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The impact of online education on carbon emissions in the context of the COVID-19 pandemic – Taking Chinese universities as examples

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HIGHLIGHTS

• Due to the COVID-19 pandemic, all kinds of educational activities in countries around the world have been converted to online education.
• The carbon emissions from electricity consumption and transportation of college students have been significantly reduced due to the COVID-19 pandemic.
• Online education can significantly reduce energy consumption and lower carbon emissions.
• The education system has become one of the key sectors to reduce carbon emissions and promote carbon neutrality.

ABSTRACT

While the COVID-19 pandemic has had various impacts on economic and social development, it may have partially reduced human energy use, thereby helping achieve the goals of reducing carbon emissions and promoting carbon neutrality. During the pandemic, online education was widely used to replace traditional education all over the world. There is a lack of empirical studies on whether and to what extent the change of education model can reduce carbon emissions. Taking Chinese universities as cases, this study, concentrating on two main elements – transportation and electricity consumption – constructs a model and calculates the impact of online education on carbon emissions. The results show that online education can significantly reduce energy consumption and lower carbon emissions. In the field of higher education alone, the carbon emissions reduction caused by online education in half a year is equivalent to the total carbon emissions reduction of college students caused by online education during the half-year is equivalent to the total carbon emissions in 1.296 h in China, 2.688 h in the United States, 5.544 h in India, 12 h in Japan and 3.864 h in European countries of OECD. Therefore, this study suggests that the impact of online education on carbon emissions should be further studied, online education should be promoted through legislation and other systemic measures, and the goals of carbon emissions and carbon neutrality should be explored further within the field of education.

1. Introduction

With the outbreak of COVID-19 pandemic, all kinds of educational activities in major countries around the world have been converted to online education [1]. People returned to their homes and used the internet to attend classes and group discussions, share assignments, earn credits [2], and more, which has revolutionized traditional educational concepts and models and has brought a major change in human educational activity [3-4]. Even if the pandemic ends, it may ultimately result in a significant increase in the use of online education and, consequently, produce changes in human behaviour patterns [5-6]. These changes in educational and behavioural patterns will eventually affect the energy sector [7] and will change the amount of energy consumption in the educational system, possibly even reversing the structure and habits of energy use within that system.

The existing literature on the development of online education
During the pandemic focuses on student mobility [8–10], internationalization of higher education [11–12], and quality of education [13–15], but it lacks discussion on carbon emissions, especially the empirical measurement of the impact of online education on carbon emissions. The COVID-19 pandemic provides a natural opportunity to study the relationship between online education and carbon emissions [16]. By comparing the differences in carbon emissions from educational activities before and after the pandemic, we can effectively analyse whether online education, the new education model, can contribute to achieving energy saving and carbon neutrality goals. We can also analyse the pros and cons of online education and its future trends from the perspective of carbon emissions.

Online education activities impact carbon emissions in two ways. First, the majority of online education takes place at home, which significantly reduces travelling across regions, thereby reducing the carbon emissions caused by public transport such as trains or airplanes [17–18]. Second, the spread of online education leads to the closure of various educational institutions or the widespread closure of educational institutions’ electricity facilities, which significantly reduces carbon emissions from electricity generation [19].

During the pandemic, online education has spread significantly around the world. However, the relevant public data have not yet been comprehensively assessed and made publicly available. Thus, this paper selects universities in mainland China as a case to compare and analyse the variation in carbon emissions of higher education systems before and after the pandemic, which will provide reference for global research in this field.

2. Research definition and data collection

2.1. Research Definition: Online education

In this study, online education is defined as education which takes place at home through the internet. It is different from online education at school, offline education at school, which is also known as traditional school education, and offline education at home, that is, tutoring services and so forth [20]. It is also distinguished from offline education in non-school and non-family situations, that is, extracurricular instruction mainly conducted by offline education institutions, and so forth. This study focuses on the scenario where classes have been completely suspended and universities have transformed classroom teaching to online teaching due to the COVID-19 pandemic. Therefore, online education in this study is recognized as academic course instruction carried out by universities and participated in by students through the internet at home. As shown in Fig. 1.

2.2. Data collection and sources

Through collecting relevant data, we analyse online education’s influence on carbon emissions in the context of the COVID-19 pandemic. The collected data are mainly as follows.

2.2.1. The scale of online education in China

This includes the scale of internet users and internet penetration rate, the scale of mobile phone internet users, the total scale and usage rate of online education and mobile phone online education users, the nationwide number of courses offered online, and the increase in online courses in recent years. The source of data is mainly the China Statistical Report on Internet Development for each year. By presenting a comprehensive overview of the development of China’s internet in recent years, this study compares and analyses the increase in the scale of online education and discusses the development of online education during the pandemic.

2.2.2. Electricity savings per student due to online education

Taking W University in H Province as an example, we collect the monthly electricity consumption per student (dormitory). H province is located in the central region of China. There are 129 colleges and universities in H province, and the number of universities ranks sixth among the provinces in China. In 2020, there were 1.6169 million
college students in H province, accounting for 4.92% of the total number of college students in the country. Moreover, during 2020, the capital of H province, W city, was the first to experience an outbreak of the COVID-19 pandemic and was the worst in China. W university is a double first-class university (formerly Project 985 university and Project 211 university) located in W city. During the pandemic period, the school’s pandemic prevention measures were applied quickly and strictly. The university was completely suspended for about half a year and is fully eligible for our study, providing an excellent sample for this investigation. Based on the basic information collected on electricity consumption of urban and rural residents in China and in H province in recent years, we calculate the electricity consumption per resident. We focus in particular on household electricity consumption per student during the pandemic, in order to compare and analyse the electricity consumption generated by offline education at school with that generated by online education at home, and to calculate the changes in total electricity consumption and carbon emissions per student due to online education. The data on monthly electricity consumption per student at W University are obtained from the relevant departments of the university, while the data on electricity consumption of urban and rural residents in China and H province are mainly obtained from the China Statistical Yearbook, the Hubei Statistical Yearbook and so on.

2.2.3. Transportation energy savings per student due to online education

Through collecting data for daily carbon emissions from ground transport and domestic aviation in China in recent years, we analyse the changes in total carbon emissions from the transportation sector during the pandemic. Meanwhile, this study divides the country into eastern, central and western regions and selects 40 representative universities as a sample to calculate the students’ reduction of transportation distance and carbon emissions due to online education; the study then extends the result to nationwide college students’ reduced carbon emissions. The data of daily carbon emissions caused by ground transport and domestic aviation are obtained from Carbon Monitor, and the data of travel reduction of college students transportation are obtained from the analysis of sampled universities.

3. Research design and methodology

3.1. Research design

3.1.1. Carbon emissions reduction due to electricity consumption

Taking the electricity consumption of students in W University as an example. First, as W university is located in H Province, and considering the consistency of the electricity system, this part of the study first assesses the growth of household electricity consumption in H province during the pandemic, and then, on this basis, calculates the change in total electricity consumption by students caused by the pandemic. Considering that in 2020, electricity consumption would increase because residents stayed at home in special periods due to the pandemic, it is necessary to predict what the normal level of residential electricity consumption in 2020 would have been without the pandemic. The study selects the trend extrapolation prediction method to establish the trend extrapolation prediction model and uses the electricity consumption of urban and rural residents from 2011 to 2019 as a time series raw data model for predicting future electricity consumption of residents. Then, by calculating the difference between the predicted residential electricity consumption under the non-pandemic situation and the real residential electricity consumption during the pandemic in 2020, the difference in residential electricity consumption caused by online education is obtained (and one can observe whether it increases and how much). Based on this, a comprehensive calculation is made to determine the reduction in electricity consumption in colleges caused by online education, and finally the reduction in electricity consumption of college students caused by online education is obtained.

3.1.2. Carbon emissions reduction due to transportation

In order to analyse the decrease of travel to university by college students due to online education. Since the geographical locations of universities and the number of college students in various regions are the decisive factors affecting college students’ transportation distance, this study uses the purposive sampling method to improve the representativeness and comparability of the sample universities and to ensure that the data are based on the actual situation within the Chinese higher education system. On the one hand, this study selects universities according to the division standards of the eastern, central and western regions of mainland China used by the National Bureau of Statistics; on the other hand, this study selects different numbers of universities in each of these three regions according to the different number of provinces, universities and college students in the different regions. For example, the number of provinces, universities and college students in the eastern region is the largest, followed by the central region and then the western region; therefore, this study uses more data from the eastern region, less from the central region, and least from the western region. This study also tries to select sample provinces (cities) with a more concentrated distribution of universities and more students. Considering that the geographical location of provinces (cities) will affect the transportation distance of students, if there are multiple provinces in the same region, the sample provinces selected should be as far apart as possible. To sum up, a total of 8 sample provinces (cities) are selected, including 5 in the eastern region, 2 in the central region and 1 in the western region. Considering the representativeness of the sample and the size of the research workload, the number of sample universities must be neither too large nor too small. Therefore, this study selects 5 representative universities from each sample province (city) (generally high-level higher educational institutions such as Project 985 and Project 211 universities), with 40 universities in total. The transportation distance of all students from the 40 universities in 2020 was collected to calculate the transportation distance of all students from each university. The sampled provinces (cities) and universities are shown in Table 1.

Fig. 2 depicts the transportation distance of students from five universities in Beijing. It can be seen that college students in Beijing come from all over the country and there is a large number of students from Hebei, Jiangsu and Henan. The transportation distance between railway stations are shown in Table 2.

Taking the railway transportation mode for students’ school trip as an example, this study calculates the transportation distance of students based on the provincial capital. For example, the transportation distance of Jiangsu students from a university in Beijing is the railway distance from Beijing to Nanjing, the capital of Jiangsu Province (unit: km). This table is calculated based on the receiving station specified in the railway freight rate odometer. If there are more than two routes between the two stations, the shortest route or the through express route is calculated.
Fig. 2. Transportation distance of students from five universities in Beijing. (Note: The size of the blue circle represents the number of students, the larger the circle, the more students.) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2

| Sample provinces/cities and universities. |
|------------------------------------------|
| NO. Province/City | Universities |
|------------------|--------------|
| 1                | Beijing Normal University, Beijing Institute of Technology, China Agricultural University, Beijing Foreign Studies University, University of Science and Technology Beijing |
| 2                | Fudan University, Shanghai Jiao Tong University, Tongji University, East China Normal University, Shanghai University of Finance and Economics |
| 3                | Nanjing University, Southeast University, Nanjing University Of Science And Technology, Nanjing University of Aeronautics and Astronautics, Soochow University |
| 4                | Wuhan University, Huazhong University of Science and Technology, Wuhan University Of Technology, Huazhong Agricultural University, China University of Geosciences (Wuhan) |
| 5                | Sun Yat-sen University, South China University of Technology, Jinan University, South China Normal University, Soth China Agricultural University |
| 6                | Shandong University, Ocean University of China, China University Of Petroleum(East China), Shandong Normal University, Qilu University of Technology |
| 7                | Zhengzhou University, He’nan University, He’nan Normal University, He’nan Agricultural University, He’nan Polytechnic University |
| 8                | Sichuan University, University of Electronic Science and Technology of China, Southwest Jiaotong University, Chengdu University of Technology, Southwestern University Of Finance And Economics |

Table 3

The regional power grid baseline emissions factors of China.

| Power grids | EF_grid, OMSimple,y |
|-------------|---------------------|
| North China grid | 0.9419 |
| Northeast China grid | 1.0826 |
| East China grid | 0.7921 |
| Central China grid | 0.8587 |
| Northwest China grid | 0.8922 |
| South China grid | 0.8042 |

1 The simple marginal emissions factor OM (unit: tCO₂/MWh) of the power system where the emissions reduction projects are located in year y.

from 40 colleges and universities by counting the source of students and the mileage of railway stations across the country in 2020. Beijing, Shanghai, Shandong, Jiangsu, and Guangdong were selected as the references of the distance to school for college students in eastern China; Hubei and Henan provinces were selected as the references of the distance to school for college students in central China; and Sichuan province was selected as the reference for college students in western China. Referring to these, this research analyses the transportation distance of all college students in China.

3.2. Carbon emissions calculation methods

3.2.1. Calculation method of electricity carbon emissions

For the CO₂ emissions generated by the purchase of electricity, this study refers to Guidelines on enterprise greenhouse gas emissions accounting and reporting-Power generation facilities [21] adopted by the Ministry of Ecology and Environment of the People’s Republic of China, which is applicable to the accounting and reporting of greenhouse gas emissions of power generation enterprises. The calculation formula of the grid emissions factor in this document is as follows:

\[
\text{E_{electric}} = \text{AD_{electric}} \times \text{EF_{electric}} \tag{1}
\]

where \(E_{electric}\) is CO₂ emissions from the (purchased) use of electricity (unit: tons of CO₂, \(\text{tCO}_2\)), \(\text{AD}_{electric}\) is (purchased) electricity consumption (unit: megawatt hours, MWh), \(\text{EF}_{electric}\) is the grid emissions factor (unit: tons of CO₂ per megawatt hour, \(\text{tCO}_2/\text{MWh}\)).

The grid emissions factor changes every year, for example, Table 3 shows regional power grid baseline emissions factors of China for emissions reduction projects in 2019 recently released by the Ministry of Ecology and Environment of the People’s Republic of China [22]. The results are unanimously recognized by relevant institutions.

The above table shows the power grid baseline emissions factors in various regions of China, and different coefficients are available in different regions. Since this study measures the carbon emissions generated by residential electricity consumption (including college students’ electricity consumption on campus), it is more suitable to adopt the carbon emissions calculation method for household electricity consumption than to use the above grid factor coefficient standard of enterprise greenhouse gas emissions. The relevant information released
by the Ministry of Natural Resources of the People’s Republic of China defines the calculation method of carbon emissions of household electricity [23], and the calculation formula is as follows:

$$\text{CO}_2 \text{ emissions of household electricity (kgCO}_2\text{)} = \text{electricity consumption (kWh)} \times 0.785$$

(2)

That is,

$$\text{CO}_2 \text{ emissions (tCO}_2\text{)} = \text{megawatt hours of electricity consumption (MWh)} \times 0.785$$

(3)

3.2.2. Calculation method of carbon emissions from railway transportation

According to the 2020 Statistical Bulletin of China National Railway Group Co. Ltd [24], in 2020, the comprehensive energy consumption per unit transportation workload in China is 4.39 tons of standard coal per million equated ton-kilometre, which can be obtained through unit conversion. That is, the coal consumption per person per kilometre in railway transportation is about 4.39 g.

According to the relevant documents of the national environmental protection standards of the People’s Republic of China [21], the CO2 emissions factor of fossil fuels adopts the following formula:

$$\text{EF}_i = \text{CC}_i \times \text{OF}_i \times 44/12$$

(4)

where \(\text{EF}_i\) is the CO2 emissions factor of type \(i\) fossil fuels (unit: ton of CO2/GJ, tCO2/GJ), \(\text{CC}_i\) is carbon content per unit calorific value of type \(i\) fossil fuel, (unit: ton of carbon/GJ, tC/GJ), \(\text{OF}_i\) is the rate of carbon oxidation of fossil fuel \(i\), expressed as '%', and 44/12 is the ratio of relative molecular mass of CO2 to carbon.

According to the Intergovernmental Panel on Climate Change (IPCC) database [25], the carbon content of typical coal is 25.8 kg/GJ (i.e., 0.025 t/GJ), the carbon oxidation rate refers to the default value of carbon oxidation rate of IPCC combustion, and the high limit of carbon oxidation rate is 100%. Based on the formula above, the CO2 emissions factor of typical coal can be deduced as follows:

$$0.0258 \times 100\% \times 44/12 = 0.0946 \text{ tCO}_2/\text{GJ}$$

(5)

China sets the calorific value of standard coal at 7000 kcal/kg [26]; by conversion, it is 29.3076GJ/t. Thus, the carbon emissions factor of standard coal is as follows:

$$29.3076 \text{ GJ/t} \times 0.0946 \text{ tCO}_2/\text{GJ} = 2.7725 \text{ tCO}_2/\text{tce}$$

That is, the carbon emissions per kilogram of standard coal is 2.77 kg of CO2.

On this basis, the coal consumption per kilometre per person in railway transportation obtained above is about 4.39 g, and the CO2 emissions per kilometre per person in railway transportation is about 4.39 g \times 2.77 = 12.16 g.

4. Research findings

4.1. Online education has developed rapidly during the period of the COVID-19 pandemic.

4.1.1. The scale of internet users and internet penetration rate

In recent years, Chinese internet facilities have been able to offer comprehensive coverage and the digital economy has been booming. According to the statistics on the scale of Chinese internet users and the rate of internet usage from 2015 to 2020, the scale of Chinese internet users has grown steadily in recent years, from 668 million in June 2015 to 989 million in December 2020. Meanwhile, the internet penetration rate in this period also increased from 48.8% to 70.4% [27]. All of these factors lay a good foundation for the development of online education.

Fig. 3 and Table 4 show that the scale of internet users expanded year by year from 2015 to 2020 and the growth rate also increased steadily. However, it is obvious that the growth rate was significantly accelerated in 2020 and the internet penetration rate increased remarkably, which was mainly due to the impact of the COVID-19 pandemic. The isolation caused by the pandemic has made citizens more prone to use the internet [28]. Residents can work online and students are able to study online. Internet users use the streaming media platform to obtain information,...
enjoy online government affairs and satisfy their needs of daily life by shopping online, causing the rapid increase in the scale of internet users and internet usage rate. It can be clearly seen that the internet industry played a positive role in combating the COVID-19 pandemic and in the normalization phase of the pandemic. The pandemic has accelerated the wave of all-round social digital transformation from individuals, enterprises to the government [29].

4.1.2. The overall scale and usage rate of online education and mobile online education users

As depicted in Fig. 4, the number of online education users in China reached 423 million in March 2020, an increase of 110.2% compared with the end of 2018, accounting for almost half of the total internet users (46.8%). The number of mobile online education users in China reached 420 million, an increase of 226 million compared with the end of 2018 and accounting for 46.9% of mobile internet users [27]. Affected by the pandemic, school openings across the country were postponed at the beginning of 2020 and 265 million students began to attend online classes, from which derived the substantial growth of the scale of online education users [30]. In the second quarter of 2020, as the prevention and control of the pandemic entered the normalization stage, students across the country gradually resumed attending schools and the number of online education users declined. In the second half of 2020, with the positive progress in the prevention and control of the pandemic, schools largely returned to the normal teaching order and the number of online education users further dropped. However, the scale of online education users still increased 109 million compared with the period before the pandemic (June 2019) and the development trend of the industry remains positive [28].

4.1.3. The number of online courses offered nationwide and the increased number of online courses

During the pandemic period, online teaching practices in China has achieved remarkable results. First, the work of online teaching in colleges and universities ran smoothly. By May 8, 2020, 1,454 colleges and universities carried out online education. Approximately 1.03 million faculty members offered 1.07 million courses online including both theoretical and experimental courses. A total of 17.75 million college students participated in online education [31]. Second, various kinds of online education resources grew rapidly. The Ministry of Education, organizing 37 online course platforms and technology platforms, took the lead in providing free online courses to colleges and universities nationwide, which drove more than 110 social and university platforms to participate. In the first quarter of 2020, 5,000 Massive open online courses (MOOCs) and 18,000 other online courses were added to the online course platforms [32]. Third, online courses have a complete range of disciplines and diversified types. The online courses offered involve 12 disciplines, including science, engineering, agriculture, medicine, economics, management, law, literature, history, philosophy, art and education. The categories of courses include public courses, basic courses, specialized courses, theoretical courses, experimental courses and so on. The teaching modes are diverse, including live courses, recorded courses, MOOCs, remote guidance, and so forth [31].
4.2. The carbon emissions caused by the reduction in electricity consumption of students due to the COVID-19 pandemic

4.2.1. Electricity consumption of students – Taking W University as an example

Taking W University as an example, the latest data on the campus official website shows that the total number of students is 58,537 as of March 2021 [33]. According to statistics, the total electricity consumption of the university in 2019 was 178,911,526 kWh, and in 2020 it was 134,923,352 kWh – a decrease of 43,988,174 kWh compared to 2019. However, based on the reason that the total electricity consumption of the university includes all the electricity consumption of teachers’ dormitories, administrative units, and residential areas, it is not reasonable to use it to calculate the average electricity consumption of students. Thus, a dormitory building of W University was taken as an example to obtain statistics on electricity consumption. In 2019, the total electricity consumption of the dormitory building was 114,174.76 kWh, and there were 684 students accommodated in the building. Based on the data, the monthly electricity consumption per student (dormitory) is 13.91 kWh. In comparison, the total electricity consumption of the dormitory in 2020 was 64,756.41 kWh, and monthly electricity consumption per student (dormitory) was 7.89 kWh, which decreased by 6.02 kWh compared to 2019.

The following data were obtained from the statistics of domestic electricity consumption of urban and rural residents in H province in 2019, 2020 and 2021 [34]. The monthly electricity consumption per resident was 61.36 kWh in 2019, 64.76 kWh in 2020, and 60.28 kWh in 2021. It can be seen that the level of electricity consumption in 2020 is much higher than that in 2019 and 2021. Considering the increase of electricity consumption generated by residents’ household lives during the pandemic and taking the data of 2019 and 2021 as a reference, it is calculated that the increase of monthly electricity consumption per resident at home due to the pandemic is ((64.76–61.36) + (60.28))/2 = 3.94 kWh. The household life of residents did not bring about a sharp increase in monthly electricity consumption per resident, but only a small increase. The pandemic caused a 6.02 kWh reduction of average monthly electricity consumption per student on campus. Thus, it is calculated that the change of electricity consumption per student caused by the pandemic is –2.08 kWh, that is, the reduction of monthly electricity consumption per student is 2.08 kWh.

4.2.2. Household electricity consumption during the COVID-19 pandemic

In 2020, Chinese overall electricity consumption increased, but at a slightly slower rate than that in previous years. Affected by the pandemic, there were many variables in electricity demand and supply, presenting many uncertainties; in particular, secondary and tertiary industries were greatly affected. According to data from the China Electricity Council, in 2020, the total electricity consumption of the whole society was 7,511 billion kWh, a year-on-year increase of 3.1%, which is much lower than the growth rate of previous years (The growth rates in 2017, 2018 and 2019 were 7.5%, 8.5% and 5.0% respectively). The growth rate of electricity consumption of secondary industry in each quarter was −8.8%, 3.3%, 5.8% and 7.6%, respectively, and the growth rate of electricity consumption of tertiary industry in each quarter was −8.03%, 0.5%, 5.9% and 8.4% [35], respectively. It can be seen that China’s industrial electricity consumption decreased rapidly due to shut-down in the context of the pandemic at the beginning of 2020. However, with the effective control of the pandemic, the gradual implementation of the national counter-cyclical regulation policies, and the continuing effective promotion of the resumption of work, production, business and market, the growth rate of electricity consumption in industry in general and tertiary industry in particular increased quarter by quarter [36]. With the positive growth of electricity consumption in all quarters due to residents living, working and studying at home during the pandemic, the domestic electricity consumption of urban and rural residents maintained a positive growth in each quarter. In 2020, the total domestic electricity consumption of urban and rural residents was 1,095 billion kWh, so the monthly electricity consumption per resident was 64.63 (retain two decimal places) kWh (calculated based on 1.411.78 million population [38]).

According to research methodology, the study uses the trend extrapolation prediction method to establish the trend extrapolation prediction model to calculate the electricity consumption of urban and rural residents of 2020. The calculation formula for the indicator that changes linearly with time is as follows:

\[ y = ax + b \]

\[ a = \frac{n\sum_{i=1}^{n}x_iy_i - \left(\sum_{i=1}^{n}x_i\sum_{i=1}^{n}y_i\right)}{n\sum_{i=1}^{n}x_i^2 - \left(\sum_{i=1}^{n}x_i\right)^2} \]

\[ b = \frac{1}{n}\sum_{i=1}^{n}y_i - a\frac{1}{n}\sum_{i=1}^{n}x_i \]

![Fig. 5. Fitting model diagram of electricity consumption of urban and rural residents (2010–2019).](image-url)
In the above formula, \( x_i \) and \( y_i \) respectively present the time point data (\( x_i = 1, 2, 3 \ldots 9; i = 2011, 2012, 2013 \ldots 2019 \)) and the actual value of the year corresponding to the time point of the indicator, and \( n \) is the number of samples. There are 9 groups in this paper, that is, \( y_i \) is the data of 2011, \( y_2 \) is the data of 2012, and so forth. According to the theory of trend extrapolation and historical data for each year, the time series table can be obtained. The parameters \( a \) and \( b \) of the linear fitting equation can be obtained as follows: \( a = 566.68 \) and \( b = 4905.47 \) through the calculation formula of trend extrapolation method. Therefore, the linear fitting equation is as follows:

\[
y = 566.68x + 4,905.47
\]  
(10)

By substituting the historical data of electricity consumption of urban and rural residents from 2011 to 2019 into the linear fitting equation, the model values of historical years can be obtained. Then, comparing the actual value of the historical year with the corresponding model value, the linear fitting modelling diagram of trend extrapolation method can be obtained. As shown in Fig. 5, the error between the predicted value and the actual value is not large, and the model fits well. Therefore, if, following this trend, the predicted value of electricity consumption of urban and rural residents in 2020 (\( i = 2020 \), \( x_i = 10 \)) is 1,057,227 billion kWh through the calculation of the fitting equation, then the predicted value of monthly electricity consumption per resident is 62.93 kWh. Compared with the predicted value, the actual value is about 1.7 kWh higher. It can be considered that the monthly electricity consumption per resident increased 1.7 kWh due to working and studying at home during the pandemic.

Taking W University as a reference, the reduction of monthly electricity consumption per student is 6.02 kWh due to the pandemic, and the increase of electricity consumption per resident generated by working at home and studying online is 1.7 kWh; therefore, the change of the monthly electricity consumption per student caused by the pandemic is –4.32 kWh, that is, the monthly electricity consumption of per student decreased by 4.32 kWh.

### 4.2.3. The carbon emissions reduction due to changes in students’ electricity consumption during online education

Due to the COVID-19 pandemic, students did not go to school in the first half of 2020 and gradually returned to school in the second half of the year. Therefore, referring to 2019 statistics, if half a year is taken as the scope of influence, the electricity consumption per student (dormitories) in W University will reduce 13.91 × 58,537 × 6 = 4,885,498.02 kWh in the first half of 2020. According to the calculation formula of electricity carbon emissions in the research design, \( E_{\text{electricity}} = AD_{\text{electricity}} \times EF_{\text{electricity}} \), and W University is located in central China, so a baseline emissions factor of grid baseline in central China is chosen as 0.8587, and we can get the following:

\[
E = 4.32kWh \times 0.785 \times 35,992,500(\text{people}) \times 6(\text{months}) = 732,346,596\text{tCO}_2
\]

That is to say, the total carbon emissions (caused by electricity consumption) reduced by online education of Chinese university students in 2020 would be approximately 732,346,596 tons.

#### 4.3. Reduced carbon emissions from student transportation trips caused by the COVID-19 pandemic

The statistical bulletin on the development of China’s transportation industry in 2020 [40] shows that the volume of annual business passenger traffic was 9,665 million, reduced by 45.1% compared with the previous year. The turnover volume of passenger traffic was 1,925,143 million person-kilometres and saw a drop of 45.5%. Railway transportation carried 2,203 million passengers, showing a decrease of 39.8% compared with the previous year. The turnover volume of passenger traffic was 826,619 million person-kilometres and plunged 43.8%. Civil aviation transportation carried 418 million people, with a decline of 36.7% over the previous year, and the turnover volume of passenger traffic was 631,125 million person-kilometres, decreasing by 46.1%. In order to control the COVID-19 pandemic, the suspension of work and classes directly reduced the demand and supply of industry and seriously impacted the transportation industry.

Fig. 6 and Fig. 7 show the daily CO\(_2\) emissions caused by ground transport and domestic aviation from 2019 to 2020 [41]. We can see that both modes of transportation maintained relatively stable emissions in 2019 and there is little difference in daily emissions. However, the carbon emissions plummeted in 2020, which indicates that the pandemic caused a stagnation of the transportation industry. The daily carbon emissions decreased sharply; in particular, the carbon emissions in the first two quarters were significantly lower than the normal level. But we cannot ignore that over time, the daily carbon emissions of both transportation modes gradually increased, which indicates that as the COVID-19 pandemic was effectively controlled, steady progress was made in the resumption of work, production, business and market, and the development of the transportation industry gradually returned to the normal.

In this context, college students could only study at home through online education, and the transportation of college students due to returning to university was also reduced.

Since this study takes the capitals of the provinces where the colleges are located as the geographical location to estimate the students’ transportation distance to school and there are also students who live in the province, this study uses two estimation methods for comparison and mutual verification of the conclusions. The first is to ignore the transportation distance of local students in various provinces and cities. For example, the transportation distance for local students from Beijing to school in Beijing is ignored (such information in the basic data is 0), and the transportation distance of students from other provinces and cities is the distance between the capital of the province where the student comes from and the capital of the province where the university is located. On this basis, the transportation distance of non-local students from 40 colleges and universities is taken as the total transportation distance of the sample students, even though the sample includes local students. Therefore, the average transportation distance of all students can be calculated. Based on the total number of college students in China and the transportation distance per student calculated above, the total transportation distance of all students can be obtained. To a certain extent, this method compresses the average transportation...
distance of non-local students, but still includes the number of local students when calculating the total transportation distance of students, which can alleviate the drawbacks of these two kinds of problems.

The second method is to classify and then calculate the local and non-local students in the colleges and universities in all provinces. First, the data of 40 sample universities were recognized as references for calculating the proportion of local students in colleges and universities in eastern, central, and western provinces. According to the number of college students in each province of China in 2020 obtained by the Bureau of Statistics, we selected the proportion coefficient of local students according to the region of each province and calculated the number of local students in each province in turn. The transportation distance of local students is calculated according to half of the longest span from north to South or east to West of each province, so as to obtain the total local students transportation distance. The transportation distance of non-local students is the distance between the capital of the province where the student comes from and the capital of the province where the university is located. Based on the data of 40 sample colleges and universities, the average transportation distance of non-local students in eastern, central, and western provinces is calculated. Through the total number of college students in each province and the number of local students calculated above, the number of non-local students in each province can be calculated as well. Thus, the total transportation distance of the non-local students can be calculated. The sum of transportation distance of local students and non-local students is the total transportation distance for all students. This method takes into account the transportation distance of local students in each province and calculates the transportation distance of local and non-local students separately; however, the lack of relevant official data has led to further estimation calculation.

4.3.1. Results of the first method

According to the latest statistics on the number of college students in each province disclosed by the National Bureau of Statistics [42], and the region of each province, it was calculated that the current proportion of students in regular higher education institutions in eastern, central, and western China is 41.03%, 32.06% and 26.37%, respectively. According to the number of 35,992.5 thousand college students nationwide in 2020, there were about 14,767,216 college students in the eastern region, about 11,735,152 college students in the central region and

![Fig. 6. Daily CO₂ emissions of Ground Transport in China (2019–2020).](image)

![Fig. 7. Daily CO₂ emissions of Domestic Aviation in China (2019–2020).](image)
about 9,490,132 college students in the western region. More detailed data are shown in Table 5.

From this, the following can be calculated: the total transportation distance of college students in eastern universities is 874,356,049 × 14,767,216 = 12,911,804,638 km; the total transportation distance for college students in central universities is 505,736,078 × 11,735,152 = 5,934,889,752 km; and the total transportation distance for college students in western universities is 1,156,405,472 × 9,490,132 = 10,974,440,575 km.

According to the above research design, the amount of CO₂ emissions caused by online education was calculated based on carbon emissions caused by online education and students staying at home increased the residential carbon emissions. In fact, carbon emissions at this stage were slightly lower than the overall levels in 2019 and 2021. It can be seen that, although the pandemic made it necessary for residents to work at home, it did not lead to a significant increase in carbon emissions and had little impact on residents’ carbon emissions. Therefore, it is not considered that online education and students staying at home increased the residential carbon emissions.

4.4. Carbon emissions reduced by college students due to the COVID-19 pandemic

According to the above calculations, the reduction of students’ carbon emissions caused by online education was calculated based on the school electricity consumption and school transportation distance of college students in China. According to statistics, the total amount of carbon emissions reduction caused by the COVID-19 pandemic made it necessary for residents to work at home, it did not lead to a significant increase in carbon emissions and had little impact on residents’ carbon emissions. Therefore, it is not considered that online education and students staying at home increased the residential carbon emissions.

The daily carbon emissions of Chinese residents from January 2019 to May 2021 according to statistics [41] are shown in Fig. 8. It is found that the residents’ carbon emissions are higher in winter (mainly due to heating in winter) and lower in summer, with the peak of carbon emissions occurring from January to February every year, then decreasing month by month, and reaching to the lowest level in June to August, and then increasing gradually. By comparison, 2020, especially the first half of the year, is the stage of residents’ home life affected by the pandemic. The carbon emissions of residents in this stage does not show an increasing trend, but is very in line with the law of carbon emissions. In fact, carbon emissions at this stage were slightly lower than the overall levels in 2019 and 2021. It can be seen that, although the pandemic made it necessary for residents to work at home, it did not lead to a significant increase in carbon emissions and had little impact on residents’ carbon emissions. Therefore, it is not considered that online education and students staying at home increased the residential carbon emissions.

4.4. Carbon emissions reduced by college students due to the COVID-19 pandemic

Overall, during the pandemic, online education was carried out throughout the whole country, and all college students studied online at home [43]. At the same time, all residents also lived at home and worked online.

More detailed data are shown in Table 5. Table 6.

### Table 5: Transportation distance to school of students in the sample.

| Region | Province/City | Transportation distance for students in grade 2020 (unit: kilometres) | The number of students in grade 2020 | Average transportation distance per student(unit: kilometres) | Average transportation distance per student in region(unit: kilometres) |
|--------|---------------|-----------------------------------------------------------------|------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|
| East   | Beijing       | 17,743,599                                                      | 13,506                             | 1313.756775                                              | 874.3560491                                               |
|        | Tianjin       | 18,384,718                                                      | 15,613                             | 1177.526292                                              | 1177.526292                                               |
|        | Hebei         | 19,832,736                                                      | 27,987                             | 708.6410111                                               | 708.6410111                                               |
|        | Liaoning      | 17,241,044                                                      | 19,360                             | 890.549734                                                | 890.549734                                                |
|        | Guangdong     | 22,384,255                                                      | 32,856                             | 681.2836316                                               | 681.2836316                                               |
| Central| Hubei         | 23,803,579                                                      | 26,784                             | 888.7238277                                              | 505.7360784                                               |
|        | He’nan        | 12,269,564                                                      | 44,544                             | 275.4481861                                               | 275.4481861                                               |
| West   | Sichuan       | 36,094,884                                                      | 31,213                             | 1156.405472                                              | 1156.405472                                               |

### Table 6: Some transportation distance to school of students in the sample.

| Region | Province/City | The number of local students (unit:10 thousand) | Average transportation distance of per local student (unit: kilometres) | Total transportation distance of local students (unit: kilometres) | The number of non-local students (unit:10 thousand) | Average transportation distance per non-local students (unit: kilometres) | Total transportation distance of non-local students(unit: kilometres) |
|--------|---------------|-----------------------------------------------|---------------------------------------------------------------------|------------------------------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|-----------------------------------------------------------------|
| East   | Beijing       | 22.31759668                                    | 88                                                                   | 1963.948504                                                      | 37.82340337                                               | 874.3560491                                                   | 33078.99073                                                    |
|        | Tianjin       | 20.01348566                                    | 94.5                                                                | 1891.274395                                                      | 33.9265143                                                | 890.549734                                                    | 29665.8330                                                  |
|        | Hebei         | 54.69017031                                    | 475                                                                 | 2597.8309                                                      | 92.70982969                                               | 65.4812069                                                   | 81061.4004                                                   |
|        | Liaoning      | 38.62817931                                    | 275                                                                 | 1062.74931                                                      | 65.4812069                                                | 57254.42602                                                   | 28959.9272                                                  |
|        | Shandong      | 19.53864624                                    | 60                                                                   | 1172.313854                                                    | 33.12143576                                                | 10364.5661                                                    | 10364.5661                                                   |
|        | Guangdong     | 69.5317515                                     | 228                                                                 | 1584.01993                                                     | 117.8748294                                               | 99.6559093                                                   | 505.7360784                                                   |
| Central| Hubei         | 85.6049855                                    | 370                                                                  | 31673.70146                                                    | 64.47540145                                                | 32607.53668                                                   | 505.7360784                                                   |
|        | He’nan        | 80.26001507                                    | 387                                                                  | 31060.62583                                                    | 60.49964893                                                | 30571.73832                                                   | 505.7360784                                                   |
| West   | Sichuan       | 55.92952345                                   | 537.5                                                                | 30060.13868                                                    | 115.405472                                               | 127486.8534                                                   | 505.7360784                                                   |
|        | Guizhou       | 25.7702832                                    | 207.5                                                                | 7666.59251                                                     | 50.7997168                                                | 58745.07049                                                   | 505.7360784                                                   |
|        | Yunnan        | 29.0786531                                    | 495                                                                  | 14393.93229                                                    | 57.3213469                                                | 66286.71921                                                   | 505.7360784                                                   |
| Total  |              | 1294.265529                                    |                                                                     | 5,592,542,112                                                  | 1737.233471                                               | 15,120,057,220                                               | 15,120,057,220                                               |
or 732,346.596 t + 503,731.0416 t = 1,236,077.638 t, i.e., 1.2361 mt

According to the latest data released by the International Energy Agency (IEA) in 2019 [44], China’s CO₂ emissions were 9,809.2 million tons, with an average daily emissions of 26,874,515.24 tons, making China the largest carbon emitter in the world; CO₂ emissions of the United States were 4,766 million tons, with an average daily emissions of 13,058,583.78 tons; India’s CO₂ emissions were 2,309 million tons, with an average daily emissions of 6,326,183.978 tons; Japan’s CO₂ emissions were 1,066 million tons, with an average daily emissions of 2,921,095.89 tons; and CO₂ emissions of European countries of OECD were 3,308 million tons, with an average daily emissions of 9,062,049.31 tons.

Therefore, if the first calculation result of this study (i.e., 1,459,596.596 tons) is used, the total carbon emissions reduction of college students caused by online education during the half-year is equivalent to the total carbon emissions in 1.296 h in China, 2.688 h in the United States, 5.544 h in India, 12 h in Japan and 3.864 h in European countries of OECD.

Electricity and heat production Industries, Manuf. Industries and construction, Transport and so on are the main sources of global CO₂ emissions. Therefore, this study will take the carbon emissions of three industries above as examples to compare the reduction of carbon emissions due to online education. The data all comes from IEA in 2018.

Electricity and heat production. The CO₂ emissions of Electricity and heat production industries in China, the United States, India, Japan and European counties of OECD are respectively 4,896.3 million tons (the average daily emissions are 13,414,520.55 tons), 1,852.1 million tons (the average daily emissions are 5,074,246.575 tons), 1,141.8 million tons (the average daily emissions are 3,128,219.178 tons), and 474.3 million tons (the average daily emissions are 1,299,452.055 tons). Thus, the total carbon emissions reduction of college students due to online education during the half-year is respectively equivalent to the carbon emissions of Transport in 13.944 h in China, 7.248 h in the United States, 41.88 h in India, 62.496 h in European countries of OECD.

5. Conclusions and recommendations

This paper shows that China’s passive launch of a national online education campaign during the pandemic resulted in an unexpectedly large reduction in the scale of carbon emissions. In the study, the main related factors of carbon emissions were calculated through the model, such as education transportation and education electricity, showing that online education can greatly reduce the scale of carbon emissions. Not only China, but also other countries all over the world have fully promoted online education during the pandemic. Global online education saves a lot of energy. The education system has become one of the key sectors to reduce carbon emissions and promote carbon neutrality. This has comparatively strong innovation and research significance. However, due to the lack of diversified official statistics, such as information from all student sources of all colleges and universities in mainland China, the real results of standardization are less likely to be achieved. Therefore, this study mainly estimates the overall situation of Chinese college students based on the data of the sample universities.

At present, China has effectively controlled the pandemic, but the Delta variant of the virus has been spread again in more than 15 provinces in China. It can be predicted that online education will replace offline education partially for at least the next few years. Even when the pandemic is over, the concept of online education will be integrated into the education system.
Therefore, this paper gives the following suggestions: First, we need to further refine research on the relationship between online education and carbon emissions and find more accurate evidence of their interaction. The model calculations based on the perspectives of transportation and electricity have certain scientific value, but still do not include all the influencing factors of carbon emissions in educational activities. For example, through online education, the frequency with which parents pick up their children from school is reduced, which reduces energy consumption and carbon emissions. In addition, online education converts a large number of paper materials (such as textbooks and test papers) into electronic materials, which reduces print activity and energy consumption. Furthermore, reducing deforestation will also help achieve the goal of carbon neutrality. If a more refined data model is formed, the carbon emissions of the education system can be significantly reduced.

Second, we should promote online activities in some education fields through system design. Due to the pandemic, education systems in various countries have promoted online education and rapidly improved its hardware and software construction, creating conditions for the large-scale promotion of online education. Especially during this period, students have formed good online education habits and teachers have developed online education abilities. This study also demonstrates that there is a close relationship between online education and carbon emissions. Thus, countries all over the world can further strengthen online education through institutional design and legislation in the following ways: (1) increase the development of online education and greatly increase the proportion of online teaching in non-degree education; (2) comprehensively develop promotion of online education in non-practical education and promote the use of online education in non-STEM education, as well as the use of non-internship training education activities in STEM subjects; (3) promote online education to partially replace traditional classroom teaching, improve the quality of course education, and reduce the energy consumption of offline education through methods such as MOOCs; (4) extend the range of use of online education in the education for international students to reduce the carbon emissions caused by cross-border mobility.

Third, we should further explore countermeasures to save energy and reduce carbon emissions in the education system. This study suggests that the amount of educational carbon emissions is huge. Furthermore, online education alone can dramatically save energy and reduce carbon emissions. So we should further explore the basic laws of carbon emissions in the education system and formulate reasonable measures to reduce carbon emissions through the design of education policies. At the same time, specific measures such as reducing the use of printed materials should be taken to help the education system to achieve carbon neutrality goals. It is also suggested that in the process of reducing carbon emissions and decomposing carbon neutral target in different nations and regions, some indicators should be allocated to the education system to encourage the education system to effectively undertake the target tasks of energy saving and emissions reduction.

CRediT authorship contribution statement

Zhaohui Yin: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. Xiaomeng Jiang: Data curation, Visualization. Songyue Lin: Software, Formal analysis, Writing – original draft. Jin Liu: Validation, Supervision, Project administration.

Declaration of Competing Interest

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

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