

Decoupling Efforts and Stability of Carbon Emissions in the Logistics Industry: A Literature Review based on the Yangtze River Economic Belt

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ABSTRACT

The logistics industry is an important support system for regional production, circulation and consumption, but it is also a major source of energy use and carbon emissions. Under China's carbon peaking and carbon neutrality goals, the relationship between logistics growth and carbon emissions has become a key topic in regional green development research. This paper reviews studies on logistics carbon accounting, carbon-emission drivers, decoupling models, decoupling efforts and decoupling stability, with special attention to evidence from the Yangtze River Economic Belt. The literature shows that existing research has formed a relatively mature methodological basis, including IPCC accounting, LMDI decomposition and the Tapio elasticity model. However, many studies still focus mainly on identifying decoupling states, while the quality of decoupling, the actual emission-reduction efforts behind decoupling, and the long-term stability of decoupling have not been fully examined. Future research should build an integrated framework that combines carbon accounting, driver decomposition, decoupling-state identification, decoupling-effort evaluation and stability testing. Such a framework can help distinguish real low-carbon transformation from short-term statistical decoupling and provide more practical policy implications for the green transition of logistics in the Yangtze River Economic Belt.

KEYWORDS

Logistics Industry; Carbon Emissions; Decoupling Effort; Decoupling Stability; Yangtze River Economic Belt; Tapio model; LMDI.

1. INTRODUCTION

Climate change and carbon-emission reduction have become core issues in sustainable development. China has proposed the goals of peaking carbon emissions before 2030 and achieving carbon neutrality before 2060, which makes the low-carbon transformation of high-energy-consuming sectors more urgent. The logistics industry is closely related to transportation, warehousing, packaging, distribution and information services. It supports regional economic circulation, but its operation depends heavily on fossil energy, especially in freight transport. Therefore, the logistics industry is a typical field in which economic growth and environmental pressure interact strongly.

The Yangtze River Economic Belt is an important national strategic region. It covers 11 provinces and municipalities, links eastern, central and western China, and undertakes a large share of national population, GDP, trade and freight movement. The original empirical study shows that logistics carbon emissions in this region increased from 2010 to 2022 and displayed a clear spatial pattern of high emissions in the east and relatively low emissions in the west. This pattern reflects differences in economic scale, logistics networks, energy consumption structure and transport intensity. For this

reason, the region provides a useful case for reviewing how scholars understand logistics carbon emissions, decoupling processes and the risk of recoupling.

The key question in this field is not only whether logistics carbon emissions can be separated from economic growth, but also whether the observed separation is supported by real emission-reduction efforts and whether it can remain stable over time. A short-term decline in emissions may be caused by economic slowdown, temporary policy pressure or external shocks. If such a change is not supported by energy efficiency improvement, clean energy substitution and structural optimization, it may not represent genuine low-carbon transition. Therefore, literature on decoupling efforts and stability is necessary for improving the explanatory power of traditional decoupling analysis.

2. CARBON ACCOUNTING IN THE LOGISTICS INDUSTRY

Carbon accounting is the starting point of logistics emission research. Existing studies generally use two types of methods. The first is the top-down method recommended by the IPCC framework, which estimates emissions according to energy consumption and emission coefficients. This method is widely used in regional and sectoral studies because it has consistent statistical rules and relatively accessible data. The second is the bottom-up method, which calculates emissions from specific activities, facilities, vehicles or logistics nodes. It can describe micro-level emission sources in more detail, but it requires high-quality activity data that are often difficult to obtain.

For China's logistics industry, researchers often use data from transportation, storage and postal services as a proxy because official statistical yearbooks do not provide a separate and complete category for "logistics industry". This practice improves data availability but may also simplify the internal structure of logistics activities. Yang et al. measured logistics carbon-emission performance at the city level and emphasized the importance of considering spatial differences in logistics development [4]. Bai et al. further showed that logistics CO₂ emissions in China have obvious spatio-temporal heterogeneity, which means that national or provincial averages may hide local differences in emission pressure [8].

Studies focusing on the Yangtze River Economic Belt or related transport sectors also confirm that emission accounting should be connected with regional characteristics. Hu et al. studied transport energy carbon emissions in the Yangtze River Economic Belt and found that regional development stages and energy use patterns strongly affect decoupling outcomes [6]. Recent work on provincial logistics emissions has also emphasized the spatial differentiation of logistics carbon emissions under high-quality development [7]. Overall, the literature suggests that reliable carbon accounting requires both unified measurement standards and sensitivity to regional economic and transport structures.

3. DECOMPOSITION OF CARBON-EMISSION DRIVERS

After estimating carbon emissions, researchers usually examine the factors that drive emission changes. Index decomposition analysis is one of the most common approaches. Among these methods, the logarithmic mean Divisia index, or LMDI, is widely used because it can achieve complete decomposition without residual terms and can clearly separate the effects of energy structure, energy intensity, economic scale and population or labor factors [3]. In logistics studies, LMDI helps explain whether emission growth is mainly caused by economic expansion or whether it is restrained by energy efficiency and structural optimization.

The reviewed empirical evidence generally shows that economic development is the main force increasing logistics carbon emissions, while energy intensity improvement is the most important factor restraining emissions. The original study on the Yangtze River Economic Belt also reaches a similar conclusion: the economic development effect contributes most to emission growth, whereas the energy consumption intensity effect gradually changes from a driving factor to an inhibiting factor.

This means that logistics output expansion still creates strong emission pressure, but technological progress and efficiency improvement have begun to reduce carbon emissions per unit of output.

Some studies have expanded decomposition analysis beyond the traditional LMDI framework. Zhang et al. used a GDIM-based indicator decomposition method to analyze the influencing factors of carbon emissions in China's logistics industry, showing that different decomposition frameworks can provide richer explanations of scale, intensity and structural effects [5]. However, regardless of the specific model, the common finding is that logistics decarbonization depends on a balance between economic growth pressure and emission-reduction forces. If economic expansion grows faster than improvements in energy efficiency and energy structure, total emissions may continue to rise even when the industry becomes more efficient.

4. DECOUPLING MODELS AND LOGISTICS ECONOMIC GROWTH

Decoupling theory was first developed to describe the separation between environmental pressure and economic growth. The OECD framework distinguishes relative decoupling from absolute decoupling: relative decoupling means that environmental pressure grows more slowly than the economy, while absolute decoupling means that environmental pressure declines while the economy continues to grow [1]. This concept provides a direct way to judge whether economic growth is becoming less dependent on resource use or pollution emissions.

Tapio proposed an elasticity-based decoupling model that divides the relationship between emissions and economic output into more detailed states, such as strong decoupling, weak decoupling, expansive coupling and expansive negative decoupling [2]. Compared with simple ratio methods, the Tapio model is easy to calculate and can describe different combinations of emission change and economic change. Therefore, it has been widely used in transport and logistics studies. For example, Fu et al. examined the decoupling status and influencing factors of China's logistics carbon emissions and showed that decoupling states vary significantly across regions and periods [9].

The Yangtze River Economic Belt case reflects this dynamic process clearly. In the early stage, many provinces were in expansive negative decoupling, meaning that carbon emissions grew faster than logistics economic output. In the middle stage, most provinces moved toward weak decoupling. In the later stage, some provinces, such as Shanghai, Anhui, Hubei and Chongqing, achieved strong decoupling, meaning that logistics output continued to grow while carbon emissions declined. This evolution indicates that the relationship between logistics growth and emissions is not fixed. It can improve with policy pressure, technology upgrading and energy efficiency gains, but it may also fluctuate under economic and external shocks.

5. DECOUPLING EFFORTS: FROM STATE IDENTIFICATION TO MECHANISM EVALUATION

Although the Tapio model can identify decoupling states, it does not fully explain why those states occur. A region may enter weak decoupling because energy efficiency has improved, but it may also appear to decouple because economic growth slows down. Similarly, strong decoupling may result from real low-carbon transformation or from temporary reductions in transport demand. Therefore, scholars have introduced the idea of decoupling effort to measure whether non-economic factors are strong enough to offset the emission pressure produced by economic growth.

In an LMDI-based decoupling-effort framework, economic output is usually treated as the pressure effect, while energy intensity, energy structure and other factors are treated as effort effects. If these effort effects can offset the emission-increasing pressure of economic expansion, the decoupling result has a stronger foundation. If not, the decoupling result may be fragile. This perspective is

important because it shifts the research focus from “what type of decoupling has occurred” to “what kind of effort supports decoupling”.

Existing logistics studies show that energy consumption intensity is often the most stable source of decoupling effort. In the Yangtze River Economic Belt, improvement in energy consumption intensity is the core reason why the total decoupling-effort index turns positive in later years. However, the contribution of energy structure is relatively weak and unstable. This suggests that the region has made progress in energy efficiency, such as improving transport organization and reducing unit energy consumption, but clean energy substitution in logistics vehicles, vessels, warehouses and logistics parks still has room for improvement.

Recent research also emphasizes the role of digitalization and spatial organization. Zhong et al. examined the influence of the digital economy on logistics carbon emissions and found that digital technologies may reduce emissions through efficiency improvement and industrial upgrading [10]. Gong and Guo, using Chongqing as a case, proposed a decomposition framework to analyze the decoupling relationship between logistics growth and carbon emissions, further showing that regional logistics systems may have different driving mechanisms [11]. These studies indicate that decoupling effort should not be limited to energy factors only; it should also include logistics organization, digital scheduling, multimodal transport and regional coordination.

Table 1. Main research streams in logistics carbon-emission decoupling

Research stream	Main focus	Common methods	Representative references
Carbon accounting	Measuring emissions from energy use and logistics activities	IPCC top-down method; activity-based accounting	[4], [6], [8]
Driver decomposition	Explaining why emissions increase or decrease	LMDI; GDIM; Kaya-type identities	[3], [5]
Decoupling state	Identifying the relationship between emissions and logistics growth	OECD framework; Tapio elasticity model	[1], [2], [9]
Effort and stability	Evaluating whether decoupling is effective and persistent	Decoupling-effort index; stability coefficient; transition analysis	[10], [11], [12]

6. DECOUPLING STABILITY AND THE RISK OF RECOUPLING

A further limitation of traditional decoupling research is that it often describes the decoupling state of a specific period but pays less attention to whether the state can continue. In practice, decoupling may be unstable. A region may move from weak decoupling to strong decoupling and then return to coupling or negative decoupling. Such changes are often related to economic fluctuations, energy price changes, infrastructure investment cycles, emergency shocks or inconsistent policy implementation.

The concept of decoupling stability is useful because it evaluates the volatility of the decoupling index over time. A smaller stability coefficient usually means that the decoupling state changes less and the low-carbon transition path is more stable. The Yangtze River Economic Belt case shows clear regional differentiation. Some provinces, such as Hunan, Guizhou and Yunnan, present relatively stable decoupling states, while others, such as Jiangxi, Anhui, Jiangsu and especially Chongqing, show greater volatility. This means that even when a province achieves strong or weak decoupling in one period, it may still face a high risk of recoupling if the supporting mechanisms are not stable.

Zhao et al. proposed the idea of a decoupling trap in the Yangtze River Economic Belt, warning that some regions may appear to have achieved decoupling but still face structural risks that can weaken long-term emission reduction [12]. This argument is closely related to decoupling stability. If decoupling depends mainly on temporary output fluctuations rather than durable efficiency improvement and clean energy transition, the decoupling result may be reversed. Therefore, future research should combine Tapio analysis with stability indicators, Markov transition analysis or Hurst persistence testing to evaluate whether the current trend is likely to continue.

7. FUTURE DIRECTIONS

The reviewed literature suggests several future directions. First, logistics carbon research should improve data quality. When possible, future studies should distinguish road, railway, waterway, aviation, warehousing and urban distribution emissions rather than using a broad proxy for the whole logistics industry. This would make policy implications more precise.

Second, decoupling studies should integrate state identification, effort evaluation and stability analysis. A complete framework should answer three questions: whether decoupling has occurred, what factors support the decoupling, and whether the state can continue. This is especially important for the Yangtze River Economic Belt because its upstream, midstream and downstream areas differ greatly in industrial structure, logistics demand and energy conditions.

Third, more attention should be paid to the role of digital logistics, multimodal transport and regional collaboration. Digital platforms, intelligent route planning, shared warehousing and multimodal transport can reduce empty running and improve energy efficiency. At the same time, clean energy substitution should be accelerated in trucks, ships, ports, logistics parks and cold-chain facilities. Only by combining efficiency improvement with structural energy transition can the region avoid fragile decoupling and reduce the risk of recoupling.

8. CONCLUSION

In summary, research on logistics carbon-emission decoupling has developed from basic carbon accounting and state classification toward deeper mechanism analysis. The OECD framework and the Tapio model provide useful tools for identifying the relationship between logistics growth and carbon emissions, while LMDI and related decomposition methods explain the driving forces behind emission changes. However, state identification alone is not enough. A region may show weak or strong decoupling in a certain period without achieving stable low-carbon transformation. Therefore, decoupling effort and decoupling stability should become important parts of future research. For the Yangtze River Economic Belt, the key task is to reduce the dependence of logistics growth on fossil energy, strengthen energy-efficiency improvement, accelerate clean energy substitution and build long-term mechanisms that prevent recoupling. An integrated research framework can provide stronger support for regional logistics decarbonization and for the realization of China's dual-carbon goals.

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