Examining the CO₂ Emission Efficiency and its Influencing Factors for the Transport Sector in Central China

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ABSTRACT. The transportation industry is the main CO₂ emission industry in China. How to formulate and implement the policies of transportation energy saving and emission reduction policies while meeting the people's growing transportation needs has become an important issue to face Chinese society. The central region, as a transportation hub connecting north and south and connecting east and west, has developed rapidly with the support of policies in recent years, and the transportation sector has also developed accordingly. This paper firstly adopts the Super-SBM model that considers undesired output to calculate and evaluate the CO₂ emission efficiency of transportation sector in 6 provinces in central region of China from 2005 to 2016; then, it considers the impact of per capita GDP, urbanization level, number of buses per 10,000, energy intensity and transportation intensity on the CO₂ emission efficiency of transportation sector. Based on the analysis results, reasonable policy recommendations are provided for further improving the CO₂ emission efficiency of transportation department and developing low-carbon transportation.

KEYWORDS: CO₂ emission efficiency, transport sector, central region, influencing factors

1. Introduction

Since the 1990s, global warming has attracted the attention of the international community. The CO₂ produced by the burning of fossil fuels is recognized as one of the main causes of global warming. China is a big country in the production and consumption of energy resources. Huge energy consumption produces a large amount of CO₂ during the process of rapid economic development. In 2017, my country's carbon dioxide emissions have reached 9.1 billion tons, accounting for 28.17% of global emissions. Therefore, as a major developing country, China is facing international pressure and having responsibility to reduce greenhouse gas emissions.
CO₂ emissions in the transport sector are an important source of CO₂ emissions in China. Residents’ daily life and social development need the support of a certain number of transportation vehicles. The use of these vehicles will generate corresponding CO₂ emissions, which will have a certain impact on the environment. The transportation industry is the basic carrier for the operation of the entire social economic system, and the trend of its industrial scale continues to develop. How to coordinate the development of the transportation industry and transportation CO₂ emissions has become an urgent problem that needs to be solved.

The central region of China included 6 provinces included Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan. The population accounts for 26.59% of the total population of the country. In 2018, GDP grew by 7.8%, ranking first among the four major regions. Located in the Central Plains of China, the central region is Chinese transportation hub, connecting the east to the west, and south to the north, and is a bridge and link for the flow of China's production factors. Its geographical location is very important. Meanwhile, the central region is also an important transportation fortress, a distribution center and transit center for passenger and freight transportation. Transportation is an important foundation for the booming economy of the central region and the key to the rise of the central region and regional coordinated development. Therefore, this article will use the super-efficiency SBM model (super-SBM) to calculate the CO₂ emission efficiency of transportation department in the central region, and use panel data to explore its main influencing factors, and propose targeted transportation CO₂ emissions reduction recommendations based on the actual conditions of each province. CO₂ emission efficiency provides guarantee for promoting the coordinated development of regional transportation industry.

2. Literature review

In recent years, transportation CO₂ emissions have become a hot issue of concern to our country and even the international community. Scholars have conducted researches on transportation CO₂ emissions from different perspectives and using various methods. Previous studies focus on the measurement and prediction of transportation CO₂ emissions [1,2,3,4], the analysis of the spatial characteristics of transportation carbon emissions [5,6,7] and indicators exploration[8,9]. In summary, there are few literatures on transportation CO₂ emissions from the perspective of CO₂ emission efficiency or environmental efficiency.

CO₂ emission efficiency generally refers to the economic benefits of CO₂ emissions released by various production factors in a certain period of time. It mainly includes two concepts: single-factor CO₂ emission efficiency and total-factor CO₂ emission efficiency. Kaya and Yokobori [10] first defined CO₂ emission efficiency from the perspective of a single element, and defined it as the ratio of GDP to CO₂ emissions. Ang [11] then measured the CO₂ emission efficiency by energy consumption per unit of GDP. In addition, some scholars have measured
CO₂ emission efficiency with single-element indicators such as CO₂ emissions per unit of energy and CO₂ emissions per unit of GDP [12, 13, 14].

The efficiency measured from the perspective of all factors is based on the frontier of production, and the efficiency is measured according to the deviation of the production unit from its production boundary, which is more comprehensive and accurate than the efficiency measured from the single factor. At present, the measurement methods of total factor carbon emission efficiency mainly include stochastic frontier analysis (SFA) and data envelopment analysis (DEA). Since DEA can avoid strong assumptions of SFA method about the model setting and the normal distribution of random interference items, it can fit multi-output activities with expected and undesired outputs better, and it has a wider scope of application than SFA. Ramanathan [15] used the DEA method to integrate four indicators of CO₂ emissions and calculated the CO₂ emissions efficiency of 17 countries in the Middle East and North Africa. Yao et al. [16] used the DEA model to measure energy efficiency from a regional perspective according to the cross-sectional data of 30 provinces in China in 2011, after integrating the regional heterogeneity. Guo et al. [17] studied the energy-saving technologies and energy structure adjustments of 29 provinces in China based on the environmental DEA model, and evaluated Chinese potential for emission reduction and energy conservation. Meanwhile, with the continuous expansion of DEA application fields, the methods have also achieved innovation and development. Tone [18] proposed the SBM model (Slack Based Measure, SBM) in 2001, this model considers the slack improvement part. It is a non-radial and non-angle DEA model, which avoids the calculation deviation caused by the difference between the radial and angular choices. Choi et al. [19] used SBM model to estimate China’s CO₂ emission efficiency and marginal abatement cost. Gómez-Calvet et al. [20] used the modified SBM-DEA method to analyze the undesired output and CO₂ efficiency of EU countries.

Regarding the influencing factors of CO₂ efficiency, the current research mainly focuses on single-element CO₂ emission efficiency relying on IPAT, STIRPAT and Kaya equations to explore the influencing factors through exponential decomposition [21]. Furthermore, econometric models can also be applied to explore influencing factors [22]. From the review of the literature, it can be seen that the previous literatures mostly started from the perspective of a single factor. There are few studies that have conducted calculations under the comprehensive consideration of the organic unity of economy, energy and environment, and most of the efficiency calculations are for the entire industry. The whole CO₂ emission efficiency cannot be a comprehensive and true reflection of the actual situation in various regions and specific industries. At the same time, it has not further explored influencing factors of transportation CO₂ emission efficiency, and most of the research is based on the entire China which did not consider from a regional perspective. Therefore, the purpose of this research is to grasp the transportation carbon emission efficiency in central region of China, clarify its differences, and put forward targeted recommendations on transportation CO₂ emission reduction based on the actual conditions of each province, which will help improve the transportation CO₂ emission efficiency of each province. The efficiency
improvement method can formulate effective strategies and methods for the industry management department.

3. Methodology and Data

3.1 Super-SBM model

The basic and typical DEA methods are CCR model proposed by Charnes et al. [23] in 1978 and BCC model proposed by Banker et al. [24] in 1984. Both of them measure efficiency from radial and angle (input or output angle), which are called radial DEA models. When this model is used to measure the efficiency, for the invalid decision-making units (DMUs), the relaxed and improved part is not taken into account, which makes the calculation results inaccurate. Based on this, Tone proposed the SBM model in 2001[18]. The model considered the improved part of relaxation and was a non-radial and non-angular DEA model. When the DEA model measures the efficiency, the efficiency values are all less than or equal to 1, and there will usually be situations where the efficiency values of multiple evaluated DMUs are all 1, that is, there are multiple effective DMUs. In this case, it cannot further judge which effective DMU has a higher efficiency level and which effective DMU has a relatively low efficiency level, that is, it is impossible to judge its effectiveness. Super Efficiency Model is a good solution to this problem.

This paper supposes that there are n DMUs, \(DMU_j (j = 1,2,3,\cdots, n)\). There are \(m\) inputs and \(r_1\) desired outputs and \(r_2\) undesired outputs which showed as follows:

\[X_i = (x_{1k}, x_{2k}, \cdots, x_{mk})\], \(Y^d_p = (y^d_{1k}, y^d_{2k}, \cdots, y^d_{r_1k})\) and \(Y^u_q = (y^u_{1k}, y^u_{2k}, \cdots, y^u_{r_2k})\).

Then the super-SBM model is constructed as follows:

\[
\min J = \frac{1 + \frac{1}{m} \sum_{i=1}^{m} s^-_i / x_{ik}}{1 - \frac{1}{r_1 + r_2} (\sum_{p=1}^{r_1} s^+_p / y^d_{r_1k} + \sum_{q=1}^{r_2} s^{-}_p / y^u_{r_2k})}
\]

s.t.

\[
\sum_{j=1, j \neq k}^{n} x_{ij} \lambda_j - s^-_i \leq x_{ik}
\]

\[
\sum_{j=1, j \neq k}^{n} y_{pj} \lambda_j + s^+_p \geq y_{pk}
\]

\[
\sum_{j=1, j \neq k}^{n} y_{qj} \lambda_j - s^{-}_p \leq y_{qk}
\]

\[
\lambda_j, s^-_i, s^+_p, s^{-}_p \geq 0
\]
3.2 Input and Output Indicators

Based on the model described above, this paper will apply the Super-SBM model to calculate the CO\textsubscript{2} emission efficiency change of transport sector of 6 provinces in central China from 2004 to 2016. The input and output indicators are described below.

Input indicators: Based on economic growth theory, labor and capital are the basic and core input factors. Therefore, we chose labor input which is characterized by the number of transportation employees. Considering the availability of data, this paper selects amount of fixed capital investment in the transportation sector as capital input as some scholars did [25, 26]. This study also selects road density as one part of capital input. Meanwhile, we choose energy consumption in the transportation industry as an energy input. Utilizing the consumption of various types of energy by the transportation industry, unified conversion into "10000 tons of standard coal."

Output indicators: We chose gross domestic product by transportation, freight turnover and passenger turnover as the desirable outputs, while the amount of CO\textsubscript{2} emissions of the transport sector from energy consumption are chosen as the undesirable output. Among them, the CO\textsubscript{2} emissions of the transport sector will be calculated according to the following formula:

\[
CO_2 = \sum_{i=1}^{5} E_i \cdot F_i
\]

Where \(E_i\) represents the total consumption of the \(i\)th fuel in the transportation sector, and \(F_i\) means carbon emission factor for the \(i\)th fuel. The main five energy carbon emission coefficients of the transportation sector are as follows:

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions coefficient</td>
<td>0.5538</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.5921</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.4483</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>0.6185</td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.5714</td>
</tr>
</tbody>
</table>

3.3 Driving factors

Based on the data availability and the relevant literature, per-capita GDP, urbanization, transportation intensity, transportation energy intensity, the number of private vehicles per 10,000 people, the number of public vehicles per 10,000 people were chosen to be the dominant driving factor of transport sector CO\textsubscript{2} emission efficiency.
Per-capita GDP (pGDP) refers to the gross domestic product divided by the total population, which was selected as the variable for the socio-economic development level.

Urbanization (UR) refers to the proportion of the permanent residents of an urban area in a region to the total resident population in that region. The level of urbanization can well describe the process and degree of population gathering in a certain area to the city.

The number of public vehicles per 10,000 people (PUV). The development of public transportation is low-carbon and environmentally friendly to a certain extent.

Energy intensity (EI) refers to the total energy consumption per unit of the industry’s unit GDP which characterizes the industry’s energy efficiency. A decrease in transportation energy intensity indicates an improvement in the efficiency of energy utilization and the technological progress level in the transport sector [27].

Transportation intensity (TI) refers to the ratio of comprehensive transportation service and the added value in transport sector, which reflects the economic efficiency of the transport sector. The converted transportation turnover is calculated by railway, highway, waterway and civil aviation passenger turnover and the corresponding conversion coefficient, which takes 1, 0.1, 1 and 0.075 respectively [28].

Therefore, the econometric model of CO$_2$ emission efficiency in the transportation sector can be expressed as:

\[ \ln CEE_{it} = a + \beta_1 \ln pGDP_{it} + \beta_2 \ln UR_{it} + \beta_3 \ln PUV_{it} + \beta_4 \ln EI_{it} + \beta_5 \ln TI_{it} + \epsilon_{it} \]

4. Results and Discussion

4.1 Analysis of CO$_2$ Emission Efficiency

Table 2 clearly shows the CO$_2$ emissions efficiency of transport sector in central China.

<table>
<thead>
<tr>
<th>Province</th>
<th>Shanxi</th>
<th>Henan</th>
<th>Hubei</th>
<th>Hunan</th>
<th>Jiangxi</th>
<th>Anhui</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>1.17</td>
<td>1.16</td>
<td>1.11</td>
<td>0.74</td>
<td>0.56</td>
<td>1.27</td>
<td>1.00</td>
</tr>
<tr>
<td>2006</td>
<td>1.26</td>
<td>1.14</td>
<td>1.01</td>
<td>0.79</td>
<td>0.52</td>
<td>1.20</td>
<td>0.99</td>
</tr>
<tr>
<td>2007</td>
<td>1.23</td>
<td>1.11</td>
<td>1.02</td>
<td>0.84</td>
<td>0.53</td>
<td>1.18</td>
<td>0.99</td>
</tr>
<tr>
<td>2008</td>
<td>1.12</td>
<td>1.07</td>
<td>1.02</td>
<td>1.01</td>
<td>0.46</td>
<td>1.29</td>
<td>0.99</td>
</tr>
<tr>
<td>2009</td>
<td>1.08</td>
<td>1.07</td>
<td>1.07</td>
<td>1.00</td>
<td>0.50</td>
<td>1.30</td>
<td>1.01</td>
</tr>
<tr>
<td>2010</td>
<td>1.09</td>
<td>1.05</td>
<td>1.01</td>
<td>0.68</td>
<td>0.56</td>
<td>1.32</td>
<td>0.95</td>
</tr>
<tr>
<td>2011</td>
<td>1.08</td>
<td>1.05</td>
<td>1.01</td>
<td>0.71</td>
<td>0.59</td>
<td>1.34</td>
<td>0.96</td>
</tr>
<tr>
<td>2012</td>
<td>1.08</td>
<td>1.05</td>
<td>1.03</td>
<td>1.07</td>
<td>0.60</td>
<td>1.27</td>
<td>1.02</td>
</tr>
<tr>
<td>2013</td>
<td>1.11</td>
<td>1.12</td>
<td>1.02</td>
<td>1.12</td>
<td>0.53</td>
<td>1.24</td>
<td>1.02</td>
</tr>
</tbody>
</table>
It can be seen from Table 2 that in the central region, Anhui Province has the highest carbon emission efficiency. During the 12 years from 2005 to 2016, the average CO₂ emission efficiency of the transport sector in Anhui Province was 1.25, which is greater than 1, indicating that they are at the forefront of production. The province's transportation CO₂ emission efficiency is at the advanced level in the country, and the resource allocation is relatively reasonable. Shanxi Province is closely followed. Shanxi Province is rich in coal resources and has a particularly large demand for cargo transportation. However, since 2009, Shanxi Province’s CO₂ emissions of transport sector have hardly increased. In recent years, Shanxi Province has adopted management skills and new technologies. For example, traditional buses have been gradually replaced by hybrid or pure electric buses. Jiangxi Province has the lowest CO₂ emission efficiency, and the annual efficiency value has been lower than 1 for 12 years, indicating that the province has insufficient investment in the treatment of environmental pollution problems, the level of transportation energy-saving technology is not high, and the effectiveness of CO₂ emission reduction work is not obvious.

4.2 Analysis of Influencing Factors of CO₂ Emission Efficiency

Using equation (3) to regress the influencing factors of carbon emission efficiency, and the results are shown in Table 3.

<table>
<thead>
<tr>
<th>Coef.</th>
<th>Std. err.</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>InpGDP</td>
<td>0.866***</td>
<td>0.143</td>
<td>6.06</td>
</tr>
<tr>
<td>lnUR</td>
<td>-2.543***</td>
<td>0.475</td>
<td>-5.35</td>
</tr>
<tr>
<td>lnPUV</td>
<td>0.141</td>
<td>0.240318</td>
<td>0.59</td>
</tr>
<tr>
<td>lnEI</td>
<td>0.334***</td>
<td>0.12</td>
<td>2.78</td>
</tr>
<tr>
<td>LnTI</td>
<td>-0.053*</td>
<td>0.0555</td>
<td>-0.96</td>
</tr>
</tbody>
</table>

R-squared 0.7067

* for p < 0.1, ** for p < 0.05, *** for p < 0.01.

The coefficient of per capita GDP is 0.866, and it has passed the significance test with a significance level of 1%. It shows that per capita GDP has a positive impact on the CO₂ emission efficiency of the transport sector in the central region. Although economic development will increase transportation activities, it has brought huge economic benefits, thus promoting the growth of CO₂ emission efficiency. The level of urbanization has a negative impact on CO₂ emission efficiency. With the continuous advancement of urbanization, people’s daily life and the construction of large-scale housing and infrastructure have led to an increase in
the demand for transportation, which drives the development of transportation at the same time. This has led to an increase in energy consumption and CO₂ emissions, and reduced transportation CO₂ emissions efficiency. Energy intensity has a positive effect on the CO₂ emission efficiency of transportation, while the transportation intensity has an inhibitory effect on the CO₂ emission efficiency of transportation. Energy intensity can characterize the energy-saving technology level of the transportation sector, which also fully demonstrates that my country's the reduction policies current transportation CO₂ emissions to improve energy efficiency are reasonable and necessary. Although the coefficient of the PUV is 0.141, it has not passed the significance test, so it has not had a significant impact on the CO₂ emission efficiency of transportation.

5. Conclusion

This paper constructs a scientific and reasonable input-output evaluation index system, introduces transportation CO₂ emissions as undesired output, and calculates the transportation CO₂ emission efficiency in central China from 2005 to 2016 based on the super-SBM model. Then, selecting per capita GDP, urbanization level, the number of buses per 10,000 people, energy intensity, and transportation intensity as the influencing factors of transportation CO₂ emission efficiency, build a suitable panel data model, and quantify the influence factors of transportation CO₂ emission efficiency. It can be seen that the overall CO₂ emission efficiency of transport sector in central China is not high, and the transportation industry has great potential for energy conservation and emission reduction. Among these six provinces, there are certain differences in transportation CO₂ emission efficiency. Therefore, when formulating transportation energy-saving and emission-reduction measures, it is necessary to formulate differentiated emission-reduction measures based on the actual conditions of each province's own economic development stage, the development scale of the transportation industry, and the transportation structure and level. At the same time, the central region should improve the level of energy-saving technologies, increase investment in energy-saving technologies in transportation, rely on technological progress to improve transportation energy efficiency, as well as popularizing the use of new energy vehicles.

References


