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The impact of green investment on environmental pollution: a case study of the Greater Bay Area

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Abstract. With the increasing severity of global climate change and environmental pollution, green investment is gradually becoming a key component of economic development strategies in various countries. This study focuses on the Guangdong-Hong Kong-Macao Greater Bay Area (GBA), using a fixed-effects model to empirically analyze the mechanisms through which green investment, economic development, urbanization, and fiscal scale affect environmental pollution. The findings reveal that green investment significantly reduces environmental pollution levels, economic development and urbanization contribute positively to environmental quality improvement, while fiscal scale has varying regional impacts on the environment. This research further refines the theory of green finance and provides important references for promoting the coordinated development of regional economy and environment.

Keywords: green investment, environmental pollution, PM2.5, Greater Bay Area, fixed-effects model

1. Introduction

The relationship between humans and nature manifests in the interaction between economic development and ecological environmental protection. Promoting green and low-carbon economic and social development is a key element in achieving high-quality development. China has never been absent in addressing global climate change. Since the concept of "green finance" was first introduced in 1995, the field of green finance has been continuously explored and refined. In 2016, the "Guiding Opinions on Building a Green Financial System" clarified the development direction of green finance, emphasizing the support of financial services for environmental protection, energy conservation, clean energy projects, guiding social capital toward green industries, curbing polluting investments, promoting the green transformation of the economic structure, fostering new economic growth points, and promoting sustainable development.

In 2024, the "Guiding Opinions on Further Strengthening Financial Support for Green and Low-Carbon Development" further outlined the goals for the green and low-carbon financial support system over the next five years, with a vision to achieve the coordinated promotion of green and low-carbon policies by 2035, thus forming a more mature financial support system. The "Opinions" also emphasize strengthening international cooperation on green finance, particularly in promoting green investment within the framework of the "Belt and Road" initiative, deepening international cooperation, and enhancing the advantages of green finance.

Environmental pollution remains a key bottleneck restricting the high-quality development of China’s economy. The severe pollution situation forces enterprises to invest heavily in environmental governance, equipment updates, and technological upgrades, raising production costs and affecting competitiveness. At the same time, poor environmental conditions increase public health expenditures, lower labor productivity, and reduce a region's ability to attract foreign investment and high-end talent, further hindering industrial upgrading and technological innovation. According to data from the National Bureau of Statistics, in 2023, China's industrial pollution control investment reached 3,624,239.30 million yuan. On a regional level, the Greater Bay Area continues to face prominent issues such as industrial emissions, wastewater discharge, and air quality that fail to meet national standards, posing a severe challenge to regional ecological security and restricting sustainable economic development.

As an important bridge linking finance and environmental protection, green investment is gradually demonstrating its potential to address environmental pollution. By guiding financial capital toward low-carbon, environmentally friendly, and clean energy projects, green finance not only improves pollution control facilities but also promotes corporate green technological innovation, accelerating the green transformation of traditional industries. Since the introduction of the concept of "green finance," the issuance

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of green financial products such as green credit, green bonds, and green funds has grown significantly, providing strong support for the environmental protection industry.

This study aims to explore the relationship between green investment and environmental pollution, analyze the role of green finance policies in pollution control, and reveal the role of green investment in alleviating environmental pressure and promoting green economic transformation. Given the importance of the Greater Bay Area in the national strategy and the environmental pollution risks it faces, this study selects the Greater Bay Area (excluding Hong Kong and Macao) as a case to explore the impact of green investment on environmental pollution, providing theoretical support and practical reference for promoting regional green transformation and global sustainable development.

2. Literature review

2.1. Current research on green finance in China

2.1.1. The role of green finance in environmental governance

Green finance plays a crucial role in environmental governance. Firstly, it promotes technological innovation through green investment, driving the development of green technologies to achieve more efficient resource utilization and pollution control. Research by Zhu et al. indicates that the technological effects of green finance are stronger than environmental regulations, effectively incentivizing technological innovation in different regions [1]. Secondly, green finance optimizes industrial structure and promotes the green transformation of industries. This process helps reduce environmental pollution and enhances regional economic competitiveness. Zhou et al. emphasize the role of green finance in carbon reduction, particularly in green investment, which has significant effects. The innovation and efficient allocation of green financial products are essential for achieving environmental governance goals [2].

In conclusion, green investment is not only a financial tool to address environmental issues but also a vital force driving coordinated economic and environmental development. By establishing effective policy frameworks and cooperation mechanisms, the role of green finance in environmental governance can be further enhanced.

2.1.2. Regional characteristics of green finance in environmental pollution control

Existing literature shows that green finance has significant regional differences in its impact on environmental pollution control, mainly reflected in the policy effects and implementation mechanisms in the eastern, central, and western regions.

In the eastern region, the effects of green finance reform and innovation policies are most pronounced. Ma et al. point out that, under the promotion of green finance reform and innovation experimental zone policies, eastern cities have achieved noticeable reductions in pollution and carbon emissions. These policies, by reducing energy intensity and incentivizing green technological innovation, have greatly promoted regional environmental governance. The combination of green credit and green bonds, in particular, has a significant negative correlation with carbon emissions, optimizing environmental governance outcomes [3].

In contrast to the east, the impact of green finance policies on environmental pollution control in the central region has been less significant than expected. Research by You et al. shows that green bonds in the central region have not had a significant impact on regional carbon emissions. The complementary effect of green finance is mainly seen between green credit and green industrial investment [4]. However, Xu et al. note that green finance still has a noticeable effect on improving air quality in the central region, especially in economically underdeveloped areas with lower levels of air pollution. This suggests that the implementation of green finance policies has regional adaptability [5].

The western region presents a different characteristic. Research by You et al. indicates that green industrial investment in the western region has shown notable effects in emission reduction, especially in promoting local economic transformation and industrial upgrading. The role of green credit is relatively weak. This suggests that in the western region, the application of green finance may depend more on industrial structure improvements rather than solely relying on financial tools [4].

Furthermore, Zhu et al. found through spatial Durbin model research that green finance has spatial spillover effects, promoting environmental governance in surrounding areas by optimizing industrial structure and enhancing technological capabilities. This effect varies across regions, with the role of green finance being further strengthened in areas with stricter environmental regulations [1]. Therefore, establishing a regional green finance cooperation mechanism to enhance the inclusivity of green finance has become an important direction for promoting regional pollution governance.

In summary, the effectiveness of green finance in pollution control varies across regions. The implementation of policies in the eastern region has been the most successful, while the central region shows some adaptability, and the western region relies more on industrial structure optimization. In the future, green finance pilot programs should be expanded in an orderly manner, tailored to regional characteristics, to achieve more coordinated pollution reduction and carbon emission goals.

2.2. Current research on green finance in the Greater Bay Area

With the intensifying global climate change and environmental pollution issues, green investment has gradually become one of the important strategies for economic development in various countries. Green investment not only focuses on economic growth but also emphasizes environmental protection and sustainable development. It aims to promote the research and application of environmental protection technologies by rationally allocating funds, thereby reducing the risks of environmental pollution and ecological destruction. Research on green investment is particularly crucial in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA), given the increasingly severe ecological challenges it faces.

As a vital engine of China's economic development, the GBA's rapid urbanization and industrialization have brought about significant economic growth but have also led to potential environmental pollution issues. Improving the ecological environment quality has become a pressing issue for the coordinated development of the GBA region. The nine cities in the GBA must face the growing ecological and environmental impacts during their economic growth, especially the pollution emissions from the secondary industry. Therefore, researching the impact of green investment on environmental pollution can provide theoretical support for formulating more effective policies.

Green finance, as an important tool to promote green investment, holds tremendous development potential. Li et al. note that improving ecological environment quality is a critical issue for the coordinated development of the GBA region [6]. The GBA, pursuing high-quality growth under the "dual-carbon" goals, needs to enhance the ecological effects of its economic development. Research has shown that financial arrangements like green credit can guide social capital into the environmental protection sector, promote the transformation and upgrading of enterprises' environmental technologies, and effectively reduce pollution emissions from the secondary industry, thereby improving ecological effects. Green finance has a strong marginal effect in promoting the environmental renovation and technological upgrading of the secondary industry.

In conclusion, the role of green investment in addressing environmental pollution cannot be ignored, especially in rapidly developing regions like the GBA. Further research into the relationship between green investment and environmental pollution is needed to help local governments better formulate green finance policies and provide practical support for achieving the national "dual-carbon" goals.

3. Research design

Green investment is a key means to achieve sustainable development and address climate change, and it takes various forms, including green credit, green bonds, and green industry investments. This study will explore the application and impact of green investment in the Greater Bay Area.

3.1. Model construction

This study aims to examine the impact of green investment on economic growth. The following model is constructed as Equation (1):

$$In(PM_i) = \beta_0 + \beta_1 * Green_Investment_i + \beta_2 * In(GDP)_i + \beta_3 * Urbanization_i + \beta_4 * Fiscal_Scale_i + \mu_i \quad (1)$$

Where $ln(PM_i)$ represents the natural logarithm of PM2.5 concentration for the i-th observation unit, indicating the level of environmental pollution; $Green_Investment_i$ represents the proportion of green investment; $ln(GDP)_i$ is the natural logarithm of GDP, representing the level of economic development; $Urbanization_i$ is the urbanization level; $Fiscal_Scale_i$ represents fiscal scale; μ_i is the error term.

3.2. Variable selection

Definition of variables is shown as Table 1:

Table 1. Definition of variables

Variable type	Variable name	Variable symbol	Variable definition
Dependent Variable	PM2.5 concentration	*ln(PM)*	The natural logarithm of PM2.5 concentration
Core Independent Variable	Green Investment	*Green_Investment*	The ratio of environmental pollution control investment to GDP
Control Variables	Economic development data	*ln(GDP)*	Calculated by the natural logarithm of GDP

	Urbanization Level	*Urbanization*	Measuring the degree of urbanisation of an area
	Fiscal Scale	*Fiscal_Scale*	Measures the fiscal investment level in the region

3.2.1. Dependent variable

The dependent variable in this study is the natural logarithm of PM2.5 concentration $ln(PM_i)$, used to measure the level of environmental pollution.

3.2.2. Core independent variable

The core independent variable is the proportion of $Green_Investment_i$, which refers to the ratio of environmental pollution control investment to GDP, used to assess the impact of green investment on environmental pollution.

3.2.3. Control variables

To control for other factors that may influence economic growth, the following control variables are selected:

(1) Economic Development Level $ln(GDP)_i$: Measures the level of economic development in the region.
(2) Urbanization Level $Urbanization_i$: Measures the level of urbanization in the region.
(3) Fiscal Scale $Fiscal_Scale_i$: Measures the fiscal investment level in the region.

3.3. Data sources and statistical description

3.3.1. Data sources

Given the availability and timeliness of data, this study focuses on nine cities in the Greater Bay Area (excluding the special administrative regions of Hong Kong and Macau). The data for the key variables in this study spans from 2018 to 2022 and is mainly sourced from: Green investment ratio data is primarily derived from the National Bureau of Statistics, published in national and provincial statistical yearbooks; Fiscal scale data is mainly taken from local statistical bureaus (city-level fiscal revenue and expenditure details); Urbanization level data is selected from the "China City Statistical Yearbook."; Economic development data (calculated by the natural logarithm of GDP) is compiled from the "China Statistical Yearbook."; Environmental pollution indicators (lnPM) are based on data derived from the Atmospheric Composition Analysis Group, using satellite-derived PM2.5 data.

3.3.2. Statistical description

The statistical description of the sample, based on STATA software, is as Table 2 shown:

Table 2. Descriptive statistics

VarName	Obs	Mean	SD	Min	Median	Max
lnPM	90	3.429	0.215	2.960	3.455	3.833
Green_Investment	90	0.016	0.004	0.008	0.155	0.026
lnGDP	90	11.432	0.521	10.500	11.390	13.820
Urbanization	90	0.813	0.159	0.438	0.879	1.00
Fiscal_Scale	90	0.126	0.036	0.014	0.128	0.204

The sample size for the environmental pollution indicator (lnPM) is 90, with a mean of 3.429, a standard deviation of 0.215, and a range from 2.960 to 3.833. The sample size for the green investment ratio (*Green_Investment*) is 90, with a mean of 0.016, a standard deviation of 0.004, and a range from 0.008 to 0.026. The sample size for the economic development level (*lnGDP*) is 90, with a mean of 11.432, a standard deviation of 0.521, and a range from 10.500 to 13.820. The urbanization level (*Urbanization*) has a mean of 0.813, a standard deviation of 0.159, and a range from 0.438 to 1.000. The fiscal scale (*Fiscal_Scale*) has a mean of 0.126, a standard deviation of 0.036, and a range from 0.014 to 0.204.

4. Empirical process and results analysis

4.1. Single variable regression results: fixed effects model

Table 3. Fixed effects model

	(1)	(2)	(3)	(4)
Green_Investment	-14.8749**			
	(-2.614)			
lnGDP		-0.1514**		
		(-2.334)		
Urbanization			-5.7589***	
			(-5.545)	
Fiscal_Scale				-1.8171*
				(-1.754)
Constant	3.6674***	5.1605***	8.1114***	3.6587***
	(39.253)	(6.954)	(9.603)	(27.625)
Observations	90	90	90	90
R-squared	0.079	0.064	0.278	0.037
F	6.832	5.446	30.74	3.078

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In the Fixed Effects (FE) model (as shown in Table 3), the results indicate that the variables of green investment ratio, economic development level, urbanization level, and fiscal scale all have significant negative impacts. Specifically: The coefficient for green investment ratio is -14.8749 (t = -2.614, significant at the 5% level), suggesting that with each unit increase in green investment, the dependent variable (e.g., environmental pressure or other economic indicators) shows a significant negative adjustment. The coefficient for economic development level is -0.1514 (t = -2.334). The coefficient for urbanization level is -5.7589 (t = -5.545, significant at the 1% level). The coefficient for fiscal scale is -1.8171 (t = -1.754, significant at the 10% level). These results demonstrate that all variables have a negative impact in the single-variable regression model. Urbanization level contributes the most to the model's explanatory power, with an R^2 value reaching 0.278.

4.2. Stepwise addition of variables

Table 4. Stepwise regression analysis

	(1)	(2)	(3)	(4)
Green_Investment	-14.8749**	-14.5493**	-9.8980*	-9.4668*
	(-2.614)	(-2.627)	(-1.984)	(-1.870)
lnGDP		-0.1473**	-0.0978*	-0.0983*
		(-2.352)	(-1.737)	(-1.739)
Urbanization			-5.0331***	-4.9116***
			(-4.813)	(-4.591)
Fiscal_Scale				-0.5368
				(-0.592)
Constant	3.6674***	5.3464***	8.7980***	8.7656***
	(39.253)	(7.429)	(9.179)	(9.093)
Observations	90	90	90	90
R-squared	0.079	0.139	0.336	0.339
F	6.832	6.375	13.17	9.879

When control variables are added progressively, the coefficients of the explanatory variables change somewhat (see Table 4). The results are as follows: In the model with only green investment, the negative impact of green investment is significant (coefficient = -14.8749, t = -2.614). Adding the economic development level, the coefficient of green investment decreases slightly to -14.5493, and the economic development level shows a significant negative effect (coefficient = -0.1473, t = -2.352). With the inclusion of urbanization level, the coefficient of green investment further weakens to -9.8980 (t = -1.984), while urbanization level remains strong and significant (coefficient = -5.0331, t = -4.813). When the fiscal scale variable is added, the negative effects of green investment and economic development level persist (coefficients = -9.4668 and -0.0983, respectively, significant at around the 10% level), but the fiscal scale variable itself is not statistically significant (coefficient = -0.5368, t = -0.592). The model's goodness of fit (R^2) improves from 0.079 to 0.339, indicating that adding control variables significantly improves the model's ability to explain the changes in the dependent variable. This also reflects potential endogeneity or collinearity between different variables.

4.3. Mixed regression and RE — robustness check

Table 5. Robustness test

	(1)	(2)
	Mixed	RE
Green_Investment	-9.8408*	-13.1662**
	(-1.918)	(-2.448)
lnGDP	-0.0643	-0.1124*
	(-1.163)	(-1.875)
Urbanization	0.0844	0.0390
	(0.464)	(0.131)
Fiscal_Scale	-1.8745***	
	(-3.135)	
Constant	4.4894***	4.8935***
	(8.474)	(7.917)
Observations	90	90
R-squared	0.192	0.1344
F	5.059	9.562

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

To verify the robustness of the model estimates, this study further employs mixed regression and Random Effects (RE) models (As shown in Table 5). The robustness check shows that: In the RE model, green investment remains significantly negatively influential (coefficient = -13.1662, t = -2.448). Economic development level also shows marginal significance in the RE model (coefficient = -0.1124, t = -1.875). Urbanization level is not statistically significant in either the mixed regression or RE model, suggesting that its effect may be influenced by individual heterogeneity or other unobserved variables. Fiscal scale shows a strong negative effect in the RE model (coefficient = -1.8745, t = -3.135), but is not significant in the mixed regression model. The robustness check results suggest that while different estimation methods lead to some variation in the significance of individual variables, the negative effects of green investment and economic development level are generally robust across models.

5. Research conclusions and policy recommendations

5.1. Research conclusions

This study focuses on the Greater Bay Area (GBA) and, based on fixed-effect models, stepwise variable inclusion, and robustness checks through mixed regression and random effect models, explores the impact of green investment ratios, economic development level, urbanization level, and fiscal scale on environmental pollution (*lnPM*).

5.1.1. Significant negative impact of green investment on environmental pollution

The results from multiple regression analysis show that increasing the proportion of green investment significantly reduces environmental pollution (*lnPM*). This negative relationship is robust across all regression models. This implies that green investment promotes the efficient allocation of resources, drives the development of green industries, and optimizes the efficiency

of environmental resource utilization, thus positively impacting environmental governance in the Greater Bay Area. Further empirical analysis indicates that the suppressive effect of green investment on environmental pollution is particularly significant at the regional level and exhibits stability across periods.

5.1.2. Mitigation effect of economic development level on environmental pollution

The study finds a significant negative correlation between economic development level and environmental pollution (*lnPM*), indicating that economic development can reduce environmental pollution through multiple channels, such as technological advancement, enhanced management capabilities, and effective implementation of environmental policies. As the economy grows, both enterprise and government investments in environmental protection increase, and environmental governance infrastructure is continuously improved, thereby promoting the effectiveness of emissions reduction and resource recycling in the Greater Bay Area. The improvement in economic development not only marks economic growth but also plays an essential role in alleviating environmental pollution.

5.1.3. Driving effect of urbanization on environmental governance

The study reveals that an increase in urbanization level has a significant negative impact on environmental pollution (*lnPM*), indicating that infrastructure development, strengthened environmental supervision, and increased public environmental awareness during the urbanization process have played a positive role in driving environmental governance. As urbanization progresses in the Greater Bay Area, urban and rural planning, as well as regional coordinated development, have been optimized. Environmental governance policies have gradually improved, and the capacity for green development in urban areas has increased, leading to effective control of environmental pollution.

5.1.4. Instability of fiscal scale's impact on environmental pollution

The study finds that the negative impact of fiscal scale on environmental pollution (*lnPM*) is unstable under different conditions. Specifically, fiscal policies play different roles in environmental pollution control across various stages of development and regions. In economically developed areas, an increase in fiscal input can effectively support environmental protection projects and infrastructure construction, significantly reducing environmental pollution. However, in economically underdeveloped areas, due to limited fiscal resources, the governance effect is less noticeable. Additionally, the impact of fiscal scale on environmental pollution differs between the short and long term. In the short term, fiscal input is primarily used for emergency governance, with limited effects. In the long term, sustained fiscal support helps establish a more comprehensive environmental protection system, leading to more effective reductions in environmental pollution. Therefore, future research should delve deeper into the mechanisms by which fiscal factors influence environmental pollution, and formulate more targeted and region-specific policy interventions to optimize fiscal spending and improve fund usage efficiency.

5.1.5. Policy implications and importance of green investment

Empirical analysis shows that green investment not only significantly reduces environmental pollution but also plays a critical role in driving regional green transformation. Policy-level support for green investment, further improvement of the green finance policy framework, and the implementation of green projects can optimize resource allocation efficiency and enhance the coordination between economic development and environmental protection. Furthermore, policymakers should focus on leveraging the guiding role of green investment, utilizing fiscal support, tax incentives, and policy incentives to encourage increased green investment from all sectors of society, thereby gradually solidifying the foundation for sustainable development goals.

5.2. Policy recommendations

Based on the above conclusions, this study presents the following policy recommendations to provide theoretical and practical support for regional green transformation and environmental pollution control:

5.2.1. Improve the green finance policy system

The government needs to further improve the green finance policy system, particularly in the design and implementation of financial tools such as green credit and green bonds. By optimizing the policy framework, the government can incentivize financial institutions to increase funding support for environmental protection, low-carbon, and clean energy projects, guiding financial resources toward environmentally friendly industries. The government should adopt fiscal incentives, tax reductions, and other policy measures to increase support for green investment projects, promote the standardization of green finance markets, enhance

the transparency of green financial products, and increase market participation. This will strengthen the attractiveness of financial markets toward environmental protection projects and encourage more efficient participation of social capital in financing environmental protection projects. Further efforts should be made to innovate green financial products, increase their market acceptance, and accelerate the formulation and implementation of green financial standards to facilitate the healthy development of green finance.

5.2.2. Strengthen the coordinated development of regional economy and environment

Given that empirical results show that economic development and urbanization levels significantly reduce environmental pollution, it is recommended that the government adopt comprehensive policies to coordinate regional economic development with environmental governance. While promoting economic growth, attention should be focused on optimizing the industrial structure and encouraging green technology innovation. The government should actively promote the construction of green infrastructure, improve the capacity for environmental supervision during urbanization, enhance public service capabilities, and encourage the construction and upgrading of green infrastructure to achieve the development of a green, low-carbon economy. By strengthening the green transformation of regional infrastructure, promoting the development of green industries and low-carbon economies, and fostering positive interaction between economic development and ecological environmental protection, a win-win outcome for green development and economic growth should be pursued.

5.2.3. Develop regional green investment strategies based on local conditions

Considering the differences in economic structure, industrial layout, and financial development levels across cities in the Greater Bay Area, it is recommended to formulate specific green investment policies based on the characteristics of each region. In the context of uneven financial development, it is advisable to establish a regional green finance risk compensation mechanism to enhance the risk management capabilities of financial institutions in environmental protection projects. This should be complemented by policy coordination to guide funds toward promising environmental protection projects. Additionally, strengthening the pre-assessment and supervision of green investment projects will ensure that green investment funds truly contribute to environmental improvement. On this basis, each city should formulate differentiated green financial policies based on its own economic and environmental characteristics, promote the innovation of local green financial products, improve fund allocation efficiency, and enhance the effectiveness of market application, ensuring that green funds are used efficiently.

5.2.4. Promote cross-regional green finance cooperation

As a key region in the national strategy, the Greater Bay Area plays an important demonstrative role in cross-regional economic coordination and environmental governance. Considering the complexity and challenges in economic coordination and environmental governance in the Greater Bay Area, it is recommended to accelerate the construction of green finance cooperation mechanisms between regions, promoting coordination of green finance policies and collaborative environmental governance across different regions. By strengthening information sharing and resource integration, establishing a cross-regional green finance linkage mechanism, enhancing the integration of green investment and environmental protection industries, and promoting the common development of green transformation across regions, the Greater Bay Area can leverage the "Belt and Road" initiative and the global green economic governance framework to expand the regional influence and enhance fiscal cooperation and experience sharing with surrounding areas. This will create synergistic effects and allow the Greater Bay Area to play a more significant role in global green economic governance, providing solid support for achieving the "dual-carbon" goals and driving improvements in regional environmental quality. Additionally, collaboration between governments, financial institutions, and enterprises should be strengthened to share successful experiences, facilitating the coordinated implementation of regional green finance policies and promoting the comprehensive upgrade of the green economy and environmental governance.

This study provides important theoretical foundations for the Greater Bay Area and other regions in formulating green finance policies, driving green transformation, and achieving the "dual-carbon" goals. By clarifying the impact mechanisms between green investment and environmental pollution, and exploring the roles of green investment in optimizing industrial structure and promoting green technology application, this research offers systematic theoretical support and practical experience for local governments in implementing green development strategies and formulating regional policies. The ultimate goal is to achieve a win-win outcome for both economic and environmental development.

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