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Regional-Level Carbon Emissions Modelling and Scenario Analysis: A STIRPAT Case Study in Henan Province, China

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Abstract: Global warming has brought increased attention to the relationship between carbon emissions and economic development. Research on the driving factors of carbon emissions from energy consumption can provide a scientific basis for regional energy savings, as well as emissions reduction and sustainable development. Henan Province is a major agricultural province in China, and it is one of most populous provinces. Industrial development and population growth are the causes of carbon emissions. The STIRPAT model was conducted for analyzing carbon emissions and the driving factors for future carbon emission in Henan Province. The results show that: carbon emissions and energy consumption in Henan Province presented a rising trend from 1995 to 2014; Energy consumption due to population growth is the main contributor to carbon emissions in Henan Province. As every 1% increase in the population, GDP per-capita, energy intensity, and the level of urbanization development will contribute to the growth of emissions by 1.099, 0.193, 0.043, and 0.542%, respectively. The optimization of the industrial structure can reduce carbon emissions in Henan Province, as suggested by the results, when the tertiary sector increased by more than 1%, the total energy consumption of carbon emissions reduced by 1.297%. The future pattern of carbon emissions in Henan Province is predicted to increase initially and then follows by a decreasing trend, according to scenario analysis; and maintaining a low population growth rate, and a high growth rate of GDP per-capita and technical level is the best mode for social and economic development.

Keywords: carbon emissions; energy consumption; STIRPAT model; driving factors; scenario predictions

1. Introduction

Global warming has become an irrefutable issue that needs to be recognized and urgently addressed by all mankind [1–5], to keep the increase in the average global temperature well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels [6,7]. Carbon dioxide emissions due to human activities contribute about 80% to the greenhouse effect [8]. With rapid economic and population growth, human activities increasingly rely on energy consumption [9–12]. In particular, excessive fossil fuel consumption produces massive emissions of carbon dioxide and the subsequent greenhouse effect [13–15]. In this context, a consensus has been reached among the international community to develop a low-carbon economy and technologies, and actively acknowledge and address climate change [16,17]. Fundamentally, reducing greenhouse gas emissions is an economic issue [18,19]; to attain sustainable and harmonious development of ecology, economy, and human society, it is necessary to correctly understand the relationship between economic development, energy consumption, and carbon emissions [20–24].

Researching the driving factors of carbon emissions will provide a scientific reference for attaining low-carbon development and taking appropriate measures on supply-side reform [25–28]. Greenhouse gas emissions produced by human activities are primarily driven by factors such as population, affluence, and technological advances [29–32]. Currently, many different methods have been used to examine the impact factors of CO_2 emissions. Among them, the logarithmic mean Divisia index (LMDI) and stochastic impact by regression on population, affluence, and technology (STIRPAT) models are the two most well-known methods for examining such factors [33]. The LMDI model can only provide limited useful information for shaping CO_2 emissions reduction strategies [34–36]. The STIRPAT model, an extension of IPAT, can examine many more impact factors than the LMDI model, and it became the mainstream method for uncovering the driving factors of energy consumption or carbon emissions over the world [37–41].

Some researchers have studied the factors influencing China's carbon emissions [24,42–45]. Their results reveal that economic development contributes significantly to China's carbon emissions in the short term, while population growth is the most significant contributor in the long term. Additionally, researchers have found that China's carbon emissions were influenced most significantly by population and industrial structure, compared with energy prices, and foreign trade intensity [46]. Related research at the Chinese provincial level has shown that the factors influencing carbon emissions vary somewhat from province to province; population, investment in fixed assets, GDP per-capita, heavy industry (secondary sector), the working-age population, and the urbanization rate are the most significant influences on carbon emissions within the Chinese provinces [35,47–52]. Evidently, spatial heterogeneity and regional differences both influence carbon emissions [53,54]. In summary, China at the national scale and provinces at the reginal scale are both inevitably facing a serious dilemma: if carbon emissions were reduced, economic development and GDP would slow down consequently [13,55].

China covers a vast territory, and socio-economic development varies from region to region [56]. If a same model is applied to different study areas, it is necessary to fully consider their social conditions and economic development characteristics. Henan Province, as a major agricultural province, has the largest population and the increasing GDP. In recent years, grain production has enabled rapid social and economic development with convenient transportation. Henan has become an attractive hut for economic activities and subsequently has been faced with continuous population growth, while striving to maintain its status as a large agricultural province. In this context, its primary concern is to optimize its industrial structure, and thus to improve economic and environmental benefits.

This study quantitatively evaluates carbon emissions from energy consumption in Henan Province, fully accounting for its status as a large agricultural province and its transformation in industrial structure. By introducing the industrial structure to the STIRPAT model, this study predicts future trends in carbon emissions. Based on the simulation results and predication model, carbon emissions in Henan Province are estimated under different development patterns, represented using a combination of factors such as population, economic level, technological advances, and industrial structure. Based on a comparison of development scenarios, this study proposes an optimal low-carbon development pattern suited to the province, thus providing a scientific basis for building a less developed area into a low-carbon society. Henan is in a period of rapid development due to its large population and extensive energy consumption. This paper can be a reference to other areas—such as Africa, Southeast Asia, Eastern Europe and South America—which also are facing the same dilemma.

2. Data Sources and Methodology

2.1. Study Area

Henan Province is located in mid-east mainland China, and includes the middle and lower reaches of the Yellow River. Most of its area is situated in plains (Figure 1). In 2015, its annual GDP was 3701 billion yuan, a year-to-year increase of 8.3%. The ratio of value added to the primary, secondary, and tertiary sectors was 11.4:49.1:39.5 in 2015. By the end of 2015, the total population of Henan Province was 107.22 million people, about three times of Canada. Total energy consumption was 23.2 billion tons, and energy consumption per 10,000 yuan of GDP was 0.63 tons, an annual decrease of 4.76%. In recent years, Henan Province has embraced rapid socio-economic development and a continued increase in urbanization, accompanied by an expansion in energy consumption. Meanwhile, carbon emissions have continued to increase for various reasons, including enormous population, imbalanced economic development, unreasonable industrial structure, low technological level, and a coal-dominated energy consumption structure.

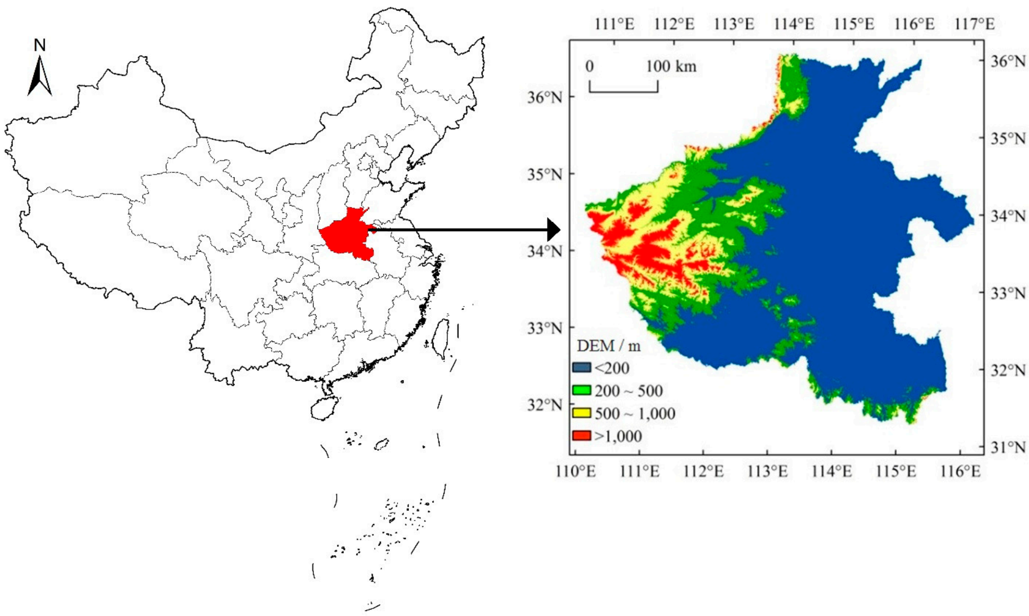

Figure 1. Study area.

2.2. Methodology

2.2.1. Carbon Emissions Estimation from Energy Consumption

Carbon emissions in Henan Province were calculated using data and methodology recommended by the IPCC (2006) [57]. The three major energy sources in Henan Province are coal, fossil oil, and natural gas, accounting for 76%, 13% and 5% of total energy consumption in 2015, respectively. Therefore, this study selected three energy sources to calculate carbon emissions from energy consumption. The calculation equations are [57–59]

$$C = \sum_{i=1}^{3} C_i = \sum_{i=1}^{3} S_i N_i = \sum_{i=1}^{3} S_i V_i N \quad (1)$$

where C indicates total carbon emissions from energy consumption, C_i represents carbon emissions from each i type of energy, S_i is the carbon emission coefficient for each i type of energy, N_i is the consumption of each i type of energy, N_i is the proportion of consumption for each i type of energy in the total energy consumption, and N is the total energy consumption. In this paper, the primary energy carbon emission coefficients used are those recommended by the Energy Research Institute of Chinese National Development and Reform Commission. The coefficients for coal, fossil oil, natural gas, and non-fossil energy are 0.5394, 0.8359, 0.5956, and 0, respectively (ton C/ton TJ).

2.2.2. STIRPAT Model

Ehrlich and Holdren established the IPAT model, and applied this model to the evaluation of environmental stress [60,61]. This model is formulated as

$$I = PAT \tag{2}$$

where I indicates environmental stress. In a traditional environmental stress model, population, economic development, and technological advances are considered the major driving factors in environmental stress, which are respectively expressed as P, A, and T. In the evaluation process, the employed coefficient is singular and fixed; its fixed substitution value can only be used to calculate the emissions of solid carbon. Therefore, this model has low precision and many limitations. Subsequently, Dietz and Rosa [62] and York et al. [33,63] proposed the STIRPAT model by extending the IPAT equation. The STIRPAT model expresses the IPAT model in stochastic rather than fixed form, specifically

$$I = \mathrm{a}P^b A^c T^d \tag{3}$$

where I indicates the environmental impact, which is denoted using the carbon emissions from energy consumption in the present research; P represents the regional population; A represents the regional GDP per-capita (affluence); T indicates the regional technological level; a is the model coefficient; b, c, and d are three exponents that need to be estimated; and e indicates the error term [51]. Applying the natural logarithm to both sides of Equation (3) results in

$$\ln\ I = \ln\ a + b\ \ln\ P + c\ \ln\ A + d\ \ln\ T + \ln\ e \tag{4}$$

As previously mentioned, Henan Province is a large agricultural province in China. While maintaining the fundamental position of its agriculture, adjusting and optimizing the industrial structure is important for the coordinated development of the social economy. Therefore, this paper introduces a few industrial structure indices to improve the model

$$\ln I = \ln a + \beta_1 \ln P + \beta_2 \ln A + \beta_3 \ln T + \beta_4 \ln U + \beta_5 \ln S + \ln e \tag{5}$$

where I indicates carbon emissions (unit: 10,000 tons) in Henan from energy consumption; P is population (unit: 10,000); A represents affluence, which is denoted by GDP per-capita (unit: yuan per capita); T is the energy consumption intensity per unit GDP (unit: ton of standard coal per 10,000 yuan); U is the percentage of urbanization; S is the proportion of tertiary sector; β_1, β_2, β_3, β_4, and β_5 are elasticity coefficients, respectively indicating the changes in β_1%, β_2%, β_3%, β_4%, and β_5% every time P, A, T, U, and S are changed by 1%.

2.2.3. Environmental Kuznets Curve (EKC)

To further study the relationship between economic development and environmental protection, this study introduces the Environmental Kuznets Curve (EKC) [64]. Specifically, the intent is to determine whether the relationship between economic growth and carbon emissions can be represented using the EKC. The EKC is shaped as an inverted U: with economic growth, carbon emissions go up at first and then go down. To study the foresaid relationship between Henan carbon emissions from energy consumption and its economic development, Equation (3) is adjusted as

$$\ln I = \ln a + \beta_1 \ln P + \beta_{21} \ln A + \beta_{22} \ln(\ln A)^2 + \beta_3 \ln T + \beta_4 \ln U + \beta_5 \ln S + \ln \varepsilon \quad (6)$$

where β_{21} is the coefficient of the GDP per-capita logarithm and β_{22} is the coefficient of the quadratic term of the GDP per-capita logarithm.

Equation (6) can be simplified as

$$\ln I = \beta_{21} \ln A + \beta_{22}(\ln A)^2 \quad (7)$$

This formula conforms to the quadratic function relationship. When β_{22} is negative, the opening is oriented downwards, thus obtaining the elasticity coefficient (EE_{IA}) of the GDP per-capita with respect to the carbon emissions from energy consumption

$$EE_{IA} = \beta_{21} + 2\beta_{22} \ln A \quad (8)$$

For negative β_{22} values, the relationship between GDP per-capita and carbon emissions can be represented with an inverted U-shape curve.

2.2.4. Ridge Regression

The danger of multicollinearity is primarily its generation of large standard errors among related independent variables; these errors are characterized by large variances in the regression model parameters, making the regression model unstable. These standard errors can be significantly reduced using a curtain method. Thus, the negative consequences of such errors can be effectively eliminated, accordingly, even when multicollinearity remains in the regression model. Ridge regression, which can obtain acceptably biased estimates with smaller mean square errors in independent variables through bias–variance tradeoffs, is one of the most effective solutions for dealing with multicollinearity [65].

2.3. Data Sources

In order to dynamically measure and analyze Henan Province carbon emissions from energy consumption, this study selected related socio-economic data for Henan Province from 1995 to 2014, including energy consumption, population, urban population, GDP, and output from tertiary industries, which are respectively available from the *China Energy Statistical Yearbook* (1996–2015) and *Statistical Yearbook of Henan Province* (1996–2015).

Coal is the main fuel for Henan, accounting for a larger amount of carbon dioxide emissions. The carbon emissions of coal continued to rise, reaching the maximum in 2011, 283.74 Mt, and then began to decrease. The proportions of other energy types—oil and gas—according to Table 1, have gradually increased in recent years, even though they are not in a large proportion in total energy consumption.

From the perspective of population, Henan has a growing population, which broke through 100 million people in 2010. The growth rate of urban population was fast. From 1995 to 2014, the urban population increased by 27 million annually. The increase in population, especially in urban areas, lead to increasing energy consumption and carbon dioxide emissions.

From an economic perspective, the development of the economy associates with carbon dioxide emissions to some extent. The total amount of GDP in Henan province increased rapidly during 1995–2014. The change from 300.27 billion yuan in 1995 to 3493.82 billion yuan in 2014. The contribution of the third industry increased significantly, which increased from 81.95 billion yuan in 1995 to 1296.17 billion yuan in 2014.

Table 1. Descriptive statistics of the data.

Years	Energy Consumption			Population		Economy	
	Coal (Million Tons)	Oil (Million Tons)	Gas (Million Tons)	Total Population (Million)	Urban Population (Million)	GDP (Billion Yuan)	Output of Tertiary Industries (Billion Yuan)
1995	79.60	4.02	0.07	91.00	15.64	300.27	81.95
1996	82.05	3.98	0.06	91.72	16.87	363.47	100.46
1997	79.75	4.48	0.07	92.43	18.11	404.11	115.07
1998	80.63	4.87	0.07	93.15	19.37	430.82	127.25
1999	82.99	5.61	0.08	93.87	20.64	451.79	138.21
2000	87.24	6.10	0.08	94.88	22.01	505.30	156.23
2001	93.25	5.98	0.09	95.55	23.34	553.30	174.67
2002	103.33	6.01	0.10	96.13	24.80	603.55	192.93
2003	114.19	6.37	0.12	96.67	26.30	686.77	225.70
2004	149.38	7.05	0.15	97.17	28.09	855.38	265.23
2005	184.68	6.69	0.17	97.68	28.75	1058.74	325.83
2006	210.03	6.97	0.22	98.20	30.50	1236.28	383.80
2007	231.71	7.14	0.24	98.69	32.14	1501.28	469.16
2008	238.68	7.04	0.27	99.18	33.97	1801.85	534.57
2009	244.45	7.86	0.30	99.67	35.77	1948.05	604.58
2010	260.50	8.35	0.34	104.37	36.21	2309.24	707.71
2011	283.74	8.75	0.39	104.89	38.09	2693.10	865.35
2012	252.40	10.10	0.53	105.43	39.91	2959.93	1000.85
2013	250.58	19.52	0.57	106.01	41.23	3219.13	1147.57
2014	242.50	19.78	0.55	106.62	42.65	3493.82	1296.17

3. Results and Discussion

3.1. Carbon Emissions and Related Driving Factors

The energy consumption structure of Henan Province from 1995 to 2014 is showed in Figure 2. Total energy, fossil oil, and natural gas consumption have continued to increase annually, while coal consumption has shown a decreasing trend. This type of consumption accounted for less than 77% in 2013 and 2014, despite it being at least 80% in other years. However, when compared to other energy sources, coal consumption accounts for a far larger proportion of the total energy being consumed; moreover, these percentages are far higher than the Chinese average, which happens to be 64%.

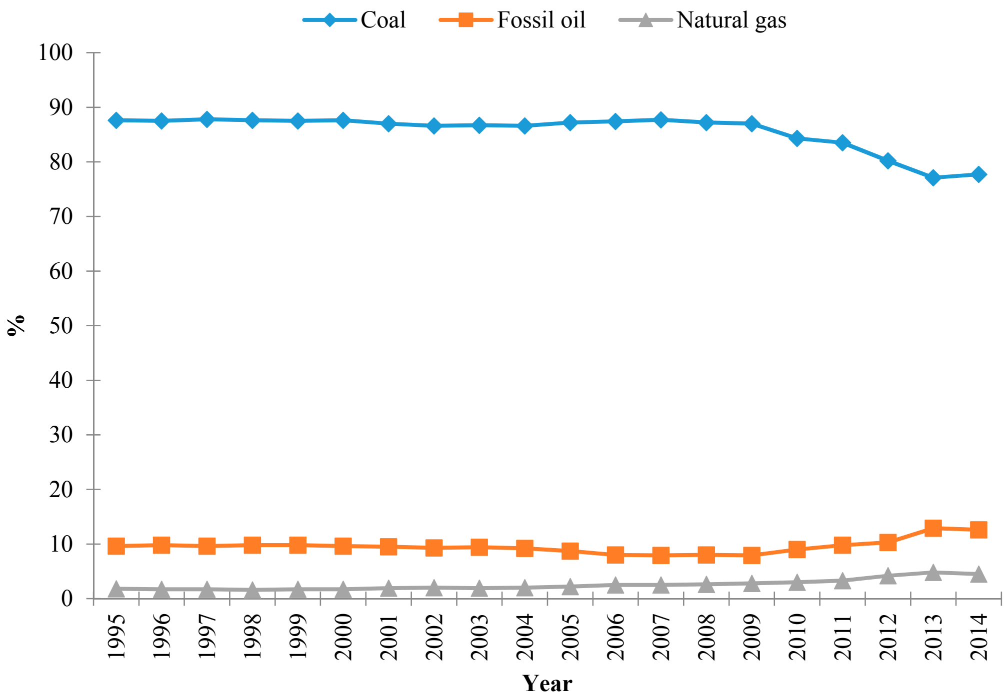

Figure 2. Energy structures in Henan Province from 1995 to 2014.

Figure 3 shows the changes in Henan Province energy consumption and its influencing factors. Overall, the trend in carbon emissions from energy consumption can be divided into two stages:

slow growth from 1995 to 2003, and rapid growth from 2004 to 2014. From 1995 to 2003, there was a slow increasing trend in carbon emissions from energy consumption due to population size, GDP per-capita, urbanization rate, and proportion of tertiary sector. During this same time, a decreasing trend in energy consumption intensity was observed. From 2004 to 2014, there was a large fluctuation in the driving factors in carbon emissions from energy consumption. Aside from the continued decline in energy consumption intensity during this time, there was a relatively rapid increase in carbon emissions, population size, GDP per-capita, urbanization rate, and proportion of tertiary sector. In 2004, the Strategy for Central China's Rising was proposed and implemented, which boosted the socio-economic development of Henan Province. Specifically, the GDP per-capita grown from 8802 yuan (2004) to 37,027 yuan (2014), with corresponding growth of carbon emissions from energy consumption. In 2014, Henan Province's carbon emissions from energy consumption reached 182.7 million tons, an increase of 60% over 2004. In addition, the urbanization rate increased from 28.91% (2004) to 45.19% (2014), and the proportion of tertiary sector increased from 31% (2004) to 37% (2014). While population growth has been very slow, the population base remains large. In 2014, the permanent resident population was as large as 94.4 million. The enormous population has been an important driving factor in the increase of carbon emissions. We also found that the trends of energy carbon emission and influencing factors of Henan Province are very similar with China, however, quite different from the world at large (Figure 3). Because Henna Province is a typical example of central and western China with coal-based energy structure and agricultural population.

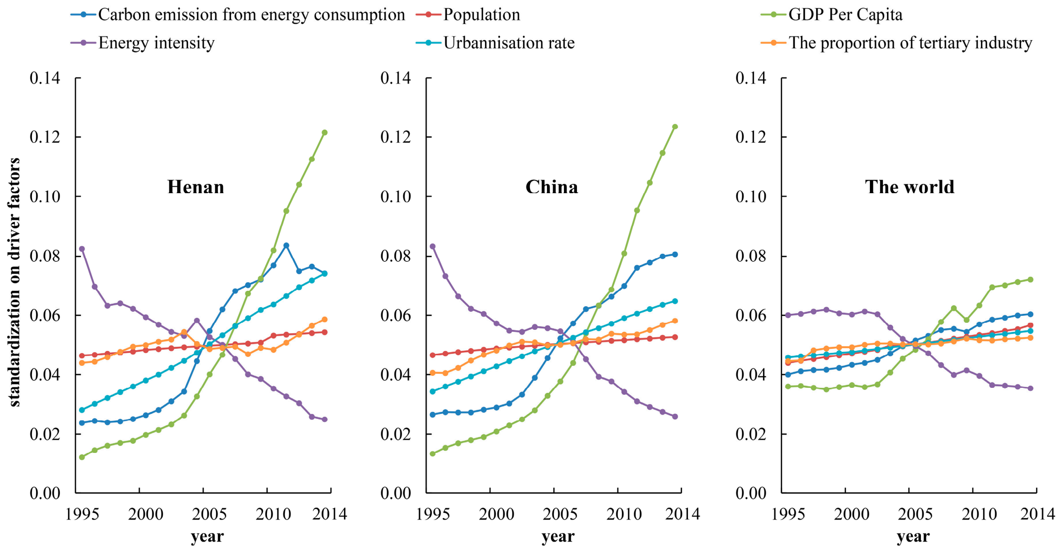

Figure 3. Comparison of energy carbon emission and influencing factors among Henan Province, China and the world from 1995 to 2014.

3.2. STIRPAT-Based Modeling

By substituting carbon emission data from Henan Province into the STIRPAT model, this study developed a model for carbon emissions from energy consumption; additionally, multiple linear regression (MLR) analyses were conducted accordingly (as described in Table 2). According to the analysis results, the variance inflation factor (VIF) values for all variables are greater than 10. For example, the VIF values for GDP per-capita and urbanization rate are as high as 681 and 786, respectively; this indicates that the results obtained using the least squares estimation method contain severe multicollinearity, and the fitting coefficients obtained from this method are also unreliable. To eliminate the influence of multicollinearity, the present research instead uses ridge regression analysis, which is a statistical method that is specially used for analysis of collinearity data. This method cedes the unbiased found in the least square method, but seeks a more practical and suitable regression equation [66,67]. The results of the ridge regression estimation for Equation (9) are described in Table 3. The results are highly reliable (R^2 = 0.983), all indices pass the test of 5% significance, and the F statistics pass the 1% significance test. Clearly, Equation (9) can explain the relationship between carbon emissions and related variables, which is expressed as

$$I = \exp(-0.888 + 1.099 \ln P + 0.193 \ln A - 0.036 (\ln A)^2 + 0.043 \ln T + 0.542 \ln U - 1.297 \ln S) \quad (9)$$

Table 2. Analysis results of multiple linear regression.

Items	Coefficients	Std. Error	Beta	*T*	Sig. *T*	Tolerance	VIF
Constant	2.182	3.558		0.613	0.550		
ln *P*	0.053	1.291	0.005	0.410	0.968	0.025	40.122
ln *A*	0.829	0.347	1.267	2.390	0.33	0.001	681.283
$(\ln A)^2$	−0.047	0.085	−0.463	−0.553	0.590	0.001	1701.400
ln *T*	1.030	0.219	0.688	4.696	0.000	0.019	52.087
ln *S*	−0.290	0.517	−0.042	−0.560	0.585	0.074	13.592
ln *U*	−0.123	0.933	−0.075	−0.132	0.897	0.001	786.108

Table 3. Analysis results of the ridge regression.

Items	Coefficients	Std. Error	Beta	*T*	Sig. *T*
Constant	−0.888	1.542	0.000	−0.548	0.093
ln *P*	1.099	0.467	0.113	2.423	0.031
ln *A*	0.193	0.141	0.291	13.472	0.000
$(\ln A)^2$	−0.036	0.003	−0.347	−12.467	0.000
ln *T*	0.043	0.076	0.173	0.343	0.074
ln *S*	−1.297	0.321	−0.185	−3.993	0.000
ln *U*	0.542	0.056	0.324	9.541	0.000

3.3. Analysis of STIRPAT Model Results

As described in Table 3, Henan Province carbon emissions from energy consumption are positively influenced by population size, GDP per-capita, energy consumption intensity, and urbanization rate, but inversely influenced by the proportion of tertiary sector. Clearly, an excessive pursuit of rapid economic development and magnitude combined with a disregard for the quality of economic development will bring a substantial increase in carbon emissions from energy consumption. To suppress carbon emissions, it is necessary to adjust and optimize the industrial structure. Population growth is the major factor driving the increase in carbon emissions; for every 1% increase in population, its carbon emissions from energy consumption will increase 1.099%. Henan Province has a large population base, and its population size has increased from 91 billion in 1995 to 106.6 billion in 2014. The huge population has led to an enormous scale of production and life consumption, thus producing a direct and continued increase in energy consumption and carbon emissions.

The rise in the urbanization rate is the second major factor driving the increase in carbon emissions; for every 1% increase in urbanization rate, its carbon emissions from energy consumption will increase 0.542%. The increase in urban population will directly lead to a demand for food, transportation, infrastructure, and housing consumption, thus causing a substantial increase in carbon emissions from energy consumption. Every time GDP per-capita increases 1%, its carbon emissions from energy consumption will increase 0.193%. The increase in per-capita income directly increases energy consumption and, consequently, increases carbon emission. The increase in per-capita purchasing power indirectly leads to an increase in energy consumption and, consequently, higher environmental stress. Every time energy consumption intensity increases 1%, its carbon emissions from energy consumption will increase 0.043%. Energy consumption intensity is positively correlated with carbon emissions from energy consumption. This shows that energy consumption is confronted with various problems, including inefficient energy utilization, unreasonable energy utilization structure, and substantial energy waste. Optimizing industrial structure is negatively correlated with carbon emission; for every 1% increase in the proportion of tertiary sector, its carbon emissions from energy consumption will decrease 1.297%. Clearly, an increase in the proportion of the tertiary sector with low energy consumption aids in achieving energy conservation and emissions reduction in Henan Province.

As described in Table 3, the $(\ln A)^2$ coefficient is negative. In the study period, Henan Province carbon emissions from energy consumption first increased with a continued increase in GDP per-capita and economic development; after the GDP per-capita increased to a certain level, carbon emissions from energy consumption began to decrease. Therefore, the relationship between them is represented with an inverted U-shape curve. The predicted elasticity coefficients for carbon emissions from energy consumption for a GDP per-capita increase from 100 yuan to 100,000 yuan is provided in Table 4. On one hand, according to the absolute values of the coefficients (absolute elastic), we may conclude that the elasticity coefficient of energy consumption (EE_{IA}) in Henan Province increases as the GDP per-capita increases. This is mainly because the increase of GDP per-capita introduces higher levels of consumption per capita. Thus, energy consumption and carbon emissions also increase accordingly. On the other hand, there was less variation in elastic coefficients of carbon emissions, which implies that the rapid increase in prosperity, along with the advance of science and technology, have contributed significantly to reducing carbon emissions.

Table 4. Changes in elasticity coefficients for GDP per-capita energy consumption at different economic development levels.

A	100	1000	2000	4000	6000	8000	10,000	20,000	40,000	60,000	80,000	90,000	100,000
EE_{IA}	−0.136	−0.300	−0.350	−0.399	−0.428	−0.449	−0.465	−0.514	−0.564	−0.593	−0.613	−0.622	−0.629
ΔEE_{IA}		0.164	0.049	0.049	0.029	0.021	0.016	0.049	0.049	0.029	0.021	0.008	0.008

3.4. Scenario Analysis

Scenario models have been widely used for quantitative evaluation [20,68,69]. The future economic scenarios, which are simulated according to (historic and current) carbon emissions and economic developments, are expected to provide useful information for the sustainable development of ecological economy.

The simulation results obtained from the STIRPAT model have allowed this study to predict future carbon emissions in Henan Province from 1995–2014. Given the various influencing factors previously mentioned, Equation (8) was used. Then, the simulated values are compared with historical values, as shown in Figure 4; the regression analysis for the simulation results have an R^2 value of 0.986, indicating that the simulation results are of high accuracy.

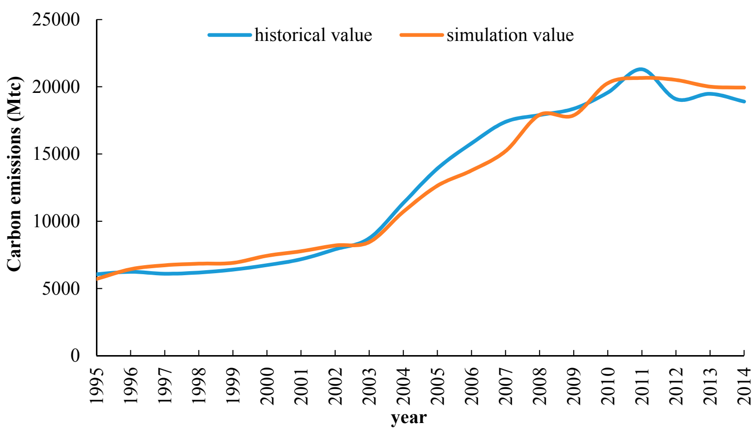

Figure 4. Comparison of simulation and observed values for carbon emissions from energy consumption.

In order to determine the urbanization rate, various sources were considered. According to *The Planning of Henan Province on New-Type Urbanization (2014 to 2020)* released in 2014, the urbanization rate for the permanent resident population will reach 56% by 2020. According to the *Blue Book of Macro-Economy* released by Zhang and Liu [70], China's urbanization rate will reach 67.81% by 2030. According to *The Report on China's Modernization: A Study of the World's Modernization*, China's urbanization rate will exceed 80% by 2040 [71]. According to United Nations predictions, the urbanization rate in developed countries will reach 86% by 2050. Based on these combined predictions, the Henan Province urbanization rate is estimated to reach 56%, 67%, 80% and 86% in 2020, 2030, 2040, and 2050, respectively. Accordingly, this study verified the urbanization rate for 1995 to 2014, and calculated the growth rate of Henan Province's urbanization for past years.

According to the related indices, including population size, GDP per-capita, proportion of tertiary sector, and energy consumption intensity for Henan Province from 1995 to 2014, respective growth rates were calculated. The maximum growth rates for population, GDP per-capita, and proportion of tertiary sector were set as the high growth rates, and their minimum growth rate was set as the low growth rates; high growth rates were 4.72%, 23.91% and 5.43%, respectively, while low growth rates were 0.49%, 4.06% and 0.67%, respectively. In addition, this study selected the maximum growth rate of energy consumption intensity as the low growth rate (−2.32%), and the minimum growth rate as the high growth rate (−15.08%). Energy consumption intensity represents the technological level in Henan Province, and the proportion of tertiary sector represents the socio-economic development level. Details on each scenario are provided in Table 5.

Table 5. Development scenarios for Henan Province.

Scenario	Population	GDP Per-Capita	Technological Level	Socio-Economic Development Level
1	H	H	L	L
2	H	H	L	H
3	H	L	H	L
4	H	L	H	H
5	H	L	L	L
6	H	L	L	H
7	H	H	H	L
8	H	H	H	H
9	L	L	H	L
10	L	L	H	H
11	L	H	L	L
12	L	H	L	H
13	L	H	H	L
14	L	H	H	H
15	L	L	L	L
16	L	L	L	H

Notes: H = high growth and L = low growth.

As shown in Figure 5, the future trends in Henan Province carbon emissions can be summarized with two patterns: (1) a continuous increase; and (2) an initial increase followed by a decrease. The first pattern covers Scenarios 1, 2, 5, 6, 11, 12, 15, and 16, and the second pattern covers Scenarios 3, 4, 7, 8, 9, 10, 13, and 14. The first pattern is in opposition to China's pursuit of harmonious development of economy and ecology, and the second pattern conforms to the relationship represented by an EKC. In the eight scenarios covered by the second pattern, peak carbon emissions all occur in 2039; specifically, they are 4.20×10^8, 4.41×10^8, 5.28×10^8, 5.55×10^8, 1.70×10^8, 1.79×10^8, 2.14×10^8, and 2.25×10^8 tons, respectively, in the eight scenarios. In 2050, the carbon emissions are 2.84×10^8, 3.03×10^8, 3.61×10^8, 3.85×10^8, 8.64×10^8, 9.21×10^8, 1.10×10^8, and 1.17×10^8 tons, respectively, in the eight scenarios. The carbon emissions from energy consumption will remain relatively low under the development patterns represented by Scenario 9, 10, 13, and 14. Under the development patterns represented by Scenario 9 and 10, carbon emissions from energy consumption will be the lowest. However, this development pattern demands that Henan Province maintain a certain growth rate in GDP per-capita and socio-economic level. Clearly, this development pattern is in opposition to trends for harmonious and sustainable development of economy, society, and the environment because it optimizes the environment at the cost of improving resident living standards and industrial structure. Under the development pattern represented by Scenario 13, carbon emissions are also low; however, this development pattern demands that Henan Province maintain a low socio-economic growth rate, and an outdated industrial structure under this development pattern is counter to trends in China's economic development. Under the development pattern represented by Scenario 14, carbon emissions are relatively low; this development pattern demands that Henan Province maintain a low growth rate in population, and a high growth rate in GDP per-capita, technological advances, and socio-economic level. Therefore, this development pattern conforms to sound and rapid socio-economic development in Henan Province. To accomplish energy conservation and emission reduction in Henan Province, the optimal development pattern is to maintain a low growth rate in population, but a high growth rate in GDP per-capita, technological advances, and socio-economic level.

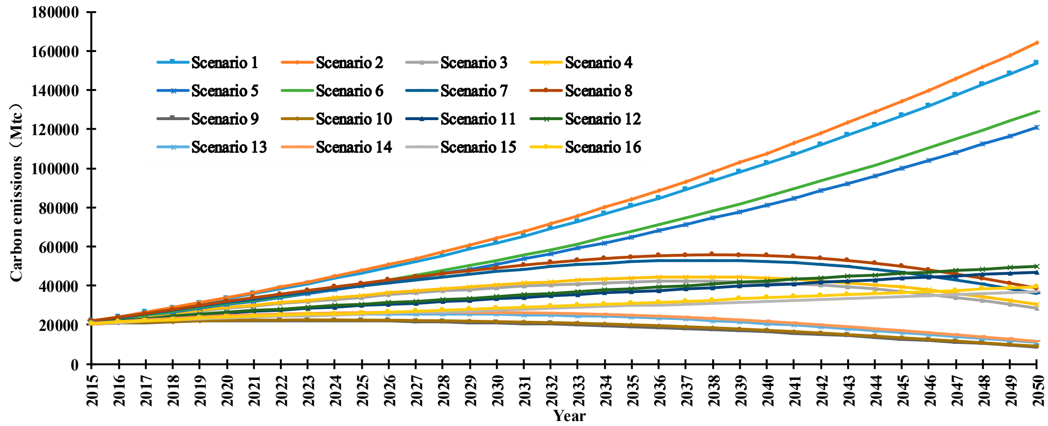

Figure 5. Evolving trends in carbon emissions from energy consumption in Henan Province under different developmental scenarios in the future.

4. Conclusions and Policy Implications

Based on primary energy consumption, this study calculated Henan Province carbon emissions from energy consumption during 1995–2014. During the study period, total energy consumption and carbon emissions continued to increase, and only energy consumption intensity decreased, while population size, GDP per-capita, urbanization rate, and proportion of tertiary sector all showed an increasing trend and clearly fluctuated. Population growth, GDP per capita, energy intensity, and the level of urbanization development are the main contributors to carbon emissions in Henan Province; the tertiary sector is the major contributor to reducing carbon emissions. While there is a continued increase in GDP per-capita (from 100 yuan to 100,000 yuan), the absolute values of the coefficients (absolute elastic) for carbon emissions from energy consumption shows a decreasing trend, but the value of the elasticity coefficient shows an increasing trend. In addition, the EKC has a standard inverted U-shape curve. Based on the 16 multi-scenarios analyses, we predicted that Henan Province's environmental quality initially deteriorated and then improved, along with the increase in GDP per-capita.

To achieve sound and rapid socio-economic development in Henan Province, the optimal development scheme is to maintain a low growth rate in population, but a high growth rate in GDP per-capita, technological advances, and socio-economic level. As China opens its two-child policy, effectively controlling carbon emissions should be a long-term mission. Henan Province development should emphasize the following points: (1) control population size and growth rate moderately; and (2) further improve energy utilization efficiency and promote the optimization and improvement in industrial structure, while ensuring continued improvement in resident living standards. In contrast, lack of effective control over population growth, inefficient energy utilization, and outdated industrial structure would result in a substantial increase in carbon emissions in Henan Province.

The "13th Five-Year" plan in China clearly stated necessary responses to global climate change. It places equal emphasis on mitigation and adaptation of carbon emissions, emission reduction commitments, the ability to adapt to climate change, the depth of participation in global climate governance, and the contributions to addressing global climate change. Henan province is a province with a large population. It is also a big economic and agricultural entity in the nation. In order to curb carbon emissions in Henan, focus should be paid on the effective control of industrial growth, and usage of electric power, building materials (iron/steel), chemicals, and other sources of carbon emissions. In the meantime, promotion of low carbon industry, energy, construction, transportation, are other key strategies. Henan should carry on different possible low carbon pilot projects and implement the demonstration projects of near zero carbon emission. We should actively promote the trading market of carbon emission, carbon emissions reporting system, and the verification, certification, and quota management of key emission units. Henan should improve the system of statistical accounting, evaluation and accountability, and improve the standard system of carbon emission. Other regions in the world with similar population and economic issues could learn the experience of emission control in Henan, and actively participate in the negotiation of global climate change, and promote the establishment of a fair, reasonable, and win–win global climate governance system.

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References

1. Crutzen, P.J.; Mosier, A.R.; Smith, K.A.; Winiwarter, W. N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmos. Chem. Phys.* **2008**, *8*, 389–395. [CrossRef]
2. Dai, A. Increasing drought under global warming in observations and models. *Nat. Clim. Chang.* **2013**, *3*, 52–58. [CrossRef]
3. Kosaka, Y.; Xie, S.P. Recent global-warming hiatus tied to equatorial Pacific surface cooling. *Nature* **2013**, *501*, 403–407. [CrossRef] [PubMed]
4. Karl, T.R.; Arguez, A.; Huang, B.; Lawrimore, J.H.; McMahon, J.R.; Menne, M.J.; Peterson, T.C.; Vose, R.S.; Zhang, H.M. Possible artifacts of data biases in the recent global surface warming hiatus. *Science* **2015**, *348*, 1469–1472. [CrossRef] [PubMed]
5. Revesz, R.L.; Howard, P.H.; Arrow, K.; Goulder, L.H.; Livermore, M.A.; Oppenheimer, M.; Sterner, T. Global warming: Improve economic models of climate change. *Nature* **2014**, *508*, 173–175. [CrossRef] [PubMed]
6. UNFCCC. Adoption of the Paris Agreement. Report No. FCCC/CP/2015/L.9/Rev.1. 2015. Available online: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf (accessed on 12 December 2015).
7. Rogelj, J.; den Elzen, M.; Höhne, N.; Fransen, T.; Fekete, H.; Winkler, H.; Schaeffer, R.; Sha, F.; Riahi, K.; Meinshausen, M. Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature* **2016**, *534*, 631–639. [CrossRef] [PubMed]

8. Friedlingstein, P.; Andrew, R.M.; Rogelj, J.; Peters, G.P.; Canadell, J.G.; Knutti, R.; Luderer, G.; Raupach, M.R.; Schaeffer, M.; van Vuuren, D.P.; et al. Persistent growth of CO_2 emissions and implications for reaching climate targets. *Nat. Geosci.* **2014**, *7*, 709–715. [CrossRef]
9. Shahbaz, M.; Tiwari, A.K.; Nasir, M. The effects of financial development, economic growth, coal consumption and trade openness on CO_2 emissions in South Africa. *Energy Policy* **2013**, *61*, 1452–1459. [CrossRef]
10. Arouri, M.E.H.; Ben Youssef, A.; M'Henni, H.; Rault, C. Energy consumption, economic growth and CO_2 emissions in Middle East and North African countries. *Energy Policy* **2012**, *45*, 342–349. [CrossRef]
11. Al-mulali, U.; Lee, J.Y.M. Estimating the impact of the financial development on energy consumption: Evidence from the GCC (Gulf Cooperation Council) countries. *Energy* **2013**, *60*, 215–221. [CrossRef]
12. Ruijven, B.J.V.; Vuuren, D.P.V.; Boskaljon, W.; Neelis, M.L.; Saygin, D.; Patel, M.K. Long-term model-based projections of energy use and CO_2 emissions from the global steel and cement industries. *Resour. Conserv. Recycl.* **2016**, *112*, 15–36. [CrossRef]
13. Zhang, Y.J.; Da, Y.B. The decomposition of energy-related carbon emission and its decoupling with economic growth in China. *Renew. Sustain. Energy Rev.* **2015**, *41*, 1255–1266. [CrossRef]
14. Liu, Z.; Guan, D.; Wei, W.; Davis, S.J.; Ciais, P.; Bai, J.; Peng, S.; Zhang, Q.; Hubacek, K.; Marland, G.; et al. Reduced carbon emission estimates from fossil fuel combustion and cement production in China. *Nature* **2015**, *524*, 335–338. [CrossRef] [PubMed]
15. Kasman, A.; Duman, Y.S. CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis. *Econ. Model.* **2015**, *44*, 97–103. [CrossRef]
16. Ripple, W.J.; Smith, P.; Haberl, H.; Montzka, S.A.; McAlpine, C.; Boucher, D.H. Ruminants, climate change and climate policy. *Nat. Clim. Chang.* **2014**, *4*, 2–5. [CrossRef]
17. Broecker, W.S. Climate change: CO_2 Arithmetic. *Science* **2014**, *315*, 1371. [CrossRef] [PubMed]
18. Belloumi, M. Energy consumption and GDP in Tunisia: Cointegration and causality analysis. *Energy Policy* **2009**, *37*, 2745–2753. [CrossRef]
19. Alshehry, A.S.; Belloumi, M. Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia. *Renew. Sustain. Energy Rev.* **2015**, *41*, 237–247. [CrossRef]
20. Wang, M.W.; Che, Y.; Yang, K.; Wang, M.; Xiong, L.J.; Huang, Y.C. A local-scale low-carbon plan based on the STIRPAT model and the scenario method: The case of Minhang District, Shanghai, China. *Energy Policy* **2011**, *39*, 6981–6990. [CrossRef]
21. Lee, S.; Chong, W.O. Causal relationships of energy consumption, price, and CO_2 emissions in the U.S. building sector. *Resour. Conserv. Recycl.* **2016**, *107*, 220–326. [CrossRef]
22. Jalil, A.; Feridun, M. The impact of growth, energy and financial development on the environment in China: A cointegration analysis. *Energy Econ.* **2011**, *33*, 284–291. [CrossRef]
23. Shahbaz, M.; Lean, H.H.; Farooq, A. Natural gas consumption and economic Growth in Pakistan. *Renew. Sustain. Energy Rev.* **2013**, *18*, 87–94. [CrossRef]
24. Zhang, X.P.; Cheng, X.M. Energy consumption, carbon emissions and economic growth in China. *Ecol. Econ.* **2009**, *68*, 2706–2712. [CrossRef]
25. Baccini, A.; Goetz, S.J.; Walker, W.S.; Laporte, N.T.; Sun, M.; Sulla-Menashe, D.; Hackler, J.; Beck, P.S.A.; Dubayah, R.; Friedl, M.A.; et al. Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nat. Clim. Chang.* **2012**, *2*, 182–185. [CrossRef]
26. Cao, Z.; Shen, L.; Zhao, J.N.; Liu, L.; Zhong, S.; Yang, Y. Modeling the dynamic mechanism between cement CO_2 emissions and clinker quality to realize low-carbon cement. *Resour. Conserv. Recycl.* **2016**, *113*, 116–126. [CrossRef]
27. Ma, M.; Shen, L.; Ren, H.; Cai, W.; Ma, Z. How to Measure Carbon Emission Reduction in China's Public Building Sector: Retrospective Decomposition Analysis Based on STIRPAT Model in 2000–2015. *Sustainability* **2017**, *9*, 1744–1759. [CrossRef]
28. Al-mulali, U. Investigating the impact of nuclear energy consumption on GDP Growth and CO_2 emission: A panel data analysis. *Prog. Nucl. Energy* **2014**, *73*, 172–178. [CrossRef]
29. Sayyed, M.Z. Effects of financial development in dicators on energy consumption and CO_2 emission of European, East Asian and Oceania countries. *Renew. Sustain. Energy Rev.* **2015**, *42*, 752–759.

30. Steen-Olsen, K.; Weinzettel, J.; Cranston, G.; Ercin, A.E.; Hertwich, E.G. Carbon, land, and water footprint accounts for the European union: Consumption, production, and displacements through international trade. *Environ. Sci. Technol.* **2012**, *46*, 10883–10891. [CrossRef] [PubMed]
31. Raupach, M.R.; Canadell, J.G.; Ciais, P.; Friedlingstein, P.; Rayner, P.J.; Trudinger, C.M. The relationship between peak warming and cumulative CO_2 emissions and its use to quantify vulnerabilities in the carbon-climate-human system. *Tellus B* **2011**, *63*, 145–164. [CrossRef]
32. Meng, M.; Niu, D.; Shang, W. CO_2 emissions and economic development: China's 12th five-year plan. *Energy Policy* **2012**, *42*, 468–475. [CrossRef]
33. York, R.; Rosa, E.A.; Dietz, T. STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecol. Econ.* **2003**, *46*, 351–365. [CrossRef]
34. Lin, S.F.; Wang, S.Y.; Marinova, D.; Zhao, D.T.; Hong, J. Impacts of urbanization and real economic development on CO_2 emissions in non-high income countries: Empirical research based on the extended STIRPAT model. *J. Clean. Prod.* **2017**, *166*, 952–966. [CrossRef]
35. Wang, C.J.; Wang, F.; Zhang, X.L.; Yang, Y.; Su, Y.X.; Ye, Y.Y.; Zhang, H.O. Examining the driving factors of energy related carbon emissions using the extended STIRPAT model based on IPAT identity in Xinjiang. *Renew. Sustain. Energy Rev.* **2017**, *67*, 51–61. [CrossRef]
36. Apergis, N.; Payne, J.E. CO_2 emissions, energy usage and output in Central America. *Energy Policy* **2009**, *37*, 3282–3286. [CrossRef]
37. Shahbaz, M.; Chaudhary, A.R.; Ozturk, I. Does urbanization cause increasing energy demand in Pakistan? Empirical evidence from STIRPAT model. *Energy* **2017**, *122*, 83–93. [CrossRef]
38. Liddle, B.; Lung, S. Age-structure, urbanization, and climate change in developed countries: Revisiting STIRPAT for disaggregated population and consumption-related environmental. *Populat. Environ.* **2010**, *31*, 317–343. [CrossRef]
39. Martínez-Zarzoso, I.; Maruotti, A. The impact of urbanization on CO_2 emissions: Evidence from developing countries. *Ecol. Econ.* **2011**, *70*, 1344–1353. [CrossRef]
40. Shafiei, S.; Salim, R.A. Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: A comparative analysis. *Energy Policy* **2014**, *66*, 547–556. [CrossRef]
41. Martínez-Zarzoso, I.; Bengochea-Morancho, A.; Moraleslage, R. The impact of population on CO_2 emissions: Evidence from European countries. *Environ. Resour. Econ.* **2007**, *38*, 497–512. [CrossRef]
42. Dhakal, S. Urban energy use and carbon emissions from cities in China and policy implications. *Energy Policy* **2009**, *37*, 4208–4219. [CrossRef]
43. Wang, S.S.; Zhou, D.Q.; Zhou, P.; Wang, Q.W. CO_2 emissions, energy consumption and economic growth in China: A panel data analysis. *Energy Policy* **2011**, *39*, 4870–4875. [CrossRef]
44. Chen, Q.L.; Cai, B.F.; Dhakal, S.; Pei, S.; Liu, C.L.; Shi, X.P.; Fangfang Hu, F.F. CO_2 emission data for Chinese cities. *Resour. Conserv. Recycl.* **2017**, *126*, 198–208. [CrossRef]
45. Li, H.N.; Mu, H.L.; Zhang, M.; Gui, S.S. Analysis of regional difference on impact factors of China's energy–related CO_2 emissions. *Energy* **2012**, *39*, 319–326. [CrossRef]
46. Xu, S.C.; He, Z.X.; Long, R.Y. Factors that influence carbon emissions due to energy consumption in China: Decomposition analysis using LMDI. *Appl. Energy* **2014**, *127*, 182–193. [CrossRef]
47. Shan, Y.; Liu, J.; Liu, Z.; Xu, X.; Shao, S.; Wang, P.; Guan, D. New provincial CO_2 emission inventories in China based on apparent energy consumption data and updated emission factors. *Appl. Energy* **2016**, *185*, 742–750. [CrossRef]
48. Feng, K.H.; Hubacek, K.; Sun, L.X.; Liu, Z. Consumption-based CO_2 accounting of China's megacities: The case of Beijing, Tianjin, Shanghai and Chongqing. *Ecol. Indic.* **2014**, *47*, 26–31. [CrossRef]
49. Ren, L.J.; Wang, W.J.; Wang, J.C.; Liu, R.T. Analysis of energy consumption and carbon emission during the urbanization of Shandong Province, China. *J. Clean. Prod.* **2015**, *103*, 534–541. [CrossRef]
50. Wang, Q.; Wu, S.D.; Zeng, Y.E.; Wu, B.W. Exploring the relationship between urbanization, energy consumption, and CO_2 emissions in different provinces of China. *Renew. Sustain. Energy Rev.* **2016**, *54*, 1563–1579. [CrossRef]
51. Wang, Z.H.; Yin, F.C.; Zhang, Y.X.; Zhang, X. An empirical research on the influencing factors of regional CO_2 emissions: Evidence from Beijing city, China. *Appl. Energy* **2012**, *100*, 277–284. [CrossRef]
52. Li, B.; Liu, X.J.; Li, Z.H. Using the STIRPAT model to explore the factors driving regional CO_2 emissions: A case of Tianjin, China. *Nat. Hazards* **2015**, *76*, 1667–1685. [CrossRef]

53. Wang, S.J.; Fang, C.L.; Guan, X.L.; Pang, B.; Ma, H.T. Urbanization, energy consumption, and carbon dioxide emissions in China: A panel data analysis of China's provinces. *Appl. Energy* **2014**, *136*, 738–749. [CrossRef]
54. Wang, Z.H.; Yang, L. Delinking indicators on regional industry development and carbon emissions: Beijing–Tianjin–Hebei economic band case. *Ecol. Indic.* **2015**, *48*, 41–48. [CrossRef]
55. Liu, Y.; Xiao, H.W.; Zikhali, P.; Lv, Y.K. Carbon Emissions in China: A Spatial Econometric Analysis at the Regional Level. *Sustainability* **2014**, *6*, 6005–6023. [CrossRef]
56. Ji, X.; Chen, B. Assessing the energy-saving effect of urbanization in China based on stochastic impacts by regression on population, affluence and technology (STIRPAT) model. *J. Clean. Prod.* **2015**, *24*, 206–209. [CrossRef]
57. Intergovernmental Panel on Climate Change (IPCC). *IPCC Guidelines for National Greenhouse gas Inventories*; Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency: Paris, France, 2006.
58. Wang, P.; Wu, W.S.; Zhu, B.Z.; Wei, Y.M. Examining the impact factors of energy-related CO_2 emissions using the STIRPAT model in Guangdong Province, China. *Appl. Energy* **2013**, *106*, 65–71. [CrossRef]
59. Albrecht, J.; François, D.; Schoors, K. A shapley decomposition of carbon emissions without residuals. *Energy Policy* **2002**, *30*, 727–736. [CrossRef]
60. Ehrlich, P.R.; Holdren, J.P. Impact of population growth. *Science* **1971**, *171*, 1212–1217. [CrossRef] [PubMed]
61. Ehrlich, P.R.; Holdren, J.P. A bulletin dialogue on the 'closing circle' critique: One-dimensional ecology. *Critique. Bull. At. Sci.* **1972**, *28*, 16–27.
62. Dietz, T.; Rosa, E.A. Rethinking the environmental impacts of population affluence and technology. *Hum. Ecol. Rev.* **1994**, *2*, 277–300.
63. York, R.; Rosa, E.A.; Dietz, T. Footprints on the Earth: The environmental consequences of modernity. *Am. Sociol. Rev.* **2003**, *68*, 279–300. [CrossRef]
64. Saboori, B.; Sulaiman, J.; Mohd, S. Economic growth and CO_2 emissions in Malaysia: A cointegration analysis of the environmental Kuznets Curve. *Energy Policy* **2012**, *51*, 184–191. [CrossRef]
65. Hoerl, A.; Kennard, R. Ridge regression: Biased estimation for nonorthogonal problems. *Technometrics* **1970**, *12*, 55–67. [CrossRef]
66. Alexandros, G.; Mohamed, E.H.; Malcolm, H. A longitudinal analysis of the UK transport sector, 1970–2010. *Energy Policy* **2009**, *37*, 623–632.
67. Xie, C.P.; Hawkes, A.D. Estimation of inter-fuel substitution possibilities in China's transport industry using ridge regression. *Energy* **2015**, *88*, 260–267. [CrossRef]
68. Gomi, K.; Shimada, K.; Matsuoka, Y. A low-carbon scenario creation method for a local-scale economy and its application in Kyoto city. *Energy Policy* **2010**, *38*, 4783–4796. [CrossRef]
69. Schandl, H.; Hatfield-Dodds, S.; Wiedmann, T.; Geschke, A.; Cai, Y.Y.; West, J.; Newth, D.; Baynes, T.; Lenzen, M.; Owen, A. Decoupling global environmental pressure and economic growth: Scenarios for energy use, materials use and carbon emissions. *J. Clean. Prod.* **2016**, *132*, 45–56. [CrossRef]
70. Zhang, P.; Liu, X.H. *Blue Book of Macro-Economics: Annual Report on China's Economic Growth (2012–2013), Macro-Economics Trends and Outlook*; Social Science Academic Press: Beijing, China, 2013. (In Chinese)
71. He, C.Q. *The Report on China's Modernization: A Study of the World's Modernization*; Peking Press: Beijing, China, 2014. (In Chinese)