Research on the Drivers of Carbon Emissions from Highway Trucks Based on Pathway Analysis

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ABSTRACT

Highway freight transport emissions provide a high contribution to carbon emissions in the transport industry, and analysing the driving factors is conducive to building a low-carbon transport structure. This paper explores the indicators of economic dynamic series level, traffic development and energy consumption structure that affect the carbon emissions of the transport industry by using the pathway analysis, and analyses the dependence of carbon emissions on the truck model through visualisation. The results show that the direct throughput coefficients of GDP of the secondary industry, freight turnover, and the structure of truck models are 0.590, 0.317, and 0.204, respectively, indicating that the economic growth has a positive pulling effect on the carbon emissions of the transport industry, and the reliance on the other two types of indicators is small. The indirect throughput coefficients were 0.358, 0.619 and 0.613, indicating that transport development and model structure are highly dependent on the economy, and that adjusting the model structure with the help of economic development can effectively promote the implementation of emission reduction measures.

Keywords: Green transport; motorway freight; carbon emissions; access analysis; vehicle structure; visualisation

1. INTRODUCTION

As an important source of carbon emissions in China[1], the carbon dioxide emissions of the transport industry are affected by many factors with complex interrelationships, such as resources, economy, environment, society and technology. An in-depth study of the driving factors and mechanisms affecting carbon emissions plays a driving role in the adjustment of the transport structure, provides strategies to achieve low-carbon transport, and is of great significance to the realisation of green transport.

Most of the scholars have studied from the perspective of influencing factors, Besma Talbi[2]et al. explored the effects of energy consumption, road transport intensity, economic growth, urbanisation and fuel prices on CO2 emissions from the transport sector in Tunisia, and found that energy consumption and fuel prices play a pulling role in reducing carbon emissions.Wang[3]et al. investigated the effects of urbanisation on energy consumption and CO2 emissions, and found that urbanisation increases energy consumption and CO2 emissions in China, with significant differences between different provinces. emissions in China, and found that urbanisation increased energy consumption and CO2 emissions in China, with significant differences among different provinces.Shen[4]et al. developed and analysed a partial least squares model for urban-scale data of 352 townships in Taiwan, and the results showed that appropriate urban form policies can reduce carbon emissions.Huo[5]et al. proposed a method to simulate vehicle emissions in cities of different sizes and stages of development in China. emissions in Chinese cities of different sizes and development stages.Wang[6]et al. used the STIRPAT model to study the influencing factors of energy-related carbon dioxide emissions in Guangdong Province, China, and the empirical results showed that population, urbanisation level, GDP per capita, industrialisation level and service level are factors that drive the increase of carbon dioxide emissions, while the technology level, the structure of energy consumption and the degree of foreign trade are factors that reduce carbon dioxide emissions.Wu[7]et al. established a quantitative analysis model for a long-term energy substitution planning framework, and the results showed that changing transport modes (e.g., public to rail) and phasing out old vehicles as early as possible have a greater effect on carbon reduction in the short term than the synergistic effect of improving fuel economy.

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Most of the past studies focused on factor analysis, lack of in-depth research on the mechanism of carbon emission drivers, limited by the complexity of data and the influence of indirect effects. Pathway analysis[8]combines the roles of regression and correlation analysis, which can clearly illustrate the direct and indirect influences between variables, and provides a research method to solve complex problems. The purpose of this paper is to explore the main driving factors and mechanisms affecting the formation of energy consumption structure of highway transport by using the real data collected by the through path analysis, combined with the ArcGIS visualisation of the characteristics of intercity freight transport.

2. RESEARCH METHODOLOGY

2.1 Methods of pathway analysis

This paper intends to develop the correlation analysis of highway freight transport carbon emissions and its key driving factors, transport carbon emissions is a multivariate system, need to choose a research and analysis method that can digitally portray the complex correlation relationship between multivariate, through path analysis is recognised by scholars in various research fields because of its outstanding factor interrelationship portrayal ability[9][10].

Pathway analysis is a multivariate statistical analysis technique based on multiple linear regression analysis, which breaks down the direct and indirect pathway coefficients between the independent variables and the target variables to obtain their quantitative relationships, eliminating the one-sidedness of the correlation of any variable in the regression analysis that is intermingled with other factors, and at the same time, solving the limitation that partial correlation coefficients with units cannot be directly compared. Decision coefficient is the decision-making index in the pathway analysis, with which it can measure the combined effect between variables and clarify the main decision-making independent variables and limiting variables.

$$P_{iY} = B \tag{1}$$

$$\sum r_{ij} \times P_{jY} = r_{iY} \tag{2}$$

$$R^2_{(i)} = 2 \times Pi \times r_{iY} - (Pi)^2 \tag{3}$$

Where:P_{iY} represents the direct path coefficient after standarisation of xi to Y, B is the standard regression coefficient of the equation,r_{ij} depicts the degree of interconnection between X_i and X_j, is the indirect path coefficient, r_{iY} depicts the degree of interconnection between X_i and Y, is the decision-making coefficient, and the relationship of the variables with each other is shown in Fig. 1.

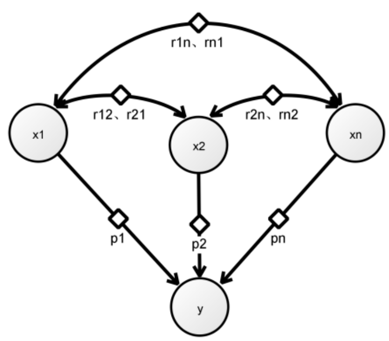


Figure 1. Plot of inter-variable flux relationships

2.2 Visualisation and analysis based on ArcGIS

Based on the results of the pathway analysis, the driving role of different influencing factors on the carbon emissions of trucks was analysed in depth, and these factors were visualised on the map using ArcGIS software in order to reflect their spatial distribution characteristics intuitively, and the relationship between the factors and the carbon emissions was analysed comprehensively to explore whether the factors were the driving law.

3. DATA SOURCES AND PROCESSING

3.1 Selection of indicators for the analysis of carbon emission pathways in the highway transport sector

This paper takes total carbon emissions as the target variable Y. Based on data availability and considering the endogenous influence between factors, it adopts 2006-2020 as the research time span and selects the following static indicators to analyse the potential influence mechanism, as shown in Table 1. All the indicator data are obtained from official published statistics such as Yunnan Provincial Statistical Yearbook (2007-2021) and China Energy Statistical Yearbook (2007-2021), etc. In this paper, we will carry out the data processing with the help of computational tools such as SPSS 26, which will enable the calculation of correlation analysis and through-trail coefficients.

Table 1 Indicators for refined analysis.

Indicator name	unit		Indicator name	unit	
CO2 Emissions	million tons	Y	Freight turnover	billion tons kilometers	X7
Primary sector	Billions	X1	Number of Type I and Type II trucks	Vehicle	X8
Secondary sector	Billions	X2	Number of Type III trucks	Vehicle	X9
Tertiary Industry	Billions	X3	Number of Type IV trucks	Vehicle	X10
Total Population	million tons	X4	Number of Type V trucks	Vehicle	X11
Length of Highway Route	kilometers	X5	Number of Type VI wagons	Vehicle	X12
Highway Cargo Volume	billion tons	X6			

4. SELECTION OF INFLUENCING FACTORS AND VISUALISATION ANALYSIS

4.1 Selection of influencing factors

There are many reasons affecting the carbon emission of the highway transport industry, which can be summarised into the following main types: (1) indicators related to the level of macroeconomic development, such as gross domestic product of the primary, secondary and tertiary industries, and the number of population, etc.; (2) indicators related to the development of transport, such as freight turnover, length of highway routes, etc.; and (3) indicators related to the structure of energy consumption, such as the number of trucks by car type (percentage), etc. The 12 indicators are selected to complete the ranking of the degree of importance by the pass-through analysis.

Specific steps are as follows, the nature of the through path analysis is a special multiple regression analysis, therefore, before carrying out the through path analysis, SPSS was used to carry out the normality test on the accounting results of the target variable carbon emissions from the transport industry, the sample size of n = 15 is a small sample of data, so the test results of the S-W were selected, and the statistic was obtained to be 0.914, and the significant level was 0.154 > 0.05, that is, the indicator y approximately obeys the normal distribution can be regression analysis, such as Table 2.

Table2 Results of normality test for target variables

	K-S			S-W		
	Statistic	df	p	Statistic	df	p
Y	.157	15	.200*	.914	15	.154

The 12 indicators were introduced into the regression equation and analysed using the backward method, which tested the indicators in the equation one by one and excluded the indicators with low significance of influence, so as to establish the optimal regression equation, and the goodness of fit of the equation was characterised by the coefficient of determination. The results of regression analysis by the backward method are shown in Table 3, with the analytical indicators in the regression equation being gradually eliminated, the coefficient of determination and iteration is 0.996, and the goodness of fit of the model is high, which indicates that X2, X7, X8, X11, X12 (gross domestic product of secondary industry, freight turnover, number of trucks with type I and II, number of trucks with type V, and number of trucks with type VI) are the high level of factors that drive the carbon dioxide emission.

Table 3 Results of regression analysis by backward method

Model	R	R^2	Std.Error	Predictors
8	.999[h]	.997	899.04919	X_2、X_7、X_8、X_{11}、X_{12}

Through the pass-through analysis of the five indicators obtained, the formula in 2.1 is used to calculate the indirect pass-through coefficients and decision-making coefficients of statistically significant independent variables screened out by the backward regression analysis, and the decision-making coefficients, as a decision-making index in the pass-through analysis, can comprehensively measure the degree of contribution of the independent variables to the target variables, and make clear the main decision-making independent variables and limiting variables, and the result is as shown in Table 4, where the economy is the pulling carbon emissions positive growth of significant factors.

Table 4 Pass-through analysis table

Analyzing indicators	P_i	r_{iy}	$r_{ij} \times P_i$					$\sum r_{ij} \times P_{jY}$	R^2（i）
			X_2	X_7	X_8	X_{11}	X_{12}		
X_2	0.590	0.948		0.277	0.014	0	0.067	0.358	0.771
X_7	0.317	0.936	0.515		0.032	0.020	0.052	0.619	0.493
X_8	0.180	0.278	0.047	0.057		-0.077	0.072	0.099	0.068
X_{11}	-0.131	-0.026	0.002	-0.047	0.106		0.045	0.106	-0.010
X_{12}	0.155	0.563	0.255	0.107	0.084	-0.038		0.408	0.151

4.2 Access map visualisation and analysis

Figure 2 shows the decomposition of the role of the analytical indicators on Y. The value on the two-way solid line on the left side indicates the relationship between the analytical indicators, i.e., the simple correlation coefficient of the analytical indicators rij, the value on the one-way solid line on the right side pointing to y indicates the direct pass-through coefficient Piy, and the values pointing to the three types of indicators indicate the direct and indirect pass-through coefficients of xi, among which, the direct role of the economic development on the carbon emissions is 0.590, which is a driver of the carbon emissions growth. The indirect effect through energy intensity (0.204) and transport intensity (0.317) is only a negative 0.358, which is a limited buffer to the direct effect of economic level on carbon emissions, indicating that economic development is highly positively driving carbon emissions in the transport sector.

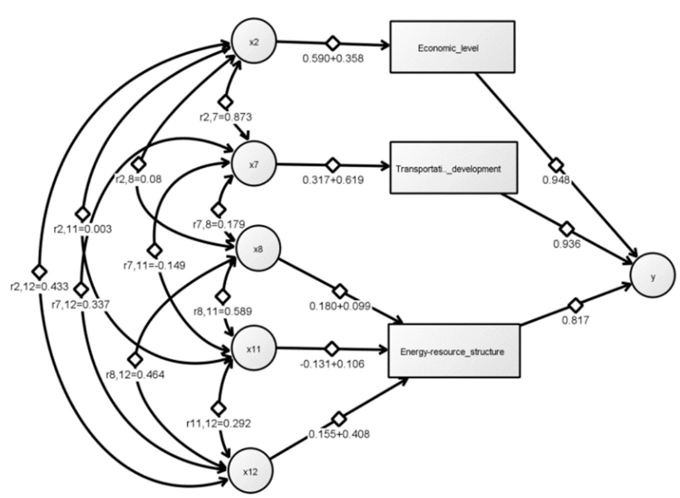


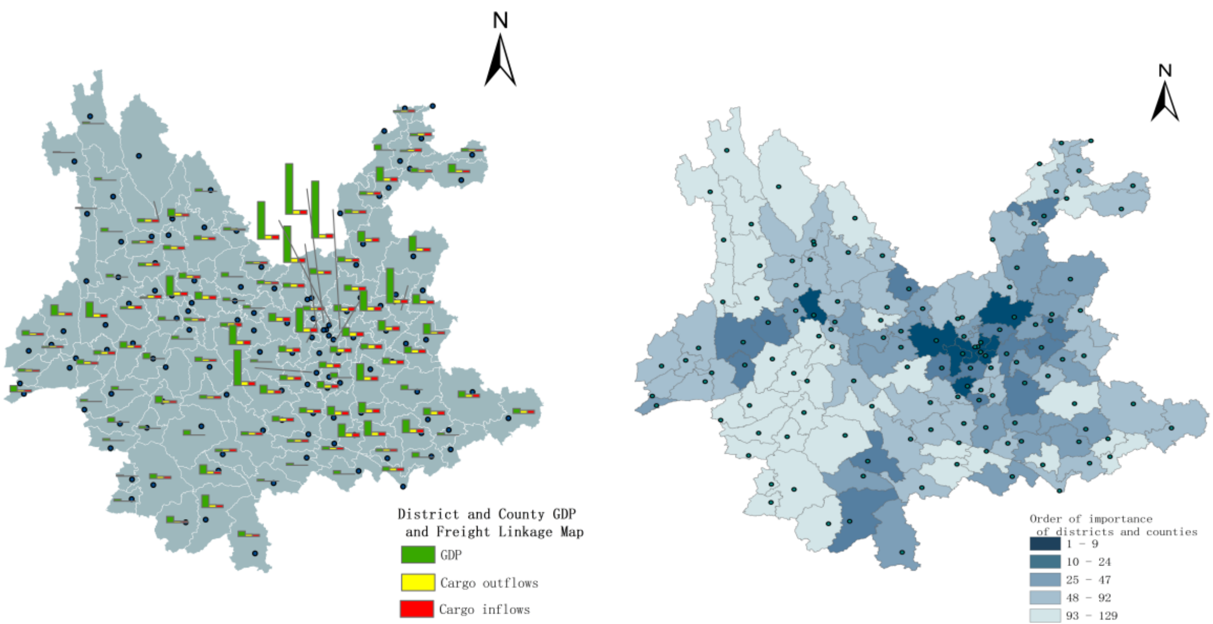
Figure 2. Decomposition of carbon emission drivers

4.3 ArcGIS visualisation and analysis

Economic factors, freight demand, etc. are the basis and important triggers for the generation of transport linkages, which determine the flow divergence characteristics of goods transport linkages. The GDP, freight traffic in and out intensity of counties in Yunnan Province are used for visualisation and analysis. Based on the natural breakpoint method in ArcGIS, the freight intensity of counties is divided into five tiers: high, high, medium, low, and low (Figure 3).The county was divided into six vehicle types and five tiers of traffic (Figure 4).

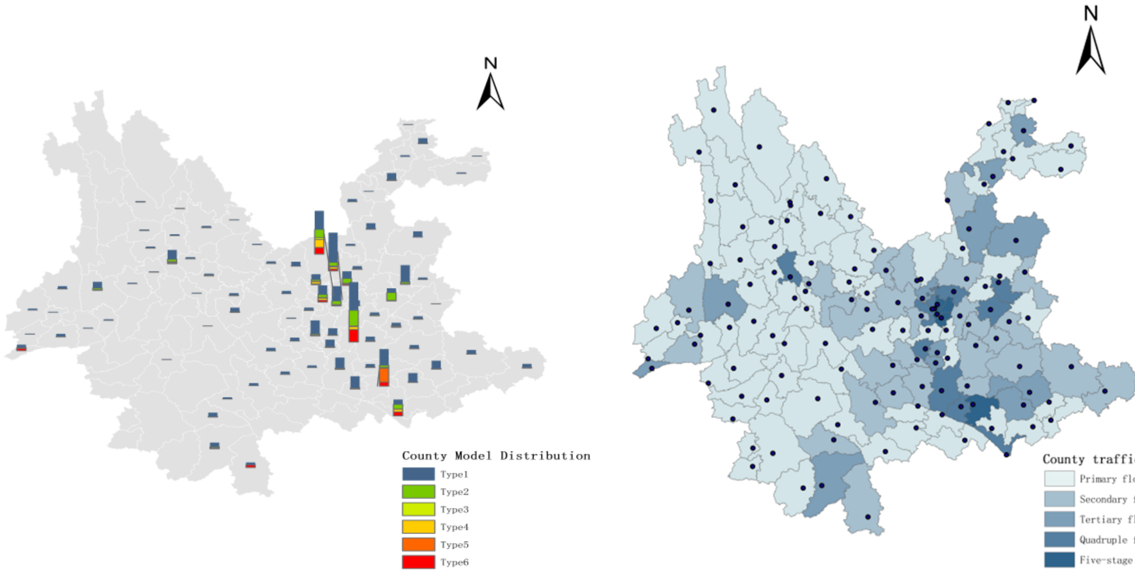
GDP is one of the significant factors affecting carbon emissions. From Figure 3(a) the GDP of central Yunnan and northeast Yunnan are in the high and higher tiers. Kunming City is located in the centre of Yunnan Province and has a good geographical location for trade and exchange with other regions. The GDP of western Yunnan and the southern border of Yunnan Province are in the low and lower tiers. Freight turnover is one of the significant factors affecting carbon emissions, with the eastern region performing better than the western region in terms of freight turnover. Vehicle type is another significant factor affecting carbon emissions. Demand is higher in the central and eastern regions, while medium and low freight demand is mainly in the western region.

Combined with Figure 3 and Figure 4, it can be found that high GDP regions generally have more demand for freight turnover, and these demands have driven changes in the structure of freight transport, with a higher proportion of Type 1 and 2 trucks in the central region, and the key areas for future model optimisation are concentrated in the central and eastern regions.



a)GDP and freight volume intensity b)Freight intensity

Figure 3. County Economy, Freight Intensity Map



a)County Model Distribution Map

b)County Traffic Map

Figure 4 .Traffic Volume Map by Vehicle Type

5. CONCLUSION

In this paper, after pre-processing the data of goods vehicles in Yunnan Province, the most significant factors affecting carbon emissions are extracted by using pass-through analysis, and then ArcGIS is used to visualise the flow and carbon emission influencing factors and deeply analyse the laws therein, and the following conclusions are obtained:

(1) The through path analysis can directly determine the importance of the features affecting the carbon emissions of goods transport on highways in Yunnan Province.

(2) Verified by examples, the gross domestic product of the secondary industry, freight turnover and the structure of truck models are the significant features affecting the carbon emission of goods transport, which indicates that while the economy is developing, the excessive transport intensity and the irrationality of the transport structure lead to the growth of carbon emission, and the output value attached to the unit of transport turnover is lower, so how to optimise the structure of truck models under the premise of ensuring the stable growth of GDP also becomes the emission reduction of the transport industry The key of the transport industry to reduce emissions.

(3) Further investigation of the characteristics of highway truck models is conducive to the optimisation of highway operation structure.

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