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Correlation analysis of CO_2 emissions, material stocks and economic growth nexus: Evidence from Chinese provinces

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ABSTRACT

A better understanding of the economy-material-emissions nexus is fundamental in order to reveal the interactions between human development and the natural environment, and more importantly, to design integrated de-carbonization and de-materialization policies. In this paper, we conducted a decoupling analysis of fossil fuel-induced CO_2 emissions and in-use material stocks in infrastructure to economic growth at the provincial level in China and investigated the trilateral causal relationships among the three indicators. The results show that the average elasticity of CO_2 emissions and material stocks to economic growth was smaller than 1, representing a status of relative decoupling. However, in many less developed provinces in central and western China, we observed increasing trends of elasticity in the past three decades, which suggest their economic growth became more tightly linked to CO_2 emissions and the accumulation of material stocks. Granger tests suggest that in the long run there existed a unidirectional causality running from CO_2 emissions, economic growth and urbanization to material stocks. In the short run, a bi-directional causality between CO_2 emissions and economic growth and a unidirectional causality from material stocks to CO_2 emissions were detected. Policy implications for the de-carbonization and de-materialization transition include enhancing renewable energy utilization, upgrading industries to less carbon-intensive ones, developing compact cities, prolonging the lifespan of infrastructure, and strengthening the life-cycle carbon management of infrastructure.

1. Introduction

Urbanization is a modern phenomenon in global development. In 2014, 54% of the world's population lived in urban areas compared to only 2% in 1800 (Zhang, 2016). The rapid economic growth in the process of urbanization impels intensive consumption of natural resources and energy, exerting great pressure on the environment. According to a survey conducted by the International Energy Agency in 2010, urban areas are responsible for 71% of global energy-related carbon emissions (Rosenzweig et al., 2010). Moreover, in order to support economic development and improve human well-being, massive investment has been made in infrastructure construction, which results in the enormous accumulation of material in-use stocks. Infrastructure stocks cause CO_2 emissions throughout their entire life cycle, including the raw material extraction, production, construction, in-use and end-of-life management phases of materials (Muller et al., 2013). Since infrastructure stocks exist in society for a relatively long time, they play an important role in sustaining the economy in the long run, as well as in driving long-term CO_2 emission pathways. Therefore, there exist complex relationships between economic growth, material stocks and CO_2 emissions.

China, as the largest developing country in the world, has experienced rapid economic growth since its economic reform in 1978, with an average annual GDP growth rate of 9.8% (NBS, 2014). Booming energy demand in all sectors has led to increasing carbon emissions during the last several decades. Fossil-fuel-induced CO_2 emissions from China in 2010 accounted for a quarter of the world's total (Lu et al., 2013). The acceleration of economic growth and urbanization was also accompanied by massive infrastructure construction, resulting in a great amount of raw material consumption. In response to climate change mitigation, the Chinese

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government committed to reduce the CO_2 intensity per unit of GDP by 40–45% by 2020 compared to 2005 (SCC, 2014). Thus, a better understanding of the economy-material-emission nexus in China would be helpful for designing emissions mitigation and resource management policies with the purpose of achieving sustainable development for both China and the world.

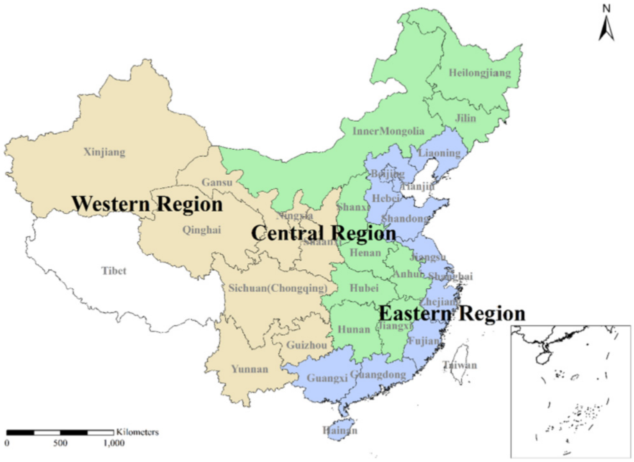
In recent years, many researchers have investigated the nexus between economic growth and environmental factors. For instance, Chen et al. (2013) conducted an ecological systems input-output simulation to investigate the CO_2 emissions instigated by global economic activities; Chen and Chen (2015) assessed energy consumption in urban economic sectors by integrating an energy flow analysis, an input-output analysis and an ecological network analysis; Zhang et al. (2018) applied an ecological network analysis to trace the carbon metabolism of global trade system and investigated the direct and indirect effects of CO_2 flows in the network. Moreover, a considerable number of studies have focused on the CO_2-economy correlation based on various methods, such as regression analyses (e.g., He and Richard, 2010; Wang et al., 2017), decomposition analyses (e.g., Freitas and Kaneko, 2011; Zhang and Da, 2015), and time series data and panel data analyses (e.g., Azomahoua et al., 2005; Jalil and Mahmud, 2009; Alam et al., 2011). The Granger causality test, an econometric method that is especially suitable for time series and panel data analyses, was recently introduced to investigate the relationship between carbon emissions and the economy. For instance, Hossain (2011) found that there existed unidirectional short-run causality from economic growth to carbon dioxide emissions, from urbanization to economic growth in newly industrialized countries. In the investigation of the Canadian industrial sector, Hamit-Haggar (2012) revealed a unidirectional causality relationship from the economy to greenhouse gas emissions in both the long run and the short run, and Wang et al. (2016) found that economic growth was a Granger cause of CO_2 emissions in China during 1995–2012.

A number of studies have also investigated the relationship between material stocks and economic growth. For example, McMillan et al. (2010) explored the relationship between U.S. aluminum in-use stocks and GDP based on a statistical time series analysis, and the results indicated that changes in GDP had a significant association with the changes in net additions to in-use stocks. Fishman et al. (2015) found that economic growth was the main driving factor for material stock accumulation in Japan, and a relative decoupling of material stocks from economic growth was observed. Zhang et al. (2017) established a framework for decoupling analyses for material cycles. Taking the aluminum cycle in the U.S. as an example, they found that material flow and stock indicators decouple from GDP in a sequential pattern, and the in-use stock of aluminum in the U.S. decoupled from GDP much more slowly than any flow indicators. In addition, some investigations were conducted to explore the correlation of material stocks and CO_2 emissions. For example, Liu et al. (2013) simulated the future global aluminum in-use stock patterns and their carbon emission pathways, demonstrating that higher stock saturation levels might incur higher emissions. Jeong et al. (2012) found that CO_2 emissions embodied in construction materials in the construction stage of apartment buildings in Korea were approximately 569.5 kg-CO_2/m^2, and among the major construction materials, steel and concrete composed 82% of the total emissions. Lin et al. (2017) investigated the relationship between global built environment stocks and emissions growth based on an empirical regression model. The results showed that introducing built environment stocks as a new determinant of CO_2 emissions can explain the asymmetric changes in CO_2 emissions well during economic growth and recession.

The recent advancements in correlation analyses of the economy, CO_2, and material stocks have increased our knowledge of the complexity of the human-nature relationship. However, there still exist many knowledge gaps regarding the inter-relationships among economic growth, in-use material stocks and CO_2 emissions. First, previous studies mainly investigated the bilateral relationships between two of the three indicators. The complex relationships among these indicators allow one indicator to serve as an intermediate variable linking the other two; for example, the accumulation of material in-use stocks driven by economic growth may consequently lead to higher CO_2 emissions. Revealing the trilateral causal relationships can provide new understandings regarding interactions between carbon mitigation and socio-economic metabolism transition. Second, studies accounting for material stocks at the Chinese provincial level are still lacking. As the world's largest developing country with the highest carbon emissions, introducing in-use material stocks as a new variable to analyze the economy-material-emissions nexus can provide more comprehensive interpretations of the physical dimension of China's urbanization. This study aims to fill the above two gaps. We compiled time-series fossil-fuel-induced CO_2 emissions and material stocks in infrastructure at the Chinese provincial level and then investigated their correlations with economic growth through a decoupling analysis and a panel Granger causality analysis. Policy implications for carbon emission mitigation and sustainable resource utilization are discussed based on the calculation results.

2. Data and methods

Our analyses are conducted at the Chinese provincial level (a total of 29 provinces in mainland China). Since China is a country with large regional differences regarding its socioeconomic development and environmental impacts, the 29 provinces are divided into three regions (as shown in Fig. 1) by their level of economic development and geographic differences, which was suggested in the seventh 5-year Plan for the National Economy and Social Development of China (State Council of China, 1986). By doing so,



	Eastern		Central		Western	
	1995	2013	1995	2013	1995	2013
Population (10^6)	496	609	430	452	274	291
GDP (10^{11} yuan)	34.1	246	15.3	108	8.18	56.2
CO_2 (10^8 ton)	15.6	52.0	10.6	32.4	5.88	21.5
Material stocks (10^8 ton)	150	408	102	274	57.2	150

Fig. 1. Provinces and three regions in China. Note: Tibet is excluded for the analysis due to the lack of statistical energy data. To keep the data consistent, Chongqing is still regarded as a part of Sichuan Province though it was designated a municipality in 1997. Data on population and GDP are from the Chinese Statistical Yearbook (NBS, 1996–2014a). Data on CO_2 and material stocks are from our own estimations. The details can be found in subsections 2.1 and 2.2.