

Life-cycle CO₂ and Air Pollutant Emission Assessment of China's Cement Industry under Planetary Boundaries

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China is the world's largest cement producer and consumer, contributing 58% of the world's total cement production in 2020. The cement industry in China is associated with 4–5% of China's total energy production and contributes 10–15% of national total CO₂ emissions, ranking second only to the power industry, and also significant air pollutant discharges such as SO₂, NO_x and particulate matter (PM). Since China's energy and environmental policies for the cement industry usually focus on specific energy/environment effects and a single manufacturing process, this study described the cradle-to-gate lifecycle covariation relationship of these effects and analyzed the potential transgression magnitude to related planetary boundaries to assist in designing low carbon and pollution industrial transition in Chinese cement industry. The multi-regional decomposition analysis model, the LMDI decomposition, and the SDA method were employed to identify the driving factors such as energy intensity, manufacturing technology, economic structure, intermediate demand and structure, and total demand. We found that the Chinese cement industry not only causes massive emissions directly but also imposes environmental burdens on other sectors through up- and downstream supply chains, especially in eastern and central regions. Scope 1 and 2 emissions decreased sharply for CO₂, SO₂, and PM thanks to stricter environmental regulations, but Scope 3 emissions of CO₂ increased by approximately 30%, contributed by energy intensity and economic structural change. Although total emissions basically presented decline trends, several national and regional planetary boundaries might be transgressed under downscaling principles based on population, and gross value added. This work improves our understanding of lifecycle carbon emissions and pollution and related total environmental burden in terms of planetary boundaries, thus offering references for the implementation of energy conservation and environment policies in the Chinese cement industry.