RESEARCH ARTICLE

Impact of green finance on economic development and environmental quality: a study based on provincial panel data from China

Xiaoguang Zhou[1] · Xinmeng Tang[1] · Rui Zhang[1]

Abstract

The goal of green finance is to pursue the coordinated development of financial activities, environmental protection, and ecological balance. This study aims to examine the impact of green finance on economic development and environmental quality. Data concerning green finance, economic development, and environmental quality for 30 provinces and municipalities in China from 2010 to 2017 are used. First, the global principal component analysis is adopted to develop a green finance development index. Second, a model of the impact of green finance on economic development is constructed, which indicates that the development of green finance plays a role in promoting economic development. Next, emissions of industrial smoke (powder) dust, industrial solid waste, and carbon dioxide are used to represent the environmental variables, and a model of the impact of green finance on environmental quality is proposed. The model shows that green finance has a positive effect on environment improvement. However, the impact of green finance on environmental quality varies for different levels of economic development. Finally, based on the theory of the environmental Kuznets curve, a model of the impact of green finance on the relationship between economic development and environmental quality is developed. The model indicates that green finance can significantly improve this relationship, creating a win-win situation regarding economic development and the environment.

Keywords Environmental quality · Environmental Kuznets curve · Green finance · Economic development

Highlights
• The green finance development index of 30 provinces and municipalities in China from 2010 to 2017 was developed.
• The impact of green finance on economic development was analyzed.
• The impact of green finance on environment quality was explored.
• The impact of green finance on the relationship between economic development and environment quality was examined using the environmental Kuznets curve theory.
• The important role of green finance in achieving sustainable economic development was discussed, and policy implications were summarized.

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Introduction

Since the reform and opening in 1978, China has achieved rapid economic growth and financial development (Xu 2018). But at the same time, China is also the world's largest energy consumption and pollutant emission country (Li et al. 2016). Coal and oil account for 70% of China's energy consumption (Liu et al. 2018), and the burning of coal and oil leads to the discharge of a large number of pollutants, including carbon dioxide, sulfur dioxide, and solid waste (Bi et al. 2014). These pollutants can seriously harm human health and ecosystems (Venners et al. 2003; Wei et al. 2014; Song et al. 2016). To this end, the Chinese government has begun to pay attention to sustainable development from the early of the twenty-first century. In 2002, the 16th National Congress of the Communist Party of China took "the continuous enhancement of sustainable development capacity" as one of the objectives of building a well-off society. Under the guidance of the concept of sustainable development, policymakers and researchers have proposed many solutions to environmental problems, such as cleaner production, resource recycling,

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climate fund, environmental pollution tax, and green finance. The definition of green finance, a financial innovation product aimed at achieving a win-win situation between economic development and environmental quality improvement, is the financing of investments that provide environmental benefits, according to the International Finance Corporation. This new financial innovation product has attracted more and more attention (Zhang et al. 2019) and has developed rapidly in China. In 2018, China issued a total of 144 green bonds, totaling 267.593 billion yuan. China has become one of the largest global green bond markets. In 2018, China's green loans amounted to 8.23 trillion yuan, accounting for 14.2% of the increase in loans from enterprises and other units in the same period. Carbon finance started late but developed rapidly in China. Since 2011, China has launched carbon emission trading pilots in seven provinces and cities including Guangdong, Hubei, Beijing, Shanghai, Tianjin, Chongqing, and Shenzhen. By the end of 2017, the cumulative trading volume of seven pilot carbon markets had been up to 200 million tons, with a total trading volume of 4.7 billion yuan. At present, China is one of the largest carbon finance markets.

Compared with traditional finance, green finance emphasizes environmental interests, and regards environmental protection and the effective use of resources as important criteria for measuring the effectiveness of its activities. Green finance pursues the coordinated development of financial activities, environmental protection, and ecological balance, and ultimately realizes sustainable development. Wang and Zhi (2016) pointed out that green finance is a new financial model that combines environmental protection and economic benefits. Wang et al. (2019b) noted that green finance emphasizes the two "hot topics" of green development and finance, and argued that the financial sector regards environmental protection as a basic policy, and any potential environmental impact shall be considered in investment and financing decisions.

This study attempts to explore whether green finance can achieve the goal of simultaneously promoting economic development and environmental improvement. The innovations of this study lie in the following three points. First, the original intention of green finance is to achieve economic development and environmental quality improvement with the help of financial instruments. However, there is a lack of literature to verify whether the development of green finance has achieved its original intention. Based on this, one of the innovations of this paper is to integrate green finance, economic development, and environmental quality into a unified system to study the direct impact of green finance on economic development and environmental quality change. Second, using the global principal component analysis (GPCA) method, this study proposes a new method to measure the development degree of green finance. The GPCA method combines the classical principal component analysis (PCA) and time series analysis method, and GPCA method can explore the trajectory of the overall level of a system over all time, so that the comprehensive score of green finance development index calculated by GPCA method can more accurately and comprehensively reflect the development degree of green finance in each year and the development difference of each province. At the same time, whereas most research have only focused on one aspect of green finance, the score of green finance development index calculated in this study incorporates green securities, green credit, green investment, and carbon finance to comprehensively reflect the degree of development of green finance. Thus, compared with existing literatures, this study obtains an advantage in measuring the development degree of green finance. Third, most of the existing literature merely focuses on the existence of environmental Kuznets curve (EKC) in China, while this study further explores the impact of green finance on the shape and turning point position of the EKC, which is also an under-researched problem at present. This study confirms that the shape and turning point position of the EKC varies for different levels of green finance.

Literature review

The impact of green finance on economic development

The positive relationship between financial development and economic growth (King and Levine 1993; Demetriades and Hussein 1996; Beck et al. 2000) has long been confirmed, and this positive relationship seems to exist in developed (Nieuwerburgh et al. 2006; Marques et al. 2013), emerging, and developing (Bittencourt 2012; Uddin et al. 2013) economies. With the maturity of financial market, the research on this issue is more in-depth. For example, scholars have explored different transmission paths of financial development to promote economic growth (Bucci et al. 2019; Gazdar et al. 2019), discovered that different financial indicators show heterogeneity in promoting economic growth (Adu et al. 2013; Wang et al. 2019a), and examined the impact of financial regulatory policies on the relationship between financial development and economic growth (Bernier and Plouffe 2019).

Green finance is a new type of financial instrument proposed to solve environmental problems, and it is the embodiment of financial innovation in the field of environmental protection (Wang et al. 2019b). Green finance has the same characteristics as traditional finance. Therefore, like financial development, the development of green finance can also promote economic growth. However, due to the short development time of green finance, there are few related researches. He et al. (2019b) found that green investment in renewable resources has a dual threshold effect on green economy development; in the long run, green investment in renewable energy

can effectively promote green economy growth. Pradhan et al. (2018), after studying the relationship between energy consumption, financial development, and economic growth in FATF (Financial Action Task Force) countries, proposed that the government should support green finance investment in clean energy fields, such as natural gas, which also contribute to environmental protection and economic growth.

After the financial crisis in 2008, financial markets experienced more volatility and uncertainty (Neaime 2012; Assaf 2016). An increasing number of studies have found that excessive financial development may inhibit economic growth (Hye and Islam 2013; Ibrahim and Alagidede 2018). Therefore, whether green finance can promote economic growth is still worth researching.

The impact of green finance on environmental quality

In 2015, 178 parties signed the Paris Agreement to jointly address the issues of global climate change. According to the statistics of International Energy Agency in 2014, by 2035, 53 trillion dollars will be needed to maintain the 2 °C temperature threshold required in the Paris Agreement. At the same time, in 2018, the trading volume of the global stock market was up to 68.212 trillion dollars. Obviously, the use of financial capital is a good way to solve this huge funding gap (Clark et al. 2018). Galaz et al. (2015) and Scholtens (2017) believed that the rapid development of financial innovation has an important impact on many aspects of human society, but the impact on the ecological environment is minimal, and thus, there is a huge room to promote ecological environment with the help of financial funds. Furthermore, scholars have studied more fundamental issues of green finance in promoting environmental protection, such as the transmission path of green finance to the environment (Wang and Zhi 2016), how to improve the participation of private green capital in environmental protection projects (Ruiz et al. 2016; Taghizadeh-Hesary and Yoshino 2019), and the role of the government in the development of green finance (Owen et al. 2018).

The financial industry itself contributes to environmental quality improvement. This is because, on the one hand, the financial industry can provide financial support for environmentally friendly enterprises and projects; on the other hand, financial development can promote the upgrading of industrial structure, which in turn plays an important role in reducing energy consumption and carbon emissions (Chang 2015; Mahdi 2015; Nasreen et al. 2017). Dogan and Seker's (2016) research found that financial development can effectively reduce domestic carbon dioxide emissions based on the data of 23 countries with the largest use of renewable energy. Guo et al. (2019) further refined the financial indicators and found that the impact of financial scale and financial efficiency on carbon dioxide emissions is heterogeneous. In addition, it was also found that

financial development can reduce emissions of various environmental indicators such as industrial solid waste (Zhao et al. 2019), industrial wastewater (Yin et al. 2019), and nitrogen oxides (Nassani et al. 2017). Therefore, the significance of developing green finance is to strengthen the characteristics of finance that can improve environmental quality. Poberezhna (2018) studied the advantages of green economy and the blockchain to address the global water shortage problem, thereby reducing the threat of environmental degradation. Gianfrate and Peri (2019) proposed that green bonds are one of the key tools to mobilize financial resources to achieve the carbon reduction targets of the Paris Agreement. Glomsrød and Wei (2018) pointed out that if the green bonds are carried out on a reasonable track, 4.7 Gt of carbon dioxide emissions can be avoided by 2030, while the proportion of non-fossil energy power will be increased from 42 to 46%, due to the development of green finance. In fact, green finance does not directly affect the environment, but it provides support for environmentally friendly enterprises and projects, thereby improving environmental quality. For example, the concept of green credit has run through the banks' loan approval process, and thus, the financing capacity of high-pollution enterprises has dropped significantly (Liu and Shen 2011; Liu et al. 2017, 2019); issuing green bonds is beneficial for shareholders, and thus, it will promote the companies to enter into green-related fields (Tang and Zhang 2018); compared with traditional projects, green projects that focus on sustainable development can bring more benefits to investors (Kudratova et al. 2018), and thus, investment funds flow more to non-traditional green projects. The government positive green finance policies may increase investments in the renewable energy sector (Romano et al. 2017).

However, some scholars' views are inconsistent with mainstream views. For instance, He et al. (2019a) found that the development of green finance has a negative impact on the bank's loan issuance, which to a certain extent inhibits the efficiency of investment in renewable energy, and thus has a negative impact on environmental quality. Pacca et al. (2020) found that in the short term after the financial crisis, the level of financial development fell sharply, but the emissions of air pollutants also dropped, which shows that financial regression has promoted the improvement of the environment instead.

It can be seen that the current research mostly proves that the development of green finance will promote the funds flowing into environmentally friendly enterprises and projects, but does not clearly show the direct relationship between green finance and environmental quality changes. This paper constructs green finance development index and environmental quality index to directly study the impact of green finance on environmental quality change, which is also an innovation of this paper.

The impact of green finance on economic development and environmental quality

Economic sustainable development refers to increasing attention to environmental protection while promoting economic growth (Campbell 1996; Grodach 2011). The goal of developing green finance is to provide financial tools for sustainable economic development (Zhang et al. 2019). Therefore, only when green finance can simultaneously accomplish the goals of economic development and environmental quality improvement, the development of green finance is of practical significance.

Simon et al. (2012) found that the stove replacement program can achieve a win-win situation between economy and environment, and the promotion of this project requires the support of green financial instruments such as carbon finance. Using the methods of Monte-Carlo simulation and dynamic programming, Brauneis et al. (2013) calculated the best carbon dioxide price floor levels and growth rates in carbon finance transactions to attract green investment in low-carbon technologies, which helped to achieve both economic growth and environment quality improvement.

In the above research, green finance, as a financing tool, provides support for enterprises or projects that can achieve a win-win situation between economy and environment, but there is little literature on the direct impact of green finance on economic development and environmental quality. Based on this, one of the innovations of this paper is to integrate green finance, economic development, and environmental quality into a unified system to study the direct impact of green finance on economic development and environmental quality change.

This paper studies the comprehensive impact of green finance on economic development and environmental quality by analyzing the change in the shape of the EKC. The inverse U-shaped relationship between per capita GDP and environmental degradation was first identified in 1991. Grossman and Krueger (1991) studied the relationship between economic development and environmental pollution and found that, as per capita income increased, the concentration of sulfur dioxide and dust in the air continued to rise, until it reached a turning point, when it began to decline. Shafik and Bandyopadhyay (1992) also found an inverted U-shaped relationship between economic development and environmental pollution. Panayotou (1993) defined the inverse U-shaped relationship between per capita GDP and an environmental pollution indicator as the EKC. Subsequently, scholars have used multinational data to confirm the existence of the EKC in different countries. For example, the EKC has been validated in the USA by Apergis and Payne (2009), in China by Jalil and Mahmud (2009) and Riti et al. (2017), and in Turkey by Halicioglu (2009), Seker et al. (2015), Ozatac et al. (2017), and Pata (2018). Furthermore,

researchers have studied the inverted U-shaped relationship between other environmental indicators and per capita income. Song et al. (2008) pointed out that the shape of the EKC is different for different industrial waste emissions. Al-Mulali et al. (2015), Dogan and Seker (2016), and Sinha and Shahbaz (2018) showed the inverted U-shaped relationship between per capita GDP and carbon dioxide emissions, and Wang et al. (2017) studied the EKCs of various greenhouse gases.

This paper further studies the impact of green finance on the shape and turning point position of EKC, which is still a relatively under-researched problem. This paper confirms that green finance can change the shape and turning point position of EKC, that is, the development of green finance will ease the competitive relationship between economic development and environmental change, which is also the innovation findings in this paper.

Research methods and theories

GPCA method

In this paper, we used the GPCA method to construct a green finance development index for various provinces and municipalities in China from 2010 to 2017. Classical principal component analysis (PCA) can be used only for cross-sectional data and is not suitable for dynamic analysis. In contrast, the GPCA method, which combines PCA and time series analysis, can analyze time series data and explore the trajectory of the overall level of a system over all time. The specific process is as follows.

Suppose that there are n provinces and municipalities in China and p indicators related to green finance X_j ($j = 1, 2, …, p$). With these data, the cross-sectional data table $(X^t)_{n \times p}$ in the tth year is constructed, which has n rows and p columns.

Suppose that there is a total of T years, and $X^1, X^2, …, X^T$ are lined in order to construct a global data table X, which has N ($N = Tn \geq n$) rows and p columns, as shown in Eq. (1):

$$X = \left(X^1, X^2, ..., X^T\right)'_{N \times p} = (x_{ij})_{N \times p}, \tag{1}$$

where x_{ij} denotes the element of the ith row and the jth column in the global data table X, $1 \leq i \leq Tn$, $1 \leq j \leq p$.

The data are normalized to eliminate the effects of the dimensions, and the normalized global data table is ZX, as shown in Eq. (2):

$$zx_{ij} = \frac{x_{ij} - \overline{X_j}}{\sigma_j}, \tag{2}$$

where zx_{ij} denotes the normalized data in the global data table

$ZX, \overline{X}_j = \frac{1}{N} \sum_{i=1}^{N} x_{ij}$, and $\sigma_j = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} \left(x_{ij} - \overline{x_j}\right)^2}$.

The centroid of the global data table ZX is defined as Eq. (3):

$$g = \left(\overline{ZX_1}, \overline{ZX_2}, ..., \overline{ZX_p}\right) = \sum_{i=1}^{N} q_i e_i, \qquad (3)$$

where q_i denotes the weight of the sample e_i, satisfying:

$\sum_{i=1}^{N} q_i = 1, \ \sum_{i=1}^{n} q_i = \frac{1}{T}$.

As can be seen from Eq. (3), the centroid of the global data table ZX is equal to the average of the centroid of each table.

The variance of the global data table ZX is:

$$S_j^2 = \mathrm{Var}\left(ZX_j\right) = \sum_{i=1}^{N} q_i \left(zx_{ij} - \overline{ZX_j}\right)^2, \qquad (4)$$

where ZX_j denotes the jth column of the global data table ZX.

The covariance of the global data table ZX is:

$$S_{jk} = \mathrm{Cov}\left(ZX_j, ZX_k\right) = \sum_{i=1}^{N} \left(zx_{ij} - \overline{ZX_j}\right)\left(zx_{ij} - \overline{ZX_k}\right), \qquad (5)$$

where ZX_k denotes the kth column of the global data table ZX, $1 \leq k \leq p$.

According to Eqs. (4) and (5), the global covariance matrix can be obtained using Eq. (6):

$$V = \left(S_{jk}\right)_{p \times p} = \sum_{i=1}^{N} q_i (e_i - g)(e_i - g)'. \qquad (6)$$

The eigenvalue of the covariance matrix V is λ_j, and the corresponding principal component of V is F_j. According to the principle of $\lambda_j \geq 1$, only the first m ($m \leq p$) eigenvalues and principal components are retained. At the same time, the variance contribution rate and cumulative variance rate of F_j can be calculated by Eqs. (7) and (8).

$$a_j = \frac{\lambda_j}{\sum_{j=1}^{p} \lambda_j}, \qquad (7)$$

$$a_1 + a_2 + ... + a_j = \frac{\sum_{j=1}^{j} \lambda_j}{\sum_{j=1}^{p} \lambda_j}, \qquad (8)$$

where a_j is the variance contribution rate of F_j.

Let r_{ij} denote the correlation coefficient between ZX and F_j. Then, the component matrix $A = (r_{ij})$ is obtained, and the component score coefficient matrix M_j is acquired as follows:

$$M_j = \frac{r_{ij}}{\sqrt{\lambda_j}}. \qquad (9)$$

Therefore, the principal component F_j of the green finance indicator X_j is obtained as shown in Eq. (10):

$$F_j = M_j \cdot ZX. \qquad (10)$$

According to Eqs. (7)–(10), the comprehensive green finance development index of the Chinese provinces and municipalities from 2010 to 2017 can be obtained by Eq. (11).

$$F = \frac{\lambda_1}{\sum_{j=1}^{m} \lambda_j} F_1 + \frac{\lambda_2}{\sum_{j=1}^{m} \lambda_j} F_2 + ... + \frac{\lambda_m}{\sum_{j=1}^{m} \lambda_j} F_m. \qquad (11)$$

EKC theory

According to the EKC theory, the inverse U-shaped relationship between per capita GDP and environmental degradation can be represented by a quadratic function, as shown in Eq. (12):

$$E_{i,t} = a Y_{i,t} + b Y_{i,t}^2 + z_k Z_{k,i,t} + c + \varepsilon_{i,t}, \qquad (12)$$

where $E_{i,t}$ denotes environmental quality indicators, $Y_{i,t}$ denotes economic development indicators, $Z_{k,i,t}$ denotes the control variables, $\varepsilon_{i,t}$ denotes a random error term, a, b, and z_k are coefficients, and c is a constant term. Only when $b < 0$, the inverted U-shape of the EKC is valid.

Owing to differences in the natural environment, environmental protection policies, population size, and other factors between regions, the EKCs have different shapes, as shown in Fig. 1. The relationship between economic development and environmental change demonstrated by EKC_2 is superior to that of EKC_1 because, at the same level of economic development, the environmental degradation associated with EKC_2 is lower than that of EKC_1. Therefore, given a certain economic development level, the goal of environmental policy is to continuously adjust the EKC so that it shifts from EKC_1 to EKC_2.

Empirical research

Samples

In this paper, we used data related to green finance, economic development, and the environmental quality for 30 provinces and municipalities in China from 2010 to 2017. The frequency of data is annual. The 30 provinces and municipalities are Beijing City (BJ), Tianjin City (TJ), Shanghai City (SH),
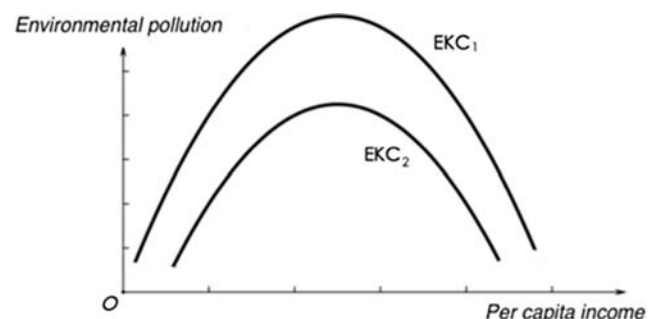

Fig. 1 The EKC

and Chongqing City (CQ), and the following provinces: Hebei (HE), Shanxi (SX), Liaoning (LN), Jilin (JL), Heilongjiang (HL), Jiangsu (JS), Zhejiang (ZJ), Anhui (AH), Fujian (FJ), Jiangxi (JX), Shandong (SD), Henan (HA), Hubei (HB), Hunan (HN), Guangdong (GD), Hainan (HI), Sichuan (SC), Guizhou (GZ), Yunnan (YN), Shaanxi (SN), Gansu (GS), Qinghai (QH), Inner Mongolia (NM), Guangxi (GX), Ningxia (NX), and Xinjiang (XJ). The data sources are the Wind database, the China Statistical Yearbook, the China Environmental Statistics Yearbook, and the China Energy Statistics Yearbook.

Constructing the green finance development index

Taking into account data availability and validity, we selected six indicators regarding green credit, green securities, green investment, and carbon finance to measure the green finance development level in various regions of China, as shown in Table 1. Listed companies in environmental protection industry in A-share[1] include the following concept sectors, such as environmental protection and energy conservation, new energy vehicles, new energy, beautiful China, wind energy, geothermal energy, and solar energy. The listed companies with ST[2] shares and *ST[3] shares were excluded.

We used the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test to determine whether the data can be analyzed using the GPCA method, with the results shown in Table 2. The result of the KMO test is 0.749 (> 0.5), which indicates that there is a strong correlation among test indicators. The approximate chi square of Bartlett's test is 1060.439 and the significance level is 0.00 (< 0.01), indicating that the result rejects the null hypothesis. Therefore, the data can be analyzed using the GPCA method.

Using Eqs. (7) and (8), the variance contribution rate and cumulative variance rate can be calculated, as shown in Table 3. Meanwhile, on the basis of the principle of $\lambda_j \geq 1$, it is obvious that the components F_1 and F_2 should be retained.

According to Eqs. (9) and (10), the principal component of the green finance indicator X_j ($j = 1, 2, …, p$) can be obtained as follows:

$$F_1 = -0.027ZX_1 - 0.265ZX_2 + 0.401ZX_3$$
$$+ 0.337ZX_4 + 0.212ZX_5 + 0.291ZX_6, \qquad (13)$$

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[1] A-share: The stock issued by a registered company in China, listed in China, with a face value in RMB, for ordinary shares of domestic institutions, organizations or individuals to subscribe and trade in RMB.

[2] ST: The listed company with abnormal financial status and special treatment by the stock exchange.

[3] *ST: The listed company with abnormal financial status and considered by the stock exchange to have a delisting risk.

$$F_2 = 0.439ZX_1 + 0.669ZX_2 - 0.194ZX_3 - 0.050ZX_4$$
$$+ 0.139ZX_5 - 0.140ZX_6. \qquad (14)$$

Finally, using Eqs. (11), (13), and (14), the comprehensive green finance development index can be obtained, as shown in Eq. (15). The results of the green finance development index for provinces and municipalities in China from 2010 to 2017 are shown in Table 4.

$$F = 0.6022F_1 + 0.3978F_2. \qquad (15)$$

The impact of green finance on economic development

Basic model

We propose a model of the impact of green finance on economic development in which the explanatory variable is the green finance development index, the explained variable is the per capita GDP, and the control variables are per capita GDP in the previous year, the ratio of total capital formation to employees, the ratio of educational expenditure to employees, and the proportion of scientific and technological expenditure to public budget expenditure. The model is shown in Eq. (16):

$$ln\text{perGDP}_{i,t} = \beta_0 + \beta_1 \text{GreenFinance}_{i,t} + \beta_2 ln\text{perGDP}_{i,t-1}$$
$$+ \beta_3 ln(\text{GCF/LAB})_{i,t}$$
$$+ \beta_4 ln(\text{FEE/LAB})_{i,t} + \beta_5 ln(\text{STE/FE})_{i,t}, \qquad (16)$$

where $\text{perGDP}_{i,t}$ denotes the per capita GDP of province i in the tth year, $\text{GreenFinance}_{i,t}$ denotes the green finance development index of province i in the tth year, $\text{perGDP}_{i,t-1}$ denotes the per capita GDP of province i in the (t-1)th year, $\text{GCF/LAB}_{i,t}$ denotes the ratio of total capital formation to employees of province i in the tth year, $\text{FEE/LAB}_{i,t}$ denotes the ratio of educational expenditure to employees of province i in the tth year, and $\text{STE/FE}_{i,t}$ denotes the proportion of scientific and technological expenditure to public budget expenditure of province i in the tth year. In order to avoid heteroscedasticity, the variables other than the core explanatory variable $\text{GreenFinance}_{i,t}$ are logarithmicized.

The data sources and expected effect of each variable are shown in Table 5.

Regression analysis and robustness test

To avoid a spurious regression, the stationarity of the data was tested. The panel unit root test methods including the Levin-Lin-Chu (LLC) test, the Im-Pesaran-Shin (IPS) test, the

Table 1   Measurement indicators of the green finance development level

The first-class index	The second-class index	Source
Green credit	Total liabilities of listed companies in environmental protection industry registered in provincial i in the tth year	Wind
Green securities	Total stock market value of listed companies in environmental protection industry registered in provincial i in the tth year	Wind
Green investment	Total energy and environmental protection expenditures of province i in the tth year	China Statistical Yearbook
	Total investment in pollution control of province i in the tth year	China Statistical Yearbook
	Total equity investment of listed companies in environmental protection industry registered in provincial i in the tth year	Wind
Carbon finance	Transaction volume of carbon finance of province i in the tth year	Wind

Phillips-Perron (PP)-Fisher test, and the augmented Dickey-Fuller (ADF) test were used for the stationarity tests, with the results shown in Table 6. The time series diagram of the data is shown in Fig. 2. As shown in Fig. 2, the data has the intercept term but not the trend term; therefore, the stationarity test was performed only for the intercept term.

As can be seen from Table 6, the variables GreenFinance and ln(STE/FE) belong to the zero-order stationary sequence, and the other variables belong to the second-order stationary sequence, so further cointegration tests are needed. The Kao test and Pedroni test were adopted, with the results shown in Table 7.

As can be seen from Table 7, although three results of the Pedroni test support the hypothesis that there is no cointegration relationship, the results of other four tests and the Kao test reject the hypothesis. Thus, on the basis of the results of the Pedroni and Kao tests, it can be inferred that there is a cointegration relationship between the variables. Therefore, regression analysis can be carried out.

The generalized least squares (GLS) method was used for the regression analysis of Eq. (16), and the likelihood ratio test was used to determine whether there were cross-sectional or time effects. In addition, the Hausman test was performed to examine whether there were individual fixed or random effects. The results of the likelihood ratio test and the Hausman test are shown in Table 8.

Based on the results of Table 8, the likelihood ratio test indicates that there is an individual effect in the cross-section and an individual effect for time. The

results of the Hausman test show that there is an individual fixed effect in the cross-section and an individual random effect for time. Therefore, the mixed-effect model should be adopted for the GLS regression analysis. Cross-section weights were used, and the panel correction standard error (PCSE) method was used to correct the results. The results of the regression analysis are shown in Table 9. Wherein, model (1) is the GLS regression for the 30 provinces in China. Models (2), (3), and (4) are GLS regressions for eastern China (11 provinces), central China (8 provinces), and western China (11 provinces), respectively. Models (2)–(4) are also used as a robustness test for model (1). The reason for undertaking subregional regressions is the great difference in the economic development levels of the eastern and western regions of China.

As can be seen from Table 9, the corresponding P values for the F statistics of the four models are all zero, indicating that the fit degrees of the models are good. The symbol of the core explanatory variable GreenFinance is positive, indicating that the development of green finance has a positive impact on economic development (perGDP). For the control variables, the symbols of perGDP$_{i,t-1}$, GCF/LAB, and STE/FE are positive, and accord with expectations. However, the symbol of FEE/LAB is contrary to expectations. It is possible that China's large population results in this ratio having a negative impact on economic development. This conclusion is consistent with the view that financial development can promote economic development in previous studies (King and Levine 1993; Demetriades and Hussein 1996; Beck et al. 2000; Levine et al. 2000), and it also confirms that the development of green finance can promote economic development (Wang and Zhi 2016; Wang et al. 2019b).

For the robustness test, the core explanatory variable GreenFinance has a positive impact on economic development in eastern, central, and western China, supporting the results of model (1). Furthermore, the symbols and

Table 2   Results of the KMO test and Bartlett's test

Test method	Statistics	Results
Kaiser-Mayer-Olkin test	Measure of sampling adequacy	0.749
Bartlett's test of sphericity	Approx. chi square	1060.439
	Df.	15
	Sig.	0.000

Table 3 Results of variance interpretation

Component	Initial eigenvalues			Rotation sums of squared loadings		
	Total	Variance (%)	Cumulative variance (%)	Total	Variance (%)	Cumulative variance (%)
1	3.603	60.042	60.042	2.827	47.109	47.109
2	1.091	18.190	78.232	1.867	31.123	78.232
3	0.736	12.271	90.503			
4	0.295	4.951	95.418			
5	0.215	3.578	98.996			
6	0.60	1.004	100.000			

significance levels of perGDP$_{i,t-1}$, GCF/LAB, and FEE/LAB are similar to those from model (1), which proves that the results of model (1) are reliable. However, STE/FE is significant in model (2), but not significant in models (3) and (4). This may be because China's central and western regions are relatively underdeveloped, and their economic development mostly depends on labor inputs, capital, and energy, rather than technology. Therefore, the impact of science and technology expenditure on economic development is not significant.

Table 4 Green finance development index for provinces and municipalities in China from 2010 to 2017

	2010	2011	2012	2013	2014	2015	2016	2017
AH	− 0.4127	− 0.3322	− 0.2485	− 0.1178	− 0.1161	− 0.0088	0.0716	0.2697
BJ	0.2515	0.4817	0.7018	0.8890	1.5467	2.0348	2.7148	3.2208
FJ	− 0.4740	− 0.4634	− 0.4137	− 0.3530	− 0.3467	− 0.1942	− 0.1149	0.0547
GS	− 0.5536	− 0.5179	− 0.5040	− 0.4851	− 0.4765	− 0.4322	− 0.4334	− 0.4322
GD	1.2977	0.7553	0.8971	1.2938	1.7759	2.5728	3.0982	3.3465
GX	− 0.5153	− 0.5370	− 0.5075	− 0.4850	− 0.4421	− 0.3597	− 0.4112	− 0.4361
GZ	− 0.5810	− 0.5651	− 0.5414	− 0.5141	− 0.4297	− 0.4110	− 0.3595	− 0.3173
HI	− 0.7027	− 0.6793	− 0.6761	− 0.6808	− 0.6830	− 0.6561	− 0.6390	− 0.6281
HE	− 0.2157	− 0.0961	− 0.0936	0.0546	0.1031	0.3059	0.3639	0.7051
HA	− 0.3871	− 0.3870	− 0.3172	− 0.2626	− 0.1877	0.0024	0.0767	0.3465
HL	− 0.4522	− 0.4466	− 0.3817	− 0.3258	− 0.3712	− 0.2858	− 0.3400	− 0.1776
HB	− 0.3589	− 0.2868	− 0.2707	− 0.2346	0.2193	0.7782	0.5033	0.5628
HN	− 0.3155	− 0.3277	− 0.2098	− 0.1567	− 0.1083	0.1406	0.0043	0.0421
JL	− 0.4432	− 0.3986	− 0.3706	− 0.3297	− 0.2870	− 0.3106	− 0.2990	− 0.2980
JS	0.3472	0.4323	0.5687	0.7942	1.0774	1.5630	1.4082	1.5192
JX	− 0.5057	− 0.4785	− 0.3785	− 0.4011	− 0.4090	− 0.3368	− 0.2075	− 0.1472
LN	− 0.4329	− 0.3416	− 0.1413	− 0.2841	− 0.3129	− 0.2528	− 0.3822	− 0.3222
NM	− 0.2697	− 0.1777	− 0.1037	− 0.0693	0.0263	0.0949	0.0229	− 0.0126
NX	− 0.6310	− 0.6118	− 0.6093	− 0.6102	− 0.5914	− 0.5413	− 0.5561	− 0.5073
QH	− 0.6456	− 0.6297	− 0.6271	− 0.5718	− 0.5932	− 0.5166	− 0.5384	− 0.5716
SD	0.0783	0.1671	0.3496	0.5439	0.5140	0.6559	0.8482	0.9889
SX	− 0.4115	− 0.3932	− 0.3392	− 0.2851	− 0.3061	− 0.2813	− 0.0950	− 0.1750
SN	− 0.4194	− 0.4104	− 0.3995	− 0.3405	− 0.2364	− 0.1209	− 0.1192	− 0.0008
SH	0.5463	0.6723	0.8617	1.0902	1.6215	1.9357	2.0716	2.7223
SC	− 0.1520	− 0.1157	− 0.0523	0.0463	0.1839	0.2219	0.2799	0.3813
TJ	− 0.5314	− 0.4769	− 0.4569	− 0.4060	− 0.2614	− 0.3094	− 0.3979	− 0.2763
XJ	− 0.4542	− 0.4301	− 0.3273	− 0.2542	− 0.1585	− 0.1606	− 0.1608	− 0.1016
YN	− 0.4961	− 0.4699	− 0.4510	− 0.4120	− 0.4213	− 0.3687	− 0.3290	− 0.2672
ZJ	− 0.1072	− 0.1741	− 0.1005	0.0143	0.2409	0.6740	0.8063	0.8990
CQ	− 0.3369	− 0.1717	− 0.1152	− 0.0724	− 0.0305	0.1347	0.1610	0.3337

Table 5 Interpretation of variables in the model of green finance and economic development

Variables	Variables description	Source	Expected effect
$perGDP_{i,t}$	Per capita GDP	Wind	
$GreenFinance_{i,t}$	Green finance development index		The expected sign is unknown.
$perGDP_{i,t-1}$	Per capita GDP last year	Wind	The expected sign is positive. Per capita GDP reflects a country's level of economic development. Due to the inertia of economic growth, the level of economic development in the previous year will have a positive impact on the level of economic development this year.
$GCF/LAB_{i,t}$	The ratio of total capital formation to employees	Wind	The expected sign is positive. The ratio of total capital formation to employees is an important indicator to measure the accumulation of social wealth. The degree of material accumulation of social wealth is an important factor affecting economic development. Therefore, it will have a positive impact on economic growth.
$FEE/LAB_{i,t}$	The ratio of educational expenditure to employees	Wind	The expected sign is positive. The ratio of educational expenditure to employees is an important indicator of human capital. According to endogenous growth theory, knowledge accumulation can promote economic growth. Therefore, it will have a positive impact on economic development.
$STE/FE_{i,t}$	The proportion of scientific and technological expenditure to public budget expenditure	Wind	The expected sign is positive. The proportion of scientific and technological expenditure to public represents the technological factors that promote economic development. According to endogenous growth theory, technical factors are the decisive factor in ensuring economic growth. Therefore, it will have a positive impact on economic development.

The impact of green finance on environmental quality

Basic model

We propose a model of the impact of green finance on environmental quality in which the explanatory variable is the green finance development index, the explained variables are the environmental indicators of the various provinces in China, and the control variables are per capita energy consumption, the secondary industry's share of GDP, and the urbanization rate, as shown in Eq. (17). To describe the environmental effects in a more comprehensive and detailed way, three environmental indicators are used: industrial smoke dust emissions, industrial solid waste emissions, and carbon dioxide emissions.

$$ln\text{EI}_{i,t} = \beta_0 + \beta_1\text{GreenFinance}_{i,t} + \beta_2 ln(\text{EC}/\text{POP})_{i,t}$$
$$+ \beta_3 ln(\text{SIGDP}/\text{GDP})_{i,t} \quad (17)$$
$$+ \beta_4 ln(\text{UPOP}/\text{POP})_{i,t},$$

Table 6 Results of the stationarity tests (test for intercept term)

Variables		ADF-Fisher	PP-Fisher	LLC	IPS
lnperGDP	I (0)	6.42122 (1.0000)	8.88917 (1.0000)	15.4755 (1.0000)	15.4289 (1.0000)
	I (2)	76.2815 (0.0764) *	79.6705 (0.0456)**	− 11.4105 (0.0000)***	− 1.28799 (0.0989)*
GreenFinance	I (0)	87.8547 (0.0545) *	89.9778 (0.0704)*	0.85273 (0.8031)	− 11.9345 (0.0000)***
ln(GCF/LAB)	I (0)	10.4285 (1.0000)	9.39734 (1.0000)	12.4795 (1.0000)	9.53200 (1.0000)
	I (2)	141.847 (0.0000) ***	178.146 (0.0000)***	− 23.8025 (0.0000)***	− 5.57105 (0.0000)***
ln(FEE/LAB)	I (0)	6.85022 (1.0000)	0.25084 (1.0000)	11.3462 (1.0000)	9.99080 (1.0000)
	I (2)	126.333 (0.0000)***	181.712 (0.0000)***	− 17.0530 (0.0000)***	− 4.28076 (0.0000)***
ln(STE/FE)	I (0)	111.101 (0.0001)***	103.975 (0.0004)***	− 15.7197 (0.0000)***	− 3.24009 (0.0000)***

The symbols *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively

Fig. 2 Time series diagram of the data
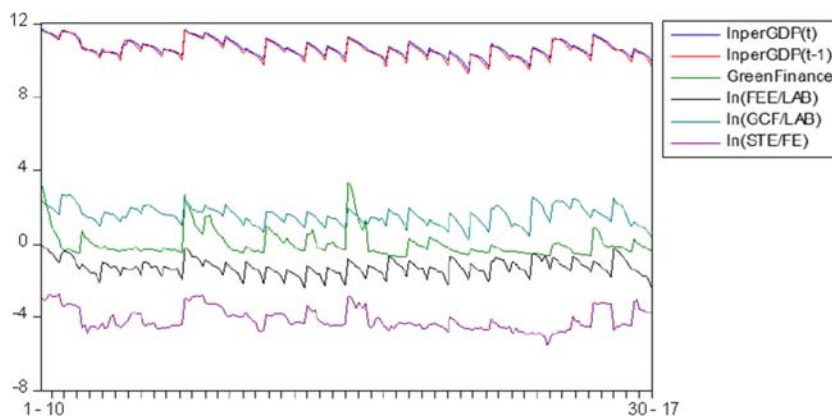
where $EI_{i,t}$ denotes the environmental indicators of province i in the tth year, comprising the industrial smoke dust emissions of province i in the tth year ($ISPDE_{i,t}$), the industrial solid waste emissions ($ISWE_{i,t}$) of province i in the tth year, and the carbon dioxide emissions ($CO_2E_{i,t}$) of province i in the tth year. $EC/POP_{i,t}$ denotes the per capita energy consumption of province i in the tth year, $SIGDP/GDP_{i,t}$ is the secondary industry's share of GDP of province i in the tth year, and $UPOP/POP_{i,t}$ denotes the proportion of the urban population to the total population of province i in the tth year, which indicates the urbanization rate of province i in the tth year. To avoid heteroscedasticity, the variables other than the core explanatory variable $GreenFinance_{i,t}$ are logarithmicized. The data sources and expected effects of variables are shown in Table 10.

Regression analysis and robustness test

First, the stationarity tests were conducted for variables. With the exceptions of $ln(EC/POP)$ and $ln(UPOP/POP)$, which belong to the first-order stationary sequence, all other variables belong to the zero-order stationary sequence. Thus, a cointegration analysis needs to be performed. The results indicate that the P values of the panel ADF and group ADF are both 0.0000. Thus, there is a long-term cointegration relationship among the variables and regression analysis. Similar to

the model of the impact of green finance on economic development, the mixed-effect model should be adopted for the GLS regression analysis. Cross-section weights were used, and the PCSE method was used to correct the results. The results of the regression analysis are shown in Table 11, wherein, models (5), (6), and (7) are GLS regressions using industrial smoke dust emissions (ISPDE), industrial solid waste emissions (ISWE), and carbon dioxide emissions (CO_2E) as explained variables, respectively.

As can be seen from Table 11, the corresponding P values for the F statistics of the three models are all zero, indicating that the fit degrees of the models are good. The core explanatory variable GreenFinance has a negative impact on ISPDE, ISWE, and CO_2E, indicating that the development of green finance slows or prevents environmental degradation, that is, it has a positive impact on environmental quality. The symbols and confidence levels of EC/POP, SIGDP/GDP, and UPOP/POP are all in line with expectations. This conclusion is consistent with the view that green finance (e.g., green credit, green investment, and green loans) can promote environmental quality in previous studies (Romano et al. 2017; Tang and Zhang 2018; Liu et al. 2019). It confirms that the development of green finance can promote environmental quality (Poberezhna 2018).

We further tested the robustness of models (5), (6), and (7). According to the EKC theory, green finance may have different impacts on environmental quality at different stages of economic development. Therefore, this paper divided the 30 provinces and municipalities into two groups: one group consisting of 15 provinces with relatively high levels of economic development, and a second group consisting of 15 provinces with relatively low economic development levels. GLS regression was carried out for each group, with the results shown in Table 12.

As can be seen from Table 12, the grouped regression results of ISPDE and CO_2E are consistent with Table 11. However, the results of ISWE differ in regions with different levels of economic development. Specifically, in regions with high levels of economic

Table 7   Results of the cointegration tests

Test method	Statistics	Statistical value (P value)
Kao test	ADF	$-8.747819(0.0000)$
Pedroni test	Panel v-statistic	$-2.866783(0.9997)$
	Panel rho-statistic	$4.977971(1.0000)$
	Panel PP-statistic	$-12.63381(0.0000)$
	Panel ADF-statistic	$-5.514402(0.0000)$
	Group rho-statistic	$7.196814(1.0000)$
	Group PP-statistic	$-22.94003(0.0000)$
	Group ADF-statistic	$-8.90919(0.0000)$

Table 8 Results of the likelihood ratio test and the Hausman test

Test summary	Effect test	Chi square statistic	Chi sq. d.f.	Prob
Likelihood ratio	Cross-section F	4.395713	29	0.0000
	Period F	12.241601	7	0.0000
Hausman test	Cross-section random	285.898720	5	0.0000
	Period random	0.000000	5	1.0000

development, the symbol of GreenFinance is negative, indicating that green finance has a negative effect on, or limits environmental degradation. However, in regions with low levels of economic development, the symbol of GreenFinance is positive, indicating that green finance has a positive effect on, or increases environmental degradation. The cause of this phenomenon can be explained by EKC theory (Nieuwerburgh et al. 2006; Bittencourt 2012; Marques et al. 2013), in regions with low levels of economic development, the turning point of the EKC for ISWE has not yet been reached, so that green finance and environmental degradation move together in the same direction. In contrast, in areas with high levels of economic development, the turning point of the EKC for ISWE has been reached, and therefore, green finance and environmental degradation move in

opposite directions. The relationship between green finance and the EKC will be studied further in the next section.

The impact of green finance on the relationship between economic development and environmental quality

Basic model

The environmental indicators, per capita GDP, the square of per capita GDP, and a number of control variables are selected to construct a model to fit the EKC in China, as shown in Eq. (18). The control variables include per capita energy consumption (EC/POP), the share of secondary industry in GDP (SIGDP/GDP),

Table 9 GLS regression results for the model of green finance and economic development

Variables	(1) Nationwide	(2) Eastern China	(3) Central China	(4) Western China
GreenFinance	0.013966 (3.063344)***	0.013658 (2.990476)***	0.044684 (1.631158)*	0.082922 (3.319922)***
lnperGDP$_{i,t-1}$	0.839096 (59.93206)***	0.773451 (28.63742)***	0.780223 (14.71232)***	0.780691 (24.32171)***
ln(GCF/LAB)	0.071270 (5.309006)***	0.133089 (6.107662)***	0.061222 (2.362455)**	0.107025 (5.212272)***
ln(FEE/LAB)	−0.044952 (−6.098148)***	−0.039022 (−3.354385)***	−0.034963 (−1.545731)*	−0.065992 (−3.832531)***
ln(STE/FE)	0.059878 (9.042359)***	0.079531 (8.276252)***	0.006212 (0.512003)	0.001556 (0.088650)
constant	1.887441 (12.55843)***	2.588441 (8.746348)***	2.295034 (4.042076)***	2.168534 (6.303988)***
R-squared	0.994893	0.994902	0.986484	0.986243
Adjusted R-squared	0.994784	0.994591	0.985319	0.985404
SE of regression	0.045792	0.035949	0.037880	0.045988
F statistic	9116.615	3200.299	846.6673	1175.679
Prob (F statistic)	0.000000	0.000000	0.000000	0.000000
Mean dependent var	13.66326	14.12780	12.91446	11.30889
SD dependent var	6.767946	5.202190	4.603509	2.595100
Sum squared resid	0.490683	0.105971	0.083222	0.173423
Durbin-Watson stat	0.926686	1.149909	1.231101	0.871116

The symbols *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively

Table 10 Interpretation of variables in the model of green finance and environmental quality

Variables	Variables description	Source	Expected effect
$ISPDE_{i,t}$	Industrial smoke (powder) dust emissions	China Environmental Statistics Yearbook	
$ISWE_{i,t}$	Industrial solid waste emissions	China Environmental Statistics Yearbook	
$CO_2E_{i,t}$	Carbon dioxide emissions	China Energy Statistics Yearbook	
$EC/POP_{i,t}$	Per capita energy consumption	China Energy Statistics Yearbook	The expected sign is positive. Per capita energy consumption is an important indicator of overall energy consumption, and it can reflect the emissions of various wastes and pollutants. The greater the per capita energy consumption, the higher the emissions of wastes and pollutants, thus exacerbating environmental degradation.
$SIGDP/GDP_{i,t}$	The proportion of the gross domestic product of the secondary industry to GDP	Wind	The expected sign is positive. Gross domestic product of secondary industry to GDP is an important indicator of the development of the secondary industry. Among the three types of industries, the secondary industry has the greatest impact on environmental degradation. Therefore, the greater gross domestic product of secondary industry to GDP, the higher the degree of environmental degradation.
$UPOP/POP_{i,t}$	The urbanization rate	Wind	The expected sign is negative. In the later stages of urbanization, a high concentration of population will result in a decline in per capita energy consumption. At the same time, due to the high population density in China, the increase in urbanization rate will result in a significant drop in per capita energy consumption. Therefore, the urbanization rate and environmental deterioration have a reverse change relationship, that is, the higher the urbanization rate, the lower the degree of environmental degradation.

and the urbanization rate (UPOP/POP). The resulting model is as follows:

$$lnEI_{i,t} = \beta_0 + \beta_1 perGDP_{i,t} + \beta_2 perGDP^2_{i,t} + \beta_3 Control_{i,t}. \quad (18)$$

The existence of the EKC in China

Similar to the model of the impact of green finance on economic development, the mixed-effect model was adopted for the GLS regression analysis. Cross-section weights were used, and the PCSE method was adopted to correct the results. The results of the EKC fitting are shown in Table 13, wherein models (14) and (15) were fitted by GLS using ISPDE as

the explained variable, models (16) and (17) using ISWE, and models (18) and (19) using CO_2E.

As can be seen from Table 13, for ISPDE, ISWE, and CO_2E, the symbol of $perGDP^2$ is negative, which indicates the existence of inverted U-shaped curves for the ISPDE-EKC, the ISWE-EKC, and the CO_2E-EKC. The turning point of the ISPDE-EKC is \$12,930, which indicates that in regions where per capita GDP is less (more) than this level, industrial smoke dust emissions increase (decrease) with economic development. The turning point of the ISWE-EKC is \$10,832, which indicates that in regions where per capita GDP is less (more) than this level, industrial solid waste emissions increase (decrease) with economic development. Finally, the turning point of CO_2E-EKC is \$5571, which indicates that in regions where per

Table 11 GLS regression results for the model of green finance and environmental quality

Variables	(5) ISPDE	(6) ISWE	(7) CO$_2$E
GreenFinance	− 0.062948	− 0.084070	− 0.174894
	(− 3.059770)***	(− 2.271265)**	(− 11.98997)***
ln(EC/POP)	1.068252	1.377371	1.291939
	(25.90727)***	(17.08783)***	(32.93314)***
ln(SIGDP/GDP)	0.452738	0.574471	0.215188
	(5.628728)***	(5.547149)***	(5.265567)***
ln(UPOP/POP)	− 0.665308	− 1.958662	− 0.372138
	(− 8.535539)***	(− 12.85388)***	(− 5.200363)***
Constant	1.153582	4.647603	− 0.026398
	(2.599395)***	(6.143220)***	(− 0.085815)
R-squared	0.771261	0.712084	0.882538
Adjusted R-squared	0.767367	0.707184	0.880539
SE of regression	0.797923	0.471793	0.364379
F statistic	198.0925	145.3028	441.4137
Prob (F statistic)	0.000000	0.000000	0.000000
Mean dependent var	5.650197	0.840258	1.449397
SD dependent var	4.090072	1.022341	0.683286
Sum squared resid	149.6201	52.30830	31.20145
Durbin-Watson stat	0.820016	0.328216	0.051873

The symbols *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively

capita GDP is less (more) than this level, carbon dioxide emissions increase (decrease) with economic development.

Figures 3, 4, and 5 illustrate models (15), (17), and (19), respectively. The points marked in the figures are the

Table 12 Robustness test results for the model of green finance and environmental quality

	ISPDE		ISWE		CO$_2$E	
	(8) Low	(9) High	(10) Low	(11) High	(12) Low	(13) High
GreenFinance	− 0.698276	− 0.086421	0.300632	− 0.195629	− 0.399778	− 0.251187
	(− 3.109621)***	(− 3.490270)***	(2.134249)***	(− 4.446681)***	(− 15.25867)***	(− 16.12024)***
ln(EC/POP)	0.900102	1.021359	0.426370	1.785156	1.063304	0.757990
	(12.02817)***	(18.68304)***	(5.134546)***	(22.21319)***	(28.7793)***	(34.60117)***
ln(SIGDP/GDP)	0.559155	0.671454	0.240667	0.043217	0.290689	0.201797
	(3.112836)***	(4.632256)***	(3.336154)***	(0.220740)	(12.61313)***	(3.916440)***
ln(UPOP/POP)	− 0.709491	− 0.364302	− 1.358018	− 2.375610	− 0.009947	− 0.124647
	(− 5.171587)***	(− 2.871389)***	(− 11.47138)***	(− 9.855457)***	(− 0.463154)	(− 1.672822)*
Constant	0.819896	− 0.814291	4.721373	7.971002	− 1.668815	− 0.190036
	(1.141597)	(− 0.889247)	(8.921015)***	(5.458838)***	(− 15.32353)***	(− 0.431807)
R-squared	0.635778	0.796411	0.524501	0.817946	0.893373	0.970300
Adjusted R-squared	0.619768	0.790195	0.503600	0.812387	0.893082	0.969393
SE of regression	0.754445	0.729489	0.351537	0.433562	0.037618	0.355912
F statistic	39.71185	128.1133	25.09452	147.1415	520.2270	1069.948
Prob (F statistic)	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Mean dependent var	4.293614	5.818901	1.215549	0.773061	0.808953	3.229758
SD dependent var	2.457782	4.248640	0.886634	1.195670	0.513541	6.556908
Sum squared resid	51.79609	69.71226	11.24559	24.62480	0.128772	16.59424
Durbin-Watson stat	0.926144	0.810188	0.544210	0.453386	0.317812	0.206949

The symbols *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively

Table 13 Results of the EKC fitting

	ISPDE		ISWE		CO$_2$E	
	(14)	(15)	(16)	(17)	(18)	(19)
perGDP	0.114983 (3.335821)***	0.034696 (1.199270)	0.115411 (3.086677)***	0.231564 (4.034594)***	0.118215 (5.398449)***	0.054534 (4.760159)***
perGDP^2	−0.007680 (−2.532931)**	−0.001903 (−0.797686)*	−0.008012 (−3.642781)***	−0.015161 (−4.747939)***	−0.008436 (−4.380416)***	−0.006942 (−7.425751)***
ln(EC/POP)		1.113882 (27.17865)***		0.351138 (2.177109)**		1.036355 (68.83352)***
ln(SIGDP/GDP)		0.471797 (5.395313)***		0.360713 (2.275955)**		−0.030818 (−0.958314)*
ln(UPOP/POP)		−0.962196 (−10.33164)***		0.803982 (1.962600)*		−0.075347 (−1.991720)*
Constant	1.093669 (11.98866)***	2.081243 (3.887992)***	0.335404 (2.631472)***	−5.028888 (−2.639829)***	0.373654 (6.941601)***	−0.127341 (−0.636155)***
R-squared	0.088687	0.789858	0.968876	0.967544	0.433109	0.960779
Adjusted R-squared	0.080997	0.785368	0.964238	0.962161	0.425793	0.959941
SE of regression	0.974579	0.787665	0.161751	0.166872	0.415550	0.150517
F statistic	11.53219	175.9064	208.8706	179.7433	18.19533	182.450
Prob (F statistic)	0.000017	0.000000	0.000000	0.000000	0.000000	0.000000
Mean dependent var	5.020557	5.344466	0.663704	0.663704	1.277450	1.176205
SD dependent var	4.516213	4.029331	0.855330	0.857857	0.961332	0.826829
Sum squared resid	225.1035	145.1774	5.441989	5.708486	40.92561	5.301364
Durbin-Watson stat	0.568770	0.790684	1.510770	1.553442	0.120669	0.608219
Turning point RMB		91,161		76,368		39,278
Dollar		12,930		10,832		5571
Shape of EKC		inverted U		inverted U		inverted U

The symbols *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively

environmental indicators and the per capita GDP of the provinces and municipalities in 2017. The provinces or municipalities located on the right-hand side of the turning point (e.g., Beijing, Shanghai, Tianjin, and Zhejiang) have achieved a synchronization between economic development and environmental improvement, such that economic development will promote environmental improvement. In contrast, the provinces or municipalities located on the left-hand side of the turning point have not achieved this synchronization, and economic development will aggravate environmental degradation.

Models (14), (16), and (18) were used for robustness tests of models (15), (17), and (19), respectively. After adding the control variables, the R-squared and adjusted R-squared of models (15) and (19) increased, indicating that the fitness of the models was improved. The symbols of all variables are unchanged, and coefficients of all variables are only slightly changed, indicating that the models are robust.

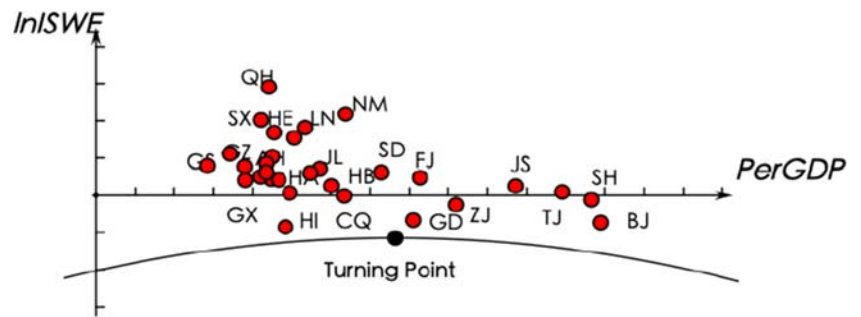### The impact of green finance on the shape of EKC

To examine the impact of green finance on the relationship between economic development and environmental quality (the shape of the EKC), we divided the 30 provinces into two groups of 15, depending on whether their levels of green financial development were high or low. The EKCs were

Fig. 3 The EKC for lnISPDE and perGDP
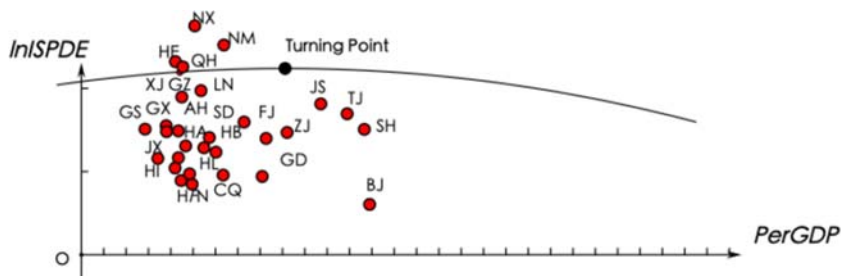
Fig. 4 The EKC for *ln*ISWE and perGDP

fitted for ISPDE, ISWE, and CO$_2$E, with the results shown in Table 14.

To clearly show the impact of green finance on the shape of the EKC, we illustrated the results of Table 14 in Fig. 6, using red (green) lines to represent the EKCs for the 15 provinces with low (high) levels of green financial development. Figure 6 a, b, and c show the effect of green finance on the shapes of the ISPDE-EKC, the ISWE-EKC, and the CO$_2$E-EKC, respectively.

As Fig. 6 shows, the EKC in regions with higher levels of green finance development is located below the EKC in regions with low levels of green finance development. This indicates that, for the same level of economic development, the degree of environmental quality in regions with higher levels of green finance development is better than in regions with low levels of green finance development. Specifically, on the left-hand side of the EKC's turning point, when economic development and environmental improvement are not synchronized, the development of green finance decreases the environmental cost of economic development. In contrast, on the right-hand side of the turning point, when economic development and environmental improvement are synchronized, the development of green finance assists in improving the environment. Furthermore, the development of green finance shifts the turning point of the EKC to the left, indicating that the development of green finance can achieve the synchronization of economic development and environmental improvement at a lower level of economic development. Through empirical research, this study not only confirms the existence of EKC curve in China (Jalil and Mahmud 2009; Riti et al. 2017),

but also explores the impact of green finance on the shape and turning point position of EKC curve in China from a new perspective.

Conclusions and recommendations

This paper has used data on green finance, economic development, and environmental quality for 30 provinces and municipalities in China from 2010 to 2017. We selected six indicators regarding green credit, green securities, green investment, and carbon finance to measure the level of development of green finance. The GPCA method was used to construct a comprehensive green finance development index. We established a model of the impact of green finance on economic development, and performed a GLS regression analysis for the 30 provinces as a whole and for various subregions.

To describe the environmental impact in a more comprehensive and detailed way, we used three environmental indicators, namely, industrial smoke dust emissions, industrial solid waste emissions, and carbon dioxide emissions. A model of the impact of green finance on environmental quality was proposed and we tested its robustness using a grouped GLS regression, with the selection of groups depending on the level of economic development.

Using the environmental indicators, the per capita GDP, the square of per capita GDP, and a number of control variables, a model was constructed to fit the EKC in China. To study the impact of green finance on the relationship between economic development and environmental quality, the grouped GLS

Fig. 5 The EKC for *ln*CO$_2$E and perGDP
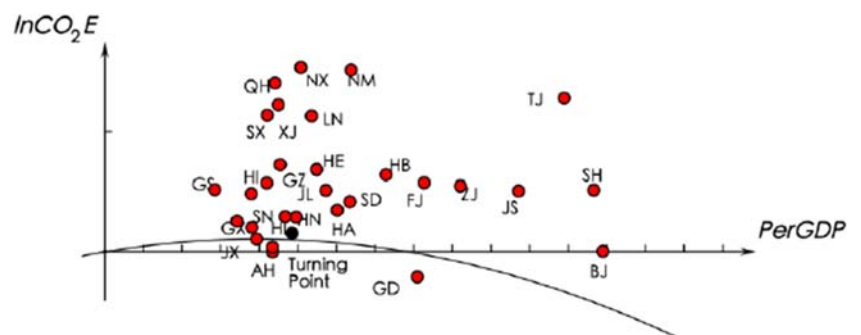
Table 14   Results of the impact of green finance on the shape of the EKCs

	ISPDE		ISWE		CO$_2$E	
	(20) Low	(21) High	(22) Low	(23) High	(24) Low	(25) High
perGDP	0.107761	0.190679	0.099860	− 0.076529	0.053019	− 0.048830
	(3.270848)***	(4.290058)***	(2.021216)**	(− 1.978708)*	(4.505067)***	(− 1.266742)*
perGDP^2	− 0.008153	− 0.016173	− 0.006722	− 0.007322	− 0.002279	− 0.005653
	(− 3.967443)***	(− 2.474597)**	(− 2.624826)***	(− 2.551743)**	(− 1.961083)*	(− 4.410983)***
ln(EC/POP)	0.916892	− 0.191727	− 0.023170	0.965419	0.993305	1.112396
	(21.45361)***	(− 3.084637)***	(− 5.136098)***	(13.48099)***	(70.76515) ***	(28.59361)***
ln(SIGDP/GDP)	0.302899	6.140694	0.011520	2.126009	0.019481	− 0.067064
	(2.537694)**	(2.092024)**	(2.052223)**	(18.01834)***	(1.655359)*	(− 1.915749)***
ln(UPOP/POP)	− 0.655930	4.536988	0.215631	− 0.595418	− 0.209634	0.209825
	(− 5.052675)***	(0.956273)	(1.604735)**	(− 4.270661)***	(− 6.088616)***	(2.246614)***
Constant	1.658474	− 40.81905	− 0.817823	− 5.565353	0.212798	− 0.984206
	(2.251993)**	(− 1.692451) **	(− 1.451182)*	(− 7.669525)***	(1.103727)	(− 1.629407)*
R-squared	0.814908	0.509034	0.985860	0.859005	0.881174	0.940617
Adjusted R-squared	0.806790	0.577751	0.983174	0.852821	0.880348	0.938012
SE of regression	0.271794	1.168004	0.097700	0.437013	0.097939	0.139446
F statistic	100.3820	2.353946	366.9636	138.9079	188.302	361.1457
Prob (F statistic)	0.000000	0.003311	0.000000	0.000000	0.000000	0.000000
Mean dependent var	2.307489	1.269366	0.383654	1.007539	1.113950	0.957499
SD dependent var	1.389780	1.288079	0.753184	1.038892	0.709688	0.799707
Sum squared resid	8.421384	136.4233	0.954527	21.77172	1.093483	2.216745
Durbin-Watson stat	0.815084	2.803852	1.541165	0.577050	0.732029	0.873616

The symbols *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively

regression was conducted according to the level of green finance development.

Based on the empirical research conducted, our main conclusions are as follows.

1. Green finance has a positive impact on economic development in China as a whole, and in the region of eastern, central, and western China.

2. At the nationwide level, green finance has a positive impact on environmental quality, that is, it reduces or limits environmental degradation. However, under different economic development levels, the impact of green finance on environmental indicators is heterogeneous, as shown particularly by the ISWE indicator.

3. The degree of environmental quality in regions with higher levels of green finance development is better than in regions with low levels of green finance development
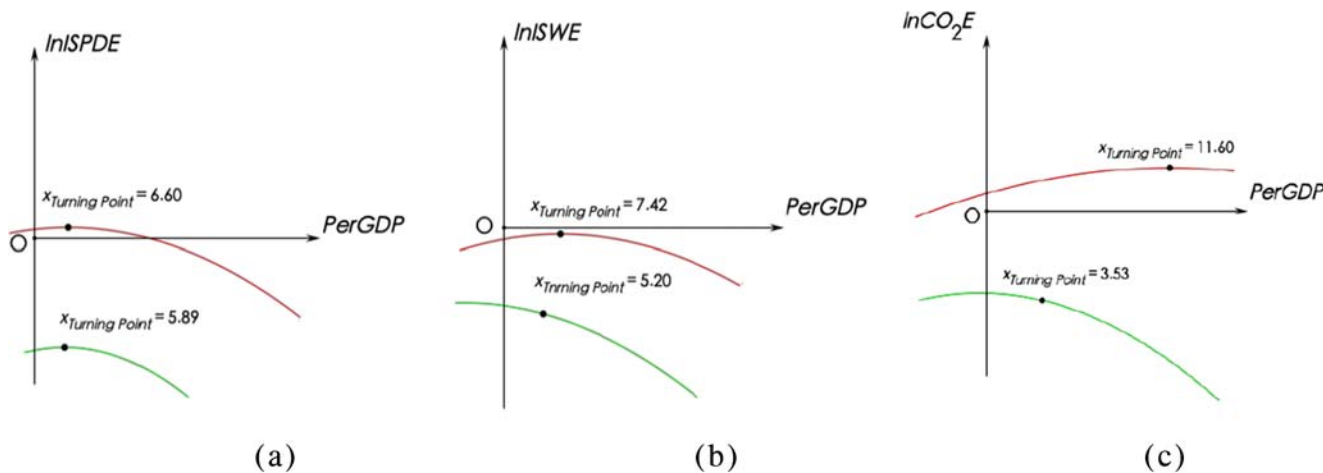
Fig. 6 The impact of green finance on the EKCs

for the same level of economic development. Furthermore, the development of green finance shifts the EKC turning point to the left, indicating that the development of green finance can achieve the synchronization of economic development and environmental improvement at a lower level of economic development.

Based on the above findings, we recommend the following policies to promote the development of green finance.

1. The government should use fiscal policies to promote the development of green finance, and use fiscal funding to guide credit funds and social capital into green investment, green credit, and green securities.

2. The government should improve the green financial system and give priority to green activities in the approvals processes, and simplify the green, ecological, and low-carbon industries application process.

3. The government should provide policy support for green financial development in underdeveloped regions, lower the issuance and trading thresholds for green bonds and green securities, and give priority to initial public offerings of green concept companies, such as new energy.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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