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RESEARCH ARTICLE

An evaluation of the impact of China's green credit policy on different pathways using a CGE model

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Abstract

The objective of the study was to quantitatively analyze the heterogeneous effects of different green credit implementation methods on energy, environmental, and economic systems by developing a computable general equilibrium model. The specific green credit implementation methods are divided into interest-penalty policy for energy-intensive industries and interest preferential policy for green industries. Various approaches to implementing green credit can lead to distinct impacts on energy consumption, environmental outcomes, and economic performance. Green credit policy experiments are carried out utilizing short-, medium-, and long-term scenarios to investigate how the consequences of green credit policies evolve. The findings demonstrate that (1) implementing a penalty interest policy for energy-intensive industries can have substantial short-term environmental effects, cutting total demand for fossil energy and lowering carbon dioxide emissions significantly. As the cycle progresses, this effect will progressively fade and have a negative economic impact. (2) The interest preferential policy for the green industry has a significant promoting effect on green technology, and its energy and environmental effects will be reflected in the long term, and the effect will continue to increase, which has a positive promoting effect on the economy. (3) There are significant differences in the policy effects brought about by the different implementation methods of green credit policies. Both policies can positively affect social energy and the environment, but the effect cycles are different. When two types of interest policies are implemented in the economy, the negative economic effect of the penalty interest policy is greater than the positive effect of the preferential interest policy, which harms the macroeconomy. These conclusions will provide theoretical and practical references for the government and banks to choose a better green credit implementation path.

Keywords Green credit policy · Policy implementation paths · Energy-environmental-economic system · China

Introduction

China intends to reach a carbon peak in 2030 and a carbon–neutral climate response objective by 2060 to meet the 2 °C targets, putting green finance on the fast track. Policy designs have become more sophisticated and developed as financial regulatory bodies continue expanding their efforts to encourage green financing (He et al. 2019). According to the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and Outline of the Vision for 2035, green financing has been designated by the central bank as a significant task for the "14th Five-Year Plan" period. China will continue to improve its monetary policy toolkit and increase support for carbon neutrality and green finance in the future. As an important component of green finance, the government uses green credit policies to guide market funds to continue to tilt towards low-carbon projects, green transformation projects, carbon capture and storage, and other green innovation projects.

Green credit means that banks utilize a company's environmental protection level as a key reference point when making credit decisions and offer different financing options for enterprises with varying levels of environmental protection and carbon emissions. As a risk criterion for government fiscal policy and commercial bank credit management, green credit policy is set to support projects with environmental benefits. Environmental benefits include supporting

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environmental improvement (such as reducing pollution emissions), addressing climate change (such as reducing carbon emissions), and effective use of resources (such as saving energy and recycling resources). The green credit policy hopes to rationally allocate credit funds through differentiated credit services to achieve the coordinated development of finance and environmental protection (Nandy and Lodh 2012). As of the end of 2020, China's green loan balance is nearly 12 trillion yuan, and the stock of green bonds is 813.2 billion yuan, ranking first and second in the world respectively. Green transportation, renewable energy, energy-saving, and environmental protection projects are at the forefront of loan balances and growth rates, which have played a positive role in supporting the green and low-carbon transition. However, as a financial policy tool used by the government to regulate the flow of market funds, are the policy benefits of different implementations of green credit policies in the economy the same? What impact will the differences in specific implementation methods have on the industrial adjustment of the economy? What kind of systemic impact will it have on energy-environment-economic systems? What are the consequences of policy implementation in different cycles? To answer the above questions, this paper establishes a financial computable general equilibrium (FCGE) model that includes financial, energy, environmental, and economic modules and observes the differential impact of green credit policies on the system in different time cycle dimensions.

Literature review

Green credit policy

How to leverage green financial instruments to promote the green transformation of economic development models is a hot topic in academic circles. Green credit is the most effective in adjusting the economic structure. Green credit can regulate the transformation of economic development models by adjusting the structure of energy consumption, promoting the innovation and application of green emission reduction technologies, and increasing the proportion of green economic structures. Green credit policies have been implemented in China to adjust the energy consumption structure (Jin et al. 2021; Luo et al. 2017; Zhang et al. 2021a; Zhang et al. 2021b). These policies aim to promote the development of green and energy-saving industries while curbing the expansion of highly polluting and high-energy consumption industries. The implementation of green credit policies has shown positive effects on the optimization and upgrading of the industrial structure, particularly in economically developed regions and non-state-owned enterprises (Qiu et al. 2022). The policies have led to a significant positive spatial correlation between green credit and energy consumption structure, with green credit optimizing the energy consumption structure in local and adjacent areas (Zhou et al. 2021). However, the impact of green credit policies on economic growth and energy consumption in the manufacturing industry has not been statistically significant (Hu et al. 2020; Shao et al. 2021; Wen et al. 2021). The effectiveness of the green credit policy in adjusting the industrial production structure has been comparatively less significant, but it has been effective in suppressing investments in energy-intensive industries (Jin et al. 2021; Luo et al. 2017; Zhang et al. 2021a; Zhang et al. 2021b). Green credit policies have been found to promote the innovation of green technologies through several mechanisms. Firstly, these policies alleviate financial constraints for firms, allowing them to invest more in green technology innovation (He et al. 2019). Secondly, green credit policies encourage firms to increase their management fund inputs, which can further drive green technology innovation (Yin et al. 2023). Thirdly, these policies promote innovative behaviors and factor allocation optimization behaviors in green enterprises, leading to increased green technology innovation (Gu and Tian 2023). Additionally, the combination of green credit policies with environmental subsidies and R&D subsidies (Li et al. 2023) can effectively enhance the green technology innovation of polluting enterprises without compromising the innovation of green enterprises (Xu et al. 2023). The impact of green credit policies on green technology innovation is more significant in non-state-owned enterprises and economically developed regions (Junchen and Guosheng 2023). State-owned firms and regions with high levels of green finance development also experience a stronger positive influence from green credit policies on green innovation (Niu et al. 2023). The effects of green credit policy on the proportion of green economic structure are varied (Hu et al. 2020; Shao et al. 2021; Wen et al. 2021). Green credit policy can reduce pollution and improve the ecological and social environment, leading to positive external effects (Hu et al. 2021; Wang et al. 2020; Zhang et al. 2021d). It can also support the development of green and environmental industries, forcing highly polluting industries to upgrade their technological innovation and reduce energy consumption and pollution emissions (Yang and Zhang 2022). Green credit issuance has a significant impact on local economies, with local GDP increasing for every increase in green credit (Yang and Zhang 2022). Green credit can reduce carbon emission intensity and contribute to environmental protection (Gao 2023). The ownership structure of banks is an important factor affecting green credit, with high ownership concentration and good loan quality being key to achieving high-level green credit (Yao et al. 2023).

Application of CGE models in evaluating environmental policies

The utilization of computable general equilibrium (CGE) models, which are mathematical models that simulate the entire economy, in the process of assessing environmental policies has proven to be of utmost significance. These models give a comprehensive and holistic approach to understanding the intricate relationship between economic activity and environmental outcomes (Ghaith et al. 2021). In the sphere of environmental policy evaluation, CGE models excel in their ability to capture the intricate dynamics and interactions that exist between economic sectors and environmental resources (An et al. 2023; Carbone et al. 2022). Through the inclusion of detailed sectoral data, these models can simulate the movement of goods, services, and factors of production across different sectors of the economy (Dzyuba and Bakalova 2022). This facilitates a meticulous investigation of how various environmental policies may impact specific industries, as well as the overall economy (Beaussier et al. 2019). Additionally, CGE models also factor in the feedback effects that emerge from changes in economic activity resulting from the implementation of environmental policies. For instance, the implementation of a carbon tax may lead to a decline in carbon-intensive industries, which can subsequently influence other sectors through supply chain connections (Cao et al. 2021). Considering these ripple effects, CGE models present a more precise picture of the potential economic consequences of environmental policies (Vrontisi et al. 2016). Besides their capacity to capture the economic consequences of environmental policies, CGE models also facilitate the assessment of environmental outcomes (Zhang et al. 2020). By incorporating environmental data, such as emissions and resource use, these models can estimate the environmental effects of diverse policy scenarios. This permits policymakers to have a better comprehension of the trade-offs and synergies between economic growth and environmental sustainability and to recognize strategies that can accomplish both objectives concurrently (Montenegro et al. 2019). Moreover, CGE models can assess the distributional impacts of environmental policies by considering income and wealth disparities across various groups within the economy. This empowers policymakers to assess the prospective equity implications of diverse policy options and to devise interventions that foster fairness and social justice (Smith and Zhao 2020).

In general, the use of CGE models in evaluating environmental policies offers a comprehensive and rigorous framework for policymakers and researchers to assess the potential impacts of various policy options. By capturing the simple dynamics and interactions between the economy and the environment, these models offer worthless insights into the trade-offs and synergies between economic growth and environmental sustainability (Chen et al. 2016; Zhang and Dong 2023; Rogerson 2015). Hence, the utilization of CGE models in environmental policy evaluation is essential for well-informed decision-making and the formulation of efficient and sustainable policies.

Application of financial CGE model in evaluating green finance policies

To utilize the CGE model framework for assessing the effects of green finance policies, some scholars have made certain modifications to the traditional CGE model (Adelman and Yeldan 2000; Bourguignon et al. 1991; Kim et al. 2017; Lemelin et al. 2013; He et al. 2023; Naastepad 2001; Robinson 1991; Yeldan 1997). These modifications are intended to relax the constraints of the traditional CGE model's assumption of monetary neutrality, which otherwise limits the ability to estimate the effects of financial policies (Liu et al. 2017). These models quantify the influences of different green credit scales on energy structures, carbon reduction, the industrial economy, and the macroeconomy (Du et al. 2023). They integrate energy, environmental, economic, and financial systems to analyze the impact of green credit on green technology innovation and CO_2 emissions (Hemanand et al. 2022). The results show that green credit can accelerate the achievement of carbon neutrality goals, with larger green credit scales leading to faster goal attainment. Additionally, the influence of green credit scales has marginal decreasing effects, and a 60% green credit scale is considered appropriate for achieving dual carbon goals in China (Wan et al. 2022). Green finance is positively correlated with economic growth and plays a significant role in decreasing CO_2 emissions and promoting renewable energy consumption (Liu et al. 2015). The integration of green finance and clean energy has apparent spatial spillover effects, promoting local green economic development (Kim and Samudro 2021; Wang and Wang 2021; Zhang et al. 2021c; Rajabi 2023). The government's leading role in green financial innovation and the promotion of green technology innovation through financial markets are crucial for achieving coordinated regional development.

In summary, current research on green credit is still evolving, with notable gaps in understanding its comprehensive impact. Studies mainly focus on the economic and environmental effects, neglecting how green credit influences energy structure and the interaction between energy, environment, and economy. Moreover, there is a lack of depth in exploring the implementation pathways of green credit, particularly regarding preferential policies for green industries and the assumption of symmetrical effects between punitive and preferential policies. Additionally, the effect of the policy implementation cycle remains under-examined, highlighting the need for more detailed and holistic research in green finance. This paper establishes a computable general equilibrium model of finance, energy, environment, and economy to quantitatively analyze the heterogeneous effects of different green credit implementation methods on energy-environment-economic systems. This research has the following contributions. First, the systemic impact of green credit has been comprehensively considered. Previous studies have only studied one or a combination of two of them, but there is an inter-influence relationship between different sectors. Second, expand the single punitive interest research on the realization path of green credit to a multi-path study that includes interest preferential policies, and comprehensively analyzes the impact of systemic differences caused by different realization paths of green credit. Third, the policy effects of different implementation paths in different cycles are studied to distinguish short-term, medium-term, and long-term policy effects.

The rest of this article is organized as follows. The "Methods" section analyzes the influence mechanism and constructs a computable general equilibrium model with finance, energy, environment, and economy modules. The empirical data and scenarios setting are described in the "Data and scenarios" section. The "Simulation result analysis" section analyzes the simulation results in different situations. Conclusions are presented in the "Conclusions" section.

Methods

Impact mechanism of green credit on energy-environment-economic system

To explore the comprehensive impact of green credit policy on energy, environment, and economy, this paper extends the traditional CGE model by introducing a financial module (Liu et al. 2017; Robinson 1991). This module can simulate the interaction between the financial sector and the real economy more comprehensively and reveal the actual impact of green credit policy on various sectors of the real economy in different periods. However, we need to moderately relax the monetary neutrality assumption in the traditional CGE model, to capture and analyze the various effects of credit policy under green finance policy more accurately. To achieve this goal, this paper combines the Keynesian macroeconomic closure theory with the actual situation of China's financial market and carefully designs the macroeconomic closure selection, model structure setting, and other aspects, such as the impact of the real interest rate on the investment decisions of enterprises and residents. This design aims to ensure that monetary policy can realistically affect the actual variables such as economy, energy, and environment, and thus better simulate the transmission process of green credit in the whole system.

Figure 1 delineates a schematic representation of a computable general equilibrium (CGE) model, incorporating a green credit policy framework. The model is segmented into distinct modules that epitomize the diverse sectors of the economy and their interrelations. The income and expenditure module epitomizes the household sector, depicting the cyclical flow of income and expenditures that fuels the broader economic dynamic. The financial module constitutes the currency market, illustrating the central bank's role in monetary issuance, and the loanable fund market, which captures the deposit and lending transactions. Intermediation by commercial banks is depicted through their deposit acceptance, loan extension, and reserve management functions. The module further encompasses the enterprise bond market and the government bond market, delineating the flow of capital through bond issuances by enterprises and governmental bodies. The central bank, serving as the fulcrum of the financial system, is portrayed as a pivotal entity managing the issuance of currency and the holding of government securities, which are fundamental to the economy's liquidity and fiscal equilibrium. The production module explicates the production mechanism where total output amalgamates quantitative inputs (QINT) with value-added (QVA). Here, QINT encompasses a range of intermediate inputs, while QVA is constituted of labor, energy, and capital inputs, thus illustrating the transmutation of these inputs into consumable products and services. The environmental module connects to the cost module and encapsulates the environmental externalities associated with economic activities, including environmental remediation and pollution control initiatives that contribute to the amelioration of the environmental subsystem. The energy module differentiates the energy consumption dichotomy between fossil fuels and renewable resources, reflecting the economy's energy consumption profile. Central to the financial module is the green credit policy, underscored as a determinant in channeling financial capital towards environmentally conducive projects.

The diagram elucidates the multifaceted interactions among government, households, and enterprises with the financial markets through mechanisms such as loans and bond issuances. Although not explicitly depicted, the role of taxation in bridging governmental activities with financial and production modules, as well as the potential impact of research and development on production and environmental outcomes, is intrinsic to the model's functionality. The schematic is a testament to the intricacies and interconnected nature of the economic, environmental, and financial domains, underscored by directional flows that manifest the causal linkages within the CGE model.

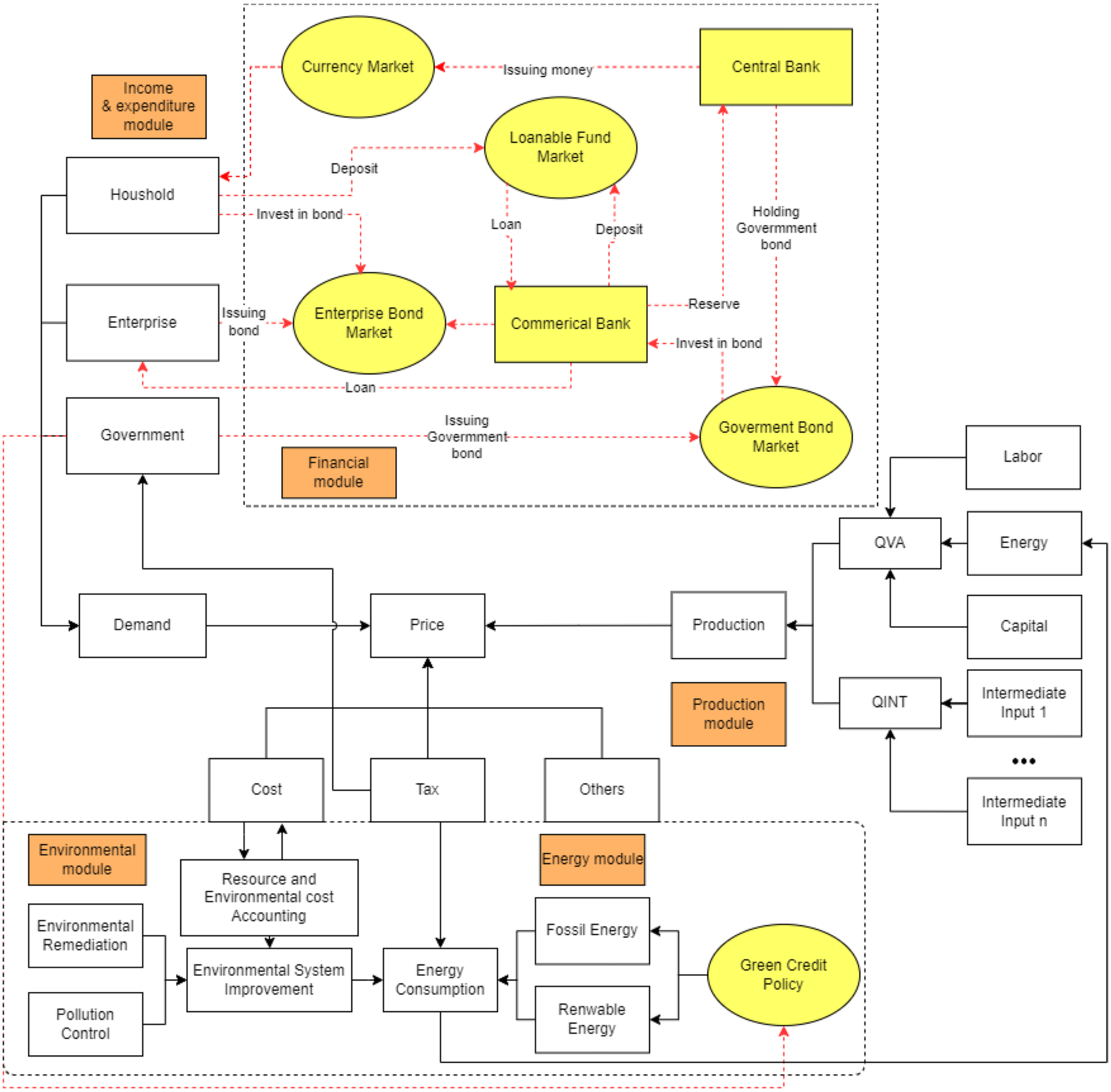

Fig. 1 Schematic diagram of the CGE model

Basic CGE module

The production module adopts the constant elasticity of substitute (CES). In the third layer of multi-layer nesting, energy is composed of coal, oil, and other elements, which obey the CES function, allowing incomplete substitution elasticity between each other, as shown in Fig. 2.

In the second layer, the total input of added value (QVA) is composed of labor (QLD), capital (QKD), and energy (QE) factors according to the CES production function, allowing incomplete substitution elasticity between each other. Total intermediate inputs ($QINTA$) are not the focus of this study, therefore, for the convenience of operating based on SAM data, this paper assumes that the production function of intermediate inputs follows the Leontief function. In the first layer, QVA and $QINTA$ constitute total output (QA), which obeys the CES function.

The main function equations of the production module include the following:

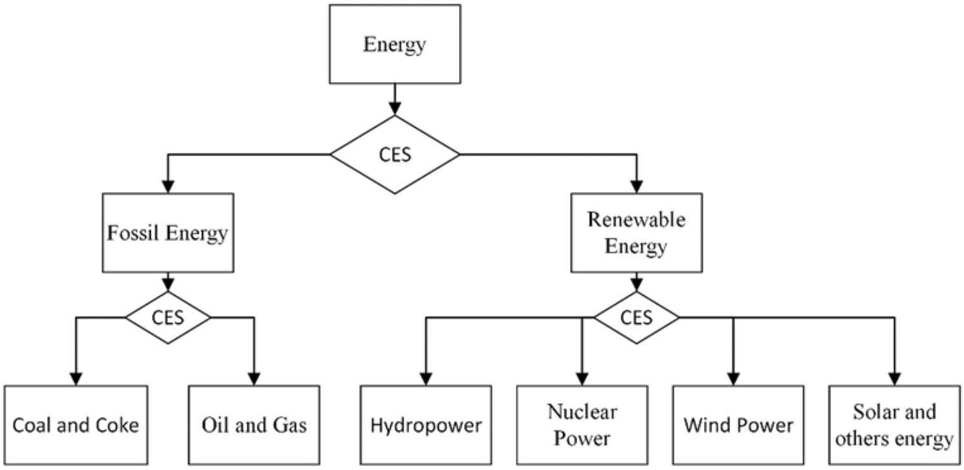

Fig. 2 Schematic diagram of energy synthesis structure

$$QA_a = \alpha_a^q\left[\delta_a^q QVA_a^{\rho_a^q} + \left(1-\delta_a^q\right)QINTA_a^{\rho_a^q}\right]^{1/\rho_a^q} a \in A \tag{1}$$

$$QVA_a = \alpha_a^{va}\left\{\delta_a^{va}\left[\alpha_a^{ke}\left(\delta_a^{ke}QKD_a^{\rho_a^{ke}} + \left(1-\delta_a^{ke}\right)QE_a^{\rho_a^{ke}}\right)^{1/\rho_a^{ke}}\right]^{\rho_a^{va}} + \left(1-\delta_a^{va}\right)QLD_a^{\rho_a^{va}}\right\}^{1/\rho_a^{va}}$$

$$a \in A \tag{2}$$

$$QINT_{aa'} = ia_{aa'} \cdot QINTA_{a'} a \in A, a' \in A \tag{3}$$

$$QE_a = \alpha_a^e\left[\delta_a^e QFE_a^{\rho_a^e} + \left(1-\delta_a^e\right)QRE_a^{\rho_a^e}\right]^{1/\rho_a^e} \tag{4}$$

where a represents the goods produced by the production activity, $a = 1, \ldots, n$, denoted as $a \in A$. QA_a represents the total production quantity of good a. The parameters α_a^* and δ_a^* are the scale parameter and share parameter in the CES function; ρ_a^* is the substitution elasticity of factor inputs. In the model, the total intermediate input ($QINTA$) is aggregated from the intermediate inputs ($QINT$) of each sector. Therefore, $QINT_{aa'}$ can be calculated based on the direct consumption coefficients ($ia_{aa'}$). QFE and QRE represent the consumption of fossil energy and renewable energy, respectively.

The income and expenditure module primarily describes the cash flows among residents, enterprises, government, and foreign countries. Residents earn capital returns ($shi_{h,k} \cdot WK \cdot QKS$) and wages($WL \cdot QLS$) by providing labor and capital through the factor market and receive transfer payments from enterprises ($transfr_{h,ent}$), the government sector ($transfr_{h,g}$), and foreign sector($transfr_{h,row} \cdot EXR$). After earning income, residents engage in consumption, savings, and paying taxes. Their utility function is based on the linear expenditure system (LES) function, which is used to simulate the long-term Engel curve. Pre-tax income for enterprises includes income derived from capital investment ($shif_{ent,k} \cdot WK \cdot QKS$), transfer payments from the government to enterprises ($transfr_{ent,g}$) (such as subsidies from the Chinese government to state-owned enterprises), and transfer payments from overseas enterprises ($transfr_{ent,row} \cdot EXR$). The income is used to pay for labor compensation, capital returns, corporate taxes, and the costs of energy and environmental policies. The government's revenue (YG) comes from direct taxes on residents ($t_h \cdot YH$), indirect taxes on enterprises ($t_{ent} \cdot YENT$), and tariffs and environmental energy taxes levied on commodity c ($\sum_{c \in C}\left(t_c \cdot M_c + EEP_c\right)$). Government revenue is ultimately used for government consumption and transfer payments. The income of the rest of the world comes from domestic imports, and foreign expenditure comes from domestic exports. The imbalance is the trade deficit.

The main function equations of income and expenditure module include the following:

$$\begin{aligned} YH &= WL \cdot QLS + shi_{h,k}WK \cdot QKS \\ &+ transfr_{h,ent} + transfr_{h,g} + transfr_{h,row} \cdot EXR \end{aligned} \tag{5}$$

$$YENT = shif_{ent,k} \cdot WK \cdot QKS + transfr_{ent,g} + transfr_{ent,row} \cdot EXR \tag{6}$$

$$YG = t_h \cdot YH + t_{ent} \cdot YENT + \sum_{c \epsilon C}\left(t_c \cdot M_c + EEP_c\right) \tag{7}$$

$$EH_c = Sub_c^{LES} + \frac{\beta_c^{LES}}{p_c^q}\left(YH - HSAV - t_h \cdot YH - \sum_{c',c' \in C} p_{c'}^q \cdot Sub_{c'}^{LES}\right) \tag{8}$$

$$EG_c = \frac{shrg_c}{p_c^q}\left(YG - transfr_{h,g} - transfr_{ent,g}\right) \tag{9}$$

where Sub_c^{LES} represents the minimum consumption quantity of commodity c, and β_c^{LES} is the marginal propensity to consume of residents for commodity c. $HSAV$ represents the household savings share. The proportion of government spending on commodity c, as a part of the total expenditure, is denoted by $shrg_c$.

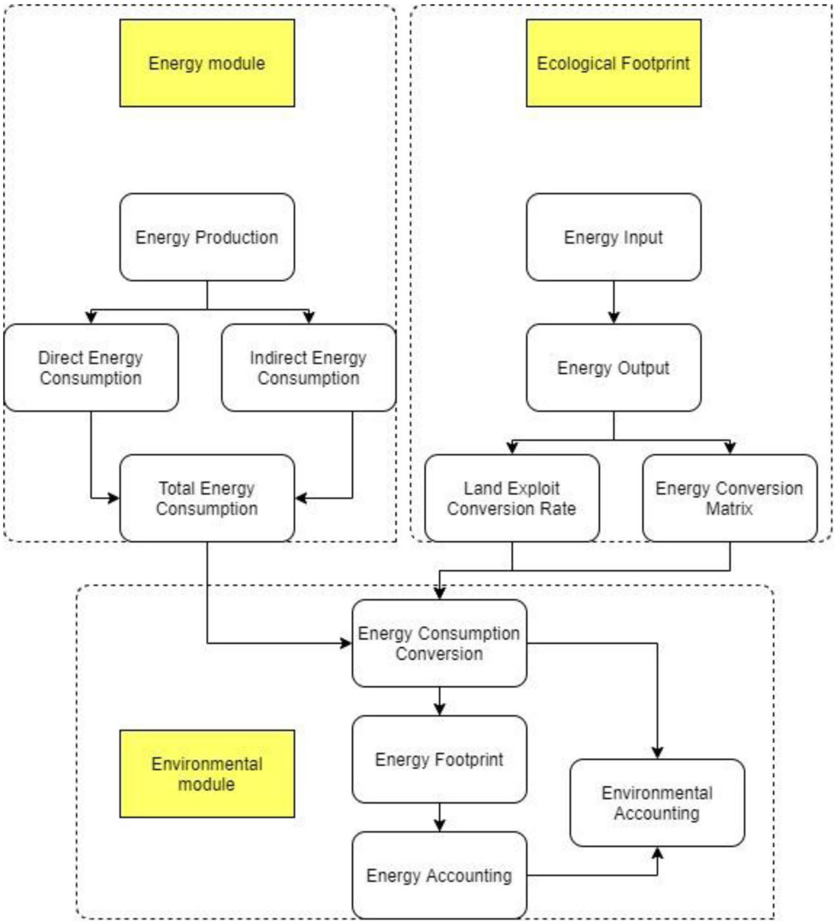

Fig. 3 The accounting process of energy and environment modules under the ecological footprint method

Extended energy-environment module

In the expansion module, the energy module nests fossil and renewable energy sources. To calculate the energy module and environmental module, this paper adopts the ecological footprint analysis method to measure energy consumption and environmental consumption, as shown in Fig. 3.

Energy endowment returns are separated from sector profits through the energy and environment account and are considered comprehensively based on resource and environmental system restoration and compensation. Environmental restoration refers to the investment of capital and labor for protection after the development and utilization of resources so that the resources can be continuously updated to achieve the effect of sustainable use. Environmental compensation refers to the profit brought by the consumption of resource products, which requires corresponding compensation for the destruction of resources and the environment and the loss of national economic wealth.

The environmental account uses the System of Integrate Environmental and Economic Accounting (SEEA) functional subsidiary account to account for environmental pollution emissions and governance. The functional equations include the following:

$$YENE = PENE \cdot QENE - PE_{COST} \tag{10}$$

$$QCO_2 = (QENE \times \delta - \beta) \times \gamma_e \times 3.67 \tag{11}$$

$$QSO_2 = 2SSO_2 \cdot FSO_2 \cdot Q_E\left(1 - NSO_2\right) \tag{12}$$

$YENE$ denotes the gain from energy, while $QENE$ signifies the consumption of energy, and PE_{COST} refers to the cost of energy. QCO_2 is the carbon dioxide emission, δ is carbon content per unit resource, β is the amount of carbon sequestration, and γ_e is oxidation rate. QSO_2 represents the emissions of sulfur dioxide, FSO_2 denotes the conversion rate of sulfur present in energy sources to sulfur dioxide, SSO_2 indicates the sulfur content in energy, and NSO_2 refers to the efficiency of desulfurization processes. The coefficient of carbon dioxide produced by unit carbon mass oxidation is 44/12 = 3.67.

In terms of smog control, PM2.5 and PM10[1] are used as the key core indicators of smog control, and the functional equation is as follows:

$$QPM_{2.5} = \sum_a CFPM_{2.5} \times Ec_{PM_{2.5}} \times QENE_a \tag{13}$$

$$QPM_{10} = \sum_a CFPM_{10} \times Ec_{PM_{10}} \times QENE_a \tag{14}$$

$$\frac{VAEC}{P_{EC}} C \times Ec_{PM_{2.5}} \times Tq_{PM_{2.5}} = VAEC \times t_{PM_{2.5}} \tag{15}$$

$$\frac{VAEC}{P_{EC}} C \times Ec_{PM_{10}} \times Tq_{PM_{10}} = VAEC \times t_{PM_{10}} \tag{16}$$

where $QPM_{2.5}$ represents the amount of $P_{PM_{2.5}}$ emission, $CFPM_{2.5}$ and $CFPM_{10}$ respectively represent the amount of $PM_{2.5}$ emission and PM_{10} emission calculated by standard coal. $Ec_{PM_{2.5}}$ and $Ec_{PM_{10}}$ represent the coefficient of $PM_{2.5}$ and PM_{10} by energy consumption, respectively. $VAEC$ represents the value of carbon-containing energy consumption. C represents the coefficient of carbon-containing energy into standard coal, $t_{PM_{2.5}}$ and $t_{PM_{10}}$ represent ad valorem tax, and $Tq_{PM_{2.5}}$ and $Tq_{PM_{10}}$ are specific tax.

Green credit policy module[2]

To study the impact of financial policy on the real economy within the CGE framework, it is necessary to relax the assumption of monetary neutrality. In our green finance module, we achieve the non-neutrality of money by endogenizing the price level and structuring the model in such a way that the investment and financing decisions of enterprises, residents, and the government are linked to the real interest rate, among other factors.

The investment demand of production activity a depends on the price of capital, the price of investment goods, the rate of return on investment, and the level of inflation.

$$QKD_a = \lambda_a \left(WF_{cap} \times WFDIST_{cap,a} / (1 + PINF) \times PK_i \right)^{\varepsilon zd_a} \times QF_{cap,a} \tag{17}$$

where QKD_a represents real investment demand by production activity a, λ_a is the scale coefficient of investment, $PINF$ is the inflation rate, the investment goods price of the activity a is PK_a, and εzd_a is the exponent parameter of investment demand equation. $QF_{cap,a}$ represents the capital input of activity a. WF_{cap} represents the rate of return on investment considering capital costs. $WFDIST_{cap,a}$ is the difference in capital costs among different industries.

Different from the general CGE model that assumes monetary neutrality, which assumes that commercial banks are at the level of zero profit, this paper assumes that commercial banks maintain a constant profit margin. State-owned commercial banks are the absolute mainstay of China's loanable capital market, and their interest rates are not fully floating. Therefore, the hypothesis of Eq. (18) is consistent with the actual situation of China's capital market.

$$\sum \left(INTRSTD \cdot FSTOCKD_{ins} \right) \times shprofitb = \sum \left(INTRSTC_{insp} \cdot FSTOCKE_{insp} \right) \tag{18}$$

where $INTRSTD$ is the deposit interest rate and $INTRSTC_{insp}$ represents a deposit interest rate of a loan for private institution (*inps*), $FSTOCKD_{ins}$ is the financial stock of the deposit for institution ins, and $FSTOCKE_{insp}$ is the financial stock of a loan for *inps*.

The capital gains in the model include interest costs and the profit of capital. YF_{cap} is calculated by the following formula:

$$\begin{aligned} YF_{cap} = & \sum \left(WF_{cap} \cdot WFDIST_{cap,a} \cdot QF_{cap} \right) \\ & + \sum \sum \left(INTRSTC_e \cdot \Omega 1_{e,a} \cdot FSTOCKC_e + INTRSTB_e \cdot \Omega 1_{e,a} \cdot FSTOCKB_e \right) \end{aligned} \tag{19}$$

$WFDIST_{cap,a}$ shows capital cost differences across industries. $\Omega 1_{e,a}$ is sector a share parameter of the real investment for enterprise e. $FSTOCKC_e$ and $FSTOCKB_e$ represent the financial stock of credit and security for enterprise e.

The change of industry investment will affect the level of industry output. Equation (20) shows that the capital input of each activity includes the initial capital stock and investment. $QKD0_a$ is the initial capital stock of industry a.

$$QKD_a = QKD0_a + QKD_a \tag{20}$$

The proportion of commercial banks' direct financing depends on the interest rate of loans and securities. The loan interest rate of enterprises is an exogenous variable and is determined by the green credit policy. At the same time, we assume that the interest rates of securities are endogenous.

$$FFLOWC_e = g2_e \times \left(FFLOWC_e + FFLOWB_e \right) \tag{21}$$

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[1] PM2.5 refers to atmospheric particulate matter (PM) that have a diameter of less than 2.5 μm. Particulate matter with an aerodynamic equivalent diameter of less than 10 microns is called PM10, also known as respirable particulate matter or fly ash.

[2] The specifications of the financial sectors of this model follow the FCGE model developed by Liu in 2017. For a detailed model description, please refer to Liu et al. (2017).

$$g2_e/\left(1-g2_e\right)=\psi_e\left(\left(1+INTRSTC_e\right)/\left(1+INTRSTA_i\right)\right)^{\varepsilon 2_e} \tag{22}$$

$FFLOWC_e$ and $FFLOWB_e$ represent the financial flow of credit and enterprise security for enterprise e, respectively. $g2_e$ is the share of commercial loans in total loans of enterprise e. $INTRSTA_a$ is the borrowing interest rate for industry a.

Data and scenarios

Data

The database of this CGE model is the social accounting matrix (SAM) with extending energy sectors, environmental sectors, and financial sectors based on China's 2017 input–output table, combined with the China Statistical Yearbook (2018) and the Balance of International Payment Table. Government activities such as the financial and tax 2018 yearbook data are used for calibration. The relevant data of energy-sensitive companies and companies in the carbon emission trading industry involved in the SAM account come from its annual statements. To establish the connection between financial capital and the real economy, we added the financial system department, the banking system, and the financial asset account based on the original entity 42 departments.

We adjusted the original product account, activity account, and savings account accordingly. The adjusted SAM account mainly includes the following changes: (1) The product account mainly contains three types of outputs, namely the total output of intermediate inputs, the total output of environmental governance, and the total output of environmental resource restoration. The total output of environmental governance and the total output of environmental resource restoration are treated with a surplus. The annual operating cost of pollution control is used as the base of the total output of pollution control. Considering the multiplier effect of environmental governance, the input of environmental governance is converted into total economic output. (2) In the activity account, we added bank system accounts (including commercial bank and central bank accounts) and financial assets accounts. Bank system accounts and financial flows accounts correspond to financial assets and financial liabilities, respectively. Resource restoration and environmental governance activities correspond to input and resource compensation in factor accounts and government accounts. In the account column, production activities, resource restoration activities, and environmental governance activities correspond to the total input and output of factors, the total input and output of resource restoration, and the total input and output of pollution respectively. (3) We have decomposed the original savings account data and split the savings data in the original SAM account into financial assets and financial liabilities. This means that the new assets and liabilities are consistent between the actual accounts and financial accounts of the corporate sector. For example, if a company saves, then its financial assets contain new savings data. In the account, the total financial assets are equal to the total fixed investment. Financial flows accounts represent multiple accounts, such as deposit account, loan account, enterprise bond account, government bond account, foreign asset account, FDI account, and foreign lending account.

Since there is a conflict between SAM and data source, the Shannon value is processed by cross-entropy method to solve the conflict between different sources. The direct energy consumption coefficient is estimated from the input–output table. The energy consumption is converted into standard coal, and the unit sulfur coefficient is processed. Emissions of major pollutants, such as carbon dioxide and sulfur dioxide, are calculated from energy consumption and energy consumption coefficients. The main core parameters, such as the elasticity parameters of the production function and the elasticity of the energy and environmental functions, are obtained through the Bayesian and generalized maximum entropy (GME) methods.

Green credit policy scenarios setting

Green credit policy is an important financial means to promote the realization of the sustainable development goals. The difference in specific implementation means will cause different responses in energy, environmental and economic systems. According to the guidance documents of domestic commercial banks and the central government, the main implementation methods of green credit policies include the implementation of penalty interest and interest preferential treatment for related industries. In the main assumption of the financial sector in the CGE model, the profit rate of commercial banks is assumed to be constant. Therefore, in previous studies, it is believed that the impact of penalty interest on energy-intensive, high-polluting, and high-emission enterprises is equivalent to reducing the cost of capital in other industries and, based on this hypothesis, examines the inhibitory effect of green credit on investment in high-polluting capital-intensive industries. However, the simulation of this shock did not take the asymmetry of the green credit policy implementation methods into account. In the financial network structure, the impact of capital cost on different industries will produce a differentiated multiplier effect because of the specific impact of the different positions of the industries in the network structure. Therefore, it is necessary to impact the two policies of penalty interest and

Table 1 Scenario settings

Scenarios	Policy target industry	Interest measures	Period
S1	Energy-intensive and high-polluting industries	2% higher	S1a short-term S1b medium-term S1c long-term
S2	Green industries	2% lower	S2a short-term S2b medium-term S2c long-term
S3	Energy-intensive and high-polluting industries	2% higher	S3a short-term
			S3b medium-term
	Green industries	2% lower	S3c long-term

Table 2 Changes in financing cost and flows. Unit: billion yuan

	Enterprise type	Bank loan	Security finance	Loan interest (%)	Security interest (%)	Average interest (%)
S1a	Energy-intensive	−14.27	4.95	2.85	0.59	1.72
S1b	Energy-intensive	−16.29	5.34	2.94	1.10	2.02
S1c	Energy-intensive	−15.89	6.16	1.96	1.42	1.69
S2a	Green-industries	14.34	0.63	−2.40	0.58	−0.91
S2b	Green-industries	12.65	0.44	−2.65	0.75	−0.95
S2c	Green-industries	12.48	1.43	−1.43	0.11	−0.66
S3a	Energy-intensive	−15.89	4.28	3.94	1.40	2.67
S3b	Energy-intensive	−16.69	3.85	2.65	1.39	2.02
S3c	Energy-intensive	−12.79	3.92	2.59	1.26	1.93
S3a	Green-industries	13.11	0.78	−1.25	0.71	−0.27
S3b	Green-industries	12.84	0.49	−1.47	0.45	−0.51
S3c	Green-industries	13.68	0.76	−1.98	−0.02	−1.00

preferential interest on different industries in the economic system to observe the asymmetric impact of the energy and environmental economic system caused by the differences in the specific implementation methods of green credit policies.

As shown in the table, we set the green credit policy scenario as three types of experiments. In the S1 scenario, we set the specific measures of the green credit policy to impose penalties on energy-intensive industries and high-pollution, high-emission industries, and other related companies, raise the loan interest rate by 2%, and set the period to span short, medium, and long terms. In the short-term scenario setting, the labor force is relatively fixed and cannot realize free flow. In the medium-term experiment, although labor can flow freely, its wage level is used as an exogenous variable, and unemployment is allowed. In the long-term experiment, labor can flow freely between industries and reach the level of full employment, while the average wage level is regarded as an endogenous variable.

In the S2 scenario, the target industries for the implementation of the green credit policy are the green industries defined in the "Green Credit Industry Guidance Catalog," including energy conservation and environmental protection industries, clean production industries, clean energy industries, ecological environment industries, and green infrastructure upgrades. Green service commercial banks implemented preferential interest policies for these industries and reduced loan interest rates by 2%. In the S2 scenario experiment, the same period setting as the first type of experiment was also carried out.

In the setting of S3, the impact of penalty interest and interest preferential treatment will be carried out at the same time, and the interest penalty will be imposed on enterprises related to energy-intensive and high-emission industries, and the loan interest rate will be increased by 2%. Interest subsidies will be provided to green industries, leading to a reduction of loan interest rates by 2%. The reason for setting up scenarios in this way is to observe the effect of green credit operating in the actual economic environment (Table 1).

Simulation result analysis

Influence on capital adjustment

Financing cost and flows

As can be seen from Table 2, the implementation of the penalty interest policy has led to a significant increase in the capital cost of energy-intensive industries, and it has been maintained at a relatively high level. Although the financing cost of security financing rises, enterprises must increase

Table 3 Percentage changes of industry investment. Unit: %

Type	Industry	Short-term			Medium-term			Long-term		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
Energy-intensive	Cement	−1.24	0.23	−0.77	−1.80	0.27	−1.81	−1.37	0.27	-1.80
	Chemical	−2.08	0.31	−1.51	−1.47	0.69	−1.99	−1.36	0.58	-1.33
	Coal	−1.30	0.38	−0.70	−1.51	0.63	−1.96	−2.24	0.91	-1.62
	Construction	−1.70	0.42	−0.98	−1.71	0.37	−1.24	−1.98	0.16	-1.25
	Metal	−1.33	0.04	−1.04	−1.78	0.31	−1.49	−1.62	0.26	-1.82
	Paper	−1.57	0.08	−1.34	−1.97	0.00	−1.41	−1.86	0.09	-1.42
	Petroleum	−1.86	0.00	−1.74	−1.61	0.65	−1.54	−1.67	0.15	-1.96
	Traffic	−1.91	0.33	−1.62	−1.97	0.43	−1.86	−1.01	0.31	-1.45
Green industry	Equipment manufacture	0.30	2.23	1.45	0.07	2.58	1.46	0.36	2.92	2.39
	Instrumentation	0.49	2.75	2.62	0.58	2.19	1.99	0.13	2.46	2.12
	IT Service	0.60	2.42	2.14	0.77	2.47	2.11	0.06	2.30	2.18
	Scientific Service	0.17	3.10	2.67	0.20	3.32	2.44	0.36	3.21	2.78
	Scrap	0.11	2.68	2.54	0.14	2.52	1.92	0.67	2.26	2.22
	Transportation equipment	0.12	2.30	1.96	0.05	2.86	2.41	0.05	2.98	3.10
Rest of world	Agriculture	0.17	0.10	0.09	0.16	0.12	0.13	0.86	0.15	0.08
	Textile	0.11	0.09	0.06	0.08	0.07	0.04	0.09	0.07	0.07
	Cultural	0.06	0.02	0.01	0.07	0.01	0.01	0.04	0.01	0.00
	Retail	0.07	0.00	0.00	0.05	0.01	0.01	0.52	0.00	0.01
	Service	0.06	0.06	0.02	0.11	0.08	0.01	0.12	0.05	0.03
Total		-11.12	17.62	3.88	−11.52	19.67	−0.76	−9.83	19.24	2.35

indirect financing with a relatively low cost, but this decision cannot make up for the funding gap caused by the decline of direct financing. In the S2 scenario, preferential interest policy reduces the capital cost of direct financing channels of the green industry. At the same time, the increase in the financing scale brought about by preferential interest rate policies to the green industry is significantly greater than the financing losses caused by the penalty interest rate at the same interest rate level. In the S3 scenario, the growth rate of direct financing of the green industry stimulated by the green credit policy is significantly greater than the growth rate of bank loans under the S2 scenario. At the same time, financing gaps in energy-intensive and high-emission industries have further increased.

In the short term, the bank loan interest rates of energy-intensive industries in the S3 scenario are increased by 3.94%. Unlike previous studies, the costs of indirect financing are also increased by 1.40%. The scale of direct financing decreases by 15.89 billion yuan. In the short term, the green credit policy effect reached the maximum effect in the S2 scenario. The bank loans of the green industry are increased by 14.34 billion yuan, and the interest rates are decreased by 2.40%.

The green credit policy has the strongest effect in the medium term, and both the capital inflows of green industries and the capital outflows of energy-intensive industries have reached the maximum value. The cost of obtaining commercial bank funds for different types of enterprises is quite different. Energy-intensive enterprises reach the highest credit cost of 2.94 in the medium-term scenario of S1, and green industries have a lower cost of capital in the medium-term scenario of S2 scenario by -2.65%.

In the long run, the implementation of green credit policies will continue to restrain the financing scale and financing costs of energy-intensive industries. The effect of implementing two policies at the same time is less than the effect of implementing one policy alone. The green industry also has a similar model. From the perspective of the policy effect of green credit, energy-intensive industries will continue to be inhibited by green credit policies, resulting in higher capital outflow financing costs, while green industries show an inverted U-shaped policy effect.

Investment

As Table 3 shows, different implementation means of green credit have achieved the expected policy effects in different scenarios. In scenario 1, the penalty interest policy has a continuous investment inhibition effect on the target industry in the short, medium, and long periods, and the investment inhibition effect is the strongest among the three measures, and the investment in the target industry is reduced by 1.02–2.24%. In the short, medium, and long periods of scenario 2, interest preferential policy has a continuous

Table 4 Percentage changes of energy consumption. Unit: %

Type of energy	Short-term			Medium-term			Long-term		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Fossil energy	−5.39	0.98	−1.04	−7.96	1.01	−1.58	−6.38	0.66	−2.13
Power supply	0.45	4.32	2.32	1.23	8.37	3.25	1.53	9.33	4.24
Total energy	−4.94	5.30	1.28	−6.74	9.38	1.67	−4.85	9.99	2.11

effect on attracting capital to the green industry, making the investment scale of the target industry increase continuously, with an increased range of 2.12–3.32%. When the two green credit policies are implemented at the same time, funds flow more obviously from energy-intensive industries to green industries. From the perspective of the impact of green credit policy on the scale of macro investment, the implementation of the penalty interest policy will result in a maximum reduction of 11.52% in the scale of macro investment in the medium term. The implementation of interest preferential policies can have a positive impact on the scale of macro investment, increasing the scale of macro investment by 19.66%. When the two policies are implemented at the same time, they will have the least impact on macro investment.

In addition to achieving the intended policy effects, the interest-penalty policy has also promoted investment growth in green industries, and as the restraint of investment in energy-intensive industries has gradually increased, the promotion of green investment has become stronger. In scenario 2, interest preferential policies have a strong investment promotion effect on green industries, but they have not had an investment inhibitory effect on energy-intensive industries and other industries. In the S2 scenario, the investment scale of energy-intensive industries still exists to a certain extent. However, as the period changes, this investment growth gradually decreases. The above results indicate that the investment promotion effect of preferential interest policies is far greater than the investment restraint effect of interest penalty policies. Combining the current dual-carbon and stable economic growth goals, policy-making departments should use more preferential interest policy measures.

Influence on total energy consumption and structure

Due to the investment restraint or promotion effect of green credit policies on different industries, different industries will adjust their total energy consumption and energy consumption structure according to the green credit policies.

Total energy consumption

From the changes in total energy consumption in Table 4, the policy impact of S1 has a serious inhibitory effect on the consumption of fossil energy, making the reduction of fossil energy consumption between 5.39 and 7.96%, and reaching the strongest in the medium term. The inhibition effect of S2 and S3 policy shocks on fossil energy is weaker than that of the S1 policy. Policy S2 has a strong promotion effect on the consumption of new energy and corresponding electricity, leading to a significant increase in the total energy consumption of the society in any period, with an increasing range of 5.30–9.99%. Compared with the impact of the policy shocks of S1 and S2 on the total social energy consumption, the impact of the policy shocks of S3 is relatively mild. As can be seen from the comparison of policy roles of S1 and S2, to achieve the dual carbon goal smoothly, interest preferential policies should be mainly implemented for green industries before 2030 to form effective green alternative energy reserves, and then penalty interest policies should be considered for energy-intensive industries to control the total consumption of fossil energy.

Energy consumption structure

As can be seen from Fig. 4, the implementation of the green credit policy has a systematic impact on the structure of energy consumption. In the S1 scenario, energy consumption decreased significantly, mainly due to the inhibition of S1 on energy-intensive industry investment, resulting in a significant decrease in fossil energy consumption. The decreased level of crude oil consumption was 9.61–14.92%. Petroleum consumption decreased by 11.03–16.34%. The inhibition persists in the short, medium, and long term. At the same time, under the impact of this policy, the consumption of natural gas increases sharply, with an increase of 10.61–12.27%. In the S2 scenario, the interest preferential policy makes the consumption of new energy increase greatly, but it does not play a corresponding inhibitory effect on the consumption of fossil energy, resulting in a significant increase in the overall energy consumption level of the society. Among them, wind energy and solar energy have the largest growth range, with the growth range of wind energy consumption ranging from 6.79 to 10.19% and solar energy consumption ranging from 6.43 to 11.42%. From the impact of the implementation of the green credit policy on the energy consumption structure, the energy consumption structure will be tilted towards new energy sources, and wind, solar, and natural gas will become the main energy sources for energy consumption.

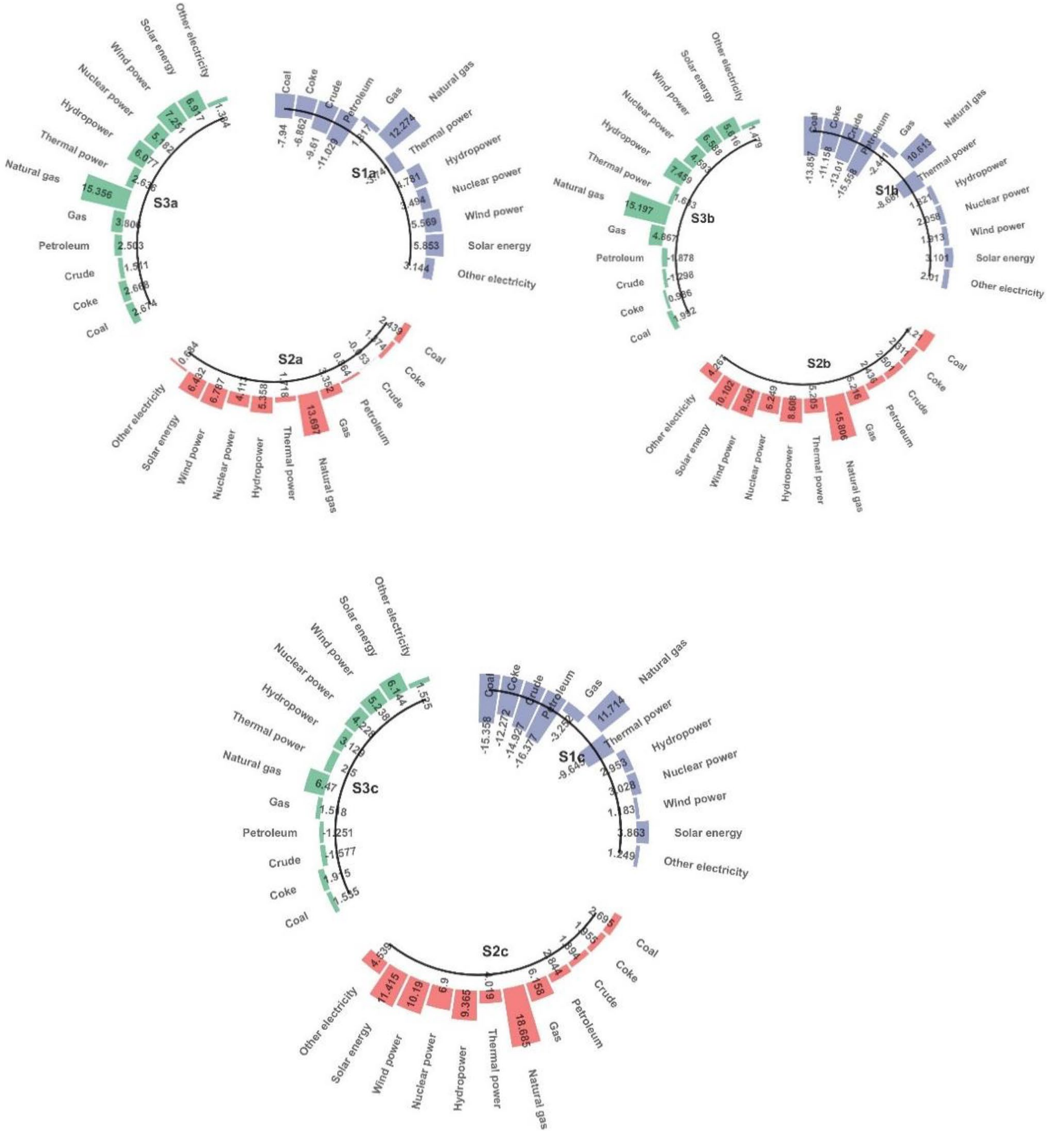

Fig. 4 Percentage change of energy consumption structure. Unit: ‰

Influence on environment

Carbon emission

As can be seen from the policy implementation results, the penalty interest policy for energy-intensive industries can achieve the most obvious carbon reduction effect in the medium term, with the total carbon dioxide emission decreasing by 8.65%. However, the effect of this policy will gradually weaken in the long term. At the same time, the interest preferential policy implemented for the green industry, due to the guiding role of investment, and the continuous expansion of investment scale lead to the continuous accumulation of green carbon reduction technology, and its carbon reduction

Table 5 Percentage changes of CO_2 emission–related indicators. Unit: %

	Short-term			Medium-term			Long-term		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Total emissions	–6.38	–3.85	–1.25	–8.65	–5.33	–2.32	–1.35	–7.35	–1.86
Emission intensity	1.21	0.55	0.78	0.56	–1.35	–0.24	0.89	–3.12	–1.09
Energy efficiency	–0.87	0.37	0.01	–0.09	2.13	0.13	0.76	3.22	1.72

Table 6 Percentage changes of major pollutant emission–related indicators. Unit: %

	Short-term			Medium-term			Long-term		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Wastewater	−10.17	1.24	−1.45	−10.61	−1.48	−2.35	−8.43	−4.77	−2.56
Solid waste	−7.97	3.01	−2.38	−8.17	−2.81	−3.86	−6.64	−5.68	−3.91
SO_2	−17.11	1.03	−5.38	−17.94	−2.92	−6.25	−14.24	−5.83	−6.22
NO_x	−16.34	3.58	−4.67	−17.30	−2.72	−5.92	−13.49	−6.19	−5.98
$PM_{2.5}$	−18.08	−2.68	−7.22	−20.18	−3.21	−8.13	−15.58	−6.18	−7.76
PM_{10}	−19.49	−3.51	−8.48	−19.93	−2.27	−9.61	−17.31	−5.13	−9.21

effect is gradually enhanced, which can gradually reach the level of 7.35% emission reduction in the long term. Emission intensity is the volume of emissions per unit of GDP. In scenario 1, the short-term change of emission intensity and energy efficiency is 1.21% and − 0.87%, respectively. However, the impact of policy 2 on carbon emission intensity will be a long-term process, and its emission intensity will show a trend of continuous decline, reaching the level of 3.12 in the long term (Table 5). In the S2 scenario, energy use efficiency also shows a rising trend, reaching 3.22% at the highest.

Major pollutant emissions

Penalty interest on energy-intensive industries can effectively restrain their inputting and output scale. Therefore, in the short term, the main pollutants in energy-intensive industries decrease significantly, and the main air pollutants decrease in the range of 16.34–19.49%. In contrast, in the S2 scenario, the emission level of major pollutants rises in the short term, mainly because the input of green industry in the early stage is largely used in the research and development of new green technology and the manufacturing of equipment, which results in the pollution level cannot be effectively controlled in the short term. However, as green energy technology and green pollution technology accumulate and mature over time, their inhibition effect on the emission of major pollutants will continue to enhance in the long-term continuous investment (Table 6).

Influence on macroeconomic

Real output

From the impact on the output of various industries, the penalty interest policy of the green credit policy in the S1 scenario has a long-term inhibitory effect on energy-intensive industries, and the inhibitory effect is the strongest in the middle stage. This research result is different from the research conclusion of Liu et al. (2020). The main reason for this difference is the different scopes of target industries. This study also conducted a corresponding green policy impact study on the energy industry, and the negative impact on the economy is greater than the results of Liu's research. Under the impact of the S2 policy, there is no negative impact on the economy; on the contrary, it has a long-term promotion effect on the output of all industries. In the S3 scenario, the policy effect has an output suppression effect in the short term and a promotion effect in the medium and long terms, while the medium-term output promotion effect is the strongest.

In the short term, the three green credit policies all harm the output of energy-intensive industries. The green credit policies in S1 have the strongest inhibitory effect on the output of energy-intensive industries. The petroleum industry saw the biggest drop in output by 8.18%, while the construction industry, the least, also saw output drop by 3.08%. In the S2 scenario, green credit policy has the least inhibitory effect on the output of energy-intensive industries and even has a promoting effect. The penalty interest policy has a strong short-term inhibitory effect on energy-intensive industries, which is mainly reflected in the large decline in energy output in the short term. The fall in energy supply and the rise in the capital cost of related industries have led to a rapid rise in the production cost of the industry in the short term. Due to the lagging effect of demand and product price adjustments, relevant companies in the industry can only reduce their output accordingly. The target industry for interest preferential policies is only a green industry, which does not have a

Table 7 Percentage changes of industry output. Unit: %

		Short-term			Medium-term			Long-term		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
Energy-intensive	Cement	−5.39	1.06	−4.90	−6.01	2.19	−5.42	−5.67	1.66	−4.35
	Chemical	−7.38	1.93	−6.32	−7.85	2.62	−4.84	−6.97	1.08	−3.85
	Coal	−3.35	1.19	−4.40	−4.30	2.45	−3.49	−3.49	1.00	−4.02
	Construction	−3.08	1.90	−2.34	−3.81	1.95	−2.40	−1.91	1.57	−3.76
	Metal	−4.10	2.59	−3.15	−4.74	3.87	−3.35	−3.48	1.39	−4.34
	Paper	−3.50	1.35	−2.63	−4.90	2.41	−3.51	−3.30	1.60	−3.98
	Petroleum	−8.18	1.84	−6.01	−9.01	2.67	−6.28	−6.04	1.37	−4.58
	Traffic	−3.46	0.40	−2.70	−4.30	1.44	−3.76	−2.85	1.08	−4.22
Green industry	Equipment manufacture	0.96	7.01	5.99	1.19	9.28	7.20	1.75	8.79	6.34
	Instrumentation	0.69	5.13	4.32	1.19	6.27	5.38	1.98	5.79	4.52
	IT service	1.12	4.25	4.02	2.11	5.50	4.61	1.65	4.18	3.71
	Scientific service	0.43	6.40	4.31	0.87	7.35	6.65	1.93	6.54	5.79
	Scrap	0.74	3.91	2.82	1.42	4.52	4.43	2.03	3.51	3.25
	Transportation equipment	0.96	6.00	4.79	1.88	6.83	4.87	1.27	5.70	4.26
ROW	Agriculture	0.89	1.11	0.56	0.36	1.35	0.79	0.77	1.26	1.06
	Textile	−1.36	0.52	0.24	−2.01	0.76	0.56	−3.12	0.82	0.75
	Cultural	−0.06	0.23	0.00	−0.09	0.05	0.01	−0.08	0.03	0.00
	Retail	−1.20	0.89	0.59	−0.98	0.91	0.10	−1.65	0.99	0.24
	Service	−0.75	0.89	0.02	−1.22	0.80	0.23	−1.02	1.02	0.76

Table 8 Percentage changes of macroeconomic variables. Unit: %

	Short-term			Medium-term			Long-term		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Nominal GDP	−8.235	7.569	−2.316	−9.012	9.871	2.768	−8.389	9.012	1.956
Real GDP	−5.365	7.328	−1.895	−5.895	8.425	1.986	−5.632	7.632	1.785
CPI	5.356	−4.35	1.753	5.469	−4.865	−1.936	5.369	−4.526	−1.865
PPI	4.789	−3.729	0.781	4.972	−4.012	−1.025	4.875	−3.852	−0.954
Investment	−5.365	4.238	−1.249	−5.986	5.147	2.135	−5.461	4.512	1.564
Employment	−2.218	1.985	−0.825	−2.822	2.036	2.238	−2.512	2.012	1.545

restraining effect on the energy industry. At the same time, due to the advantages of the green industry's capital cost, its investment scale has also expanded accordingly. The output of the green industry has also led to an increase in the overall output of the economy. From the results of the short-term S3 scenario, the economic restraint effect of the penalty interest policy is significantly stronger than the economic promotion effect of the interest preferential policy, resulting in a decrease of 4.796% in the output of the entire industry.

In the medium term, when labor is allowed to flow between different industries and unemployment is allowed to exist, the impact of green credit policies in S1 and S2 on the output of energy-intensive industries continues to have a short-term impact and is further strengthened. In the S2 scenario, the promotion effect of green credit policy on energy-intensive industries is weakened, and the output of green industries begins to rise substantially. From the results of S3 on the medium-term dimension of industry output, the effect of preferential interest on the economy is stronger than the economic restraint of the penalty interest policy. Due to the accumulation of technology in the green industry, combined with the adjustment of the energy consumption structure, the output of the green industry is gradually deviating from the limitation of fossil energy (Table 7).

In the long-term period, the output of green industries in the S2 scenario continues to rise, while the output of energy-intensive industries in the S1 scenario continues to decline. In the S2 scenario, the output of the energy-intensive industry that originally had a promotion effect appeared a suppression effect, and only the output of the metal industry maintained a unique promotion effect. Combined with the results of the long-term adjustment of the energy structure, after the increase in the proportion of new energy and green technologies, the consumption of traditional fossil energy continues to decline.

Macroeconomic variables

As Table 8 shows, the penalty interest policy for energy-intensive industries has a significant restraining effect on nominal GDP and real GDP in the short and medium terms. This effect will weaken in the long term, but it still has a negative effect. The preferential interest policies for green industries will have an economic boost to nominal GDP and real GDP, and this boost will continue to increase. When the two policies simultaneously impact their target industries, GDP will decline in the short term, but it will have a positive impact on the economy in the medium and long term. Therefore, the implementation of green industry financial support brings more economic promotion than economic inhibition of energy-intensive industries in the long run, but it must experience economic pain in the short run. In the short-term dimension, in the S1 scenario, CPI increased by 5.356%, PPI increased by 4.789%, total investment scale decreased by 5.365%, and employment level decreased by 2.218%. The main reason for this phenomenon is that the implementation of the green credit policy in the short term will cause the total output of the industry to decline and push up the producer price index. In the short term, labor cannot flow freely between industries, the total demand remains unchanged while pushing up the CPI, and this trend continues to increase in the long term. In the S2 and S3 scenarios, the same logical structure exists, that is, the green credit policy increases the output level of the industry in the short term, and the increase in supply leads to a decline in PPI and affects CPI in the same direction.

Conclusions

To ensure the smooth realization of the dual carbon target, the Chinese government has intensified the implementation of environmental policies. Although China started to implement the green credit policy in 2007, its importance has been elevated to an unprecedented level after 2020, becoming an important means for the financial and fiscal sectors to help achieve the dual carbon goal. However, few studies have quantitatively studied the energy-environment-economy systemic impact of policies from the perspective of policy differences in different implementation paths of green credit. This study divides the specific implementation paths of green credit policies into two scenarios: penalty interest policy for energy-intensive industries, namely, a credit interest rate increase of 2%, and interest preferential policy for green industries, namely, credit interest rate decreases of 2%, and there is simultaneous implementation of the two policies. Using the computable general equilibrium model with finance, energy, environment, and economy modules, this study quantitatively analyzed the heterogeneous impact of different green credit implementation methods on energy, environment, and economic systems and conducted green credit policy experiments in short-term, medium-term, and long-term scenarios to study the changes in the effects of green credit policies in different periods. The main research conclusions are as follows:

First, the green credit policy can adjust the cost and flow of market credit funds. From the perspective of the cost and flow of credit funds caused by policies, energy-intensive industries will continue to be restrained by the interest-penalty policy, leading to higher financing costs and outflows of funds. In the short term, the cost of credit has risen to 2.85%, and the outflow of funds is 14.27 billion yuan, and this scale continues to increase. On the other hand, the interest preferential policy for the green industry showed an inverted U-shaped effect, which reduced the cost of credit capital by 2.39% in a short period, and the capital inflow was 14.34 billion yuan. Overall, the policy effect remains a relatively strong positive stimulus. The simultaneous implementation of the two green credit policies will strengthen the flow of credit funds from energy-intensive industries to green industries. The change in the flow of credit has caused a change in the scale of investment in the industry. The penalty interest policy leads to a decrease of 1.02–2.25% in the investment scale of the target industry. The preferential interest policy will promote an increase in the investment scale of the target industry by 2.19–3.32% in different cycles. The simultaneous implementation of the two policies will have the least long-term impact on the macro investment scale, and the investment scale increased by 2.35%.

Second, the green credit policy has a differential control and adjustment effect on the total energy consumption and energy structure. The implementation of penalty interest policies on energy-intensive industries will result in a relatively significant decline in the total consumption of fossil energy, ranging from 5.38 to 7.96%, and the inhibitory effect decreases as the cycle increases. The energy consumption structure shows a decrease of fossil energy consumption and an increase of new energy consumption. Crude oil consumption decreased by 9.61–14.92% and petroleum consumption decreased by 11.02–16.37%. The preferential interest policies of the green industry will lead to an increase in the consumption of renewable energy by 4.13–11.42%. The energy structure is tilted towards renewable energy, and wind, solar, and natural gas will become the main energy sources.

Third, the green credit policy has an environmental improvement effect. Different green credit implementation paths have positive environmental improvement effects, but their impact mechanisms are different. The penalty interest policy can achieve a relatively obvious reduction in total carbon emissions and major pollutant emissions in the short term, mainly due to the decline in fossil energy consumption caused by the shrinking scale of investment and operation. In the short term, carbon dioxide emissions will drop by 6.38%, and the major pollutants will also drop significantly, but this effect will gradually weaken as the cycle increases. The preferential interest policy of the green industry cannot achieve the reduction of carbon dioxide and major pollutant emissions in the short term mainly because green technology takes time to accumulate. But in the long run, the emission reduction effect of green technology is more obvious.

Fourth, different green credit implementation paths have differentiated macroeconomic impacts. The implementation of penalty interest policies on energy-intensive industries has led to continuous reductions in investment in the energy industry, resulting in corresponding changes in industry output. Energy-intensive enterprises will make decision-making adjustments to their production and operation based on the market capital environment. The direct result of their decision-making will be a substantial drop in fossil energy consumption in a short time, which will have a greater negative impact on overall economic activities. On the contrary, the implementation of corresponding preferential interest policies in the green industry will only reduce the capital cost of the green industry, promote the increase of green industry capital investment, and increase the industrial scale of new energy and renewable energy. Therefore, the long term will not have much impact on the stable transition of the social economy. Different implementation paths of credit policy have a differentiated impact on the energy consumption structure, and the penalty interest policy has a more significant inflation due to its direct impact on fossil energy consumption. The preferential interest policy is mainly reflected in the price suppression of fossil energy, and this suppression effect continues to strengthen with the cycle, so the simultaneous implementation of the credit policy in the S3 scenario does not show obvious inflation.

The different realization paths of green credit have differentiated policy effects in the three aspects of energy, environment, and economy. According to different stages of the carbon reduction process, the emphasis of policy implementation means should be different. In the early stage of carbon reduction, interest preferential policies should be more implemented for green industries, and green technological innovation should be encouraged, to form a certain basis for energy substitution based on new energy and to reduce the impact on economic stability brought by the direct imposition of penalty interest policies on energy-intensive industries. In the middle stage of carbon reduction activities, penalty interest policies will be mainly applied to energy-intensive industries. In this stage, significant energy structure and environmental governance effects will be achieved, while continuous investment in green technological innovation will be maintained. To achieve the goal of carbon neutrality, we can only rely on the progress of green technology, so continuous credit investment is very necessary.

Author contribution Yangyang Chen wrote the manuscript and polished the language of this article. Lei Wang put forward the original idea. Yuhan Yang was responsible for collecting the data.

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Data availability The datasets used during the current study are available from the first author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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References

Adelman I, Yeldan E (2000) The minimal conditions for a financial crisis: a multiregional intertemporal CGE model of the Asian crisis. World Dev 28(6):1087–1100. https://doi.org/10.1016/s0305-750x(00)00014-0

An K, Zhang S, Zhou J, Wang C (2023) How can computable general equilibrium models serve low-carbon policy? A Syst Rev Environ Res Lett 18(3):033002. https://doi.org/10.1088/1748-9326/acbbe2

Beaussier T, Caurla S, Bellon-Maurel V, Loiseau E (2019) Coupling economic models and environmental assessment methods to support regional policies: a critical review. J Clean Prod 216:408–421. https://doi.org/10.1016/j.jclepro.2019.01.020

Bourguignon F, Melo JD, Suwa A (1991) Modeling the effects of adjustment programs on income distribution. World Dev 19(11):1527–1544. https://doi.org/10.1016/0305-750x(91)90004-2

Cao J, Dai H, Li S, Guo C, Ho M, Cai W, He J, Huang H, Li J, Liu Y, Qian H, Wang C, Wu L, Zhang X (2021) The general equilibrium impacts of carbon tax policy in China: a multi-model comparison. Energy Econ 99:105284. https://doi.org/10.1016/j.eneco.2021.105284

Carbone JC, Bui LTM, Fullerton D, Paltsev S, Wing IS (2022) When and how to use economy-wide models for environmental policy analysis. Ann Rev Resour Econ 14(1):447–465. https://doi.org/10.1146/annurev-resource-111820-015737

Chen Y-HH, Paltsev S, Reilly JM, Morris JF, Babiker MH (2016) Long-term economic modeling for climate change assessment. Econ Model 52:867–883. https://doi.org/10.1016/j.econmod.2015.10.023

Du Q, Pan H, Liang S, Liu X (2023) Can green credit policies accelerate the realization of the dual carbon goal in China? Examination based on an endogenous financial CGE model. Int J Environ Res Public Health 20(5):4508. https://doi.org/10.3390/ijerph20054508

Dzyuba YA, Bakalova IK (2022) Application of CGE models as a climate policy assessment tool: bibliometric analysis.

Interexpo GEO-Siberia 2(4):129–140. https://doi.org/10.33764/2618-981x-2022-2-4-129-140

Gao J (2023) Research on the impact of green credit on carbon emission and mechanism analysis. Adv Econ Manag Res 6(1):319. https://doi.org/10.56028/aemr.6.1.319.2023

Ghaith Z, Kulshreshtha S, Natcher D, Cameron BT (2021) Regional computable general equilibrium models: a review. J Policy Model 43(3):710–724. https://doi.org/10.1016/j.jpolmod.2021.03.005

Gu X, Tian Z (2023) Does the green credit policy promote the technological innovation of clean energy enterprises? Empirical evidence from China. Front Energy Res 11. https://doi.org/10.3389/fenrg.2023.1112635

He L, Zhang L, Zhong Z, Wang D, Wang F (2019) Green credit, renewable energy investment and green economy development: empirical analysis based on 150 listed companies of China. J Clean Prod 208:363–372. https://doi.org/10.1016/j.jclepro.2018.10.119

He H, Li S, Wang S, Zhang C, Ma F (2023) Value of dual-credit policy: evidence from green technology innovation efficiency. Transp Policy 139:182–198. https://doi.org/10.1016/j.tranpol.2023.06.007

Hemanand D, Mishra N, Premalatha G, Mavaluru D, Vajpayee A, Kushwaha S, Sahile K (2022) Applications of intelligent model to analyze the green finance for environmental development in the context of artificial intelligence. Comput Intell Neurosci 2022:1–8. https://doi.org/10.1155/2022/2977824

Hu Y, Jiang H, Zhong Z (2020) Impact of green credit on industrial structure in China: theoretical mechanism and empirical analysis. Environ Sci Pollut Res 27(10):10506–10519. https://doi.org/10.1007/s11356-020-07717-4

Hu J, Li J, Li X, Liu Y, Wang W, Zheng L (2021) Will green finance contribute to a green recovery? Evidence from green financial pilot zone in China. Front Public Health 9. https://doi.org/10.3389/fpubh.2021.794195

Jin Y, Gao X, Wang M (2021) The financing efficiency of listed energy conservation and environmental protection firms: evidence and implications for green finance in China. Energy Policy 153:112254. https://doi.org/10.1016/j.enpol.2021.112254

Junchen D, Guosheng Z (2023) Green finance policy promotes corporate green innovation. In Springer Nature Singapore, pp 573–582. https://doi.org/10.1007/978-981-19-7826-5_58

Kim E, Samudro YN (2021) Reducing fuel subsidies and financing road infrastructure in Indonesia: a financial computable general equilibrium model. Bull Indones Econ Stud 57(1):111–133. https://doi.org/10.1080/00074918.2019.1643824

Kim E, Hewings GJD, Amir H (2017) Economic evaluation of transportation projects: an application of financial computable general equilibrium model. Res Transp Econ 61:44–55. https://doi.org/10.1016/j.retrec.2016.09.002

Lemelin A, Robichaud V, Decaluwé B (2013) Endogenous current account balances in a world CGE model with international financial assets. Econ Model 32:146–160. https://doi.org/10.1016/j.econmod.2013.01.046

Li B, Chen Y, Cao S (2023) Carrot and stick: does dual-credit policy promote green innovation in auto firms? J Clean Prod 403:136863. https://doi.org/10.1016/j.jclepro.2023.136863

Liu J, Fujimori S, Takahashi K, Hasegawa T, Wu W, Geng Y, Takakura J, Masui T (2020) The importance of socioeconomic conditions in mitigating climate change impacts and achieving Sustainable Development Goals. Environmental Research Letters 16

Liu J-Y, Lin S-M, Xia Y, Fan Y, Wu J (2015) A financial CGE model analysis: oil price shocks and monetary policy responses in China. Econ Model 51:534–543. https://doi.org/10.1016/j.econmod.2015.08.025

Liu J-Y, Xia Y, Fan Y, Lin S-M, Wu J (2017) Assessment of a green credit policy aimed at energy-intensive industries in China based on a financial CGE model. J Clean Prod 163:293–302. https://doi.org/10.1016/j.jclepro.2015.10.111

Luo C, Fan S, Zhang Q (2017) Investigating the influence of green credit on operational efficiency and financial performance based on hybrid econometric models. Int J Financ Stud 5(4):27. https://doi.org/10.3390/ijfs5040027

Montenegro RC, Lekavičius V, Brajković J, Fahl U, Hufendiek K (2019) Long-term distributional impacts of European cap-and-trade climate policies: a CGE multi-regional analysis. Sustainability 11(23):6868. https://doi.org/10.3390/su11236868

Naastepad CWM (2001) The macro-economic effects of directed credit policies: a real-financial CGE evaluation for India. Dev Chang 32(3):491–520. https://doi.org/10.1111/1467-7660.00214

Nandy M, Lodh S (2012) Do banks value the eco-friendliness of firms in their corporate lending decision? Some empirical evidence. Int Rev Financ Anal 25:83–93. https://doi.org/10.1016/j.irfa.2012.06.008

Niu R, Chen L, Xie G, Khan I, Zhao L (2023) Green credit policy and corporate green innovation: do banker directors matter? Total Qual Manag Bus Excell 34(11–12):1553–1578. https://doi.org/10.1080/14783363.2023.2188185

Qiu W, Bian Y, Irfan M, Li Y (2022) Optimization path of green credit to energy consumption structure: a symbiotic development perspective of resource-based and non-resource-based industries. Energy Environ 0958305X2211202. https://doi.org/10.1177/0958305x221120258

Rajabi MM (2023) Carbon tax accompanied by a revenue recycling increases Australia's GDP: a dynamic recursive CGE approach. J Clean Prod 418:138187. https://doi.org/10.1016/j.jclepro.2023.138187

Robinson S (1991) Macroeconomics, financial variables, and computable general equilibrium models. World Dev 19(11):1509–1525. https://doi.org/10.1016/0305-750x(91)90003-z

Rogerson R (2015) A macroeconomic perspective on evaluating environmental regulations. Rev Environ Econ Policy 9(2):219–238. https://doi.org/10.1093/reep/rev005

Shao C, Wei J, Liu C (2021) Empirical analysis of the influence of green credit on the industrial structure: a case study of China. Sustainability 13(11):5997. https://doi.org/10.3390/su13115997

Smith VK, Zhao MQ (2020) Economy-wide modeling, environmental macroeconomics, and benefit-cost analysis. Land Econ 96(3):305–332. https://doi.org/10.3368/le.96.3.305

Vrontisi Z, Abrell J, Neuwahl F, Saveyn B, Wagner F (2016) Economic impacts of EU clean air policies assessed in a CGE framework. Environ Sci Policy 55:54–64. https://doi.org/10.1016/j.envsci.2015.07.004

Wan Q, Qian J, Yu M (2022) Analysis of green financial policy utility: a policy incentive financial mechanism based on state space model theory algorithm. J Sens 2022:1–13. https://doi.org/10.1155/2022/5978122

Wang X, Wang Q (2021) Research on the impact of green finance on the upgrading of China's regional industrial structure from the perspective of sustainable development. Resour Policy 74:102436. https://doi.org/10.1016/j.resourpol.2021.102436

Wang Y, Lei X, Long R, Zhao J (2020) Green credit, financial constraint, and capital investment: evidence from China's energy-intensive enterprises. Environ Manage 66(6):1059–1071. https://doi.org/10.1007/s00267-020-01346-w

Wen H, Lee C-C, Zhou F (2021) Green credit policy, credit allocation efficiency and upgrade of energy-intensive enterprises. Energy Econ 94:105099. https://doi.org/10.1016/j.eneco.2021.105099

Xu Z, Xu C, Li Y (2023) Green credit policy, environmental investment, and green innovation: quasi-natural experimental evidence from China. Sustainability 15(10):8290. https://doi.org/10.3390/su15108290

Yang Y, Zhang Y (2022) The impact of the green credit policy on the short-term and long-term debt financing of heavily polluting enterprises: based on PSM-DID method. Int J Environ Res Public Health 19(18):11287. https://doi.org/10.3390/ijerph191811287

Yao F, Qin Z, Wang X (2023) The influence of bank governance structure on green credit. PLoS ONE 18(3):e0281115. https://doi.org/10.1371/journal.pone.0281115

Yeldan AE (1997) Financial liberalization and fiscal repression in Turkey: policy analysis in a CGE model with financial markets. J Policy Model 19(1):79–117. https://doi.org/10.1016/s0161-8938(96)00048-8

Yin X, Wang D-Y, Lu J, Liu L (2023) Does green credit policy promote corporate green innovation? Evidence from China. Econ Change Restruct. https://doi.org/10.1007/s10644-023-09521-9

Zhang W, Dong J (2023) The polarization effect and mechanism of China's green finance policy on green technology innovation. Sustainability 15(13):10114. https://doi.org/10.3390/su151310114

Zhang W-W, Zhao B, Gu Y, Sharp B, Xu S-C, Liou K-N (2020) Environmental impact of national and subnational carbon policies in China based on a multi-regional dynamic CGE model. J Environ Manage 270:110901. https://doi.org/10.1016/j.jenvman.2020.110901

Zhang D, Awawdeh AE, Hussain M S, Ngo Q-T, Hieu VM (2021a) Assessing the nexus mechanism between energy efficiency and green finance. Energy Effic 14(8). https://doi.org/10.1007/s12053-021-09987-4

Zhang D, Tong Z, Zheng W (2021b) Does designed financial regulation policy work efficiently in pollution control? Evidence from manufacturing sector in China. J Clean Prod 289:125611. https://doi.org/10.1016/j.jclepro.2020.125611

Zhang Q, Xu L, Wang K, Shi X (2021c) What effect did the Green Credit Policy have on China's energy or emission intensive firms? Int J Emerg Mark 18(9):2363–2382. https://doi.org/10.1108/ijoem-04-2021-0555

Zhang S, Wu Z, Wang Y, Hao Y (2021d) Fostering green development with green finance: an empirical study on the environmental effect of green credit policy in China. J Environ Manage 296:113159. https://doi.org/10.1016/j.jenvman.2021.113159

Zhou G, Liu C, Luo S (2021) Resource allocation effect of green credit policy: based on DID model. Mathematics 9(2):159. https://doi.org/10.3390/math9020159