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Erika Remy, Rosina Engert, Laurenz Werner, Michael Bittner

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Investigating Germany's progress in decoupling air pollution emissions from economic activity using satellite-based measurements of NO₂.

Erika Remy¹, Rosina Engert¹, Laurenz Werner¹, and Michael Bittner^{1,2}

¹Institute of Physics, University of Augsburg, Augsburg, Germany

²German Remote Sensing Data Center, German Aerospace Center, Oberpfaffenhofen, Germany

In efforts to mitigate the effects of global climate change several prominent policies and guidelines which emphasize the importance of sustainable growth have been introduced in recent years. Examples include the 2019 European Green Deal, and the subsequent Clean Industrial Deal in 2025. A key aspect of these goals is the reduction of air pollutant emissions, particularly from fossil fuel combustion, without sacrificing economic growth. The Green Deal commits to an EU wide emission reduction of at least 55% by 2030, as compared to 1990 levels. Remote sensing offers many advantages for tracking progress towards reduction of pollutant emissions. In particular, the global coverage allows for analysis of regions which do not have sufficient ground-based measurement networks. This study presents a method of using spectral analysis with tropospheric NO₂ column density and the gross domestic product (GDP) to track and compare progress of the German federal states towards decoupling emissions from economic growth. Most studies evaluating economic decoupling focus on CO₂, or CO₂ equivalences. There is a current lack of studies which investigate other key combustion products. This study focuses on NO₂ as a proxy for emissions related to economic activity. NO₂ originates primarily from anthropogenic combustion sources, and has a short tropospheric lifetime, making it suitable to represent localized fossil fuel emissions. Measurements of NO₂ used in this study are obtained from the Ozone Monitoring Instrument (OMI) launched aboard the NASA Aura satellite in 2004. The application of spectral analysis techniques, such as the wavelet analysis, gives additional insight into temporal variability of NO₂, to better observe the path of decoupling for each region. Decoupling between GDP and NO₂ variability is observed for all regions of Germany in the period between the two most recent global economic recessions (the 2008 financial crisis, and the Covid-19 pandemic). Similar decreasing trends are observed for both the yearly average tropospheric column density and the calculated yearly variability. The variability obtained from the wavelet analysis shows greater sensitivity to changes in NO₂ emissions than the absolute tropospheric column density. Further regional differences such as the main economic sectors and types of emission regulations in place are discussed to contextualize the differences present in decoupling processes between the federal states. Overall, NO₂ variability is found to be a sensitive and effective indicator for tracking and comparing decoupling progress across different administrative regions.