design, empirical modeling, manuscript drafting, and text refinement. Contributions to each chapter are outlined below.

Guangyue Xu, as General Editor, was responsible for the overarching academic framework, structural design, and theoretical coordination of the volume. He provided consistent guidance and oversight throughout the development of all chapters, ensuring analytical coherence and methodological integrity.

Chapter 1, focusing on the carbon neutrality framework of the United States, was developed under Xu's direction. HongYu Dang carried out the data analysis and drafted the manuscript. Mingqi Jiang strengthened the argumentation and improved the overall exposition of the chapter.

Chapter 2, which examines emission trends and policy implications in Canada, was coordinated by Xu. JianBing Li conducted modeling and drafted the main text. Mingqi Jiang undertook translation and language refinement.

Chapter 3, addressing the European Union's carbon neutrality progress, was guided by Xu. Xiayu Xu performed the gray model forecasting and composed the draft. Linhai Wang revised and edited the manuscript for clarity and consistency.

Chapter 4, on the United Kingdom, was structured by Xu. Cunlong Zhao conducted the empirical analysis and wrote the draft. Xiaolong Li contributed substantially to the refinement of the analytical framework and the coherence of the narrative.

Chapter 5, centered on Germany, was framed by Xu. Zuqiang Bi developed the data projections and wrote the manuscript. Lu Wen revised and polished the text.

Chapter 6, examining France’s pathway, was organized under Xu’s guidance. Yiwu Bai undertook the modeling and drafted the chapter. Lu Wen contributed to language refinement.

Chapter 7, presenting Italy’s emission projections through 2050, was designed by Xu. Ruochen Zhu carried out empirical work and prepared the draft. Qichan Zhang and Adnan Bashir revised the content and improved the structure and clarity of the analysis.

Chapter 8, analyzing Japan’s carbon neutrality trajectory, was co-developed by Xu and Huayue Guo, who completed the modeling and drafted the text. Mingqi Jiang revised the structure and style. Muhammad Sarmad Raza Gorsi ensured clarity and fluency of expression, while Rong Xing contributed additional content on the challenges in Japan's decarbonization process.

Chapter 9, focused on New Zealand, was developed with Xu’s oversight. Tingting Zhou performed the data modeling and composed the main text. Hafizur Rehman ensured logical coherence and accuracy of expression throughout the chapter.

Chapter 10, studying Australia’s emission pathway, was led by Xu. Zimeng Hua completed the analysis and drafted the manuscript. Zhongzhou Li and Lubna Shaheen assisted with final revisions.

Chapter 11, which forecasts China's external energy dependence to 2060, was structured by Xu. Jianan Zhao and Lingqiang Meng conducted ARIMA modeling and wrote the analytical report. Hafizur Rehman edited and refined the text.

Chapter 12, addressing natural gas dependence, was organized by Xu. Siqi Yu performed the data analysis and authored the draft. Haolin Wang revised the argument structure and improved clarity.

Lu Wen coordinated the final integration of materials across chapters. Mingqi Jiang contributed to the structural revision of the entire volume and enhanced textual consistency throughout.

All authors reviewed and approved the final versions of their respective chapters. In completing this volume, contributors demonstrated sustained commitment to academic rigor, cross-disciplinary collaboration, and the pursuit of analytical clarity across a diverse set of national contexts. Each chapter reflects the integration of theoretical depth, methodological care, and collective scholarly effort.

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Part I
– North America

Chapter 1
An Analysis of the U.S. Carbon Neutrality Policy Framework and Carbon Emission Trajectory Forecasting

Guangyue Xu, HongYu Dang, Mingqi Jiang

Abstract: As global climate change continues to intensify, the design of carbon neutrality policy frameworks and the monitoring of carbon emission trajectories have become key concerns for governments worldwide. Based on an analysis of major U.S. carbon neutrality–related policies from 1970 to 2021, this study finds that the U.S. carbon neutrality policy framework exhibits multiple distinctive features. These include a governance structure combining federal and state levels, an emphasis on absolute carbon emission levels as the primary policy indicator, and a reliance on energy structure adjustment as a key entry point for emission reduction. Furthermore, using U.S. carbon emission data from 2007 to 2021 and carbon stock data from 1990 to 2020, this study applies the gray forecasting model GM(1,1) to analyze future trends. The results indicate that U.S. carbon emissions from 2022 to 2050 are projected to follow a downward trajectory, reaching 3,960.95 million tonnes by 2050. Over the same period, carbon sink levels are projected to exhibit an upward trend, reaching 287.23 million tonnes by 2050. These findings suggest that by 2050, U.S. carbon emission levels will remain substantially higher than carbon sink capacity. Under existing policy intensity and natural carbon sink capacity, achieving carbon neutrality through current pathways alone remains infeasible.

Keywords: carbon neutrality; policy framework; gray forecasting model; carbon trading market

1.1 Introduction

Against the backdrop of increasingly severe global climate change risks, achieving a long-term balance between economic development and emission reduction constraints has become a core issue in public policy worldwide[1]. In this process, the United States occupies a distinctive and irreplaceable position in global mitigation efforts. On the one hand, it is a major economy with one of the largest cumulative historical carbon emissions and one of the highest current emission levels globally. As a result, changes in its emission reduction trajectory directly affect the evolution of total global greenhouse gas emissions. On the other hand, the United States has long played a key role in the international climate governance system. It has acted both as a rule shaper and as an institutional enforcer. Its policy orientation and the pace of its actions therefore generate significant spillover effects on global climate cooperation mechanisms and emission reduction expectations[2]. For these reasons, a systematic analysis of the U.S. carbon neutrality policy framework and its emission reduction pathway is relevant not only for domestic policymaking but also for international comparison.

From the perspective of policy practice, U.S. carbon neutrality policies did not emerge as a concentrated initiative within a short period. Instead, they have evolved through a long and gradual process. Since environmental protection was incorporated into the public policy agenda in the 1970s, the United States has progressively constrained greenhouse gas emissions. These constraints have been implemented through environmental regulation, energy efficiency standards, and market-based policy instruments. Entering the twenty-first century, climate change issues became increasingly globalized and institutionalized. In response, the United States intensified its policy efforts in areas such as clean energy development, the exploration of carbon pricing mechanisms, and the formulation of medium- and long-term emission reduction targets. Gradually, a multi-level climate governance system took shape. This system is characterized by federal planning as overall guidance and subnational policies as important complements. However, under the federal system, policy authority and responsibilities are highly decentralized. Political cycles fluctuate, and regional differences persist. These factors jointly increase the complexity of the U.S. carbon neutrality pathway. As a result, a notable gap often emerges between institutional design and actual policy implementation outcomes.

Existing studies have examined U.S. climate policy and emission reduction issues from multiple perspectives. One strand of the literature focuses on the evolution logic and institutional characteristics of U.S. climate policy. These studies emphasize the influence of federal–state relations, political bargaining, and policy instability on the emission reduction process[3][4][5]. Another strand highlights the role of energy structure adjustment and technological progress. It argues that power sector decarbonization and the expansion of renewable energy are key drivers of U.S. emission reductions[6][7]. In addition, some studies apply econometric models or scenario analyses to project future carbon emission trends in the United States[8][9]. Despite these contributions, several limitations remain in the existing literature. First, policy analysis, emission structure analysis, and quantitative forecasting are often conducted separately. The internal linkages among these dimensions are not sufficiently integrated. Second, discussions on the feasibility of achieving carbon neutrality frequently remain at the level of policy declarations or assessments of technological potential. Quantitative analyses of real-world structural constraints are relatively limited.

In response to these gaps, this paper conducts a systematic analysis of the U.S. carbon neutrality pathway from an integrated "policy–structure–trajectory" perspective. Specifically, the paper first reviews the U.S. carbon neutrality policy framework and its governance status. Particular attention is paid to coordination mechanisms between federal and subnational policies, as well as to the characteristics of major policy instruments. Second, the paper examines the structural features and evolutionary inertia of U.S. carbon emissions. This analysis focuses on sectoral structure, energy structure, and temporal dynamics. On this basis, the gray forecasting model GM(1,1) is employed to quantitatively predict future carbon emission trajectories and changes in carbon sinks in the United States. Finally, the paper combines the forecasting results with institutional and structural analysis. It discusses the practical challenges facing the U.S. carbon neutrality pathway and derives corresponding policy implications.

The potential contributions of this paper can be summarized in three aspects. First, by integrating policy analysis, emission structure analysis, and quantitative forecasting, the study develops a holistic understanding of the U.S. carbon neutrality pathway. Second, building on structural analysis, it extrapolates medium- and long-term carbon emission trends. This allows for a quantitative evaluation of the emission reduction effects under existing policy pathways. Third, the paper examines real-world constraints from the perspectives of institutional coordination, structural dependence, and transition costs. These discussions provide references for policy adjustment and pathway optimization.

The remainder of the paper is organized as follows. Section 2 analyzes the U.S. carbon neutrality policy framework and governance status. Section 3 examines the structural characteristics and evolutionary patterns of U.S. carbon emissions. Section 4 presents an empirical prediction of carbon emission trajectories based on the gray forecasting model. Section 5 discusses the practical issues and challenges facing the carbon neutrality pathway. Section 6 concludes and presents policy implications.

1.2 Analysis of the Carbon Neutrality Policy Framework and Governance Status in the United States

The carbon neutrality policy system in the United States did not take shape at a single point in time. Instead, it evolved gradually under the interaction of multiple policy objectives, including environmental regulation, energy security, and climate governance. From the perspective of institutional formation, the U.S. policy framework exhibits a clear "incremental construction" characteristic. That is, at different historical stages, policy instruments targeting pollution control, energy efficiency improvement, and greenhouse gas emission reduction were continuously added. Over time, these instruments collectively developed into a comprehensive carbon neutrality policy system. This system covers both federal and subnational levels and requires coordination across multiple sectors. Compared with centralized institutional design, this gradual evolutionary path enhances policy adaptability. At the same time, it also leads to a governance structure characterized by high complexity and decentralized authority[10].

1.2.1 A Parallel Policy Framework at the Federal and State Levels

At the federal level, the United States incorporated environmental protection and energy efficiency into the public policy agenda at an early stage. Since the 1970s, the enactment of the National Environmental Policy Act and the establishment of the Environmental Protection Agency (EPA) laid the institutional foundation for unified federal regulation of air, water, and soil environmental quality.

Subsequently, the Energy Policy and Conservation Act introduced mandatory requirements for vehicle fuel efficiency for the first time. This legislation institutionalized energy efficiency targets and incorporated them into the emission reduction policy toolkit. Entering the late twentieth century and early twenty-first century, legislative acts such as the Clean Air Act Amendments and the Energy Independence and Security Act further incorporated greenhouse gases into the regulatory framework. Through renewable energy standards, energy-saving targets, and fuel economy requirements, these policies guided the transformation of the energy consumption structure toward a low-carbon direction.

After rejoining the Paris Agreement, the U.S. federal government further clarified its medium- and long-term policy orientation with respect to emission reduction targets and energy transition pathways. Carbon neutrality goals were gradually incorporated into the national strategic agenda. At this stage, policy priorities were reflected not only in the timelines for emission reduction targets, but also in comprehensive planning for clean electricity, low-carbon transportation, and energy system transformation. These arrangements provided directional constraints for subsequent policy implementation.

Under the federal policy framework, the United States has gradually formed a multi-level governance structure in which subnational policies play an important complementary role (Figure 1-1). Under the federal system, state governments possess considerable legislative and policy autonomy. While complying with the basic requirements of federal environmental laws, states formulate and implement differentiated emission reduction policy instruments based on their own resource endowments, industrial structures, and energy conditions. For example, some states, represented by California, have adopted more stringent emission reduction targets. They have also carried out institutional innovations in areas such as clean electricity standards, promotion of zero-emission vehicles, and the construction of regional carbon trading markets. These subnational policy experiments exhibit a certain "bottom-up" characteristic. They enhance the effectiveness of emission reduction policies and provide practical experience for national-level institutional design.

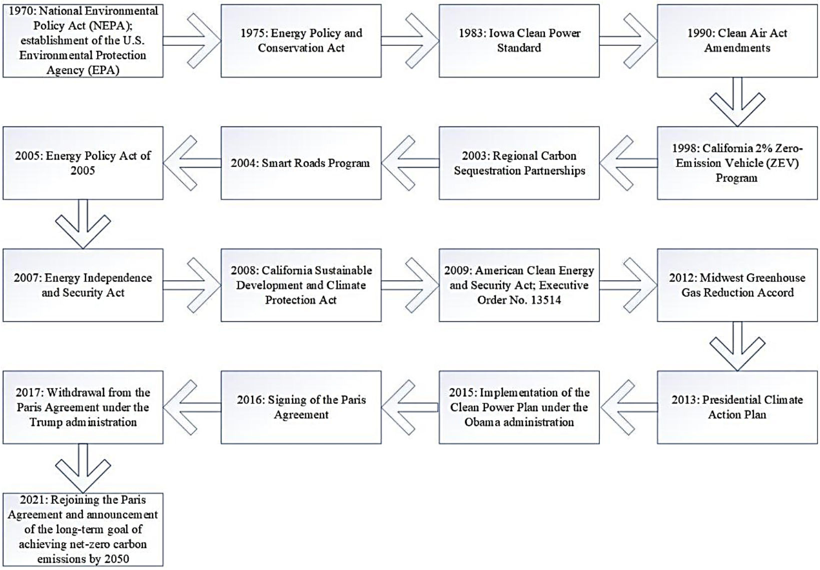

Figure 1-1: U.S. Carbon Neutrality Policy Framework

Source: Compiled by the author based on publicly available information

A comprehensive review of federal and state-level policy practices reveals several prominent characteristics of the U.S. carbon neutrality policy framework. First, the vertical governance structure combines federal coordination with subnational autonomy. This arrangement improves policy flexibility but increases cross-regional coordination costs. Second, in terms of target management, emission reduction planning has gradually shifted from relative indicators to constraints based on absolute emission levels. This shift enhances the verifiability of policy objectives. Third, in terms of policy focus, the carbon neutrality pathway relies heavily on energy structure adjustment. Low-carbon transformation in the power, transportation, and industrial sectors plays a particularly important role.

Within this policy framework, the United States has established several key milestones in its medium- and long-term planning. These nodes provide phased guidance for the carbon neutrality pathway. As shown in Table 1-1, the years 2030, 2035, and 2050 are designated as core milestones. They correspond respectively to the "decisive decade" for emission reduction, full decarbonization of the power system, and the long-term national goal of achieving carbon neutrality. This sequential planning is relatively clear at the level of target setting. However, whether these targets can be effectively realized under real-world conditions depends on policy enforcement strength, the pace of technological progress, and the degree of cross-sector coordination.

Table 1-1: Key Time Nodes for Carbon Emission Control in U.S. National Policy Planning[11]

Year	2030	2035	2050
Policy Objectives	Total carbon emissions are to be reduced to 5 $GtCO_2e$ during 2020–2025 and further reduced to 3.2–3.3 $GtCO_2e$ during 2025–2030.	Achieve 100% clean electricity generation and realize full decarbonization of the power sector.	Achieve net-zero emissions across broader socio-economic systems, including international aviation and maritime transport.
Significance	These targets correspond to the nationally determined	When combined with electrification on the energy	Achieving net-zero emissions at the national level represents

Year	2030	2035	2050
	contribution (NDC) target years and constitute a critical foundation for achieving carbon neutrality by 2050. This period is often referred to as the "decisive decade."	consumption side, these objectives represent a key technological pathway for achieving both the 2030 interim targets and the 2050 long-term goal.	the most important milestone in the realization of current carbon neutrality objectives.

1.2.2 State-led Carbon Pricing Mechanisms and Institutional Characteristics

At the level of specific policy instruments, carbon pricing mechanisms have gradually become an important component of the U.S. carbon neutrality policy system. Carbon pricing internalizes the cost of greenhouse gas emissions. It guides market participants to balance emission reduction efforts against economic returns. For this reason, it is widely regarded as an effective means of reducing overall social mitigation costs[12]. The United States introduced emissions trading concepts at an early stage in air pollution control. Under the framework of the Clean Air Act, early emissions trading systems were established. These systems provided an institutional foundation for the subsequent development of carbon markets. The evolution of carbon pricing mechanisms in the United States is summarized in Table 1-2.

Table 1-2: Evolution of Carbon Pricing Mechanisms in the United States

Year	Measures
1990	The U.S. government began to explore the role of an emissions trading system (ETS) in reducing air pollutant emissions and enacted the Clean Air Act, which established the first emissions trading system.

Year	Measures
1997	The United States signed the Kyoto Protocol, under which carbon emission allowances were recognized as tradable commodities, and three flexible carbon mitigation mechanisms were proposed.
2003	The United States initiated discussions on introducing carbon trading markets to strengthen constraints on and guidance for carbon dioxide emissions.
2005	California launched a state-level cap-and-trade program under the Global Warming Solutions Act (AB 32), which sets upper and lower emission limits for firms and converts emission allowances into tradable carbon permits.
2009	The U.S. House of Representatives passed the American Clean Energy and Security Act, which included provisions for establishing a more comprehensive carbon trading market and promoted the Regional Greenhouse Gas Initiative (RGGI).
2012	California implemented a cap-and-trade system covering multiple emission sources.
2014	The California carbon trading market was linked with the Quebec carbon market in Canada.
2018	The California carbon trading market was linked with the Ontario carbon market in Canada.
2021	The Biden administration announced the rejoining of the Paris Agreement, committed to more stringent emission reduction measures, and considered restoring a federal-level carbon pricing mechanism.

Source: ICAP China Carbon Emissions Trading Network

Unlike some countries that have established unified national carbon trading systems, carbon pricing in the United States has developed primarily through state-led and regionally fragmented arrangements. Due to difficulties in federal legislative coordination and fluctuations in political cycles, the United States has not yet formed a nationwide carbon trading market. Instead, regional carbon markets have been promoted by individual states or interstate alliances. Among these, the Regional Greenhouse Gas Initiative (RGGI) and the California cap-and-trade system are the most representative institutional practices[13].

In terms of emission caps, allowance auctions, and trading mechanism design, these regional markets exhibit a high degree of similarity with mainstream international carbon market systems.

From the perspective of operational outcomes, regional carbon markets have played a role in guiding emission reduction through price signals. In recent years, allowance auction prices in the RGGI market have shown an overall upward trend (Figure 1-2). This trend reflects the gradual tightening of emission constraints and changes in market expectations regarding the value of carbon allowances (Figure 1-3).

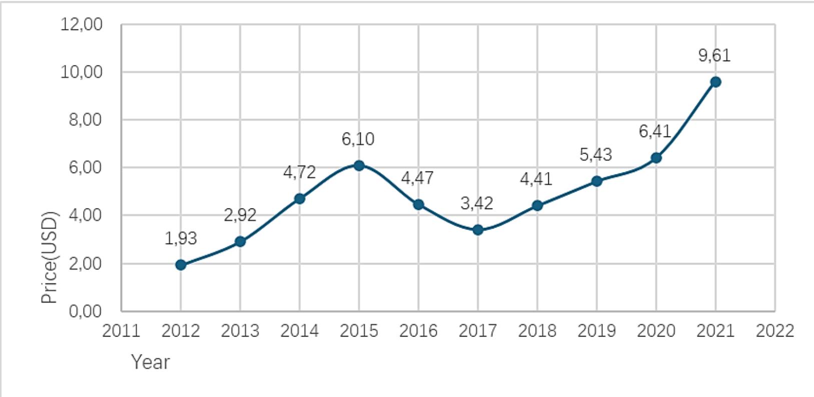

Figure 1-2: Annual Clearing Prices of RGGI Allowance Auctions

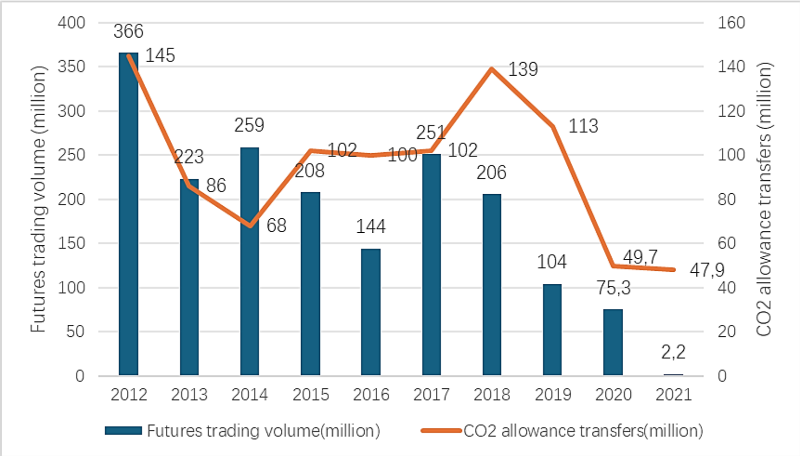

Figure 1-3: Trading Volume of RGGI CO_2 Allowances and Allowance Futures

Data source: RGGICO Market Annual Report. https://www.rggi.org/

However, it should be noted that differences remain across regional carbon markets. These differences relate to coverage scope, covered sectors, and institutional rules. Institutional fragmentation objectively weakens the coordinated effect of carbon pricing mechanisms at the national level. While state-led arrangements have generated valuable practical experience, they also create real challenges for coordination and integration in the future construction of a unified carbon pricing system.

1.2.3 Summary of the Policy System

Overall, the United States has established a carbon neutrality policy system that covers both federal and state levels and advances through multiple policy instruments in parallel. This system exhibits certain advantages in terms of institutional completeness and policy diversity. At the same time, it also faces problems such as a fragmented governance structure, high policy coordination costs, and potential