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## Industrial hydrogen demand and decentralized supply in North Rhine-Westphalia (NRW): a cluster-based spatial scenario analysis towards net-zero production by 2045

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**Motivation:** Renewable hydrogen is considered essential for reducing GHG emissions in the industrial sector to achieve net-zero energy systems by 2045. Previous studies on assessing prospective hydrogen demand for industrial production lack high spatial resolution and detailed differentiation of industrial processes.

**Methodology:** This paper addresses that gap by integrating a georeferenced site-level database with scenario-based modelling to estimate hydrogen demand in industrial clusters in North Rhine-Westphalia (NRW), Germany. Three scenarios are developed to account for uncertainties in production, efficiency, and technology adoption.

**Results:** The results indicate that hydrogen demand in NRW could rise from 16.5 TWh/a today to 142 TWh/a by 2045, under an upper-bound full-substitution scenario assuming 2018 activity levels, with over 90 % concentrated in four industrial clusters dominated by chemicals and steel production. Centralized supply options, such as pipelines or imports, would be required to meet this growth, while decentralized hydrogen provision is not possible to suffice under current renewable expansion plans despite its potential ecological and economic benefits. Consequently, a regional supply gap of up to 208 TWh emerges, indicating the need for both electricity and hydrogen imports assuming constant industrial production levels. The study highlights the importance of integrating additional policy strategies, including resource efficiency, material demand reduction, and multi-level infrastructure planning. These could complement targeted imports and accelerated permitting processes to ensure sustainable production and industrial value creation in NRW by 2045.

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