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An Analysis of the Current State and Future Trends in Climate Finance Research

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Abstract

Climate finance constitutes a pivotal driver of global climate governance. Drawing upon bibliometric methodology, this study presents a comprehensive review of climate finance research spanning the period from 2015 to 2024. The analysis reveals a notable asymmetry in existing research perspectives, characterized by a "mitigation-dominant" imbalance, with insufficient scholarly attention devoted to adaptation financing and issues of distributive justice in fund allocation. Core research themes predominantly concentrate on the impact of climate policies on climate finance efficacy, as well as the catalytic role of climate finance in fostering energy economy transitions and low-carbon technological advancement. However, extant scholarship primarily emphasizes aggregate assessment, while lacking dynamic analyses of capital flow tracking and the allocation of transnational responsibilities. Future research endeavors should transcend prevailing climate policy frameworks, expand the scope of climate financing subjects and objects, strengthen information disclosure mechanisms among multiple financing entities, and enhance investigations into the economic consequences of climate finance.

Keywords

Climate Finance; Funding Governance; Climate Governance

1. Introduction

The concept of climate finance originated under the framework of the United Nations Framework Convention on Climate Change (UNFCCC). It refers to subnational, national and transnational financing flows sourced from public, private or alternative channels, which are earmarked to support climate change mitigation and adaptation actions. Existing academic literature posits that climate finance is a type of financial innovation designed to improve energy efficiency and advance energy transition[1]. By providing financial support for the research, development and deployment (RD&D) of low-carbon technologies, climate finance can accelerate the commercialization and diffusion of such technologies[2], thereby facilitating the low-carbon transition of developing countries[3].However, compared with

project-oriented financing mechanisms, climate finance expenditure modalities supporting price-based national policies have more prominent comparative advantages. Meanwhile, climate policy uncertainty exerts significant impacts on multiple dimensions including corporate green investment and carbon emission performance[4-6] In addition to the impacts of policy uncertainty, climate finance faces a range of other constraints. For instance, the allocation of climate finance presents a salient imbalance: a disproportionate share of capital flows to climate change mitigation projects, while adaptation finance accounts for a relatively low proportion of aggregate climate finance and is also subject to uneven distribution [7]. This structural allocation bias leaves climate-vulnerable regions with weak governmental institutions lacking necessary financial support for climate change response[8].Taken together, as a foundational theoretical research topic, no fully consistent consensus has been reached on the conceptual connotation of climate finance. Core issues including climate finance instruments, capital allocation mechanisms, the pathways through which climate finance facilitates low-carbon transition in developing countries, and the heterogeneous impacts of climate policy uncertainty still require further in-depth exploration.

Research Contributions of This Study: (1) Using CiteSpace-based bibliometric analysis, this study reviews global climate finance research, examining publication trends, methods, and core topics. Existing studies mainly focus on policy, energy, and climate change, particularly the heterogeneous effects of climate policies on finance performance and the role of climate finance in promoting renewable energy and low-carbon technologies.(2) Three major research gaps are identified: the lack of a systematic theoretical framework for climate finance policies and structures; an overemphasis on mitigation finance at the expense of adaptation finance; and the concentration of research in developed countries, which marginalizes evidence from developing nations.(3) Accordingly, this study proposes future research directions: expanding beyond existing policy frameworks to include broader actors and targets, prioritizing information disclosure mechanisms for multiple financing entities, and advancing research on the macro- and micro-level economic impacts of climate finance.

2. Data Sources and Research Methods

2.1. Data Sources

The data of this study are extracted from the Science Citation Index Expanded (SCI-E) and Social Sciences Citation Index (SSCI) in the Web of Science (WoS) Core Collection database. To systematically sort out international research on climate finance, the retrieval strategy is designed as follows: The search query is set as the subject term "climate finance" under the WoS Topic (TS) field (covering title, abstract and keyword fields) to ensure capture of all core climate finance research topics; the time range is set from 2015 (the year of the adoption of the Paris

Agreement) to 2024; publication types are limited to peer-reviewed journal articles and review papers, to exclude non-original academic outputs including conference abstracts, book reviews and editorial materials. Finally, we manually screened the titles, keywords, abstracts and full texts of the initially retrieved publications, and obtained a final analytical sample of 345 publications highly relevant to the core research theme of climate finance.

2.2. Research Methods

This study adopts the bibliometric analysis method, with the analytical framework arranged as follows: First, we analyze the annual publication output of the sample to clarify the evolutionary trend of research in the climate finance field. Second, we conduct keyword analysis on the sample: we map the strategic coordinate diagram of keywords to identify the core research domains of climate finance; we further perform keyword co-occurrence and clustering analysis to unpack the thematic structure, hot topic distribution and knowledge evolution trend in the field. Finally, we systematically collate and synthesize existing research findings through in-depth interpretation of core representative publications in the sample. All the above analyses are implemented using CiteSpace (version 6.4.R1).

3. Literature Data Analysis

3.1. Annual Publication Output Analysis

We plot the time-series trend chart of annual publication output of international climate finance research, as presented in Figure 1.

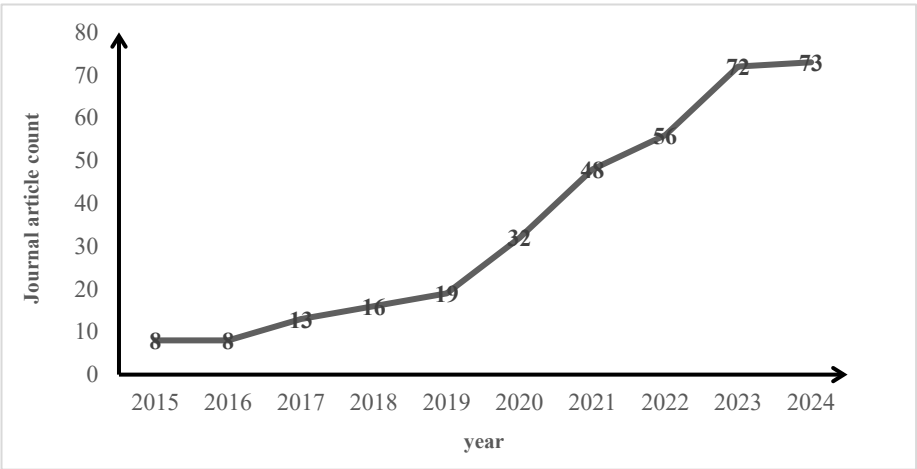


Figure 1. Time-series Trend Chart of Annual Publication Output in Climate Finance Research

As shown in Figure 1, the annual publication output of international climate finance research exhibited a gradual upward trend from 2015 to 2018, expanded at a significantly faster pace during 2018–2022, and reached its peak over the sample observation period in 2022–2024.The marked upward trajectory of climate finance research after 2015 can be attributed to the adoption of the Paris Agreement at the

21st Session of the Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change held in December 2015. The subsequent signing of the Agreement sparked widespread research interest among the global academic community in studies on climate mitigation and adaptation finance.

3.2. Keyword Analysis

3.2.1. Strategic Coordinate Analysis of Keywords

The strategic coordinate diagram is a visualization tool developed on the basis of keyword clustering analysis. It positions keywords in a two-dimensional coordinate system by calculating two core indicators for each keyword: density and centrality, so as to intuitively demonstrate the relative position and evolutionary trend of different research themes in a specific research field. Following the methodological framework proposed by Callon et al.[9], we set the centrality of keywords as the Y-axis and the occurrence frequency of keywords as the X-axis, with the median values of the two indicators taken as the coordinate origin to plot the strategic coordinate diagram of keywords. Specifically, the occurrence frequency of a keyword captures the connection strength of basic knowledge units within the corresponding research theme: a higher frequency indicates higher research maturity of the theme. The centrality of a keyword measures the strength of its association with other keywords: a higher centrality value indicates a more prominent core position of the corresponding theme across the entire research field. Given the excessively high occurrence frequency of the generic keywords climate change and climate finance, we exclude these two terms prior to plotting to avoid introducing substantial bias into the bibliometric analysis. The final strategic coordinate diagram of keywords for the sampled climate finance literature is presented in Figure 2.

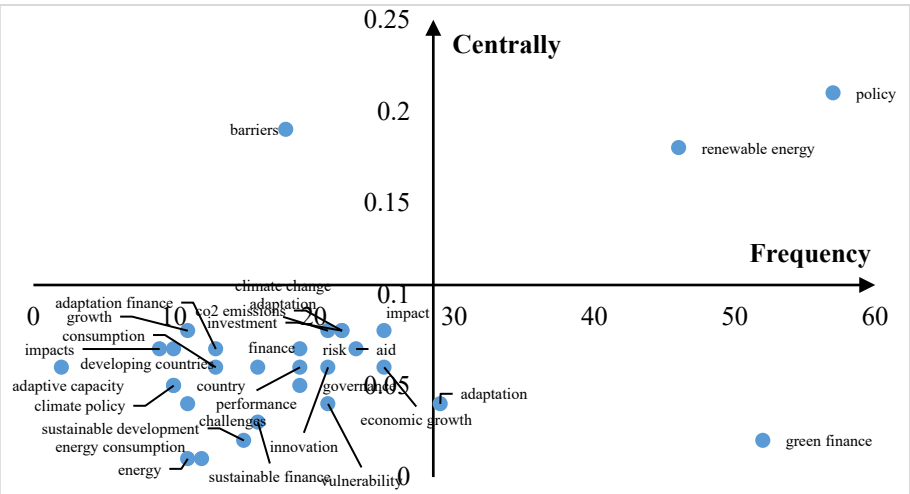


Figure 2. Strategic Coordinate Diagram of Keywords for Climate Finance Literature

As illustrated in Figure 2, the four quadrants exhibit distinct characteristics as outlined below:

Quadrant I: Keywords here show high maturity, strong interconnections, and central importance, with both high frequency and centrality. Renewable energy and policy are key hotspots, indicating strong academic attention to climate and climate finance policies.

Quadrant II: These keywords represent in-depth but weakly connected themes, with high centrality and low frequency. "Barriers" can be integrated with Quadrant III topics such as finance, sustainable development, and energy transition to advance research on financing constraints and transition challenges.

Quadrant III: Keywords here reflect underdeveloped and weakly connected themes, with low frequency and centrality, representing either emerging or declining topics. The future of areas like energy consumption, economic growth, and climate adaptation depends on their integration with other fields. Notably, climate adaptation finance shows strong potential as a future hotspot.

Quadrant IV: These keywords indicate less in-depth but closely connected themes, with high frequency and low centrality, showing foundational and interdisciplinary features. Green finance is relatively mature and can further integrate with emerging fields.

3.2.2. Keyword Co-occurrence and Clustering Analysis

The keyword co-occurrence network map is presented in Figure 3. The network comprises 334 nodes and 988 inter-node links, with an overall network density of 0.0178, which indicates that the research themes of climate finance are widely distributed with extensive coverage and a broad academic scope. A "diversified, multi-branched" theoretical research landscape has been formed centering on core themes including climate change, climate finance, green finance, renewable energy and policy.

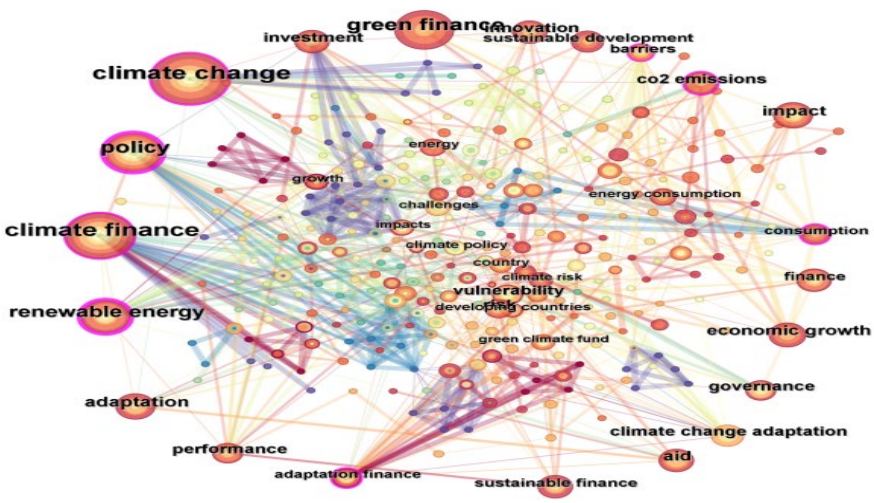


Figure 3. Keyword Co-occurrence Network Map of Climate Finance Research Field

To further verify the distribution of hot research themes in the climate finance field, we introduce a specialized formula to determine the threshold of high-frequency

keywords. This formula is developed based on Donohue-Zipf's Second Law[10]: $T = {}^{1}/_{2} \times \left[-1 + \sqrt{(1 + 8 \times I)}\right]$,where T denotes the minimum occurrence frequency threshold for high-frequency keywords, and I denotes the number of distinct keywords in the sample.

The keyword clustering map is presented in Figure 4. A total of 11 clusters (numbered #0 to #10, with a smaller cluster ID indicating a larger number of keywords within the cluster) are identified in climate finance research.

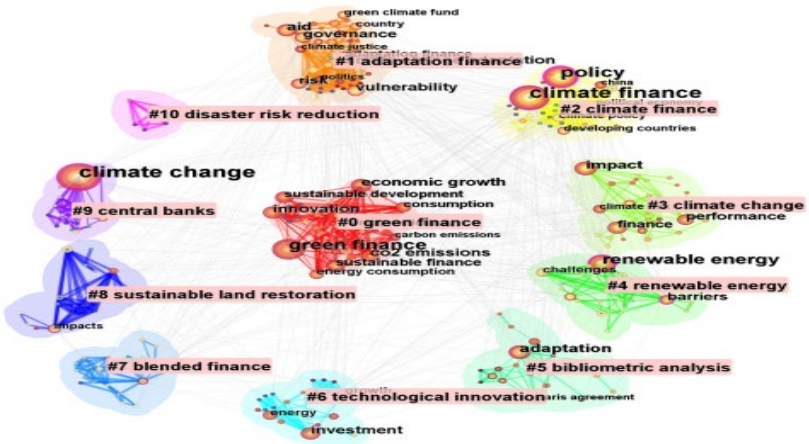


Figure 4. Keyword Clustering Map of Climate Finance Research Field

Publications in Clusters #0, #1, #2 and #7 focus on climate investment and financing, including climate finance, green finance, and adaptation-aligned development. Cluster #0 examines sustainable development and carbon-related issues within green finance; Cluster #1 addresses governance, climate justice, and support for LDCs; Clusters #2 and #7 explore financing mechanisms such as blended finance, multi-stakeholder participation, financing gaps, and policy impacts on finance flows.

Clusters #3, #8, #9 and #10 focus on climate-related challenges. Clusters #3 and #9 analyze climate change impacts and institutional responses, while Clusters #8 and #10 address disaster risk reduction and land restoration through climate finance.

Clusters #4, #5 and #6 center on energy and technological innovation. Cluster #4 examines barriers to renewable energy deployment; Cluster #5 provides bibliometric analyses; Cluster #6 explores technological solutions for scaling renewable energy.

Overall, climate finance research shows four key features:

(1) Research growth is closely linked to climate policy, with rapid expansion after the Paris Agreement and maturation after 2023.

(2) Core themes focus on energy transition and policy, with renewable energy, climate policy, and carbon emissions as central topics, while adaptation finance

remains peripheral but promising.

(3) Research forms a "three-pillar" structure: financing mechanisms, climate impacts and adaptation, and energy technology innovation.

(4) Significant imbalance exists, with developed countries dominating research and mitigation finance prioritized, while adaptation, transparency, and governance remain underexplored.

4. Further Analysis Based on Literature Content

4.1. Further Analysis of Climate Finance Policy and Model Research

4.1.1. Further Analysis of Climate Finance Policy Research

Climate policy exerts profound, multi-layered impacts on the development of climate finance: it can guide capital flows and unlock market dynamism through institutional design, but may also pose structural challenges due to variations in the effectiveness of different policy instruments. The Paris Agreement establishes the core institutional framework for climate finance provision from developed to developing countries through legally binding financing obligation clauses, which stipulate that developed countries shall assume quantified climate finance obligations to mobilize at least USD 100 billion per year between 2020 and 2025 to support climate action in developing countries. This mandatory rule has not only served as a key driver for improving the global climate policy system, but also exerts complex impacts on capital flows due to uncertainties in policy implementation. The quantified financing target set by the Paris Agreement has compelled developed countries to accelerate domestic policy innovation, guiding public and private capital to flow into low-carbon sectors through policy tools including carbon pricing mechanisms, green finance standards and public fund leverage[11]-[12]. This has driven the scale of global climate finance to climb from an average annual volume of less than USD 60 billion before the Agreement was signed to the current USD 100-billion level. However, the actual effectiveness of climate finance policy instruments is constrained by multiple structural contradictions: On the one hand, delayed progress in fulfilling financing commitments by developed countries and the distortion of financing modalities (e.g. excessive reliance on non-grant loans) have undermined policy credibility, raised financing costs and debt risks for developing countries accessing climate funds, and dampened the willingness of private capital to participate[13]. On the other hand, national climate policies are constrained by political cycles, disputes over technological pathways, and limitations of climate economics and financial risk models, making it difficult to fully capture the characteristics of climate risks and the needs of climate adaptive transition. This further exacerbates climate policy uncertainty[14], which in turn intensifies climate financing constraints[15].

To summarize, existing research on climate finance policy can be categorized into three streams: First, studies on climate policies introduced by countries after the

Paris Agreement and their impacts on climate capital flows; second, in-depth discussions on the drivers of climate policy uncertainty; third, research on the impacts and influencing mechanisms of climate policy uncertainty. Current studies are mostly based on static panel data, and future research can be strengthened in areas including dynamic policy simulation and cross-country comparative analysis.

4.1.2. Further Analysis of Climate Finance Model Research

In response to the structural contradictions between the Global North and Global South in climate responsibility sharing, scholars have constructed multi-dimensional decision-making models. Urpelainen developed a game theory model incorporating recipient countries' participation incentive mechanisms, capacity building and private capital mobilization to address strategic issues in North-South climate finance cooperation[16]. To quantify the marginal emission reduction effectiveness of capital input, GU et al. constructed a climate-economy-technology integrated assessment model (IAM) named CIECIA-TD-F[17] to examine the effects of low-carbon technology financing on climate mitigation, technology diffusion and economic development in the context of climate change cooperation, and concluded that the carbon emission reduction effect is limited under the currently pledged scale of climate finance. To help policymakers simulate and assess climate risks and identify more effective climate financing schemes, Chukwudum et al. proposed a candidate climate finance model, the Burr mixture model[18]. To address the demand for dynamic adjustment of climate finance policies in response to climate change and solve multi-criteria decision-making problems, Haseli proposed a novel group decision support model adopting the Logarithmic Methodology of Additive Weights (LMAW) and the Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) framework[19].

In addition, existing research reveals a non-linear association between capital flows and climate vulnerability: the relationship between adaptation finance and vulnerability follows a parabolic curve[7], indicating that countries with "moderate vulnerability" may receive more funding than "most vulnerable" countries[20]. Therefore, the construction of climate finance management models needs to incorporate more contextual factors. Climate finance management models involve multiple dimensions and are affected by various factors; meanwhile, there are persistent inequities in climate finance governance, which requires strengthened oversight of distributive justice in climate fund allocation.

4.2. Further Analysis of Research on the Application of Climate Finance in Energy Economics and Technology Fields

First, climate finance plays a critical role in promoting global low-carbon economic development and energy transition. International climate finance can enhance the climate adaptation capacity of developing countries, especially Small Island

Developing States (SIDS), help them achieve their national self-determined development objectives, and facilitate energy transition and sustainable development[21]. The impact of climate finance on economic growth is complex and multi-dimensional: studies by Li et al. show that climate finance aid promotes the optimization of the energy mix in recipient countries and drives the displacement of coal consumption by renewable energy[22]. It can boost economic growth by supporting low-carbon and climate adaptation-aligned projects[23]. Official aid-funded climate finance can strengthen catalytic mechanisms: for example, the Advance Market Commitment (AMC) can play a greater role in facilitating deep decarbonization of heavy industries in developing countries, thereby effectively reducing the carbon emission levels of recipient countries[24]. It can also provide necessary funding for clean technology and renewable energy projects in recipient countries, facilitate green economic development, and deliver best practices for achieving climate targets and environmental sustainability[25], thus creating jobs, improving energy efficiency, advancing economic restructuring and reducing transition costs[26]. However, the returns on such investments may take an extended period to materialize[27], and their short- and long-term impacts on economic growth may diverge.

Second, climate finance plays a key role in promoting technological innovation. As an effective policy instrument, climate finance can support green innovation and enterprise development, and enhance the R&D and absorptive capacity of developing countries for low-carbon technologies[17]. It can help countries receiving climate finance improve their innovation capacity and facilitate the application and diffusion of low-carbon technologies[21], which in turn encourages funded enterprises to carry out green technology innovation and improves their carbon emission efficiency[28]. In addition, climate finance can accelerate technological innovation in health and agricultural systems, promote the development of climate-smart agriculture (CSA), and improve the climate resilience of health systems and the agricultural sector[29]-[30].

To summarize, existing studies have revealed the core roles of climate finance in energy structure transition and technological innovation: first, accelerating the displacement of coal by renewable energy through capital injection to reduce fossil energy intensity; second, catalyzing low-carbon technological innovation in heavy industries, such as using the AMC mechanism to break decarbonization bottlenecks in energy-intensive sectors including steel and cement. However, existing research has three major limitations: First, it focuses heavily on the energy supply side, ignoring transmission mechanisms such as demand-side electricity pricing reform and energy poverty. Second, there is insufficient estimation of systemic costs required for renewable energy grid integration and accommodation, including energy storage investment and smart grid supporting facilities. Third, the correlation between stranded fossil fuel asset risks and financing exit mechanisms has not been

fully revealed. Future research should strengthen intertemporal cost-benefit analysis of energy system transition, explore synergistic pathways between the Carbon Border Adjustment Mechanism (CBAM) and climate finance, and quantify differences in financing leverage effects under different energy technology pathways.

4.3. Further Analysis of Research on Climate Change Adaptation and Response

Climate finance and its supporting measures can effectively alleviate hunger and poverty among residents in impoverished regions[31], and improve food supply and overall food security in climate-vulnerable areas[32]. Climate finance has a significant positive impact on environmental sustainability and social development, but is constrained by population size, income heterogeneity and types of climate finance. It can support green growth in sectors including renewable energy, agriculture and forestry, and enhance national climate adaptive capacity[33]. Climate finance mechanisms can redirect climate-damaging capital toward climate-compensatory water infrastructure to improve global water security[34].

In climate change response, attention must be paid to the issue of distributive justice in climate finance. Grasso’s research indicates that climate finance should align with the framework of procedural justice and distributive justice[35], but this framework is often not fully implemented in practice. Studies by Schulan and Heilinger identify three core drivers of climate finance injustice: First, vulnerable groups that originally had no need to adopt defensive adaptation measures are forced to bear adaptation costs due to climate crises caused by other parties. Second, the adaptation finance gap continues to widen: Global North countries have neither provided sufficient funding to mitigate climate risks nor fulfilled their established financing commitments. Third, injustice is rooted in procedural failures of existing climate fund allocation criteria, where the allocation mechanism for scarce resources instead solidifies structural oppression[36]. Establishing a new monitoring and reporting mechanism centered on "adaptation-led investment" and enhancing the alignment of private capital with standards across dimensions including predictability, transparency and mobilization efficiency[37] are critical measures to address the climate adaptation finance gap and climate injustice.

To summarize, existing research reveals that climate injustice stems from imbalanced responsibility allocation, widening funding gaps and procedural failures, indicating that the public sector needs to refine financing evaluation models and catalyze private capital provision to solve the climate adaptation funding shortage. Future research should strengthen synergistic studies on climate justice theoretical frameworks and financing instrument innovation, with a particular focus on institutional design for shared responsibility and fund redistribution between Global North and Global South countries, to build a comprehensive allocation paradigm that balances procedural justice and implementation effectiveness.

5. Research Conclusions and Future Research Priorities

5.1. Research Conclusions

Employing the bibliometric analysis method, this study conducts visualization analysis and systematic interpretation of international climate finance literature published from 2015 to 2024, and draws the following conclusions: First, although the volume of climate finance literature has shown a prominent upward trend after the signing of the Paris Agreement, all relevant studies are carried out under the framework of the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate finance as primarily public capital. For example, existing studies note that China's climate finance sources include public funds provided by developed countries in the form of grants and concessional loans, as well as domestic capital from policy banks and social security funds, and that a considerable climate financing gap persists. Second, core research priorities in the climate finance field, including renewable energy, energy transition and low-carbon technologies, all fall under the domain of mitigation finance, while research on adaptation finance is significantly insufficient. In terms of methodology, most existing studies adopt the multiple regression approach based on static panel data. Third, although some scholars have developed research models for climate finance governance, these models are mainly applied to assessing the overall development trend of climate finance, while research on core issues including the delimitation of climate responsibilities between developed and developing countries, climate fund allocation and monitoring mechanisms is notably insufficient.

5.2. Future Research Priorities

As a core issue of global low-carbon transition, climate finance is currently faced with a large funding gap and significant divergences between developed and developing countries on funding scale, sources and allocation structures. Against this background, research needs to be strengthened in the following aspects:

5.2.1. Break Through the Constraints of Existing Climate Policy Frameworks and Expand the Scope of Participating Subjects and Target Objects of Climate Finance

Climate finance corresponds to climate projects, which can be categorized into three types: pure public goods, private goods and mixed goods (i.e. impure public goods). Adaptation finance aligns more with the positioning of public goods, which are supported by public capital. Research should first conduct modeling analysis based on historical, current and projected greenhouse gas emissions generated by economic development across countries, determine appropriate parameter ratios to improve the delimitation of climate responsibilities between developed and developing countries in climate finance models. Second, comprehensive assessment should be carried out based on the incurred loss and damage from climate disasters

in each country and potential losses caused by global warming, to determine the scale of public funding support for each region. Third, research on climate fund use monitoring mechanisms and performance evaluation should be strengthened, to strictly verify whether fund use falls within eligible climate-related fields. Mitigation finance targets specific industries and fits the positioning of mixed goods with incomplete non-rivalry and non-excludability, which correspond to blended finance. Research on sector-specific climate finance should be enhanced for this category. Private goods, such as the development and operation of climate ecological functional zones, conform to the profit-seeking nature of capital and fall under the research scope of patient capital. Such goods are supported by private sector capital, dominated by corporate equity investment. Future research should further standardize the statistical framework of climate finance models, and strictly distinguish between public and private capital sources to avoid double-counting, which may lead to overestimation of the contribution of private capital.

5.2.2. Strengthen Research on Climate Finance Information Disclosure

The multi-stakeholder nature of climate finance leads to differentiated information disclosure mechanisms, which requires further in-depth research. Research on information sharing platforms should also be prioritized: such platforms can be developed as an integrated third-party certification and service system covering functions including climate finance policy release, industry standard formulation, climate project management, and monitoring and reporting. To avoid redundant platform construction, research should identify which climate finance indicators can be incorporated into the ESG (Environmental, Social and Governance) framework, including both corporate ESG and government ESG systems. As research on government ESG is still in its infancy, future studies should focus on the synergy mechanisms between government ESG and corporate ESG.

5.2.3. Strengthen Research on the Economic Consequences of Climate Finance

At the macro level, research should focus on the economic and social benefits of climate finance in areas including public finance, international capital flows and green transition. Public finance and social welfare: Research should estimate the scale of capital raised by governments through climate finance and its impact on fiscal deficits or debt levels, and monetize the economic value of environmental performance delivered by climate finance in terms of social welfare gains. International capital flows and global cooperation: Research should examine whether climate finance provided by developed to developing countries alleviates the unequal distribution of global emission reduction costs, and analyze whether climate finance promotes international technology transfer and trade cooperation. Economic growth and green transition: Research should analyze how climate finance promotes low-carbon technology investment and green industrial upgrading to drive GDP

growth, and evaluate whether climate finance mitigates the contraction risk of traditional high-carbon industries to balance short-term adjustment costs and long-term benefits in economic transition.

At the micro level, research should focus on the direct impacts of climate finance on enterprises: Corporate investment decision-making: Research should analyze whether climate finance instruments can lower the investment threshold for low-carbon technologies for enterprises, and evaluate the long-term benefits obtained by enterprises through climate finance (e.g. energy cost savings, carbon asset appreciation). Project feasibility assessment: Research should compare the risk-return ratios of traditional projects and climate-friendly projects, and explore how climate finance improves the financial viability of climate-friendly projects through subsidies, guarantees or risk-sharing mechanisms. Consumer behavior and market incentives: Research should analyze the role of climate finance in promoting green product consumption, and evaluate how mechanisms such as carbon labeling and green certification guide consumers to choose low-carbon products through market signals.

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