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Cost-effective climate benefits through fluorocarbon lifecycle management in China

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Achieving global climate goals requires heightened ambition and innovative measures. Banks of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), potent non-CO_2 greenhouse gases, represent a significant yet untapped mitigation opportunity. Globally, fluorocarbon refrigerant banks are estimated at 24 Gt CO_2-eq and continue to grow, forming a massive and expanding reservoir of greenhouse gases that will eventually be released into the atmosphere if left unaddressed. While the Montreal Protocol and its Kigali Amendment regulate the production and consumption of fluorocarbons, emissions from existing stocks remain largely unregulated. Fluorocarbon lifecycle management (FLM) – encompassing leakage prevention, recovery, recycling, reclamation and destruction – presents a viable solution to mitigate these emissions. In China, the world's largest producer and consumer of HCFCs and HFCs, implementing FLM could unlock substantial mitigation potential beyond current climate action, serving as a critical step toward net-zero goals. This study provides the necessary systematic evaluation to harness this opportunity.

To comprehensively assess the emission profiles of banked fluorocarbons with or without FLM, we developed the Extended Lifecycle Emissions Framework (ELEF), a refined emission modeling approach rooted in IPCC methodologies. ELEF expands conventional frameworks to cover both direct and indirect emissions across the entire lifecycle of fluorocarbons in equipment/product. A bottom-up cost analysis, adapted from the widely applied Greenhouse gas and Air pollution Interactions and Synergies (GAINS) framework to capture sector- and substance-specific treatment nuances, was conducted to assess the cost-effectiveness of FLM in China. Leveraging detailed activity data and localized emission factors, we reconstructed the country's fluorocarbon banks and emissions from 2000 and projected them through 2060. Mitigation potential was then quantified across varying ambition levels defined by abatement cost cap, with climate impacts assessed using impulse response functions (IRFs) that incorporate climate-carbon feedback.

Our results reveal that China currently holds 3.6 ± 0.1 Gt CO_2-eq of fluorocarbon banks, which are projected to peak at 4.5 ± 0.1 Gt CO_2-eq by 2034. If unmanaged, emissions from these banks could contribute an additional 0.014□ to global warming by mid-century. FLM, however, could prevent

up to 8.0 Gt CO^2-eq of cumulative emissions by 2060, reducing the peak temperature increase contribution by 62.4%. Notably, 57 out of 76 mitigation options analyzed exhibit average abatement costs below 10 USD/t CO_2-eq, enabling 93.2% of the maximum mitigation potential at a total cost of 18.9 billion USD. These cost-effective measures could deliver additional mitigation equivalent to over 50% of the 13 Gt CO_2-eq reductions pledged under the Kigali Amendment in China, or reduce the surface warming contribution of global HFC emissions in 2050 by more than 10%.

This study introduces a robust framework for assessing the costs and benefits of FLM. By applying it to China, we demonstrate the significant mitigation scale and feasibility of national-level implementation. Our findings highlight the substantial and cost-effective climate benefits achievable through FLM, offering policymakers an actionable pathway to bridge the emission gap and echoing recent international calls for immediate action.