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Do commercial building sector-derived carbon emissions decouple from the economic growth in Tertiary Industry? A case study of four municipalities in China

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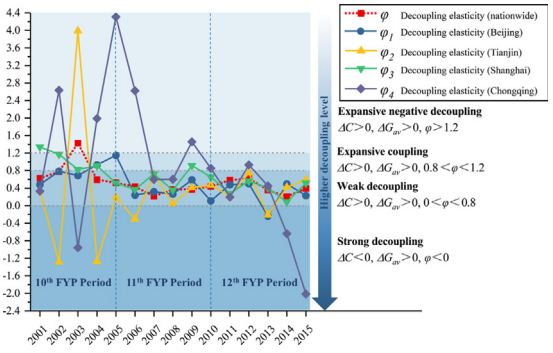
HIGHLIGHTS

- A decoupling analysis using Kaya and Logarithmic Mean Divisia Index methods is proposed.
- The ordering of decoupling levels for 2001–2010 is Tianjin > Beijing > Shanghai > Chongqing.
- The ordering of decoupling levels for 2011–2015 is Chongqing > Beijing > Tianjin > Shanghai.
- More significant decoupling effects can be achieved by enhancing levels of energy efficiency.

GRAPHICAL ABSTRACT

Decoupling elasticity values in China's commercial building sector at both national and municipal levels for 2000–2015.



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ABSTRACT

Decoupling economic development from carbon emissions generated from China's commercial buildings (CECCB) is regarded as an important indicator for evaluating the energy efficiency of the commercial building sector in China. Our study is the first to propose a decoupling method based on a Logarithmic Mean Divisia Index (LMDI) decomposition analysis with the Kaya identity to analyze the relationship between economic development in China's Tertiary Industry and the CECCB growth at both national and municipal levels. The following three main results are found. (1) At the national level, commercial building sector decoupling from 2001 to 2015 is limited. Only four decoupling stages are observed at the municipal level with the ordering of municipal decoupling measured as follows: Tianjin > Beijing > Shanghai > Chongqing (2001−2010), Chongqing > Beijing > Tianjin > Shanghai (2011–2015). (2) Two extended versions of Environmental Kuznets Curves further show what drives different decoupling levels in the four municipalities. (3) More significant decoupling effects observed in recent years can be attributed to significant improvements made in the energy efficiency work of China's commercial building sector. Overall, our approach successfully covers a research gap relevant to the decoupling of the relationship between CECCB growth and the economic development of China's Tertiary Industry. Furthermore, we believe our results can be used to guide the evaluation of energy efficiency work in China's commercial building sector, and such efforts can also enrich diverse research conducted on China's low carbon economic systems.

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Nomenclature

CABEE	China Association of Building Energy Efficiency
CECCB (i.e., C)	Carbon emissions generated from China's commercial buildings
CDBECCE	*China Database of Building Energy Consumption and Carbon Emissions*
CNY	Chinese Yuan (the currency of PR China)
EEW	Energy efficiency work
EKC	Environmental Kuznets Curve
FYP	Five-Year Plan
GFA	Gross floor area
MOHURD	Ministry of Housing and Urban-Rural Development, PR China
NBS	National Bureau of Statistics, PR China
c	CECCB intensity
c_p	Per capita carbon emissions generated from China's commercial building sector
F	GFA of commercial buildings in China
f	Per capita GFA of commercial buildings in China
G_{av}	GDP of the Tertiary Industry in China (added values)
g	Reciprocal of G_{av} per capita
I	Economic activity levels of commercial buildings in China
i	Code numbers for China's four municipalities [$i = 1$, Beijing (BJ); $i = 2$, Tianjin (TJ); $i = 3$, Shanghai (SH); $i = 4$, Chongqing (CQ)].
P	Population employed in China's Tertiary Industry
ΔC_c	Impact of c on C
ΔC_F	Impact of F on C
ΔC_f	Impact of f on C
ΔC_g	Impact of g on C
ΔC_I	Impact of I on C
φ	Decoupling elasticity
φ_{C_c}	Decoupling elasticity of c
φ_{C_F}	Decoupling elasticity of F
φ_{C_f}	Decoupling elasticity of f
φ_{C_g}	Decoupling elasticity of g
φ_{C_I}	Decoupling elasticity of I

1. Introduction

As the largest carbon emitter worldwide, China has struggled with the low levels of carbon development and with rapid economic growth for over two decades (Chen et al., 2018a; Chen et al., 2018c; Li et al., 2018a). In the three sectors most closely related to carbon emissions (i.e., industry, transportation, and building sectors), the carbon mitigation mode of the building sector is expected to be an effective driver in promoting a 2030 peak in carbon emissions in China and to make over 50% of contributions to China's 2050 carbon mitigation conditions (Lynn et al., 2017; Zhou et al., 2013). Thus, low carbon development in the building sector is central to achieving sustainable development in China (Lin and Liu, 2015). As a key facet of the civil building sector, the commercial building sector has consumed large volumes of fossil fuel and has released large amounts of carbon dioxide with unparalleled economic growth occurring in China's Tertiary Industry (Hong et al., 2015; Lin and Liu, 2015). As demonstrated by the *China Database of Building Energy Consumption and Carbon Emissions* [i.e., CDBECCE (CABEE, 2017; Ma and Cai, 2018)], carbon emissions generated from China's commercial buildings (CECCB) constitute approximately 40% of carbon emissions generated through China's civil building sector over the past decade.

Reliable *energy efficiency work* (EEW) can effectively promote carbon mitigation in the building sector (Kong et al., 2012; Zuo et al., 2014). Throughout the development of EEW in China's civil building sector, the "double-control" (i.e., total and intensity value control over carbon emissions) strategy has been officially implemented since 2017 (Cai et al., 2018; Yao et al., 2018), and the decoupling economic development from carbon emissions generated from civil buildings has been regarded as an important indicator for evaluating this strategy according to studies of related sectors [e.g., the construction industry (Wu et al., 2018)]. The decoupling approach reveals the relationship between carbon emissions and economic development in one or multiple sectors at the quantitative level to achieve low carbon development. Such studies have been widely conducted at both the global and regional levels [e.g., Chen et al., 2017; Cohen et al., 2018] or on key carbon-emitting sectors such as the industrial sector [e.g., Hardt et al., 2018; Zhao et al., 2017; Zhao et al., 2016a] and transportation sector [e.g., Jiborn et al., 2018; Tapio, 2005; Wang et al., 2017b]. However, decoupling the connection between carbon emissions and economic development in the civil building sector is far from straightforward and especially in China (Wu et al., 2018). Only the economic activities of the commercial building sector are actually affected by China's three major economic divisions, and this is especially the case for the Tertiary Industry (Ma et al., 2017a). It is meaningful to explore the decoupling status of the relationship between CECCB and the economic growth of Tertiary Industry. As typical pilot cities for EEW implementation in the commercial building sector, China's four major municipalities (as shown in Fig. 1) exhibit typical patterns of growth in CECCB within the active Tertiary Industry (Jia et al., 2018). Low carbon development roadmaps on CECCB in the four municipalities can be treated as a guide to EEW development in China's commercial building sector.

In view of this, utilizing the CDBECCE as data support, we propose a decoupling method based on a Logarithmic Mean Divisia Index (LMDI) decomposition analysis with the extended Kaya identity to analyze the relationship between economic development in China's Tertiary Industry and the CECCB growth at both the national and municipal levels during 2001–2015. After evaluating decoupling levels in China's commercial building sector, two typical extended versions of Environmental Kuznets Curves (EKCs) for the national and municipal levels are presented to determine what actually drives decoupling levels in the four municipalities. Furthermore, we propose a decadal retrospection for the EEW of China's commercial building sector for both the national and municipal levels in retrospect to identify the root cause of significantly increasing decoupling effects of CECCB resulting from economic development in China's Tertiary Industry.

In what follows Section 2 presents a literature review. In Section 3 we propose the methodology employed involving the use of the Kaya identity, decoupling method, LMDI decomposition analysis, and EKC theory. Meanwhile, data collection method is also involved. The results of LMDI decomposition and specifically decoupling elasticity values for the national and municipal scales in 2001–2015 are illustrated in Section 4. Section 5 covers two issues. Section 5.1 explores what drives decoupling levels in the four municipalities, and Section 5.2 reviews the EEW in the commercial building sector for the national and municipal scales during 2007–2017. Section 6 lists our main findings, policy implications, and avenues for further research.

2. Literature review

The relationship between carbon emissions and economic development has been widely discussed in a series of studies. EKC theory and decoupling methods are two typical focuses of such research.

Regarding EKC theory, Grossman and Krueger (1991, 1995) state that economic development initially spurs environmental degradation,

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