Research on Carbon Emission Measurement and Decoupling Analysis of the Construction Industry in Liaoning Province

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Abstract. In the process of energy structure adjustment guided by the "dual carbon" target, the decoupling of carbon emissions from economic development is widely considered an important indicator for evaluating the effectiveness of regional low-carbon emission reduction efforts. This paper takes the construction industry in Liaoning Province as an example to study its carbon emissions. By accurately calculating carbon emissions from 2009 to 2022, a solid data foundation for the study is established. Based on this, the Tapi decoupling model is used to analyze the decoupling relationship between carbon emissions and economic development in the construction industry of Liaoning Province. Furthermore, the Lmdi model is used to systematically analyze the driving factors of carbon emissions in the construction industry, comprehensively exploring various influencing factors and revealing their mechanisms and impact. The results show that from 2009 to 2022, the carbon emissions of the construction industry in Liaoning Province exhibited an unstable decoupling trend with economic development, and carbon emissions were driven by multiple interacting factors. Finally, based on the characteristics of the construction industry, this paper proposes corresponding low-carbon development strategies to help the industry achieve carbon emission reduction targets while promoting economic development.

Keywords: Construction Industry, Carbon Emission, Tapio and Lmdi Model

1 Introduction

Under China's "dual carbon" targets, the construction industry faces urgent low-carbon transformation demands. Liaoning Province serves as a representative case for regional low-carbon research due to its distinct construction industry and emission patterns. This study focuses on estimating carbon emissions during the construction phase in Liaoning. Using data from the Liaoning Statistical Yearbook(2010–2023), we develop a carbon emission measurement model to quantify contributions from different energy types. Additionally, the Tapio and LMDI models are employed to analyze the decou-

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pling relationship between emissions and economic growth and identify driving factors, supporting emission reduction strategy formulation.

2 Carbon Emissions Estimation of the Construction Industry in Liaoning Province

This section measures carbon emissions during the construction phase in Liaoning, focusing on energy-related emissions. Data are sourced from the Liaoning Statistical Yearbook(2010–2023). By compiling construction industry energy consumption data and integrating carbon emission coefficients, an emission measurement model is established to quantify the contributions of different energy types.

2.1 Carbon Emissions Accounting in the Construction Industry

First, to ensure the accuracy and accessibility of the data, the scope of statistics on carbon emissions from the construction industry in this paper is clearly limited to the construction stage, specifically covering the carbon dioxide emissions generated by the consumption of seven types of energy, including coal, gasoline, kerosene, diesel, fuel oil, natural gas and electricity[1]. This paper uses the direct emission factor method for measurement, which can intuitively reflect the relationship between different energy consumption and carbon emissions. LetC_{sum}be the carbon emissions generated by energy consumption in the construction industry, and its calculation formula is:

$$C_{sum} = \sum_{i=1}^{n} F_i \times \varphi_i \tag{1}$$

Where n is the total number of energy types, and here n is 7; F_i is the annual consumption of the i-th type of energy in the construction industry, and φ_i is the carbon emission coefficient corresponding to the i-th type of energy.

2.2 Carbon Emissions Results and Analysis

Based on the carbon emission data calculated earlier, this section presents a time-series analysis of the construction industry's emissions in Liaoning from 2009 to 2022. Using visualization methods (see **Fig. 1**), it reveals trends, cyclical variations, and economic linkages in emissions dynamics, providing data support for the region’s low-carbon transition.

3 Tapio Decoupling Model

In order to deeply analyze the intrinsic relationship between the development of the construction industry and carbon emissions in Liaoning Province, this section introduces the Tapio decoupling model [2], which aims to evaluate the decoupling status between economic growth and carbon emissions growth through quantitative methods and identify the potential and challenges of low-carbon transformation in the construction industry.

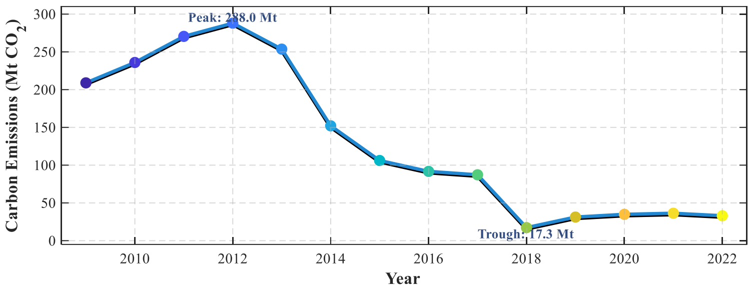

Fig. 1. Overall changes in carbon emissions in the construction industry.

3.1 Model Principle

Among common decoupling models, mainstream approaches include the decoupling index method, the Tapio decoupling model, and the IPAT [3]equation-based decoupling evaluation method. The decoupling index method is significantly affected by the choice of base period data. The IPAT equation method involves multiple factors and is less commonly used in construction carbon emissions research. Based on this analysis, this paper selects the Tapio decoupling elasticity model to examine the decoupling relationship between construction carbon emissions and economic growth in Liaoning Province.

$$W = \frac{\Delta(C_{CO_2}) / C_{CO_2}}{\Delta(I_{GDP}) / I_{GDP}} \tag{2}$$

In the formula, W is the decoupling elasticity value, which quantifies the correlation strength between carbon emissions and economic growth and is the core indicator for judging the decoupling status; $\Delta(C_{CO_2}) / C_{CO_2}$ is the carbon emission change rate of the construction industry in Liaoning Province; $\Delta(I_{GDP}) / I_{GDP}$ is the GDP change rate of the construction industry in Liaoning Province; Based on the decoupling W and the signs and values of carbon dioxide emissions and the gross domestic product of the construction industry, it is possible to effectively judge whether there is a decoupling relationship between carbon emissions and economic development, and the degree of decoupling is divided into eight specific situations according to the literature [4].

3.2 Analysis of the Decoupling of Carbon Emissions and Economic Growth

This section uses data on carbon emissions from Liaoning Province's construction sector (unit: 10,000 tons of CO_2) and GDP (unit: 100 million yuan) from 2009 to 2022 to calculate the decoupling elasticity W and assess the decoupling status. As a traditional industrial base in Northeast China, analyzing the decoupling of construction sector carbon emissions from economic development is of great significance. See **Table 1** for details.

Table 1. Analysis of decoupling in Liaoning Province's construction industry.

years	Carbon emissions (10,000 tons)	GDP	ΔC_{CO_2}	ΔI_{GDP}	Decoupling resilience W	Decoupling state
2009	208.9592	3384.6000				
2010	235.9256	4690.3000	0.1291	0.3858	0.3345	Weak decoupling
2011	270.4858	6218.2956	0.1465	0.3258	0.4497	Weak decoupling
2012	288.0127	7543.2898	0.0648	0.2131	0.3041	Weak decoupling
2013	253.6177	8629.6638	-0.1194	0.1440	-0.8292	Strong decoupling
2014	152.0686	7851.1248	-0.4004	-0.0902	4.4382	Recession decoupling
2015	106.1481	5413.7623	-0.3020	-0.3104	0.9727	Decay Link
2016	91.7461	3926.9726	-0.1357	-0.2746	0.4940	Decay Link
2017	87.2316	3688.3257	-0.0492	-0.0608	0.8097	Decay Link
2018	17.2905	3528.4135	-0.8018	-0.0434	18.4929	Recession decoupling
2019	31.2610	3554.5585	0.8080	0.0074	109.0420	Negative growth decoupling
2020	34.8853	3816.2000	0.1159	0.0736	1.5751	Negative growth decoupling
2021	36.3229	4044.9000	0.0412	0.0599	0.6876	Weak decoupling
2022	33.0236	3936.9000	-0.0908	-0.0267	3.4019	Recession decoupling

During the growth phase (2009–2012), W averaged 0.3628, showing weak decoupling as emissions grew slower than the economy. The transition period (2013–2018) was a mixed decoupling phase with fluctuating W values, ranging from strong to recessionary decoupling and linkage. In the recovery phase (2019–2020), high W values of 109.04 and 1.58 indicated negative decoupling, with emissions rising much faster than economic output. During the decoupling reversal (2021–2022), W values of 0.69 and 3.40 reflected a continued mix of weak and recessionary decoupling amid economic fluctuations.

4 Kaya Identity and Lmdi Decomposition Model

To conduct a more in-depth analysis of the driving factors behind changes in carbon emissions in the construction industry of Liaoning Province, this section employs the Lmdi (Linearized Mean Divisia Index)[5] decomposition model. Based on the Kaya identity and considering the energy consumption structure of the construction industry in Liaoning Province, this model constructs an analytical framework to quantify the contributions of various factors to changes in carbon emissions, identify key influencing variables, and provide data support for formulating scientific and reasonable emission reduction strategies.

4.1 Model Principle

This paper constructs an analytical framework based on the Kaya[6] identity and conducts a systematic analysis of carbon emission changes in the context of Liaoning Province's construction industry. From this, we can derive a carbon emission expression in the Kaya form:

$$C=\sum_{i=1}^{7}\frac{C_i}{E_i}\times\frac{E_i}{E}\times\frac{E}{GDP}\times\frac{GDP}{P}\times P \tag{3}$$

Among them, C represents the total carbon emissions of the construction industry in Liaoning Province; C_i represents the carbon emissions of the i-th energy; E_i represents the actual consumption of the i-th energy; E represents the total energy consumption of the construction industry in Liaoning Province in that year; GDP represents the gross domestic product of the construction industry in Liaoning Province in that year; and p represents the total population of Liaoning Province.

Based on the Kaya and Lmdi decomposition frameworks, the following systematically analyzes carbon emission changes. Assuming the carbon emissions in year t are C_t and the carbon emissions in the base year are C_0, the change in carbon emissions from the base year to year t, ΔC, in Liaoning Province's construction industry can be decomposed using the Lmdi additive method as follows:

$$\begin{aligned}\Delta C=C_t-C_0&=\frac{C_t-C_0}{lnC_t-lnC_0}\times ln\frac{C_t}{C_0}\\&=\frac{C_t-C_0}{lnC_t-lnC_0}\times ln\frac{T_t\times N_t\times Q_t\times M_t\times P_t}{T_0\times N_0\times Q_0\times M_0\times P_0}\\&=\Delta C_T+\Delta C_N+\Delta C_Q+\Delta C_M+\Delta C_P\end{aligned} \tag{4}$$

Where ΔC_T, ΔC_N, ΔC_Q, ΔC_M and ΔC_p represent the carbon emission coefficient factor, energy structure factor, energy intensity factor, per capita regional GDP factor of the construction industry and population size factor of Liaoning Province respectively. See **Table 2** for details.

Based on the data in the table, we analyze the changing characteristics of the factor k influencing carbon emissions in Liaoning Province's construction industry from 2009 to 2022. Each factor contributes to the fluctuations in carbon emissions in the construction industry, and trends are presented through the combined impact value (Sum_k) and the "change" (where "+" indicates positive changes and "-" indicates negative changes).

Combined with the data, we can see: $|k_{2013\text{-}2014}| > |k_{2017\text{-}2018}| > |k_{2014\text{-}2015}| > |k_{2012\text{-}2013}| > |k_{2015\text{-}2016}| > |k_{2016\text{-}2017}| > |k_{2021\text{-}2022}|$ During these periods, the energy intensity factor k_Q was mostly significantly negative. This, combined with the contractionary effect of the per capita output value factor kM, which shifted from positive to negative, jointly drove a downward trend in carbon emissions. The larger $|k|$, the more significant the actual reduction in carbon emissions. Comparing the absolute values of the intensity of change, based on the data patterns, we find the following: $|k_{2011\text{-}2012}| > |k\_{2010\text{-}2011}| > |k\_{2009\text{-}2010}| > |k\_{2018\text{-}2019}| > |k\_{2019\text{-}2020}| > |k\_{2020\text{-}2021}|$. During this period, the per capita output value factor kM remained at a long-term high, partially reflecting the impact of the construction industry's expansion on energy demand, which in turn led to positive changes in carbon emissions. The larger |*k*|, the more significant the actual increase in carbon emissions.

The trend in carbon emissions is deeply correlated with both Sumk and |*k*|: During the negative phase, factors such as energy intensity and per capita output value synergistically suppress carbon emissions; the larger |*k*|, the stronger the emission reduction efforts. During the positive phase, factors such as scale expansion and structural adjustment jointly drive carbon emissions growth; the larger |*k*|, the more significant the emission increase effect. In summary, carbon emissions from the construction industry in Liaoning Province from 2009 to 2022 were driven by the interaction of multiple factors, showing the stage characteristics of "growth-recession-fluctuation".

Table 2. Changes in influencing factors of carbon emissions.

Year	k_T	k_N	k_Q	k_M	k_P	Sum_k	change
2009-2010	-1.0519E-14	-0.6537	-44.8490	72.7099	-0.2246	26.98257615	+
2010-2011	9.71416E-15	0.1616	-36.8735	71.0967	0.1961	34.58097053	+
2011-2012	9.19451E-15	0.8259	-37.2175	54.5928	-0.6700	17.53125181	+
2012-2013	-1.06916E-14	5.0796	-76.1606	36.8220	-0.4336	-34.69265614	-
2013-2014	7.85973E-15	5.3032	-83.8273	-19.0613	0.2902	-97.29517518	-
2014-2015	-1.18697E-15	0.0177	-0.9230	-47.0438	-0.4371	-48.38623622	-
2015-2016	1.49885E-14	0.4128	16.8753	-31.7670	0.0537	-14.42519827	-
2016-2017	-7.52046E-15	-0.4217	1.7521	-4.8557	-0.7537	-4.279097305	-
2017-2018	-1.88669E-15	2.4541	-87.7697	-1.8681	-0.0474	-87.23111409	-
2018-2019	1.33494E-15	-5.6409	20.9354	0.1837	-0.0096	15.46869496	+
2019-2020	0	-0.9132	2.2557	2.5388	-0.1922	3.689116417	+
2020-2021	0.00E+00	-0.1575	-0.4741	2.1901	-0.1181	1.440366901	+
2021-2022	3.44571E-15	0.1585	-2.4985	-0.8315	-0.1061	-3.277670056	-
Total	1.47327E-14	6.6265	-328.7748	134.7064	-2.4523	-189.8942	-

5 Conclusions and Recommendations

5.1 Conclusions

In summary, from 2009 to 2022, the relationship between carbon emissions and economic growth in Liaoning's construction industry displayed an unstable decoupling pattern. The LMDI decomposition further revealed that, driven by multiple factors, total carbon emissions showed a trend of "increase–decrease–fluctuation," indicating a continued high energy dependence in the industry. As a representative old industrial base, Liaoning's case can provide methodological and policy insights for regions with similar industrial structures or facing comparable low-carbon transition challenges.

5.2 Recommendations

In summary, the decoupling relationship between carbon emissions and economic development in Liaoning's construction industry exhibited volatility during 2009–2022. LMDI decomposition reveals that carbon emissions fluctuated dynamically under multi-factor influence, indicating a continued high dependence on energy. As a representative old industrial base, Liaoning’s case offers methodological and policy insights for structurally similar regions facing comparable low-carbon transition challenges.

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