Study on Carbon Emission and Impact Factor based on LMDI method: the Case of Jiangsu

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***Abstract*— Correctly measuring the carbon emission and analyzing its impact factors are the cornerstone of devising energy-related policies and guidance for future development. In previous research and off-the-shelf database, the carbon emission of some important factors was neglected, and the analysis of impact factors was not fully comprehensive. Thus, in this paper, a study on carbon emission and impact factors based on Logarithmic Mean Divisia Index (LMDI) method are conducted, and the Jiangsu province is analyzed as an example. First, the carbon emission of Jiangsu province is investigated using energy balance table. As an important factor, the electricity received from other provinces is taken into account. Moreover, the Kaya equation and LMDI are reformulated that they can both cope with the impact from energy and industrial structures simultaneously. Finally, the carbon emission and its impact factors in Jiangsu province are studied, and practical suggestions are provided.**

***Keywords*—carbon emission, impact factor, energy balance table, Logarithmic Mean Divisia Index**

I. Introduction

With the worldwide concerns for the low-carbon and sustainable energy utilization, China has introduced a series of concrete policies to constrain the carbon emissions throughout the energy production, transmission, and utilization stages, including the "peaking carbon dioxide emissions" and "carbon neutrality" blueprints. In the thirteenth Five-Year Plan, China guarantees that by 2020, the carbon intensity would be reduced by 18% [1]. Jiangsu, as a developed coastal province, has promised a 20.5% carbon intensity reduction and delivered ahead of schedule [2]. However, in the next five years to come, Jiangsu, as well as other provinces, is still under the continuous pressure of carbon emission reduction. Therefore, correctly measuring the carbon emission, as well as understanding its inner driving force, is the prerequisite for reducing carbon emission reasonably and scientifically.

Generally, the most used carbon emission calculation methods including inventory analysis, input-output analysis, and remote sensing simulation and inversion [3]. The input-output analysis is usually combined with life circle analysis, aiming to chase back the carbon emission from upstream of the production process [4]. However, it is extremely independent and sensitive to the data, which is usually difficult to obtain accurately. The remote sensing simulation and inversion method uses the light image by satellites during the night, and uses certain algorithms to inverse the carbon-related human activities. Though this method has some applications, such as in Carbon Emission Accounts & Datasets association (CEAD), it has high requirements for the data, and the accuracy is difficult to guarantee [5]. Therefore, it is usually used as a crosscheck method. As for the inventory analysis, it usually uses the energy balance table as the data source. For its easier implementation, it is widely used by the National Bureau of Statistics and other relevant associations [6, 7].

As for the research on impact factor decomposition of carbon emission, there are three kinds of methods in general, including structure decomposition analysis (SDA), index decomposition analysis (IDA), and regression-based methods [8]. SDA is more applicable for decoupling the effect from economic and technical aspects, while SDA is more applicable for a specific time in a given region based on data. The influencing factors of industrial carbon emission in Shanghai were decoupled using Logarithmic Mean Divisia Index (LMDI) method in [9]. More specifically, the pathway of emission reduction of the chemical industry in China was investigated in [10]. Modeling of the multiple benefits of electricity savings for emissions reduction on the power grid level was studied in [11], and China's chemical industry was set as a typical example. Carbon abatement in China's commercial building sector was investigated in [12] using a bottom-up measurement model based on the Kaya-LMDI method.

However, in the studies above, some factors have been neglected in the carbon emission calculation, which will lead to different results and conclusions. First, both of the studies above, the results from the CEAD database, and the national and provincial Bureau of Statistics did not count the carbon emission from outside electricity. Since Jiangsu is an important receiving province of outside electricity from Sichuan, Shanxi, etc., it may be an injustice to overlook these parts of carbon emissions. Moreover, these studies decomposed the impact factors from either energy structure or industrial structure, and these two factors cannot be measured simultaneously.

Under the ever-increasing carbon emission reduction pressure on China, this paper studied the carbon emission and analyze its main driving factors for Jiangsu province, aiming to provide practical suggestions for future energy reform. First, the methodology of calculating the carbon

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emission in different aspects was illustrated in Section 2. The decomposition method for impact factors was developed in Section 3, based on the extended Kaya equation and LMDI model. Finally, the carbon emission and its impact factors for Jiangsu in 2010-2019 were investigated, and detailed suggestions are concluded.

II. CARBON EMISSION CALCULATION USING THE ENERGY BALANCE TABLE

In the energy balance table given by the national or provincial Bureau of Statistics, the energy consumption and production of each energy category during the primary energy supply, transformation, loss, and final consumption are given. Thus, the total energy-related carbon emission can be calculated either from the supply or consumption perspective (the energy loss during the transformation can be neglected).

$$c_t = \sum_{i \in I} \sum_{j \in J} e_{i,j,t} \alpha_{i,t} \tag{1}$$

where c_t is the total carbon emission in year t. I is the set of primary energy supply categories, as listed in Table 1. J is the set of consumption categories also listed below. $e_{i,j,t}$ is the consumption of energy category i in consumption sector j. $\alpha_{i,t}$ is the carbon emission factor of energy i in year t.

TABLE 1. ENERGY SUPPLY CATEGORY AND ENERGY CONSUMPTION SECTOR

Energy supply:

- Coal: raw coal, cleaned coal, other washed coal, briquettes, gangue, coke, coke oven gas, blast furnace gas, converter gas, other gas, other coking products.
- Petroleum products: crude oil, gasoline, kerosene, diesel oil, fuel oil, naphtha, lubricants, paraffin waxes, white spirit, bitumen, asphalt, petroleum coke, liquefied petroleum gas, refinery gas, other petroleum products.
- Gas: natural gas, liquefied natural gas.
- Heat.
- Electricity from outside.
- Other Energy.

Energy consumption:

- Agriculture, forestry, animal husbandry, and fishery.
- Industry.
- Construction.
- Transport, storage, and post.
- Wholesale and retail trades, hotels, and catering services.
- Residential.
- Others.

III. IMPACT FACTOR ANALYSIS

Kaya identical equation is usually adopted to decompose the impact factors of carbon emission [13]. Its classic form is consisting of four factors, including population, economic growth, energy consumption intensity, and average carbon emission factor:

$$c_t = p_t \times \frac{g_t}{p_t} \times \frac{e_t}{g_t} \times \frac{c_t}{e_t} \tag{2}$$

where p_t and g_t are the population and gross domestic product (GDP) in year t.

However, the classic form of the Kaya equation is limited to these factors only. Considering that Jiangsu is a receiver of outside electricity, and it has complex energy and industrial structure, the content of the Kaya equation is extended as follows:

$$\begin{aligned} c_t &= \sum_{i \in I} \sum_{j \in J} c_{i,j,t} \\ &= \sum_{i \in I} \sum_{j \in J} p_t \times \frac{g_t}{p_t} \times \frac{e_{i,j,t}}{e_{j,t}} \times \frac{g_{j,t}}{g_t} \times \frac{e_{j,t}}{g_{j,t}} \times \frac{c_{i,j,t}}{e_{i,j,t}} \\ &= \sum_{i \in I} \sum_{j \in J} p_t \times A_t \times B_{i,j,t} \times C_{j,t} \times D_{i,t} \times \alpha_{i,t} \end{aligned} \tag{3}$$

where A_t, $B_{i,j,t}$, $C_{j,t}$, and $D_{i,j,t}$ represent the impact factors of population, economic growth, energy structure in industrial category j, industrial structure of category j, and energy consumption intensity of energy i in the industrial category j. It should be noted that all the energy consumption in this equation is measured by standard coal.

The difference between the carbon emissions in year t and the base year, Δc_t, can be also decomposed as:

$$\begin{aligned} \Delta c_t &= \sum_{i \in I} \sum_{j \in J} c_{i,j,t} - c_{i,j,0} \\ &= \sum_{i \in I} \sum_{j \in J} \Delta c_{i,j,t}^{P} + \Delta c_{i,j,t}^{A} + \Delta c_{i,j,t}^{B} + \Delta c_{i,j,t}^{C} + \Delta c_{i,j,t}^{D} + \Delta c_{i,j,t}^{\alpha} \end{aligned} \tag{4}$$

where $c_{i,j,0}$ is the carbon emission of energy consumption i in the industry sector j in the base year. $\Delta c_{i,j,t}^{P}$, $\Delta c_{i,j,t}^{A}$, $\Delta c_{i,j,t}^{B}$, $\Delta c_{i,j,t}^{C}$, $\Delta c_{i,j,t}^{D}$ and $\Delta c_{i,j,t}^{\alpha}$ are the carbon emission increases from population, economic growth, energy structure, industrial structure, energy consumption intensity, and the change of carbon emission factors, respectively.

Using the LMDI method to decompose the equations above, we can obtain [14]:

$$\begin{aligned} \Delta c_t^{P} &= \sum_{i \in I} \sum_{j \in J} \Delta c_{i,j,t}^{P} \\ &= \sum_{i \in I} \sum_{j \in J} \frac{(c_{i,j,t} - c_{i,j,0})(\ln p_t - \ln p_0)}{\ln c_{i,j,t} - \ln c_{i,j,0}} \end{aligned} \tag{5}$$

Likewise, we can decompose other impact factors.

IV. SOURCE OF DATA

In this paper, the data of population, GDP, energy consumption, etc., are obtained from China and Jiangsu statistical yearbook [15]. GDP and its growth are calculated according to its current price. The carbon emission factor is obtained from the guideline of the provincial greenhouse gas inventories [16].

V. CASE STUDIES

A. *Carbon emission in Jiangsu*

As shown in Fig.1, in 2019, energy-related carbon emission in Jiangsu province reaches 870 million tons, taking up 7.08% of the total carbon emission in China. During 2010-2019, carbon emission grows steadily by 27.28%. Coal is always the dominant source of carbon emission. However, its share in the total carbon emission is decreasing from 81.13% in 2010 to 67.39% in 2019. Petroleum products are the second dominant source of carbon emission, and their share is relatively steady. On the other hand, we can also find that the carbon emission from outside electricity is growing rapidly by 220.90% in ten years, as the electric load grows. With the require for cleaner energy sources, the carbon emissions of natural gas and liquefied natural gas also grows by 299.13% within ten years.

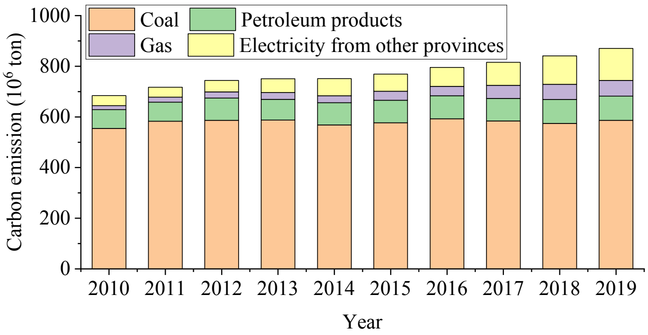

Fig 1 Carbon emission structure in Jiangsu

Though the carbon emission quantity in Jiangsu is increasing in recent years, the its intensity is decreasing smoothly, as indicated in Fig.2. Among the typical coastal provinces, the carbon emission intensity in Jiangsu province remains at a relatively low level, which is 29.92% lower than the average value in China. Moreover, the decoupling index remains between 0-0.6, which indicates that the economy and carbon emission are weakly de-linked.

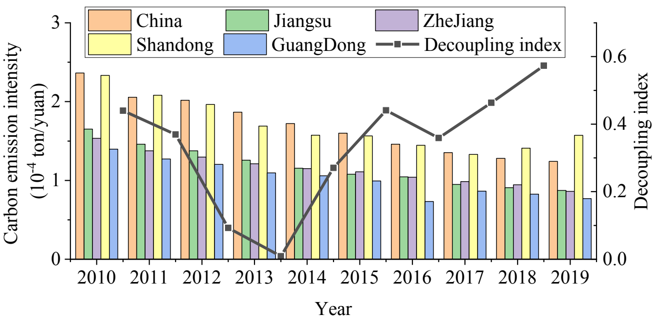

Fig 2 Carbon emission intensity in typical provinces and decoupling index in Jiangsu

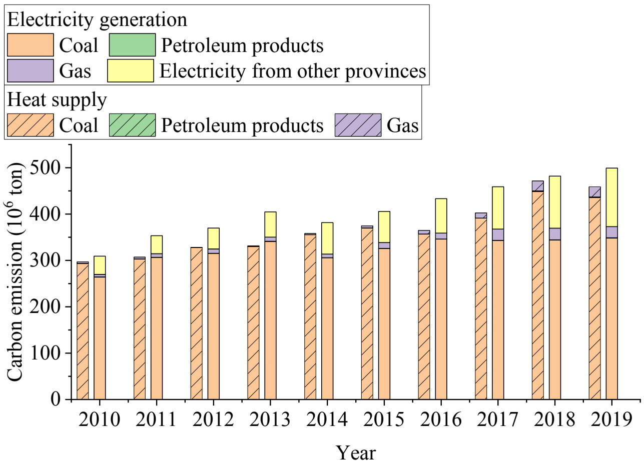

Fig 3 Carbon emission structure of energy sector in Jiangsu

The total electricity generation and heat supply in Jiangsu in 2019 is 3143.81 TWh and 66.32 trillion kJ. The electricity receives from other provinces is 179.56 TWh, taking the proportion of 5.71%. As presented in Fig 3, the electricity generation sector mainly relies on coal as its primary energy source, the carbon emission of which occupies 69.84% in 2019. Electricity from other provinces is the second, which accounts for 28.29% in 2019. On the other hand, the carbon emission of coal decreases by 18.35% in recent ten years, while the carbon emission from gas and electricity grows rapidly by 183.14% and 98.66%, respectively. As for the heat supply sector, coal is also the dominant source of carbon emission, which is 94.89% in 2019. Nature gas is the next, which takes up 4.83%. On the other hand, the carbon emission of coal also slightly reduces by 3.88%, while the natural gas grows dramatically by 324.37%.

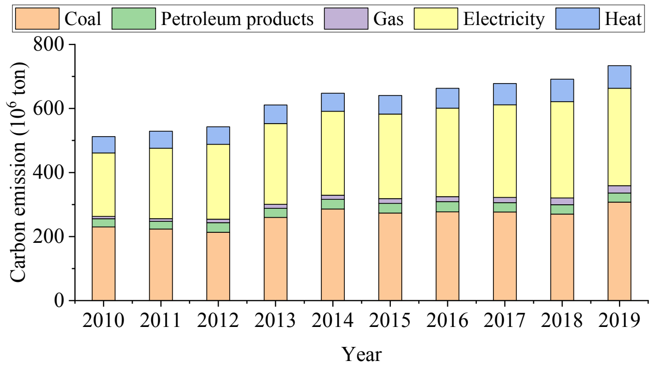

Fig 4 Carbon emission structure of the industrial sector in Jiangsu

The carbon emission structure of the industrial sector in Jiangsu is shown in Fig 4. The carbon emissions from coal and electricity are the two highest, which are 41.92% and 41.49%, respectively. The general trend of the total quantities of carbon emissions from each energy category in ten years is increasing. However, the proportion of the carbon emission from gas is increasing, while the petroleum products decrease from 5.01% to 3.90%.

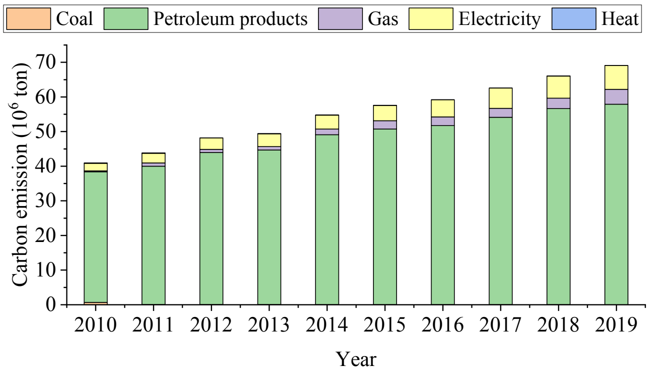

Fig 5 Carbon emission structure of the transportation sector in Jiangsu

The carbon emission structure of the transportation sector in Jiangsu is shown in Fig.5. the carbon emission from petroleum products is the highest, which accounts for 83.81%. T hough the quantity of carbon emission from petroleum products grows, its relative share is decreasing from 92.10% in 2010 to 83.81% in 2019. As cleaner energy sources, the shares of gas and electricity grow slightly, from 0.57% and 5.33% in 2010 to 6.22% and 9.94% in 2019.

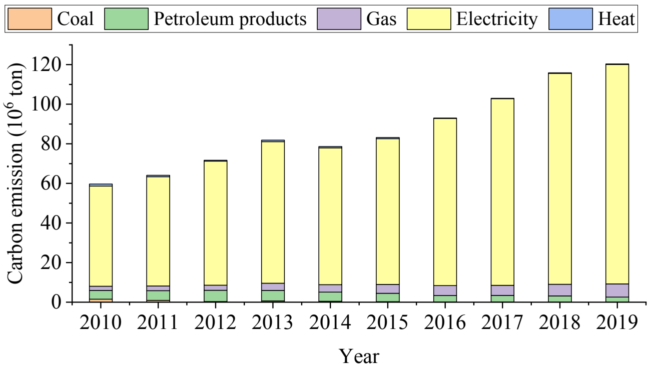

Fig 6 Carbon emission structure of the building sector in Jiangsu

The carbon emission structure of the building sector in Jiangsu is shown in Fig.6. The carbon emission from the electricity is the highest, and its proportion is also increasing from 84.83% in 2010 to 92.08% in 2019. On the contrary, the carbon emissions from coal, petroleum product, and heat decrease from 2.52%, 7.47%, and 1.73% in 2010 to 0.05%, 2.08, and 0.22%, respectively.

B. *Impact factor analysis*

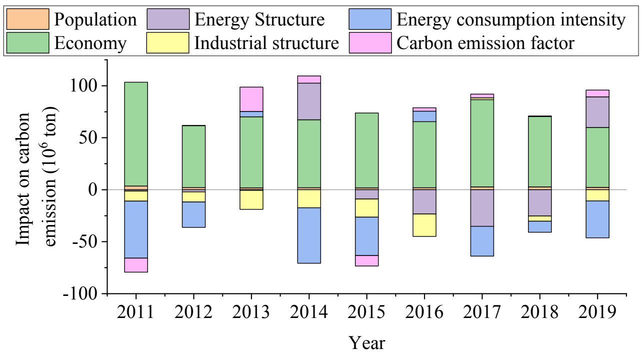

Fig 7 impacts of different factors on the carbon emission in Jiangsu

Based on the extended LMDI method, we decompose the contribution of different impact factors on the carbon emission year by year, as presented in Fig.7. the impacts of population, economy, energy structure, industrial structure, energy consumption intensity, and carbon emission factor throughout ten years are 20.86, 637.79, -31.91, -108.36, -299.21, and 21.05 million tons, respectively.

In general, population is the positive driving force for carbon emission. That is, the growth of the population can lead to an increase in carbon emission. In each year, the population effects are all positive, but the absolute values are relatively small. It only accounts for 6.72% of the carbon emission growth. Therefore, the impact of population on carbon emission remains in a reasonable range.

Economy growth is the main driving force, as it accounts for 205.60% of the increase in carbon emission. In each year, the values are all positive, which means the economic growth is achieved partly by consuming a lot amount of energy and producing carbon emissions accordingly. Looking into different industrial sectors, as presented in Fig.8, Fig.9, and Fig. 10, respectively, economic growth is the main driving force for all the sectors, especially in industrial and building sectors. It indicates that the economy in Jiangsu is tightly related to these two industrial sectors.

The contribution of energy structure is negative in general, but positive in some years. This pattern is consistent with the fluctuated share of coal consumption in the overall energy structure. The impact of industrial structure is negative, which means it was effective in the reduction of carbon emission by optimizing the industrial structure in the past years. As for specific sectors, the effect of industrial structure is negative for the industrial and transportation sector, while positive for building sectors, as shown in Fig 10. The industry sector has great weight in the GDP of Jiangsu, which means it will still cause somewhat pressure in the adjustment of industrial structure in the future.

The contribution of energy consumption intensity to the carbon emission is negative in the past ten years, especially in the industrial sectors and building sectors. It validates the effectiveness of the clean energy substitution strategy by the State Grid Jiangsu. However, in the transportation sector, for it still heavily rely on the traditional fossil energy source like petroleum products, its contribution to the carbon emission is positive in some years. This shows in the future, the transportation sector is still promising in the carbon emission reduction, by electrifying the vehicles and replacing with the cleaner energy source, such as methanol or hydrogen.

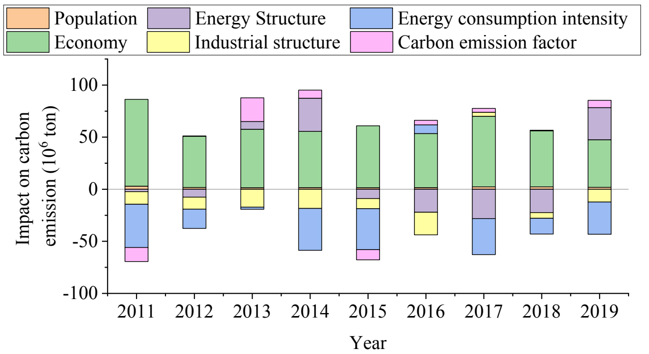

Fig 8 impacts of different factors on the carbon emission of the industrial sector in Jiangsu

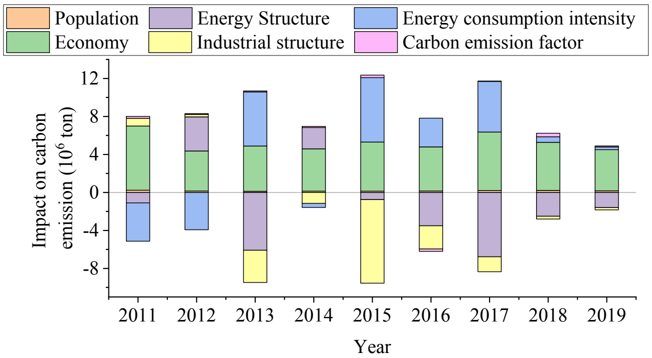

Fig 9 impacts of different factors on the carbon emission of the transportation sector in Jiangsu

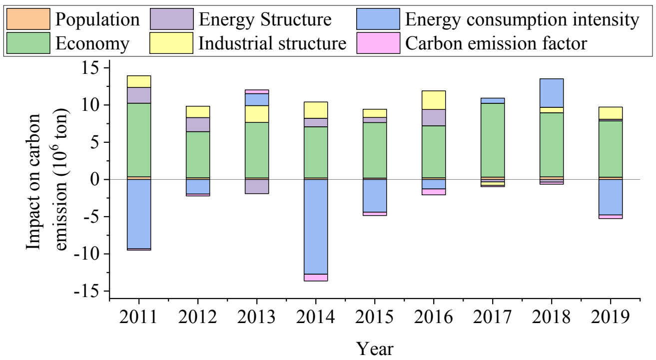

Fig 10 impacts of different factors on the carbon emission of the building sector in Jiangsu

VI. Conclusion

In this paper, the carbon emission in Jiangsu province is investigated using the energy balance table. An extended Kaya equation and LMDI method are developed to study the impact factors of carbon emission, including population, economic growth, energy structure, industrial structure, energy consumption intensity, and the change of carbon emission factors.

The analyzing results indicate that though the carbon emission in Jiangsu is still increasing, its intensity is turning in to a good direction. The economic growth and carbon emission are gradually decoupled. On the other hand, from historical data, we can find that economic growth is the main driving force for the increase in carbon emissions. As Jiangsu is now making efforts in optimizing the energy and industrial structure, as well as improving energy utilization efficiency, they are the main forces that drive carbon emission to decrease in recent years. From the study in this paper, we also find that though the economic growth lay a great pressure on carbon emission, some sectors, such as the industrial and transportation sectors, are still presenting a great potential and space for optimizing their energy-related activities in the future. The conclusion in this paper can assist the decision-makers in Jiangsu in devising future energy policies.

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