Developing the transformation of scientific and technological achievements in colleges and universities to boost the development of low-carbon economy

Weijuan Li¹,* and Pengcheng Zhang²
¹Department of Chinese Law and Economics Management, Shengli College China University of Petroleum, Dongying, Shandong 257061, China; ²Department of Engineering Cost Center, Sinopec Petroleum Engineering Corporation, Dongying, Shandong 257061, China

Abstract

In this work, the network data envelopment analysis (DEA) model was used to divide the transformation of scientific and technological achievements in colleges and universities into two stages, which makes up for the lack of process measurement in a single DEA model. Also, the relationship between the transformation efficiency of scientific and technological achievements in universities and the development of a low-carbon economy was quantitatively analyzed. The research results show that: (1) the transformation efficiency of scientific and technological achievements of universities in China is increasing year by year and which is significantly higher in the eastern region than that in the central and western regions. (2) The efficiency of the transformation of scientific and technological achievements of the university promotes the reduction of carbon emission intensity and the development of a low-carbon economy, indicating that the improvement of the transformation efficiency of scientific and technological achievements of the university has a good role in promoting the ecological environment protection. However, compared with the developed countries, the quantity and quality of science and technology supply and ecological environment protection in China's universities are still insufficient. In this regard, the development suggestions are put forward from the aspects of government policy guidance, professional talent cooperation and strengthening the docking between universities and industrial low-carbon economic development. The purpose of this paper is to promote the development of a low-carbon economy by improving the efficiency of scientific and technological achievements transformation in universities, to achieve the goal of ecological environment protection.

Keywords: university scientific and technological achievements, transformation efficiency, network DEA model, low-carbon economy, environmental protection

*Corresponding author: liweijuan666@163.com

Received 22 July 2020; revised 30 July 2020; editorial decision 12 August 2020; accepted 12 August 2020

1. INTRODUCTION

The sustainable development of the world is inseparable from the protection of the environment. The extensive development, which only pursues economic benefits at the cost of consuming the environment, is no longer suitable. In October 2006, the stern report called for a global transition to a low-carbon economy to reduce carbon dioxide emissions [1]. The development of a low-carbon economy is not only a country's courage to bear the responsibility of environmental protection and respond to the requirements of international energy conservation and consumption reduction indicators but also conducive to the country's improvement of energy efficiency. However, at present, the government's policy guidance demand for ecological environment governance and the enterprises' demand for pollution control technology have increased significantly, and the corresponding supply capacity of technical services is still insufficient. Therefore, it is necessary to vigorously promote the transformation of scientific and tech-
nological achievements in universities and alleviate the above contradictions through technological innovation [2].

The low-carbon economy efficiency is presently a core indicator used in China’s policy development [3]. To this end, extensive research has been conducted, including industries such as electricity, manufacturing, agriculture and energy [4–11]. While developing, China is facing a severe challenge of an imbalance in economic growth and CO$_2$ emissions [12–18]. From literature, the research methods currently used to analyze the transformation efficiency of scientific and technological achievements are stochastic frontier analysis (SFA) and data envelopment analysis (DEA) [19–23]. The existing research mainly analyzes the development of a low-carbon economy from the perspective of the industry, combined with the quantitative analysis method. It puts forward the importance of scientific and technological innovation in the proposal part. Still, the research on the source of scientific and technological innovation is insufficient, and colleges and universities are the keys to improve the level of scientific and technological innovation. The conventional efficiency analysis method cannot reflect the effect of the basic research stage and the application and promotion stage of scientific and technical achievements. Therefore, it is necessary to study the transformation of scientific and technological achievements in colleges and universities with the network DEA model and explore its promotion role and promotion countermeasures for the development of a low-carbon economy.

The scientific and technological innovation from colleges and universities supports the continued development of the regional low-carbon economies and supplies the necessary talent to support growth. For colleges and universities, the development of the low-carbon economy provides opportunities to improve their scientific and technological innovation ability and help promote the growth of these academic institutions through demand-pull. In 2016, the Ministries of Education and Science and Technology in China jointly issued several declarations regarding the strengthening of the transfer and transformation of scientific and technological achievements in colleges and universities (JJ [2016] No. 3). Some of the new policies include requiring colleges and universities to prioritize the transformation of scientific and technological achievements and to strengthen the close combination with socioeconomic development to better support the growth of the social economy. In a low-carbon economy, greater emphasis has to be given towards improving the scientific and technological innovation capacity of colleges and universities and transforming their scientific and technical achievements. At present, the production of scientific and technological achievements mainly comes from universities and scientific research institutes. However, at present, the research on the combination of the transformation of scientific and technical achievements in colleges and universities with a low-carbon economy is insufficient. The main problems are as follows: first, scientific and technological achievements mainly stay in the stage of research and development and lack of transformation power; second, the promotion of scientific and technical achievements in colleges and universities to low-carbon economy lacks quantitative analysis.

Set against the above background, in this work, the transformation of scientific and technical progress was divided into two stages using the network DEA model, i.e. basic research and achievement application. The approach produced more objective calculation results in analyzing the relationship between the overall efficiency of scientific and technological achievements transformation in four regions and increments of carbon emission intensity. Also, this work was able to assess the various efforts of transforming scientific and technical achievements of colleges and universities for the development of a low-carbon economy, which can be used as scientific and technological support and reference in promoting the global development of the low-carbon economy. The remainder of this paper is structured into the following sections. Section 2 introduces the relevant policies and the current situation of China’s low-carbon economy and the status quo of science and technology development in Chinese universities in order to preliminarily understand the necessity of low-carbon economic development and the supporting role of scientific and technological development in colleges and universities. Afterward, Section 3 gives the specific research method to analyze the relationship between the transformation efficiency of scientific and technological achievements and the development of low-carbon economy, after which Section 4 illustrates the results and discussion. Finally, Section 5 concludes this paper.

2. OVERVIEW OF RELEVANT POLICIES AND LITERATURE

2.1. Relevant policies

A low-carbon economy is to reduce energy consumption and carbon emissions as much as possible through technological innovation and industrial transformation under the guidance of the concept of sustainable development, so as to achieve the coordination of economic development and ecological environment protection. At present, the development of a low-carbon economy has become an essential part of green environmental protection. The Kyoto Protocol adopted in Tokyo, Japan, in 1997 is the key to the formation of a low-carbon economic concept. In 2003, the British government published a white paper on energy policy, which first proposed the idea of a low-carbon economy. At present, China plans to launch a unified national carbon trading market, comprehensively promote sustainable development and actively transition towards a green and low-carbon economy.

2.2. Current situation of China’s low-carbon economy

A study by the Intergovernmental Panel on Climate Change found that every ton of global CO$_2$ emission corresponds to at least $85$ worth of damages [24]. Thus, establishing a development model characterized by a low-carbon economy has become an inevitable choice for sustainable development. Two metrics that can be used to measure the progress of transitioning into a low-carbon economy are carbon emission intensity and energy consumption. Carbon emission intensity indicates the total amount
of CO\textsubscript{2} emitted per unit of gross domestic product (GDP) and is an important index that reflects the relationship between economic development and CO\textsubscript{2} emissions. In China, carbon emission intensity was 1.62 tons/10,000 yuan in 2015 and decreased to 1.53 tons/10,000 yuan in 2016. Another useful indicator for the progress of the low-carbon economy is energy consumption, which serves as a practical gauge for CO\textsubscript{2} emissions. In using energy consumption as a metric for economic development, the energy consumption per ten thousand yuan GDP was selected as the unit of assessment. In 2016, China’s energy consumption was valued at 0.63 tons of standard coal/10,000 yuan, and in 2016, the value decreased to 0.6 tons of standard coal/10,000 yuan. Based on these two statistics, China is making progress towards its goal of having a low-carbon economy. In order to further contribute to global eco-environmental protection, China needs to take more measures to strengthen its low-carbon economic development, including utilizing the scientific and technological innovation of its academic and research institutions. In 2016, China’s Ministry of Education and the Ministry of Science and Technology jointly issued several opinions on strengthening the transfer and transformation of scientific and technological achievements in colleges and universities ([J] [2016] No. 3), requiring colleges and universities to attach importance to the transformation of scientific and technical progress, strengthen the close combination with social and economic development, so as to better support the transformation and upgrading of social economy. This study combines the transformation of scientific and technological achievements of colleges and universities with the development of low-carbon economy, so as to play the role of colleges and universities in environmental protection.

3. EVOLUTION AND CLUSTER ANALYSES OF TRANSFORMATION EFFICIENCY

In this work, the transformation of scientific and technological achievements in colleges and universities is divided into two stages: the stage of basic research and the stage of application of accomplishments. Based on the two-stage network DEA model, the first stage, the second stage and the overall transformation efficiency of scientific and technological achievements in colleges and universities in each province are measured. Then the genealogy of 31 regions is made by using the system clustering method. According to the hierarchical clustering map, the provinces and cities are divided into i-high clustering area, ii-high clustering area, iii-low-high clustering area and iv-low clustering area, and the clustering results are analyzed. At the same time, in order to analyze the relationship between the transformation efficiency of scientific and technological achievements and the regional ecological environment, the paper calculates the total carbon dioxide emission and carbon emission intensity indexes of each province and city, respectively and further calculates the regional incremental carbon emission intensity indexes of high clustering area, II high and low clustering area, III low and high clustering area, IV low and low clustering area, etc. Finally, the paper analyzes the correlation between the transformation efficiency of scientific and technological achievements and regional incremental carbon emission intensity index in four regions. The flow chart is shown in Figure 1.

3.1. Method

(1) Network DEA model

The transformation of scientific and technological achievements in colleges and universities can be divided into two phases: the basic research stage and the achievement application stage. The first stage deals with the formation of research achievements, while the second stage is concerned with the transformation of research achievements into economic benefits. In this study, the network DEA model is used to analyze the two stages of transformation. Färe and Grosskopf [25] proposed the concept of network DEA and utilized the frontier analysis method to deal with a multi-stage production system. This method can reflect the effect of input and intermediate processes on the final output.

Assume that for the first investment stage in the transformation of scientific and technological achievements in colleges and universities, the input is given by the expression

$$x = (x_{1j}, x_{2j}, \ldots, x_{nj})^T$$

The output of the first stage is given by

$$Z_j = (z_{1j}, z_{2j}, \ldots, z_{dj})^T$$

which is then used as the input in the second stage. The output in the second stage is given by the expression

$$Y_j = (y_{1j}, y_{2j}, \ldots, y_{nj})^T.$$
3.2. Index selection
Based on the availability and scientific of the data, the input-output index is determined. In the first stage (basic research stage) of the transformation of scientific and technological achievements in Colleges and Universities, the investment is mainly composed of funds and human resources. This paper uses research and development funds and research and development of full-time personnel to measure. The output of scientific and technological achievements mainly includes achievements appraisal, monographs, academic papers, and authorized patents. In order to further transform the output of scientific and technical achievements into economic benefits, relevant personnel should provide auxiliary services to complete. Therefore, at the second stage (achievements application stage), the output of the first stage and the services provided by full-time scientific and technical service personnel are taken as input indicators. Then, the final output indicators include the number of contracts and the number of patent sales. The design of the index can well reflect the applicability of the transformation of scientific and technological achievements in colleges and universities.
Developing the transformation of scientific and technological achievements in colleges and universities

### Table 1. Calculation results of the transformation efficiency of scientific and technological achievements of Chinese universities (2015–16).

| Region       | 2015 | 2016 | Range of change |
|--------------|------|------|-----------------|
|              | Stage 1 | Stage 2 | Overall efficiency | Stage 1 | Stage 2 | Overall efficiency | Stage 1 | Stage 2 | Overall efficiency |
| Beijing      | 0.37  | 0.81  | 0.57            | 1.00   | 1.00   | 1.00            | 0.63    | 0.19    | 0.43            |
| Tianjin      | 0.18  | 0.09  | 0.09            | 0.11   | 0.83   | 0.46            | −0.07   | 0.74    | 0.37            |
| Hebei        | 0.23  | 0.04  | 0.08            | 0.51   | 0.26   | 0.29            | 0.28    | 0.22    | 0.21            |
| Shanxi       | 0.34  | 0.15  | 0.17            | 0.41   | 0.28   | 0.27            | 0.07    | 0.14    | 0.10            |
| Inner Mongolia | 0.41 | 0.30  | 0.29            | 0.12   | 0.10   | 0.08            | −0.29   | −0.20   | −0.20           |
| Liaoning     | 0.15  | 0.03  | 0.06            | 0.72   | 0.38   | 0.44            | 0.57    | 0.35    | 0.38            |
| Jilin        | 0.05  | 0.01  | 0.02            | 0.16   | 0.00   | 0.18            | 0.10    | 0.26    | 0.16            |
| Heilongjiang | 0.16  | 0.05  | 0.07            | 0.26   | 0.80   | 0.32            | 0.10    | 0.76    | 0.45            |
| Shanghai     | 0.38  | 0.66  | 0.50            | 0.97   | 0.49   | 0.60            | 0.58    | −0.20   | 0.10            |
| Jiangsu      | 1.00  | 1.00  | 1.00            | 1.00   | 1.00   | 1.00            | 1.00    | 0.00    | 0.00            |
| Zhejiang     | 0.57  | 0.62  | 0.54            | 0.70   | 1.00   | 0.85            | 0.13    | 0.38    | 0.31            |
| Anhui        | 1.00  | 1.00  | 1.00            | 0.76   | 0.71   | 0.68            | −0.24   | −0.29   | −0.32           |
| Fujian       | 0.69  | 0.28  | 0.43            | 1.00   | 0.10   | 0.31            | 0.67    | 0.52    | 0.57            |
| Jiangxi      | 0.30  | 0.03  | 0.09            | 0.49   | 0.25   | 0.28            | 0.19    | 0.22    | 0.19            |
| Shandong     | 0.25  | 0.08  | 0.11            | 0.36   | 0.15   | 0.27            | −0.07   | 0.27    | 0.14            |
| Henan        | 0.43  | 0.04  | 0.13            | 0.36   | 0.31   | 0.27            | −0.06   | 0.06    | 0.03            |
| Hubei        | 0.39  | 0.21  | 0.22            | 0.37   | 0.27   | 0.25            | −0.02   | 0.06    | 0.03            |
| Hunan        | 0.23  | 0.03  | 0.07            | 1.00   | 1.00   | 1.00            | 0.77    | 0.97    | 0.93            |
| Guangdong    | 0.31  | 0.21  | 0.20            | 0.32   | 0.52   | 0.39            | 0.02    | 0.31    | 0.19            |
| Guangxi      | 0.26  | 0.04  | 0.09            | 0.63   | 0.25   | 0.32            | 0.37    | 0.21    | 0.23            |
| Hainan       | 1.00  | 1.00  | 1.00            | 1.00   | 0.42   | 0.56            | 0.00    | −0.58   | −0.44           |
| Chongqing    | 1.00  | 0.66  | 0.74            | 0.40   | 0.44   | 0.36            | −0.60   | −0.22   | −0.38           |
| Sichuan      | 0.32  | 0.25  | 0.23            | 0.41   | 0.68   | 0.52            | 0.09    | 0.43    | 0.29            |
| Guizhou      | 0.38  | 0.16  | 0.19            | 1.00   | 1.00   | 1.00            | 0.62    | 0.84    | 0.80            |
| Yunnan       | 0.16  | 0.07  | 0.08            | 0.22   | 0.31   | 0.23            | 0.06    | 0.24    | 0.15            |
| Tibet        | 1.00  | 1.00  | 1.00            | 1.00   | 1.00   | 1.00            | 0.00    | 0.00    | 0.00            |
| Shanxi       | 0.50  | 0.25  | 0.28            | 0.65   | 0.44   | 0.45            | 0.15    | 0.19    | 0.18            |
| Gansu        | 0.32  | 0.09  | 0.13            | 0.20   | 0.46   | 0.30            | −0.12   | 0.37    | 0.17            |
| Qinghai      | 1.00  | 1.00  | 1.00            | 0.54   | 0.17   | 0.24            | −0.46   | −0.83   | −0.76           |
| Ningxia      | 1.00  | 1.00  | 1.00            | 1.00   | 1.00   | 1.00            | 0.00    | 0.00    | 0.00            |
| Xinjiang     | 1.00  | 1.00  | 1.00            | 0.29   | 0.38   | 0.29            | −0.71   | −0.62   | −0.71           |

#### 3.3. The calculation and cluster analysis of the transformation efficiency of scientific and technological achievements

A one-year lag processing feature was adopted in this study to consider the delay between the input and output. For example, the output for 2015 is assumed to be the result of 2014 inputs. Using the data sets for 2014–16, the dynamic changes of the transformation efficiency of scientific and technological achievements were assessed for 31 provinces and cities in China. The weight of the two stages is 1:1.

First, calculate the efficiency value of scientific and technological achievements transformation in 31 provinces of China in two stages, the results are shown in Table 1 and then combine the data to cluster analysis the efficiency fluctuation of scientific and technological achievements transformation in 2015 and 2016. In this paper, systematic clustering method is used to analyze the transformation efficiency of scientific and technological achievements in colleges and universities in 2014 and 2016, and SPSS V23 is used for calculation. Technological achievements in colleges and universities for 2015 and 2016 were grouped into four spatial clusters: high–high clustering (HH, cluster of high values), high–low clustering (HL, high value surrounded by low values), low–high clustering (LH, low value surrounded by high values) and low–low clustering (LL, cluster of low values). The clustering results are presented in Figures 2 and 3 and Table 2.

Table 2 shows in terms of regional distribution, the increase of high clustering in the second stage of transformation efficiency of scientific and technological achievements is in the eastern, central and western regions in turn. In specific provinces, the clustering classification significantly changed over the two-year analysis period. For western provinces of Xinjiang and Qinghai, the HH cluster in 2015 changed into LL in 2016. The scientific and technological backslide in these areas is caused by insufficient research and development (R&D) allocation and workforce investment. In contrast, Guizhou and Hunan transitioned from the LL cluster in 2015 to the HL cluster in 2016. The number of patents sold in Hunan Province was worth 23 million yuan in 2015 and increased significantly to reach 238 million yuan in 2016, representing an increase of 932.69%. In the first stage of 2016, the output in Guizhou Province increased significantly, with the number of achievement appraisals, monographs, academic papers and authorized patents increasing by 12.07%, 35.42%, 7.32% and...
45.28%, respectively. The eastern province of Tianjin and the central province of Heilongjiang transformed from LL cluster to LH cluster, achieving better output efficiency from the same level of input. In Tianjin, the contract quantity and patent sales revenue increased by 42.42% and 14.78%, respectively, in 2016. For Heilongjiang, these parameters increased by 208.77% and 159.68%.

When analyzing how these provinces were able to achieve high levels of transformation of achievements in universities, we found some specific details that can provide some explanation. With the overall revitalization of the northeast industrial base, Heilongjiang increased support for the transformation of scientific and technological achievements and emphasized the construction of market-oriented exchange platform carriers. In 2018, the province also promulgated the special program for the transformation of scientific and technological achievements towards the revitalization of the Northeast China Action Implementation Plan.

3.4. Relationship analysis between clusters and low-carbon economic level
In this work, carbon emission intensity is used to quantify the development level of the low-carbon economy. Using the clustering classification of transformation efficiency, we analyzed the
Developing the transformation of scientific and technological achievements in colleges and universities

Figure 3. 2016 pedigree cluster.

The relationship between the transformation of scientific and technological achievements by colleges and universities and the level of development of the low-carbon economy using the exhibition relationship (Table 3). To calculate carbon emission intensity (CEI), the following expression can be used:

\[
CEI_{ij} = \frac{CDE_{ij}}{GDP_{ij}} = \frac{C_{ij} \times r}{GDP_{ij}}
\]

where \(CEI_{ij}\) is the carbon emission intensity of the \(j\) province in region \(i\) (unit: ton/10,000 yuan), \(CDE_{ij}\) is the carbon dioxide emission of the \(j\) province in region \(i\) (unit: 10,000 tons), \(GDP_{ij}\) is the GDP of the \(j\) province in region \(i\) (unit: 100 million yuan), \(C_{ij}\) is the annual standard coal consumption of the \(j\) province in region \(i\) (unit: 10,000 tons) and \(r\) is the carbon dioxide emission coefficient (unit: ton carbon dioxide/ton standard coal). In this work, the carbon dioxide emission coefficient is set to 2.62. We can then calculate the difference in carbon emission intensity between two time periods using the formula:

\[
\Delta CEI_i = CEI_{it1} - CEI_{it0} = \sum_{j=1}^{m} \frac{CDE_{ij}^{t1}}{GDP_{ij}^{t1}} - \sum_{j=1}^{m} \frac{CDE_{ij}^{t0}}{GDP_{ij}^{t0}}
\]
where \( \Delta CEI_i \) is the regional \( i \) incremental carbon emission intensity (unit: ton/10,000 yuan), \( CEI_{i,t+1} \) and \( CEI_{i,0} \) are the carbon emission intensity of region \( i \) in \( t+1 \) and \( t \) (unit: ton/10,000 yuan), \( CDE_{ij,t}^{i} \) and \( CDE_{ij,0}^{i} \) are the total carbon dioxide emissions of the \( j \) province in region \( i \) in \( t+1 \) and \( t \) (unit: 10,000 tons) and \( GDP_{ij,t} \) and \( GDP_{ij,0} \) are the GDP of the \( j \) province in region \( i \) in \( t+1 \) and \( t \).

Table 4 presents a summary of the incremental carbon intensity values by spatial clusters for 2015 and 2016. Our findings show that the carbon emission intensities for all cluster groups in 2016 are considerably lower than in 2015. The reduction in carbon emission intensity in the HH cluster is significantly higher than in the LL cluster. This suggests that improvements in the achievement transformation efficiency in colleges and universities help in reducing carbon emission intensity and promote a regional low-carbon economy. Clean energy technology can reduce carbon emissions (Jaffe 2002). Therefore, the active development of clean energy technology in colleges and universities is conducive to the realization of environmental protection.

### 4. RESULTS AND DISCUSSION

In terms of the overall transformation efficiency, the average value of the transformation efficiency of scientific and technological achievements in China’s 31 provinces has considerably improved from 2015 to 2016. In particular, the regions of Hunan and Guizhou increased their transformation efficiency by as much as 0.93 and 0.81, respectively, in 2016. From the regional perspective, the transformation efficiency of scientific and technological achievements varies significantly among geographical areas, with some provinces exhibiting substantial fluctuations. The eastern region was found to have considerably higher transformation efficiency than the central and western regions. Part of the reason lies in the difference in R&D investment funds. The smaller R&D allocation in the less developed central and western provinces significantly limits their capacity to transform their scientific and technological achievements into economic benefits. Even with R&D budget constraints, academic institutions should strive to increase their transformation efficiency by optimizing their systems to focus on delivering outputs in the second stage. Our results show that R&D allocation is not the sole determinant of scientific and technological achievements. For instance, Jiangsu does not have the highest R&D expenditure allocation nor the largest research workforce, but it still leads in the number of contracts and patent sales. We also found that policy and government support play vital roles in transforming scientific achievements into economic gains. In provinces like Guizhou, Hunan and Tianjin and Heilongjiang, special policies, financial incentives and other government instruments have been used to support the transformation efficiency of scientific and technological achievements, which are reflected by these provinces’ high-efficiency levels. Finally, our analyses show that the market transformation of patents is particularly crucial in improving transformation efficiency.

Also, this work found that the efficiency of the transformation of university achievements promotes the reduction of carbon emission intensity and supports improvements towards a low-carbon economy. This finding highlights the critical role of science and technology in developments towards a green economy. From 2014 to 2016, carbon emission intensity in the four spatial clusters decreased in varying degrees. In 2015, the overall transformation efficiency showed a weak negative correlation with the intensity of incremental carbon emission; in 2016, these two parameters had a strong negative correlation.

| Category | Region | 2015 | Stage 1 | Stage 2 | 2016 | Stage 1 | Stage 2 |
|----------|--------|------|--------|--------|------|--------|--------|
| i. High–high clustering | East (2): Hainan, Jiangsu Central (1): Anhui West (4): Ningxia, Qinghai, Xinjiang, Tibet | 1.00 | 0.95 | | East (4): Beijing, Fujian, Jiangsu, Zhejiang Central (2): Anhui, Hunan West (3): Guizhou, Ningxia, Tibet | 0.85 | 0.87 |
| ii. High–low clustering | East (1): Fujian Central (0): West (0): | 0.69 | 0.38 | | East (2): Shanghai, Hainan Central (0): West (0): | 0.98 | 0.45 |
| iii. Low–high clustering | East (3): Shanghai, Zhejiang, Beijing Central (0): West (0): | 0.44 | 0.70 | | East (1): Tianjin Central (1): Heilongjiang West (0): | 0.18 | 0.82 |
| iv. Low–low clustering | East (6): Guangdong, Tianjin, Guangxi, Hebei, Liaoning, Shandong Central (7): Shanxi, Henan, Hubei, Jiangxi, Heilongjiang, Hunan, Jilin West (7): Sichuan, Shanxi, Inner Mongolia, Chongqing, Guizhou, Gansu, Yunnan | 0.28 | 0.11 | | East (5): Liaoning, Shandong, Guangxi, Hebei, Guangdong Central (5): Jilin, Jiangxi, Shanxi, Henan, Hebei West (8): Sichuan, Shanxi, Inner Mongolia, Yunnan, Xinjiang, Qinghai, Chongqing, Gansu | 0.40 | 0.33 |
Developing the transformation of scientific and technological achievements in colleges and universities

| Region   | Standard coal 10 000 tons | Total CO₂ emissions 10 000 tons | Gross product: 100 million yuan | Carbon emission intensity tons/10 000 yuan |
|----------|---------------------------|---------------------------------|---------------------------------|--------------------------------------------|
| Beijing  | 6831                      | 17 897.22                       | 21 330.83                       | 0.84                                       |
| Tianjin  | 8145                      | 21 339.9                        | 17 562.93                       | 1.36                                       |
| Hebei    | 29 320                    | 76 818.4                        | 29 421.15                       | 2.61                                       |
| Shandong | 19 863                    | 52 041.06                       | 12 761.49                       | 4.08                                       |
| Shandong | 18 309                    | 47 969.58                       | 17 770.19                       | 2.70                                       |
| LiaoNing | 21 803                    | 57 123.86                       | 28 626.58                       | 2.00                                       |
| Jilin    | 22 427.2                  | 130 808.4                       | 14 063.13                       | 1.62                                       |
| HeilongJiang | 11 955                  | 31 322.1                        | 15 039.38                       | 2.08                                       |
| Shanghai | 11 085                    | 290 424.7                       | 23 567.7                        | 1.23                                       |
| Jiangsu  | 29 863                    | 78 241.06                       | 65 088.32                       | 1.50                                       |
| Zhejiang | 18 826                    | 49 324.12                       | 40 173.03                       | 1.23                                       |
| Anhui    | 12 011                    | 31 468.82                       | 20 848.75                       | 1.51                                       |
| Fujian   | 12 110                    | 31 728.2                        | 24 055.76                       | 1.32                                       |
| Jiangxi  | 8055                      | 21 101.4                        | 15 714.63                       | 1.34                                       |
| ShanDong | 36 511                    | 95 658.82                       | 59 426.59                       | 1.61                                       |
| Henan    | 22 890                    | 59 971.8                        | 34 938.24                       | 1.72                                       |
| Hubei    | 16 320                    | 42 758.4                        | 27 379.22                       | 1.56                                       |
| Hunan    | 15 317                    | 40 130.54                       | 27 037.32                       | 1.48                                       |
| Guangdong| 29 593                    | 77 533.66                       | 67 809.85                       | 1.14                                       |
| Guangxi  | 9515                      | 24 929.3                        | 15 672.89                       | 1.59                                       |
| Hainan   | 1820                      | 4768.4                          | 35 000.72                       | 1.36                                       |
| Chongqing| 8593                      | 22 513.66                       | 14 262.60                       | 1.58                                       |
| Shandong | 19 879                    | 52 082.98                       | 28 536.66                       | 1.83                                       |
| Guizhou  | 9709                      | 25 437.58                       | 92 663.39                       | 2.75                                       |
| Yunnan   | 10 455                    | 27 392.1                        | 12 814.59                       | 2.14                                       |
| Shanxi   | 11 222                    | 29 401.64                       | 17 689.94                       | 1.66                                       |
| Gansu    | 7521                      | 19 705.02                       | 6836.82                         | 2.88                                       |
| Qinghai  | 3992                      | 10 459.04                       | 2303.32                         | 4.54                                       |
| Ningxia  | 4946                      | 12 958.52                       | 2752.10                         | 4.71                                       |
| Xinjiang | 14 926                    | 39 106.12                       | 9273.46                         | 4.22                                       |

Note: the energy consumption of each region comes from China Energy Statistical Yearbook (2015–17) and the GDP of each region comes from China Statistical Yearbook (2015–17). Because Tibet data is not included in the statistical yearbook, the article does not consider the carbon emission from Tibet.
et al  an essential indicator of academic excellence. Under the ‘double universities, achievement transformation has been regarded as strategy and the subject evaluation index system for colleges and development. Given the current education development research and development results rather than stay in the research colleges and universities to focus on the application effect of the research and development of science and technology in into technological innovation and marketable goods and guide assessment system focused on converting academic research much room for improvement.

In Japan, Sweden, Austria and Taiwan, the R&D expenditure is for GDP 2015 and 2016 were 2.06% and 2.11%, respectively. South Korea’s R&D expenditure accounts for 4.22% and 4.23% of GDP. In Japan, Sweden, Austria and Taiwan, the R&D expenditure is more than 3% of the GDP. China’s R&D expenditure still has much room for improvement.

Second, the government needs to establish an effective assessment system focused on converting academic research into technological innovation and marketable goods and guide the research and development of science and technology in colleges and universities to focus on the application effect of research and development results rather than stay in the research and development. Given the current education development strategy and the subject evaluation index system for colleges and universities, achievement transformation has been regarded as an essential indicator of academic excellence. Under the ‘double first-class’ university construction plan in 2015, efforts have been undertaken to promote achievement transformation as a vital construction task, highlighting the degree of national attention being placed on the transformation of scientific and technological achievements. However, the phenomenon of ‘emphasizing declaration while neglecting research, emphasizing academic and neglecting application’ is still widespread among colleges and universities. Therefore, many academic institutions are still focused on publishing papers in high-quality international and local journals and focusing almost exclusively on theoretical research, often neglecting the transformation component. The practical application value of scientific research achievements is not fully developed, resulting in low transformation efficiency of academic achievements, where high research investments result in a relatively small market and application value.

5. RECOMMENDATIONS AND CONCLUSIONS

5.1. Give full play to the role of the government, boost investments in R&D funds and strengthen assessment and guidance

Jung and Lee targeted government S&T programs that may increase the efficiency of university research [26]. Sooryamoorthy et al. [27] figured out that the importance of science has been gaining the interest of scholars and policymakers alike who find that the relationship between science and development is getting stronger than ever. The government provides critical guidance and supervision in the transformation of scientific and technological achievements in colleges and universities. To further promote transformation efficiency, it should play a more proactive role in setting policy guidance to create conducive environments for the promotion and transition of academic achievements into economic benefits. For example, the Japanese government has created a law promoting technology transfer in universities to speed up the commercialization of scientific research achievements. The government can provide support through two primary aspects: increasing R&D investment in academic institutions and strengthening the evaluation and guidance of colleges and universities. First, sufficient investment is a necessary condition for the transformation of scientific and technological achievements. Although R&D expenditure in most Chinese universities has been increasing annually, there remains a sizeable disparity compared with other developed countries. According to the China Statistical Yearbook of Science and Technology (2018), China’s R&D expenditure in proportion to GDP for 2015 and 2016 were 2.06% and 2.11%, respectively. South Korea’s R&D expenditure accounts for 4.22% and 4.23% of GDP. In Japan, Sweden, Austria and Taiwan, the R&D expenditure is more than 3% of the GDP. China’s R&D expenditure still has much room for improvement.

Second, the government needs to establish an effective assessment system focused on converting academic research into technological innovation and marketable goods and guide the research and development of science and technology in colleges and universities to focus on the application effect of research and development results rather than stay in the research and development. Given the current education development strategy and the subject evaluation index system for colleges and universities, achievement transformation has been regarded as an essential indicator of academic excellence. Under the ‘double

5.2. Enhance the cooperation between professionals and build a composite service team

At present, the common transformation modes in China mainly include self-production, technology transfer, joint production, high-tech industrial zones and science and technology parks. Based on the finding of this study, patent market value is crucial in scientific and technological achievement transformation, particularly at the second stage; however, patent R&D and authorization is only the initial step [28]. To properly realize market value, various steps would still have to be undertaken, such as professional product assessment review, market evaluation, marketing promotion design, risk monitoring studies and financial support applications. At present, many academic institutions are unable to provide their teaching and research personnel the necessary support beyond the research development stage. In 2016, the Chinese Academy of Sciences highlighted the need to ‘cultivate a high-end compound professional talent team that understands the internal laws of intellectual property operation and achievements transformation and is proficient in scientific research, management and law.’ To strengthen the construction of the service platform, R&D achievements application and technical support services need to be installed and continuously improved to better facilitate the transformation of scientific and technological achievements into economic benefits [29].

5.3. Connect the research and development of colleges and universities with the low-carbon development of regional industries

The primary basis of scientific and technological achievement transformation is to meet market demand. Colleges and universities should be more open to knowledge exchange and research collaboration and move past research behind closed doors. For example, the transformation efficiency in the provinces of Heilongjiang and Tianjin needs to be improved to meet the needs of its local industries. The integrated development of ‘revitalizing the old industrial base in Northeast China’ and ‘Beijing Tianjin Hebei’

| Region                  | 2015   | 2016   |
|-------------------------|--------|--------|
| High–high (HH) clustering | -0.053 | -0.094 |
| High–low (HL) clustering  | -0.053 | -0.091 |
| Low–high (LH) clustering  | -0.065 | -0.082 |

Table 4. Regional incremental carbon emission intensity.
Developing the transformation of scientific and technological achievements in colleges and universities

provides unique opportunities for the achievement transformation. Research tracks in colleges and universities should be in conjunction with the development and growth needs of enterprises and the local economy to achieve precise docking. Likewise, enterprises should actively explore various channels and establish long-term relationships with colleges and universities to build trust. They should proactively assist and support academic institutions in upgrading and modifying research and develop systems of tracking and feedback. Enterprises should help the practicability of scientific research achievements to improve the efficiency of transformation. At the same time, science and technology activities are based on a low-carbon economy, to give full play to the development of a low-carbon economy in the regional industry of university service. Guided by the demand, focusing on the critical battle of pollution prevention and control, optimizing the whole chain of project approval, output and application of scientific research projects, actively developing and applying technologies and products that are conducive to energy conservation and ecological environment protection, speeding up the development of energy conservation and consumption reduction technologies, strengthening the transformation of scientific and technological achievements and improving social productivity. Tsinghua University established the institute of low-carbon economy in 2008, the international institute of low-carbon economy in university of international economic and trade and the center of low-carbon research and education in Beijing jiaotong University. University teachers should actively investigate the difficulties faced by the government and enterprises in environmental protection, so as to improve the applicability and adaptability of scientific research. Besides, colleges and universities are encouraged to strengthen cooperation with science and technology parks to promote the transformation efficiency of scientific and technological achievements in the second stage. Albahari et al. [30] pointed out the higher involvement of a university in the science and technology park (STP) is positively related to the number of patent applications.

5.4. Conclusions and implications

Protecting the ecological environment is the common responsibility of all countries in the world. Facing the increasingly serious global environmental pollution problem, China regards the ecological environment protection as an insurmountable red line. The bottom line is to implement a low-carbon economy with coordinated economic and environmental development and take various measures to carry out the anti-pollution struggle. The promotion of scientific and technological achievements in universities is an essential driving force for ecological environment protection. By using the network DEA model, the transformation efficiency of scientific and technical progress in universities in China is calculated in stages, and the impact of scientific and technological investment in universities on the low-carbon economy is analyzed quantitatively. The carbon emission intensity is selected as the measurement index of the development level of the low-carbon economy. The carbon emission intensity in 2016 is significantly lower than that in 2015, and the reduction of high polymer is considerably higher than that of low polymer, which shows that improving the efficiency of university achievement transformation can promote the reduction of carbon emissions and strengthen the regional low-carbon economy. It shows that the transformation of scientific and technological achievements in universities in China has played a useful role in promoting the protection of the ecological environment. However, compared with developed countries, there is still much room to improve the efficiency of the transformation of scientific and technological achievements in China's colleges and universities. In order to better play China's role in global ecological environment protection, it is suggested to continue to adhere to the bottom line of ecological environment protection, give full play to the leading role of governments at all levels, encourage colleges and universities to combine the transformation of scientific and technological achievements with the development of low-carbon economy and improve the applicability of scientific and technical research.

ACKNOWLEDGEMENT

The authors express many thanks go to the financial supported by Shandong Provincial Natural Science Foundation (ZR2019GQ011), Teaching Reform Research Project of Undergraduate Colleges and Universities in Shandong Province (Z2016M096) and Major teaching reform project of Shengli College China University of Petroleum (ZDJG201903).

REFERENCES

[1] Li C, Xi Z. Social stability risk assessment of land expropriation: lessons from the Chinese case. Int J Environ Res Public Health 2019;16:3952. https://doi.org/10.3390/ijerph16203952.
[2] Li C, Gao X, He BJ et al. Coupling coordination relationships between urban-industrial land use efficiency and accessibility of highway networks: evidence from Beijing-Tianjin-Hebei urban agglomeration. China Sustainability 2019;11:1446. https://doi.org/10.3390/6a1101446.
[3] Liu X, Liu J. Measurement of low carbon economy efficiency with a three-stage data envelopment analysis: a comparison of the largest twenty CO2 emitting countries. Int J Environ Res Public Health 2016;13:1116. https://doi.org/10.3390/ijerph13111116.
[4] Yan D, Lei Y, Li L et al. Carbon emission efficiency and spatial clustering analyses in China's thermal power industry: evidence from the provincial level. J Clean Prod 2017;156:518–27. https://doi.org/10.1016/j.jclepro.2017.04.063.
[5] Bi K, Huang P, Wang X. Innovation performance and influencing factors of low-carbon technological innovation under the global value chain: a case of Chinese manufacturing industry. Technol Forecast Soc Change 2016;111:275–84. https://doi.org/10.1016/j.techfore.2016.07.024.
[6] Liu Y, Feng C. What drives the fluctuations of ‘green’ productivity in China’s agricultural sector? A weighted Russell directional distance approach. Resour Conserv Recy 2019;147:201–13. https://doi.org/10.1016/j.resconrec.2019.04.013.
[7] Luthra S, Mangla SK. Evaluating challenges to industry 4.0 initiatives for supply chain sustainability in emerging economies. Process Saf Environ 2018;117:168–79. https://doi.org/10.1016/j.pse.2018.04.018.
[8] Nie Y, Cheng D, Liu K. The effectiveness of environmental authoritarianism: evidence from China’s administrative inquiry for environmental protection. *Energy Econ* 2020;88:104777. https://doi.org/10.1016/j.eneeco.2020.104777.

[9] Wang H, Xu J, Sheng L. Purification mechanism of sewage from constructed wetlands with zeolite substrates: a review. *J Clean Prod* 2020;258:120760. https://doi.org/10.1016/j.jclepro.2020.120760.

[10] Zhang P, Qin G, Wang Y. Risk assessment system for oil and gas pipelines laid in one ditch based on quantitative risk analysis. *Energies* 2019;12:981. https://doi.org/10.3390/en12060981.

[11] Wang C, Li W, Xin G et al. Prediction model of corrosion current density induced by stray current based on QPSO-driven neural network. *Complexity* 2019;2019:3429816. https://doi.org/10.1155/2019/3429816.

[12] Cai BF, Wang JN, Yang WS et al. Low carbon society in China: research and practice. *Adv Clim Change Res* 2012;3:106–20. https://doi.org/10.3724/SP.J.1248.2012.000106.

[13] Zhang N, Liu Z, Zheng X et al. Carbon footprint of China’s belt and road. *Science* 2017;357:1107. http://doi.org/10.1126/science.aao6621.

[14] Zhang P, Wang Y, Qin G. Fuzzy damage analysis of the seismic response of a long-distance pipeline under a coupling multi-influence domain. *Energies* 2019;12:62. https://doi.org/10.3390/en12010062.

[15] Song Y, Zhang J, Song Y et al. Can industry-university-research collaborative innovation efficiency reduce carbon emissions? *Technol Forecast Soc Change* 2020;157:120094. https://doi.org/10.1016/j.techfore.2020.120094.

[16] Venkataraman S. Regional transformation through technological entrepreneurship. *J Bus Venturing* 2004;19:153–67. https://doi.org/10.1016/j.jbusvent.2003.04.001.

[17] Yoon H, Yun S, Lee J et al. Entrepreneurship in East Asian regional innovation systems: role of social capital. *Technol Forecast Soc Chang* 2015;100:83–95. https://doi.org/10.1016/j.techfore.2015.06.028.

[18] Wang X, Ding H, Liu L. Eco-efficiency measurement of industrial sectors in China: a hybrid super-efficiency DEA analysis. *J Clean Prod* 2019;229:53–64. https://doi.org/10.1016/j.jclepro.2019.05.014.

[19] Qin G, Zhang P, Hou X et al. Risk assessment for oil leakage under the common threat of multiple natural hazards. *Environ Sci Pollut Res* 2020;27:16507–20. https://doi.org/10.1007/s11356-020-08184-7.

[20] Lampe HW, Hilgers D. Trajectories of efficiency measurement: a bibliometric analysis of DEA and SFA. *Eur J Oper Res* 2015;240:1–21. https://doi.org/10.1016/j.ejor.2014.04.041.

[21] Qin G, Zhang P, Wang Y. Investigating an assessment model of system oil leakage considering failure dependence. *Environ Sci Pollut Res* 2020;1–13. https://doi.org/10.1007/s11356-020-09999-0.

[22] Wang C, Li W, Wang Y et al. Study of electrochemical corrosion on Q235A steel under stray current excitation using combined analysis by electrochemical impedance spectroscopy and artificial neural network. *Construct Build Mater* 2020;247:118562. https://doi.org/10.1016/j.conbuildmat.2020.118562.

[23] Li C, Gao X, Wu J et al. Demand prediction and regulation zoning of urban-industrial land: evidence from Beijing-Tianjin-Hebei urban agglomeration. *China Environ Monit Assess* 2019;191:412. https://doi.org/10.1007/s10661-019-7547-4.

[24] Stern N. 2006. *Stern Review: The Economics of Climate Change*. Cambridge University Press, United Kingdom.

[25] Färe R, Grosskopf S, Whittaker G. 2007. Network DEA. In Zhu J, Cook WD (eds). *Modeling Data Irregularities and Structural Complexities in Data Envelopment Analysis*. Springer, Boston, MA.

[26] Sooryamoorthy R. The production of science in Africa: an analysis of publications in science disciplines, 2000–2015. *Forensic Sci Tech* 2018;115:317–49. https://doi.org/10.1016/j.fst.2018.04.004.

[27] Venkataraman S. Regional transformation through technological entrepreneurship. *J Bus Venturing* 2004;19:153–67. https://doi.org/10.1016/j.jbusvent.2003.04.001.

[28] Yoon H, Yun S, Lee J et al. Entrepreneurship in East Asian regional innovation systems: role of social capital. *Technol Forecast Soc Chang* 2015;100:83–95. https://doi.org/10.1016/j.techfore.2015.06.028.

[29] Wang X, Ding H, Liu L. Eco-efficiency measurement of industrial sectors in China: a hybrid super-efficiency DEA analysis. *J Clean Prod* 2019;229:53–64. https://doi.org/10.1016/j.jclepro.2019.05.014.

[30] Qin G, Zhang P, Hou X et al. Risk assessment for oil leakage under the common threat of multiple natural hazards. *Environ Sci Pollut Res* 2020;27:16507–20. https://doi.org/10.1007/s11356-020-08184-7.