


Pollution mitigation for agricultural machinery in China

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China's agricultural sector is undergoing rapid mechanization. Sustainable development of the sector will require low-carbon fuel substitutions and region-specific agricultural management strategies to remain within emission reduction targets.

Reducing carbon dioxide (CO₂) emissions and controlling air pollution have garnered substantial attention across various sectors, including energy, heavy industry and transportation, as part of global efforts to mitigate climate change and enhance human well-being. However, emissions from non-road mobile machinery and associated mitigation strategies remain underexplored. Among non-road mobile machinery, agricultural machinery is important for global food security and sustainability¹, yet it is also an important source of CO₂ and air pollutant emissions owing to its reliance on fossil fuels². China, home to the world's largest stock of agricultural machinery, was estimated to contribute approximately 1.3%, 2.5% and 13.6% of the nation's total CO₂, fine particulate matter (PM_{2.5}) and nitrogen oxide (NO_x) emissions from agricultural machinery use in 2020, respectively³. These emissions are expected to rise further as China's agricultural sector undergoes rapid mechanization, yet spatiotemporal patterns, key drivers and future trajectories of agricultural machinery emissions in China remain poorly understood. Furthermore, the mitigation potential of various strategies, including the adoption of alternative clean energy sources and electrification, has yet to be comprehensively assessed.

Now, writing in *Nature Food*, Zhuang et al.⁴ provide a compelling analysis of CO₂ and air pollutant emissions from agricultural machinery in China with previously unexplored spatial and temporal resolution. Their study compiled an extensive dataset, encompassing the quantity, annual working hours and total engine power of agricultural machinery at the provincial level from 1985 to 2020. By leveraging this dataset, Zhuang et al. used an index decomposition analysis to quantify the contributions of diverse socio-economic drivers. In addition, they projected emission trends to 2050 and assessed mitigation potential under different clean energy development pathways. Their findings indicated that emissions of CO₂, PM_{2.5}, NO_x and total hydrocarbons from agricultural machinery in field production have increased significantly, with average annual growth rates of 5.7%, 4.2%, 4.5% and 5.6%, respectively. The rapid increase in these emissions can be primarily attributed to the expansion of agricultural mechanization in China, which has resulted in a substantial increase in machinery stock and energy consumption. Population growth and the implementation of stringent emission standards have also influenced emission trends. The study further highlighted notable spatial heterogeneity in emissions across provinces, linked to variations in cultivated area, total engine power and machinery composition.




Given the projected increase in emissions from agricultural machinery, Zhuang et al. concluded that application of alternative fuels is imperative to achieve air pollution reduction and decarbonization in agricultural machinery. Their analysis suggests that emissions could be reduced by approximately 10–70% by 2050 compared with the baseline scenario, depending on the energy transition pathway. In the short term, biofuels and natural gas offer cost-effective mitigation solutions, as they require minimal modifications to existing propulsion systems⁵. In the long term, electrification integrated with clean electricity and hydrogen are expected to contribute towards lower air pollution rates and reduce carbon emissions^{6,7}, potentially enabling near-zero or even net-zero emissions from agricultural machinery. However, the widespread adoption of alternative fuels faces several challenges. For example, integrating photovoltaic technology with electric agricultural tractors presents a promising avenue for emissions reduction, yet power electronics components of photovoltaic system may lack the durability required to withstand the extreme operating conditions of agricultural fieldwork. Similarly, the high investment costs associated with hydrogen fuel cell systems hinder their large-scale deployment in agricultural machinery.

Zhuang et al. highlight the importance of considering CO₂ and air pollutant emissions from agricultural machinery in China and provide preliminary insights into their mitigation potential through low-carbon fuel substitution. Their findings offer valuable guidance for policymakers seeking to facilitate the green transition of agricultural machinery, not only in China but also globally. Yet, several research gaps and challenges remain. Their analysis focuses exclusively on emissions from field operations, whereas a more comprehensive life-cycle assessment is needed to capture the full emissions profile of agricultural machinery. The extensive agricultural machinery dataset used in this study may not be readily available in other countries, limiting the feasibility of conducting similar analyses on a global scale. Future research should explore the integration of diverse

data sources, including remote sensing imagery and ground-based observations, to enhance assessment accuracy and reduce uncertainties. Finally, given the pronounced spatial heterogeneity in agricultural machinery composition, further studies should investigate the optimal combination of management strategies tailored to local conditions to maximize mitigation potential and support a sustainable and low-carbon transition in the agricultural sector.

To effectively curb emissions from agricultural machinery, additional measures beyond low-carbon fuel substitution are necessary⁸. First, advanced exhaust treatment technologies such as exhaust gas recirculation and selective catalytic reduction should be widely implemented to minimize pollutant emissions. In addition, optimizing agricultural management practices, including precision agriculture, no-till farming, mulching and optimized crop rotation can help reduce machinery usage, thereby lowering energy consumption and emissions⁹. Enhancing the operational efficiency of agricultural equipment through improved training for farmers and machinery operators can further contribute to emission reductions. Tailoring these mitigation strategies to regional conditions is essential for achieving a cost-effective low-carbon transition in agricultural machinery.

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Competing interests

The authors declare no competing interests.