Working Paper

A Pro-Growth Pathway for Reducing Net GHG Emissions in China

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World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

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Key messages

- A focused programme to mitigate GHG emissions and sequester carbon in rural China could achieve an estimated net GHG emission reduction of 740 $MtCO_2$ yr^{-1} from 2010-2030, equivalent to 14% of China's 2005 CO_2 emissions from energy use.

- Activities included in this rural climate programme would include: reducing the overuse of nitrogen-based fertilizers, encouraging rural households to replace inefficient burning of biomass with more efficient energy carriers, finding alternatives to agricultural residue burning, and sequestering carbon in agricultural soils, forests, and rangelands.

- All of the mitigation and sequestration activities we include in this paper have broader societal benefits. Reducing overuse of nitrogen fertilizers, for instance, could increase net incomes for farmers and improve water quality. Sequestering carbon in agricultural soils could increase soil fertility and moisture, increase agricultural yields and improve watershed functions.

- At an average abatement cost of \$20 tCO_2^{-1}, such a programme would require US\$14.8 billion (104 billion yuan) per year in funding, equal to 0.3% of China's GDP and 2.5% of government expenditures in 2008.

- A number of innovative mechanisms outside of public finance could be used to fund a rural climate programme, including the creation of a national offset programme or imposing a small fee on some emission intensive industrial sectors. For instance, funded as a carbon fee on China's most carbon-intensive sectors, the cost to producers would be 1.1% of 2005 sales.

- Implementing a rural climate programme would require overcoming the human, financial, and technology constraints that have historically limited progress against policy goals for rural areas. For instance, extension agencies often lack the skills and funds to do what is currently asked of them, and extension would be even more important under a rural climate programme. Carbon revenues could play an important role in improving human resources, in encouraging adoption of practices and technologies, and in developing new technologies that overcome cost and scale hurdles.

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A Pro-Growth Pathway for Reducing Net GHG Emissions in China

Through a national programmeme that sequesters carbon and reduces greenhouse gas (GHG) emissions in rural areas — a rural climate programmeme — China could achieve significant net GHG emission reductions while meeting policy priorities for economic growth, rural development, and environmental sustainability. The programmeme would be an important investment in China's medium- to longer-term future, and could be funded domestically at relatively low cost through a variety of mechanisms.

This paper examines the potential for a rural climate programmeme in China. The paper first provides a detailed description of GHG mitigation options in agriculture and rural energy (Section 1) and carbon sequestration potential in agricultural soils, forests, and rangelands (Section 2). The final two sections (Sections 3 and 4) discuss the scope, financing, and barriers to implementation of a rural climate programmeme in China.

1. Avoided GHG emissions in agriculture and rural energy

Although there are a number of GHG mitigation options in agriculture, livestock, and rural energy, in China the three strategies with the highest potential include:

- *Fertilizer management programmemes* that reduce fertilizer use per unit agricultural output and per area;
- *Rural energy technology programmemes* that reduce dependence on biomass combustion as a source of cooking and heating; and
- *Agricultural residue management programmemes* that reduce or eliminate burning of agricultural residues.

All three strategies have the potential to achieve significant GHG reductions, at relatively low cost, and with benefits for rural economic growth.

Agricultural landscape

Algae blooms in Dianchi Lake due to eutrophication and over use of fertilizer

1.1 Fertilizer

Nitrogen-based (N-) fertilizer production and use is a major source of GHG emissions. Carbon dioxide (CO_2) emissions are produced as a byproduct in the production of hydrogen from fossil fuel feedstocks and through the energy required to react hydrogen with nitrogen to produce ammonia (NH_3). High use of N-fertilizers also leads to N_2O emissions through the nitrification-denitrification process. China is the world's largest user of N-fertilizers, accounting for 31% of world consumption.[1] Using a total estimated N-fertilizer emission factor of 4.4-17.0 $tCO_2e\ tN^{-1}$ (default 7.6 $tCO_2e\ tN^{-1}$) for China,[2] we estimate that N-fertilizer use in China led to total GHG emissions of 130-510 $MtCO_2e$ (230 $MtCO_2e$ using IPCC default values) in 2005, equivalent to 3-10% of China's total 2005 energy-related CO_2 emissions (5,101 $MtCO_2$).

N-fertilizer use levels in China are high both on a per yield and a per area basis relative to countries with similar agricultural profiles.[3] Reducing fertilizer use to levels needed to sustain current yields would decrease GHG emissions, reduce water pollution from nitrates, and would bring a net economic benefit to farmers by lowering their input costs. While a more precise characterization of the potential for N-fertilizer reduction in China requires rigorous field assessment and demonstration, as a first order approximation China could achieve a roughly 30% reduction in N-fertilizer use by reducing fertilizer use to U.S. average levels.[4] At the emissions estimates above, this reduction would lead to a 40-160 $MtCO_2e$ (74 $MtCO_2e$ using IPCC default values) decline in GHG emissions.

There are a number of factors that contribute to high N-fertilizer use in China, including revenue needs for agricultural extension bureaus that sell fertilizer to farmers, inadequate crop insurance programmemes, and insufficient skills, information, and awareness on the part of both extension agents and farmers. Strategies for reducing fertilizer use might include changing incentives for extension bureaus, more robust crop insurance programmemes, and direct or in-kind payments to villages, all of which can be funded in part through carbon revenues. At a hypothetical cost of \$20 tCO_2e^{-1}, per area payments would likely be on the order of \$10 ha^{-1} of cropland[5] or, on average, \$425,000 (3.0 million yuan) per county.[6]

1.2 Rural energy

Rural residential biomass combustion is an important source of CO, CH_4, N_2O, and black carbon emissions, and potentially CO_2 emissions depending on whether the biomass is sustainably harvested. China is the world's largest user of residential biomass energy, accounting for an estimated 25% of total global non-commercial biomass combustion.[7] Using GHG emission factors of 0.6-1.9 $kgCO_2e\ kg^{-1}$ and 0.5-1.9 $kgCO_2e\ kg^{-1}$ for rural wood and agricultural residue burning,[8] respectively, we estimate that residential biomass combustion in China led to GHG emissions of 150-520 $MtCO_2e$ in 2005,[9] equivalent to 3-10% of China's total 2005 energy-related CO_2 emissions (5,101 $MtCO_2$).

Accelerating the transition to modern energy carriers and technologies in rural areas could significantly reduce China's GHG emissions, even if biomass substitutes are high carbon energy carriers like coal-fired electricity. In addition, this transition in energy use would have extensive benefits for public health, gender equality, and the environment.[10] Achieving a 30% reduction over 2005 levels of residential biomass use in rural areas by substituting electricity (rice cookers), biogas (biogas stoves and rice cookers), and gaseous fuels (e.g. LPG stoves) for biomass used in cooking might be a realistic 2030 goal. Assuming that these reductions are met with one-third of each of these fuels, China could achieve an estimated 20-70 $MtCO_2e$ reduction in GHG emissions.[11]

Upland households may use more than 10 m^3 of fuelwood per year

Upland households use at leat 10 m^3 of fuelwood per year. A national programmeme to modernize energy carriers in rural areas would need to address historical obstacles to the adoption of biomass substitutes, such as high upfront and fuel cost barriers, inadequate service support for energy technologies, insufficient opportunity costs for biomass resources, and lack of awareness of the health consequences of biomass burning. The three substitutes listed above would cost \$5-35 tCO_2^{-1} for electricity, \$30-110 tCO_2^{-1} for biogas, and \$140-630 tCO_2^{-1} for LPG.[12] Through cost sharing arrangements actual programmeme costs could be much lower, and research in new and improved energy technologies (e.g. cost-effective small-scale gasifiers or rooftop solar PV) could have high payoffs. Reducing residential use of coal in rural areas is both more cost-effective and has higher health benefits than reducing residential biomass use,[13] but coal is often used for space heating and is arguably more difficult to substitute.

1.3 Agricultural residue management

A significant source of GHG (CO, CH_4, N_2O, and NO_2) emissions, agricultural residue burning is widely used across the world to prepare fields for planting, control weeds and pests, and remove residues after harvest. This burning of agricultural residues occurs on a large scale in China, with upwards of 20% of total crop residues burned.[14] Using the same emission factor range (0.5-1.9 $kgCO_2e\ kg^{-1}$) for agricultural residues as above,[15] we estimate that residue burning in China led to GHG emissions of 60-230 $MtCO_2e$ in 2000,[16] equivalent to 1-5% of China's total 2005 energy-related CO_2 emissions (5,101 $MtCO_2$).

Controlling agricultural residue burning can be an important GHG mitigation strategy, and also has significant co-benefits for reducing local concentrations of criteria (PM, SO_2, N_2O)[17] and toxic air pollutants.[18] To a large extent, decreasing the amount of residue burning is a matter of finding economically viable alternative uses for residues. Six frequently mentioned alternative uses include: returning a greater share of residues to the soil; expanding the use of residues for feed; gasifying residues in small-scale gasifiers for local gas use to offset inefficient biomass combustion; converting residues to liquid biofuels to offset petroleum use; producing electric power in small-scale power plants either using residues as a direct feedstock or first converting to a syngas; and co-firing residues with coal in coal-fired power plants.

These six alternative uses all face economic, logistical, and technical obstacles. If these obstacles can be overcome, GHG emission reductions could be achieved directly through reducing residue burning and indirectly through restoring soil carbon, offsetting lifecycle GHG emissions from feed production, and offsetting fossil fuel use. Assuming, hypothetically, that 50% of residues burned in 2000 (total 122 Tg) are used to

More than 20% of crop residues are burned in China

produce power in small-scale power plants, reducing agricultural residue burning by half would lead to a GHG emission reduction of 70-150 $MtCO_2e$.[19] At current feed-in tariffs for biomass power (0.25 yuan kWh^{-1}), the abatement cost of residue-based power generation that displaces residue burning would be roughly $10-20 tCO_2^{-1}.[20]

Since 1999, China's central government has had a regulatory framework in place that requires provinces to develop management plans for agricultural residues,[21] but efforts to promote more centralized collection and use of residues have run up against challenges of scale. The 61 Tg project above (i.e., half of the 122 Tg burned in 2000), for instance, would likely involve more than 20 million households.[22] With projects often scaled to the availability of agricultural residues to reduce transaction and transport costs, farmers can gain market power and feedstock prices rise beyond what projects can absorb.[23] Similarly, more intensive use of agricultural residues at a plot level requires targeted training efforts that could incur high administrative costs because of the sheer number of farmers that would require training.

For more centralized collection and use of agricultural residues, policymakers must address the cost dilemma — that farmers need high returns to offset opportunity costs but project developers need low feedstock costs to make their investments economically viable. Carbon revenues could provide a means to bridge these divergent interests, and new technologies that reduce transaction and transport costs could open up new uses for residues. However, these is also a need to better understand the opportunity cost of agricultural residues and the drivers behind the "supply" of burnable residues, such as mechanization and greater penetration of modern energy carriers. In particular, the relationships among residue availability, livestock fodder, tractor use, soil fertility, and household energy use are still poorly understood.

Rangeland landscape in Tibetan Plateau

2. Carbon sequestration in agricultural soils, forests, and rangelands

Worldwide, terrestrial carbon sequestration provides a near-term, low cost means of transferring large quantities of CO_2 from the atmosphere to long-lived carbon pools in agricultural, forest, and grassland ecosystems. With an extensive land mass, China has significant potential for sequestering carbon in agricultural soils, forests, and rangelands. Although both globally and in China soils are the dominant pool of terrestrial carbon storage, as we discuss below forest biomass could be an equally, if not more, important carbon sink in China over the next two decades.[24]

The relationship between changes in land use and climate is complex, involving, for instance, the nonlinear effects of changes in surface albedo and evapotranspiration on local and global climate systems. The below discussion takes a narrower view, focusing on carbon only rather than the broader links between land use, vegetation, soils, and climate.

2.1 Agricultural soils

Agricultural soils are often highly perturbed ecosystems that have lost a significant portion of their soil organic carbon (SOC) through land conversion and soil degradation. Because they are both intensively managed and highly degraded, agricultural soils are also thought to be the most promising option for soil carbon sequestration, and improved agricultural management practices could restore a significant portion of the SOC that existed under original vegetation.[25] China accounts for 10% of the world's arable land,[26] and agricultural soil carbon sequestration could be an important part of both global and China's own efforts to reduce net GHG emissions.

A number of agricultural management practices can restore organic matter to soils, including low or zero tillage, agricultural residue management, nutrient management, improved agronomy, and agroforestry.[27] Using a combination of these practices, estimates of agricultural soil carbon sequestration potential in China have centered at a value of around 117 $MtCO_2$ yr^{-1} (32 GtC yr^{-1}) for 20-80 years,[28] or around 1.0 tCO_2 yr^{-1} per ha of cultivated land.[29]

With 20% of the world's population but only 10% of its arable land, ensuring longer-term food security is the predominant concern for Chinese agricultural policy. Although China's population growth has slowed dramatically over the last two decades,[30] a combination of continued population growth and changing diets will continue to place pressure on the country's agricultural land. China is already the world's largest agricultural producer,[31] and a long history of intensive agriculture has degraded the country's agricultural soils. Soil carbon sequestration could be part of a strategy to improve the longer-term land productivity in China. In addition to the benefits of a large-scale agricultural soil sequestration programmeme for erosion control, water conservation, and nutrient cycling, evidence from China suggests that restoring soil organic matter could also increase productivity for cereal crops.[32] Improving longer-term land productivity would also mean less required land conversion to agriculture, both domestically and abroad through imports.[33] Although costs for agricultural soil carbon sequestration are likely to be higher than the \$4-6 tCO_2^{-1} currently offered in voluntary carbon markets, payments of \$20-30 tCO_2^{-1} may provide sufficient incentives to encourage farmers' adoption of practices that sequester carbon in agricultural soils.[34]

2.2 Forests

Forest ecosystems account for about half of the global stock of terrestrial carbon, storing carbon in soils, litter, and vegetation.[35] Additional carbon can be sequestered in forests by expanding forest area and increasing the amount of above- and below-ground biomass in forests. In China, much of the potential for forest-based sequestration lies in increasing biomass in existing forests. China's central government undertook several large-scale afforestation-reforestation (AR) programmemes in the late 1990s, and the potential for new AR projects is now more limited. Alternatively, there is a significant potential for sequestration in increasing the standing volume of existing forests through a transition toward sustainable forest management (SFM) practices.

Poorly managed collective forest, Yunnan

China accounts for 5.0% of the world's forested area[36] but less than 2% of the total carbon stored in forest vegetation,[37] suggesting that China's forests are currently below their storage capacity. More specifically, China had an average standing volume of 67 m^3 ha^{-1} in 2005, well below the world average (110 m^3 ha^{-1}).[38] Increasing average standing volume in China to 90 m^3 ha^{-1} would sequester an additional 1.5 GtC in forest biomass.[39] Assuming that this increase in forest volume can be achieved over a 20-year period, the average sequestration rate would reach 280 $MtCO_2$ yr^{-1}.

Extending forest area through AR projects and conservation, if feasible, could also provide an

important sink for carbon. Based on current plans, this sink could be as large as 9 GtC over 1990-2050 (550 $MtCO_2$ yr^{-1}), with forest soils accounting for about 20% of total net sequestration[40] Although the technical potential for sequestering carbon through increasing forest area in China may be large, there is a need to be realistic about the competing needs of agriculture and forestry and we argue that intensive management is likely to be more realistic than extensive management in the short run. In aggregating mitigation and sequestration potentials, we assume that most of the nearer-term potential for forest carbon sequestration in China lies in increasing the standing volume of existing forests.

The low standing volume of China's forests has its roots in shortcomings in forest management. Local forest bureaus use a limited range of trees species in AR projects, focus on planted area (forested ha) rather than standing volume (m^3 ha^{-1}), and strict requirements on thinning and harvesting mean that timber forests are not optimally managed. Wider-scale dissemination of SFM principles could help to overcome these shortcomings and provide an alternative rubric for evaluating forest management. A transition to SFM could, in principle have a net societal benefit (i.e., a positive total net present value or a negative abatement cost), although the economics of SFM are dependent on a variety of factors, such as discount rates, fuelwood demand, and forest tenure.[41]

2.3 Rangelands

Grasslands cover as much as 36% of the earth's total land area, accounting for an estimated 579 GtC of total global SOC stocks (~1,500 GtC) and 71-231 GtC of total vegetation carbon stocks (~560 GtC).[42] Forty-two percent of China's total land area is grassland,[43] and China's grasslands store more than one quarter of the country's total soil carbon.[44] Due to extensive degradation, grasslands are the source of the majority of soil carbon lost in China in recent decades.[45] Often with lower opportunity costs than agricultural land, grasslands

Livestock dung is a fuel in grassland areas

will play an important role in China's carbon sequestration policies, both through practices that store additional carbon and through policies that reduce carbon emissions resulting from land conversion.

A number of practices can sequester carbon in rangelands, including: changing grazing intensity, retirement of degraded grassland, conversion of arable land to rangeland or pasture, reseeding and planting grass or shrubs on degraded lands, and nutrient management. Adoption of these practices in China could store an estimated 73-147 $MtCO_2$ yr^{-1} (20-40 GtC yr^{-1}) for 25-50 years.[46] Direct implementation costs of rangeland sequestration practices vary, but are generally below \$10 tCO_2^{-1}. At average sequestration rates of 0.3-0.5 tCO_2 ha^{-1} yr^{-1},[47] this equates to \$3-5 ha^{-1} yr^{-1}.

Conversion of grassland to other uses (e.g., arable land) is now restricted by law, and, except in some localities, is currently not the main cause of carbon losses from grasslands in China. A better understanding of the factors that influence sequestration rates, costs, and management practices is needed to design larger-scale sequestration programmemes. For instance, while practices that require specific inputs such as additional fencing will generally incur high costs, opportunity costs for herders are less well understood.

3. Programmeme scope and financing

At mid-range values for the mitigation and sequestration activities described above, China could achieve a net GHG emissions reduction of roughly 740 $MtCO_2e$ yr^{-1}, equivalent to 14% of China's energy-related CO_2 emissions in 2005. Although the activities listed above are representative, they are not exhaustive of the total potential for mitigating GHG emissions and sequestering carbon in rural areas. Instead, these activities would be part of a realistic, focused programmeme that focuses on lower cost solutions that have net benefits for rural economies.

Forest landscape

Although we treat the activities in Table 1 separately in this analysis, in many cases there are important linkages among them. For instance, there are close interactions among rural energy use, crop residue management, livestock management, and soil carbon. The potential for improved forest management will depend, at some level, on the ability to reduce demand for fuel wood. These linkages should be accounted for in the design of a rural climate programmeme.

Table 1: **Mid-range mitigation and sequestration estimates from the text**

Activity area	Mid-range estimate ($MtCO_2e\ yr^{-1}$)	Range reported ($MtCO_2e\ yr^{-1}$)
Fertilizer	74	40-160
Rural Energy	45	20-70
Agricultural Residues	110	70-150
Agricultural Soils	117	No range reported
Forests	280	No range reported
Rangeland	110	73-147
Total	**737**	

Note: These estimates are intended to be representative. The large range in these estimates suggests the considerable uncertainty that still exists in emissions, GWP values, and sequestration rates. The estimates do, however, give a sense of both the scale of potential mitigation and cost.

At a representative average cost of \$20 tCO_2^{-1}, a programme to mitigate and sequester 737 $MtCO_2e\ yr^{-1}$ in rural areas would cost \$14.8 billion per year (104 billion Yuan yr^{-1}). This amount is trivial (0.3%) relative to China's GDP (30,067 billion Yuan in 2008), and significant but still small (2.5%) relative to annual government expenditures (407 billion Yuan in 2008).[48] Outside of public coffers, there are a number of mechanisms available to fund the programme domestically. For instance, the programme could be funded through a small carbon fee (1.1% fee on total 2005 sales) on China's most carbon-intensive sectors — chemicals, building materials and non-metal minerals, and metal products.[49] The programme might also be funded as part of a broader offset programme, where industries with relatively high abatement costs (e.g., > \$50 tCO_2^{-1}) could offset emissions with lower cost (< \$20 tCO_2^{-1}) options in rural areas. In either case the added cost to Chinese industry is relatively small.

While the bulk of net emission reductions in this paper are in sequestration, this weighting is to some extent an artifact of our assumptions about what might be realistic to achieve over the next 20 years, and what activities to include and exclude. For instance, we have not included potential CH_4 emission reductions from rice paddy management, or CH_4 and N_2O emission reductions from changing livestock management practices. Neither of these, and a host of other, activities have obvious societal benefits outside of GHG emission reductions, but they may indeed be low cost mitigation options.

4. Barriers to implementation

All of the six activities described above — rationalizing fertilizer use, disseminating modern energy technologies in rural areas, reducing residue burning, investing in agricultural soil fertility, increasing the standing volume of forests, and restoring and maintaining grassland ecosystems — are policy priorities for China. Most if not all of the activities above would create broader societal benefits beyond the narrower scope of net GHG reductions. Investments in rural energy, for instance, could improve human health and quality of life in rural areas, particularly for women. Investments in soil carbon sequestration could improve yields and watershed functions over the longer term.

However, progress in all of these six activities has historically been slowed by human resource, financial, and technology constraints. A more detailed analysis of these constraints is beyond the scope of this paper. Nevertheless, the discussion below provides some illustrative examples of both barriers and possible means of overcoming them.

Human resource constraints. Implementing the activities highlighted in this paper require a significant upgrade of the management capacity and skills of rural extension agencies, improvements in their incentives, as well as more gradual changes to the structure and focus of the entire extension system. China's local extension bureaus often work under central government mandates and metrics that prioritize quantity over quality (e.g. prioritizing increased forest cover over increased provision of forest ecosystem services). Extension agencies are also typically under-funded relative to the tasks required of them.[50] For instance, agricultural extension bureaus often sell fertilizer and other inputs to farmers as a means to generate revenues, creating disincentives for a more scientific approach to agriculture. In rangeland areas funding for basic staff is limited, with only 8,000 grassland monitoring personnel nationwide. Investing in human resources — by improving skills of existing staff, recruiting more qualified extension agents and improving their incentives to provide effective services — will be an important part of a rural climate programme.

Financial constraints. Several of the activities above have high up-front costs and would require external financing to encourage adoption. For instance, activities that sequester carbon in agricultural soils are likely to be labor intensive, which would require households to either dedicate more of their own labor to farming or hire additional labor. In both cases, there is an opportunity cost that must be offset to encourage adoption of carbon sequestering practices. These practices may indeed increase yields over the long term, but farmers tend to have high discount rates and need to see nearer-term returns on their investments. In both this and other cases (e.g. energy technologies), carbon revenues could provide a means to overcome up-front cost hurdles and encourage improved practice and technology adoption.

Technology constraints. In some cases, new technologies will be required to overcome cost and scale barriers to rural GHG reducing or carbon sequestering activities. For instance, new technologies that decrease the minimum efficient scale for centralized use of agricultural residues could make alternative uses of residues more economically viable. Technologies that reduce the labor requirements of soil sequestering practices could improve adoption of those practices. Training programmes and services for farmers that make use of advanced communications technologies could reduce the transaction costs for providing tailored extension services.

If these constraints can be overcome, a rural climate programme would provide a vehicle for investing in economically, socially, and environmentally sustainable growth in rural China. More simply, a rural climate programme is a smart investment in China's future.

References

Bond T., Venkataraman C., Masera O. 2004. 'Global atmospheric impacts of residential fuels.' *Energy for Sustainable Development* 8(3): 20-32.

Brown S., Sathaye J., Cannell M., Kauppi P.E. 1996. 'Management of forests for mitigation of greenhouse gas emissions.' In R.T. Watson, M.C. Zinyowera, R.H. Moss and D.J. Dokken (eds.) *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Cambridge: Cambridge University Press.

Cao G., Zhang X., Zheng F. 2006. 'Inventory of Black Carbon and Organic Carbon Emissions from China.' *Atmospheric Environment* 40: 6516-6527.

Fang J., Liu G., Xu S. 1996 'Carbon pools in terrestrial ecosystems in China.' In Wang R., Fang, J., Gao, L., Feng, Z. (eds.) *Hot Spots in Modern Ecology*. Beijing: China Science and Technology Press.

Fang J., Chen A., Peng C., Zhao S., Ci L. 2001. 'Changes in Forest Biomass Carbon Storage in China Between 1949 and 1998.' *Science* 292(5525): 2320-2322.

FAO [Food and Agriculture Organization of the United Nations]. 2005. 'Global Forest Resources Assessment 2005: Progress towards sustainable forest management'. FAO Forestry Paper 147. Rome: FAO.

Hu R., Yang Z., Kelly P., Huang J. 2009. 'Agricultural Extension System Reform and Agent Time Allocation in China.' *China Economic Review* 20(2): 303-315.

Huang J., Hu R., Cao J., Rozelle S. 2008. 'Training programmes and in-the-field guidance to reduce China's overuse of fertilizer without hurting profitability.' *Journal of Soil and Water Conservation* 63(5): 165A-167A.

IEA [International Energy Agency]. 2007. *World Energy Outlook 2007*. Paris: OECD/IEA.

Kahrl F., Su Y., Tennigkeit T., Yan M. 2009. 'China's Forests as a Carbon Resource: An Options Assessment.' Paper presented at the 17th European Biomass Conference and Exhibition, 29 June – 2 July, Hamburg, Germany.

Lal R. 2002. 'Soil Carbon Sequestration in China through Agricultural Intensification, and Restoration of Degraded and Desertified Ecosystems.' *Land Degradation and Development* 13: 469-478.

Lal R. 2004. 'Soil Carbon Sequestration Impacts on Global Climate Change and Food Security.' *Science* 304: 1623-1626.

Li Z., Han F., Su Y., Zhang T., Sun B., Monts D.L., Plodinec M.J. 2007. 'Assessment of soil organic and carbonate carbon storage in China.' *Geoderma* 138: 119-226.

NBS [National Bureau of Statistics]. 2009. *China Statistical Yearbook 2008*. Beijing: China Statistics Press

NBS/ NDRC [National Bureau of Statistics / National Development and Reform Commission]. 2009. *China Energy Statistical Yearbook*. Beijing: China Statistics Press

NDRC [National Development and Reform Commission]. 2004. *Medium and Long-term Plan for Energy Efficiency*. Beijing: NDRC (available at http://www.sdpc.gov.cn/xwfb/t20050628_27571.htm)

NREL [National Renewable Energy Laboratory]. 2006. 'Biomass Support for the China Renewable Energy Law.' Subcontract Report NREL/SR-710-40625.

Ni J. 2001. 'Carbon storage in terrestrial ecosystems of China: estimates at different spatial resolutions and their responses to climate change.' *Climatic Change* 49: 339–358.

Ni J. 2002. 'Carbon Storage in Grasslands of China.' *Journal of Arid Environments* 50: 205-218.

Pan, G., P. Smith, W. Pan. 2009. 'The role of soil organic matter in maintaining the productivity and yield stability of cereals in China.' *Agriculture, Ecosystems, and Environment* 129: 344-348.

Paustian K., Cole C.V., Sauerbeck D., Sampson N. 1998. 'CO_2 Mitigation by Agriculture: An Overview.' *Climatic Change* 40: 135-162.

Sagar A.D., Kartha S. 2007. 'Bioenergy and Sustainable Development?' *Annual Review of Environment and Resources* 32: 131-167.

Schlesinger W.H. 1997. *Biogeochemistry: An Analysis of Global Change*, San Diego: Academic Press.

SEPA [State Environmental Protection Agency]. 1999. 'Regulations Supporting Management of Agricultural Residue Burning and Comprehensive Use'. Beijing: SEPA

Smith K.R., Uma R., Kishore V.V.N., Zhang J., Joshi V., Khalil M.A.K.. 2000. 'Greenhouse Gas Implications of Household Stoves: An Analysis for India.' *Annual Review of Energy and Environment* 25: 741-763.

Smith P., Martino D., Cai Z., Gwary D., Janzen H., Kumar P., McCarl B., Ogle S., O'Mara F., Rice C., Scholes B., Sirotenko O., Howden M., McAllister T., Pan G., Romanenkov V., Schneider U., Towprayoon S., Wattenbach M., Smith J. 2008. 'Greenhouse Gas Mitigation in Agriculture.' *Philosophical Transactions of the Royal Society* 363: 789-813.

UN [Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat]. 2007. *World Population Prospects: The 2006 Revision*. Accessed from earthtrends.org.

White R., Murray S., Rohweder M. 2000. *Pilot Analysis of Global Ecosystems: Grassland Ecosystems*. Washington, DC: World Resources Institute.

Xie Z., Zhu H., Liu G., Cadisch G., Hasegawa T., Chen C., Sun H., Tang H., Zeng Q. 2007 'Soil Organic Carbon Stocks in China and Changes from 1980s to 2000s.' *Global Change Biology*, 13: 1989-2007.

Yan H., Cao M., Liu J., Tao B. 2006. 'Potential and sustainability for carbon sequestration with improved soil management in agricultural soils of China.' *Agriculture, Ecosystems and Environment* 121: 325-335

Yan X., Ohara T., Akimoto H. 2006. 'Bottom-up Estimate of Biomass Burning in Mainland China.' *Atmospheric Environment* 40: 5262-5273

Yang S., He H., Lu S., Chen D., Zhu J. 2008. 'Quantification of crop residue burning in the field and its influence on ambient air quality in Suqian, China.' *Atmospheric Environment* 42: 1961-1969.

Zhang Q., Huang J., Yu G. 2008. 'Polychlorinated dibenzo-p-dioxins and dibenzofurans emissions from open burning of crop residues in China between 1997 and 2004.' *Environmental Pollution* 151: 39-46.

Zhang X., Xu D. 2003. 'Potential Carbon Sequestration in China's Forests.' *Environmental Science & Policy* 6: 421-432.

Endnotes

[1] In 2005, China consumed 30 million out of a total world consumption of 98 million tons of N-fertilizer (in N). Data are from FAOSTAT.

[2] This emission factor is based loosely on IPCC methodology and a number of sources and assumptions that reflect Chinese conditions. Drawing from the NDRC (2004), we use a middle of the road total fuel use estimate of 38 GJ $tNH3^{-1}$ (1,300 kgCE t^{-1} ammonia) for ammonia production. Using rules of thumb for China, we assume that 70% of total feedstock use is coal and 30% is natural gas, and apply IPCC emission factors of 25.8 tC GJ^{-1} and 15.3 tC GJ^{-1}, respectively, to each. We make the simplifying assumption that feedstock use shares are equivalent to total fuel use shares, which likely underestimates emissions, and another simplifying assumption that all N-fertilizer is ammonia based. Using these data and assumptions, we estimate a gross CO_2 emission factor for N-fertilizer of 3.8 tCO_2 tN^{-1}. To account for by-product CO_2 from ammonia synthesis used in urea production, we assume that 100% of urea production uses by-product CO_2 and use the 2005 share of urea in N-fertilizer production (~55%), average urea N content (46%), and the stoichiometric CO_2:NH_2COONH_4 ratio of 0.733 tCO_2 t^{-1} urea to calculate an average by-product CO_2 use factor of 0.88 tCO_2 tN^{-1}. Subtracting this from the total emission factor gives a net CO_2 per unit N estimate of 3.0 tCO_2 tN^{-1}. N_2O emission factors are based on the IPCC's low, default, and high values and a GWP value of 298, which yield CO_2e emission factors of 1.4, 4.7, and 14.0 tCO_2e tN^{-1}, respectively. Combining CO_2 and N_2O emission factors leads to total estimates of 4.4, 7.6, and 17.0 tCO_2e tN^{-1}. Although the CO_2 emission factor should ideally also incorporate uncertainty, uncertainty in total N-fertilizer (CO_2e) emission factors is much more likely to be driven by uncertainty in N_2O emission factors.

[3] In 2005 China used an average of 55 kgN ha^{-1} of agricultural land and 70 gN t^{-1} of total cereal crop yield, whereas the U.S., which has a similar crop profile, used an average of 37 kgN ha^{-1} and 42 gN t^{-1}. These values represent normalized indicators, rather than actual use. Data are from FAOSTAT.

[4] In a 16-village experiment in Guangdong, Hunan, Hubei, and Jiangsu Provinces, Huang et al. (2008) report a 23% reduction in total fertilizer use as part of a training project to encourage farmers to use less fertilizer. Against this estimate, the 30% reduction in the text may seem somewhat high, but over a 20-year period may in fact be realistic

[5] This estimate assumes that farmers use 2 bags of 40 kg N fertilizer (urea at 46% N) on 0.5 ha (8 mu) of land. It is important to note that carbon payments would be unlikely to offset the cost of fertilizer.

[6] In 2007 China had an estimated 121.7 million ha of cultivated land and 2,859 counties, or 42,580 ha per county. At \$10 ha^{-1} payments would be on average \$425,800 per county. Data are from NBS (2009)

[7] Based on IEA (2007).

[8] This estimate assumes a carbon content for wood of 0.45 and a combustion efficiency of 0.9. Methane (CH_4) and nitrous oxide (N_2O) emission factors and global warming potential (GWP) values are from the IPCC's 2006 guidelines. Carbon monoxide (CO) and non-methane hydrocarbon (NMHC) emission factors and GWP values are from Smith et al (2000). Black and organic carbon emission factors are from Cao et al (2006). Black and organic carbon GWP values are from Bond et al (2004). The upper bound assumes that 20% of all wood energy harvesting is unsustainable (i.e. annual harvesting exceeds the annual increment). The lower bound here includes CO, NMHCs, BC, and OC, despite the fact that their contributions to radiative forcing are still highly uncertain. Not including them at all, however, is inaccurate.

[9] According to NBS/NDRC (2009), wood volume and agricultural residue mass used for energy were 181 million m^3 and 372 billion kg, respectively, in 2005. NBS/NDRC (2009) reports wood energy density in 2005 at 16.7 GJ m^{-3}, which, at reasonable values for wood heating values, gives a wood density greater than 1 ton m^{-3}. Given that a significant amount of wood energy use in rural areas of China consists of young pine, such a high density value is not realistic, and we convert wood volume to mass using a more modest value of 500 kg m^{-3}. This conversion leads to a total mass of wood energy of 90 billion kg in 2005. As Yan et al. (2006) summarize, official crop residue energy statistics are likely overestimated by a factor of around 2, and we scale down total residue energy use to 186 billion kg to reflect this. In general, Chinese official wood and crop residue energy use statistics should be treated with caution. Wood use is likely underestimated, while residue use is likely overestimated.

[10] For an excellent discussion of these issues see Sagar and Kartha (2007).

[11] For this calculation, we assume that 30% includes a 15% reduction each in wood and agricultural residue energy use, or 1.4×10^{10} kg of wood and 2.8×10^{10} kg of agricultural residues. For electricity, we assume that the reduction in wood and agricultural residue use comes through increased use of rice cookers. Based on the authors' experience in rural Yunnan, a 500 W rice cooker used for 0.5 hours per day can offset 2 kg of biomass use. Using an estimate of average thermal power plant efficiency of 35% and a national grid emission factor of 0.9 $kgCO_2$ kWh^{-1} and the wood and agricultural residue emission factors above, rice cooker use would lead to a net GHG emission reduction of 0.2-1.6 $kgCO_2$ per kg wood or agricultural residues, or a total emission reduction of 3-22 $MtCO_2e$. We assume that biogas is carbon neutral, which, using the emission factors for wood and agricultural residues, gives its deployment a total GHG emission reduction of 8-26 $MtCO_2e$. For gaseous fuels, we assume that 0.1 kg of LPG can offset 2 kg of biomass use. Using the IPCC's emission factor for LPG (63.1 gCO_2 MJ^{-1}) and the wood and agricultural residue emission factors above, LPG stove use would lead to an emission reduction of 0.4-1.7 $kgCO_2$ per kg wood or agricultural residues, or a total emission reduction of 5-24 $MtCO_2e$.

[12] Costs for electricity and LPG are calculated as the variable (fuel) cost of replacing biomass. Biogas costs are calculated as the annualized digester costs, and assume a digester cost of 5,000 Yuan. Electricity costs here assume an electricity price of 0.45 Yuan kWh^{-1}. LPG costs assume an LPG cost of 5 Yuan per kg. All costs assume an exchange rate of 7 Yuan per US Dollar.

[13] Using an IPCC emission factor of 96.1 gCO_2 MJ^{-1}, a lower heating value of 22 MJ kg^{-1}, and assuming that 1 kg of coal can substitute for 2 kg of biomass, coal has a higher emission factor (2.1 $kgCO_2$ kg^{-1}) than either wood or crop residues.

[15] Emission factors for residue combustion in a stove and in a field will be slightly different, but from Yan et al. (2006) the difference in emission factors is relatively small and this approach allows us to maintain consistency between estimates.

[16] According to NBS/NDRC (2009), wood volume and agricultural residue mass used for energy were 181 million m^3 and 372 billion kg, respectively, in 2005. NBS/NDRC (2009) reports wood energy density in 2005 at 16.7 GJ m^{-3}, which, at reasonable values for wood heating values, gives a wood density greater than 1 ton m^{-3}. Given that a significant amount of wood energy use in rural areas of China consists of young pine, such a high density value is not realistic, and we convert wood volume to mass using a more modest value of 500 kg m^{-3}. This conversion leads to a total mass of wood energy of 90 billion kg in 2005. As Yan et al. (2006) summarize, official crop residue energy statistics are likely overestimated by a factor of around 2, and scale down total residue energy use to 186 billion kg to reflect this. In general, Chinese official wood and crop residue energy use statistics should be treated with caution. Wood use is likely underestimated, while residue use is likely overestimated.

[17] See Yang et al (2008).

[18] See Zhang et al (2008).

[19] The direct GHG emission reduction from reducing burning of agricultural residues is simply half of estimated emissions from residue burning. Fossil fuel offset emission reductions assume that residue combustion is GHG neutral and use a thermal efficiency of 25% and an LHV of 10 GJ t^{-1} for residues. Yan et al. (2006) estimate that total field burning of agricultural residues was 122.1 Tg in 2000; 50% of this is 61 Tg, or 61 million tons, which at the efficiency and LHV above would produce 152.6 PJ_e, or 42,389 GWh , of electricity. At a grid emission factor of 0.9 $kgCO_2$ kWh^{-1}, this leads to a GHG emission reduction of 38.2 tCO_2, which we round to 40 tCO_2.

[20] Feed-in tariff for biomass power is as of 2009. Carbon costs would need to be higher than this to overcome the feedstock cost dilemma. At 0.25 Yuan kWh^{-1} and at a levelized cost of coal of 0.30 Yuan kWh^{-1}, the wholesale rate given to biomass generators would leave roughly 0.20 Yuan kWh^{-1} (0.5 Yuan kWh^{-1} total rate - 0.2 Yuan kWh^{-1} for capital costs - 0.1 Yuan kWh^{-1} for total O&M costs) for feedstock costs, or 240 Yuan t^{-1} (dry) at a LHV for biomass of 12 MJ kg^{-1} and a thermal efficiency of 25%. After accounting for transportation costs, this feedstock price may not be high enough to incentivize farmers. On the other hand, at higher feedstock prices power producers are unlikely to invest in power plants. Carbon revenues could bridge that divide.

[21] In response to several serious haze incidents that, for instance, forced airport closures, in 1999 the State Environmental Protection Agency (SEPA) issued a document "Regulations Supporting Management of Agricultural Residue Burning and Comprehensive Use" that required local governments to develop management plans for agricultural residues (SEPA 1999).

[22] Average grain yields in China were 5.5 t ha^{-1} in 2008, which, at a rule of thumb 0.5 ha per household and a rough average residue crop ratio of 1 for grain crops, leads to 2.7 t hh^{-1} yr^{-1} of residues. A programme that involved 61 Tg (61 Mt) of agricultural residues would require 21.9 million households.

[23] For a more detailed discussion of the challenges to agricultural residue collection, see NREL (2006).

[24] Forests account for roughly half of the world's stock of vegetative carbon (560 GtC) or less than one-fifth of the organic carbon stored in soils (1,500 GtC). Li et al. (2007) estimate SOC storage of 147.9 GtC for China, which is more than 30-fold more than Fang et al.'s (2001) 4.75 GtC estimate of the carbon stored in forest vegetation in China.

[25] For instance, out of a potential of 0.4-1.2 GtC yr^{-1}, Lal (2004) estimates a sequestration potential for cropland soils of 0.4-0.8 GtC yr^{-1} for 20-50 years. Paustian et al. (1998) reach a similar estimate of 0.4-0.9 GtC yr^{-1} for 50-100 years. Lal (2004) argues that 50-66% of historic soil carbon losses can be sequestered.

[26] Data are from FAOSTAT.

[27] For a description of these practices and their global potential, see Smith et al (2008).

[28] Yan et al. (2007) estimate that no-tillage and residue management would lead to a 32.5 MtC yr^{-1} sequestration in agricultural soils for 20-80 years. Lal (2002) estimates that cropland management could lead to sequestration of 25-37 MtC yr^{-1} for 20-25 years.

[29] In 2007 China had an estimated 121.7 million ha of cultivated land (NBS 2009).

[30] From 1950-1985, China's annual average population growth rate was 1.9% yr^{-1}; from 1985-2005 that rate slowed considerably to 1.0% yr^{-1}. The UN predicts that China's population will peak in 2032 at 1.46 billion people, an increase of 147 million people (11%) over 2005 levels (UN 2007).

[31] China accounted for 18% of world grain production and 29% of world meat production in 2004. Data are from FAOSTAT.

[32] See Pan et al (2009).

[33] For instance, because of continued pressures on China's land base, Li et al. (2007) argue that stabilizing the release of carbon from soils is a higher priority than sequestration programmes.

[34] More research is needed on this topic. Many of the SOC enhancing practices listed in the text are labor intensive and time sensitive, which suggests that payments to for agricultural sequestration would need to be sufficient to overcome labor constraints. Assuming two-

[35] Brown et al. (1996) estimate a forest vegetation and soil stock of 987 GtC in the 1980s. The total carbon stored in land vegetation (560 GtC) and as soil organic carbon (1,500 GtC) is around 2060 GtC (Schlesinger, 1997). thirds of the carbon payment actually ends up on the farm, at \$30 tCO_2 and a sequestration rate of 1.0 tCO2 $ha^{-1}yr^{-1}$ carbon payments to farmers would be equivalent to 7 days ha^{-1} of labor at a wage of \$4.29 day^{-1} (30 Yuan day^{-1}). Average farm size in China is around 0.5 ha per household, and 3.5 days of additional labor may be sufficient to implement carbon sequestering practices. Additionally, if these practices are indeed productivity enhancing, then payments to farmers need only be large enough to cover the initial periods where before productivity gains have begun to materialize.

[36] FAO (2005).

[37] Fang et al. (2001) estimate China's forest carbon pool as 4.38-4.75 GtC in the 1980s and 1990s. Brown et al. (1996) estimate a total global forest vegetation pool of 331 GtC during the 1990s.

[38] See note 36 for the source of these estimates. In principle, because China has undertaken extensive AR projects over the past two decades its growing stock should be younger, which might account for some of why standing volume is so low. However, FAO data does not immediately appear to bear this out, as the annual change in growing stock in China between 1990-2000 (0.31 m^3 $ha^{-1}yr^{-1}$) was actually lower than in the U.S. (0.50 m^3 $ha^{-1}yr^{-1}$) over the same time period.

[39] Assuming a dry weight carbon content of 0.45.

[40] This estimate is from Zhang and Xu (2003).

[41] See Kahrl et al (2009).

[42] Based on the total SOC (1,484 GtC) and vegetative carbon (268-901 GtC) estimates used in White et al. (2002), grasslands account for 39% and 26% of the total global pools of SOC and vegetative carbon, respectively. Aggregate estimates in the text are from Schlesinger (1997).

[43] Land use data are from NBS (2009).

[44] There are a range of estimate for the amount of carbon stored in grassland vegetation and soils in China. Ni (2002) reports a total storage of 44.09 GtC, while Ni (2001) and Fang et al. (1996) have more aggressive estimates of 58.38 GtC and 75.91 GtC, respectively. Li et al. (2007) estimate a total SOC pool for China of 147.9 GtC, which, using the Ni (2002) estimate, implies that grasslands account for 28% of China's total SOC stocks. Using a much lower estimate of the total soil carbon stock (89.6 GtC), Xie et al. (2007) estimate that the grasslands (37.7 GtC combined surface and subsurface) account for 42% of the total SOC pool.

[45] Xie et al. (2007) estimate that, while agricultural and forest soils in China have accumulated carbon over the past two decades, grassland soils in China have lost 3.5 PgC over this time period.

[46] This estimate is from Lal (2002).

[47] Sequestration rates here are based on grassland sequestration potential from Lal (2002) and grassland area estimates from Xie et al. (2007).

[48] Data are from NBS (2009).

[49] Sales data are from the 2005 I/O table for China, from NBS (2009).

[50] For more on the funding of extension agencies, see Hu et al (2009).

Who we are

The World Agroforestry Centre is the international leader in the science and practice of integrating 'working trees' on small farms and in rural landscapes. We have invigorated the ancient practice of growing trees on farms, using innovative science for development to transform lives and landscapes.

Our vision

Our Vision is an 'Agroforestry Transformation' in the developing world resulting in a massive increase n the use of working trees on working landscapes by smallholder rural households that helps ensure security in food, nutrition, income, health, shelter and energy and a regenerated environment.

Our mission

Our mission is to advance the science and practice of agroforestry to help realize an 'Agroforestry Transformation' throughout the developing world.

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