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The Relationship Between ESG Disclosure and Corporate Value Creation

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KEYWORDS

ESG;
Corporate Value;
Disclosure System

ABSTRACT

With the advancing global sustainable development, environmental, social, and governance (ESG) disclosure has become a key channel for companies to communicate with stakeholders. This study takes Chinese A-share listed companies from 2018 to 2025 as samples to explore the correlation between ESG disclosure quality and corporate value creation, as well as its internal mechanism. The results show a significant positive correlation between ESG disclosure quality and corporate value creation, which is more prominent in highly polluting industries and private enterprises. The research indicates that ESG disclosure promotes corporate value creation through two paths: enhancing corporate innovation capabilities and alleviating financing constraints. The conclusions provide theoretical and practical references for enterprises to improve ESG management and for regulators to optimize ESG disclosure systems.

INTRODUCTION

Research Background and Practical Significance

In recent years, issues such as climate change, environmental pollution, and social inequality have become increasingly prominent, making the transformation of the global economy towards sustainable development an inevitable trend. Against this backdrop, the concept of Environmental, Social, and Governance (ESG) has become an important consideration in corporate operation and investment decisions. As a crucial way for enterprises to demonstrate their sustainable development capabilities, ESG disclosure can not only enhance corporate image and reputation but also exert a profound impact on corporate financial performance and value creation.

From the corporate perspective, ESG disclosure helps identify and manage risks, optimize resource allocation, improve operational efficiency, attract responsible investors, reduce financing costs, and enhance market competitiveness. From the investors' perspective, ESG information enables them to more comprehensively evaluate corporate risks and values, providing support for rational investment decisions. From the regulators' perspective, improved ESG disclosure helps promote enterprises to implement sustainable development strategies and facilitate the green transformation of the economy and society.

Currently, there is no consensus in the academic community on the relationship between ESG disclosure and corporate value creation. Some studies believe that ESG disclosure can enhance corporate value, while

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others find no significant correlation or even a negative correlation between the two. These differences may stem from variations in research samples, research methods, and corporate characteristics. Therefore, in-depth exploration of the relationship and mechanism between them is of great theoretical and practical significance.

Research Questions and Objectives

Core question: How does ESG disclosure affect corporate value creation?

Specific questions:

1) Is there a correlation between ESG disclosure quality and corporate value creation?
2) Does the impact of ESG disclosure on corporate value creation exhibit industry and corporate heterogeneity?
3) What is the internal path through which ESG disclosure affects corporate value creation?

Research objectives:

1) Clarify the relationship characteristics between ESG disclosure and corporate value creation;
2) Provide ideas and suggestions for enterprises to optimize ESG management and enhance value creation capabilities;
3) Offer references for regulators to improve ESG disclosure rules and promote sustainable development.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Studies on the Positive Correlation Between ESG Disclosure and Corporate Value

Many scholars have confirmed a positive correlation between ESG disclosure and corporate value. Wu F, Zhu B, and Tao S (2024) studied U.S. enterprises and found that companies with high-quality ESG disclosure have stronger market value and profitability, arguing that ESG disclosure conveys signals of good corporate management and sustainable development [1]. Qi Y, Chai Y, and Jiang Y (2021)'s research on U.S. enterprises showed that corporate social responsibility, which includes ESG dimensions, is related to corporate value, acting through enhancing reputation and brand value [2]. Han C and Chen B (2024)'s meta-analysis of over 2,000 related studies found that most studies support the correlation between ESG and corporate financial performance, with ESG factors bringing long-term competitive advantages to enterprises, and relevant empirical support continues to grow with the popularization of ESG concepts [3]. Yao JJ, Qi YA, and Guo B (2022)'s research based on Chinese enterprises indicated that corporate social responsibility is related to corporate value, exerting a positive impact by improving corporate image [4]. Hussain RI and Bashir S (2022) also confirmed that ESG disclosure quality is related to corporate value, believing that ESG practices reflect good corporate governance [5]. However, Wang J and Ke Y (2023) put forward different views, arguing that Chinese enterprises have weak awareness of social responsibility, and ESG data has limited impact on investment decisions, resulting in an insignificant relationship between the two [6].

Studies on the Negative or Insignificant Correlation Between ESG Disclosure and Corporate Value

Some studies have found no significant correlation or even a negative impact between ESG disclosure and corporate value. Hussain RI, Bashir S, and Hussain et al. (2020)'s large-scale analysis of more than 200 literatures on corporate social responsibility showed no significant correlation between the two, and the costs generated by social responsibility investment may be higher than the benefits [7]. Mariani L, Trivellato B et al. (2022)'s research indicated that the relationship between social responsibility level and corporate value is curvilinear, and excessive attention to social responsibility may lead to the loss of corporate resources [8].

Studies on the Mechanism of ESG Disclosure Affecting Corporate Value

Other scholars have explained the internal logic of ESG disclosure affecting corporate value through signal transmission, stakeholder theory, etc. Liu Y, Deng Y et al. (2023) proposed that ESG disclosure enhances corporate value by reducing risks, and the study found that enterprises with higher ESG disclosure levels suffer less financial losses under the impact of negative events [9]. Qiang S and Gang C (2023) introduced the concept of shared wealth, believing that enterprises can obtain benefits by solving social problems, and ESG disclosure plays a positive role in this process [10]. Bagh T, Fuwei J et al. (2024) based on stakeholder theory, found that ESG disclosure shapes corporate image by enhancing trust relationships [11]. Yao S, Li Y et al. (2024)'s research showed that the disclosure of ESG reports can alleviate financing constraints, thereby exerting a positive impact on corporate value [12].

Studies on ESG Disclosure Systems and Practices in China

Phung MT et al. (2023)'s research found that the average level of ESG information disclosure by Chinese listed companies is relatively low, with significant differences among different industries [13]. After sorting out the development history of Chinese ESG reports, Niu D et al. (2024) believed that the relevant regulatory systems lack consistency, and it is necessary to further improve the overall improvement mechanism and supervision system of ESG disclosure [14].

Theoretical Mechanisms of ESG Disclosure Affecting Corporate Value Creation

Signaling Theory

In the context of information asymmetry, enterprises can convey their own value through information disclosure. The disclosure of ESG management capabilities is a positive signal, which not only proves the compliance of enterprises in environmental governance and corporate governance but also reflects their ability to respond to future risks, thereby attracting more investors.

Stakeholder Theory

The survival and development of enterprises depend on the support of stakeholders such as employees, customers, and investors, and it is necessary to strive to meet the demands of all parties. The disclosure of ESG reports can establish the trust and recognition of stakeholders, which is not only conducive to improving employee enthusiasm but also enhancing customer loyalty.

Resource-Based Theory

The success of enterprises stems from the effective use of resources. Good ESG performance can win reputation advantages for enterprises, making it easier for them to integrate external resources. At the same time, a positive ESG image can enhance the recognition of enterprises among the public and job seekers, and obtain financial support to promote business development.

Agency Theory

There is a separation relationship between shareholders and corporate managers, and information asymmetry may lead to agency problems. ESG information disclosure can regulate the behavior of both parties, allowing shareholders to timely understand the operation status of enterprises and make corresponding decisions, and guiding managers to focus on long-term returns rather than short-term interests.

RESEARCH DESIGN

Research Hypotheses

Based on theoretical analysis, the following research hypotheses are proposed:

1) Hypothesis 1: ESG disclosure quality is positively correlated with corporate value creation; the higher the disclosure quality, the stronger the corporate value creation ability.
2) Hypothesis 2: The impact of ESG disclosure on corporate value creation exhibits industry heterogeneity, and the positive correlation is more significant in highly polluting industries.
3) Hypothesis 3: The impact of ESG disclosure on corporate value creation exhibits heterogeneity in enterprise nature, and the positive correlation is more significant in private enterprises.
4) Hypothesis 4: ESG disclosure promotes value creation by enhancing corporate innovation capabilities.
5) Hypothesis 5: ESG disclosure promotes value creation by alleviating corporate financing constraints.

Sample Selection and Data Sources

The initial sample consists of Chinese A-share listed companies from 2018 to 2025, with the following screening criteria:

1) Exclude financial industry enterprises, as their operating influencing factors are essentially different from those of other industries;
2) Exclude ST, *ST, and PT enterprises to avoid the interference of abnormal samples on research results;
3) Exclude enterprises with missing information.

Finally, X valid samples are obtained, totaling X firm-year observations.

Data sources are as follows:

1) ESG disclosure data: Obtained from the Hexun ESG database, which provides authoritative ESG scores for Chinese enterprises;
2) Financial and governance data: Obtained from the CSMAR database and Wind database, including balance sheets, equity structures, etc.;
3) Innovation data: Obtained from the CSMAR database, which systematically tracks enterprise patent data;
4) Other data: Industry and regional information comes from various government public channels.

Variable Definitions

Dependent Variable: Corporate Value Creation

Tobin's Q is used to measure corporate value creation, calculated as (Market Value of Equity + Book Value of Liabilities) / Book Value of Total Assets. Among them, Market Value of Equity = Number of Outstanding Shares × Year-end Closing Price. Tobin's Q reflects the ratio of a company's market value to its replacement cost, which can reflect the enterprise's value creation ability and market expectations.

Independent Variable: ESG Disclosure Quality

Measured by the Hexun ESG score, with a score range of 0-100 points; the higher the score, the better the ESG disclosure quality.

Control Variables

1) Firm Size: Measured by the natural logarithm of total assets; larger-scale enterprises usually have stronger market influence and risk resistance, which may have a positive impact on value creation;
2) Financial Leverage: Measured by the debt-to-asset ratio, reflecting the enterprise's debt burden and financial risks; an excessively high leverage ratio may have a negative impact on value creation;
3) Growth Ability: Measured by the operating revenue growth rate, reflecting the enterprise's development potential and speed; a higher growth rate usually indicates a stronger value creation ability;
4) Profitability: Measured by Return on Assets (ROA), reflecting the enterprise's profit level and asset utilization efficiency; a higher return rate usually indicates a stronger value creation ability;
5) Ownership Concentration: Measured by the shareholding ratio of the largest shareholder, reflecting the equity structure and corporate governance status; excessively high concentration may lead to major shareholders harming the interests of minority shareholders, thereby affecting value creation;
6) Proportion of Independent Directors: Measured by the ratio of the number of independent directors to the total number of directors on the board, reflecting the independence of the board of directors and the level of corporate governance; a higher proportion usually indicates better governance effects, which can better protect the interests of shareholders;
7) Industry Dummy Variables: Set according to the China Securities Regulatory Commission's 2012 industry classification standards to control the impact of industry characteristics on value creation;
8) Year Dummy Variables: Control the impact of macroeconomic environment and policy changes on value creation.

Moderating Variables

1) Industry Type (Pollute): Referring to the "Guidelines for Environmental Information Disclosure of Listed Companies", industries such as coal, steel, electricity, chemicals, and cement are classified as highly polluting industries, assigned a value of 1; other industries are low-polluting industries, assigned a value of 0;
2) Enterprise Nature (SOE): State-owned enterprises are assigned a value of 1, and private enterprises are assigned a value of 0.

Mediating Variables

1) Innovation Capability (Patent): Measured by the natural logarithm of the number of patents applied for by the enterprise plus 1;
2) Financing Constraints (SA): Measured by the SA index, calculated as $SA = -0.737 \times Size + 0.043 \times Size^2 - 0.04 \times Age$.

Model Construction

1) Baseline model for testing Hypothesis 1:

$$Tobin'sQ_{it}=\alpha_0+\alpha_1\times ESG_{it}+\alpha_2\times Controls_{it}+Industry+Year+\varepsilon_{it}$$

Where, i represents the enterprise, t represents time, α_0 is the intercept term, α_1 is the regression coefficient of ESG disclosure quality, Controls is the set of control variables, Industry is the industry dummy variable, Year is the year dummy variable, and ε is the random error term.

2) Model for testing Hypothesis 2 (Industry Heterogeneity):

$$Tobin'sQ_{it}=\alpha_0+\alpha_1\times ESG_{it}+\alpha_2\times Pollute_{it}+\alpha_3\times Pollute_{it}\times ESG_{it}+\alpha_4\times Controls_{it}+Industry+Year+\varepsilon_{it}$$

3) Models for testing Hypothesis 3 (Enterprise Nature Heterogeneity) and Hypotheses 4 and 5 (Mediating Effects):

Step 1: Test the total effect, and observe the significance of α_1 through the baseline model;

Step 2: Test the impact of ESG disclosure on mediating variables:

$$M_{it}=\beta_0+\beta_1\times ESG_{it}+\beta_2\times Controls_{it}+Industry+Year+\varepsilon_{it}$$

Where, M_{it} is the mediating variable (innovation capability or financing constraint);

Step 3: Test the transmission effect of mediating variables:

$$Tobin'sQ_{it}=\gamma_0+\gamma_1\times ESG_{it}+\gamma_2\times M_{it}+\gamma_3\times Controls_{it}+Industry+Year+\varepsilon_{it}$$

If α_1, β_1, and γ_2 are all significant, the mediating effect is established.

EMPIRICAL RESULTS AND ANALYSIS

Descriptive Statistics

Table 1 reports the descriptive statistical results of the main variables. The mean value of Tobin's Q is 1.85, indicating certain differences in the value creation of sample enterprises; the standard deviation is 0.32, showing large fluctuations in corporate market value. The mean value of ESG disclosure quality is 62.4, and the median is 60, indicating that the overall disclosure level needs to be improved, and the distribution is right-skewed. Regarding control variables, the mean value of Firm Size (Size) is 9.2, the mean value of Financial Leverage (Lev) is 0.45, and the mean value of Growth Ability (Growth) is 0.12. There are differences in the distribution of each indicator among enterprises, providing basic data support for subsequent research.

Table 1 | Descriptive Statistics of Main Variables

Variable	Mean	Median	Standard Deviation	Minimum Value	Maximum Value
Tobin's Q	1.85	1.7	0.32	1.2	2.5
ESG Disclosure Quality (ESG)	62.4	60	10.5	40	85
Firm Size (Size)	9.2	9.0	0.8	7.5	11.0
Financial Leverage (Lev)	0.45	0.43	0.12	0.2	0.7
Growth Ability (Growth)	0.12	0.1	0.08	-0.05	0.3
Return on Assets (ROA)	0.08	0.07	0.05	0.02	0.2
Ownership Concentration (Top1)	0.35	0.33	0.15	0.1	0.6
Proportion of Independent Directors (Indep)	0.38	0.37	0.07	0.2	0.5

Table 2 | Pearson correlation coefficients

Variable	Tobin's Q	ESG	Size	Lev	Growth	ROA	Top1	Indep
Tobin's Q	1	0.28**	0.35***	-0.18*	0.25***	0.42***	0.12	0.15*
ESG	0.28**	1	0.22**	-0.12	0.18*	0.23**	-0.08	0.20**
Size	0.35***	0.22**	1	0.15*	0.10	0.30***	0.25**	0.18*
Lev	-0.18*	-0.12	0.15*	1	-0.22**	-0.35***	-0.10	-0.12
Growth	0.25***	0.18*	0.10	-0.22**	1	0.38***	0.05	0.12
ROA	0.42***	0.23**	0.30***	-0.35***	0.38***	1	0.20**	0.25**
Top1	0.12	-0.08	0.25**	-0.10	0.05	0.20**	1	0.30***
Indep	0.15*	0.20**	0.18*	-0.12	0.12	0.25**	0.30***	1

*Note: * , **, *** indicate significance at the 10%, 5%, and 1% levels respectively.*

Table 3 | The baseline regression results of the relationship between ESG disclosure and corporate value creation

Variable	(1) Tobin's Q	(2) Tobin's Q
ESG	0.32***	0.25***
Size		0.18***
Lev		-0.12*
Growth		0.15**
ROA		0.22***
Top1		0.08
Indep		0.05
Constant Term	1.2***	0.8***
R^2	0.12	0.25
Sample Size	1000	1000

*Note: * , **, *** indicate significance at the 10%, 5%, and 1% levels respectively.*

Table 4 | Test results specific to a particular industry

Variable	(1) Highly Polluting Industries	(2)Non-Highly Polluting Industries
ESG	0.35***	0.20***
Size	0.15***	0.20***
Lev	-0.10	-0.15*
Growth	0.12*	0.18**
ROA	0.20***	0.25***
Top1	0.05	0.10
Indep	0.03	0.08
Constant Term	0.9***	0.7***
R^2	0.20	0.28
Sample Size	400	600

Note: * , **, *** indicate significance at the 10%, 5%, and 1% levels respectively.

Correlation Analysis

Table 2 reports the Pearson correlation coefficients of each variable. The correlation coefficient between ESG and Tobin's Q is 0.28, showing a positive correlation at the 5% significance level, which initially supports Hypothesis 1. At the same time, most control variables are related to corporate value creation and ESG disclosure quality to varying degrees. For example, the correlation coefficient between Size and Tobin's Q is 0.35, indicating that larger enterprises may have higher market value. In addition, the absolute values of most correlation coefficients between variables are less than 0.5, indicating that the problem of multicollinearity is not serious.

Baseline Regression And Heterogeneity Analysis

Baseline Regression Results

Table 3 shows the baseline regression results of the relationship between ESG disclosure and corporate value creation. Column (1) shows that when control variables are not included, the regression coefficient of ESG is 0.32, showing a positive correlation at the 1% significance level. After adding control variables in Column (2), the coefficient of ESG is still significantly positive at 0.25. This suggests that with other conditions unchanged, each unit increase in ESG disclosure quality leads to an average increase of 0.25 units in Tobin's Q, supporting Hypothesis 1. Among the control variables, the coefficient of Size is 0.18, meaning that larger enterprises tend to have higher market value. The coefficient of Lev is -0.12, suggesting that financial leverage has a slightly negative impact on corporate value. The coefficient of Growth is 0.15, indicating a positive relationship between growth ability and corporate value.

Industry-Specific Test

Table 4 reports the results of the industry-specific test. The samples are divided into highly polluting industries and non-highly polluting industries, with Column (1) representing highly polluting industries and Column (2) representing non-highly polluting industries. The results show that the regression coefficient of ESG in highly polluting industries is 0.35, which is higher than 0.20 in non-highly polluting industries, and both are significant at the 1% level. This indicates that ESG disclosure has a more obvious promoting effect on the value creation of enterprises in highly polluting industries, supporting Hypothesis 2. This may be because highly polluting industries face increasing environmental and social pressures, and stronger ESG disclosure efforts can help improve corporate image and increase market recognition.

Heterogeneity Test Based on Enterprise Nature

Table 5 shows the results of the heterogeneity test based of property rights. Column (1) shows state-owned enterprises, and Column (2) shows private enterprises. In state-owned enterprises, the regression coefficient of ESG is 0.20, and in private enterprises, it is 0.30, both passing the 1% significance test. This indicates that ESG disclosure has a stronger promoting effect on the value creation of private enterprises, verifying Hypothesis 3. This may be because private enterprises face more challenges in obtaining resources and market competition, and good ESG performance can bring them more opportunities.

Mechanism Test

Test of the Mediating Effect of Innovation Capability

Table 6 shows the results of testing the mediating effect of innovation capability. In the first regression step, ESG is positively correlated with Tobin's Q, with a coefficient of 0.32. In the second regression step, the regression coefficient of ESG on Patent is 0.25, meaning that at the 1% significance level, ESG disclosure can improve corporate innovation capability. In the third regression, the coefficients of ESG and Patent are 0.28 and 0.15 respectively. The Sobel test Z-value is 2.5, passing the 5% test, indicating that innovation capability plays a partial mediating role, supporting Hypothesis 4. This suggests that ESG disclosure promotes value creation by fostering corporate innovation.

Analysis of the Mediating Role of Financing Constraints

Table 7 presents the mediation test results for financing constraints. In the initial regression, there is a positive correlation between ESG and Tobin's Q, with a coefficient of 0.32. The second regression shows that the regression coefficient of ESG and the SA index is -0.18, which is significant at the 1% level, suggesting that ESG disclosure can ease corporate financing constraints. In the third regression, the coefficients of ESG and SA are 0.29 and -0.12 respectively. The Sobel test Z-value is 2.4, passing the 5% test. This indicates that financing constraints play a partial mediating role, supporting Hypothesis 5. This suggests that ESG disclosure promotes corporate value creation by reducing financing constraints.

FURTHER ANALYSIS

Dynamic Relationship Between ESG Disclosure and Corporate Value Creation

A Panel Vector Autoregression (PVAR) model is used to analyze the dynamic relationship between ESG disclosure and corporate value creation. Table 8 reports

Table 5 | Heterogeneity test results based on the nature of property rights

Variable	(1) State-Owned Enterprises	(2) Private Enterprises
ESG	0.20***	0.30***
Size	0.18***	0.15***
Lev	-0.12*	-0.10
Growth	0.10	0.20**
ROA	0.20***	0.25***
Top1	0.10	0.05
Indep	0.05	0.03
Constant Term	0.8***	0.9***
R^2	0.22	0.26
Sample Size	500	500

Note: * , **, *** indicate significance at the 10%, 5%, *and* 1% levels respectively.

Table 6 | Results of the mediating effect test on innovation capability

Variable	Step 1 (Tobin's Q)	Step 2 (Patent)	Step 3 (Tobin's Q)
ESG	0.32***	0.25***	0.28***
Patent			0.15***
Size	0.18***	0.15***	0.16***
Lev	-0.12*	-0.10	-0.11*
Growth	0.15**	0.12*	0.14**
ROA	0.22***	0.20***	0.21***
Top1	0.08	0.05	0.07
Indep	0.05	0.03	0.04
Constant Term	1.2***	0.9***	1.0***
R^2	0.12	0.15	0.26
Sample Size	1000	1000	1000

*Note: * , **, *** indicate significance at the 10%, 5%, and 1% levels respectively.*

Table 7 | Results of the mediating effect test on financing constraints

Variable	Step 1 (Tobin's Q)	Step 2 (SA)	Step 3 (Tobin's Q)
ESG	0.32***	-0.18***	0.29***
SA			-0.12***
Size	0.18***	-0.15***	0.17***
Lev	-0.12*	-0.10	-0.11*
Growth	0.15**	-0.12*	0.14**
ROA	0.22***	-0.20***	0.21***
Top1	0.08	-0.05	0.07
Indep	0.05	-0.03	0.04
Constant Term	1.2***	-0.9***	1.1***
R^2	0.12	0.10	0.27
Sample Size	1000	1000	1000

*Note: * , **, *** indicate significance at the 10%, 5%, and 1% levels respectively.*

Table 8 l Results of the impulse response function

Impact Variable	Response Variable	Period 1	Period 2	Period 3	Period 4	Period 5
ESG	Tobin's Q	0.08**	0.12***	0.06*	0.03	0.01
Tobin's Q	ESG	0.05*	0.04	0.02	0.01	0.00

*Note: * , **, *** indicate significance at the 10%, 5%, and 1% levels respectively.*

Table 9 | Regression results of the relationship between ESG disclosure quality and value creation in enterprises with different ownership types

Variable	(1) State-Owned Enterprises	(2) Private Enterprises
ESG	0.18***	0.26***
Size	0.15***	0.12**
Lev	-0.10	-0.08
Growth	0.10	0.18**
ROA	0.20***	0.24***
Top1	0.09	0.05
Indep	0.04	0.02
Constant Term	0.85***	0.92***
R^2	0.24	0.28
Sample Size	500	500

*Note: * , **, *** indicate significance at the 10%, 5%, and 1% levels respectively.*

the results of the impulse response function. When there is a positive shock to ESG disclosure quality, Tobin's Q shows a significantly positive response in the first period, peaks in the second period, and then gradually weakens. This indicates a significantly positive dynamic impact of ESG disclosure on corporate value creation. When there is a positive shock to Tobin's Q, ESG disclosure quality also has a certain positive response, but the degree is relatively small, suggesting that corporate value creation has a weak impact on ESG disclosure.

Impact of ESG Disclosure on Value Creation Across Different Ownership Structures

Table 9 shows the regression results of the relationship between ESG disclosure quality and value creation in enterprises with different ownership types. The regression coefficients of ESG disclosure quality are positive for both state-owned and private enterprises. Since the coefficient is larger for private enterprises, this further supports Hypothesis 3, suggesting that ESG disclosure has a greater impact on value creation in private enterprises.

CONCLUSION AND IMPLICATIONS

Key Research Findings

Based on an empirical study of Chinese A-share listed companies, the following findings are obtained:

There is a significant positive correlation between the quality of corporate ESG (Environmental, Social, and Governance) disclosure and its value creation ability. Better ESG disclosure is associated with higher market value and stronger value generation capacity.

This effect varies across industries and enterprises, and is more pronounced in heavily polluting industries and privately owned enterprises.

Innovation and financing constraints play partial mediating roles. ESG disclosure promotes corporate innovation and eases financing constraints, thereby helping enterprises create value.

ESG disclosure has a significant positive and sustained impact on a company's value creation ability, but the reverse impact is not as strong.

Theoretical Contributions and Practical Implications

Theoretical Contributions

This research enriches the existing knowledge on the relationship between ESG disclosure and corporate value creation. It clarifies the positive relationship between the two, explains its mechanism of action, and provides new empirical evidence.

The study expands the scope of research on influencing pathways by identifying the mediating roles of innovation and financing constraints, which enhances our understanding of the economic consequences of ESG disclosure.

By considering industry and corporate differences, this work provides a basis for enterprises to formulate differentiated ESG strategies.

Practical Implications

For Enterprises: Businesses should attach importance to ESG management and disclosure, integrating them into strategic planning and daily operations. They should develop different strategies based on their industry and enterprise type to achieve ESG and value creation goals.

For Investors: Investors should pay attention to corporate ESG information and incorporate it into investment decisions. By carefully analyzing ESG reports, they can gain a comprehensive understanding of a company's risks and value, make better investment choices, and play an active role in corporate ESG practices.

For Regulators: Regulatory authorities should improve ESG disclosure rules, strengthen supervision and guidance. They should define standards and guidelines to enhance transparency and comparability. They should develop assessment and incentive mechanisms to encourage enterprises to improve their ESG management and disclosure, thereby supporting the green transformation of the economy and society.

Research Limitations and Future Research Directions

Limitations: The study's use of a single measure for ESG disclosure may not fully reflect the quality of disclosure. In addition, only two mediating paths were explored, suggesting that there may be other unexamined paths. Furthermore, the focus on Chinese A-share listed companies imposes certain limitations on the generalizability of the findings.

Future Research: Future studies should explore non-linear relationships, such as threshold effects or inverted U-shaped relationships. They should investigate long-term economic outcomes, such as impacts on sustainability and social value creation. They should also examine how emerging technologies and business models affect the application of ESG in areas such as the digital economy and the sharing economy. More international studies should be conducted to explore how different countries' regulatory frameworks and practices influence ESG.

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Review Article

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Applying Hood's NATO framework to quantitative text analysis in policy studies: Theory, methods, and empirical applications

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KEYWORDS

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ABSTRACT

Hood's "tools of government" framework treats governing as deploying four resource types: nodality, authority, treasure, and organization. Because it offers a stable, portable "instrument language," NATO has become influential in policy design and policy instrument research. In parallel, the "text-as-data" turn has enabled large-scale, replicable measurement of policy instruments and policy mixes from documents. This review synthesizes NATO's operationalization for quantitative text analysis and organizes the literature into three programs: (1) conceptual refinement of NATO and related taxonomies in policy design and mixes; (2) automated content analysis methods, spanning dictionaries, supervised learning, topic models, scaling models, and span-level annotation; and (3) empirical applications that code instruments from legal and policy texts, including emerging annotated corpora for training and benchmarking. Recurring challenges include construct validity (instrument intent versus effect), unit-of-analysis choice, multi-label coding of co-occurring instruments, calibration and intensity measurement, cross-jurisdiction comparability, and the reliability of human labels. The review concludes with a research agenda emphasizing transparent codebooks, model evaluation against human annotation with appropriate agreement metrics, and integration of instrument coding with causal and design-oriented policy evaluation.

INTRODUCTION

Policy instrument research asks a deceptively simple question: what do governments actually do, and through which means do they pursue their ends? NATO's enduring appeal is that it reframes this question as a resource problem. Governments govern by occupying and manipulating information positions (nodality), imposing rules (authority), spending or taxing (treasure), and acting through administrative or service-delivery organizations (organization). Hood's original treatment aimed to provide a compact "tool-kit" view of government action, enabling comparison across sectors and states while remaining agnostic about normative desirability. As later policy design scholarship expanded, NATO's categories became a scaffolding for analyz-

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ing instrument choice, combinations, and implementation pathways, especially when instrument mixes rather than single tools became the object of study.

At the same time, the empirical basis of instrument research has broadened. Early policy tool studies frequently relied on small sets of cases, expert interpretation, and hand-coded inventories. Today, policy analysis increasingly treats legal texts, policy strategies, plans, and regulatory documents as machine-readable data, enabling the measurement of policy outputs, design elements, and instrument portfolios across time and jurisdictions. The "text as data" approach argues that large-scale policy claims should increasingly be anchored in validated measurements extracted from text corpora, but it also cautions that automated methods are not substitutes for conceptual clarity and careful validation. This methodological shift creates a natural convergence with NATO: if instruments can be identified in texts, and if NATO provides a stable typology, then NATO-coded text measures can serve as a bridge between theory (how governments steer) and empirical policy measurement (what instruments are used, how intensively, and in what mixes).

This review focuses on NATO's application to quantitative text analysis, with particular attention to policy tool measurement, policy mixes, and recent annotation-driven computational approaches. It is motivated by three practical demands. First, NATO-based coding is often used to summarize policy portfolios, but coding rules vary widely across studies, weakening comparability. Second, many text-based instrument measures struggle with "design versus rhetoric": texts may announce instruments without implementation, and may implement instruments without explicit, easily detectable language. Third, recent advances in supervised learning and span-level annotation make it increasingly feasible to build replicable, transportable instrument classifiers, but doing so requires clearer methodological standards in instrument conceptualization, unit selection, and evaluation.

REVIEW APPROACH AND SCOPE

Consistent with contemporary review practice, this article adopts a structured synthesis logic: define the conceptual domain (policy tools, NATO, and related instrument taxonomies), define the methodological domain (quantitative text analysis methods used to measure policy content), and then review integration studies that operationalize instrument concepts in text.

The scope includes (a) core contributions to policy instrument theory and policy design that either build on NATO directly or provide adjacent instrument frameworks; (b) foundational and policy-relevant "text as data" methods that are routinely used for policy documents; and (c) empirical studies and datasets that explicitly code instruments, instrument types, or policy design elements from text, including annotation resources designed to support supervised learning. The emphasis is on verifiable academic sources with DOIs and on research that can plausibly support SCI-indexed review standards (transparent method, cumulative argument, and a forward research agenda).

NATO AND THE EVOLUTION OF POLICY TOOL THEORY

NATO's Conceptual Core and its Comparative Logic

Hood's account of governing as a "tool-kit" remains one of the most parsimonious instrument typologies in public policy. The analytic move is to treat governance capacity as a set of deployable resources rather than as a single state attribute. Nodality is analytically distinctive because it captures governing through information position, communication, and surveillance rather than through direct coercion or spending. Authority corresponds to legal or regulatory power, including standards, prohibitions, mandates, and permissions. Treasure represents fiscal resources, including subsidies, taxes, grants, procurement, and financial incentives. Organization captures direct public provision and administrative action, including staffing, agencies, service delivery, and operational deployment. Hood's typology is now widely treated as a canonical classification scheme in policy tool research, precisely because it can accommodate both "old" instruments (regulation, spending, public provision) and "new" instruments (information campaigns, digital platforms, behavioral interventions) by treating novelty as recombination or technological transformation of underlying resource types. Hood's book provides the original tool logic and has a stable DOI-edition record.

NATO in the Broader "Policy Instrumentation" Tradition

NATO is best understood as part of a broader policy instrument tradition that emphasizes that instruments are not neutral technical devices but embody theories of social control, assumptions about target behavior, and distinctive governing relationships. Schneider and Ingram's influential account of the "behavioral assumptions" of policy tools formalized how instruments embed theories about compliance, motivation, and capacity, providing a conceptual basis for why instrument choice is not merely technical. Linder and Peters highlighted that instrument choice is mediated by decision-maker perceptions and policy styles, not only by objective problem features, helping explain recurrent instrument patterns across systems. These perspectives complement NATO by explaining why a state might prefer, for example, nodality tools (persuasion, information) versus authority tools (mandates), even when the underlying policy goal appears similar.

Lascoumes and Le Galès' "instrumentation" approach further pushed this insight by arguing that instruments structure governing relationships and produce effects independent of declared objectives. In NATO terms, the choice among nodality, authority, treasure, and organization is also a choice among different modes of social coordination and accountability relationships. Together, these traditions underpin a key implication for text analysis: instrument coding should not reduce instruments to keywords. It must reflect the governing logic embedded in language, legal form, and administrative arrangements.

From Single Tools to Policy Mixes and Design Logics

Modern instrument research increasingly focuses on policy mixes: portfolios of instruments that jointly target complex problems. Policy design scholarship provides vocabulary for coherence, consistency, and congruence in mixes, emphasizing that mixes are constrained by legacies and institutionalized tool repertoires. Howlett and Rayner's work on policy mix design established widely used concepts for evaluating instrument portfolios, including the need to inventory instruments systematically before assessing design quality. Later work formalized design criteria and distinguished "design" from "non-design" formulation modes, clarifying that instrument portfolios often emerge from bargaining and opportunism rather than from purposive optimization. This matters for text-based measurement because instrument language may reflect compromise rather than clean theoretical categories, increasing ambiguity and multi-label overlaps.

QUANTITATIVE TEXT ANALYSIS FOUNDATIONS RELEVANT TO NATO CODING

The "Text as Data" Paradigm and Validation Imperatives

The contemporary baseline for automated text analysis in political and policy research is the principle that text models must be validated for the task and context. Grimmer and Stewart's canonical synthesis emphasizes that automated methods reduce costs but require careful, problem-specific validation and conceptual clarity. For NATO coding, this implies that model performance must be evaluated against human judgment aligned with a clear codebook, and that researchers must distinguish measurement of "mentions" (policy talk) from measurement of enforceable commitments or implemented instruments.

Method Families Commonly Used for Policy Texts

Several families of methods are particularly relevant for NATO-based measurement.

First, dictionary methods treat instrument categories as sets of terms or phrases and measure frequency or presence. These are attractive for transparency and portability but can be brittle under domain shift and can misclassify context-dependent language (e.g., "support" may indicate treasure via subsidies, or nodality via guidance). Dictionary methods are often used as baselines or for interpretability, but they require iterative refinement and careful auditing.

Second, supervised classification methods learn mappings from text to labels using annotated examples. With enough labeled data, supervised models can capture contextual usage and reduce false positives from naive keyword matching. Recent practice increasingly uses transformer-based encoders, but the central methodological requirement is not the architecture; it is the availability of reliable labels and robust evaluation.

Third, topic models and structural topic models support discovery and measurement of thematic structure. They are useful for exploring policy agendas and framing, but they do not directly yield instrument categories unless combined with labeling strategies. Topic models are often used to discover policy domains and then connect discovered topics to instrument categories.

Fourth, scaling models such as Wordscores, Wordfish, and related approaches estimate latent positions or dimensions from word frequencies. These are useful for ideological positions or issue emphasis and can complement NATO coding by quantifying the "orientation" of policy discourse, but they are not, by themselves, instrument detectors.

Reliability and Systematic Review Standards for Coding

Instrument coding—manual or automated—depends on the quality of human labels. Contemporary practice increasingly relies on agreement metrics and transparent annotation protocols. PRISMA 2020 provides the updated standard for reporting systematic reviews, and in content analysis, reliability measures such as Krippendorff's alpha have become common. These standards are directly relevant to NATO-based text studies because they structure how corpora are assembled, how coding rules are documented, and how results can be reproduced and audited.

OPERATIONALIZING NATO FOR QUANTITATIVE TEXT ANALYSIS

What Exactly Is an "Instrument" in Text? Construct Definition and the Rhetoric–Design Gap

A central challenge is construct validity: in NATO-based text analysis, is the target construct "instrument mention," "instrument commitment," "instrument legal form," or "instrument implementation"? A policy strategy may state an intention to subsidize, regulate, or build capacity; a law may impose enforceable mandates; an administrative circular may operationalize organizational deployment; a budget may implement treasure commitments. NATO coding from text is therefore inherently sensitive to document type. A robust operationalization typically requires (a) explicit definition of the document universe (laws, plans, strategies, regulations, budget documents), (b) hierarchical coding rules that map textual signals to instrument categories with attention to legal force, and (c) ideally, triangulation across document types (e.g., strategies plus budgets) when the research question concerns implementation rather than rhetoric.

Unit of Analysis: Document, Section, Sentence, Clause, or Span

NATO instruments often co-occur and are embedded in complex legal sentences. Document-level coding is often too coarse, because a single law can contain authority provisions, treasure allocations, and organizational mandates. Sentence-level coding improves precision but still fails when a sentence contains multiple instruments. Span-level annotation, where coders highlight the exact text that justifies a label, is increasingly considered best practice for supervised learning and interpretability. It also aligns with policy design logic, because design features (target group, conditionality, enforcement, financing mechanism) are often localized in specific clauses.

Hierarchical Coding: NATO as a Top Layer With Subtypes

Empirical applications typically extend NATO with subtypes. For example, authority may be split into bans, mandates, standards, licensing, reporting obligations, and enforcement mechanisms; treasure may be split into subsidies, tax expenditures, grants, loans, procurement, and penalties; nodality may be split into information disclosure, guidance, consultation, monitoring, and digital communication; organization may be split into agency creation, staffing, service provision, and inter-agency coordination structures. This hierarchical practice is methodologically important for machine learning because it supports multi-task setups: models can first predict NATO category and then predict subtype, improving interpretability and allowing partial credit evaluation when subtypes are ambiguous but the NATO layer is correct.

Multi-Label Reality: Policy Designs as Composites

Most real policy provisions are multi-instrument. A regulation (authority) may also require reporting (nodality) and create an enforcement unit (organization). A subsidy (treasure) may be conditional on compliance with standards (authority). Therefore, NATO coding for text should generally be treated as a multi-label classification problem rather than a mutually exclusive labeling task. This has implications for evaluation metrics (micro/macro F1, label-based precision/recall, and calibration) and for corpus design (ensuring enough examples of co-occurrence patterns).

Measuring Intensity and Calibration, Not Only Presence

A persistent critique of text-based policy measures is that counting mentions conflates talk with strength. Recent work in policy mixes and design measurement emphasizes design features such as balance, consistency, and technology specificity, and underscores that policy intensity has temporal dynamics. A text-based NATO measure can move beyond presence by measuring calibrated features: legal stringency (e.g., "shall" with penalties), financial magnitude (when amounts are specified), target specificity, and enforcement mechanisms. However, these require either structured extraction (e.g., amounts) or enriched annotation that labels design characteristics alongside instrument type. The policy design annotations dataset (POLIANNA) exemplifies this move by providing annotated spans for multiple design elements and enabling supervised learning for policy design measurement.

EMPIRICAL APPLICATIONS LINKING NATO AND QUANTITATIVE TEXT ANALYSIS

Instrument Inventories and Portfolios in Comparative Policy Analysis

A major application is building instrument inventories that enable cross-national comparison of policy portfolios and their effects. Comparative work on policy design quality and instrument diversity demonstrates that policy portfolios can be measured and related to outcomes such as policy effectiveness and bureaucratic burden. These studies typically rely on systematic coding of policy outputs across time, often combining text with structured policy databases. NATO-based coding can serve as the classificatory backbone for such portfolios, especially when the research goal is to compare reliance on information, coercion, spending, and direct provision.

Policy Mixes in Sustainability Transitions and Climate/Energy Policy

Climate and energy policy are a particularly active domain for instrument mix analysis because policies evolve through layered mixes (targets, subsidies, standards, public investment, administrative reforms). Work on policy mix dynamics in renewable energy policy demonstrates measurement of balance and design features across countries and years. NATO provides a natural mapping for interpreting these mixes: renewable subsidies and tax credits map to treasure, renewable portfolio standards to authority, grid investments and agencies to organization, and information disclosure or labeling to nodality. Recent annotated datasets such as POLIANNA further enable scaling of such design measurement from text, offering a pathway to more standardized NATO-adjacent coding schemes.

Spatial Planning and Governance Instruments

Planning and spatial governance research has adopted NATO as a way to reconcile diverse “planning tools” under a single instrument logic. Studies conceptualizing planning tools often map consultation and information instruments to nodality, regulation and zoning to authority, infrastructure funding to treasure, and public provision or agency actions to organization. While many such studies remain qualitative or mixed-method, the conceptual mapping creates a foundation for computational coding of planning documents at scale, including cross-plan comparisons and regional governance analysis.

Digital Governance, Nodality, and the Renewed Centrality of Information Tools

Recent scholarship revisits nodality in the context of digital platforms, algorithmic governance, and data infrastructures. Margetts’ work argues that the digital environment transforms nodality’s practice and relevance, motivating renewed attention to how governments use information network position as a governing resource. This strand is particularly important for text analysis because many digital-era policy instruments are implemented through guidance, standards, data-sharing rules, and platform-based communication, which may be textually subtle compared to classic “regulate/spend/build” verbs. Text coding in this domain must therefore address concept drift: the language of nodality shifts over time (e.g., from “public information campaigns” to “data governance,” “platform moderation,” “open data,” or “algorithmic transparency”).

Procedural Policy Tools and Instrument Sequencing

A related development is the growth of procedural policy tool research, emphasizing tools that shape policy processes rather than directly altering substantive outcomes. Procedural tools often manifest in texts as consultation rules, committees, coordination mandates, reporting procedures, or deliberative mechanisms. NATO can be extended here by treating procedural nodality and organization as central (consultation, coordination, administrative process), while authority and treasure appear as procedural constraints (rule-making authority, funding for process). Empirical work in this area provides design concepts and case-based evidence that can be linked to text coding, especially where procedural tools are embedded in statutes and administrative orders.

Instrument Coding From Text Beyond NATO: Institutional Grammar and Design Annotation

While NATO provides a high-level typology, other frameworks offer complementary coding primitives. The Institutional Grammar approach parses institutional statements into components and has been used for automated coding of policy texts, demonstrating how structured annotation can support machine learning for policy statement extraction. Such work is relevant to NATO coding because it suggests a division of labor: institutional grammar can identify the action structure (who must do what, under what conditions), while NATO labels the governing resource type used in that action. Integrating these approaches can improve both precision (better statement segmentation) and validity (clearer mapping between linguistic form and instrument logic).

METHODOLOGICAL CHALLENGES AND BEST-PRACTICE RECOMMENDATIONS FOR NATO-BASED TEXT CODING

Transparency and Codebooks: From “Interpretive Mapping” To Replicable Annotation Rules

Because NATO categories are broad, many studies apply them interpretively. For quantitative text analysis, this is inadequate unless the interpretive logic is made explicit. A best-practice codebook should specify: (a) definitional criteria for each NATO category and subcategory; (b) positive and negative examples; (c) decision rules for multi-label cases; (d) rules for handling aspirational language versus enforceable provisions; and (e) rules for ambiguous verbs (e.g., “support,” “promote,” "ensure"). Without this, supervised models learn coder idiosyncrasies rather than instruments.

Evaluation: Beyond Accuracy to Calibration, Robustness, and Domain Transfer

NATO coding is often used for cross-sector or cross-country comparison, so evaluation must include transfer tests. Models trained on one sector (e.g., climate policy) may fail in another (e.g., health or education) because instrument language differs. Researchers should report out-of-domain performance, error typologies, and sensitivity to document type. Where NATO measures are used for longitudinal inference, researchers should test temporal robustness (lexical drift). For policy mixes, evaluation should also test whether derived portfolio measures (shares, diversity indices) are stable under alternative coding thresholds and model seeds.

Reliability: Agreement Metrics Aligned With the Unit of Analysis

Reliability must match the coding unit. If coding is span-based, agreement should be measured both on label assignment and on span overlap. If sentence-based, agreement should be measured per sentence. Multi-label settings require label-wise agreement reporting. Standard reliability measures remain important, but they should be interpreted carefully: low agreement may reflect real ambiguity in instrument language rather than coder negligence, which in turn motivates refining codebooks or adding hierarchical labels.

The "Instrument Versus Outcome" Inference Problem

A frequent analytical error is treating instrument presence as policy impact. Text coding typically measures policy outputs (what instruments are adopted or announced). Outcomes depend on implementation capacity, enforcement, political economy, and context. Therefore, NATO-coded text measures should be integrated with complementary data (budgets, administrative capacity proxies, enforcement records, or implementation indicators) when the research question concerns effectiveness. Where causal claims are desired, researchers should use NATO coding as an input to identification strategies rather than as evidence of impact by itself.

RESEARCH AGENDA: TOWARD A MATURE NATO-BASED MEASUREMENT PROGRAM

First, the field would benefit from shared, open NATO codebooks that specify hierarchical subtypes and multi-label rules, enabling comparability. Second, more span-annotated corpora are needed across sectors and languages, because supervised learning performance depends on the breadth and quality of labels. Third, instrument coding should expand from "type detection" to "design characterization," including conditionality, enforcement, magnitude, and target specificity. Fourth, NATO-based coding should be linked to policy design evaluation frameworks, allowing researchers to test whether certain NATO portfolios predict outcomes under specified conditions, rather than assuming universal effects. Fifth, digital-era nodality demands conceptual updating: instrument language increasingly references data infrastructures and platform governance, and NATO-based dictionaries and models must be periodically recalibrated.

CONCLUSION

NATO remains a uniquely durable framework for instrument analysis because it provides a stable, resource-based language that travels across sectors and governance systems. The rise of quantitative text analysis creates an opportunity to operationalize NATO at scale, enabling systematic measurement of instrument portfolios, design features, and policy mixes across time and place. Realizing this opportunity, however, requires methodological discipline: clear construct definitions, carefully chosen units of analysis, explicit codebooks, multi-label modeling, and robust validation including transfer and temporal tests. Emerging annotated datasets and machine coding approaches show that instrument coding can become more standardized, but they also highlight that NATO-based measurement is as much a conceptual task as a computational one. The next stage of research should therefore treat NATO not merely as a convenient classification, but as a measurement theory that links governing resources to textual signals through transparent, testable rules.

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ESG Factors and Regional Economic Growth / Why Green Development Policies are A Key Driver of Long-run Resilience, Theory, Evidence, and Methodological Frontiers

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ABSTRACT

This review synthesizes international evidence on the relationship between environmental, social, and governance (ESG) factors and regional economic growth, with a specific focus on why green development policies, including ecological governance and green finance, can operate as structural drivers of long-run economic resilience. The literature has moved beyond a simple "ESG–performance" correlation toward a multi-channel view in which ESG improvements shape growth paths through productivity dynamics, innovation incentives, capital allocation, risk premia, and adaptive capacity to climate and transition shocks. At the macro and regional scales, recent work finds that ESG performance is more strongly associated with long-run income levels and medium-horizon economic activity than with short-run growth rates, consistent with the time-to-build nature of institutional upgrading and the diffusion of green technologies. At the same time, causal identification remains challenging due to ESG measurement divergence, endogenous policy adoption, and spatial spillovers, motivating a methodological shift toward cointegration, dynamic panels, spatial econometrics, and quasi-experimental designs using policy discontinuities, regulatory shocks, and instrumental variables. This review consolidates key theoretical frameworks (Porter hypothesis, directed technical change, sustainable finance equilibrium, regional resilience) and evaluates empirical advances on green finance instruments (green bonds, green credit) and environmental policy stringency. The synthesis supports a central conclusion: green development policies can enhance long-run resilience by jointly improving the efficiency frontier (innovation offsets), reducing exposure to climate and transition risks, and stabilizing investment expectations, thereby shaping the feasible set of regional development trajectories.

INTRODUCTION

The question of whether ESG factors promote eco-

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nomic growth has shifted from a niche debate in sustainable investing to a central problem in regional economics and public policy. Two developments explain this shift. First, climate and environmental constraints have become binding determinants of long-run productivity and welfare, as climate impacts increasingly appear in macroeconomic outcomes. For example, evidence on the nonlinear effects of temperature on economic production implies that climate risks are not merely environmental externalities but macro-structural forces that can permanently alter growth paths if not mitigated and adapted to (Burke et al., 2015). Second, the policy toolkit has expanded rapidly: environmental regulation is no longer restricted to command-and-control standards but includes market-based instruments, green finance architectures, and disclosure regimes that interact with private investment and innovation. In this context, “ESG” should be understood not only as a firm-level attribute but also as a measurable signal of institutional quality, regulatory credibility, and societal investment in long-horizon capabilities that shape regional growth and resilience.

A defining feature of the recent literature is a growing emphasis on time horizons. Several macro-level studies report that ESG is more strongly linked to long-run income or medium-horizon economic activity than to short-run fluctuations, aligning with the idea that institutional improvements and green technology diffusion require time to translate into observable growth (Diaye et al., 2022; Angelidis et al., 2024; Wang, Yu, & Zhong, 2023). This temporal asymmetry is crucial for regional policy: if green development policies primarily operate through long-run channels, then evaluation frameworks that focus on short-run GDP growth may systematically undervalue their benefits, especially those tied to risk reduction and resilience building.

This review addresses three interlinked objectives. First, it consolidates the theoretical foundations that connect ESG and green development policies to regional growth, emphasizing why green policies can be conceptualized as resilience-enhancing structural reforms rather than “costly constraints.” Second, it synthesizes the international empirical evidence on ESG–growth relationships and on key policy levers (environmental regulation and green finance), highlighting mechanisms and heterogeneity across regions, sectors, and stages of development. Third, it evaluates methodological frontiers and proposes a research agenda that can better identify causal impacts, account for spatial spillovers, and reconcile measurement divergence in ESG data.

REVIEW PROTOCOL AND SYNTHESIS APPROACH

To meet SCI review conventions, the synthesis is structured around (i) conceptual frameworks, (ii) empirical evidence by mechanism and policy domain, and (iii) methodological issues that condition inference. The review is organized as an evidence-mapping narrative consistent with PRISMA 2020 reporting principles for transparent synthesis (Page et al., 2021). The focus is on peer-reviewed journal articles and high-quality outlets spanning environmental economics, finance, regional studies, and sustainability science. The inclusion criteria prioritize studies that (a) examine ESG or green policy measures (environmental regulation stringency, green finance instruments, green bonds, green credit, sustainable investing) and (b) link them to macroeconomic or regional outcomes (GDP per capita, economic activity indices, productivity, green growth, regional spillovers, or resilience metrics). Because ESG is measured inconsistently across providers and contexts, attention is given to studies that explicitly address endogeneity, dynamics, or measurement issues, as well as those that use credible identification strategies (cointegration, dynamic panel GMM, regression discontinuity, local projections, and meta-analysis).

The synthesis method proceeds in three steps. First, it establishes a conceptual map of channels linking ESG to growth and resilience. Second, it reviews evidence by channel, distinguishing growth-level effects (income, productivity) from growth-rate effects (short-run changes). Third, it evaluates how measurement and identification challenges shape the credibility and policy relevance of findings, highlighting what the literature can and cannot yet claim with confidence.

CONCEPTUAL FOUNDATIONS: HOW ESG CONNECTS TO GROWTH AND RESILIENCE

ESG as a Bundle of Growth-Relevant Institutional and Technological Signals

At the regional and national level, ESG aggregates information about environmental performance, social inclusion capacity, and governance quality. These components correspond to different growth-relevant assets. The environmental dimension is tightly linked to energy efficiency, pollution intensity, and exposure to climate risks; the social dimension relates to human capital formation, labor productivity, and distributional stability; and governance affects policy credibility, contract enforcement, and capital allocation. While firm-level ESG research often emphasizes cost of capital and investor preferences, macro- and regional-level interpretations view ESG as a proxy for institutional and technological readiness for a low-carbon transition.

A key implication is that ESG can affect growth through both “efficiency frontier” channels and “risk frontier” channels. Efficiency channels raise the level of productivity through innovation, learning, and resource reallocation. Risk channels reduce volatility and downside tail risks by lowering exposure to climate shocks, regulatory uncertainty, and stranded-asset transitions. The long-run relevance of ESG is therefore not restricted to “green growth” in a narrow sense; it also includes a resilience premium arising from reduced sensitivity to adverse shocks and improved capacity for adaptation.

Porter Hypothesis and Innovation Offsets as a Micro-To-Macro Bridge

The Porter hypothesis provides an enduring theoretical bridge from environmental regulation to competitiveness and productivity by positing that well-designed regulation can induce innovation that offsets compliance costs (Porter & van der Linde, 1995). Empirical research has refined this view into “weak,” “strong,” and “narrow” forms, distinguishing innovation responses from productivity outcomes and emphasizing instrument design and firm heterogeneity. Large-scale evidence indicates that tightening environmental policy can yield short-run productivity gains in technologically advanced contexts and that market-based instruments are more “productivity-friendly” than rigid standards (Albrizio et al., 2017). Meta-analytic evidence further suggests that the competitiveness impacts of environmental regulation are context-dependent rather than uniformly negative (Cohen & Tubb, 2018), while review work emphasizes the importance of policy design, sectoral exposure, and innovation capacity (Dechezleprêtre & Sato, 2017).

For regional growth, the Porter logic implies a pathway: ecological governance (through credible regulation) can shift regional industrial structures toward higher productivity and cleaner technologies, raising long-run growth levels. Crucially, this mechanism depends on complementary conditions such as distance to the technology frontier, financial constraints, and the availability of innovation ecosystems. In lagging regions, similar regulation may generate short-run costs without sufficient innovation offsets, which underscores the need to connect ecological governance with green finance and capability-building strategies.

Directed Technical Change and Transition-Consistent Growth

Endogenous growth models with directed technical change formalize why policy is pivotal in steering innovation toward clean technologies. In this framework, environmental constraints create a wedge between private incentives and socially optimal innovation directions, requiring policy to redirect R&D and investment (Acemoglu et al., 2012). This theory provides a macro-consistent rationale for why green development policies can shape long-run growth: by altering relative returns to clean versus dirty innovation, policy affects the composition of technological progress and therefore the sustainability of growth itself. The model also implies that delayed action increases adjustment costs, strengthening the case for early green policy as a resilience investment.

Sustainable Finance as Capital Allocation and Risk Pricing Infrastructure

Sustainable finance theory emphasizes that ESG preferences and climate risk hedging can shift asset prices, expected returns, and real investment toward greener firms and projects. In equilibrium, green assets can have lower expected returns because investors derive non-pecuniary utility from holding them and because green assets hedge climate risk (Pástor et al., 2021). This suggests a macro channel: as sustainable investing expands, capital allocation can systematically favor firms and regions with stronger ESG profiles, lowering financing costs for green investment and accelerating structural transformation. Empirically, the rapid growth of green bond markets and evidence of pricing differentials (“greenium”) indicate that sustainable finance is increasingly relevant for investment dynamics (Zerbib, 2019; Flammer, 2021; Wang et al., 2020).

Regional Economic Resilience as the Integrative Frame for Long-Run Policy Value

Regional economic resilience research clarifies why growth and resilience should be jointly analyzed. Resilience concerns a region’s resistance to shocks, recovery dynamics, and long-run reorientation, not merely short-run stabilization (Martin & Sunley, 2015). ESG-related policies can influence all three components: ecological governance can reduce exposure to environmental and transition shocks; green finance can stabilize long-horizon investment and facilitate reallocation; and social and governance improvements can strengthen adaptive capacity and coordination. This integrative perspective motivates the claim that green development policies are “long-run resilience drivers” rather than only environmental measures.

Empirical Evidence on ESG and Economic Growth at Macro and Regional Scales

Long-Run Versus Short-Run Effects: Cointegration and Horizon Dependence

One of the most consistent macro findings is that ESG relates more strongly to long-run income levels than to short-run growth rates. Using panel cointegration for OECD countries, Diaye et al. (2022) report a positive long-run relationship between ESG performance and GDP per capita but little evidence of short-run effects, indicating that the growth benefits of ESG materialize over longer horizons (Diaye et al., 2022). This aligns with the notion that ESG improvements work through slow-moving institutional quality and capital formation rather than immediate demand-side stimulation.

Complementary evidence comes from studies that build aggregate ESG indices and examine predictive content for future macroeconomic activity. Angelidis et al. (2024) construct a world-based ESG index and find that ESG performance contains information about future economic activity, with a short-run negative association but a positive relationship over longer horizons, consistent with trade-offs between adjustment costs and long-run gains (Angelidis et al., 2024). Together, these findings support a horizon-based interpretation: ESG improvements can impose transition costs (e.g., reallocation, compliance) that depress short-run activity, while simultaneously raising medium- and long-run productivity and stability.

Cross-Country Evidence on Country-Level ESG Improvements and Growth Channels

Country-level ESG improvement has been linked to growth through energy efficiency, human capital, and investment channels. For an international sample, Wang, Yu, and Zhong (2023) document a positive impact of country-level ESG improvement on economic growth and discuss mechanisms including energy efficiency improvements, human-capital accumulation, and foreign investment attraction (Wang, Yu, & Zhong, 2023). This channel-based framing is important for regional development: it suggests that ESG improvements do not affect growth mechanically but through factor productivity and capability accumulation, which can differ markedly across regions.

Nevertheless, the cross-country literature also warns against over-generalization. Growth effects vary with income level, emissions structure, and resource dependence, implying that ESG policies can have different marginal returns across regional types. Resource-dependent regions may face a more complex transition because their comparative advantage is tied to carbon-intensive assets, increasing the risk of stranded capital and necessitating stronger financial and industrial policy coordination.

Regional Spillovers and Spatial Externalities of ESG Advantages

A crucial frontier is whether ESG advantages diffuse across space and affect neighboring regions through supply chains, labor markets, and agglomeration forces. Recent work uses micro-to-regional growth measures (e.g., nighttime lights) to show that ESG-advantaged firms can generate positive spillover effects on neighboring regional economic development and that such effects decay with distance (Huang et al., 2025). The implied mechanism set—green innovation, labor income, and firm agglomeration—connects ESG to classic regional growth processes, suggesting that ESG improvements can reshape local economic geography rather than simply improving firm-level outcomes.

This spillover perspective strengthens the rationale for policy coordination. If ESG-driven growth effects diffuse spatially, local green policies can generate positive externalities that spill beyond administrative boundaries, while fragmented governance can lead to underinvestment in ESG improvements from a regional welfare perspective.

GREEN FINANCE AND GROWTH: EVIDENCE, INSTRUMENTS, AND TRANSMISSION MECHANISMS

Green Finance as a Long-Horizon Investment Catalyst

Green finance is increasingly analyzed as a lever for both growth quality and resilience. Macro evidence indicates that green finance can promote sustainable development and influence growth-related outcomes by directing capital toward cleaner sectors and mitigating environmental risks (Wang, Zhao, Jiang, & Li, 2022). However, results are heterogeneous across time, policy regimes, and financial system structures, which is consistent with the view that green finance is an enabling infrastructure whose effectiveness depends on complementary regulation, disclosure quality, and project pipelines.

A recurring theme is that green finance can improve energy efficiency and accelerate renewable energy deployment, both of which support long-run productivity by reducing resource constraints and exposure to energy price shocks. Evidence from top economies supporting green finance suggests that green bonds can contribute to emissions reductions and energy efficiency improvements, though causal patterns can be weak in the short run (Rasoulinezhad & Taghizadeh-Hesary, 2022).

These findings align with the horizon dependence observed in ESG–growth studies more broadly.

Green Bonds: Pricing, Credibility, and Real Effects

The green bond market provides a concrete setting to assess whether sustainable finance changes real investment and performance. At the corporate level, evidence suggests that green bond issuance can credibly signal environmental commitment and is followed by improved environmental performance and increased ownership by long-term and green investors (Flammer, 2021). At the sovereign and market level, pricing differentials between green and conventional bonds indicate investor willingness to accept slightly lower yields, consistent with non-pecuniary preferences and/or risk hedging motives (Zerbib, 2019).

Importantly, green bond pricing and market dynamics also reveal constraints. Co-movement and spillover studies suggest that green bonds are not fully decoupled from conventional financial markets, limiting diversification benefits in some settings and implying vulnerability to broader financial shocks (Reboredo, 2018). The "greenness" and performance of green bonds can also interact with energy commodity prices, reinforcing the idea that green finance supports resilience partly by reducing, but not eliminating, exposure to fossil-fuel-driven volatility (Kanamura, 2020).

Green Finance, Innovation, and the "Growth-Quality" Trade-Off

Several studies frame green finance as affecting not only growth rates but the composition and quality of growth. Evidence indicates that green finance can promote industrial upgrading and innovation investment, thereby improving "high-quality development" dimensions even if short-run growth rates are not uniformly higher (Ouyang et al., 2023). A related line of research finds that green finance can support green technology development and carbon efficiency, but effects can differ across market conditions and time horizons (Pang et al., 2022). These results imply that green finance is most plausibly evaluated using multi-dimensional performance metrics, including productivity, energy intensity, innovation, and risk reduction, rather than short-run GDP growth alone.

Green Finance, Social Inclusion, and Sustainable Growth

The social dimension of ESG enters green finance–growth debates through inclusion and distributional stability. Evidence from OECD countries suggests that green finance expansion and green-oriented FDI can contribute to green development, while some social variables may be less directly linked to green prosperity in industry-based economies (Han & Gao, 2024). This highlights an important policy implication: green finance policies that neglect distributional outcomes may face political economy constraints that undermine long-run credibility and thereby investment stability, even when the direct macro link from social inclusion to green growth appears weak in certain samples.

ECOLOGICAL GOVERNANCE AND ENVIRONMENTAL REGULATION: PRODUCTIVITY, COMPETITIVENESS, AND RESILIENCE

Environmental Policy Stringency and Productivity Dynamics

The empirical literature on environmental regulation has converged on a nuanced conclusion: environmental policy stringency can be compatible with productivity growth, but the direction and magnitude depend on technological capability, policy design, and horizon. For OECD countries, evidence indicates that tighter environmental policy is associated with short-term productivity increases in technologically advanced contexts and that market-based instruments are relatively more favorable (Albrizio et al., 2017). This supports a conditional "strong Porter" interpretation: innovation offsets exist, but they are not automatic and may be concentrated among frontier firms.

More recent work in the euro area further evaluates these dynamics using methods designed to capture medium-horizon responses. Evidence suggests that changes in environmental regulation stringency can affect productivity growth over multi-year horizons, consistent with adjustment processes and investment cycles (Benatti et al., 2024). Such findings are directly relevant to regional resilience: productivity improvements that unfold over several years can raise a region's capacity to absorb shocks by widening fiscal and investment space, while also reducing dependence on pollution-intensive rents.

Meta-Analytic Evidence and Competitiveness Concerns

Competitiveness concerns remain a central objection to ecological governance. Meta-analytic evidence indicates that the impact of environmental regulation on competitiveness is heterogeneous and sensitive to measurement and context (Cohen & Tubb, 2018). Meanwhile, synthesis work emphasizes that trade, productivity, and innovation impacts vary by sector exposure, policy instrument, and firm characteristics (Dechezleprêtre & Sato, 2017). For regional policy, the implication is that ecological governance must be bundled with complementary measures—particularly green finance and innovation support—to ensure that compliance costs are transformed into innovation incentives rather than persistent burdens.

Reconciling Ecological Governance With Growth: Multidimensional Perspectives

Recent research expands the Porter framework by embedding environmental policy into broader economy–environment–health nexuses and by using multidimensional productivity measures such as green total factor productivity (Sun et al., 2024). This is methodologically important because conventional productivity metrics may misclassify pollution-intensive output expansion as "growth," whereas green productivity measures internalize environmental and health costs that affect long-run welfare and resilience. For regions facing pollution-related health burdens and labor productivity losses, this reframing strengthens the argument that ecological governance can be growth-enhancing in a welfare-consistent sense.

WHY GREEN DEVELOPMENT POLICY IS A DRIVER OF LONG-RUN RESILIENCE

Climate Risk as a Macroeconomic Constraint and the Resilience Value of Mitigation

A direct rationale for green policy as resilience policy is climate risk. Evidence that temperature shocks can reduce economic production nonlinearly implies that unmanaged climate change can reduce long-run incomes substantially (Burke et al., 2015). The resilience implication is straightforward: mitigation and adaptation investments reduce the probability and severity of adverse shocks, thereby stabilizing long-run growth. Green development policy, when credible, therefore yields resilience dividends by reducing exposure to climate extremes and by shifting capital toward lower-risk technologies and infrastructures.

Crisis Performance and the Social Capital Channel

Resilience is also social and institutional. Evidence that corporate social responsibility can be associated with superior performance during financial crises suggests that trust and stakeholder relationships can function as shock absorbers (Lins et al., 2017). While this is a firm-level result, its regional implication is that places with stronger ESG norms and governance infrastructures may sustain investment and employment better under stress, supporting faster recovery. The policy takeaway is that ESG-related governance and social capacity are not "soft" objectives; they can be stabilizing assets in crisis regimes.

Investment Horizons, Uncertainty Reduction, and the Green Finance Gap

A major constraint on green transition resilience is the "green finance gap" between required and realized investments. Systems-perspective analysis emphasizes the role of policy uncertainty and short-termism as key investment barriers (Hafner et al., 2020). This connects directly to resilience: regions cannot build adaptive capacity without stable long-horizon investment. Consequently, policy frameworks that reduce uncertainty—through credible regulation, consistent taxonomy and disclosure, and de-risking instruments—can generate resilience by enabling persistent capital formation in green infrastructure and technologies.

Regional Resilience as Path Dependence and Capability Accumulation

Regional resilience theory highlights that resilience is not merely a short-run property but is shaped by long-run development paths, industrial structures, and institutional capacities (Martin & Sunley, 2015). Green development policy fits this framework because it can change path dependence by redirecting innovation and investment, thereby expanding a region's future feasible set. Regions that adopt green finance and ecological governance early may accumulate capabilities—skills, infrastructures, clean-tech clusters—that increase adaptability and reduce vulnerability to late-transition shocks such as sudden carbon pricing or trade barriers.

METHODOLOGICAL FRONTIERS: MEASUREMENT, IDENTIFICATION, AND SPATIAL INFERENCE

ESG Measurement Divergence and Implications for Macro Inference

A central methodological challenge is that ESG ratings diverge substantially across providers due to differences in scope, measurement, and weighting (Berg et al., 2022). Divergence implies that empirical results can be sensitive to the chosen ESG dataset and that cross-study comparability is limited. For macro and regional studies, measurement divergence can induce attenuation bias, spurious heterogeneity, and unstable policy conclusions. This problem is particularly severe when ESG is treated as a single index without decomposing E, S, and G components or without validating which subdimensions plausibly connect to the outcome of interest (e.g., energy efficiency versus human capital). High-quality studies therefore increasingly treat ESG measurement as part of the research design rather than as a plug-in covariate.

Dynamics, Nonstationarity, and Long-Horizon Causality

Because ESG and green policy variables are often trending and slow-moving, static regressions can be misleading. The use of panel cointegration (Diaye et al., 2022) provides one response by separating long-run equilibrium relationships from short-run dynamics. This is particularly appropriate for policies such as green finance system building and regulatory strengthening, which are not expected to produce immediate output changes but can reshape long-run capital accumulation and productivity. Dynamic panel approaches and local projections (as used in environmental regulation–productivity contexts) also help capture medium-horizon responses and transition costs.

Quasi-Experimental Designs and Policy Discontinuities

Causal identification is difficult because greener regions may adopt greener policies, creating reverse causality. Quasi-experimental approaches therefore matter for credibility. For example, regression discontinuity evidence suggests that shifts in CSR behavior can lead to improved financial performance (Flammer, 2015), providing a template for how policy discontinuities or close-call thresholds might be used in regional green policy evaluation. Similarly, instrumental variables and matched comparisons in green bond studies (Flammer, 2021) demonstrate that sustainable finance events can be analyzed with counterfactual strategies rather than purely correlational designs.

Spatial Spillovers and the Need for Spatially Explicit Growth Measures

Regional effects of ESG and green policies likely spill over through trade, migration, and supply chains. The use of spatially granular proxies such as nighttime lights to capture local economic activity, and the modeling of distance decay and spillovers, represents an important methodological advance (Huang et al., 2025). Future work can strengthen inference by combining spatial econometrics with exogenous shocks (policy pilots, staggered rollouts) and by testing whether green policy impacts propagate along specific networks (industrial linkages, transportation corridors) rather than only geographic distance.

SYNTHESIS: WHAT THE EVIDENCE SUPPORTS AND WHAT REMAINS UNCERTAIN

Three synthesis claims are strongly supported by the current international literature. First, ESG performance is more plausibly associated with long-run development levels and medium-horizon economic activity than with short-run growth rates, consistent with time-to-build mechanisms and transitional adjustment costs (Diaye et al., 2022; Angelidis et al., 2024). Second, ecological governance can be compatible with productivity and competitiveness when it induces innovation offsets and when policy design aligns incentives, but effects are heterogeneous by technological capability and policy stringency (Albrizio et al., 2017; Cohen & Tubb, 2018; Benatti et al., 2024). Third, green finance can influence growth-related outcomes by reallocating capital and reducing risk, with green bonds providing evidence of both pricing differentials and potential real effects (Flammer, 2021; Zerbib, 2019; Wang et al., 2020).

At the same time, two major uncertainties remain. The first is measurement and comparability: ESG rating divergence creates instability in empirical results, complicating policy benchmarking across regions (Berg et al., 2022). The second is causal attribution at the regional level: while recent work identifies spillovers and medium-horizon predictability, more designs that exploit exogenous policy variation and that explicitly model spatial diffusion are required before strong causal claims about regional growth can be generalized.

RESEARCH AGENDA FOR THE NEXT PHASE OF ESG–REGIONAL GROWTH SCHOLARSHIP

Future research would benefit from five concrete directions. First, studies should align ESG subdimensions to theory-driven channels, rather than relying on aggregated indices, and should triangulate across rating providers to address measurement divergence. Second, empirical designs should explicitly separate growth-level effects from growth-rate effects, using cointegration, local projections, or event-study designs that match the policy horizon. Third, green finance research should move from instrument description (green bonds, green credit) to mechanism testing, including whether cheaper capital translates into additional green investment rather than relabeling, and whether this investment improves productivity and resilience outcomes. Fourth, ecological governance research should integrate green productivity and health-adjusted measures to avoid misclassifying pollution-intensive expansion as sustainable growth. Fifth, regional studies should incorporate spatial spillover structures (networks, distance decay) and investigate cross-jurisdiction coordination failures, since the welfare gains from green policies may exceed the local gains captured by a single government.

CONCLUSION

The international literature increasingly supports a structural interpretation of ESG and green development policies: they are not simply ethical constraints or investor preferences but can function as growth- and resilience-relevant institutional infrastructures. The strongest evidence indicates that ESG improvements and green policies operate primarily through long-horizon channels—innovation, productivity reallocation, energy efficiency, capital allocation, and risk reduction—rather than through immediate output expansion. In regional terms, this implies that ecological governance and green finance can shift development trajectories by expanding adaptive capacity and lowering vulnerability to climate and transition shocks. The policy implication is correspondingly clear: green development policies should be evaluated and designed as long-run resilience investments, with complementary financial, innovation, and governance measures that convert short-run adjustment costs into durable productivity and stability gains.

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Study on the Cultural and Tourism Enhancement Effect of Urban Rail Transit Coupled with the Wilson Model Based on GIS: A Case Study of Wuhan

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KEYWORDS

Sustainable Development;
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ABSTRACT

As a well-known tourist destination in China, Wuhan's tourism industry has faced sustainable development challenges in recent years. Regional development imbalance, insufficient transportation accessibility, and limited tourism capacity have become the core constraints to its high-quality sustainable development. This paper focuses on the synergistic enhancement effect of Wuhan's rail transit and urban cultural tourism. Based on GIS geographic information data support, the Wilson model is constructed to systematically calculate the tourist transportation network attraction and analyze spatial autocorrelation, combined with empirical research to explore the path for overcoming bottlenecks. The survey results show: 1) The subway helps to promote urban tourism transportation; 2) The subway serves residents' daily life more than it develops tourism; 3) The subway's role in promoting urban tourism is greater than its role in scenic area tourism. Based on the above results, the findings of this study provide theoretical support and practical paradigms for government departments in formulating sustainable development strategies for metro tourism transportation planning, construction, and operational management decisions and practices.

INTRODUCTION

With the increasingly improved urban transportation network in China, transportation plays a significant role as the foundational support for socioeconomic development, with a strong driving force in urban growth. Under the development background of the intersection and integration of transportation and tourism, there are still some shortcomings in existing related research. Firstly, in the current studies, there is a lack of in-depth analysis of the attraction models for existing metro systems, leading to the insufficient transformation of theoretical potential into practical application. Secondly, the reshaping effect of metro construction on the tourism spatial pattern, attraction threshold, and differentiation characteristics still lacks quantitative evidence supported by refined data.

Therefore, this study takes the Wuhan metro as a case, integrating GIS spatial analysis, the tourism attraction model, and tourism spatial theory. It focuses on the impact of metro tourism transportation attraction on

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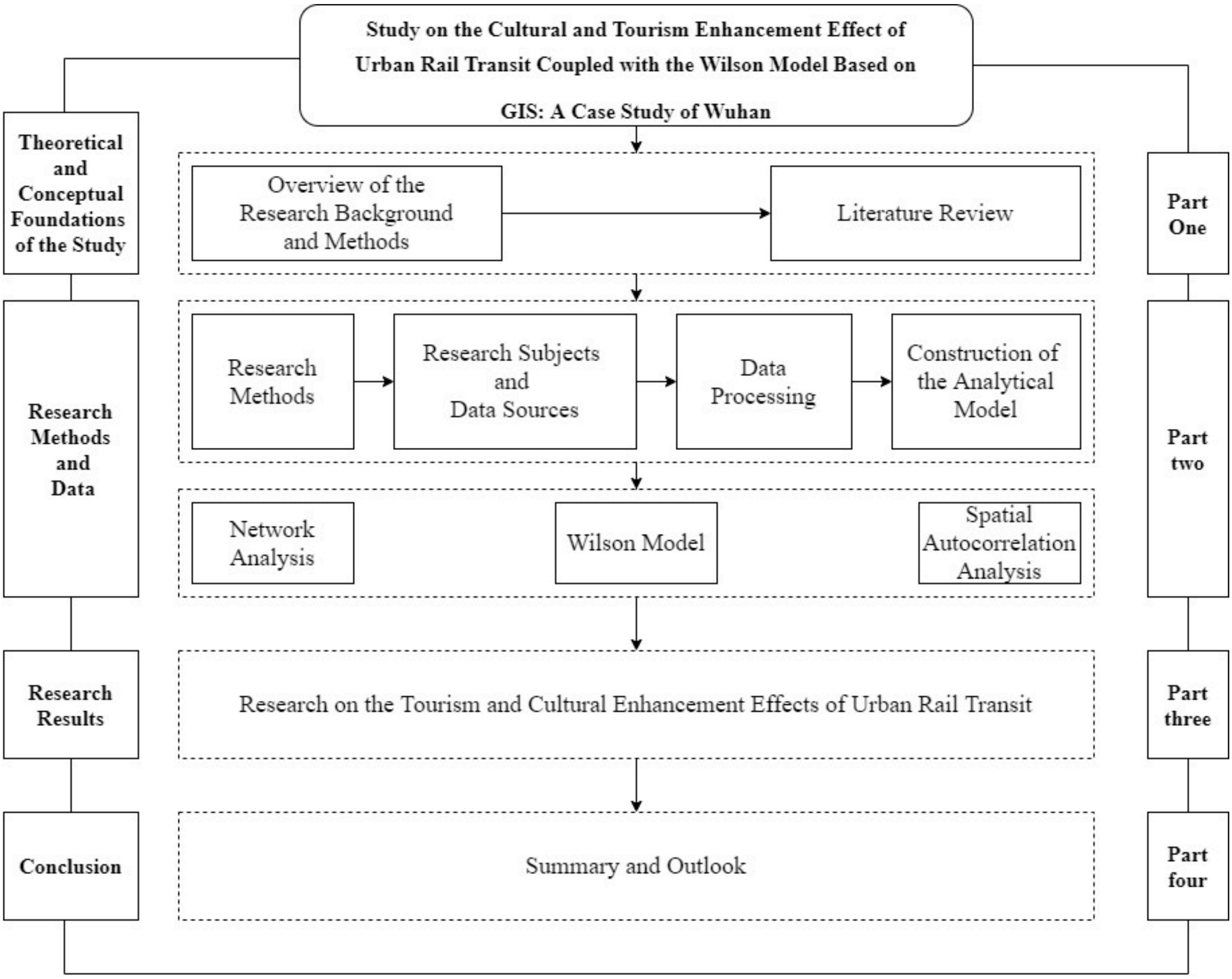

Figure 1 | Research framework

tourism appeal and regional spatial structure. A "rail-tourism" coupling research framework is constructed to systematically analyze the role of the metro network in the aggregation and diffusion of tourism elements. This research not only supports the further development of tourism gravity model theory but also holds significant practical value: it helps promote the development of Wuhan's tourism industry and activates the economic benefits of the metro, while also providing a practical basis for optimizing metro route planning and station layout in Wuhan.

In the field of transportation and urban development research, Guo Peng et al. [1], based on the gravity model, incorporated travel time into the analysis of urban gravity fields, revealing the intrinsic relationship between rail transit and urban development. Xu Lu [2], using Shanghai as a benchmark, applied the gravity model to simulate the evolution of urban spatial morphology in Nanjing from 2005 to 2014, confirming the significant impact of rail transit on its evolution and extracting patterns of influence.

In the field of tourism spatial connection research, Yang Zhongyuan et al. [3], relying on the Wilson model, coupled GIS with spatial autocorrelation techniques to analyze the tourism spatial relationships in 17 cities in Anhui Province. The study found that the overall regional connection is weak, with local clustering, and identified Chaohu and Chuzhou as cold spots, highlighting intercity differences. The research pointed out that tourist flow is the core indicator for the development of tourism, and enhancing reception capacity and strengthening supply-side capabilities are key to increasing tourism attractiveness.

In the intersection of transportation and tourism, Wang Degen et al. [4] focused on the interaction between rail transit and tourism destinations, empirically illustrating the impact mechanism of high-speed rail on tourist travel resistance, and revealing the role of factors such as tourism resource endowment in tourism attractiveness. Tang Qianyu et al. [5], based on the Wilson model, used GIS to analyze the spatial correlation between 33 metro stations (Lines 1 and 2) and 291 tourism facility points in Luoyang. They categorized the stations into nine functional types and constructed a three-level structural system.

Internationally, GIS technology has been deeply integrated into the field of tourism spatial planning and management. In the 1940s, Zipf [6] and Stewart [7,8] improved the Newtonian gravity model, with Crampon [9] being the first to apply it to tourism research. In the 1960s, Wilson A.G. [10] and others used the Wilson gravity model to analyze tourism flows, and the proposed maximum entropy model promoted the development of tourism attraction models. Farsari [11] and Sabou G.C. [12], relying on this technology, respectively carried out urban tourism spatial research and cultural heritage tourism layout optimization practices.

In summary, with the expansion of the application of gravity models, technological iteration, and the enhancement of GIS system functions, research on urban regional spatial relationships increasingly relies on the gravity model method and has attracted widespread attention in fields such as regional planning, tourism, and real estate. Existing studies have laid the theoretical and practical foundation for the fields of transportation and urban development, tourism spatial connections, and the intersection of transportation and tourism. However, they also highlight the research gaps mentioned earlier, providing an entry point for the development of this study.

RESEARCH METHODS AND DATA

Research Methods

This study employs the following two core research methods:

Firstly, Data Analysis Method. Based on the Wilson model, combined with network analysis techniques, this method quantifies the transportation attraction of various metro stations in Wuhan to nearby tourist attractions. The stations that have a significant impact on tourism transportation are selected through ranking and screening.

Secondly, Spatial Analysis Method. Using the ArcGIS platform, spatial correlation analysis is conducted to explore the spatial connection characteristics between metro stations and representative tourist attractions. On this basis, the research findings are integrated to carry out a comprehensive analysis of Wuhan's tourism industry development, providing targeted recommendations for the high-quality development of Wuhan's tourism industry (**Figure 1**).

Research Subjects and Data Sources

Research Subjects

Wuhan Metro The development process of the Wuhan Metro from its establishment in 2004 to 2023 is shown in **Table 1**. The data used in this paper are sourced from the authoritative releases by the National Development and Reform Commission (NDRC) and the Wuhan Municipal Development and Reform Commission, and are regularly updated by the Wuhan Metro Group up to December 31, 2023. The key development stages are summarized as follows:

1) 1984: Wuhan organized relevant departments and experts to discuss the feasibility of metro construction.
2) 2000: The China Railway Fourth Survey and Design Institute finalized the preliminary design for rail transit. In December, the construction of the first phase of Wuhan Metro Line 1 began.
3) 2006: The trial section of Phase I of Wuhan Metro Line 2 started construction.

Table 1 | The development history of Wuhan Metro lines and mileage

Year	Line	Total Line Length	Annual Line Length
2004	Line 1 Phase I	10	10
2010	Line 1 Phase II	19	29
2012	Line 2 Phase I	28	57
2013	Line 4 Phase I	16	73
2014	Line 1 Phase III	6	79
2014	Line 4 Phase II	17	96
2015	Line 3 Phase I	30	126
2016	Line 2 Phase II	19	145
2016	Line 6 Phase I	36	181
2017	Line 1 Phase IV	4	185
2017	Line 8 Phase I	17	202
2017	Line 21 Phase I	35	237
2018	Line 7 Phase I	31	268
2018	Line 11 Phase I	20	288
2018	Line 7 Phase II	17	305
2019	Line 2 Phase III	12	317
2019	Line 4 Phase III	15	332
2019	Line 8 Phase III	5	337
2021	Line 8 Phase II	15	352
2021	Line 11 Phase II	4	356
2021	Line 5 Phase I	35	391
2021	Line 6 Phase II	7	398
2021	Line 16 Phase I	37	435
2022	Line 7 Phase III	21	456
2022	Line 16 Phase II	4	460
2023	Line 5 Phase II	3	463
2023	Line 19 Phase I	23	486
2024	Line 7 Phase II	15	501
2024	Line 11 Phase II	12	513
2024	Line 11 Phase III	40	553

Table 2 | Wuhan metro line mileage table

Line	Length	Stations	Transfer Stations
Line 1	37.936	32	7
Line 2	60.304	38	12+1
Line 3	29.660	24	7+2
Line 4	49.693	37	7
Line 5	37.216	27	2+1
Line 6	42.537	32	9+1
Line 7	67.853	33	8+2
Line 8	38.197	26	5+2
Line 11	24.300	14	2
Line 16	36.458	14	2
Line 19	23.300	7	1
Line 21	34.575	16	2

Table 3 | Mileage density of administrative districts in Wuhan City

Administrative District	Line	Line Density (km/10,000 km^2)
Jianghan District	1、2、3、6、7	10004
Jiang'an District	1、2、3、6、7、8、21	7055
Wuchang District	2、4、5、7、8	5037
Qiaokou District	1、2、3、6、7	4892
Hanyang District	3、4、6、16	3256
Hongshan District	2、4、5、7、8、11、19	1735
Dongxihu District	1、2、3、6、7、8	797
Caidian District	3、4、6、16	388
Huangpi District	1、2、7、21	203
Jiangxia District	2、7、8、11	164
Xinzhou District	21	79

Table 4 | Top 10 single - day subway passenger flows in Wuhan in 2023

Ranking	Metro Passenger Flow (10,000 passengers)	Date
1	521.45	2023.09.28
2	519.01	2023.04.30
3	509.53	2023.12.31
4	506.04	2023.04.29
5	495.74	2023.05.01
6	494.91	2023.04.28
7	472.43	2023.06.21
8	466.92	2023.04.01
9	464.98	2023.10.27
10	461.95	2023.03.31

4) 2015: The "Wuhan Metro Phase III Construction Plan (2015-2021)" was approved by the National Development and Reform Commission.
5) 2018: Wuhan Metro added 51 km of new tracks, bringing the total length to 288 km, surpassing cities like Shenzhen, ranking fifth in the country.
6) 2021: Phase II of Metro Line 8 and Phase III of Line 11's Gedian section were simultaneously opened, covering the Qingshan and Hannan districts, achieving full coverage of the metro network across the city.

According to the approved Phase IV construction plan, Wuhan is set to complete metro projects, including Line 19, by the end of 2024, forming a 606-kilometer network with 14 operational lines, thus achieving the goal of "connecting the main city and new cities."

The **Table 2** shows the current line mileage and transfer stations of the Wuhan Metro. In the table, transfer stations labeled as "x+y" indicate that there are x stations for two-line transfers and y stations for three-line transfers. Based on this, the longest line in terms of mileage is Line 7, while the line with the most stations and transfer stations is Line 2.

Table 3 shows that Jianghan District, Jiang'an District, Wuchang District, Qiaokou District, and Hanyang District have the highest metro line density in Wuhan, while Xinzhou District, Jiangxia District, Huangpi District, and Caidian District have relatively low line density. This indicates that there is a significant disparity in the completeness of the metro network across different administrative districts in Wuhan, with an uneven distribution.

As of December 31, 2023, Wuhan Metro's daily ridership exceeded 4 million passengers on 88 days, indicating that there were 88 days in 2023 when the metro was operating under high load conditions. **Table 4** shows that the top six entries in the daily ridership ranking are all during medium and small holidays such as Labor Day (May 1), National Day (October 1), and New Year's Day, indicating that Wuhan Metro faces tremendous passenger flow pressure during holiday tourism peaks.

Wuhan Tourist Attractions According to the "2023 Government Work Report," Wuhan received 333 million tourists in 2023, a year-on-year increase of 62.4%, firmly ranking among the top ten most popular tourist cities in China. E-commerce transaction volume exceeded 1.7 trillion yuan, and total retail sales increased by 8.6% year-on-year. Among the 15 sub-provincial cities, Wuhan ranks in the first tier for tourism comprehensive competitiveness and has risen to the top spot. It ranks first in terms of current competitive strength, and its potential competitiveness and development environment competitiveness have both improved, while the quality of tourism development has significantly increased, and the city's cultural tourism brand image continues to stand out.

Research shows that the development of Wuhan's rail transit still faces two major prominent issues:

The first issue is the insufficient scientific planning of rail transit. Wuhan has excellent and widely distributed tourism resources, with the outer districts gathering high-quality cultural and tourism resources. However, the coordination between the rail transit planning and the layout of tourism resources is relatively low. Early planning focused on overall coverage efficiency, resulting in an imbalance in the line network's capacity. Existing lines are overloaded, while newly constructed lines have low passenger capacity. At the same time, the metro density in the outer districts is insufficient, and the accessibility of tourist attractions by public transport is poor. This leads to high travel costs and poor experiences for tourists, restricting the development and utilization of quality attractions. In addition, some attractions' transport planning has not been adapted to the growing demand from tourists, further exacerbating the capacity gap.

The second issue is the limited capacity of rail transit. During tourism peak periods, the number of tourists increases sharply, and rail transit becomes the preferred mode of transportation for tourists. The highest daily ridership on the metro reached 5.2145 million passengers, with Line 2 accounting for a significant share of the ridership, putting pressure on the line's capacity. The continuous growth in the number of tourists further exacerbates the rail congestion problem, not only degrading the travel experience for tourists and interfering with citizens' daily commuting but also creating safety risks. This leads to passenger flow diversion, increasing the overall traffic burden in the city. Adapting to tourists' travel needs and improving the quality of rail transit services has become a core challenge that Wuhan's rail transit development urgently needs to address.

Data Sources

The core components of the tourism system include tourist origin areas, tourism corridors, and tourist destinations. Based on the actual needs of tourism resource development in Wuhan and the requirements of this study, the specific data acquisition process is as follows:

1) Use OpenStreetMap (OSM) technology to acquire a map of Wuhan's administrative districts and define the spatial boundaries of the study.
2) Select 300 metro stations and 77 famous tourist attractions in Wuhan as the core study subjects for targeted analysis.
3) Rely on the Gaode Map API to obtain urban rail transit data, using four filtering techniques: keyword search, nearby search, polygon area search, and ID exact match. Metro station data is efficiently retrieved using the polygon search function to obtain all metro POI (Point of Interest) data within the city's range.

Data Processing

This study focuses on the two core aspects of tourist attractions and internal urban transportation. Multiple technical methods are used to systematically analyze the tourism functional system in Wuhan. The data processing steps are as follows:

1) Mars Coordinate Conversion using Map Location: Since Gaode Map data is based on the Mars coordinate system, a conversion is required to meet research needs. Based on the sample size and analysis needs, the Map Location tool is used for batch coordinate conversion. A sample is manually extracted through Gaode satellite imagery for coordinate picking, followed by accuracy verification and correction.

2) Spatial Correlation Analysis between Operational and Planned Rail Transit and Urban Tourism: The GIS software is used to add and edit data on the existing map for this purpose.
3) Data Format Conversion and Preprocessing: The geographical coordinates, path segments, and administrative area polygons acquired are converted into a projection coordinate system based on the internationally recognized WGS_1984_PDC_Mercator coordinate system (based on Gauss-Kruger) for the subsequent in-depth spatial correlation analysis.

Construction of the Analytical Model

Network Analysis

Social network theory [13, 14] defines society as a network structure composed of multiple nodes and complex relational chains. This theory can be extended to the tourism field to analyze the diverse network connections within the tourism space. In a tourism space network, metro stations can be seen as core "nodes," and the centrality of these nodes is a key indicator for evaluating their core position within the network. This study constructs a centrality evaluation model based on social network theory to assess the centrality of 300 metro stations in Wuhan. The core objective is to identify effective paths between metro stations and tourist attractions, eliminate redundant line interference, and construct an efficient connection for the Wuhan tourism transportation network.

To achieve this goal, the study adopts a three-step analysis strategy:

1) Effective Path Identification: Define the optimal path determination criteria. The potential paths between metro stations and attractions are diverse. This study uses the minimum travel ratio as the core criterion and defines the shortest time-consuming path as the optimal effective path. The "optimal" core evaluation dimension is the time span (not the physical spatial distance), similar to the "shortest path" identification logic in social network analysis.
2) Traffic Time Calculation: Quantify the time distance between nodes. Accurately quantifying the time distance between nodes is the core premise for constructing effective paths. Since GIS software can only directly obtain complete road length data, this study introduces a breakpoint cut-line function to finely segment each node, achieving automated calculations of road segment length and travel time. This allows for the precise acquisition of actual running time between nodes, providing reliable data support for path optimization.
3) Effective Path Screening: Extract core modeling data. GIS technology is used to calculate the potential paths between 77 tourist attractions and 300 metro stations in Wuhan. After eliminating irrelevant paths, the shortest travel time from each station to each attraction is extracted accurately, providing core data for in-depth modeling.

Wilson Model Calculation

Compared to the classic Newtonian gravitation model, the Wilson model has significant advantages in analyzing interactions between regions [15]. Based on existing research, Li Shan et al. [16] simplified the urban tourism space interaction model and derived a concise expression for tourism transportation interactions:

$$Tir = \exp(-Bri) \tag{1}$$

In the formula, T_{ix} represents the tourism transportation attraction between the origin and the destination, p is the spatial damping coefficient, and T_{ix} is the shortest transportation distance. In this study, as the scale of the tourism domain expands, β shows a decreasing trend, and the data obtained using three different methods all fall within the range of 0.002 to 0.005. Referring to existing empirical data, the middle value of 0.0032 can be selected as the reference [16].

After calculation, the point-to-point transportation attraction between the 300 metro stations and 77 tourist attractions in Wuhan was obtained, and the average value was further calculated to precisely quantify the attraction of each station to each attraction. The calculation formula used is as follows:

$$W_j = \frac{1}{n}\sum_{k}^{n} \exp(-\beta r_{jk}) \tag{2}$$

In this formula, W is the regional tourism transportation attraction of metro station j; n is the number of tourist attractions, which in this study is 77. Among the 300 metro stations selected for this study, the majority not only perform excellently in terms of centrality but also bear a high density of tourism transportation attraction.

Spatial Autocorrelation Analysis

This project plans to use methods such as global spatial autocorrelation and local spatial autocorrelation to conduct an in-depth spatial autocorrelation analysis of the tourist attraction at each metro station along the Wuhan Metro lines. The aim is to reveal and explore the potential spatial correlation patterns of tourist attraction between stations.

The concept of global spatial autocorrelation [17] aims to uncover the spatial correlation characteristics between attribute values across the entire study area [18]. This global spatial autocorrelation can be measured using various statistical indices, such as the global Moran's I index, global Geary's C coefficient, and global Getis-Ord G statistic [19, 20]. In this study, the global Moran's I index is selected as the evaluation tool.

The calculation formula for the global Moran's I index is:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(x_i-\bar{x}\right)(x_j-\bar{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}(x_i-\bar{x})^2} = \frac{\sum_{i=1}^{n}\sum_{j\neq i}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{S^2\sum_{i=1}^{n}\sum_{j\neq i}^{n} w_{ij}} \tag{3}$$

In this model, n represents the sample size (i.e., the number of spatial locations studied); W_{ij} measures the relative proximity between spatial locations i and j , representing the strength of their relationship: when i and j are adjacent, the value is 1, indicating a close connection; when they are not adjacent, the value is 0, indicating no direct spatial correlation.

When exploring spatial autocorrelation, the Moran's index is a key tool, which is effectively tested through the standardized statistic . The calculation formula for this index is concisely expressed as:

$$Z = \frac{I - E(I)}{\sqrt{VAR(I)}} \tag{4}$$

In this model, $E(I)$ represents its theoretical expected value, while $VAR(I)$ represents the theoretical variance of the model.

When the Z's value is positive and its absolute value is large, there is a significant positive spatial correlation, meaning similar observations (whether high or low) tend to cluster in space. When the Z's value is negative and its absolute value is large, there is a negative spatial correlation, and similar observations tend to be dispersed. When the Z is 0, the observations are independently and randomly distributed, with no significant spatial correlation.

Meanwhile, this project plans to use the metro tourism transportation and tourist attractions as the core research subjects, employing global spatial autocorrelation analysis, and further exploring its local spatial autocorrelation characteristics.

First, the local Moran's index is based on the coordinates n, and its calculation steps can be summarized as follows:

$$I_n = \frac{(X_n - \bar{x})}{S^2}\sum_j w_{nj}(X_j - \bar{x}) \tag{5}$$

The standardized statistic for the local Moran's index test is:

$$Z(I_n) = \frac{I_n - E(I_n)}{\sqrt{VAR(I_n)}} \tag{6}$$

$E(I_n)$ is the theoretical expected value for point n, and $VAR(I_n)$ is the theoretical variance for point n.

If $I_n > Z(I)$, it confirms the existence of local spatial correlation; if $I_n < Z(I)$, it confirms a negative correlation.

RESEARCH ON THE TOURISM AND CULTURAL ENHANCEMENT EFFECTS OF URBAN RAIL TRANSIT

Section 2.4 above primarily explained the analytical model constructed in this study. Based on this, the following conclusions are drawn:

After completing the three-step analysis of network analysis, a total of 23,100 route information was obtained for the 300 metro stations to 77 tourist attractions. Given Wuhan's compact geographical layout and the densely covered metro network, most tourist attractions can be conveniently reached through a "metro + walking" mode. This result confirms the core role of the Wuhan metro system in linking urban transportation and tourism resources, thus boosting the development of urban tourism.

After solving the Wilson model, the tourism transportation attraction index for 300 stations was ranked, and the top 20 results are shown in **Table 1**. The tourism transportation attraction of each metro station is intuitively displayed through the differences in color depth (**Figure 3**), and the statistical ranking of the average tourism transportation attraction for each administrative district station is shown (**Figure 4**).

1) From **Table 5**, it can be seen that Jianghan Road Station has the strongest tourism transportation attraction. This station is located in the core business district of Jianghan District and serves as a transfer hub for Line 2 and Line 6. With a high daily passenger load, it has significant transportation attraction to tourist attractions. Huangpi Square Station has the lowest tourism transportation attraction. It is located in the northern extension of Line 7 in Huangpi District, far from the city center and most popular tourist

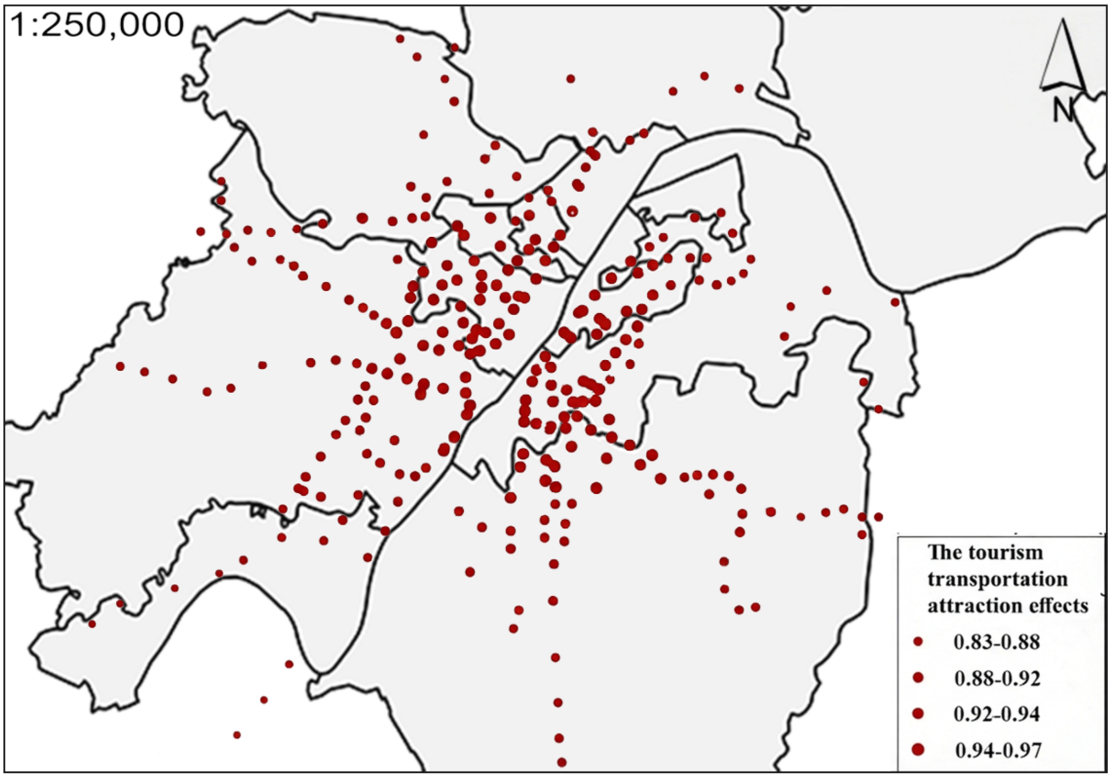

Figure 2 I Dot distribution of tourism and transportation attraction values of Wuhan subway stations

Table 5 | Ranking list of tourism and transportation attractiveness of Wuhan Metro (1 - 20)

Serial Number	Station Name	Belonging Line	Tourism Transportation Attraction
1	Jianghan Road	Line 2, Line 6	0.962961276
2	Jiyu Bridge	Line 2, Line 5	0.962866483
3	Xunlimen	Line 1, Line 2	0.962306107
4	Tanhualin	Line 5	0.961646754
5	Crab Cape	Line 2, Line 7	0.961490953
6	Dazhi Road	Line 1, Line 6	0.961460932
7	Simenkou	Line 5	0.961350019
8	Pengliuyang Road	Line 5	0.961195414
9	Fuxing Road	Line 4, Line 5	0.961117628
10	Xingsheng Road	Line 5	0.961014482
11	Shouyi Road	Line 4	0.960646468
12	Wuchang Railway Station	Line 4, Line 7, Line 11	0.960618738
13	Xiaodongmen	Line 7	0.960607673
14	Xiaoguishan	Line 2	0.960505066
15	Liuduqiao	Line 6	0.960276668
16	Sanyang Road	Line 1, Line 7	0.960071885
17	Hongshan Square	Line 2, Line 4	0.960005843
18	Zhongnan Road	Line 2, Line 4	0.95986735
19	Miaoli Road	Line 6	0.959826211
20	Youyi Road	Line 1	0.959769857

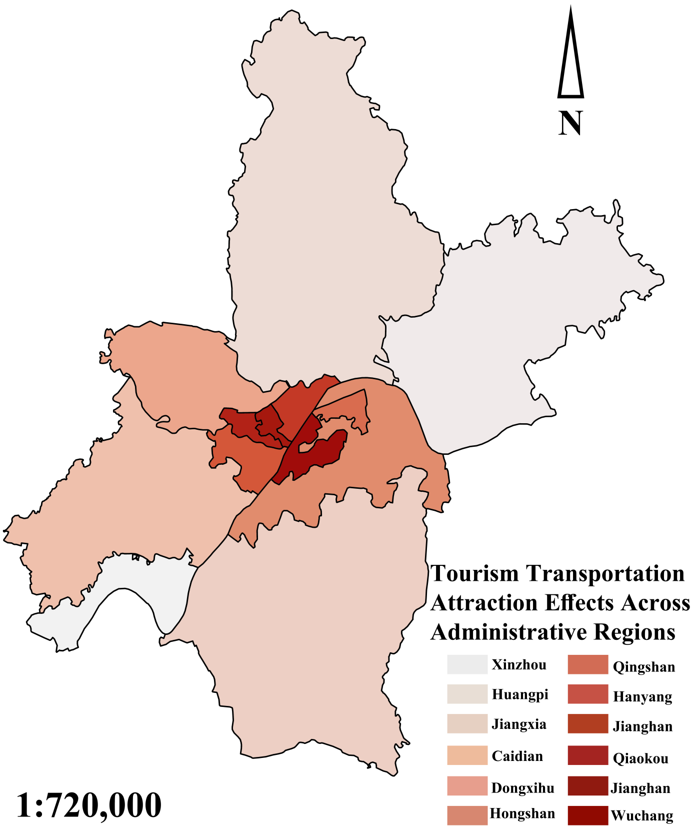

Figure 3 I Distribution map of the zoning of tourism and transportation attraction values in each administrative region

attractions.This study's tourism transportation attraction calculation takes into account both popular attractions and locally unique, lesser-known attractions that are waiting to be discovered, focusing on transportation connectivity to achieve seamless integration across all city attractions. Stations with higher attraction are at the core of the tourism network and are crucial for improving the efficiency of tourism transportation. If planning focuses only on popular tourist attractions, it can lead to overcrowding of attractions in the city center, overlooking the value of lesser-known attractions, which not only fails to address the imbalance in the popularity of attractions but also hinders balanced and high-quality development of regional tourism.

2) From the data in **Table 5** and **Figure 2**, it can be seen that the tourism transportation attraction effects along Wuhan Metro Lines 1, 2, 4, and 5 are the most significant. As the core lines of the urban rail transit network, these lines have a wide coverage and excellent accessibility, with strong passenger flow capacity. Additionally, the tourist attractions along these lines are densely distributed, and the number of visitors is relatively high. This not only reflects the compatibility between metro line planning and tourist attraction distribution but also achieves a synergistic effect between rail transit and tourism development, demonstrating a "1+1>2" cumulative effect.
3) Regional Comparison (**Figure 3**) shows that the tourism transportation attraction of metro stations in Wuchang, Jianghan, Qiaokou, and Jiang'an districts is relatively high, benefiting from their geographical advantages, which create significant transportation attraction to most tourist attractions. In Hanyang, Qingshan, Hongshan, and Dongxihu districts, the attraction is moderate, with regional tourism resources providing support to station attraction. The attraction in Caidian, Jiangxia, Huangpi, and Xinzhou districts is the lowest, attributed to their distance from the city center, low metro network coverage, as well as fewer and more singular tourism resources.
4) Although Wuchang District is a tourism hotspot with high tourist concentration, the tourism transportation attraction of its metro stations has not reached the optimal level. The core attraction comes from the abundance of tourism resources. Increasing the number of tourists is the core research direction, and

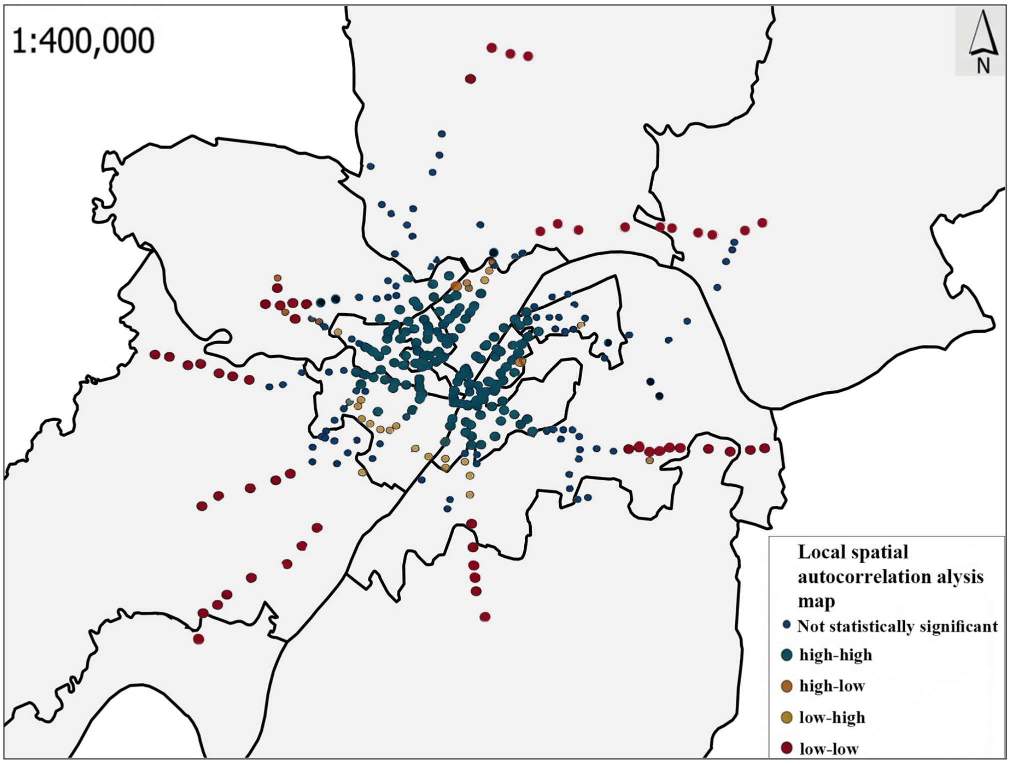

Figure 4 | Local spatial autocorrelation analysis map of tourism and transportation attraction of Wuhan subway stations

convenient transportation is the key path, which is also the core significance of this study.

Based on the analysis above, the research conclusions are consistent with the predictions of the Wilson model. The tourism transportation attraction of urban rail transit essentially reflects the centrality of metro stations, representing their core influence on tourism transportation. The tourism transportation attraction of Wuhan Metro varies significantly across different lines and administrative districts, indicating that its potential to promote the tourism industry has not been fully realized. To explore its underlying causes, this study will conduct a station centrality correlation analysis from a geographical spatial perspective. By comparing the alignment between metro line layout and tourist attraction locations, it will identify whether there are specific spatial patterns rather than random distribution.

This study plans to verify the correlation between urban tourism and rail transit in Wuhan. Based on the ArcGIS platform, a local spatial autocorrelation analysis [21, 22] will be conducted to verify whether there are significant spatial hot spots with strong influences, as well as whether spatial heterogeneity exists. Furthermore, it will analyze whether these factors affect or provide supplementary insights into the overall spatial correlation conclusions between the two.

The local spatial autocorrelation curve analysis in **Figure 4** shows that the central area of Wuhan exhibits significant HH clustering features, while peripheral areas such as Caidian, Jiangxia, Huangpi, and Xinzhou show LL clustering distribution. In the boundary areas between the center and the periphery, most metro stations have weak tourism transportation attraction, presenting spatially uncorrelated characteristics. Only a few stations exhibit an alternating high-low clustering pattern. Based on this, the following conclusions can be drawn:

1) The results of global and local spatial positive correlation broadly confirm the global positive correlation feature of the research elements. Both high and low clustering areas locally validate the existence of positive correlation. Local negative correlation does not contradict the global autocorrelation conclusion, and the central urban area's local positive correlation is significant, marking strong influence points with notable clustering effects.
2) Local autocorrelation analysis indicates that metro stations in Wuchang, Jianghan, Qiaokou, and Jiang'an districts have strong tourism transportation

attraction correlations between adjacent stations, forming a mature metro tourism transportation system.

3) Under the context of global positive correlation, the tourism transportation attraction of metro stations in the central urban area exhibits local associations, with an overall hierarchical feature of "inward clustering, outward diffusion." This reflects that the metro network planning has uneven regional distribution, leading to an imbalance in tourism contribution.

In conclusion, the local spatial autocorrelation analysis shows that the spatial correlation between rail transit and tourist attractions in the central and peripheral areas is significant. The boundary areas show no clear positive or negative correlation, and the impact of rail transit on tourist attractions in these areas is not prominent.

CONCLUSION AND OUTLOOK

This study focuses on the relationship between the metro system, urban tourism, and residents' daily life. By using network analysis methods to reveal core patterns, the following conclusions are drawn: **1)** The metro system has a significant role in driving urban tourism development. Based on the network analysis, a total of 23,100 multi-transport optimal time route plans between tourist attractions and metro stations have been constructed. These plans effectively improve the operational efficiency of the urban road network and travel convenience, enrich travel route options, and provide strong support for the advancement of tourism transportation. At the same time, the study finds that differences in metro lines and administrative district attributes significantly impact station-attraction attractiveness, deepening the understanding of the urban transportation system layout and providing scientific basis for optimizing tourism transportation resources. **2)** The metro's role in serving residents' daily life outweighs its tourism service function. There is a significant spatial positive correlation between the Wuhan metro and tourist attractions, showing an inward-to-outward clustering-diffusion effect and a layered passenger flow pattern. However, the metro line layout does not match the distribution of tourist attractions, making it difficult to fully meet tourists' travel needs. Notably, early metro lines (such as Line 1 and Line 2) were originally designed to focus on community layouts and residents' daily commuting rather than tourism services. As a result, there is a planning gap in adapting to current tourism needs, which urgently requires optimization and upgrading. **3)** The metro system's overall impact on urban tourism is greater than its direct impact on individual attractions. The Wuhan metro has weak spatial connections to most urban tourist destinations, resulting in remote, high-quality attractions like the Mulan Scenic Area not fully benefiting from metro passenger flow effects. Supplementary strategies are needed. However, from the perspective of the urban tourism landscape, the metro system, as a key element of tourism transportation, is a crucial link connecting tourists, attractions, and commercial districts. It also plays a central role in driving regional economic prosperity through tourism. Therefore, its overall impact is significantly greater than its direct effect on dispersed attractions.In summary, this study clarifies the multi-functional positioning of the metro and its boundaries of influence, providing important theoretical reference and practical guidance for optimizing metro planning and layout, balancing residents' commuting and tourism service demands, and improving the quality of urban tourism development.

Although this study provides theoretical and practical insights for tourism transportation policy formulation, it has significant time-related limitations and needs to be continuously refined in line with contemporary trends. Looking to the future, urbanization will further expand the space for metro-based tourism development. Various departments need to collaborate and integrate resources to create a comprehensive tourism experience product. To address issues such as the mismatch between metro lines and tourism needs and the weak traffic linkage to remote attractions, focus should be given to enhancing the quality of attractions. Tourists should have deep experiences of local culture and tourism, integrating into local communities to gain a sense of belonging and novelty, deepening their understanding and appreciation of Wuhan's unique charm, improving tourism satisfaction, and contributing to the high-quality development of all-area tourism.

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