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Decoupling of Electricity Consumption Efficiency, Environmental Degradation and Economic Growth: An Empirical Analysis

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Abstract: The present study investigates electricity consumption, carbon dioxide (CO_2) emission, and economic growth decoupling using data from 1971 to 2020 for the economy of China. The study uses decoupling analysis (DA) as the prime methodology for analysis. Furthermore, the findings put forward a significant contribution to an economic picture of the economy of China and a sizeable addition to related research and findings under the assigned issues discussed in the study. The study's main contribution is to decouple electricity consumption from the gross domestic product (GDP), which is rare in the existing literature in the context of China. Moreover, the study shows the decoupling of environment affects electricity consumption, and GDP growth. The DA model shows that electricity consumption is the main driving force enhancing economic growth. However, industrialization has increased greenhouse gases, global warming, and climate change due to production and consumption. China's economy uses coal for energy resources, which indicates that China produces a large proportion of electricity with coal, which causes high CO_2 emissions. Finally, further analysis with the Granger causality test confirms the main findings.

Keywords: China; decoupling analysis (DA); electricity consumption; carbon dioxide (CO_2) emission; economic growth

Citation: Laghari, F.; Ahmed, F.; Li, H.-X.; Bojnec, Š. Decoupling of Electricity Consumption Efficiency, Environmental Degradation and Economic Growth: An Empirical Analysis. *Energies* **2023**, *16*, 2620. https://doi.org/10.3390/en16062620

Academic Editor: Behnam Zakeri

Received: 2 January 2023
Revised: 14 February 2023
Accepted: 2 March 2023
Published: 10 March 2023

1. Introduction

The development of the social economy requires massive inputs of natural resources, especially energy efficiency, also known as the main driver of economic growth [1]. China is a "world factory" which consumes plenty of energy resources to meet the local demand of manufacturers and serves the international market with commodities "made in China". The effect on economic growth is generally apparent; however, the impacts on energy consumption and consequently the environmental footprint are yet to be fully understood [2]. As a newly industrialized country, electricity is an influential energy source and supports economic and social development in China [3]. The rapid growth of industrial and domestic electricity consumption indicates China's rapid economic development. In the process, China has become a significant contributor to the growth of global electric power demand [4]. The electricity consumption of China was 612, 97.09 kWh in 2016, over double what it was ten years ago.

A lot of research has emerged concerning energy resources, economic growth, and environmental efficiency [5–13]. All these researches have used regression analysis or other shared estimation techniques for the nexus of energy consumption and economic growth. All these techniques and methods cannot completely relate to the different features influenced by the decoupling of China's economic growth. Moreover, to the best of our knowledge, researches dedicated to electricity consumption, CO_2 emissions, and economic growth using the decoupling analysis method are scarce in the case of China. In that regard, in the case of China, reference [14] explains the main aspects of the distressing levels of CO_2 emissions from the electric power industry by the relation of CO_2 emissions and growth in the regional economy with the decoupling index and LMDI model for the Jing-jin-ji region of China, and declare that there is weak decoupling. In that regard [15] analysed the consumption of electricity and carbon dioxide emissions in relation to decoupling for more than 600 counties in China, and indicated higher decoupling for 2016. However, these studies have used decoupling analysis but considered only the heterogeneous factors of the sample and have not related it on macro grounds.

Moreover, understanding the direct and indirect effects of electricity consumption on the economy of China is a prerequisite for proper energy conservation policy formulation [3]. As China is the world's largest electricity end user, a coal-ruled electric power system has put accumulative force on climate variation and pollution in the air. Considering these factors, the present study aims to explore electricity consumption, CO_2 emissions, and economic growth decoupling. Against this background, our paper investigates three significant problems grounded on the decoupling analysis technique: (1) What is the influence of electricity consumption and economic growth decoupling? (2) What is the influence of electricity consumption and CO_2 emissions decoupling? (3) What is the influence of CO_2 emissions and economic growth decoupling? To report these three concerns, firstly, the present study uses the unique methodology of the decoupling model of Tapio [16] to determine the influence of economic growth and electricity consumption, decoupling of carbon (CO_2) emissions and economic growth, and carbon (CO_2) emissions and electricity consumption decoupling. Then the study applied the unit root test, proper lag length selection criteria, and Granger causality test to validate all the relations under investigation in the study.

Our study contributes significantly to the present literature linked to energy efficiency for domestic and industrial electricity consumption, environmental efficiency, environmental degradation, and economic growth. The main highlight of the study is to relate electricity consumption as a function driving economic expansion and development, which to the best of our knowledge, is less investigated in the context of China. Secondly, the present study relates the electricity consumption function to environmental degradation as an outcome of sustainable economic growth and development which is rare in the existing literature from the decoupling perspective for the economy of China. Moreover, our study significantly contributes on methodological grounds by using decoupling analysis. It is scarce in circular economy and economic development research in relation to the economy of China.

The main highlights of the present study's findings contribute novel empirical results on the decoupling effect between electricity consumption and economic growth, CO_2 emissions and economic growth, and CO_2 emissions and electricity consumption. The findings show weak and expansive negative decoupling for electricity consumption and economic development. It indicates that weak decoupling happens when there is faster economic growth, and electricity consumption grows rapidly with expansive negative decoupling. The findings show strong and weak decoupling for CO_2 emissions and GDP growth, which illustrates that weak decoupling happens when there is faster economic growth, and CO_2 emissions also grows rapidly with strong decoupling. Moreover, the study shows strong and weak decoupling for CO_2 emissions and electricity consumption. These results conclude that weak decoupling happens when there is fast growth in electricity consumption, and CO_2 emissions also grow rapidly with strong decoupling. In addition, to validate the main findings, the present study incorporates the test of Granger analysis for causality, which illustrates unidirectional causality for CO_2 emissions and electricity consumption. The study finds unidirectional causality between the growth of economic development and CO_2 emissions growth. Finally, the relationship between the growth of electricity consumption and the growth of the economy shows unidirectional causality.

The remainder of the paper is formulated as follows. Section 2 discusses a theoretical framework for decoupling. Section 3 reviews the recent literature. Section 4 discusses the materials and method. Section 5 illustrates the analysis of results and discussions. Section 6 discusses the conclusions of the study. Section 7 shows policy implications and directions for future research.

2. Theoretical Framework on Decoupling

Decoupling electricity consumption from economic development defines the values of elasticity under 1.0, where the percentage change in electricity consumption (%ΔEL_c) is divided by the percentage change of economic growth (%ΔGDP_g) in a given period.

Several unlike theories have been used to show the various features of decoupling [17]. For instance, decoupling by equation one of this study is likewise denoted as non-materialized, qualitative evolution, and structural variation [18]. The decoupling stated by equation two of this study is also referred to as dematerialized, economic effectiveness, and elementary practical growth [18,19]. Decoupling stated by equation three of this study may also be stated as non-carbonization, non-relating, and dissimilar element theories [19]. Occasionally de-linking is used as a broader replacement for decoupling, irrespective of the theory's particular meaning [17].

The discourse of decoupling economic development from electricity consumption growth narrates the broader discipline of delinking economic development from collective environmental issues. At one point in the subject it said that in the initial stages of economic growth, growth leads to growing ecological problems, that is, pollution and misuse of resources. As the progress lasts, the economy will become less damaging to the environment due to investment in technology, and economic and energy efficiency. With consuming economic productivity per capita as the *x*-axis and environmental damage as the *y*-axis, a reversed U-curve will appear. This curve is termed the environmental Kuznets curve (EKC) hypothesis [20].

Several practical researches investigated whether to confirm or discard the EKC hypothesis. The outcomes of the research differ intensely by state, period, and the set of environmental factors examined [21,22]. Some researchers have proposed that in various western industrial nations, concerning entire material streams and CO_2 emissions, the hypothesis did hold for the period from 1970 to 1985, but not after that [22]. The EKC defined the growth of sulphur discharges (measured in SO_2) as somewhat sound, as it was not as effective in relating the development of nitrogen dioxide emissions and the minimum effective link to CO_2 emissions growth in the UK, USA, western Germany, the Netherlands, and Finland [19]. According to prior studies, the reversed U-curve of CO_2 emissions has somewhat changed to an N-curve. As the reversed U-curve signifies de-linking or dematerializing, the latter stage of the N-curve is defined by the terms relinking or re-materialization [17].

Grounded on an assessment of the problem, Vehmas et al. (2003) constructed a broad framework of the different decoupling features [17]. They incorporated the notion of de-linking, imitating the jargon used in environmental economics. The study uses the decoupling term as it is applied more frequently in economic development. Vehmas et al. also applied the notion of re-linking, which here is called negative decoupling. There has not been abundant proof of decoupling in electricity consumption, nor CO_2 emissions driven by electricity consumption hence would the notion of re-coupling possibly give a deceptive meaning to the N curve?

According to the background, eight rational options can be formed (Figure 1). The development rate of GDP and a factor of electricity consumption (see Equation (1)) can be coupled, decoupled, or negatively decoupled. Equations (1)–(3) may also be examined on a similar basis. To avoid over-estimating minor variations as significant, ±20% disparity of the elasticity values of about 1.0 are here still viewed as coupling. Therefore, coupling is defined by elasticity values of 0.8 . . . . . . 1.2. On the contrary, the development of the factors per se can be positive or negative, also known as expansive coupling and recessive coupling.

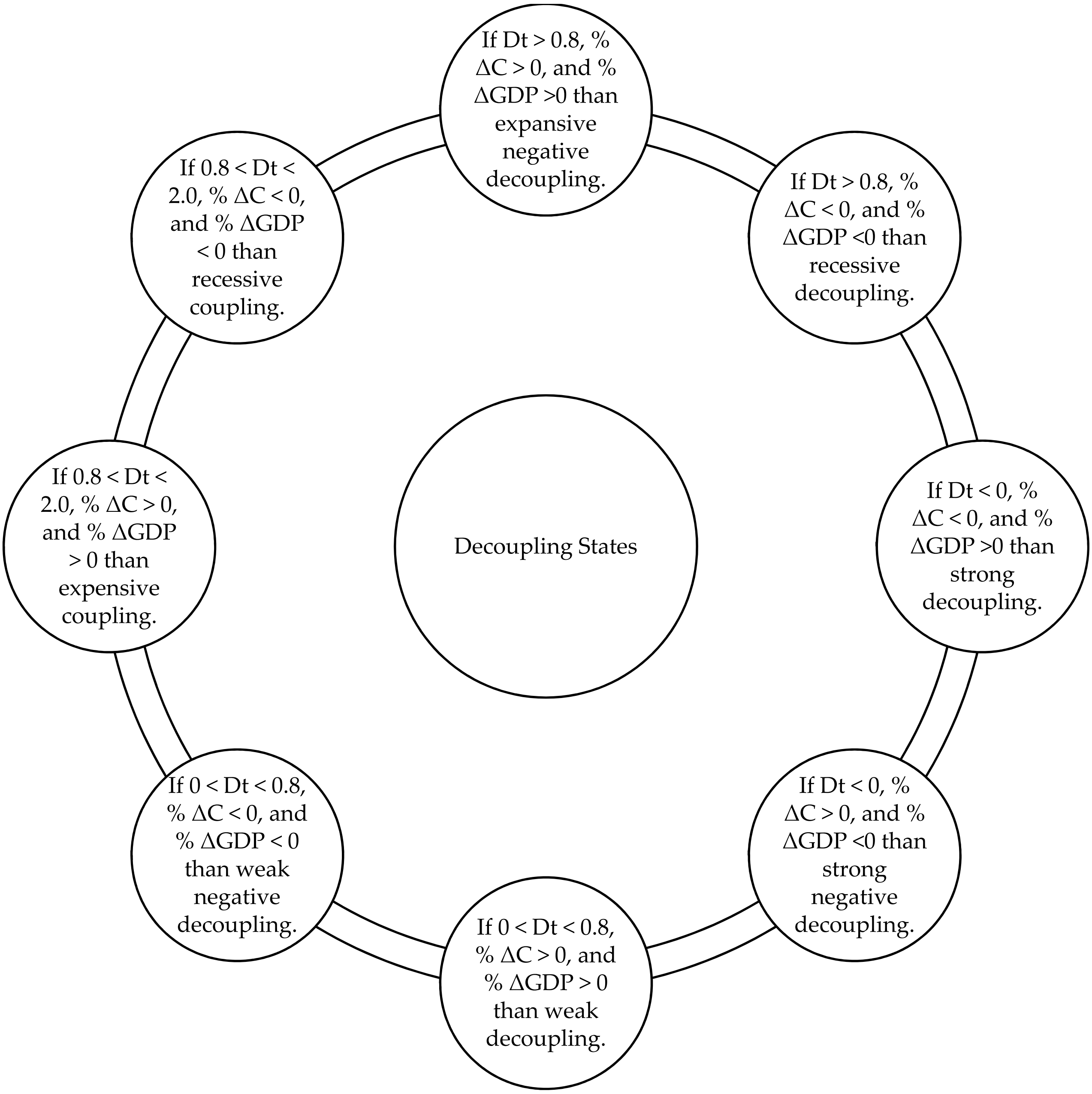

Figure 1. Decoupling States. Source: Tapio (2005) [16].

Decoupling further separates into three subgroups. In weak decoupling, economic development and electricity consumption rise together (and 0 < elasticity < 0.8). Strong decoupling happens when GDP increases and electricity consumption falls (and elasticity < 0). Recessive decoupling shows when GDP and electricity consumption equally decline (and elasticity > 1.2). Likewise, negative decoupling contains three subgroups: in expansive negative decoupling, GDP and electricity consumption rise equally (elasticity > 1.2). In strong negative decoupling, GDP falls, and electricity consumption increases (elasticity < 0). Weak negative decoupling happens when both factors decrease (0 < elasticity < 0.8). Negative GDP growth has been very infrequent in China for several years, and some of the rational likelihoods may appear impractical from the emerging markets perspective, for instance, strong negative decoupling where the growth of GDP drops and electricity consumption rises. However, there seem to be various states in the emerging economies where this perhaps occurred in the past.

3. Review of Related Literature

The existing literature has put forward sizeable research on the relationship between CO_2 emissions and economic development by applying research methods such as the Granger causality test, the environmental Kuznets curve hypothesis (EKC), and the decoupling model [23,24]. The study by Boamah et al. (2017) [25] shows the one-way causal relationship between the consumption of energy and the growth of the economy of China over the long term and suggests that China should alter its trade growth mode. The study by Wang et al. [26] conducted comparative research on the economy of China and the United States (US). They declare that collectively the United States and China produce about 1/3 of the output of the global economy and discharge over 2/5 of the CO_2. They indicate weak and expansive decoupling for China. They also reveal that from 2000 to 2014 the economy of China witnessed strong and weak decoupling for most of those years.

A study by Wu et al. [27] discussed decoupling world economic growth trends and CO_2 emissions based on decoupling theory from 1965 to 2015 for developed and developing economies. They show that strong decoupling exists in developed countries. The decoupling state in the United Kingdom (UK) and Germany is more stable than that of the US and France. Developing countries exhibit weak decoupling due to high fluctuation and lack of regularity. Due to stabilization and optimization in China, the decoupling process is higher than in Brazil and India. Bildirici (2019) [14] conducted research by analyzing the Granger causality between CO_2 emissions and economic development for the US and China, and findings show a one-way causal relationship between CO_2 emissions and economic development in China. On the contrary, the US shows opposing results.

Piłatowska et al. (2020) [15] examined the relationship between renewable energy and nuclear energy consumption, carbon dioxide emissions, and economic growth with the Granger causality and nonlinearity impulse response function for the Spanish business cycle from 1970 to 2018. Further analysis shows that economic growth and carbon dioxide emissions positively correlate during expansion but not during a recession. Therefore, they find that growing nuclear energy consumption leads to a reduction in carbon dioxide emissions expansion, and this impact increases due to renewable energy consumption and carbon dioxide emissions, which is negative but insignificant. Moreover, there is a positive feedback relationship between nuclear energy consumption and economic growth, but a one-way positive cause and effect relation between renewable energy consumption and the turnaround in economic growth. These findings show that nuclear and renewable energy consumption help reduce CO_2 emissions; however, rising economic activity leads to even greater CO_2 emissions increases, which offset the positive effect of green energy.

The paper by Wang and Zhang (2020) [28] investigates the R&D investments and CO_2 emissions using the fully modified ordinary least squares estimation method from 1996 to 2014 for BRICS (Brazil, Russia, India, China, and South Africa) states. The results show that with every 1% increase in R&D investment, carbon emissions reduce by 0.8122% for the BRICS states and indicate that a growing number of R&D investments positively influence the decoupling of economic growth from environmental pressure. The results vary for individual countries, however; in China, the impact is the most substantial, while it is weak in Russia and India. Their findings further reveal that economic activity, industrialization, and urbanization negatively affect decoupling, and renewable energy consumption upholds decoupling. The study by Gao et al. (2021) [29] applied the Tapio decoupling model to analyze the decoupled state of provincial carbon emissions from its economic development and combine the logarithmic mean divisia index model (LMDI) and Cobb–Douglas production function to study the emissions driving force, especially from the perspective of the economy. Their results show that CO_2 emissions and economic decoupling specifically depend on the decoupling of energy consumption during the study period. Huge change exists in the level of provincial CO_2 emissions and its driving forces. The emissions–economic decoupling trend tends to converge to a club, more or less implying coherent low-carbon cross-province progress. They show that economic development usually represents the energy demand and ultimately leads to carbon emissions.

Moreover, Wang and Zhang (2021) [30] examined the decoupling of CO_2 emissions from economic growth by the influence of protectionism through trade openness. They show that the heterogeneous impact of trade openness on CO_2 emissions specifies that trade openness negatively influences economic growth decoupling from CO_2 in poor economies and positively impacts developed economies. Linked to that, Shan et al. (2021) [31] presented the most detailed and up-to-date accounts of CO_2 emissions in 294 cities in China and the degree to which their economic growth decoupled from emissions. The results show that from 2005 to 2015, only 11% of cities participated in strong decoupling, 65.6% showed weak decoupling, and 23.4% said no decoupling. They attribute this economic—CO_2 emissions decoupling in cities to several socio-economic factors (i.e., structure and size of the economy, emission intensity, and population size) and find a decline in emissions intensity by improving production and carbon efficiency (e.g., by decarbonizing the energy mix, and building renewable energy systems) is the most important one.

Additionally, Rao et al. (2022) [32] explored correlations of the sectoral CO_2 emissions impact by defining the comprehensive sectoral CO_2 emissions impact on the consumption of fossil energy as initial input, middle product, final product, and circular correlation of the input–output process, and broke it down into direct effects, full effect, spread effect, and sensitive effect. Then they created a related method of an influence decoupling index to discover their decoupling status and source. Finally, the specific inspection plate is the breaking point of the CO_2 emissions reduction in the Yangtze River Case Study Economic Belt (YREB) sector for China. Their results show that: (1) CO_2-related emissions effects are higher in the Yangtze River Economic Belt (YREB) energy-intensive industries. (2) Decoupling of the YREB sector economic growth from carbon dioxide significantly reduces emissions, i.e., it is affected by the decoupling correlation, which reduces the impact of CO_2 emissions energy-intensive industries. (3) Carbon dioxide emissions of key sectors of the Yangtze River Economic Belt decline with the energy-intensive industries' focus on the decoupling part of the correlation, which reduces the impact of sectoral CO_2 emissions.

The study by Zhao et al. (2022) [33] analyzed relationships between economic development and carbon emissions with panel data from 2009 to 2019 for China by applying the Tapio decoupled model and logarithmic mean divisia index model (LMDI). The result shows carbon emissions and economic development is increasing year by year. The economic development trend growth rate and carbon emissions growth rate present the feature of stability and stage. They show that Chinese carbon emissions and economic development are basically in a weak decoupled state and are positively related. The significant differences pointed out by the decoupling index between the four areas are mainly that the central region is better than the eastern region, the east zone is better than the northeast region, the northeast region is better than the western region, and the growth of the province in the section is unstable. From the driver's perspective, population size elasticity and economic intensity can control carbon emissions decoupling, while the elasticity of energy intensity and carbon intensity have a positive influence.

The study by Sun et al. (2022) [34] used carbon emissions from agricultural energy consumption (CEAEC) with data from the Yangtze River Economic Belt (YREB) from 2000 to 2017 with the decoupling model and LMDI decomposition model. The results showed that carbon emissions from CEAEC from the YREB showed a phased increase with a peak of 1732.25104 tons in 2012, except for some reduction in Shanghai, Chongqing, and Guizhou, which shows that all provincial CEAEC have risen to varying degrees. In contrast, the strength of CEAEC in the YREB has been declining since 2005. The economic output effect is a significant contributor to growth in CEAEC, followed by the population effect. In contrast, the energy intensity effect and energy structure effects are the main reasons for the reduction in CEAEC. Spatial differences in CEAEC of the YREB saw a significant increase from 2000 to 2017. A study by Li et al. (2022) [35] explains the main aspects of the distressing levels of CO_2 emissions from the electric power industry by the relation between CO_2 emissions and growth in the regional economy with the Tapio decoupling index and LMDI model for the Jing-jin-ji section of China from the period 2000–2017. They find that in the region of Jing-jin-ji, the decoupling state moved in a weak decoupling in 2004–2017 from the ranges 0.85 to 0.38, respectively, due to China's 11th five-year plan.

Finally, a study by Liu et al. (2022) [36] analyses the consumption of electricity and carbon dioxide emissions with the Tapio index of decoupling of more than 600 counties in China from 2009 to 2016. They indicated higher decoupling for the year 2016 for most counties for carbon dioxide emissions and consumption of electricity than in 2009. Moreover, they found that the more poverty-stricken counties have more pronounced electricity consumption decoupling from CO_2 emissions relative to non-poverty-stricken counties. They also declare that as the secondary industry's carbon intensity has seen a downward trend in current times, the secondary industry development can benefit the decoupling of electricity consumption from CO_2 emissions, and renewable energy's advancement can perform a similar role.

4. Materials and Methods

The present study investigates electricity consumption, CO_2 emissions, and GDP growth decoupling. Furthermore, this section identifies the variables of the study. Additionally, the study uses the decoupling analysis (DA) methodology to investigate the influence and association between constructs.

4.1. Data

The study uses the World Development Indicators from the World Bank database [36]. The data covers annual observations from 1971 to 2020 for the economy of China for selected variables of the study. Table 1 presents the details of the variables of the study. To examine the data for selected variables of the study, which consist of electricity consumption, GDP growth, CO_2 emissions, energy use, total population, and urban population. Furthermore, the study incorporated a linear interpolation scheme to handle missing values in the sample.

Table 1. Data and the sources for China, 1971–2020.

Variable	Notation	Description	Source
Economic Development	GDP_g	GDP per capita (current US dollars)	WDI
Electricity Consumption	EL_c	Electric power consumption (kWh per capita)	WDI
CO_2 Emissions	CO_2_em	CO_2 emissions (metric tons per capita)	WDI
Energy Use	ENE_u	Energy use (kg of oil equivalent per capita)	WDI
Population Total	POP_t	Population, total (ten thousand)	WDI
Population Urban	POP_u	The population in urban areas (percentage of population in total)	WDI

Source: WDI (2022) [37].

4.2. The Decoupling Analysis (DA)

The study uses the decoupling method of Tapio as the scheme of methodology. Tapio methodology uses the percentage change in growth elasticity. The decoupling analysis (DA) authenticates the correlation among the interrelated variables. In the present study, the decoupling is illustrated as %Δ in consumption of electricity (%Δ EL_c) to the %Δ in the growth of GDP after the (0) base year towards the target year (t). Hence, our study proposes model (1) as:

$$\text{GDP\_g elasticity of EL\_c} = \%\ \Delta\ \text{EL\_c}/\%\Delta\text{GDP\_g} \quad (1)$$

In model (1), GDP shows the GDP growth of China measured in per capita, EL_c represents the electricity consumption measured in units of kilowatt hours per capita (KWH), and (% Δ) depicts the percentage change of interrelated variables from (0) to the base year (t).

Electricity consumption involves the emission of greenhouse gases from devices and machinery run on electricity. So, we computed the decoupling effect of electricity consumption on CO_2 emissions. Commencing electricity consumption is shown in Equation (2) as:

$$\text{EL\_c elasticity of } CO_2\text{\_em} = \%\Delta\ CO_2\text{\_em}/\%\Delta\ \text{EL\_c} \quad (2)$$

The Equations (1) and (2) collectively provide the product of them in Equation (3) as:

$$\text{GDP\_g elasticity of (EL\_c) of } CO_2\text{\_em} = \%\Delta\ CO_2\text{\_em}/\%\Delta\text{GDP\_g} \quad (3)$$

Here (%Δ CO_2_em) signifies the percentage change in CO_2 emissions measured in metric tons per capita, and (%ΔGDP_g) represents the percentage change in GDP growth measured in units per capita. Tapio [6] illustrates the decoupling states in eight subsections. Figure 1 represents all the rational options of decoupling amid EL_c and GDP_g.

5. Results of the Analysis and Discussion

5.1. Summary Statistics and Correlation Analysis

Table 2 depicts the results of the summary statistics. The results show that the mean of CO_2_em in China is 3.452 with a median of 2.515. The average of EL_c is 1553.395 and shows a median value of 795.6806. The average value for ENG-u is 1934.640 with a median of 868.0965. The average value for China for GDP_g is 2318.828 with a median of 2318.828. The variable POP_t shows a mean value of 1.18×10^9 with a median of 1.21×10^9. The average value for the Chinese economy for the variable POP_u is 4.27×10^8, with a median of 3.81×10^8.

Table 2. The Summary Statistics of Variables.

Statistics	CO_2_em	EL_c	ENG_u	GDP_g	POP_t	POP_u
Mean	3.452557	1553.395	1934.640	2318.828	1.18×10^9	4.27×10^8
Median	2.515556	795.6806	868.0965	659.5352	1.21×10^9	3.81×10^8
Maximum	7.413452	5787.219	43380.78	10434.78	1.41×10^9	8.67×10^8
Minimum	1.042240	151.9893	464.9332	118.6546	8.41×10^8	1.45×10^8
Std.Dev.	2.262846	1652.723	6008.991	3198.695	1.73×10^8	2.28×10^8
Skewness	0.748070	1.193946	6.758475	1.403665	−0.363526	0.440920
Kurtosis	1.937867	3.117083	47.13242	3.487179	1.826624	1.885087
Jarque–Bera	7.013671	11.90778	4438.288	16.91344	3.969617	4.209737
Probability	0.029992	0.002596	0.000000	0.000212	0.137407	0.121862

Moreover, to specify more dataset characteristics, we present a detailed summary with Std. Dev. Skewness, Kurtosis, and Jarque–Bera test. The detailed summary analysis of CO_2_em for Std. Dev. Skewness, Kurtosis, and Jarque–Bera shows values of 2.262846, 2.262846, 1.937867, and 7.013671, respectively. The detailed summary analysis of EL_c for Std. Dev. Skewness, Kurtosis, and Jarque–Bera shows values of 1652.723, 1.193946, 3.117083, and 11.90778, respectively. The detailed summary analysis of ENG-u for Std. Dev. Skewness, Kurtosis, and Jarque–Bera shows 6008.991, 6.758475, 47.13242, and 4438.288, respectively. The detailed summary analysis of GDP_g for Std. Dev. Skewness, Kurtosis, and Jarque–Bera shows values of 3198.695, 1.403665, 3.487179, and 16.91344, respectively. The detailed summary analysis of POP_t for Std. Dev. Skewness, Kurtosis, and Jarque–Bera shows values of 1.73×10^8, −0.363526, 1.826624, and 3.969617, respectively. The detailed summary analysis of POP-u for Std. Dev. Skewness, Kurtosis, and Jarque–Bera shows values of 2.28×10^8, 0.440920, 1.885087, and 4.209737, respectively.

Additionally, Table 3 depicts the values of the correlation matrix. In the table, it is evident that EL_c and GDP_g show a significant positive correlation. A significant positive correlation shows CO_2_em and EL_c. Finally, the correlation matrix shows a significant positive correlation for the CO_2_em and GDP_g nexus.

Table 3. Correlation Matrix.

Variables	1	2	3	4	5	6	7
1. GDP_g	1.0000						
2. EL_c	0.9895 *** 0.0000	1.0000					
3. CO_2_em	0.9400 *** 0.0000	0.9677 *** 0.0000	1.0000				
4. EN_u	0.9775 *** 0.0000	0.9957 *** 0.0000	0.9851 *** 0.0000	1.0000			
6. POP_t	0.7441 *** 0.0000	0.8160 *** 0.0000	0.8724 *** 0.0000	0.8425 *** 0.0000	0.7288 *** 0.0000	1.0000	
7. POP_u	0.9060 *** 0.0000	0.9516 *** 0.0000	0.9716 *** 0.0000	0.9646 *** 0.0000	0.8953 *** 0.0000	0.9478 *** 0.0000	1.0000

Note: *** shows significance at ($p < 0.01$).

5.2. Empirical Analysis Results and Discussions

5.2.1. The Trends in Consumption of Electricity, Carbon (CO_2) Emissions and the Economy of China

Figure 2 shows the electric power consumption trend for the economy of China from the period 1971–2020. In Figure 2, the *X*-axis illustrates the annual time window, and the *Y*-axis presents electric power consumption in kWh per capita. It shows the upward trend in the graph, which indicates electricity demand is increasing over time. This trend shows that the increasing domestic electricity demand in households and industries in China is drastically increasing due to economic development. Figure 3 depicts annual measures of GDP per capita for the economy of China from the year 1971 to 2020. In Figure 3, the *X*-axis exhibits the yearly time frame, and the *Y*-axis shows GDP per capita in US dollars and depicts an upward trend over time. Figure 4 displays the CO_2 emissions trend for the economy of China from the period 1971–2020. In Figure 4, the *X*-axis presents CO_2 emissions in metric tons per capita, and the *Y*-axis illustrates the annual time–space. The increasing trend in CO_2 emissions shows a sharp increase over time due to economic expansion, energy production, industrial development, and the use of devices and machinery.

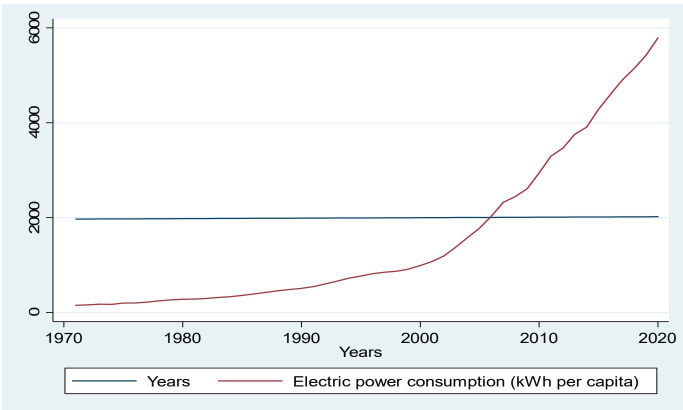

Figure 2. The electric power consumption trend for the economy of China for the period 1971–2020.

5.2.2. The Decoupling Analysis (DA) of Consumption of Electricity and the Economy of China

Here we have explored the linkage between the consumption of electricity and economic growth with a decoupling states comparison. Table 4 and Figure 5 present six types of decoupling states: strong decoupling, weak decoupling, expansive coupling, strong negative decoupling, expansive negative decoupling, and recessive coupling. The economy of China has seen a 2318.828 annual upsurge in the data window, and electricity consumption has also increased In line with the passage of this time frame. The economy of China from the period 1971 to 2020 experienced weak and expansive negative decoupling in large numbers. These results show that weak decoupling happens when there is faster economic growth, and the expansive negative decoupling shows that electricity consumption has also grown faster.

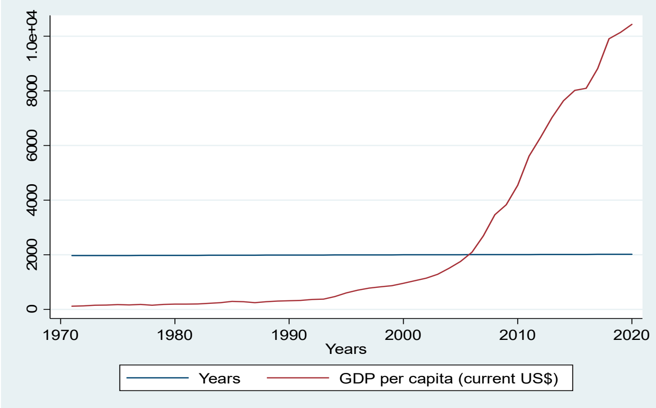

Figure 3. The GDP per capita trend for the economy of China for the period 1971–2020.

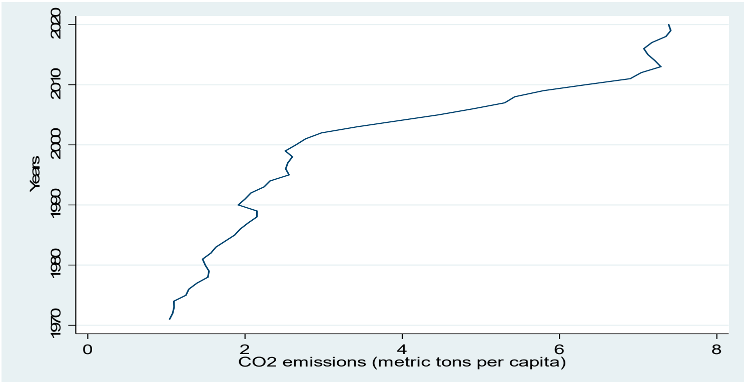

Figure 4. The CO_2 emissions trend for the economy of China for the period 1971–2020.

Table 4. The states of decoupling of electricity consumption total and GDP in China during 1971–2020.

Years	% ΔEL_Con	% Δ GDP	% ΔEL_Con/% ΔGDP	States of Decoupling
1971–1972	0.078443534	0.111491556	0.703582735	Weak Decoupling
1972–1973	0.073343095	0.191129302	0.383735482	Weak Decoupling
1973–1974	−0.009664907	0.019413789	−0.497837251	Strong Decoupling
1974–1975	0.142374357	0.113661267	1.252619836	Expansive Coupling
1975–1976	0.025073636	−0.072536432	−0.34566955	Strong Negative Decoupling
1976–1977	0.081491244	0.12101948	0.67337295	Weak Decoupling
1977–1978	0.11737091	−0.15654191	−0.749773083	Strong Negative Decoupling
1978–1979	0.084437257	0.17639003	0.478696312	Weak Decoupling
1979–1980	0.053297657	0.058818266	0.906141251	Expansive Negative Decoupling
1980–1981	0.014888924	0.011636023	1.279554278	Expansive Coupling
1981–1982	0.046813555	0.031782606	1.47293005	Expansive Coupling
1982–1983	0.059567044	0.108672969	0.548131194	Weak Decoupling
1983–1984	0.061167648	0.112149332	0.545412505	Weak Decoupling
1984–1985	0.078476567	0.174481221	0.449770847	Weak Decoupling
1985–1986	0.078662082	−0.042555106	−1.848475761	Strong Negative Decoupling
1986–1987	0.089952017	−0.106822136	−0.842072825	Strong Negative Decoupling
1987–1988	0.082622562	0.125989801	0.655787703	Weak Decoupling
1988–1989	0.055382833	0.096439442	0.574275749	Weak Decoupling
1989–1990	0.04769791	0.022525468	2.117510271	Expansive Decoupling

Table 4. *Cont.*

Years	% ΔEL_Con	% Δ GDP	% ΔEL_Con/% ΔGDP	States of Decoupling
1990–1991	0.075073262	0.04799688	1.564127977	Expansive Negative Decoupling
1991–1992	0.101538481	0.100013005	1.015252777	Expansive Negative Decoupling
1992–1993	0.095822669	0.029823518	3.212990087	Expansive Decoupling
1993–1994	0.097293555	0.254650309	0.382067297	Weak Decoupling
1994–1995	0.059376213	0.287574701	0.206472311	Weak Decoupling
1995–1996	0.065950826	0.163628283	0.403052726	Weak Decoupling
1996–1997	0.038558721	0.101958002	0.378182386	Weak Decoupling
1997–1998	0.020963625	0.059912587	0.349903517	Weak Decoupling
1998–1999	0.049787926	0.053955631	0.922756811	Expansive Negative Decoupling
1999–2000	0.086414765	0.098576317	0.87662806	Expansive Negative Decoupling
2000–2001	0.084199903	0.097705282	0.861774317	Expansive Negative Decoupling
2001–2002	0.109894822	0.090589024	1.213114097	Expansive Coupling
2002–2003	0.154519282	0.122014758	1.266398299	Expansive Coupling
2003–2004	0.149587857	0.170741472	0.876107342	Expansive Negative Decoupling
2004–2005	0.123892399	0.16222901	0.763688312	Weak Decoupling
2005–2006	0.144027805	0.197221449	0.730284691	Weak Decoupling
2006–2007	0.140711155	0.283313781	0.496661881	Weak Decoupling
2007–2008	0.051782493	0.287432496	0.180155318	Weak Decoupling
2008–2009	0.067891459	0.104930758	0.647011999	Weak Decoupling
2009–2010	0.126751706	0.1874145	0.676317501	Weak Decoupling
2010–2011	0.119648089	0.233800679	0.511752531	Weak Decoupling
2011–2012	0.05165224	0.122233691	0.422569586	Weak Decoupling
2012–2013	0.084005744	0.114230651	0.735404579	Weak Decoupling
2013–2014	0.039426461	0.087713451	0.449491612	Weak Decoupling
2014–2015	0.096095822	0.049804744	1.929451163	Expansive Coupling
2015–2016	0.074043751	0.009721524	7.616475579	Expansive Decoupling
2016–2017	0.065731976	0.089274907	0.736287256	Weak Decoupling
2017–2018	0.050004064	0.123438439	0.405093135	Weak Decoupling
2018–2019	0.053465927	0.02407753	2.220573573	Recessive Coupling
2019–2020	0.067784388	0.028681157	2.363377041	Recessive Coupling
Average	0.0777	0.099629	0.860635	

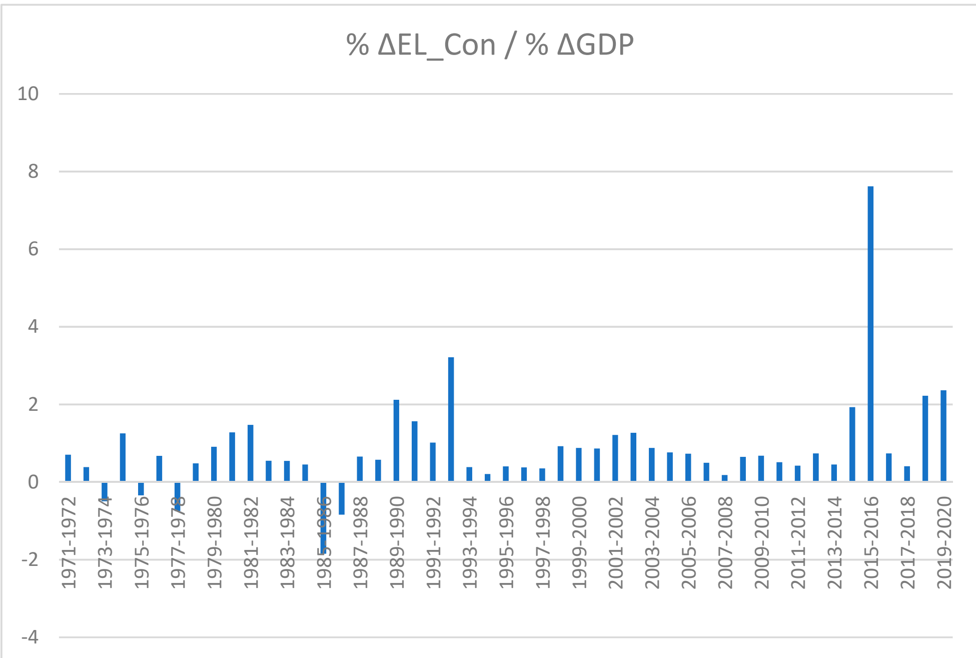

Figure 5. The states of decoupling of electricity consumption total and GDP in China during 1971–2020.

Overall, from 1971 to 2020, the decoupling effect for CO_2 emissions and economic development has shown a weak decoupling effect and positive correlation. In this period, the growth rate for electricity consumption (% ΔEL_c) is 0.077699904, and the average growth of economic development (% Δ GDP_g) is 0.099628643. Here it is evident that the growth of an economy is higher than the average growth of electricity consumption and shows the effect of weak decoupling. The decoupling index from the period 1971–2020 shows variations and expansive decoupling in 2014–2016.

5.2.3. The Decoupling Analysis (DA) of CO_2 emissions and Consumption of Electricity

Here we have explored the linkage between CO_2 emissions and consumption of electricity with decoupling states comparison. Table 5 and Figure 6 display the decoupling states in five types: strong decoupling, weak decoupling, expansive coupling, expansive negative decoupling, and recessive coupling. The economy of China has seen an average of 2318.828 annual upsurges, and electricity consumption has also increased in line with the passage of this time frame. The economy of China during the period from 1971 to 2020 experienced weak and strong decoupling in large numbers for the decoupling relation between CO_2 emissions and consumption of electricity. These results show that weak decoupling happens when there is a sharp increase in electricity consumption over time. The expansive negative decoupling shows that CO_2 emissions have also grown at a quicker pace over time.

Table 5. The states of decoupling of CO_2 emissions and electricity consumption in China during 1971–2020.

Years	% ΔCO_2_em	% ΔEL_Con	%ΔCO_2_em/% ΔEL_Con	States of Decoupling
1971–1972	0.036879175	0.078443534	0.470136583	Weak Decoupling
1972–1973	0.01621119	0.073343095	0.221032266	Weak Decoupling
1973–1974	−0.000754493	−0.009664907	0.078065187	Recessive Coupling
1974–1975	0.139203174	0.142374357	0.977726442	Expansive Negative Decoupling
1975–1976	0.02812444	0.025073636	1.121673803	Expansive Coupling
1976–1977	0.0805735	0.081491244	0.988738125	Expansive Coupling
1977–1978	0.10106126	0.11737091	0.8610418	Weak Decoupling
1978–1979	0.00881113	0.084437257	0.104351205	Weak Decoupling
1979–1980	−0.030741631	0.053297657	−0.576791423	Strong Decoupling
1980–1981	−0.02328635	0.014888924	−1.564004961	Strong Decoupling
1981–1982	0.072792078	0.046813555	1.554935911	Expansive Coupling
1982–1983	0.03977446	0.059567044	0.667725923	Weak Decoupling
1983–1984	0.074516873	0.061167648	1.218239962	Expansive Coupling
1984–1985	0.068900491	0.078476567	0.877975354	Weak Decoupling
1985–1986	0.036545945	0.078662082	0.464594171	Weak Decoupling
1986–1987	0.051033662	0.089952017	0.567343159	Weak Decoupling
1987–1988	0.055187376	0.082622562	0.667945586	Weak Decoupling
1988–1989	0.001010126	0.055382833	0.018238978	Weak Decoupling
1989–1990	−0.11078807	0.04769791	−2.322702814	Strong Decoupling
1990–1991	0.044921901	0.075073262	0.59837417	Weak Decoupling
1991–1992	0.037588204	0.101538481	0.370186784	Weak Decoupling
1992–1993	0.080694359	0.095822669	0.84212181	Weak Decoupling
1993–1994	0.033783088	0.097293555	0.347228422	Weak Decoupling
1994–1995	0.104068176	0.059376213	1.752691369	Expansive Coupling
1995–1996	−0.016839125	0.065950826	−0.255328498	Strong Decoupling
1996–1997	0.010412521	0.038558721	0.270043227	Weak Decoupling
1997–1998	0.023206335	0.020963625	1.106981052	Expansive Coupling
1998–1999	−0.03405495	0.049787926	−0.684000173	Strong Decoupling
1999–2000	0.053551239	0.086414765	0.61970011	Weak Decoupling
2000–2001	0.046988923	0.084199903	0.558063859	Weak Decoupling
2001–2002	0.072630465	0.109894822	0.660908895	Weak Decoupling
2002–2003	0.151658787	0.154519282	0.981487779	Expansive Negative Decoupling
2003–2004	0.15367184	0.149587857	1.027301563	Expansive Negative Decoupling

Table 5. *Cont.*

Years	% ΔCO_2_em	% ΔEL_Con	%ΔCO_2_em/% ΔEL_Con	States of Decoupling
2004–2005	0.129478476	0.123892399	1.045088138	Expansive Negative Decoupling
2005–2006	0.099151752	0.144027805	0.688420907	Weak Decoupling
2006–2007	0.080830995	0.140711155	0.574446249	Weak Decoupling
2007–2008	0.024330694	0.051782493	0.469863317	Weak Decoupling
2008–2009	0.066966099	0.067891459	0.98637	Expansive Negative Decoupling
2009–2010	0.092629812	0.126751706	0.730797359	Weak Decoupling
2010–2011	0.089382011	0.119648089	0.747040853	Weak Decoupling
2011–2012	0.020533047	0.05165224	0.397524813	Weak Decoupling
2012–2013	0.035403017	0.084005744	0.421435668	Weak Decoupling
2013–2014	−0.010457644	0.039426461	−0.265244302	Strong Decoupling
2014–2015	−0.012279385	0.096095822	−0.12778272	Strong Decoupling
2015–2016	−0.007344557	0.074043751	−0.099192127	Strong Decoupling
2016–2017	0.014571688	0.065731976	0.2216834	Weak Decoupling
2017–2018	0.024713029	0.050004064	0.494220409	Weak Decoupling
2018–2019	0.00832254	0.053465927	0.15566063	Weak Decoupling
2019–2020	−0.003539735	0.067784388	−0.052220503	Strong Decoupling
Average	0.042041	0.0777	0.428166	

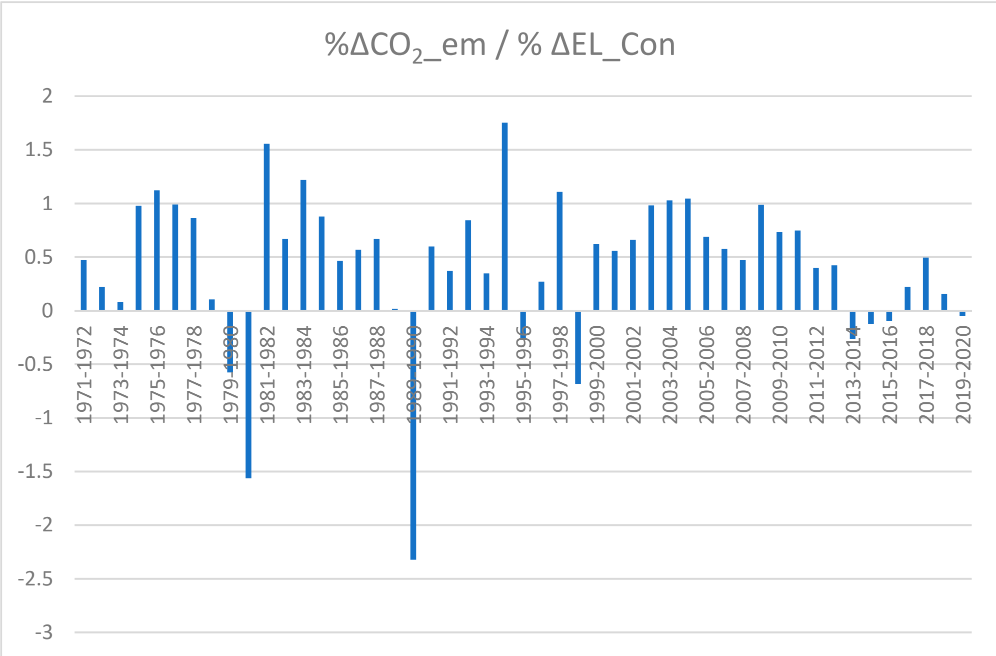

Figure 6. The states of decoupling of CO_2 emissions and consumption of electricity in China during 1971–2020.

Collectively, from 1971 to 2020, CO_2 emissions and electricity consumption have shown a weak decoupling effect and positive correlation. In this period, the growth rate for electricity consumption (% ΔEL_c) is 0.077699904, and the average growth of CO_2 emissions (% ΔCO_2_em) is 0.042041386. Here it is evident that the electricity consumption growth is higher than the average growth of CO_2 emissions and shows the effect of weak decoupling. The decoupling index from 1971 to 2020 shows variations and a downward trend from 0.47 to −0.05. From a static view, the power generation sector contributes massively to CO_2 emissions. China is much more reliant on fossil fuels that produce heat and electricity and emit a large amount of CO_2.

5.2.4. The Decoupling Analysis (DA) of CO_2 Emissions and the Economy of China

Here we have shown the relationship between CO_2 emissions and economic growth with a decoupling states comparison. Table 6 and Figure 7 show the decoupling states in five types: strong decoupling, weak decoupling, recessive coupling, expansive negative decoupling, and strong negative decoupling. The economy of China has seen a 2318.828 annual average increase, and the CO_2 emissions have also increased in line with the passage of this time frame. The economy of China during the period from 1971 to 2020 experienced weak decoupling and strong decoupling in large numbers amid CO_2 emissions and the growth of the economy. These results show that weak decoupling happens when there is faster economic growth. Strong decoupling shows that CO_2 emissions also rose faster from 1971 to 2020.

Table 6. The states of decoupling of CO_2 emissions and GDP in China during 1971–2020.

Years	% ΔCO_2_em	% Δ GDP	% ΔCO_2_em/% ΔGDP	States of Decoupling
1971–1972	0.036879175	0.111491556	0.330779982	Weak Decoupling
1972–1973	0.01621119	0.191129302	0.084817923	Weak Decoupling
1973–1974	−0.000754493	0.019413789	−0.038863758	Strong Decoupling
1974–1975	0.139203174	0.113661267	1.224719536	Expansive Negative Decoupling
1975–1976	0.02812444	−0.072536432	−0.387728479	Strong Negative Decoupling
1976–1977	0.0805735	0.12101948	0.665789508	Weak Decoupling
1977–1978	0.10106126	−0.15654191	−0.645585965	Strong Negative Decoupling
1978–1979	0.00881113	0.17639003	0.049952537	Weak Decoupling
1979–1980	−0.030741631	0.058818266	−0.522654502	Strong Decoupling
1980–1981	−0.02328635	0.011636023	−2.001229238	Strong Decoupling
1981–1982	0.072792078	0.031782606	2.290311828	Recessive Coupling
1982–1983	0.03977446	0.108672969	0.366001408	Weak Decoupling
1983–1984	0.074516873	0.112149332	0.66444331	Weak Decoupling
1984–1985	0.068900491	0.174481221	0.394887718	Weak Decoupling
1985–1986	0.036545945	−0.042555106	−0.858791064	Strong Negative Decoupling
1986–1987	0.051033662	−0.106822136	−0.477744256	Strong Negative Decoupling
1987–1988	0.055187376	0.125989801	0.438030501	Weak Decoupling
1988–1989	0.001010126	0.096439442	0.010474203	Weak Decoupling
1989–1990	−0.11078807	0.022525468	−4.918347065	Strong Decoupling
1990–1991	0.044921901	0.04799688	0.935933779	Recessive Coupling
1991–1992	0.037588204	0.100013005	0.37583316	Weak Decoupling
1992–1993	0.080694359	0.029823518	2.705729029	Recessive Coupling
1993–1994	0.033783088	0.254650309	0.132664625	Weak Decoupling
1994–1995	0.104068176	0.287574701	0.361882237	Weak Decoupling
1995–1996	−0.016839125	0.163628283	−0.102910847	Strong Decoupling
1996–1997	0.010412521	0.101958002	0.102125592	Weak Decoupling
1997–1998	0.023206335	0.059912587	0.387336563	Weak Decoupling
1998–1999	−0.03405495	0.053955631	−0.631165818	Strong Decoupling
1999–2000	0.053551239	0.098576317	0.543246505	Weak Decoupling
2000–2001	0.046988923	0.097705282	0.480925101	Weak Decoupling
2001–2002	0.072630465	0.090589024	0.801757898	Weak Decoupling
2002–2003	0.151658787	0.122014758	1.242954454	Expansive Negative Decoupling
2003–2004	0.15367184	0.170741472	0.900026442	Expansive Negative Decoupling
2004–2005	0.129478476	0.16222901	0.798121596	Weak Decoupling
2005–2006	0.099151752	0.197221449	0.50274325	Weak Decoupling
2006–2007	0.080830995	0.283313781	0.285305554	Weak Decoupling
2007–2008	0.024330694	0.287432496	0.084648375	Weak Decoupling
2008–2009	0.066966099	0.104930758	0.638193226	Weak Decoupling
2009–2010	0.092629812	0.1874145	0.494251043	Weak Decoupling

Table 6. *Cont.*

Years	% ΔCO_2_em	% Δ GDP	% ΔCO_2_em/% ΔGDP	States of Decoupling
2010–2011	0.089382011	0.233800679	0.382300047	Weak Decoupling
2011–2012	0.020533047	0.122233691	0.167981896	Weak Decoupling
2012–2013	0.035403017	0.114230651	0.30992572	Weak Decoupling
2013–2014	−0.010457644	0.087713451	−0.119225089	Strong Decoupling
2014–2015	−0.012279385	0.049804744	−0.246550517	Strong Decoupling
2015–2016	−0.007344557	0.009721524	−0.755494411	Strong Decoupling
2016–2017	0.014571688	0.089274907	0.163222662	Weak Decoupling
2017–2018	0.024713029	0.123438439	0.200205295	Weak Decoupling
2018–2019	0.00832254	0.02407753	0.345655881	Weak Decoupling
2019–2020	−0.003539735	0.028681157	−0.123416738	Strong Decoupling
Average	0.042041	0.099629	0.163948	

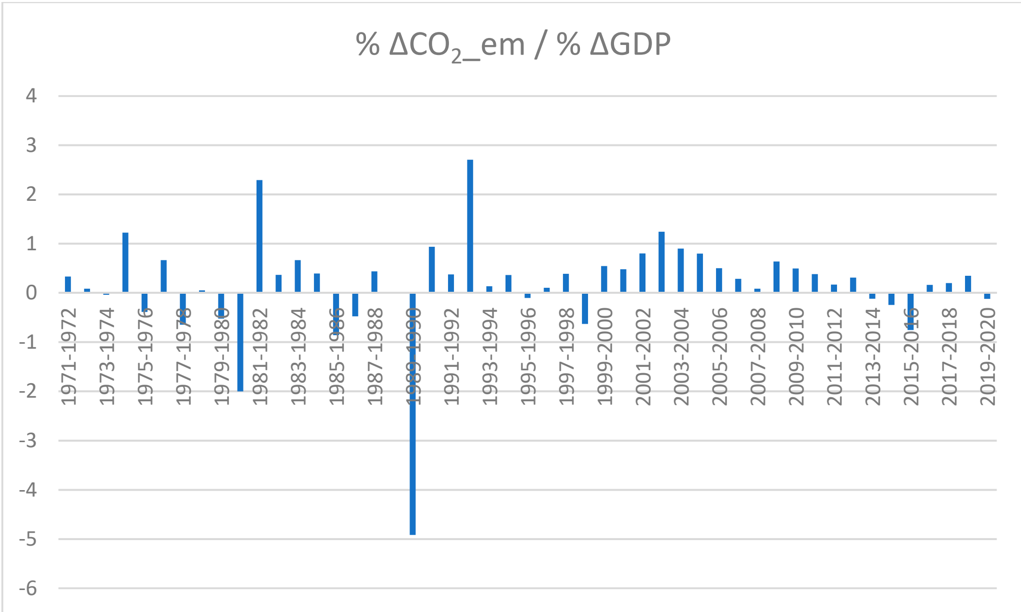

Figure 7. The states of decoupling of CO_2 emissions and GDP in China during 1971–2020.

In addition, from 1971 to 2020, the decoupling effect for CO_2 emissions and economic development has shown a weak decoupling effect and positive correlation. In this period, the growth rate for CO_2 emissions (% ΔCO_2_em) was 0.042041386, and the average growth of economic development (% Δ GDP_g) was 0.099628643. Here it is evident that the economic growth was higher than the average growth of CO_2 emissions and shows the effect of weak decoupling. The decoupling index from 1971 to 2020 shows variations and a downward trend from 0.33 to −0.12, which is due to careful measures taken into account by the government of China for CO_2 emissions to alter the industrial arrangement by increasing the dynamic policy for the low-CO_2 and green economy with the collaboration of international settings to change the climate.

5.3. Additional Analysis: Granger Causality Test

To know the direction of causality among the main variables of the study, we incorporated an analysis of Granger Causality [38]. The given model for Granger causality is:

$$Y_t = £_i + \sum_{n=1}^{n} \delta_i{}^{(n)} \; Y_{it\_n} + \sum_{n=1}^{n} \beta_{it}{}^{(n)} \, X_{it\_n} + \varepsilon_{it} \quad (4)$$

In the model (4) X and Y are the stationary variables to represent the time and the state of the economy. The given test assumes that explicit effects are stationary and have a common lag order. Whereas $\delta_i^{(n)}$ states the autoregressive parameter, the expression $\beta_{it}^{(n)}$ shows the coefficient's slope. For the state in which elder ideal X variables observe continuing entity i, the estimate is upgraded for the Y variables intended at that element i, in which case it is safe to forecast that X lands at the Y.

Table 7 shows the experiential results for the Granger causality analysis. The test of the Granger analysis illustrates unidirectional causality for CO_2 emissions and electricity consumption. The unidirectional causality appears between the growth of economic development and the growth in CO_2 emissions. Finally, the relationship between the growth of electricity consumption and the growth of the economy shows unidirectional causality.

Table 7. Test of Granger Causality.

Null Hypothesis	Prob:	F-Stat:	Obs.
% Δ EL_c does not Granger Cause %ΔCO_2_em	0.4998 *	0.85505	48
%ΔCO_2_em does not Granger Cause %ΔEL_c	0.0001	2.64803	
%ΔGDP_g does not Granger Cause %ΔCO_2_em	0.0022 *	3.2480	48
%ΔCO_2_em does not Granger Cause %ΔGDP_g	4.0×10^{-8}	7.66489	
%ΔGDP_ does not Granger Cause %ΔEL-c	0.0157 *	4.57900	48
%ΔEL_c does not Granger Cause %ΔGDP_g	0.0001	11.5548	

Note: * shows significance level ($p < 0.01$).

To find the direction of the causality, it is essential first to explore the stationarity of the series of data with the unit root test, with the assumption that at the first difference, the variable series have to be stationary since the causality test requires stationary series as a prerequisite; moreover, the projected estimates are considered to be spurious if the data series is not stationary [38]. Here we have applied augmented Dickey–Fuller (ADF) test and Phillips–Perron (PP) test with a series of intercepts and trends, as shown in Table 8. The ADF and PP tests are both based on the criterion of Akaike information (AIC), as shown in Table 9, for the selection of the optimal length of lag. Moreover, both ADF and PP tests use the chi-square Fisher distribution, and the likelihood for the Fisher test is computed asymptotically via Chi-square distribution.

Table 8. Test of Unit Root.

Variables	ADF-Test		PP-Test	
	I(0)	I(1)	I(0)	I(1)
%ΔCO_2_em	−0.575134 (0.86657)	−3.326939 ** (0.0190)	−0.575134 (0.8665)	−3.328565 ** (0.0189)
%ΔEL_c	−0.833895 (0.8004)	−3.035079 ** (0.0387)	−0.637644 (0.8524)	−3.035079 ** (0.0387)
%ΔGDP_g	−1.992755 (0.2890)	−6.560591 * (0.0000)	−1.992755 (0.2890)	−6.447658 * (0.0000)

Notes: *, ** show significance level ($p < 0.01$), and ($p < 0.05$).

Table 9. Selection of Optimal Lag Length for test of Granger Causality based on (AIC).

Null Hypothesis	(AIC)-Lag Length L (0)	L(1)	L (2)	L(4)	L (5)	L (6)
CO_2_em => GDP_g GDP_g => CO_2_em	−2.549832 *	−2.629116	−2.080886	−1.485861	−1.180183	−0.978388
CO_2_em => EL_c EL_c => CO_2_em	−4.488560 *	−4.399347	−4.228746	−3.916094	−2.929532	−2.753448
EL_c => GDP_g GDP_g => EL_c	−2.668898	−2.703904 *	−2.593575	−2.495889	−2.348120	−2.305389

Note: * shows significance level ($p < 0.01$).

5.4. Discussion

The following section discusses the significant outcomes of the research.

First, the average growth in electricity consumption driven by GDP growth was 0.860635 during 1971–2020. In China, households and industrial sectors are the major contributors to the increase in electricity consumption. These findings of the study relate to the researches Wang et al. (2010) [39], and Zhang et al. (2019) [40], who used the IDA model to evaluate electricity consumption in industry and overall electricity usage for the whole of China. Energy efficiency in terms of electricity utilization and economic growth or GDP has a dynamic relationship. Therefore, the findings also show an upward trend in electricity consumption and GDP along with time, which is also evident in Figures 2 and 3.

Second, the average growth in CO_2 emissions driven by electricity consumption was 0.428166 during 1971–2020. At the industry level, the power sector is the main source of CO_2 emissions in China since it is based on thermal power utilizing coal resources. Therefore, the role of energy in terms of efficiency which promotes the decoupling with CO_2 has increased. The findings also present an upward trend in electricity consumption and CO_2 with time, which is also evident in Figures 2 and 4. These findings relate to the research of Diakoulaki et al. (2017) [41], and Li et al., 2019 [42]. Most of the literature focuses on the energy consumption phase. For example, Karmellos et al. (2016) [43], Sumabat et al., (2016) [44], Jiang & Li, (2017) [45], and Goh et al., (2018) [46] investigated the variations in CO_2 emissions using the LMDI technique to decompose the dynamic elements.

Third, the average growth in CO_2 emissions driven by economic growth was 0.163948 from 1971 to 2020. From the viewpoint of the features of economic growth and CO_2 emissions, CO_2 emissions and economic development are growing equally year by year, the GDP growth rate is comparatively fast, and the CO_2 growth trend is relatively flat, which relates to the policy objective of low CO_2 along with economic growth from 1971 to 2020. CO_2 emissions and economic development have shown a weak decoupling effect and positive correlation. In this period, the growth rate for CO_2 emissions (% ΔCO_2_em) was 0.042041386, and the average growth of economic development (% Δ GDP_g) was 0.099628643. Here it is evident that the economic growth was higher than the average growth of CO_2 emissions, and showed weak decoupling, as shown in Figure 7. The effect is due to careful measures taken into account by the government of China for CO_2 emissions to alter the industrial arrangement by increasing the dynamic policy for the low-CO_2 and green economy, with the collaboration of international settings to change the climate. These findings relate to the study of Zhao et al. (2022) [33].

6. Conclusions

This research aims to determine whether the economy of China has achieved effectively stable electricity consumption, and a CO_2 emissions reduction driven by sustainable economic growth in recent years. Investigating this research problem revealed the significant influence of decoupling among these relations. The present study contributes novel empirical results on the decoupling effect between electricity consumption and economic growth, CO_2 emissions and economic growth, and CO_2 emissions and electricity consumption. The main findings of the study are summarized as follows:

- The findings of the study show weak and expansive negative decoupling for electricity consumption and economic growth. It indicates that weak decoupling happens when there is faster economic growth, and consumption of electricity also grows at a faster pace with the expansive negative decoupling.
- The findings show weak and strong decoupling for CO_2 emissions and economic growth. These findings illustrate that weak decoupling happens when there is faster economic growth, and CO_2 emissions also grows at a faster pace with the strong decoupling.
- Moreover, the findings of the study show weak and strong decoupling for CO_2 emissions and electricity consumption decoupling. These results conclude that weak decoupling happens when there is fast growth in consumption of electricity, and CO_2 emissions also grow at a faster pace with strong decoupling.

- Additionally, empirical findings show unidirectional causality for CO_2 emissions and electricity consumption. The unidirectional causality appears between the growth of economic development and the growth of CO_2 emissions. Finally, the relationship between the growth of electricity consumption and the growth of the economy shows unidirectional causality.

Referring to the results of the present research, the subsequent inference and conclusion can be drawn. The decoupling analysis (DA) model shows that electricity is the main driving force enhancing the economic growth of China. However, industrialization has increased greenhouse gases, global warming, and climate change as a result of heavy production and consumption. China's economy is mostly based on coal for energy resources, which indicates that China produces a major proportion of its electricity with coal which produces high CO_2 emission. Therefore, industrialization in China exerted significant influence on the decoupling stability status as well as on prosperity, which leads to the increased steady status of decoupling, combining strong decoupling and weak decoupling. Precisely, the rise of the secondary industry sector leads to decoupling electricity consumption from CO_2 emissions, which is mainly due to substantial progress in the intensity of carbon from China's secondary industry in the current timeframe.

7. Policy Implications, Limitations and Recommendations for Future Studies

The present study offers some policy implications from the findings. Firstly, it may be a concrete policy to attain viable economic development by further reducing the intensity of CO_2 emissions of subordinate industry rather than by unseeingly endorsing the renovation of the business arrangement to a tertiary industry-ruled one. China is a state with a leading industrialized, value-added economy and broad business structure in the domain. Secondly, in November 2021, the Ministry of Industry and Information Technology revealed the 14th Five-Year Plan for green innovation and the development of industry. This strategy identifies the role of industry in China's economy and appeals for additional discounts in the CO_2 emissions concentration for industrial divisions over the subsequent five years. The strategy is appreciable and maintained by policymakers to enhance green innovation and the traditional industrial sector with low energy inputs and a higher level of value addition. Third, policymakers should endorse that renewable energy is reasonable for companies and domestic users. Policymakers can subsidize continuous technological innovation in renewable energy in the short and long term. Moreover, recently the government of China has initiated a project named Photovoltaic Poverty Alleviation (PVPA) which supports the energy requirements of people in underdeveloped areas', and this project also helps them to earn additional income from the generation of energy. Therefore, to keep this step more useful, policymakers should help maintain the trend of green innovation and maintain the operation of these plants by regularly employing experts.

Among issues for future research is the inclusion of some other macroeconomic variables and their role in the transition to renewable energy production [47], and cross-country comparisons. Though the present study has presented enough evidence in concept, future research should still build a theoretical framework to provide the decoupling conceptualization of economic growth from CO_2 emissions and electricity consumption in the context of emerging economies. Due to the unavailability of data on households' electricity consumption, future research should collect data for this sector from the survey. Moreover, the dynamic elements of CO_2 emissions are various and composite, and the present study covers only a few features. Therefore, future research can further measure additional factors, for instance, the industry structure and financial and economic arrangements.

Practically, the findings assist academic professionals, policymakers, and government agencies who formulate strategies and policies for institutions, macro and micro forefronts, the economy, and industry. The findings assist analysts and industry experts in supporting and improving the industry structure and policies to maintain industrial innovation in the energy sector. The evidence supports the government implementation of green innovation to enhance energy efficiency and lower environmental degradation. This research will help policymakers to formulate strategies to strengthen the legal support for the energy market, confirm the uniform process of the energy market, and stimulate the strong decoupling of China's economic growth, CO_2 emissions, and energy efficiency in terms of capacity utilization and production.

Author Contributions: Conceptualization, F.L.; methodology, F.L.; software, F.L. and F.A.; validation, Š.B. and H.-X.L.; formal analysis, F.L.; investigation, H.-X.L.; resources, F.A.; data curation, F.L.; writing—original draft preparation, F.L.; writing—review and editing, F.L, Š.B. and F.A.; visualization, F.L. and F.A.; supervision, H.-X.L. and Š.B.; project administration, H.-X.L. and Š.B. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the Xi'an Social Science Fund Project (2022) under the topic "Research on the Impact Mechanism and Implementation Path of ESG Ratings on Enterprise Performance—Taking Xi'an City as an Example" (Grant No. 22GL85).

Data Availability Statement: The data used in this study is in the public domain, and the relevant sources are cited in the text.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chen, G.; Wu, X. Energy overview for globalized world economy: Source, supply chain and sink. *Renew. Sustain. Energy Rev.* **2017**, *69*, 735–749. [CrossRef]
2. Klemeš, J.J.; Van Fan, Y.; Jiang, P. The energy and environmental footprints of COVID-19 fighting measures–PPE, disinfection, supply chains. *Energy* **2020**, *211*, 118701. [CrossRef] [PubMed]
3. Zhang, Y.; Chen, Q.; Chen, B.; Liu, J.; Zheng, H.; Yao, H.; Zhang, C. Identifying hotspots of sectors and supply chain paths for electricity conservation in China. *J. Clean. Prod.* **2020**, *251*, 119653. [CrossRef]
4. Zhang, C.; Zhou, K.; Yang, S.; Shao, Z. On electricity consumption and economic growth in China. *Renew. Sustain. Energy Rev.* **2017**, *76*, 353–368. [CrossRef]
5. Kraft, J.; Kraft, A. Relationship between energy and GNP. *J. Energy Finance Dev.* **1978**, *3*, 401–403.
6. Aqeel, A.; Butt, M.S. The relationship between energy consumption and economic growth in Pakistan. *Asia Pac. Dev. J.* **2001**, *8*, 101–110.
7. Mushtaq, K.; Abbas, F.; Ghafoor, A. Energy Use for Economic Growth: Cointegration and Causality Analysis from the Agriculture Sector of Pakistan. *Pak. Dev. Rev.* **2007**, *46*, 1065–1073. [CrossRef]
8. Shahbaz, M.; Feridun, M. Electricity consumption and economic growth empirical evidence from Pakistan. *Qual. Quant.* **2011**, *46*, 1583–1599. [CrossRef]
9. Tang, C.F.; Shahbaz, M. Sectoral analysis of the causal relationship between electricity consumption and real output in Pakistan. *Energy Policy* **2013**, *60*, 885–891. [CrossRef]
10. Ge, F.; Ye, B.; Xing, S.; Wang, B.; Sun, S. The analysis of the underlying reasons of the inconsistent relationship between economic growth and the consumption of electricity in China e a case study of Anhui province. *Energy* **2017**, *128*, 601–608. [CrossRef]
11. Meng, M.; Niu, D. Annual electricity consumption analysis and forecasting of China based on few observations methods. *Energy Convers. Manag.* **2011**, *52*, 953–957. [CrossRef]
12. Gao, C.; Su, B.; Sun, M.; Zhang, X.; Zhang, Z. Interprovincial transfer of embodied primary energy in China: A complex network approach. *Appl. Energy* **2018**, *215*, 792–807. [CrossRef]
13. Iyke, B.N. Electricity consumption and economic growth in Nigeria: A revisit of the energy-growth debate. *Energy Econ.* **2015**, *51*, 166–176. [CrossRef]
14. Bildirici, M.E. Cement production, environmental pollution, and economic growth: Evidence from China and USA. *Clean Technol. Environ. Policy* **2019**, *21*, 783–793. [CrossRef]
15. Piłatowska, M.; Geise, A.; Włodarczyk, A. The Effect of Renewable and Nuclear Energy Consumption on Decoupling Economic Growth from CO2 Emissions in Spain. *Energies* **2020**, *13*, 2124. [CrossRef]
16. Tapio, P. Towards a theory of decoupling: Degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. *Transp. Policy* **2005**, *12*, 137–151. [CrossRef]
17. Vehmas, J.; Malaska, P.; Luukkanen, J.; Kaivo-oja, J.; Hietanen, O.; Vinnari, M.; Ilvonen, J. *Europe in the Global Battle of Sustainability: Rebound Strikes Back?—Advanced Sustainability Analysis*; Publications of the Turku School of Economics and Business Administration, Series Discussion and Working Papers 2003; Turun Kauppakorkeakoulu: Turku, Finland, 2003; Volume 7.
18. Tapio, P. *The Limits to Traffic Volume Growth, The Content and Procedure of Administrative Futures Studies on Finnish Transport CO_2 Policy*; Acta Futura Fennica 8; Finnish Society for Futures Studies & Finland Futures Research Centre: Turku, Finland, 2002; 148p.
19. de Bruyn, S.M.; van den Bergh, J.C.J.M.; Opschoor, J.B. Economic growth and emissions: Reconsidering the empirical basis of environmental Kuznets curves. *Ecol. Econ.* **1998**, *25*, 161–175. [CrossRef]

20. Arrow, K.; Bolin, B.; Costanza, R.; Dasgupta, P.; Folke, C.; Holling, C.S.; Jansson, B.-O.; Levin, S.; Maler, K.-G.; Perrings, C.; et al. Economic growth, carrying capacity, and the environment. *Ecol. Econ.* **1995**, *15*, 91–95. [CrossRef]
21. Canas, A.; Ferrao, P.; Conceicao, P. A new environmental Kuznets curve? Relationship between direct material input and income per capita: Evidence from industrialized countries. *Ecol. Econ.* **2003**, *46*, 217–229. [CrossRef]
22. Seppala, T.; Haukioja, T.; Kaivo-oja, J. The EKC Hypothesis does not hold for direct material flows. An environmental Kuznets curve hypothesis tests for direct material flows in 5 industrial countries. Population and Environment. *J. Interdiscip. Stud.* **2001**, *23*, 217–238.
23. Bojnec, Š.; Papler, D. Economic efficiency, energy consumption and sustainable development. *J. Bus. Econ. Manag.* **2011**, *12*, 353–374. [CrossRef]
24. Dagar, V.; Ahmed, F.; Waheed, F.; Bojnec, Š.; Khan, M.K.; Shaikh, S. Testing the Pollution Haven Hypothesis with the Role of Foreign Direct Investments and Total Energy Consumption. *Energies* **2022**, *15*, 4046. [CrossRef]
25. Boamah, K.B.; Du, J.G.; Bediako, I.A.; Boamah, A.J.; Abdul-Rasheed, A.A.; Owusu, S.M. Carbon dioxide emission and economic growth of China-the role of international trade. Environ. *Sci. Pollut. Res.* **2017**, *24*, 13049–13067. [CrossRef]
26. Wang, Q.; Zhao, M.; Li, R.; Su, M. Decomposition and decoupling analysis of carbon emissions from economic growth: A comparative study of China and the United States. *J. Clean. Prod.* **2018**, *197*, 178–184. [CrossRef]
27. Wu, Y.; Zhu, Q.; Zhu, B. Decoupling analysis of world economic growth and CO2 emissions: A study comparing developed and developing countries. *J. Clean. Prod.* **2018**, *190*, 94–103. [CrossRef]
28. Wang, Q.; Zhang, F. Does increasing investment in research and development promote economic growth decoupling from carbon emission growth? An empirical analysis of BRICS countries. *J. Clean. Prod.* **2019**, *252*, 119853. [CrossRef]
29. Gao, C.; Ge, H.; Lu, Y.; Wang, W.; Zhang, Y. Decoupling of provincial energy-related CO2 emissions from economic growth in China and its convergence from 1995 to 2017. *J. Clean. Prod.* **2021**, *297*, 126627. [CrossRef]
30. Wang, Q.; Zhang, F. The effects of trade openness on decoupling carbon emissions from economic growth—Evidence from 182 countries. *J. Clean. Prod.* **2020**, *279*, 123838. [CrossRef]
31. Shan, Y.; Fang, S.; Cai, B.; Zhou, Y.; Li, D.; Feng, K.; Hubacek, K. Chinese cities exhibit varying degrees of decoupling of economic growth and CO2 emissions between 2005 and 2015. *One Earth* **2021**, *4*, 124–134. [CrossRef]
32. Rao, G.; Liao, J.; Zhu, Y.; Guo, L. Decoupling of economic growth from CO2 emissions in Yangtze River Economic Belt sectors: A sectoral correlation effects perspective. *Appl. Energy* **2022**, *307*, 118223. [CrossRef]
33. Zhao, X.; Jiang, M.; Zhang, W. Decoupling between Economic Development and Carbon Emissions and Its Driving Factors: Evidence from China. *Int. J. Environ. Res. Public Heal.* **2022**, *19*, 2893. [CrossRef] [PubMed]
34. Sun, D.; Cai, S.; Yuan, X.; Zhao, C.; Gu, J.; Chen, Z.; Sun, H. Decomposition and decoupling analysis of carbon emissions from agricultural economic growth in China's Yangtze River economic belt. *Environ. Geochem. Health* **2022**, *44*, 2987–3006. [CrossRef] [PubMed]
35. Li, R.; Chen, Z.; Xiang, J. A region-scale decoupling effort analysis of carbon dioxide emissions from the perspective of electric power industry: A case study of China. *Environ. Dev. Sustain.* **2022**, 1–26. [CrossRef]
36. Liu, F.; Kang, Y.; Guo, K. Is electricity consumption of Chinese counties decoupled from carbon emissions? A study based on Tapio decoupling index. *Energy* **2022**, *251*, 123879. [CrossRef]
37. WDI. *World Development Indicators*; World Bank: Washington, DC, USA, 2022.
38. Granger, C.W.J. Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econometrica* **1969**, *37*, 424–438. [CrossRef]
39. Wang, W.; Mu, H.; Kang, X.; Song, R.; Ning, Y. Changes in industrial electricity consumption in china from 1998 to 2007. *Energy Policy* **2010**, *38*, 3684–3690. [CrossRef]
40. Zhang, C.; Su, B.; Zhou, K.; Yang, S. Analysis of electricity consumption in China (1990–2016) using index decomposition and decoupling approach. *J. Clean. Prod.* **2018**, *209*, 224–235. [CrossRef]
41. Kopidou, D.; Diakoulaki, D. Decomposing industrial CO_2 emissions of Southern European countries into production-and consumption-based driving factors. *J. Clean. Prod.* **2017**, *167*, 1325–1334. [CrossRef]
42. Li, Z.; Sun, L.; Geng, Y.; Dong, H.; Ren, J.; Liu, Z.; Tian, X.; Yabar, H.; Higano, Y. Examining industrial structure changes and corresponding carbon emission reduction effect by combining input-output analysis and social network analysis: A comparison study of China and Japan. *J. Clean. Prod.* **2017**, *162*, 61–70. [CrossRef]
43. Karmellos, M.; Kopidou, D.; Diakoulaki, D. A decomposition analysis of the driving factors of CO_2 (Carbon dioxide) emissions from the power sector in the European Union countries. *Energy* **2016**, *94*, 680–692. [CrossRef]
44. Sumabat, A.K.; Lopez, N.S.; Yu, K.D.; Hao, H.; Li, R.; Geng, Y.; Chiu, A.S. Decomposition analysis of Philippine CO_2 emissions from fuel combustion and electricity generation. *Appl. Energy* **2016**, *164*, 795–804. [CrossRef]
45. Jiang, R.; Li, R. Decomposition and Decoupling Analysis of Life-Cycle Carbon Emission in China's Building Sector. *Sustainability* **2017**, *9*, 793. [CrossRef]

46. Goh, T.; Ang, B.W.; Xu, X.Y. Quantifying drivers of CO2 emissions from electricity generation–Current practices and future extensions. *Appl. Energy* **2018**, *231*, 1191–1204. [CrossRef]
47. Jamil, M.; Ahmed, F.; Debnath, G.C.; Bojnec, Š. Transition to Renewable Energy Production in the United States: The Role of Monetary, Fiscal, and Trade Policy Uncertainty. *Energies* **2022**, *15*, 4527. [CrossRef]