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An empirical study on the influencing factors of transportation carbon efficiency: Evidences from fifteen countries

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HIGHLIGHTS

- Transportation carbon efficiency is redefined.
- A new model—virtual frontier DEA is applied.
- Fifteen countries' transportation carbon efficiencies are evaluated.
- The influencing degree of a structure factor is relatively small.

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ABSTRACT

In this paper, transportation carbon efficiency is redefined, and its inputs and outputs are obtained from a literature review. Carbon, capital and labor are selected as the inputs, and passenger turnover volume and freight turnover volume are defined as the outputs. A new model, a virtual frontier DEA (virtual frontier Data Envelopment Analysis), is applied to evaluate transportation carbon efficiencies, and cases from 15 countries during the period of 2003–2010 are analyzed to verify the results. Next, a Tobit regression model is applied to identify the important influencing factors of transportation carbon efficiency. The results indicate that compared to the technology factor and management factor, the influencing degree of a structure factor is relatively small.

1. Introduction

In recent years, public concern over greenhouse gas emissions from the transportation sector has increased. According to the literature [1], the transportation sector accounts for 26% of the total global CO_2 emissions and is one of the few sectors with continually increasing emissions. Controlling the carbon dioxide emissions from transportation is important for sustainable development. Many countries and regions have imposed CO_2 emissions caps on the transportation sector, such as California [2], Canada [3], London [4], Brazil [5], and Taiwan [6].

Much research has focused on how to realize these emission caps. The main strategies have been described as follows: energy and technology innovation (Advenier et al. [7]; Steenhof and McInnis [3]; Grahn et al. [8]; Thomas [9]; Yang et al. [10]; Kaufman et al. [11]; Lutsey [12]; Andress et al. [13]; Wang et al. [14]; Blackman et al. [15]), policy implementation (DeCicco and Mark [16]; Piattelli et al. [17]; Bristow et al. [18]; Hickman et al. [4]; Schipper et al. [19]; Abrell [20]; Morrow et al. [21]; Yan and Crookes [22]; Waisman et al. [23]), transportation structure adjustment (Knittel [24]; Brogan et al. [25]) and other methods (Higgins [26]; Banister et al. [27]).

In the realm of policy implementation, Morrow et al. [21] analyzed the typical impacts of the following: fuel taxes, continuous increases in fuel economy standards, new vehicle purchase tax credits and a combination of these strategies. The results indicated that all of the modeled policy scenarios failed to meet the Obama administration's goal of reducing greenhouse gas emissions by 14% below 2005 levels by 2020. Piattelli et al. [17] analyzed the impact of carbon taxes on transportation carbon emissions; the results indicated that a carbon tax could significantly increase fiscal revenues rather than reduce carbon dioxide emissions. In the realm of energy and technology innovation, Advenier et al. [7] analyzed the impacts of different technologies and different energy sources on CO_2 transportation emissions. Steenhof and McInnis [3] compared the influence of alternative technologies on CO_2 emissions from Canada's passenger transportation and concluded that ethanol could reduce 13% of the emissions; furthermore, he concluded that hydrogen and electricity could reduce 14% of the

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Table 1
The inputs and outputs defined in several energy efficiency papers.

Papers	Inputs	Outputs
Boyd and Pang [36]	Electric, fuel	Add value
Clinch et al. [37]	Labor input, cost input, energy input	Energy benefit, environmental benefit
Ramanathan [38]	CO_2 emissions per capita, fossil fuel energy consumption	Gross Domestic Product per capita, non-fossil-fuel energy consumption
Onut and Soner [39]	Number of employees, annual electricity consumption, annual water consumption, annual liquefied petroleum gas consumption	Occupancy rate, annual total revenue, total number of guests
Azadeh et al. [40]	Final consumption of electricity, thermal aggregation of all fossil fuels total consumption	Gross output, value added from both categories
Hu and Kao [41]	Labor input, capital input, energy input	Gross Domestic Product
Wei et al. [42]	Industrial capital stock, industrial labor force, industrial energy consumption	Industrial value added, industrial CO_2 emissions
Mukherjee [43]	Labor, capital, energy, materials	Gross value of manufacturing production
Mukherjee [44]	Capital, labor, energy, materials, services	Gross output
Shi et al. [45]	Annual data on industrial investments in fixed assets, industrial energy consumption, industrial labor	Industrial added value, volume of industrial waste gas from fuel burning
Wang and Zhou [46]	Capital input, labor input, energy input	The gross product value of industrial enterprises
Zhou and Ang [47]	Capital stock, labor force	Gross Domestic Product, CO_2 emissions
Martínez et al. [48]	Labor, energy, capital, materials	The gross value of manufacturing deflated by the wholesale price index
Blomberg et al. [49]	Labor, electricity, oil	Pulp or paper
Wang et al. [50]	Capital input, labor input, energy input	The gross product value of industrial enterprises above a designated size
Cui et al. [51]	Number of employees in energy industry, energy consumption amount, energy services amount	CO_2 emissions per capita, Industrial profit amount
Cui and Li [52]	Labor input, capital input, energy input	Passenger turnover volume, freight turnover volume
Wang et al. [53]	Energy consumption, labor input, capital input	Gross Domestic Product, CO_2 emissions
Wang and Wei [54]	Labor input, capital input, energy input	Total volume of industrial sulfur dioxide emissions, total volume of industrial carbon dioxide emissions
Wang et al. [55]	Capital stock, energy consumption, labor	GDP, environmental pollutants
Wang and Feng [56]	Capital stock, labor, energy consumption	GDP, positive environmental indicator

emissions. In the realm of transportation structure adjustment, Brogan et al. [25] analyzed the impact of adjusting the freight proportion of truck, rail, water, air and pipelines on transportation carbon emissions.

Some literature focused on analyzing the main influencing factors of transportation CO_2 emissions (Schipper et al. [28]; Wang et al. [29]; Wang and Yang [30]; Wang et al. [31]) and the impact of transportation on the environment (Chester and Horvath [32]; Zhang and Wang [33]). Schipper et al. [28] reviewed the carbon emissions of 10 industrialized countries from 1973 to 1992, and the results indicated that trucks were the main reason for carbon emissions increases. Chester and Horvath [32] evaluated the life-cycle emissions of the transportation sector, and their results indicated that the total life-cycle greenhouse gas emissions contributed an additional 63% from roads, 155% from rails, and 31% from aviation systems above vehicle tailpipe emissions.

Many research papers focused on the changing trends of transportation CO_2 emissions. Blesl et al. [34] examined the impacts of additional efficiency improvement measures over the baseline, and their results indicated that bio-fuels and methanol are the most expensive means of reducing CO_2 to achieve efficiency targets. Xu et al. [35] utilized a Logarithmic Mean Divisia Index (LMDI) decomposition analysis to study emission changes from a sectoral perspective, and their conclusions indicated that the energy intensity of the transportation sector declined by 23.74% from 1996 to 2011.

The literature review indicates that many countries have undertaken substantial initiatives to control carbon dioxide emissions from the transportation sector. However, it is unfortunate that little research has focused on evaluating these efforts.

To resolve the gap in published research, this paper proposes a new definition for evaluating efforts to achieve transportation carbon efficiency. This new definition is intended to reflect the relationship between transportation carbon inputs and outputs, which is a type of efficiency analysis.

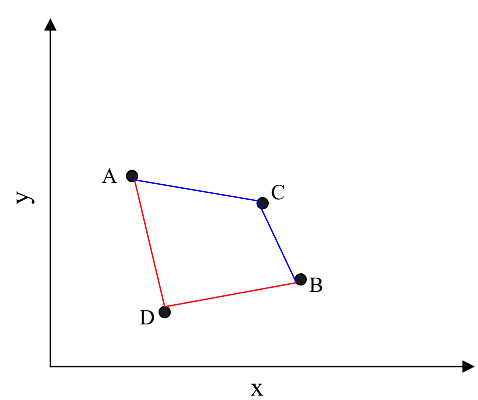

Fig. 1. A diagram of the examples.

Table 2
Examples.

DMUs	Inputs	Outputs
A	3	6
B	7	2
C	6	5
D	4	1

2. The evaluation of transportation carbon efficiency

2.1. The selection of inputs and outputs

According to the analysis above, transportation carbon efficiency is defined as an efficiency that is calculated by comparing the relationship between outputs and inputs; therefore, the selection of inputs and outputs is very important. To select inputs and outputs of transportation carbon efficiency, this paper begins by summarizing the existing efficiency literature. Energy efficiency