Working Paper

China's Bioenergy Future

Through the Lens of Yunnan Province

Fredrich Kahrl, Yan Mei, Su Yufang, Timm Tennigkeit, Andreas Wilkes and David Roland-Holst

Southeast Asia

World Agroforestry Centre
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World Agroforestry Centre
Transforming Lives and Landscapes
ICRAF China, Beijing Office
#12 Zhongguancun Nan Dajie, CAAS Mailbox 195
Beijing 10081
PR China
Tel: +86-10-62119430, fax: +86-10-62119431

ICRAF China, Kunming Office
Centre for Mountain Ecosystem Studies
C/O Kunming Institute of Botany
Heilongtan, Kunming, 650204
PR China
Tel: +86-871-5223014, Fax: +86-871-5216350
Website: http://cmes.kib.ac.cn

ICRAF Southeast Asia Regional Office
Jl. CIFOR, Situ Gede, Sindang Barang, Bogor 16680
PO Box 161, Bogor 16001, Indonesia
Tel: +62 251 625415, fax: +62 251 625416
Email: icraf-indonesia@cgiar.org
ICRAF Southeast Asia website: http://www.worldagroforestrycentre.org/sea

About the authors

Fredrich Kahrl and David Roland-Holst are energy economists with a research interest on climate change economics and regional economic development in China
Center for Energy, Resources, and Economic Sustainability (CERES).
University of California at Berkeley
337 Giannini Hall, Berkeley, CA 94720, USA
EM: dwrh@are.berkeley.edu

Su Yufang, Yan Mei and Timm Tennigkeit are working on carbon finance and rural bioenergy issues at CMES, a joint research centre between the Chinese Academy of Sciences and the World Agroforestry Centre (ICRAF), Kenya, hosted by Kunming Institute of Botany.
Centre for Mountain Ecosystem Studies
c/o Kunming Institute of Botany
Heilongtan, Kunming, 650204
PR China
Tel: +86-871-5223014, fax: +86-871-5216350
Website: http://cmes.kib.ac.cn
EM: timm@mail.kib.ac.cn

Andreas Wilkes is senior specialist in climate change adaptation at ICRAF-China.
ICRAF China, Beijing Office
#12 Zhongguancun Nan Dajie, CAAS Mailbox 195
Beijing 10081 PR China
Tel: +86-10-62119430, fax: +86-10-62119431
Website:http://www.chinaagroforestry. org
EM: a.wilkes@cgiar.org

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Abstract

Few issues are as cross-cutting as biomass-based energy ("bioenergy"). Bioenergy involves rural livelihoods and development; indoor air quality and human health; conservation and commercial forestry; agricultural productivity; climate change mitigation and adaptation; and energy and timber security. As the world's largest consumer of bioenergy, China is in a long transitional phase between "traditional" and modern bioenergy use. Reducing the impacts of traditional bioenergy use, while setting the organizational, market, and technological grounds for modern bioenergy, is an important national policy priority. Globally, the direction of China's bioenergy future could have significant implications for efforts to mitigate climate change.

This paper examines China's bioenergy future through the lens of Yunnan Province, a province in the country's southwest region. The paper provides an overview of the status of bioenergy in China and Yunnan Province, highlights past successes, examines current challenges, and offers recommendations on future strategies to improve the effectiveness and efficiency of bioenergy-related policy and programmatic interventions.

Key Words: China, Bioenergy, Biomass, Improved Stoves, Biogas, Biofuels, Climate Policy

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Few issues are as cross-cutting as biomass-based energy ("bioenergy"). Bioenergy involves rural livelihoods and development; indoor air quality and public health; conservation and commercial forestry; agricultural productivity; climate change mitigation and adaptation; and energy and timber security. It spans both age-old and modern energy conversion technologies, is the main energy source for about one-third of the world's population,[1] and will be critical to sustainable development across the developing world.[2] As the world's largest bioenergy consumer, bioenergy will be an important part of China's demographic, energy, and environmental transitions.

Rural energy, and by extension bioenergy, has been an important policy issue in China since the early 1980s. The scale and speed of the Chinese government's efforts to disseminate improved stoves and biogas digesters in and extend electricity access to rural areas are unparalleled in both the developing and the developed world. More recently, the scale of modern bioenergy in China has grown rapidly with government targets and support for liquid biofuels, biomass power, and centralized biomass-based heating. Despite achievements, significant challenges remain. Determining whether, where, and how much to intervene in addressing these challenges will be a key policy consideration for governments at all levels in China over the next decade.

This paper examines China's bioenergy future through the lens of Yunnan Province, a province in the country's southwest with high dependence on biomass for rural energy and high modern bioenergy potential. The paper provides an overview of the status of bioenergy in China and Yunnan Province, highlights past successes, examines current challenges, and offers recommendations on future strategies to improve the effectiveness and efficiency of bioenergy-related interventions.

Key Messages

- As the world's largest bioenergy consumer, China is in a long transitional phase between "traditional" and modern bioenergy use. Reducing the impacts of traditional bioenergy use, while setting the organizational, market, and technological grounds for modern bioenergy, is an important policy priority.

- Thus far, China has had remarkable success in disseminating improved stoves and biogas digesters, and in extending electricity services. China undertook by far the world's largest improved stove program over the 1980s and 1990s, accounts for most of the world's household-scale biogas digesters, and has electrification rates that exceed those in many middle income countries. China is also actively supporting the development of modern bioenergy, with demonstration and commercial projects that produce biomass power, centralized biomass heating, and liquid biofuels.

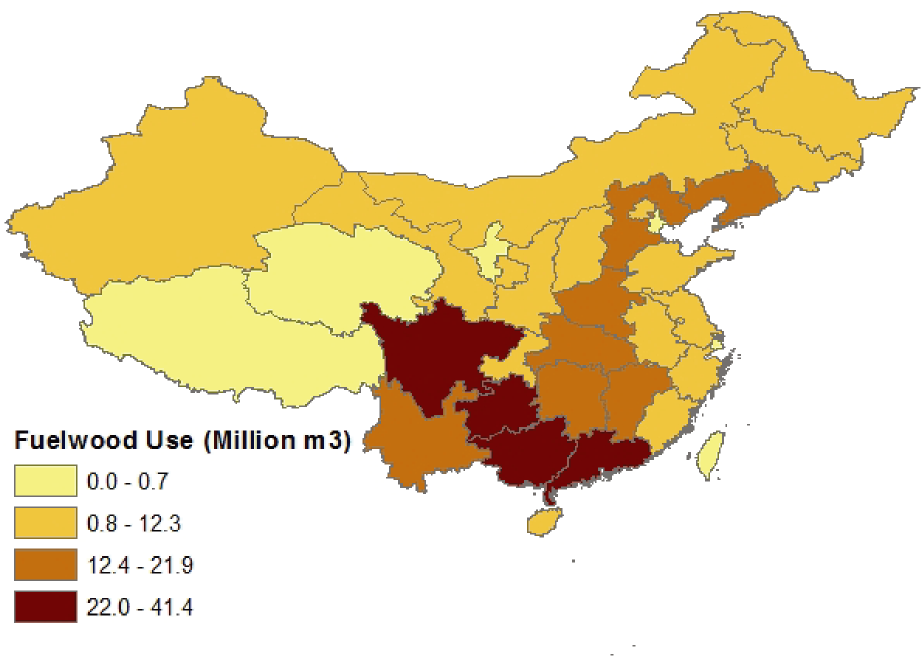
- China faces a number of challenges in reducing the impacts of traditional bioenergy use and developing viable business models for modern bioenergy. Major challenges include: low on-the-ground performance of some bioenergy technologies; a historical emphasis on quantity rather than quality in public sector implementation of bioenergy programs; and the lack of a framework for evaluating the potential positive and negative impacts of different bioenergy-related policy choices.

- We describe three specific actions that can improve the foundation for bioenergy-related policymaking: Improving the information base on which decisions are made; developing a decision-making framework that allows policymakers to evaluate, for instance, socioeconomic and environmental trade-offs; and greater attention to the design and support of self-sustaining markets for energy technologies in rural areas.

- We identify five main research priorities for advancing a bioenergy agenda in China, including research on: demographic shifts and economic, energy, and environmental changes in rural China; rural energy technology adoption and use; rural and bioenergy technology comparisons; the economics of modern bioenergy; and rural carbon balances.

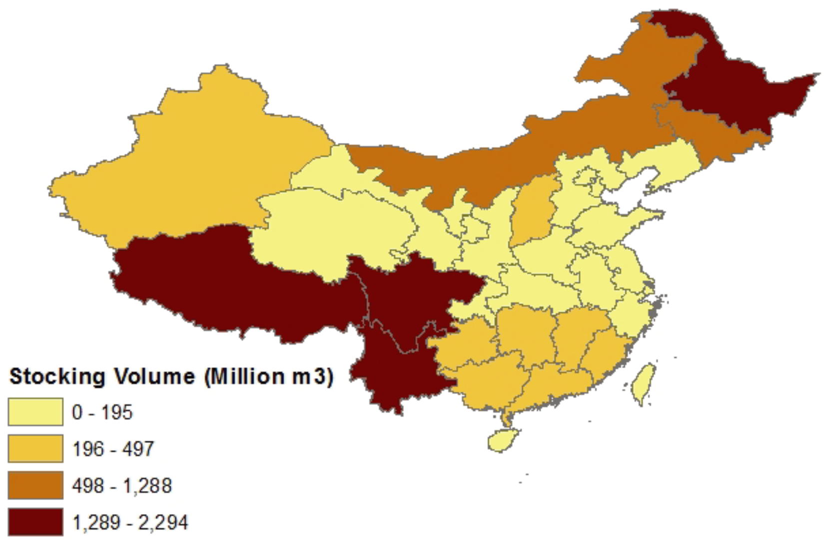
Bioenergy in China and Yunnan Province

China is the world's largest user of bioenergy, accounting for an estimated 20 percent of global bioenergy consumption in 2005.[3] The vast majority of China's bioenergy is used for cooking and heating in rural areas, where it is the dominant source of energy (70 percent of residential energy in 2005)[4] and is often burned in low efficiency stoves in what is commonly referred to as "traditional" biomass use. Because of the sheer number of people who live in rural China (737.4 million, 56 percent of China's total population in 2006),[5] bioenergy is also a significant part of the country's total energy supply (11-13 percent in 2005).[6] Yunnan Province is part of a group of provinces in Southern China that have among both the highest fuelwood consumption and the largest volume of forest in China (Maps 1 and 2). Bioenergy plays an important role in Yunnan, representing 71 percent of rural residential energy consumption and 13 percent of the province's total primary energy consumption in 2005. [7]



Map 1. Fuelwood Use in China, 2006

Source: Data are from the Department of Industry and Transport Statistics, National Bureau of Statistics, and National Development and Reform Commission Energy Bureau, 2008, China Energy Statistical Yearbook 2007, Beijing: China Statistics Press.



Map 2. Stocking Volume of Forests in China, 2006

Source: Data are from the National Bureau of Statistics, 2008, China Statistical Yearbook 2007, Beijing: China Statistics Press.

Bioenergy in China is not synonymous with rural fuelwood use. Instead, agricultural residues (e.g., corn stover, rice husks) are the dominant source of bioenergy for many rural households in China, reportedly accounting for more than 60 percent of total residential bioenergy use in 2006 (Figure 1). High consumption of agricultural residues is, however, limited to major agricultural producing areas; five provinces account for 43 percent of agricultural residue consumption. In Yunnan, wood is the larger source of rural bioenergy consumption and fuelwood will often be a focus in this paper.

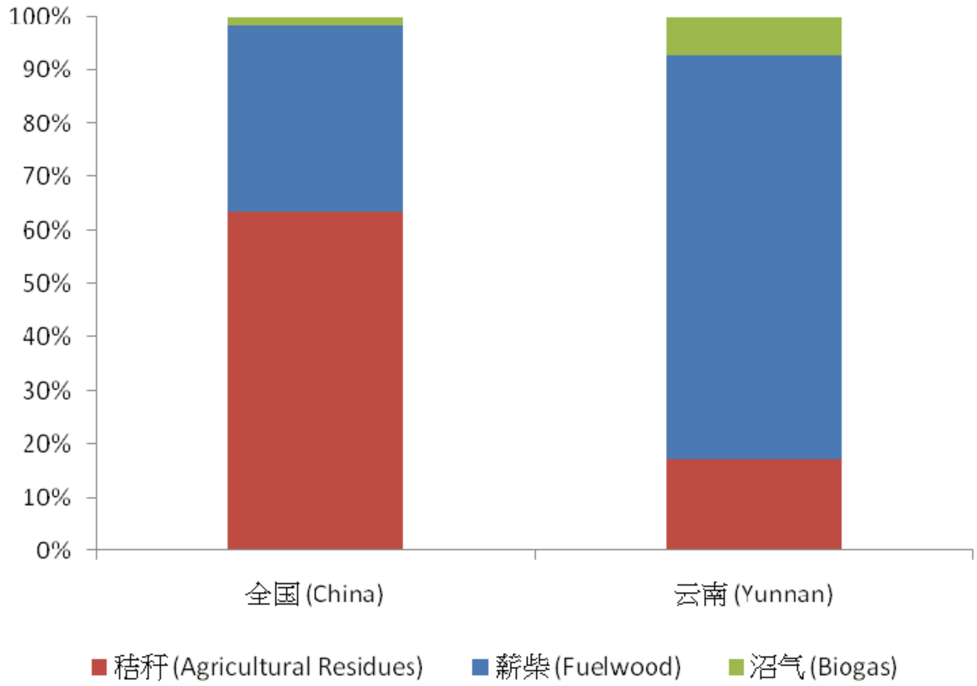


Figure 1. Shares of Household Bioenergy Consumption, China and Yunnan, 2006

Source: Data are from the Department of Industry and Transport Statistics, National Bureau of Statistics, and National Development and Reform Commission Energy Bureau, 2008, China Energy Statistical Yearbook 2007, Beijing: China Statistics Press.

Traditional bioenergy use is a major development challenge for all of China.[9] Supply-side concerns include impacts on human health, productivity, ecosystems, and climate. The World Health Organization estimates that indoor air pollution from solid fuel combustion, both coal and biomass, causes 420,000 premature deaths annually in China,[10] 40 percent more than exposure to outdoor air pollution[11] and on the order of a mid-size European city. Fuelwood collection, often done by women and children, represents a substantial time commitment for rural households. In Yunnan fuelwood collection requires an estimated average of 3 hours per trip, often more than more than 1 trip per day, for an average of 50 days per year.[12] High reliance on fuelwood also leads to localized deforestation in some parts of China, although the full extent of this problem is unknown. Regardless of the sustainability of biomass harvesting, greenhouse gas (GHG) emissions from the incomplete combustion of biomass are likely to be substantial,[14] but the magnitude of these emissions has yet to be formally estimated for China.

Traditional bioenergy use also has a high opportunity cost in China, particularly in terms of timber, carbon, and commercial energy. At least part of the driving force behind the 5-fold increase in China's timber imports[15] over the past decade has been low forest productivity; the UN Food and Agricultural Organization (FAO) estimates that China's mean stocking density (67 m^3/ha) is significantly lower than averaged estimates for Asia (82 m^3/ha) and the world (110 m^3/ha).[16] Improving forest management is a priority both for increasing timber supplies, but also carbon stocks. China's forests currently store an estimated 4.3 GtC;[17] increasing average stocking densities to Asian or global levels would allow for another 1-3 GtC. Lastly, commercial bioenergy has the potential to play a major role as a domestically produced, low net carbon energy source in China. Theoretically available bioenergy in China has been estimated at 12.1 exajoules (EJ),[18,19] or roughly 15 percent of its 2006 primary energy consumption (80.4 EJ).[20]

Changes in bioenergy use in China will be part of the country's tremendous structural transition in demographics, energy systems, and agriculture and forestry that has been underway for more than two decades and is set to continue. However, reducing the negative impacts and increasing the value of biomass use will require strategic interventions to ensure that these changes in bioenergy use enhance the quality of life in rural areas, raise agricultural and forest productivity, improve energy security, and lead to a model of low carbon rural development that both developed and developing countries can emulate. China and Yunnan have had several successful such interventions in the past, but bioenergy continues to be a major challenge throughout China. Moving forward, new thinking is needed to guide China's bioenergy future.

Past Successes

Over the past three decades, the Chinese central government has achieved major successes in developing and disseminating energy technologies in rural areas, particularly improved stoves, biogas, and electricity. In response to concerns over rural energy security, in the early 1980s the central government officially began the world's most successful stove replacement effort, the National Improved Stove Program (NISP), which had disseminated improved stoves (Figure 2) to approximately 150 million households by the end of the 1990s.[21,22,23] In Yunnan, an estimated 6-7 million households had received and were using improved stoves by 2006,[24] equivalent to roughly 75-80 percent of the province's rural households.[25] Within villages, adoption rates are highly variable, depending on, among other factors, whether households are able to remodel their kitchens.[26]

Figure 2. An Improved Stove in Yunnan Province

Notes: There are in fact a variety of "improved stoves" in China. This particular stove illustrates three of the six main improvements over older stoves: a chimney, a smaller feeding door, and a means to heat water while cooking (above the bucket). In addition, improved stoves are equipped with a grate for improving combustion and heat transfer, have larger combustion chambers, and are better insulated than older stoves.

The Chinese central government has actively promoted household-scale anaerobic digesters since the 1950s, but early efforts to disseminate digesters had only mixed success and a more effective biogas program did not coalesce until the 1990s. Building on more than a decade of intensive research and extension, the number of households with biogas digesters in China rose from 7 million in 1980 to 18 million in 2005;[27] in Yunnan their numbers rose from 68,000 in 1990 to 1.7 million by 2006.[28] To put these numbers in context, by one estimate China accounted for 80 percent of the world's household-scale biogas digesters in 2006.[29] For China as a whole, about 8 percent of rural households had a biogas digester in 2005; in Yunnan, roughly 20 percent of rural households had a digester in 2006.[30]

Although not explicitly a biomass-based energy source, electricity is also an important part of bioenergy considerations in China because it is a direct substitute for many tasks currently carried out using bioenergy, such as steaming rice (rice cooker), cooking food (electric stove), and space heating (electric heater). Here, too, the speed and scale of China's efforts are without precedent. From 1949 to 1999, China extended electricity services to more than 900 million rural residents, reaching more than 98 percent of all households by 1999.[31] Yunnan's efforts have been no less prodigious, particularly during the past decade. From 1998-2005, the share of rural households with electricity access increased from 85 percent to 96 percent; more than 99 percent of Yunnan's villages had electricity access, an increase from 92 percent in 1998. [32]

China has been conducting research, development, and demonstration with biomass gasification, power generation, and biochemical conversion technologies since the 1980s.[33] As of 2004, there were 525 village-level biomass gasifier facilities (in the ten to hundred kilowatt range) in China, producing enough gas to meet the basic needs of more than 325,000 households.[34] Yunnan currently has 7 biomass gasifiers that provide centralized heating to 1,768 rural households.[35] China had about 2 GW of biomass power generation capacity in 2007, most of which comprised combined heat and power (CHP) plants in the sugarcane industry but with an increasing number of power plants using agricultural residues.[36] China had been the world's third largest ethanol producer before the central government's moratorium on grain-based ethanol in December 2006, but promoting non-grain biofuels and research on cellulosic ethanol remain a priority. Because of its lack of oil refining capacity and rich biological resources, Yunnan has been conducting research on ethanol since the 1980s and has actively supported a biofuels industry since 2006. [37]

Current Challenges

Despite dramatic accomplishments over the past three decades, bioenergy continues to be a major challenge for both Yunnan and China as a whole. This challenge now extends along two fronts. The first front involves the challenge of continued household use of traditional bioenergy and attempts to incentivize households to use newer fuels and technologies that reduce the health, socioeconomic, and environmental impacts of inefficient biomass combustion. The second front involves the challenge of developing modern bioenergy as a potential source of both rural and urban energy in an economically, environmentally, and socially sustainable manner.

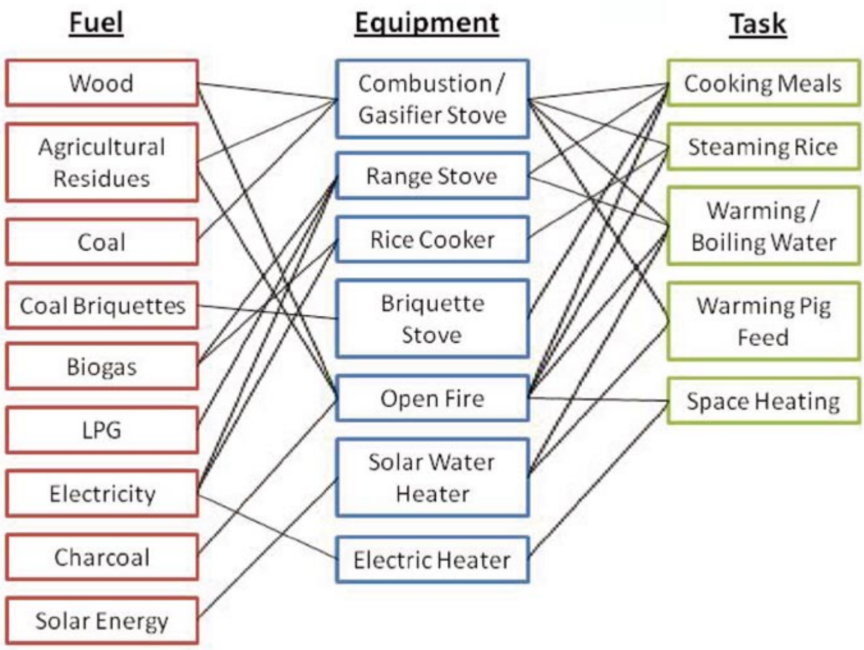


Figure 3. Fuels, Energy Equipment, and Energy-related Cooking and Heating Tasks in Rural Yunnan

Energy substitution in rural China is exceedingly complex and task-specific, as Figure 3 shows. Indeed, as more choices have evolved this picture has become more complicated. Households with biogas digesters, for instance, may reduce their consumption of fuelwood for cooking non-grain foods, but will often still cook rice on an improved stove or open fire if they do not have a biogas-powered rice cooker. There are generally three ways in which traditional bioenergy consumption in rural areas can be reduced:

1) fuel switching to alternative fuel sources;
2) upgrading to more efficient equipment; and
3) reducing energy-using tasks, or the energy needed per task.

Adoption of an LPG stove, for instance, can displace the wood needed to cook meals. Adoption of a more efficient stove can reduce the amount of bioenergy needed for all food-based tasks. Adoption of new variety pigs can obviate the need for warming pig feed, which can significantly reduce overall household energy consumption. As a rule, using newer fuels, and particularly electricity, requires task-specific equipment. Rice cookers are not used to boil water for tea, for instance. Of all "equipment," the open fire is the most versatile, both in terms of backward (fuel) and forward (tasks) linkages. It is also the most inefficient and deleterious to human health. These linkages define both the feasibility and ultimate impact of rural energy-related interventions.

Three problems are central to the past and current implementation of China's bioenergy and other rural energy interventions. First, technologies have in many cases performed below expectations, which, in turn, means that the benefits of interventions were less than was originally anticipated. Second, the historical emphasis on quantity rather than quality and on "task completion" by government agencies was and continues to be a barrier to more effective interventions. Third, there has been and is currently no framework at a sub-national level to evaluate the costs and benefits of different energy and energy-related interventions. China and Yunnan's experience with stoves, biogas, electricity, and modern bioenergy all reflect these issues.

Stoves

Although the NISP has likely led to a dramatic improvement in rural health and environment in China, it is only a first step. The improved stoves disseminated as part of the NISP (known collectively as "grate stoves" [Ch: lutiao zao]) often do not operate at the 20-30 percent thermal efficiencies that the program originally envisioned,[38] both because of construction inadequacies and normal wear on the construction materials. In addition, the national standard for evaluating the efficiency of NISP stoves was only 18 percent,[39] and it is perhaps unreasonable to expect thermal efficiencies significantly in excess of that standard. Even an increase to 18 percent thermal efficiency could still represent an improvement over pre-NISP stoves (10-15 percent efficiency).[40] China's reported mean annual fuelwood consumption per rural household decreased by an estimated 20 percent from 1979 to 2006 (Figure 4), but because the number of households in rural China is increasing[41] it is not clear if and to what extent the NISP has actually reduced total biomass energy consumption (Figure 5).

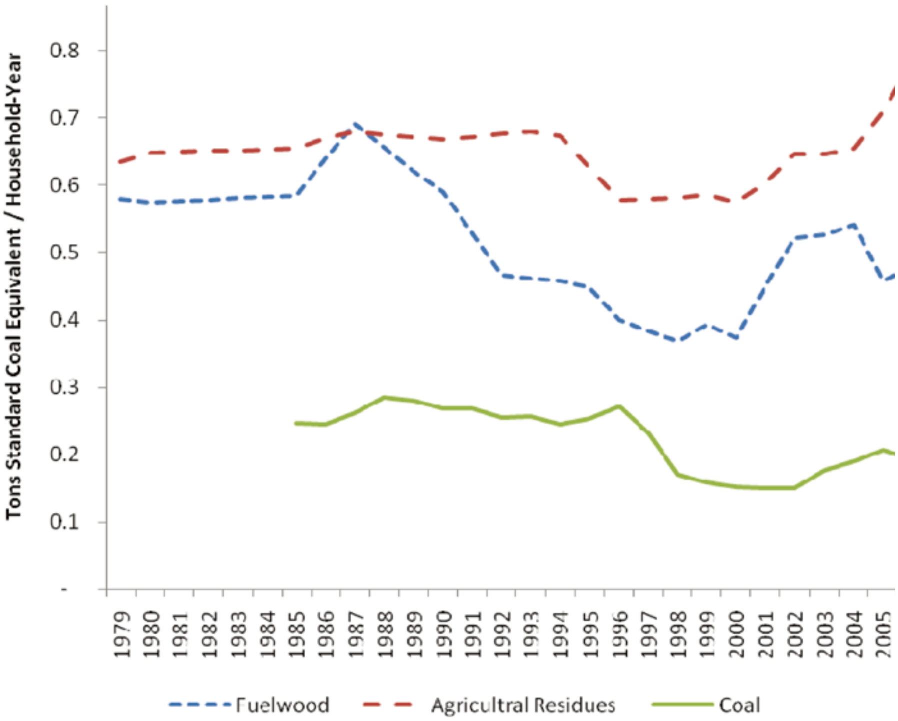


Figure 4. Per Household Consumption of Fuelwood, Agricultural Residues, and Coal in Rural China, 1979-2006

Notes and Sources: These data should be interpreted with caution. We provide a more extensive explanation and critique of the data in the endnotes.[42] Data for 1979, 1980, 1985, 1987, and 1990-1996 are from the China Energy Databook; data from 1998-2006 are from the China Energy Statistical Yearbook. Missing data were filled in by assuming constant annual average growth rates. Demography — that rural household size has declined faster than rural population — plays an obvious role in the above figure, and we discuss these trends in greater detail in the endnote.

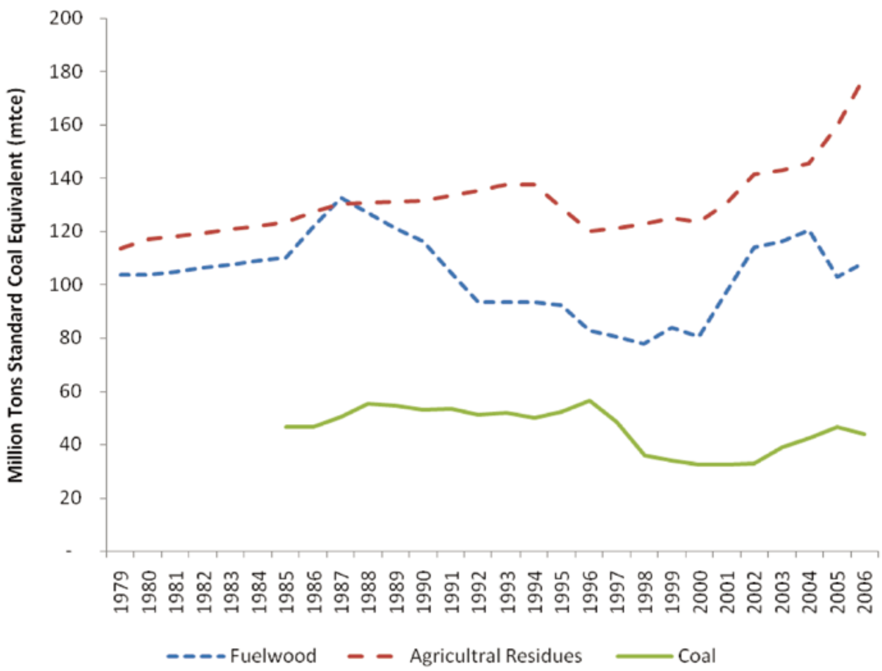


Figure 5. Total Consumption of Fuelwood, Agricultural Residues, and Coal in Rural China, 1979-2006

Sources: See Figure 4.

An additional consideration in evaluating the scope of NISP effectiveness is that the stoves replaced by NISP stoves represent only part of household bioenergy consumption. Households are often specialized in their use of energy technologies. For instance, many households in China use an open fire for space heating, heating water, steaming smaller amounts of rice, and cooking smaller meals. In some areas of Yunnan, this open fire can account for as much as half of a household's annual bioenergy consumption.[43] Open fires are notoriously inefficient and polluting because they have poor heat transfer and no exhaust, but because of their convenience and cultural significance they are more difficult than larger-scale stoves to replace. Even with NISP stoves, indoor air quality remains a problem; particulate matter pollution with NISP stoves is still as much as twice as high as national standards for indoor air allow. [44]

Newer combustion and gasifier stoves can achieve much higher efficiencies than the NISP improved stoves, with reported efficiencies between 30-50 percent,[45] though these newer stoves have yet to be more rigorously tested in the field. High efficiency stoves are comparatively inexpensive, at roughly 350-450 yuan per stove,[46] which in many areas of Yunnan is equivalent to about 5-10 percent of annual household income.[47] However, these stoves suffer from the key drawback that their adoption will not accompany kitchen redesign, and integrating them into kitchens in a way that would replace either a significant portion of NISP stove or open fire use may require stove design tailored to at least regional conditions. One complaint about new stoves in northwest Yunnan, for instance, is that gasifier stoves are not designed to accommodate typical cooking pot size.[48] Additionally, the indoor air quality impacts of gasifier stoves have not been adequately tested in the field.

Finally, many households in Yunnan do not have an apparent economic incentive to buy new stoves, because:

- households often do not pay for fuelwood or agricultural residues;
- fuelwood collection, largely by women and children, has a low perceived opportunity cost;
- poor indoor air quality is not currently perceived to have economic consequences;
- household timber management is not optimized and, even if it were, timber production is constrained by a logging quota system (cutting trees for fuelwood is generally not); and
- households are not paid either for reducing GHG emissions associated with biomass combustion or for increasing carbon sequestered in forest landscapes.

The Yunnan Provincial government has set a target of achieving stove efficiencies of 30 percent,[49] but achieving an average efficiency of 30 percent across all stoves would likely require either replacing some of the NISP stoves with higher efficiencies stoves or increasing the efficiency of existing stoves through, for instance, replacing and improving insulation.

Biogas

During the 1970s and 1980s, China's biogas program was plagued by an overemphasis on quantity at the expense of quality.[50] Digester quality was poor, and households often prematurely abandoned them. By one estimate, in 1986 more digesters were discarded (400,000) than built (350,000).[51] Although significant progress has been made in addressing quality concerns, problems with underuse and disuse persist. In Yunnan, for instance, households in many cases build the digester themselves because of the labor cost savings, and are often not provided any training on how to manage the manure feedstock.[52] As a result, digesters can leak and, even when well built, may not produce sufficient biogas to meet cooking needs. Leaky biogas digesters are potentially a net source of methane (a GHG with a global warming potential 21 times higher than CO_2) emissions because microbes in anaerobic digesters convert manure that might have decomposed aerobically without emissions into a more highly concentrated methane gas[53] that is emitted into the atmosphere. The scale of this problem in China is unknown.

Biogas production is also tied to livestock commodity cycles. When pork prices in particular are high, farmers raise more pigs, which increases the manure available for producing biogas. When pork prices are low, farmers raise fewer pigs and may not have enough manure to make managing their digester worthwhile. Household labor also plays an important role in biogas production. Smaller households and households with several family members that work seasonally off-farm may discover that they do not have the labor resources to maintain a digester. Maintenance problems may become even more widespread as more households participate in the wage labor force. A final consideration for biogas is its longer-term attractiveness to rural residents. There is at least some evidence in China's coastal areas that biogas is seen as an inferior good once incomes reach a certain level.[54]

Many of the concerns over biogas can be narrowed down to questions of cost-effectiveness. In Yunnan a new digester reportedly costs 3,000 yuan. Of this, the central government provides a 1,000 yuan subsidy, county governments provide a 500 yuan subsidy, and households pay the remaining 1,500 yuan.[55] Based on the authors' experience, for working biogas digesters the costs can often be much higher. For the central government and local governments, the cost-effectiveness of this investment depends on its benefits. If a significant portion of digesters are underused or unused, these benefits become more expensive. For instance, in Yunnan biogas digesters are assumed to reduce fuelwood consumption by 2-3 tons per household per year,[56] equivalent to about 1.5-2.2 m^3 of biogas per day (530-800 m^3/year) per digester.[57] Based on this assumption, each digester would increase the stocking volume of forests in Yunnan by 5-7 m^3 per year, at a cost of 200-300 yuan per m^3 (US\$39-58/tCO_2) of forest biomass.[58] If, hypothetically, 20 percent of the digesters in Yunnan are not producing any biogas and another 20 percent are producing only half of the above amount (i.e., 267-400 m^3/year), the average cost of increasing forest biomass via biogas would rise to 233-350 yuan per m^3 (US\$45-68/tCO_2) of forest biomass. In other words, non-performing biogas digesters dilute the benefits of well functioning digesters.

For households, determining cost-effectiveness is even more difficult. Researchers often impute a value on estimated fuelwood and fertilizer savings to determine payback periods. However, in many areas of China, including Yunnan, households often do not pay cash for fuelwood and commercial fertilizer use is not necessarily determined by the amount of organic fertilizer available. In these cases, the benefits of biogas, such as improved indoor air quality, may be more subtle. For households with well functioning biogas digesters, biogas clearly decreases fuelwood consumption, but it is unclear by how much. For households that only have a biogas range stove, the only two tasks where biogas offsets fuelwood are typically cooking meals and, to a lesser extent, heating water; for households with a biogas-powered rice cooker, fuelwood reductions are more substantial.

Electricity

Although physical electricity access is no longer a constraint for many households, actual use of electricity in many parts of China, including Yunnan Province, remains low. Electricity can be a significant portion of household expenditures, particularly in areas where electricity prices remain high. Standard rates in villages in Yunnan that have undergone an upgrade to their distribution lines are typically in the 0.4-0.5 yuan (US\$0.06-0.07) per kilowatt-hour (kWh) range, but in places that have not had the upgrade electricity prices can be as high as 0.8-0.9 yuan (US\$0.11-0.12) per kWh. Rural households in China are highly sensitive to price; all other things being equal, at higher electricity prices households consume less electricity.

Once households have electricity access, electricity can be a fairly immediate substitute for bioenergy, particularly with rice cookers. In many parts of China, rice cookers are often the third item on the "appliance ladder" (after light bulbs and a television). In Yunnan, we estimate that rice cooker adoption across rural households is, on average, around 60 percent, but in poorer villages can be as low as 20-30 percent.[59] Moreover, in poorer areas many households only use a rice cooker during the agricultural busy season, when it becomes a time saving device. At 0.8 yuan per kWh, the cost of using a 750-watt (W) rice cooker once a day every day over the course of a year would be about 110 yuan (US$15). The rice cooker itself costs about 100 yuan (US$14). [60]

Depending on local conditions, cooking rice typically requires 1-2 kg of fuelwood in Yunnan, which makes the rice cooker about 3-5 times more efficient in terms of primary energy use than the improved stove.[61] Importantly, part of this efficiency is due to the fact that rice cookers are inherently more thermally efficient than stoves, but a second reason for the rice cooker's higher efficiency is that it is more precise. Stove users are likely to over- rather than underestimate the amount of fuelwood required for a given task, whereas even the simplest rice cooker powers down once all the water has boiled off. If all of Yunnan's 8.2 million rural households used a 750 W rice cooker once a day, the electricity required (1.1 TWh) would be equivalent to only 1.7 percent of Yunnan's total 2006 electricity demand (64.6 TWh); the increase in CO_2 emissions (1.1 mmtCO_2) would be proportional and could in fact be net negative if fuelwood harvesting is currently unsustainable.[62]

This example is only meant to be illustrative; there are certainly trade-offs involved in transitioning more household uses of energy to electricity. The challenge is to understand these tradeoffs and their potential costs and benefits. In one village in Yunnan Province, for instance, villagers were subsidized with lower electricity prices (0.2 yuan per kWh) in exchange for a cessation of all wood harvesting to protect a nearby reservoir. Average daily household electricity consumption in this village (450 kWh) is higher than the average for urban China (350 kWh).[63]

Commercial Bioenergy

Both China and Yunnan's efforts to commercialize bioenergy have recently run up against significant obstacles. Centralized gasifier heating systems have proved expensive and difficult to justify at a larger scale. Biomass power production has faced difficulty securing feedstocks. Across the world, liquid biofuels have become more ambiguous in their ratio of costs and benefits, both through their direct competition with food production and concerns over their actual climate benefits as a result of induced land use change.[64] However, for heat, power production, and liquid fuels bioenergy could be an important part of China's longer-term commercial primary energy supply. OECD countries have only recently begun to explore the question of how to make better use of biomass residues. For China, the challenge is to time the larger-scale commercialization of bioenergy with the country's demographic and agricultural transitions.

Gasification technologies have made significant strides over the past two decades, but are still technologically immature and expensive compared with combustion technologies.[65] In China, gasification facilities with current technologies require either high willingness to pay or significant household coverage to recover costs[66] and justify larger-scale dissemination. Capital costs for village-level gasifiers are relatively high, of which the pipe infrastructure can be as high as 60 percent of total capital costs.[67] Although capital costs (by one estimate, 2,000 yuan per household) are generally not thought to be at a level that rural households can afford, financing (typical terms in Yunnan would be 3 years at 8 percent interest) could help to lower the cost threshold. Operating costs (for instance, at 100 yuan per household per year) are also currently out of range for most households, particularly in areas where gas would substitute for a "free" biomass resource.

A significant portion of China's non-bagasse residue-based power production has occurred in high agricultural producing provinces, primarily Shandong Province, the northeast region (Heilongjiang, Liaoning, and Jilin Provinces), and Sichuan Province. In these regions, the mechanization of agriculture has led to a surplus of agricultural residues that were once used to, for instance, feed draft animals. As this transition occurred, many farmers began to burn larger amounts of excess residues back into the soil, leading to a pollution problem and prompting the central government to require provinces to develop utilization plans,[68] one of which was smaller scale (< 50 MW) electricity generation. However, power plants have in many cases run into a trade-off between scale and power cycle efficiency gains, and the increased logistical complexity and cost of securing adequate feedstocks as power plant capacity gets larger. Co-firing biomass with coal remains a possibility in China, but would require government support. Going forward, more research is required to assess:

- Current availability — how much biomass from agricultural residues is economically available for energy production;
- Potential availability — how the availability of agricultural residues might change with changes in both agricultural and livestock production practices; and
- Impacts — how removing a greater share of agricultural residues from the field will affect productivity and carbon storage.

The future of liquid biofuels as a petroleum product substitute in China is uncertain. Although there are still plans to expand the land area dedicated to non-grain (mainly yam-, cassava-, and sweet potato-based) ethanol in China, it is not clear whether non-grain feedstocks can contribute to a meaningful blend of China's gasoline supplies. Experience with cassava at a major ethanol refining facility in Guangxi suggests that securing cost-effective feedstocks will be a difficult challenge; cassava feedstock prices rose from 300 yuan per ton in 2006 to 600-700 yuan per ton in 2008.[69] Plans for biodiesel are equally uncertain. Biodiesel feedstocks, such as Jatropha curcas, have not shown signs of being commercially viable without substantial subsidies from the central government. [70]

For both biomass power and liquid biofuels, an overarching concern is their potential to create conflicts between urban and rural needs for biomass and, indirectly, for land. In the case of heat and power, agricultural and forest residues are not competitive with rural production needs only to the extent that they use biomass resources that are truly "unused." For liquid biofuels, competition is more likely to be land- rather than resource-based. In both cases, it is difficult to determine more precisely what portion of rural biomass is available for modern bioenergy production. Without safeguards in place to regulate this reallocation of biomass, competition between rural production needs and commercial bioenergy has the potential to impact rural livelihoods and agricultural and forest productivity.

Future Strategies

Biomass-based energy will continue to play an important role in China and Yunnan's future through its links to public health, agricultural productivity, timber security, energy security, modern biofuels, and environmental impacts. Although many of the changes that shape rural China over the next 20 years will be driven by larger socio-economic forces, effective interventions focused around bioenergy could help to improve rural livelihoods, further agricultural and forest productivity, enhance energy and timber security, and meet environmental goals.

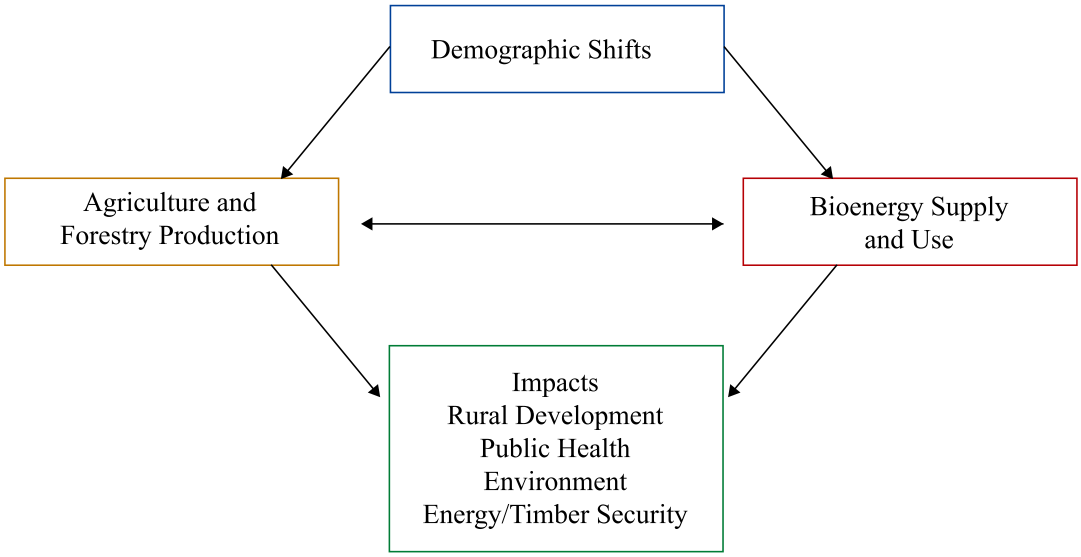


Figure 6. Linkages Among Demographic Shifts, Bioenergy Supply and Use, Agriculture and Forest Production, and Socioeconomic and Environmental Impacts

Note: All of these interactions are mediated by both government policies and market forces; although government projects have been the larger driver historically, increasingly households and the private sector are directly driving changes in rural demographics, health, production, and environment.

Figure 6 provides a simplified diagram of the linkages among demographic shifts, bioenergy supply and use, agriculture and forest production, and socioeconomic and environmental impacts. Demographic shifts, such as an increase in household land area due to off-farm migration, will have a significant influence on both agriculture and forest production and bioenergy supply and use. Agriculture and forest production and bioenergy supply and use are interrelated; a shift from open-access forestry to commercial or conservation forestry, for instance, would reduce the amount of wood available for use as fuel. This interaction among demographic shifts, agriculture and forest production, and bioenergy supply and use will determine the extent of rural development, public health, environment, and energy/timber security impacts. Managing these impacts will, in turn, require finding effective and efficient points of intervention in bioenergy, agriculture, and forestry.

More effective and efficient interventions will need to be rooted in a stronger institutional foundation. We identify three specific, near-term actions that could strengthen this foundation and have a high return on investment for both China's central government and the Yunnan Provincial government:

- Improving the base of information (the data base) on which rural energy- and land-use related interventions are grounded;
- Building a decision-making framework to evaluate trade-offs among different policy goals; and
- Designing and developing rural markets for energy and energy-related technologies.

Improving the Data Base

An important first step in building a more effective basis for bioenergy focused interventions would be to improve the quantity and quality of information on biomass supply and use. More and better information is needed primarily in three areas: rural energy technology ownership and fuel use; carbon balances, including forest inventories, agricultural residue utilization cycles, and farm-level inventories of the integrated crop-livestock systems that are common in China today; and commercial biofuel yields, costs, and potential business models.

Given the diversity of energy use in rural China, it is incredibly difficult to undertake regular, systematic assessments of bioenergy use in the country's vast rural areas. However, sampling and survey strategies that allow for more meaningful accuracy and representation can improve government agencies' understanding of the relationships among and within the variables highlighted in Figure 6, which would improve the effectiveness and efficiency of interventions.

Similarly, while there is, in theory, significant potential in China for carbon finance to reduce the socioeconomic, health, and environmental impacts of rural energy and land use, accounting methods and inventories specific to China have not been developed to either assess potential or facilitate carbon finance projects. Forestry in China suffers from a similar problem; reliable, empirically-based estimates for forest growth in different ecological zones and growing conditions are not available. The biofuels industry is perhaps plagued by even greater uncertainty, as a number of biofuel projects have been undertaken without a rigorous analysis of potential costs and benefits.

Making information more widely available is also an important strategy. For instance, raising awareness among rural households of the dangers of cooking with solid fuels could provide substantial benefits, but there is little understanding of how information might change behavior as incomes rise, and what kind of information campaigns are most effective. Information provision could be a relatively simple and extremely cost-effective means of reducing health burdens from indoor air pollution, but it is important that information be accompanied with greater choice in rural energy technologies.

Information development and analysis is particularly important at a sub-national level. For the Yunnan Provincial government, for instance, developing the capacity among government agencies and research institutes to collect, manage, and analyze data would be an important foundation for attracting energy and land use projects. Collaboration with domestic universities could help government agencies to develop and build on these skills, and international organizations can similarly help to build capacity among sub-national governments through "soft" technology transfer as part of joint projects.

Building a Decision-making Framework

Bioenergy is associated with a number of policy goals, as disparate as public health and timber supply. Meeting all of these goals together may prove difficult, and ultimately there may be trade-offs among them. For instance, 1,500 yuan subsidies on biogas digesters have a high opportunity cost, and may be at the expense of other, more effective interventions. Consolidation of forest land into professionally managed stands, referred to as 'scale forestry' by China's State Forest Administration, could improve timber supplies, but could also lead to conflicts over property values and produce a negative economic impact on households depending on whether any revenues from leasing land or selling timber can offset the loss of fuelwood supplies. More strategic interventions to achieve the numerous goals related to bioenergy will require a decision-making framework to evaluate and reduce potential trade-offs between these goals.

A strong decision-making framework would help to evaluate the cost-effectiveness, potential social impacts, and potential environmental impacts of different interventions. It would help both the central and local governments to be more technology neutral and targeted in their interventions, and to determine the appropriate scale of subsidies to accelerate adoption of specific technologies. Biogas, for example, is probably more appropriate for some areas and some households more than others, but without a better understanding of its benefits and costs in different areas vis-à-vis alternatives, it is difficult to determine a reasonable scale and strategy for offering subsidies.

Designing and Developing Markets

While strategic government interventions can help to accelerate the process of energy and energy-related technology adoption in rural areas, ultimately the private sector and markets may play a larger role in providing rural households with greater choice in energy services. Large-scale programs like the NISP are unlikely to happen again, nor is it clear that large-scale, national programs would be as effective as they once were because rural China is changing so rapidly.

The contrast between biogas digesters and solar water heaters illustrates the distinction between government-led and market-based approaches to technology dissemination. Biogas digesters are heavily subsidized by central and local governments. Alternatively, the vast majority of solar water heaters are not subsidized, though their cost is on par with biogas digesters. Solar water heaters are not "cost-effective" for many households in a narrower sense; aside from households that use them to pre-heat water for cooking pig feed, solar water heaters represent a new use of energy (i.e., showering more frequently) and a status symbol rather than a savings from reduced fuelwood use. While solar water heaters have post-sales support if they malfunction, biogas digesters do not, and rural households that have dysfunctional biogas digesters have no means to fix them.

This is not to argue against subsidies for rural energy technologies, but rather for a greater role for the market in providing greater choice in, better targeting of, and more support services for rural energy technologies. Rural household biogas systems, for instance, would benefit greatly from post-installation service support, which currently is non-existent. Understanding the lessons of the emergence of markets for solar water heaters could assist in the design of markets for biogas, high efficiency stoves, more efficient electrical appliances, and next generation technologies such as centralized heating.

Research Priorities

In closing, we provide a short list of research priorities that will help to guide bioenergy policymaking in China. In addition to potential health and socioeconomic benefits, research in these areas will support the Chinese central government's goal of increasing carbon sinks while reducing greenhouse gas sources.

- **Demographics Shifts and Economic, Energy, and Environmental Changes in Rural China.** Understanding the implications of demographic shifts in rural China over the next two decades is a critical question for China's health, development, agricultural, forestry, rural energy, and environmental policy. For instance, as the number of farm households declines and average farm size increases, where can government interventions be most successful in achieving policy goals?
- **Rural Energy Technology Adoption and Use.** Improving the effectiveness of rural energy technology interventions will require a more systematic, nuanced understanding of how households in rural China adopt and use energy technologies. Based on this kind of research, public-private partnerships and more sustainable business models can be developed to help expand access to modern energy services.

- **Energy Technology Comparisons.** The number of energy options for most households in rural China has increased dramatically over the past decade, but government support is often still needed. The fledging commercial bioenergy industry similarly cannot sustain itself without government support. Which technologies to support, and how to design this support, remains an open question. For instance, in remote areas of Yunnan that lack electricity, is it more cost-effective to subsidize grid extension, to subsidize off-grid generation, or to develop electricity substitutes? Should China's central government continue to support non-grain starch-based ethanol development in order to create the industrial infrastructure necessary for a biofuels industry, or should it focus its efforts on cellulosic ethanol.
- **Economics of Modern Bioenergy.** Although desk studies have examined the technical potential of modern bioenergy in China, field-based assessments to examine the economic potential of biomass power and heating and liquid biofuels are necessary both to determine the appropriate scale, business models, and necessary social and environmental safeguards for the development of modern bioenergy.
- **Rural Carbon Balances.** Rural China is potentially a huge net carbon sink, but more research is needed to determine the technical and economic potential of that sink, how and at what cost it might be achieved, and how sources and sinks — and particularly energy use, greenhouse gases, and land use — interact and might be shaped in rural China.

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[1] Jose Goldenberg, Amulya K.N. Reddy, Kirk R. Smith, and Robert H. Williams, "Rural Energy in Developing Countries," in United Nations Development Programme, World Energy Assessment: Energy and the Challenge of Sustainability: New York, UNDP.

[2] Ambuj D. Sagar and Sivan Kartha, 2007, "Bioenergy and Sustainable Development?" Annual Review of Environment and Resources 32: 131-167.

[3] International Energy Agency (IEA), 2008, World Energy Outlook, Paris, IEA/OECD. The IEA's category for biomass-based energy sources is "biomass and waste." The word bioenergy here is intended to encompass all biomass-based energy sources.

[4] Based on Department of Industry and Transport Statistics (DITS), National Bureau of Statistics (NBS), and National Development and Reform Commission Energy Bureau (NDRC-EB), 2007, China Energy Statistical Yearbook 2006, Beijing: China Statistical Press.

[5] National Bureau of Statistics, 2006, China Statistical Yearbook 2007, Beijing: China Statistical Press.

[6] Based on energy consumption data from DITS, NBS, and NDRC-EB (2007), bioenergy accounted for 11 percent of total primary energy consumption in 2005. The IEA (2008) estimates that "biomass and waste" accounted for 13 percent of total primary energy demand in 2005.

[7] DITS, NBS, and NDRC-EB, 2007.

[8] DITS, NBS, and NDRC-EB, 2007.

[9] Zhu Chengzhang, 2006, "Focusing on Energy Poverty: Developing Renewable Energy for Building a New Socialist Countryside," Energy Policy Research 22-29. [朱成章，关注能源贫困：开发可再生能源为建设社会主义新农村服务，能源政策研究]

[10] Kirk R. Smith, Sumi Mehta, Mirjam Maeusezahl-Feuz, 2004, "Indoor Smoke from Solid Household Fuels," in Majid Ezzati, Anthony Rodgers, Alan Lopez, and Christopher Murray (eds.) Comparative Quantification of Health Risks, Volume 2, Geneva: World Health Organization: 1435–1493; cited from Junfeng (Jim) Zhang and Kirk R. Smith, 2007, "Household Air Pollution from Coal and Biomass Fuels in China: Measurements, Health Impacts, and Interventions," Environmental Health Perspectives 115(6): 848-855.

[11] Alan Cohen, H. Ross Anderson, Bart Ostro, Kiran Pandey, Michal Krzyzanowski, Nino Künzil, Kersten Gutschmidt, C.A.

Pope III, Isabelle Romieu, James M. Samet, and Kirk R. Smith, 2004, "Urban Air Pollution," in Majid Ezzati, Anthony Rodgers, Alan Lopez, and Christopher Murray (eds.) Comaparative Quantification of Health Risks, Volume 2, Geneva: World Health Organization: 1353–1433; cited from Zhang and Smith (2007).

[12] Based on a subset of 468 rural households surveyed across 10 village committees in different climate and altitudinal zones of Yunnan Province. The average reported time spent collecting fuelwood was 3.0±1.9 hours per day for 50.1±58.6 days per year. The high variance in these estimates is found both within and among villages.

[13] Our definition of 'localized deforestation' here is annual withdrawals (m3/ha-year) exceeding mean annual increment (m3/ha-year) for any given area (ha).

[14] Rufus D. Edwards, Kirk R. Smith, Junfeng Zhang, and Yunqing Ma, 2004, "Implications of Changes in Household Stoves and Fuel Use in China," Energy Policy 32: 395–411.

[15] In 1995 China was the world's sixth largest importer of roundwood at 6.2 million m3; by 2005 China was the world's largest roundwood importer at 30.5 million m3. Data are from FAOSTAT accessed through the World Resource Institute's Earthtrends website (www.earthtrends.org).

[16] All data are from the FAO's Forest Resource Assessment (FRA) 2005 Global Tables, accessible from http://www.fao.org/forestry/home/en/. The NBS uses a narrower definition of forest land (175 million ha as opposed to FAO's 197 million ha) to estimate a somewhat higher average stocking density for China of 77.9 m3/ha.

[17] Pan Yunde, Tianxiang Luo, Richard Birdsey, John Hom, and Jerry Melillo, 2004, "New Estimates of Carbon Storage and Sequestration in China's Forests: Effects of Age-Class and Method on Inventory-based Carbon Estimation," Climatic Change, 67: 211–236.

[18] Li Jingjing, Zhuang Xing, Pat DeLaquil, and Eric D. Larson, 2001, "Biomass Energy in China and its Potential," Energy for Sustainable Development V(4): 66-80.

[19] Shuyang Fan, Bill Freedman, and Jixi Gao, 2007, "Potential Environmental Benefits from Increased Use of Bioenergy in China," Environmental Management 40: 504-515.

[20] NBS, 2007.

[21] Qiu Daxiong and Gu Shenhua, 1996, "Diffusion of Improved Biomass Stoves in China," Energy Policy 24(5): 463-469.

[22] Kirk R. Smith, Gu Shuhua, Huang Kun, and Qiu Daxiong, 1993, "One Hundred Million Improved Cookstoves in China: How Was It Done?" World Development 21(6): 941-961.

[23] Zhang Xiliang and Kirk R. Smith, 2005, "Programmes Promoting Improved Household Stoves in China," Boiling Point 50: 14-16.

[24] Yunnan Province Rural Energy Station (YRES), 2007, "Report on the Development of Rural Energy in Yunnan Province," Report to the Yunnan Provincial National Development and Reform Commission, August 8. [云南省农村能源工作站，关于云南农村能源建设和发展的汇报]. YRES (2007) lists the number of functioning stoves as "approximately 6 million," but a news report (Liu Yunda and Huang Huo, 2000, "Yunnan Promotes New Rural Energy to Protect the Environment," Xinhuashe, 7 December) reports that, based on Yunnan Forestry Bureau data, by 2000 7.23 million households had adopted stoves and 6.8 million stoves were still in use.

[25] Using the 2005 population census average county and sub-county household size estimate of 3.79 persons/household and a 2006 rural population estimate of 32.457 million, Yunnan had an estimated 8.2 million households in 2006. Census data are from the China Data Online website; rural population data are from NBS (2007).

[26] Based on a subset of 722 households surveyed in 10 villages in Yunnan Provinces, the average adoption rate for improved stoves across all 10 villages was 80 percent, at a village level ranging from a low mean of 57 percent to a high mean of 94 percent.

[27] Li Jingming, 2007, "Rural Biogas Development in China," Paper Presented at the Workshop on "Challenges and Strategies to Implement Anaerobic Digestion in Agrisystems," Buenos Aires, Argentina, May.

[28] YRES, 2007.

[29] Renewable Energy Policy Network for the 21st Century (REN21). 2008, Renewables 2007 Global Status Report, Paris: REN21 Secretariat and Washington, DC: Worldwatch Institute.

[30] In 2005, China had an estimated 230 million rural (county and below) households. Population data are from NBS (2007); average household size data are based on the 2005 census, accessed from China Data Online. The estimated number of households in Yunnan is based on footnote 19.

[31] Pan Jiahua, Peng Wuyuan, Li Meng, Wu Xiangyang, Wan Lishuang, Hisham Zerriffi, Becca Elias, Chi Zhang and David Victor, 2006, "Rural Electrification in China 1950-2004: Historical Processes and Key Driving Forces," Stanford Program on Energy and Sustainable Development Working Paper #60.

[32] "Yunnan Rural Grid Project Provides 30,000 Households with Electricity in 2006," The Central People's Government of the People's Republic of China website, 23 January 2007. ［云南农网工程2006年解决3万户无电人口用电问题］

[33] Li et al., 2001.

[34] Zhao Lixin, 2006, "The Current Status and Prospect of China Biomass Development," Presentation from Center of Energy and Environment Protection Technology Development, Ministry of Agriculture, 16 January. Zhao 2006 estimates that village-level gasifiers produced 0.18 billion m3 of gas in 2004, which, assuming a basic requirement of 1.5 m3/household-day, would meet the demand of roughly 329,000 households.

[35] YRES, 2007.

[36] Eric Martinot and Li Junfeng, 2007, Powering China's Development: The Role of Renewable Energy, Washington, DC: Worldwatch Institute.

[37] Research on biofuels in Yunnan began in 1984; Yunnan's first bioethanol producing facility came online in Yuxi Municipality in 2006.

[38] Zhang and Smith, 2005.

[39] Efficiency tests were based on a water boiling test (WBT) approach, Qiu and Gu, 1996.

[40] This is a widely cited number in the international literature for inefficient or open-air stoves, but as far as we know there has been no systematic evaluation of older "tiger" stoves (Ch: laohu zao) in China.

[41] Based on population estimates and census data, the number of households in rural China has increased from 184 million (a rural population of 802 million and a "village" household size of 4.36) in 1982 to 229 million (a rural population of 745 million and a village household size of 3.25) in 2005, an average annual increase of roughly 1 percent. Data are from the China Statistical Yearbook and census data, both accessed from China Data Online.

[42] Data on fuelwood use and agricultural residues are most likely calculated based on forest and agricultural production data are should be treated as reflective of use over time, but not necessarily on an annual basis. For fuelwood and agricultural reside data before 1998, the China Energy Group's China Energy Databook points out that the values in Figure 4 are not strictly comparable since they are from different sources. For our purposes, the key question is whether the longer-term trend holds. From official statistics, it appears that there was a sharp upswing in biomass energy consumption beginning in 2001, driven in part, we argue, by demographics. The average household size in rural China fell from 4.36 in 1982 to 3.25 in 2005 (based on census data accessed from China Data Online). We assume that the number of households, rather than household size, decreases at a constant rate from 1979-2006.

[43] Based on a subset of 722 households surveyed in 10 villages in Yunnan Provinces.

[44] Zhang and Smith, 2005.

[45] See, for instance, Yunnan Zhenghong Environmental Protection & Energy Conservation Co. ［云南正红环保节能有限公司］ website, http://www.zhlz.net/newEbiz1/EbizPortalFG/portal/html/index.html.

[46] Prices are based on price lists for Yunnan Zhenghong Environmental Protection & Energy Conservation Co. from summer 2008.

[47] The NBS reports that mean net per capita income for Yunnan was 2,250 yuan in 2006 (NBS, 2007), but income in rural areas of all of China is often underreported. Based on the authors' research experience in rural Yunnan, a rough inter-quintile income

range is 1,000-3,000 yuan/person-year, or about 4,000-12,000 yuan/household-year. We round the percentages reported here to account for uncertainty.

[48] Based on a small trial of six gasifier stoves in Baoshan Municipality by the authors in July 2008.

[49] Yunnan Provincial Government Announcement 103, "Yunnan Provincial Government Viewpoint on Strengthening Rural Energy Development and Reducing Forest Consumption," August 1. [云南省政府关于加强农村能源建设降低森林资源消耗的意见，103好公布]

[50] Qiu Daxiong, Gu Shuhua, Liange Baofen, and Wang Gehua, 1990, "Diffusion and Innovation in the Chinese Biogas Program," World Development 18(4): 555-563. Qiu et al. (1990) discuss implementation failures in the 1950s and 1970s; Li (2007) discusses failures in the 1980s.

[51] Li, 2007.

[52] Personal communication, extension agent, Yunnan Province, June 2008.

[53] Digesters are even more concentrated than other manure management systems. For instance, methane in a digester has an estimated methane conversion factor (MCF) of 90, compared with an MCF of 42 for a liquid-slurry system at 20°C. See US Environmental Protection Agency, 2008, "Climate Leaders Greenhouse Gas Inventory Offset Project Methodology: Manure Management with Biogas Recovery Systems."

[54] Wang Xiaohua and Li Jingfei, 2004, "Influence of Using Household Biogas Digesters on Household Energy Consumption in Rural Areas: A Case Study in Lianshui County in China," Renewable and Sustainable Energy Reviews 9(2): 229-236.

[55] Zhimin Li, Runsheng Tang, Chaofeng Xia, Huilong Luo, and Hao Zhong, 2005, "Towards Green Rural Energy in Yunnan, China," Renewable Energy 30: 99-108.

[56] YRES, 2007. Two to three tons is most likely an overstatement; a 1-2 ton reduction in fuelwood (267-533 m3 biogas per year) would be a more realistic estimate.

[57] Fuelwood-biogas equivalency is calculated by assuming a higher heating value (HHV) for air-dried fuelwood of 14 MJ/kg, a 20 percent thermal efficiency for improved stoves, an HHV of 21 MJ/m3 for biogas, and a 50 percent efficiency for biogas stoves.

[58] Assuming a wood density of 400 kg/m3 for Yunnan.

[59] Based on a subset of 722 households surveyed in 10 villages in Yunnan Province, the average adoption rate for rice cookers across all 10 villages was 63 percent, with a low of 26 percent.

[60] Cost of rice cooker estimated based on interviews conducted with rural households in spring and summer 2008.

[61] Assuming a 15 percent line loss and a 30 percent conversion efficiency for electricity, the primary energy required for a 750 W rice cooker operating for 0.5 hours is 5.3 MJ. At 1-2 kg of air-dried fuelwood with a higher heating value of 14 MJ/ton cooking in a 20 percent efficient (stove to pot) stove, cooking rice requires 14-28 MJ.

[62] Yunnan 2006 electricity demand data is from NBS (2008); CO2 emissions are based on a China-wide grid emission factor of 975 g/kWh.

[63] Village electricity consumption is based on household survey data. Average electricity use for China is from NBS (2008).

[64] See, for example, Renewable Fuels Agency (RFA), 2008, The Gallagher Review of the Indirect Effects of Biofuels Production, East Sussex: RFA.

[65] Alexander E. Farrell and Anand R. Gopal, 2008, "Bioenergy Research Needs for Heat, Electricity, and Liquid Fuels," MRS Bulletin, 33: 373-380.

[66] C.Z. Wu, H. Huang, S.P. Zheng, and X.L. Yin, 2002, "An Economic Analysis of Biomass Gasification and Power Generation in China," Bioresource Technology 83: 65-70.

[67] Yunnan Rural Energy Station (YRES), 2003, "Brief Report on the Development of Rural Energy in Yunnan Province," Report to the Yunnan Provincial National Development and Reform Commission, August 8. [云南省农村能源工作站，关于云南农村能源建设情况的简要汇报]

[68] State Environmental Protection Agency (SEPA), 1999, "Regulations Supporting Management of Agricultural Residue

Burning and Comprehensive Use," SEPA Policy Document. [关于发布《秸秆禁烧和综合利用管理办法》的通知]

[69] Lou Schwartz, 2008, "China Fuels Ethanol Industry with Yams, Sweet Potatoes and Cassava," Renewable Energy World, May 16.

[70] See, for example, Horst Weyerhaeuser, Timm Tennigkeit, Su Yufang, and Fredrich Kahrl, 2007, "Biofuels in China: Opportunities and Challenges for Jatropha curcas in Southwest China", Kunming: World Agroforestry Centre.Working Paper No. 53.

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 in 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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United Nations Avenue, Gigiri - PO Box 30677 - 00100 Nairobi, Kenya
Tel: +254 20 7224000 or via USA +1 650 833 6645
Fax: +254 20 7224001 or via USA +1 650 833 6646
Southeast Asia Regional Programme - Sindang Barang, Bogor 16680
PO Box161 Bogor 16001, Indonesia
Tel: +62 251 625 415 - Fax: +62 251 625 416
www.worldagroforestry.org