GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

Residential Solid Fuel Combustion and Impacts on Air Quality and Human Health in Mainland China

Executive Summary

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A large proportion of Chinese residents continue to use solid fuels for cooking and heating. Although there is a rapid trend to replace traditional household solid fuels with cleaner fuels, approximately 600 million Chinese people are still using coal or biomass fuels for cooking, and almost 30% of households continue to heat their homes with solid fuels. As a result, an estimated 81 Tg of coal and 580 Tg of biomass fuels were consumed in the residential sector of mainland China in 2007. The total residential solid fuel consumption was equivalent to 12.3 EJ, accounting for 13% of the total anthropogenic energy consumption in China. Geographically, households in rural areas or interior provinces use more solid fuels than those in urban areas or coastal regions. Even though the population of China is evenly distributed into rural and urban areas, approximately 70% of residential coal and 84% of residential biomass fuels are used in rural areas. In addition, households in provinces with rich coal reserves or high grain production tend to use more coal or crop residues respectively.

Residential solid fuel combustion is a major source of emissions for many air pollutants. Emission factors of many pollutants for solid fuels used in household stoves are orders of magnitude higher than those burned in power stations or industrial facilities due to the large fraction of bituminous coal, poor combustion conditions, and lack of abatement facilities. Consequently, relative contributions of household solid fuels to the total anthropogenic emissions are significant for many air pollutants, and the dominant source for some of them, despite the fact that residential solid fuels account for merely 13% of the total anthropogenic energy consumption in China. For example, household solid fuels contribute 52%, 53%, 67%, 81%, and 84% of total anthropogenic emissions of primary $PM_{2.5}$, CO, black carbon (BC), organic carbon (OC), and benzo(a)pyrene in China, respectively (**Figure A**). Emissions in rural areas are generally higher than those in urban areas, although the populations in each area are similar. For example, the total emissions of $PM_{2.5}$ are 4.26 and 0.91 Tg in rural and urban areas, respectively. The significate contribution of residential solid fuels to total emissions is not limited to China, but reflects a global phenomenon due to extensive use of these fuels in most developing countries. Globally, 30-55% of total anthropogenic emissions of CO, primary TSP, and BC and over 70% of OC and BaP occur as a result of residential solid fuel emissions.

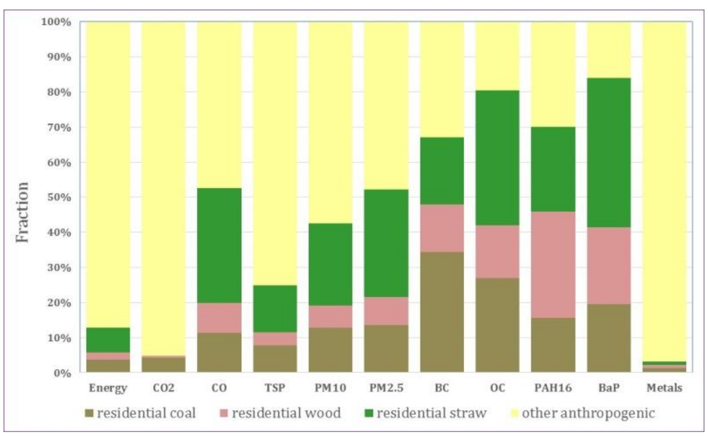

Figure A Relative contributions of residential combustion of coal, wood, and crop residue to total energy consumption and emissions of CO_2 and other selected air pollutants from anthropogenic combustion sources

Low-skilled rural to urban migrants are stuck in the middle of the energy ladder, and their contribution to emissions is distinctive from rural or urban residents. Without "Hukou", an officially recognized status to live in cities within the household registration system, the living conditions and energy mix of low-skilled rural-to-urban migrants differ significantly from urban residents with "Hukou". They tend to use less clean energy and generate higher emissions, and this pattern does not change much over time. When the total migrant population of over 260 million in China is taken into consideration, the implications in terms of the influence of urbanization on emissions and environmental quality cannot be overemphasized.

Emissions vary geographically, and are dependent on many factors, including population density, temperature, and economic development. Emission densities of various pollutants are unevenly distributed geographically, and have similar distribution patterns, with 'hot spots' in eastern China, North China Plain, and the Sichuan Basin. The distribution of BC emissions is shown as an illustrative example **Figure B**. Emission densities are most influenced by population density, temperature, and living conditions. In general, emission densities in northern China are higher than those in the south due to residential heating. Residents in poor interior provinces tend to use more coal and biomass fuels, and less electricity and liquefied petroleum gas (LPG) than those in coastal regions.

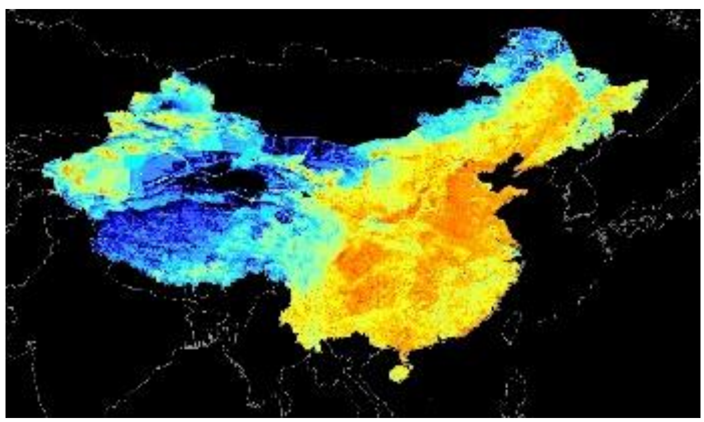

Figure B Spatial distribution of total residential emissions of BC within mainland China, 2007.

Temporal trends for most pollutants are inversely U-shaped, and peak around 1990. Temporal trends for many air pollutants emissions, especially those dominated by the residential sector, are similar to one another (**Figure C**). The trend for CO_2 emission follows coal consumption almost exactly, while variations in the emissions of other pollutants depend on both coal and biomass fuel use. From 1960 to 1990, residential energy consumption and associated emissions increased, driven primarily by population growth. Since 1995, although total population has increased continuously, rural population has decreased because of rapid urbanization, resulting in slight decrease of total biomass fuel consumption and associated emissions. However, the major driving-force for the decrease in emissions is the drop of coal use in both rural and urban households since 1990, when cooking coal was extensively replaced with piped natural gas (PNG), LPG, and electricity. Meantime, centralized heating systems have been extensively promoted in many cities in northern China. All these changes are driven by economic development and policy.

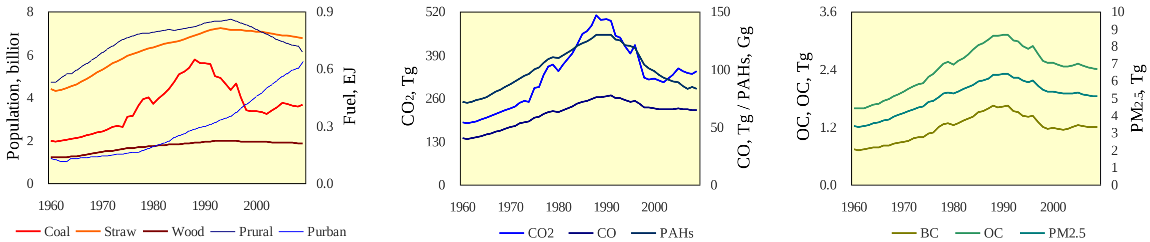

Figure C Temporal trends of emissions of major air pollutants from the residential sector in China, 1960 to 2009. Trends in residential energy consumption and rural (P_{rural}) and urban (P_{urban}) populations are also shown for comparison.

Indoor air in households using solid fuels is often severely polluted, resulting in high respiratory intake fractions. Elevated concentrations of a range of pollutants, including $PM_{2.5}$, SO_2, CO, BC, and PAHs, are often tens or even hundreds times greater than indoor air quality standards, have been observed in many rural households using solid fuels for cooking or heating. The highest concentrations are usually found in kitchens. These high pollutant concentrations result in high exposures. Based on the limited data available, population weighted mean exposure concentrations of $PM_{2.5}$ in rural areas were calculated as 190, 184, and 168 μg/m^3 for households using coal, wood, and straw, respectively, compared to 94 μg/m^3 for clean energy using households.

Emissions from residential solid fuel burning are a significant, but overlooked contributor to local and regional ambient air pollution. Residential solid fuels are an important contributor to emissions, and affect ambient air quality. Severe ambient air pollution observed in rural villages in northern China during the heating season provides direct evidence for such influence. However, attention to ambient air quality, as well as air pollution research and control efforts, tends to be city-focused. As a result of overlooking solid fuel emissions, data needed to conduct a quantitative evaluation of local and regional ambient air quality and health impacts in rural China are limited.

The adverse health effects of household air pollution are apparent in an increasing local evidence base. The increasing epidemiologic evidence base in China is consistent with the global evidence showing that household air pollution in China can cause a range of health outcomes, including respiratory disease (respiratory symptoms, lung function reduction, asthma, lung cancer, and COPD), cardiovascular disease (heart disease, stroke, and elevated blood pressure), neural tube defects, and immune system impairment. Household air pollution ranks the fifth among all risk factors in China, leading to over one million premature deaths each year.

The potential impact of household solid fuels on climate is primarily driven by BC and PM emissions. Since combustion of all crop residues and a large fraction of wood fuels in China is carbon neutral, the contribution of this sector to total anthropogenic CO_2 emissions is merely 4.2%. On the other hand, since household solid fuels account for more than half of the anthropogenic BC emission in China, its contribution to climate forcing should not be overlooked. Similarly, the impact of primary $PM_{2.5}$, more than 40% of which comes from combustion of household solid fuels, on climate is not negligible.

The ultimate solution is to replace solid fuels with clean energy, and promotion of improved

high efficiency stoves offer an interim solution. An accelerated process of adopting electricity, PNG, LPG, and biogas for cooking is underway in China, driven by improvements in living conditions. This is particularly true in cities. In the meantime, replacement of chunk coal and biomass fuels with relatively clean honeycomb briquettes and processed biomass fuels, together with clean stoves, can reduce emissions significantly. It will be difficult to promote processed biomass fuel without government subsidy, however. For heating in cities, centralized heating systems, which can reduce emissions substantially, have been well promoted and the scale up will continue. In rural China, individual household heating systems (a single stove for a house), which have been adopted by many households in recent year, can improve household air quality substantially without necessarily reducing emissions or impacting ambient air pollution. The ultimate, though difficult solution will be to eliminate the use of household coal and traditional biomass fuels.

Institutional, regulatory, policy, and educational instruments are equally, if not more important. In additional to economic driving force, legislation, institutional, and policy instruments are all critical for promoting clean energy. In this regards, an *Indoor Air Pollution Prevention and Control Law* and low level regulations will provide sound legislative basis. Both indoor air quality standards and stove standards need to be updated, and new standards for clean fuels will help. Institutionally, there is no government agency in charge of rural household air quality at present. A coordination mechanism among relevant ministries with one designated lead is critical for solving the problem in the long-term. Other stakeholders including enterprises, researchers, media, and the public, should also share the responsibility of indoor air pollution control. Market oriented economic measures, green finance, and pricing are potential policy alternatives beside subsidy for clean fuels and stoves. Risk communication can encourage public involvement at community and household levels.

More research is needed to better understand the impacts of household solid fuel use and inform the development of practical abatement strategies. Although adverse effects of household solid fuels are well recognized, the quantification of these effects have great uncertainty, primarily due to data gaps (e.g. quantities of residential solid fuel consumption, usage of traditional and clean stoves, field measured emission factors, household air quality, exposure rate, and disease statistics etc.) and knowledge gaps (e.g. trends of solid fuel and stove uses, emission dynamics, factors affecting the emission, relationship between fuel and indoor air quality, association between indoor and ambient air quality, and influence of urbanization on the emission etc.). The following research priorities have been identified to fill these gaps: 1) field survey and observation on solid fuel and stove use, emission dynamics, household air quality, and personal exposure; 2) development of highly resolved emission inventories, simulation of regional household air quality, population exposure, contribution of household solid fuel combustion to ambient air quality, and quantification of health/climate impacts; and 3) cost-benefit (health/climate) analysis-based abatement strategy formulation.

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