Incentive or constraint? Comprehensive impacts of green credit policy on industrial energy intensity

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Abstract
Green credit policy (GCP) has dual attributes of being both an "environmental regulation" and a "financial instrument". Understanding its role in facilitating industrial green transformation is crucial. However, there is limited theoretical and empirical evidence on the impact of GCP on industrial green transformation. This research fills this gap by comprehensively investigating the impacts and mechanisms of GCP on industrial energy intensity (EI) in China, considering both incentive and constraint effects. Theoretically, the environmental and financial impacts of GCP are merged into a unified analytical framework based on a heterogeneous enterprise model. Empirically, diverse empirical methods, including difference-in-differences (DID), difference-in-differences-in-differences (DDD), and mediating effects models, are adopted to examine whether GCP can promote green innovation or accelerate financial constraints. Results show that (1) GCP significantly decreases EI, especially among high-polluting enterprises (HPEs). The impact of incentives is far greater than that of constraints. (2) Regarding the incentive effect, energy substitution and innovation offsets exert a primary influence on reducing EI. (3) The constraint effect is caused primarily by rising financing and pollution abatement costs. (4) Heterogeneity analysis shows that the inhibiting effect of GCP is more significant in non-state-owned enterprises, underdeveloped financial markets, and abundant energy endowments. This paper provides a theoretical framework and new empirical evidence for policymakers to design effective policies for promoting industrial green transformation.
Keywords Green credit policy · Energy intensity · Heterogeneous enterprise model · Incentive effect · Constraint effect

Introduction

Emerging nations are keen to finding solutions to the major issue of the deterioration of the natural environment brought about by industrial economic expansion, necessitating the call for green industrialization. For instance, industrialization and urbanization have led to an exponentially rising level of economic development in China. However, with credence to the environmental Kuznet curve, it is ascertained that rapid economic expansion may lead to severe ecological deterioration (Zhang et al. 2021a).

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Improving energy efficiency is generally considered a critical way to improve ecological environment while stimulating economic growth (Zeinab et al. 2022). However, according to the International Energy Agency (IEA), global energy efficiency investment in 2022 was only $560 billion, which is far less than $1 trillion in the demands for energy efficiency investment (IEA 2022). China's government has launched a series of energy and environmental policies designed to improve energy efficiency and achieve the carbon neutrality target, which require significant financial support (Zhu et al. 2021). Yet, the ecological bane remains continuous and industrial emissions continue to soar exponentially (Duceux, 2023). This situation has led to the need to assess prior conventional financial models, leading to the revolutionary concept of green finance.

In contrast to conventional Chinese finance prioritizing economic growth, China's green finance focuses more on sustainable development by encouraging green innovation among Chinese businesses (Lu et al. 2022). As embodied by green credit, green financing is more successful than traditional policies in terms of enhancing environmental quality. The rationale behind this finding is that green financing initiatives strive to lower the intensity of carbon emissions via economic restructuring and advancements in pollution control technology rather than by directly limiting the overall amount of carbon emissions (Jiakui et al. 2023; Li et al. 2022). The National Climate Strategy Centre predicts that China's demand for additional climate investments will reach 139 trillion yuan by 2060. Among these investments, the development of green finance is crucial for raising funds that might be used to assist environmental improvement and address climate change (Pan et al. 2021).

The Chinese government has implemented many green financing measures since 2007, including green bonds (He et al. 2023) and green credits (Guo et al. 2023), to supplement existing environmental regulations. As a vital component of green finance, green credit financing accounts for more than 90% of total green financing and plays a major role in realizing the carbon neutrality target. GCP refers to the differentiated credit policies adopted by banks and other financial institutions for various businesses. These policies provide financial support for non-high-polluting enterprises (non-HPEs) with favourable loan interest rates while placing financial restrictions on HPEs with punitively high loan interest rates. Through green credit allocation, GCP can direct funds from HPEs to non-HPEs to support carbon emission reductions. Along with providing financial funds, GCP also has some regulatory responsibilities regarding environmental preservation. In this respect, GCP is both an "environmental regulation" and a "financial instrument" (Wang et al. 2021).

There has been a hot debate over the relationship between GCP and EI (Ma et al. 2021; Song et al. 2021; Shen et al. 2020). Most scholars argue that GCP can significantly decrease EI of HPEs. GCP can guide more capital to flow to green industries such as clean energy industry and foster the transition from fossil fuels to clean energy alternatives, effectively improving the energy consumption structure and reduce the consumption of fossil energy (Tan et al. 2022; Cheng et al. 2023). In addition, GCP includes the environmental performance of enterprises as a prerequisite for credit approval, forcing enterprises to surge in terms of their demand for green technology innovation. So, GCP can motivate enterprises to launch green technology innovation by increasing R&D investment and enhancing energy efficiency (Guo et al. 2023; An et al. 2023). Other scholars believe that GCP can significantly increase EI of HPEs. As an environmental regulation, GCP internalizes the negative externality costs of environmental pollution. The resulting increase in costs not only undermines the incentive of HPEs to engage in energy efficiency technology innovation, but also crowds out their energy efficiency investments (Dirckinck-Holmfeld 2015; Li et al. 2023a), which is detrimental to the energy efficiency of HPEs. Luo et al. (2023) found that GCP aggravated financing constraints and limited the innovation impetus of HPEs, which greatly prevented them from taking energy conservation initiatives, even directly giving up green credit financing (Wen et al. 2021), or unethically defrauding green credit financing by means of greenwashing (Flammer 2021; Xing et al. 2021). Some scholars have also found that there is a significant positive U-shaped relationship between GCP and EI of HPEs. When GCP was first proposed during the initial period, it was not conducive to decreasing EI of HPEs, instead having the constraint effect. When GCP is gradually perfect during the mature period, a large amount of green capital can be put towards energy conservation projects, which can significantly promote EI of HPEs and transform into the incentive effect (Zhang et al. 2021b; Ma et al. 2022; Meng et al. 2023).

The differences in research samples, especially for HPEs, may be to blame for this dispute. As the dominant source of industrial carbon emissions, HPEs are essential in lowering industrial carbon emissions. On the one hand, the high-carbon attributes of HPEs and the low-carbon investment requirements of GCP make it more difficult for HPEs to obtain green credit financing (Sai et al. 2023); on the other hand, HPEs have a more urgent need for green credit financing due to their great technical difficulty and long cycle in terms of carbon reduction activities (Fan et al. 2021; Li et al. 2023b). The majority of previous research ignores the characteristics of HPEs in favour of focusing on the emission reduction effect of GCP from the micro perspective of enterprises (Zhang et al. 2020).

The differences in observed objects may be another main reason for this debate. The literature focuses mainly on the impact of GCP on carbon emission reduction (Zhang et al. 2022a). Most studies advocating the effectiveness of GCP on carbon emission reduction believe that “energy efficiency” plays an important intermediary role in this relationship (Lee et al., 2022; Gao et al. 2022a). However, the improvement in energy efficiency may not be synchronized with the decrease in carbon emission, which can be verified by energy rebound (Steren et al., 2016). It is mainly because that technological progress improves energy efficiency and decrease energy consumption, which in turn stimulates energy demand and causes energy consumption to rebound. Therefore, it is a crucial theoretical and practical issue whether GCP can improve energy efficiency or reduce EI and further help enterprises to achieve industrial green transformation.

However, the exploration of GCP affecting EI of HPEs is inadequate. First, the theoretical foundation is insufficient. Most previous studies evaluate the effects of GCP based on the effectiveness of public policies (Ren et al. 2020; Wang et al. 2022). This analytical paradigm is difficult to compare horizontally and cannot be falsified. Among the few referential researchers, Raberto et al. (2019) adopted the Eurace model to integrate households, enterprises, government, commercial banks, and central banks into a unified analytical framework and found that credit regulation policies promote capital accumulation and investment in the short term, thereby lowering EI. However, the Eurace model is a multi-agent macroeconomic model and does not correctly depict how enterprises respond to GCP or explain how GCP affects EI.

Second, the dual attributes of GCP are disregarded, especially in the institutional context of China. The majority of previous research analyses the effect of GCP from a single attribute, which makes it easy to draw partial conclusions (Su et al. 2022). The immature market environment and unique institutional background make GCP with dual attributes in the Chinese context both an "environmental regulation" and a "financial instrument". Few studies have systematically analysed the dual attributes of GCP in a unified research framework, and even fewer studies have explored the micromechanisms from the perspectives of both "the incentive effect" and "the constraint effect".

Third, it is challenging to resolve the conflict between the incentive and constraint effects of GCP. From the perspective of financial instruments, scholars have largely concurred that GCP aggravates the financial constraints of HPEs (Jiang et al. 2022). However, it is still controversial whether the effect of financial constraints imposed by GCP on EI of HPEs is an incentive or constraint (Zhou et al. 2022; Pang et al. 2022). Some scholars believe that the incentive effect of GCP on EI of HPEs is achieved mainly by increasing financing constraints and debt financing costs (Tan et al. 2022). In contrast, other scholars hold the opposite viewpoint that GCP has a constraining effect on HPEs and enhances their EI by increasing financial constraints and decreasing investment levels (Yao et al. 2021). From the perspective of environmental regulation, researchers have generally accepted that GCP influences the green innovation of HPEs based on the Porter hypothesis. However, there is controversy regarding whether the effect of GCP on the green innovation of HPEs is incentivized or constrained. Supporters assert that GCP can promote the green innovation of HPEs and produce the Porter effect (Gao et al. 2022c), mainly because GCP increases the degree of R&D investment of HPEs (Zhang et al. 2022b). The resulting incentive effect can significantly decrease EI of HPEs (Song et al. 2021). Opponents claim that GCP can inhibit the green innovation of HPEs and fail to exert the Porter effect, mainly because GCPs decrease the level of debt financing of HPEs, particularly long-term debt financing (Hong et al. 2021). The resulting constraint effect can markedly increase EI of HPEs (Yu et al. 2022). In brief, existing debates are divided on whether GCP affects EI of HPEs by incentive or constraint effects. Few studies have considered the two effects simultaneously and reasonably unified the controversy between them.

Against the above background, this paper focuses on the relationship between GCP and EI of industrial enterprises and analyses the following crucial inquiries: (i) Does GCP promote the sustainable development of industry in China? (ii) Does GCP serve as a motivator or a barrier for enterprise prospects to switch to a low-carbon economy? Finally, (iii) does GCP foster innovation or accelerate financial constraints inside the Chinese industrial structure? To solve these problems, this paper introduces energy factors and green credit into the enterprise production function on the basis of a heterogeneous enterprise theoretical model and reveals the microcosmic mechanism and potential impact of GCP on EI of HPEs. Taking the implementation of GCP in 2007 as a quasi-natural experiment, we employ the microeconomic database from 2001-2011 and adopt DID and DDD approaches and a mediating effects model to empirically examine the above theoretical mechanism.

Our study answers pertinent issues to offer cogent policy reforms, including whether GCPs can support the green transformation of HPEs by altering China's growth model. Investigating how HPEs change in response to GCP based on data at the business level advances our knowledge of the micro dynamism mechanism of GCP and speeds up the accomplishment of the aforementioned objectives. Additionally, decision-makers will gain insight into how to manage the green industrial transition from a GCP viewpoint by comprehending the connection between GCP and the green revolution of HPEs. This approach will help maintain the focus of the industrial transformation on green development. Specific contributions and innovations are concentrated primarily in the below three areas.

First, this study offers a comprehensive and unified theoretical framework for analysing the environmental and financial impacts of GCP. By integrating these two dimensions into a single analytical framework, we are able to provide a complete understanding of the mechanism behind GCP. Specifically, we examine the impact of GCP on EI of industrial enterprises and explore the mechanisms through which GCP affects EI. This analysis allows us to better understand how GCP can promote green industrialization in emerging economies and identify areas where policy interventions may be most effective.

Second, building on the literature, we also provide a unified explanation of the debate between the incentive and constraint effects of GCP. By considering both the environmental and financial properties of GCP, we propose a feasible explanation for the existing research controversy. Specifically, we argue that GCP can act as both an incentive and a constraint, depending on the specific context and the targeted enterprise type. We provide empirical evidence to support this argument and discuss the implications for policymakers and researchers.

Finally, through an empirical examination of the concrete effects of GCP on Chinese industrial enterprises, we provide new and comprehensive support for current empirical research. Our analysis is based on the microscopic data of industrial enterprises, which allows us to explore the influencing mechanism of GCP in greater detail. Specifically, we examine the impact of GCP on EI of industrial enterprises in China and identify the factors that mediate this relationship. Our analysis provides important insights into how GCP can be used to promote green industrialization in emerging economies and highlights the need for targeted policy interventions to address the specific challenges faced by different types of enterprises.

The remainder of this paper is organized as follows. Section 2 conducts a theoretical analysis and proposes research hypotheses. Section 3 introduces the methodology and describes the data and variables. Section 4 presents the empirical findings and emphatically discusses the influencing mechanism. Section 5 summarizes our key findings and proposes some policy implications.

Theoretical analysis and research hypotheses

Existing heterogeneous enterprise models mostly adopt Melitz's (2003) model under the assumption of the Constant Elasticity of Substitution utility function. Although Melitz's (2003) model is simplified and easy to solve, the price elasticity of demand derived from the Constant Elasticity of Substitution utility function is constant, which means that the cost-plus pricing of different enterprises is the same. This situation is obviously contrary to economic reality and does not truly reflect the difference in the impact of different cost-plus pricing on enterprises' energy-saving and consumption-reduction behaviours. On the one hand, the incentive effect of green technology investment on different cost-plus enterprises will be different, and on the other hand, exogenous shocks, such as the intensification of market competition and the implementation of environmental policies, will affect the cost-plus of enterprises. Based on the research objectives of this paper, GCP, as an exogenous shock, is more suitable for the heterogeneous enterprise model based on quasilinear preferences, and energy and GCP are simultaneously introduced into the enterprise production function for extended research.

Consumer preferences

Referring to Melitz and Ottaviano (2008), we assume that there are L identical consumers and that the utility function of representative consumers is the quasi-linear form:

$$U = \alpha \int_{i\in\Omega} q_i^c \, di - \frac{1}{2}\gamma \int_{i\in\Omega} (q_i^c)^2 \, di - \frac{1}{2}\eta \left(\int_{i\in\Omega} q_i^c \, di\right)^2 - \int_{i\in\Omega} z_i \, di \qquad (\alpha, \gamma, \eta > 0) \qquad (1)$$

In Eq. (1), q_i^c represents the consumption of each consumer in heterogeneous product category i; Ω represents the set of heterogeneous product categories; α,γ,η is the given demand parameter; z_i is the pollution emission of each enterprise; $\int_{i\in\Omega} z_i \, di$ is the disutility brought to consumers by pollution; and $\frac{\partial \int_{i\in\Omega} z_i di}{\partial z_i} > 0$. Then, for each category i in the heterogeneous product industry, the market inverse demand function faced by each enterprise is as follows:

$$p_i = A - bq_i \qquad (2)$$

In Eq. (2), $A = \frac{\alpha\gamma + \eta P}{\gamma + \eta N}$, $b = \frac{\gamma}{L}$, and $P = \int_{i\in\Omega^*} p_i \, di$ is the total price index, and N is the total number of heterogeneous product categories.

Enterprise production behaviour

It is assumed that the heterogeneous product industry has a monopolistic competitive market structure and that enterprises have the freedom to enter or exit the market; however, these enterprises need to pay entry cost f_e and randomly acquire productivity φ_i. According to Helpman et al. (2004), φ_i follows the Pareto distribution $G(\varphi_i) = 1 - \left(\frac{\varphi_0}{\varphi_i}\right)^\rho$, where φ_0 is the scale parameter, equal to the minimum productivity of the enterprise engaged in industrial production activities, and ρ is the shape parameter of the Pareto distribution function.

Assume that enterprises use three factors: labour, capital and energy. It may be assumed that $K = 1$; then, $l = \frac{L}{K}$ and $e = \frac{E}{K}$ represent labour and energy per unit of capital, respectively, that is, efficient labour and efficient energy. The unit prices of L and E are p_l and p_e, respectively.

The original intention of GCP is to increase the energy and production costs of HPEs by strengthening credit constraints and incentivizing HPEs to carry out green technology innovation to achieve green and low-carbon development. Therefore, GCP forces HPEs to bear not only the same energy costs as those before but also the additional energy cost due to policy internalization. This paper adopts $\tau = 1 + \sigma(\tau \geq 1)$ to represent the unit variable cost of energy under GCP, where σ is the increasing energy cost due to policy internalization. The larger the value of τ is, the greater the increase in energy costs caused by policy implementation. In addition, following Forslide et al. (2018), the corporate green technology investment functional is $h(f_A) = f_A^{\rho}$ $(\rho > 0, f_A \geq 1)$.

Referring to Copeland and Taylor (1994), the production function of intermediate input is $x_i = {e_i}^s {l_i}^{1-s} (0 < s < 1)$, and the variable production cost function is $c_i x_i = \tau p_e e_i + p_l l_i$. According to the principle of cost minimization, the unit variable cost of intermediate input can be deduced as $c_{1i} = \frac{\tau^s}{s^s(1-s)^{1-s}}, \frac{\partial c_i}{\partial \tau} > 0$. The production function of the final product is $x_i = \frac{f(q_i)}{\varphi_i f_A^{\rho}}$ under the given productivity and green technology investment levels. Usually, we assume that $f(q_i) = {q_i}^2$; then, enterprise production unit q_i of the final product production function is $q_i = \sqrt{\varphi_i f_A^{\rho} {e_i}^s {l_i}^{1-s}}$, and the variable cost function is $c_i x_i = \frac{p_l c_{1i} {q_i}^2}{\varphi_i f_A^{\rho}} \left(\frac{p_e}{p_l}\right)^s$. Additionally, enterprises have to pay fixed costs $\tau^{\beta} f$, where $\beta > 0$ measures the elasticity of fixed cost expenditure to GCP regulation.

Equilibrium analysis under GCP

When GCP is implemented, the profit maximization problem faced by HPEs is as follows:

$$max\left(p_i q_i - \tau p_e e_i - p_l l_i - a f_A^{\rho} q_i - \tau^{\beta} f\right)$$
$$= max\left[(A - b q_i) q_i - \frac{p_l c_{1i} {q_i}^2}{\varphi_i f_A^{\rho}} \left(\frac{p_e}{p_l}\right)^s - a f_A^{\rho} q_i - \tau^{\beta} f\right] \; (a > 0) \tag{3}$$

By solving the above profit maximization problem, the optimal EI of HPEs can be deduced as follows:

$$ee_{1i}^*(\varphi_i; f_A, c_{1i}) = \frac{e_i^*}{q_i^*} = \frac{s c_{1i}\left(A - a f_A^{\rho}\right)\left(\frac{p_e}{p_l}\right)^{s-1}}{2\tau\left[b\varphi_i f_A^{\rho} + p_l c_{1i}\left(\frac{p_e}{p_l}\right)^s\right]} \tag{4}$$

Comparative static analysis

The chain rule is adopted to further analyse how GCP affects EI of HPEs. The partial derivative of Eq. (4) with respect to τ can be obtained as follows:

$$\frac{\partial ee_i^*}{\partial \tau} = \frac{s\left(\frac{p_e}{p_l}\right)^{s-1}}{2\tau\left[b\varphi_i f_A^{\rho} + p_l c_{1i}\left(\frac{p_e}{p_l}\right)^s\right]} \left\{ \underbrace{-\frac{c_{1i}\left(A - a f_A^{\rho}\right)\left[(1-s) b\varphi_i f_A^{\rho} + p_l c_{1i}\left(\frac{p_e}{p_l}\right)^s\right]}{\left[b\varphi_i f_A^{\rho} + p_l c_{1i}\left(\frac{p_e}{p_l}\right)^s\right]\left(\frac{p_e}{p_l}\right)} \frac{\partial\left(\frac{p_e}{p_l}\right)}{\partial \tau}}_{\textbf{Energy substitution} < 0} \right.$$

$$\left. \underbrace{-\frac{\rho f_A^{\rho-1} c_{1i}\left[Ab\varphi_i + a p_l c_{1i}\left(\frac{p_e}{p_l}\right)^s\right]}{b\varphi_i f_A^{\rho} + p_l c_{1i}\left(\frac{p_e}{p_l}\right)^s} \frac{\partial f_A}{\partial \tau}}_{\textbf{Innovation offsets} < 0} + \underbrace{\frac{b\varphi_i f_A^{\rho}\left(A - a f_A^{\rho}\right)}{b\varphi_i f_A^{\rho} + p_l c_{1i}\left(\frac{p_e}{p_l}\right)^s}}_{\textbf{Financial constraints} > 0} \frac{\partial c_{1i}}{\partial \tau} - \frac{c_{1i}\left(A - a f_A^{\rho}\right)}{\tau} \right\} < 0 \tag{5}$$

In Eq. (5), $\frac{c_{1i}}{\tau} - \frac{\partial c_{1i}}{\partial \tau} = \frac{\tau^{s-1}(1-s)^s}{s^s} > 0$.

Based on the above analysis, we propose Hypothesis 1.

Hypothesis 1. GCP can effectively reduce EI of HPEs.

As seen from Eq. (5), there are two main paths through which GCP can affect EI of HPEs. One path is through the incentive effect represented by energy substitution and innovation offsets, which is reflected in the first and second items on the right of Eq. (5), and another path is the constraint effect that includes both financing and pollution abatement costs, which are reflected in the third item on the right of Eq. (5). The two paths jointly affect EI of HPEs, but the effects are completely opposite.

Incentive effect

The incentive effect of GCP prompts the green transformation of HPEs by strengthening the substitution relationship between energy and non-energy and stimulating green technology innovation to reduce energy consumption and increase output, which is favourable for reducing EI.

Specifically, the incentive effect has two main mechanisms. The first mechanism is energy substitution, which refers to the substitution relationship between energy and non-energy caused by changes in relative energy prices, thus changing the energy structure. If there is a substitution relationship between energy and non-energy, then it indicates that the similarity of the two factors in the production process of enterprises is extremely high. When the relative price of energy rises due to the price discovery function of the GCP, it can timely guide HPEs in fully adjusting the proportion of energy according to the price signal, increase the use of non-energy with a low relative price, conserve the use of energy with a high relative price, and finally improve the efficiency of energy utilization to expand output. Therefore, a decrease in the relative input of energy and an increase in output significantly reduce EI.

The second mechanism is innovation offsets, which focus mainly on the “Porter hypothesis”. According to the “Porter hypothesis”, stringent but properly designed environmental regulations can trigger technology innovation and improve productivity and competitiveness, thus partially or more than fully offsetting the costs of complying with them; that is, these regulations produce innovation offsets (Porter, 1991; Porter and Linde, 1995). GCP increases the production cost of HPEs in the short term, which would stimulate HPEs to incorporate green technology innovation into their production decisions. Hence, GCP can incentivize HPEs to carry out process and product innovation by increasing green innovation investment and developing green innovation technology in the long run. The resulting innovation benefits exceed compliance costs, which is conducive to achieving a “win–win” situation of increasing output and reducing energy consumption, thus reducing EI (Zhang et al. 2021c). Based on these analyses, we propose Hypothesis 2 as follows:

Hypothesis 2. GCP can reduce EI of HPEs through the incentive effect.

Constraint effect

The constraint effect of GCP internalizes the externality of environmental pollution by affecting the investment and financing behaviours of HPEs. The increase in cost will force HPEs to change their optimal decision, thus hindering energy conservation behaviour, which is the negative factor leading to an increase in EI.

The constraint effect has the following two main mechanisms. First, GCP increases the financing cost of HPEs. Based on signal transmission theory, the GCP adopts the differentiated high interest rate policy for HPEs, which in essence conveys the green credit supply to the financial market and directly influences credit allocation for HPEs. The weakening of investment intention and the reduction of capital supply sharply decrease the level of external financing and increase financing costs. In addition, the green flow of credit funds increases the environmental costs and investment risks of HPEs and decreases the willingness of external creditors to provide debt capital (Chai et al. 2022). As a result, non-traditional bank loans, such as private loans and social financing, are gradually moving away from HPEs and flowing more towards non-HPEs, which further raises the financing costs of HPEs.

Second, GCP increases the pollution abatement cost of HPEs. The essence of pollution emissions is energy consumption (Wan 2022). GCP requires financial institutions to make "environmental compliance, energy conservation, carbon reduction and social responsibility conditions for credit approval", which forces HPEs to bear additional costs for energy consumption and pollution emissions (Lin et al. 2021). Driven by the goal of profit maximization, HPEs tend to temporarily increase their level of investment in terminal pollution treatment, such as by paying pollution taxes or purchasing pollution treatment facilities, rather than continuously improving the capacity of front-end pollution abatement, such as relying on green technology innovation to improve energy efficiency. However, terminal pollution abatement is disconnected from the production process of enterprises, which may force HPEs to transfer factors, such as labour, capital, and energy originally used in the production process, to energy-saving activities and further crowd out productive investment; thus, it is not conducive to reducing EI of HPEs.

In short, the simultaneous increase in financing costs and pollution abatement costs makes HPEs face tighter financial constraints, the external financing demands cannot be met, and the incentive effect of pollution abatement is difficult to achieve. Therefore, HPEs will eventually be forced to reduce their level of production due to the reduction in loans and the increase in costs, which will lead to a decline in actual output. Under the given energy situation, the increased financing cost and pollution abatement cost caused by the constraint effect of GCP significantly increase EI of HPEs. Based on these analyses, we propose Hypothesis 3 as follows:

Hypothesis 3. GCP can improve EI of HPEs by the constraint effect.

Fig. 1 clearly shows the mechanism and effect of GCP on EI of industrial enterprises.

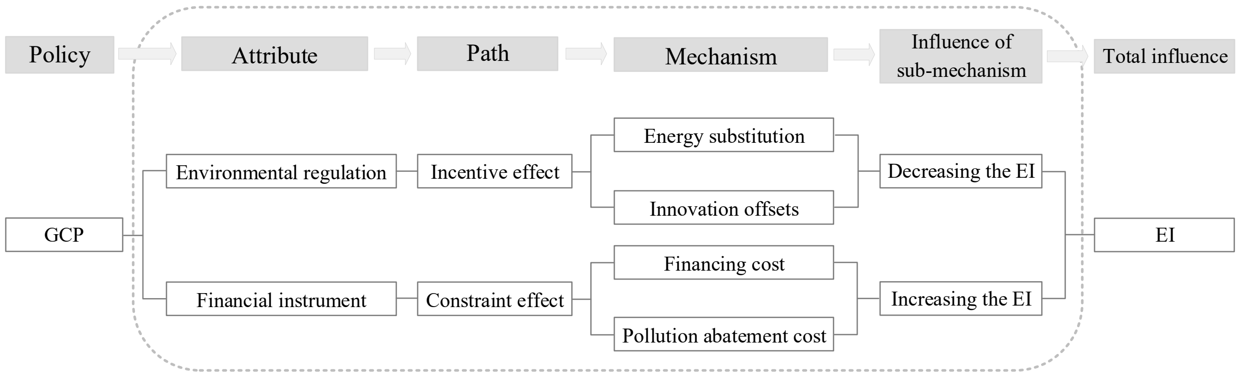

Fig. 1. Mechanism and effect of GCP on EI of industrial enterprises.

Methodology and data

Econometric methodology

DID model

By creating a quasi-natural experimental scenario with differences between the experimental and control groups and between the pre- and post-experiment, the DID method has been widely used in policy evaluations to precisely identify the effect of policies. Although GCP is an unanticipated “exogenous shock”, it directly influences the energy consumption behaviour of enterprises, offering an ideal quasi-natural experimental scenario. Given this situation, non-HPEs, which are less affected by GCP, are used as the control group, and HPEs, which are more affected by GCP, are used as the experimental group[†].

[†] The identification of the experimental group is based mainly on the Guidance on Industry Classification of Listed Companies revised by China Securities Regulatory Commission in 2012, the Management List of Industry Classification of Environmental Verification of Listed Companies formulated by the Ministry of Environmental Protection in 2008, and the Guidance on Environmental Information Disclosure of Listed Companies published in 2012, which includes 16 high-polluting industries: thermal power, steel, cement, electrolytic aluminium, coal, metallurgy, chemical, petrochemical, building materials,

Taking the implementation of the GCP in 2007 as an exogenous policy shock, this paper empirically tests the effect of the GCP on EI of HPEs. The following econometric model is suggested in accordance with the above theoretical analysis:

$$e\_intensity_{it} = \alpha_0 + \alpha_1 did_{it} + \sum_j \alpha_j\, control_{it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{6}$$

Specifically, subscripts i and t denote region i and year t, respectively. $e_intensity_{it}$, or EI of industrial enterprises, is the dependent variable. did_{it} is the key independent variable, which is obtained by multiplying two dummy variables, $treat_i$ and $post_t$. $treat_i$ is the dummy variable of the treatment group, while $treat_i = 1$ indicates that the enterprise belongs to the polluting industry; otherwise, it is 0. $post_t$ is the dummy variable of the experimental period, while $post_t = 1$ indicates that the year is 2007 or later; otherwise, it is 0. Thus, only if GCP has been implemented and the firm is in a polluting industry does $did_{it} = 1$; otherwise, it is 0. $control_{it}$ is a series of control variables, including firm- and city-level control variables. λ_t is the year-time fixed effect, μ_i is the individual fixed effect, and ε_{it} is the random disturbance term. α_1 is the effect of GCP on EI of HPEs, and the expected sign is negative.

DDD model

To effectively alleviate the endogenous interference that cannot be excluded from DID, referring to Lu et al. (2021), this paper selects "net receivable/total assets" to quantitatively measure the commercial credit constraint of enterprises and construct a DDD model. The higher the value of this indicator is, the more likely the enterprise is to become a supplier of commercial credit, the less dependent it is on external financing, and the less affected it should be by GCP. Accordingly, the dummy variable $credit_{it}$ is generated, while $credit_{it} = 1$ indicates that the enterprise's commercial credit constraint is tight and is greatly affected by GCP; otherwise, it is 0. ddd_{it}, the multiplication term of $credit_{it}$ and did_{it}, is the triple difference term in this paper, and the DDD model is shown in Eq. (7).

$$e\_intensity_{it} = \alpha_0 + \alpha_1 did_{it} + \alpha_2 ddd_{it} + \sum_j \alpha_j\, control_{it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{7}$$

Variable selection

The dependent variable is EI of industrial enterprises (e_intensity), which reflects the energy consumption per unit output value and is obtained by dividing industrial coal consumption by total industrial output value. The core independent variable is GCP (did), which is logistically generated based on the DID model.

Control variables consider mainly certain important factors that may affect EI of enterprises, except for GCP, and eleven control variables are selected based on both macro and micro perspectives (Lv et al. 2020; Wu et al. 2021).

The firm-level control variables from the micro perspective include mainly the following: (1) Firm age (lnage) is measured by the current year minus the year of firm establishment. The earlier the firm is established, the less willingness it has to introduce pollution treatment equipment and reduce EI (Yuan 2023). (2) The assets-to-liabilities ratio (lia_ratio) is expressed by the ratio of total liabilities to total assets, which reflects the long-term solvency of enterprises. The higher this ratio is, the greater the risk of creditors funding enterprises and the less willing they are to reduce EI (Tian et al. 2022). (3) Return on equity (roe) is generated by the ratio of total profit to the owner's equity, which reflects the profitability of enterprises. The higher the return on equity is, the greater the willingness to increase production efficiency and reduce EI (Cui et al. 2022). (4) The turnover of total assets (turnover) is measured by the ratio of total revenue to total assets, which reflects the operational capacity of enterprises. The faster the speed of asset turnover is, the greater the willingness to increase R&D investment and reduce EI (Feng et al. 2022).

The city-level control variables from the macro perspective specifically include the following: (1)

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papermaking, brewing, pharmaceutical, fermentation, textile, tanning and mining.

Economic development (lnpgdp) is measured by GDP per capita. The greater the regional economy develops, the more it can provide strong support for enterprises to decrease EI (Li et al. 2023c). (2) Industrial structure (ind_constr) is gained by the ratio of industrial output value to GDP. Given the tremendous energy consumption of industry, the proportion of industrial output value in the national economy is an important factor affecting EI (Hu et al. 2020; Gao et al. 2022b). (3) Financial development (finance_level) is represented by the ratio of RMB loan balance by financial institutions to GDP. Regional financial development can provide strong financial support for enterprises to reduce EI (Liu et al. 2017). (4) Openness to the outside world (openness) is expressed as the ratio of foreign direct investment (FDI) to GDP. The impact of FDI on EI of industrial enterprises is uncertain. If foreign-invested enterprises bring about more efficient production methods, they will reduce EI; however, if foreign-owned enterprises invest in high-polluting projects, they will increase EI (Guo et al. 2022). (5) Pollution treatment (wuranzhi) is measured by the ratio of investment in pollution treatment to GDP. Investment in pollution treatment can trigger the innovation of cleaner production technology and reduce EI (Ma et al. 2021). The descriptive statistics for each variable are shown in Table 1.

Table 1 Descriptive Statistics.

Variable type	Variables abbreviation	Variable definition	Observation	Mean	St.dev
Dependent variable	e_intensity	Logarithm of the ratio of energy consumption to industrial output	262,991	0.1284	0.1995
Independent variables	did	Cross-product of treat and post	262,991	0.4391	0.4963
	ddd	Cross-product of treat, post and credit	207,642	0.1731	0.3784
Firm-level control variable	lnage	Logarithm of enterprise age	262,991	2.1833	0.9454
	lia_ratio	Logarithm of the ratio of total liabilities to total assets	262,991	0.6181	0.2970
	roe	Logarithm of the ratio of total profit to ownership interest	262,991	0.2175	0.6366
	turnover	Logarithm of the ratio of operation revenue to average total assets	262,991	1.8307	2.0711
City-level control variable	lnpgdp	Logarithm of GDP per capita by region	262,991	9.7778	0.7839
	ind_constr	Logarithm of the ratio of secondary sector output to GDP by region	262,991	0.6127	0.1515
	finance_level	Logarithm of the ratio of loans from financial institutions to GDP by region	262,991	1.2580	0.7250
	openness	Logarithm of the ratio of FDI to GDP by region	262,991	0.0334	0.0400
	wuranzhi	Logarithm of the ratio of investment in pollution abatement to GDP by region	262,991	0.0279	0.0576

Data sources

Enterprise-level data are from the Chinese Industrial Enterprise Database and Chinese Enterprise Pollution Emission Database, and city-level data are from the China City Statistical Yearbook. With reference to the sequential identification and matching method of Brandt et al. (2012), we match the Chinese Industrial Enterprise Database with the Chinese Enterprise Pollution Emission Database according to legal person codes and enterprise names and further delete the following samples: (1) enterprises with missing, negative or abnormal key variables, such as gross industrial output value, consumption of all kinds of energy, total assets and fixed assets; (2) enterprises with fewer than 5 employees; and (3) enterprises that appear less than twice in the sample period. In addition, since the industry classification standard of the national economy was adjusted in 2003 and 2011, we use the latest Industry Classification of the National Economy (GB/T 4754-2011) to unify industry codes. With China’s access to the WTO beginning in 2001, the concept of green finance began to be introduced in China. Moreover, the data on coal consumption by industrial enterprises were only disclosed up until 2011, and thus, the sample period is determined to be 2001-2011. Generally, five years is enough to show the effectiveness of macroeconomic policies. If the research window is too long, then it is easy to introduce other interfering factors, confuse the net effect of policies, and only add endogeneity problems. At the data level, in addition to generating corresponding variables, the following processes are also carried out: (1) for missing variables for a few years (mainly 2010), a linear interpolation method is used to complete the missing values; (2) in view of the large difference in price levels among different industries, the industrial output value is deflated by the producer price index of different industries, the fixed assets are deflated by the fixed asset investment price index, urban GDP is deflated by the GDP deflator, and foreign direct investment is converted according to the RMB/US dollar exchange rate over the years, after which the GDP deflator is used to deflate, and all are converted to comparable prices based on 2001; (3) for continuous variables, shrinking-tail treatment at the 1% level is carried out to preliminarily eliminate the influence of extreme values in the data; and (4) logarithms are taken for all data using absolute values to alleviate the heteroscedasticity and deviation problems that may be caused by differences in data magnitude.

Empirical results

Benchmark regression

This paper examines the impact of GCP on EI of HPEs. The benchmark regression results are displayed in Table 2 under the entity fixed and time fixed effects. Columns (1-2) show the benchmark regression results of the DID method; Column (1) does not include any additional control variables, while Column (2) joins control variables at the enterprise and city levels to alleviate omitted variable bias. The regression coefficient of GCP is significantly negative at the 1% level, regardless of whether the control variable is added, indicating that GCP significantly reduces EI of HPEs. Similarly, Columns (3-4) reflect the benchmark regression results of the DDD method under the introduction of the intersection term. Hypothesis 1 is verified.

Table 2 Results of benchmark regression.

Variables	(1) e_intensity	(2) e_intensity	(3) e_intensity	(4) e_intensity
did	-0.0081*** (0.0015)	-0.0064*** (0.0015)	-0.0068*** (0.0017)	-0.0055*** (0.0017)
ddd			-0.0038** (0.0015)	-0.0030** (0.0015)
Constant	0.1448*** (0.0009)	0.2198*** (0.0182)	0.1479*** (0.0008)	0.2071*** (0.0240)
Firm control	NO	YES	NO	YES
City control	NO	YES	NO	YES
Year fixed effects	YES	YES	YES	YES
Firm fixed effects	YES	YES	YES	YES
N	262,991	262,991	207,642	207,642
R^2	0.0128	0.0263	0.0107	0.0261
F	154.3	147.3	89.04	102.5

Note: The standard error of the corresponding coefficient is shown in parentheses; *, **, *** represent significance at the levels of 10%, 5%, and 1%, respectively. Unless otherwise specified, the following is the same and will not be repeated.

Robustness tests

Parallel trend test

Treatment and control groups must adhere to the parallel trend test for the effectiveness of the DID approach; that is, EI of high-polluting and green enterprises had a similar or even parallel development trend before GCP. According to Jin and Chen (2022), dummy variables six years before the GCP and five years after the GCP were introduced, and 11 annual DID variables were generated as explanatory variables by multiplying them by the treatment variable. EI of enterprises was still taken as the explained variable, and the following model was built to check whether the parallel trend hypothesis is satisfied.

Figure 2 shows the coefficients of the regression results under the 95% confidence interval. The impact of virtual GCP on EI was zero, fluctuating up and down at zero before GCP. In addition, the regression coefficient is non-significant before the GCP but significantly negative after the GCP. This finding not only indicates that there is no systematic difference between high-polluting and green enterprises before GCP but also further demonstrates that EI of HPEs significantly decreased after GCP. Moreover, the regression coefficient generally continued to increase after 2007, which also indicates that the effect of GCP presents a certain time lag. As time passes, the vitality of GCP becomes stronger, which plays a greater role in reducing EI of HPEs.

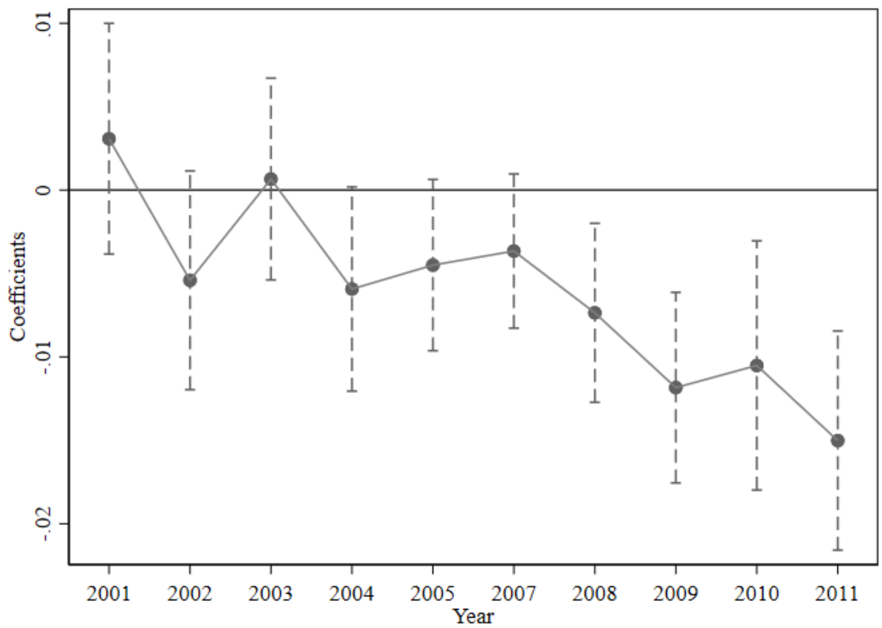

Fig. 2 Test of the parallel trend hypothesis for HPEs and non-HPEs.

PSM-DID

Although the results of the parallel trend hypothesis indicate that there is no significant difference between high-polluting and green enterprises before GCP, the potential difference between high-polluting and green enterprises may still interfere with the estimation results of DID. However, propensity score matching (PSM) can help in the choice of the most similar green enterprises for HPEs through observable covariates and minimize the difference between high-polluting and green enterprises as much as possible. Therefore, the combination of the PSM and DID approaches can better mitigate intergroup bias to obtain more robust results. Based on Huang and Guo (2021), the dummy variable of whether an enterprise belongs to the high-carbon industry is taken as an explained variable, the covariates of enterprise and city characteristic control variables are treated as explanatory variables, probit regression is carried out, and the propensity score values of each enterprise are obtained. After matching, enterprises with large differences that fail to match the corresponding samples are eliminated, and then, DID estimation is carried out on the matched samples. The estimation results are shown in Table 3. Columns (1)-(3) use the one-, two- and four-nearest-neighbour-matching methods, respectively.

Placebo test

As mentioned above, before 2007, when GCP was not implemented, there was no significant difference between HPEs and non-HPEs. Therefore, if the policy implementation time lags several periods, then according to the previous inference, the coefficient of did will no longer be significant at this time; if the opposite is true, then it indicates that there are other unobservable potential factors or ignored interference factors, which lead to the decline in the level of EI of HPEs, rather than GCP only reducing EI of HPEs. Columns (4)-(5) of Table 3 report the estimation results of the DID model under the assumption that GCP was implemented in 2006 and 2005, respectively. It can be seen that the regression coefficients are not significant, and even assuming that the coefficient when the policy was implemented in 2006 is positive, there is still a large deviation. Therefore, to a certain extent, the influence of other potential and interference factors is excluded, and the policy effect of GCP is once again confirmed to reduce EI of HPEs.

Table 3 PSM-DID approach and placebo test

Variables	(1)	(2)	(3)	(4)	(5)
	One-Nearest-Neighbour Matching	Two-Nearest-Neighbour Matching	Four-Nearest-Neighbour Matching	e_intensity	e_intensity
	e_intensity	e_intensity	e_intensity		
L1did	-0.0071***	-0.0051***	-0.0051***		
	(0.0023)	(0.0009)	(0.0009)		
L2did				-0.0020	
				(0.0015)	
L3did					-0.0022
					(0.0015)
Constant	0.1498***	0.1661***	0.1654***	0.2196***	0.2196***
	(0.0247)	(0.0131)	(0.0131)	(0.0182)	(0.0182)
Firm control	YES	YES	YES	YES	YES
City control	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES
Firm fixed effects	YES	YES	YES	YES	YES
N	79,812	261,792	262,843	262,991	262,991
R^2	0.0112	0.0186	0.0186	0.0262	0.0262
F	29.23	155.1	155.0	147.4	146.9

Eliminating the interference of contemporaneous factors

In terms of eliminating the interference of the 2008 international financial crisis, the severe impact of the international financial crisis is mainly through inhibiting the investment and financing demands of HPEs and then affecting EI. On the one hand, referring to Durnev and Kim (2005), the potential external financing needs of enterprises $External$[‡] are used to measure the scale of funds that HPEs need to raise from the capital market through financial activities. On the other hand, referring to Ding and Knight (2011), $Salegrowth$ is measured by the annual growth rate of enterprises' main business revenue, which could reflect changes in the investment demand of HPEs. Two control variables are introduced simultaneously in Eq. (10), and the estimation results are shown in Columns (1)-(2) of Table 4. After considering the interference of the 2008 international financial crisis, whether other control variables are added or not, the impact of GCP on EI of HPEs is still significantly negative.

The "dual control of energy consumption" policy was first proposed during the 11th Five-Year Plan,

[‡] The potential external financing needs of enterprises ($External$): $External = (Asset_t - Asset_{t-1})/Asset_{t-1} - ROE_t/(1 - ROE_t)$, where $Asset$ is the total assets of enterprises and ROE is the return on equity of enterprises.

aiming to implement the dual control of total energy consumption and EI for key energy-using units. Given the similarity in time and goal between the "dual control of energy consumption" policy and GCP, it is necessary to eliminate its interference. According to the list of key industries with outdated production capacity eliminated during the 11th Five-Year Plan period defined in the Comprehensive Work Plan for Energy Conservation and Emission Reduction in 2007[§], this paper conducts regression analysis on the basis of excluding the enterprise samples covered by the above industries. The estimated results are shown in columns (3)-(4) of Table 2. Regardless of whether some samples are excluded, the regression results after alleviating the interference of the "dual control of energy consumption" policy are still significant at the 1% level, which again supports the robust impact of GCP on EI of HPEs.

Table 4 Eliminating the interference of contemporaneous factors.

Variables	(1) e_intensity	(2) e_intensity	(3) e_intensity	(4) e_intensity
did	0.0049*** (0.0015)	0.0056*** (0.0015)	0.0057*** (0.0010)	0.0061*** (0.0010)
external	0.0006 (0.0004)	0.0005 (0.0004)		
salegrowth	-0.0001*** (0.0000)	-0.0001*** (0.0000)		
Constant	0.1270*** (0.0009)	0.2083*** (0.0148)	0.0721*** (0.0007)	0.1379*** (0.0184)
Firm control	NO	YES	NO	YES
City control	NO	YES	NO	YES
Year fixed effects	NO	YES	NO	YES
Firm fixed effects	NO	YES	NO	YES
N	165,521	165,521	157,454	157,454
R^2	0.0129	0.0249	0.0146	0.0271
F	127.91	130.51	113.5	87.08

Heterogeneity analysis

Heterogeneity of enterprise property rights

There are significant differences between state-owned and non-state-owned enterprises in terms of financing channels and financing structures, which have a great impact on the effectiveness of GCP. Thus, according to the differing nature of property rights, this paper divides sample enterprises into state-owned and non-state-owned enterprises and carries out regressions by group. Column (1) takes state-owned enterprises and HPEs as the regression samples, and Column (2) takes non-state-owned enterprises and HPEs as the regression samples. The estimated coefficient of non-state-owned HPEs is significantly negative, while the estimated coefficient of state-owned HPEs is not significant, indicating that the effect of GCP on reducing EI of non-state-owned HPEs is more significant than is that of state-owned HPEs. Perhaps due to the narrow financing channels of non-state-owned enterprises and their strong dependence on bank loans, the implementation of GCP forces enterprises to carry out green transformation and undertake social responsibilities to obtain more green credit financing.

Heterogeneity of the degree of financial marketization

The financial marketization environment faced by enterprises largely affects their financing convenience and costs. Therefore, this paper takes the median of the financial marketization index of each province as the standard and divides enterprises into HPEs with a high degree of financial marketization

[§] The elimination of backwards production capacity during the 11-th Five-Year Plan period involves mainly 13 industries: power, iron, steel, electrolytic aluminium, ferroalloy, calcium carbide, coke, cement, glass, papermaking, alcohol, monosodium glutamate and citric acid.

and those with a low degree of financial marketization for grouped regressions. In Column (3), HPEs with a high degree of financial marketization are used as regression samples, and in Column (4), HPEs with a low degree of financial marketization are used as regression samples. GCP has a greater effect on reducing EI of HPEs with a low degree of financial marketization. A possible explanation for this is that the more developed the financial market is, the more convenient the financing for HPEs, and the lower the financing cost. When the extra cost of GCP is higher than the cost of other financing methods, the profit-seeking nature of HPEs guides them not to pursue green credit financing, and thus, HPEs are less affected by GCP in an environment with a high level of financial marketization.

Heterogeneity of energy endowments

The richness of energy endowments in the province where the enterprise is located directly determines the energy cost and factor structure, thus making the impact of GCP on EI show obvious differences. Therefore, this paper takes the median of the energy self-sufficiency rate of each province as the standard and divides enterprises into HPEs with a high level of energy endowments and those with a low level. The results of the grouping regression are shown in Columns (5)-(6) of Table 5. In Column (5), HPEs with a high level of energy endowments are used as regression samples, and in Column (6), HPEs with a low level of energy endowments are used as regression samples. The effect of GCP on reducing EI of HPEs with a high level of energy endowments is more significant. A possible reason for this is that when the energy endowment is relatively abundant, the cost of enterprises to obtain energy is relatively low. However, to obtain green credit financing, enterprises are forced to greatly reduce the input of polluting energy, and thus, GCP has a greater impact on HPEs in an environment with a high level of energy endowments.

Table 5

Heterogeneity analysis.

Variables	(1) State-owned HPEs	(2) Non-state-owned HPEs	(3) High degree of financial marketization	(4) Low degree of financial marketization	(5) High level of energy endowments	(6) Low level of energy endowments
	e_intensity	e_intensity	e_intensity	e_intensity	e_intensity	e_intensity
did	-0.0030	-0.0054***	-0.0041***	-0.0081***	-0.0089***	-0.0037***
	(0.0028)	(0.0009)	(0.0010)	(0.0018)	(0.0018)	(0.0010)
Constant	0.2254***	0.1509***	0.1553***	0.2326***	0.2310***	0.1444***
	(0.0380)	(0.0141)	(0.0146)	(0.0315)	(0.0256)	(0.0153)
Firm control	YES	YES	YES	YES	YES	YES
City control	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
Firm fixed effects	YES	YES	YES	YES	YES	YES
N	40,860	222,131	198,497	64,494	90,237	172,754
R^2	0.0129	0.0200	0.0174	0.0235	0.0196	0.0190
F	12.16	143.4	109.5	49.25	59.63	101.3

Test of incentive effect

According to the above theoretical analysis, on the one hand, the incentive effect can reduce energy consumption by changing the energy structure, that is, by energy substitution; on the other hand, it can increase output by promoting green technology innovation, that is, innovation offsets, effectively reducing EI of HPEs. Referring to Sun et al. (2012), this paper takes industrial coal consumption, the number of employees at the end of year and capital stock as input variables and the total industrial output value as the output variable and decomposes energy efficiency into energy substitution efficiency and technical efficiency**. Energy substitution efficiency is the proxy variable for energy substitution, while technical efficiency is the proxy variable for innovation offsets.

The test results of the incentive effect are shown in Table 6. In Column (1), the coefficient representing GCP on the energy substitution efficiency of HPEs is significantly positive, indicating that GCP adjusts the proportion of energy and non-energy and further improves the energy substitution efficiency of HPEs. In Column (2), the coefficients representing GCP and energy substitution efficiency in terms of EI of HPEs are both significantly negative, indicating that energy substitution presents a significant mediating effect between GCP and EI of HPEs. In Column (3), the coefficient representing GCP on the technical efficiency of HPEs is significantly positive, indicating that GCP can effectively guide capital to increase R&D investment and improve the technical efficiency of HPEs. This finding is inconsistent with the analysis of Lu et al. (2021), which adopts the number of invention patent applications or grants as a proxy variable for technology innovation and pays more attention to product innovation, while we use technical efficiency after energy efficiency decomposition and pay more attention to process innovation, which is more consistent with the original intention of the incentive effect. In Column (4), the coefficients representing GCP and technical efficiency in terms of EI of HPEs are both significantly negative, thus verifying the positive path of "GCP→(improving) technical efficiency→(reducing) EI". The overall empirical results of the incentive effect are consistent with the research conclusion of Chen et al. (2021) that GCP has an incentive effect on the green transformation of brown enterprises, and thus, Hypothesis 2 is verified.

Table 6 Test results of the incentive effect.

Variables	(1) energy substitution efficiency	(2) e_intensity	(3) technical efficiency	(4) e_intensity
did	0.0115*** (0.0028)	-0.0081*** (0.0012)	0.0019*** (0.0005)	-0.0075*** (0.0012)
energy substitution efficiency		-0.0088*** (0.0018)		
technical efficiency				-0.3993*** (0.0148)
Constant	0.8126*** (0.0416)	0.1828*** (0.0203)	0.0049 (0.0180)	0.1776*** (0.0209)
Firm control	YES	YES	YES	YES
City control	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES
Firm fixed effects	YES	YES	YES	YES
N	184,961	184,961	184,961	184,961
R^2	0.3627	0.0330	0.1807	0.0572
F	3713	121.1	536.8	132.9

Test of constraint effect

It can be seen from the above theoretical model that the constraint effect is essentially a cost constraint. GCP is not only directly limited by financing costs but also indirectly affected by pollution abatement costs. Thus, we intend to conduct an empirical test on the intermediary path of "GCP→the constraint effect →EI". The ratio of interest expenditure to total debt is used as the proxy variable of financing cost (Pittman and Fortin,2004). Given the differences in enterprise scale, the number of emission reduction facilities per 10,000 persons is used as the measurement standard of pollution abatement cost, including the number of wastewater and waste gas treatment facilities per capita (Liu et al. 2021).

The test results of the constraint effect are shown in Table 7. In Column (1), the coefficient of GCP on the financing cost of HPEs is significantly positive, indicating that the constraint effect narrows the

** Due to space limitations, the decomposition process is tedious and will not be displayed here. Interested readers are requested from the author.

financing channel and sharply increases financing costs. This finding is basically consistent with the research conclusion of Si and Cao (2022). In Column (2), the coefficients of GCP and financing cost on EI of HPEs are both significant, indicating that financing costs play a negative intermediary role in the relationship between GCP and EI. In Column (3), the coefficient of GCP on the pollution abatement cost of HPEs is significantly positive, indicating that GCP triggers HPEs to invest more in energy conservation activities through the internalization of pollution externalities. The resulting "resource crowding effect" increases the pollution abatement cost. In Column (4), the coefficients of GCP and pollution abatement cost on EI of HPEs are both significant, thus verifying the negative transmission path of "GCP→(increasing) pollution abatement cost→(increasing) EI", which is consistent with the findings of Lin et al. (2021). Thus, Hypothesis 3 is verified.

Table 7 Test results of the constraint effect.

Variables	(1) financing cost	(2) e_intensity	(3) pollution abatement cost	(4) e_intensity
did	0.0023*** (0.0004)	0.0069*** (0.0011)	0.0144** (0.0074)	-0.0056*** (0.0014)
financing cost		0.0753*** (0.0090)		
pollution abatement cost				0.0118*** (0.0024)
Constant	0.0685*** (0.0018)	0.3224*** (0.0083)	0.5256*** (0.1161)	0.1279*** (0.0258)
Firm control	YES	YES	YES	YES
City control	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES
Firm fixed effects	YES	YES	YES	YES
N	173,655	173,655	115,335	115,335
R^2	0.0469	0.0400	0.0801	0.0377
F	263.5	121.4	269.2	67.33

In summary, the incentive and constraint effects brought about by GCP indeed coexist but play an opposite mediating role in reducing EI of HPEs. The sum effects of energy substitution and innovation offsets far exceed financing and pollution treatment costs, and thus, the incentive impact is significantly greater than is the constraint effect in general. This finding may be due to the following two reasons: on the one hand, compared with the constraint effect, the incentive effect plays an intermediary role in promoting fundamental changes, such as the optimization of the energy structure and the innovation of energy-saving technology, and the corresponding impact will be larger, while on the other hand, the incentive effect promotes HPEs to transfer from the original passive reduction to the current proactive reduction. The resulting positive effect brought about by the incentive effect will be far greater than the negative effect brought about by the constraint effect, which is exactly consistent with the intention of GCP.

Conclusions and implications

Green credit has the dual attributes of "environmental regulation" and "financial instruments"; therefore, it is very important to discuss its role in the process of industrial green transformation. However, the majority of previous research analyses the effectiveness of GCP from the perspective of a single attribute; furthermore, the evaluation of the policy effects remains controversial, and the exploration of specific microcosmic mechanisms is inadequate. To fill the research gap, energy factors and green credit are introduced into the enterprise production function, and the environmental and financial impacts of green credit are incorporated into the unified analytical framework on the basis of a heterogeneous enterprise theoretical model to reveal the comprehensive mechanisms and impacts of GCP on EI of HPEs in terms of the incentive and constraint effects, respectively. Taking the implementation of the GCP in 2007 as a quasi-natural experiment, we employ the Chinese Industrial Enterprise Database and Chinese Enterprise Pollution Emission Database during 2001-2011 as research samples and construct DID and DDD methods and mediating effect models to empirically examine whether GCP can promote innovation or accelerate financial constraints.

The main research conclusions are as follows. First, the theoretical model and empirical analysis are mutually verified, with both indicating that GCP has a significant inhibiting effect on EI of HPEs. Second, the analysis of the mediating mechanism shows that the incentive and constraint effects of GCP coexist but are opposites. Specifically, the incentive effect significantly reduces EI of HPEs, while the constraint effect obviously enhances EI of HPEs. Furthermore, the impact of incentives is far greater than is that of constraints, which indicates that industrial enterprises have produced offset benefits exceeding compliance costs. Third, the incentive effect originates mainly from energy substitution and innovation offsets, while the constraint effect stems primarily from the increase in financing costs and pollution abatement costs. Finally, heterogeneity analysis shows that the inhibiting effect of GCP on EI of HPEs is more significant in non-state-owned enterprises, underdeveloped financial markets and abundant energy endowments.

Based on the above conclusions, the following policy implications are proposed. First, the government should further improve the incentive and constraint mechanism of GCP to stimulate the green transformation of HPEs. GCP has both incentive and constraint effects, but the constraint effect is merely the means, while the incentive effect is the ultimate goal, aiming to trigger HPEs to realize green transformation and sustainable development (Wu et al. 2022). Hence, financial management departments should formulate subsidy and reward standards for green credit and take incentives, such as green refinancing, discount interest on green credit, and targeted rate reduction on green credit, to guide funds to invest more in green fields to better play the incentive effect of GCP.

Second, the clean energy substitution and green technology innovation of HPEs should be positively encouraged. The financial management department should prompt banks to incorporate the indicators of social responsibility, such as energy saving and environmental protection, into the GCP rating system and take differentiated financing measures according to the evaluation results. For HPEs using clean energy and innovating green technologies, financial institutions should prioritize providing green credit to accelerate their green industrialization.

Third, mitigation of the financial constraints of HPEs is necessary. For the serious financial constraints and strong intention to green transform of HPEs, financial institutions should try their best to meet reasonable credit demands, such as by appropriately lowering the risk weight of green assets, giving priority to the compensation of green assets' equities, and carrying out energy efficiency financing, carbon emission right financing and pollution emission right financing, to alleviate financial constraints and guide them to transform into green enterprises.

Finally, the differences in enterprises and their levels of financial marketization and energy endowments should be fully considered to promote GCP according to local conditions. For non-state-owned enterprises, the underdeveloped financial market and scarce energy endowments, their demand elasticity for green credit is relatively small. Hence, financial institutions should moderately relax loan conditions, lower loan thresholds, broaden loan channels and lower loan costs to better guide heterogeneous HPEs to decrease their level of EI.

However, there are also several limitations in our research that represent potential directions for future research. First, the data in this paper are from 2001-2011 due to data availability. With the disclosure of the coal consumption of industrial enterprises in the future, the data will be updated. Additionally, this paper is unable to empirically verify the difference between the short- and long-term impacts of incentive and constraint effects due to the limitations of the utilized research methods. In practice, the impact of the incentive and constraint effects may not be synchronized. The constraint effect often plays a role in the short run, while the incentive effect usually takes a relatively long time to come to fruition. This finding means that the incentive effect may usually lag behind the constraint effect.

Author contribution

Jinkai Li: Conceptualization, Project administration. Can Zhang: Data curation, Formal analysis, Methodology; Writing-original draft. Jin Zhang: Writing-review & editing, Validation, Supervision. Zhifu Mi: Project administration, Writing-review & editing. Zhuang Liu: Methodology, Software, Writing-review & editing. Liutang Gong: supervision, Writing -original draft. Gang Lu: analysis, Writing -original draft.

Funding

This work is supported by National Social Science Foundation of China (Grant No. 20BJL034), Major project of the National Social Science Foundation of China (Grant No. 21&ZD108), Youth Program of National Natural Science Foundation of China (Grant No. 72204230) and Foundation of He'nan Social Science Program (Grant No.2023-YYZD-21).

Availability of data and materials: The data will be available upon reasonable request.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare no conflicts of interest.

The authors of this article also assure that they have followed the publishing procedures and agree to publish it as any form of access article, confirming to subscribed access standards and licensing.

Ethical approval: Not applicable.

Consent to publish: Not applicable.

Consent to participate: Not applicable.

Competing interests: The authors declare no competing interests.

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