Rural Energy in China

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1. Overview of Rural Energy Development
2. Energy and Rural Environment
3. Energy and Rural Economy
4. Energy and Rural Society
5. Looking Forward

Glossary

chronic obstructive pulmonary disease (COPD) A disease characterized by a progressive airflow limitations caused by an abnormal inflammatory reaction to the chronic inhalation of particles.

global warming potential (GWP) The GWP of one molecule of CO_2 is set = 1, to which the GWP of other gases are placed in relation. For instance, in a period of 20 years, one molecule of CH_4 causes a direct warming effect, which corresponds to that of 35 molecules of CO_2.

ren min bi (RMB) The official currency of the People's Republic of China. One U.S. dollar is about 8.3 RMB.

small hydro In China, capacity less than 25,000 KW is categorized as small hydro.

Substantial changes have taken place in China. Energy development, as both a driving force and a consequence of such tremendous changes, has had profound impact on economic, social, and environmental development. Rural energy has always been a critical issue due to years of energy shortage for both households and industries. Biomass, for long time, has been the only available fuel in many rural areas. A series of policies and strategies have gradually been put in place to encourage alternative fuel exploration and utilization as well as area-based integrated energy systems. As a result, unelectrified rural population dropped from 60% in the 1950s to 5%, while the share of commercial fuel use increased to 43%. The importance of renewable energy has been recognized, not only because of its potential in rural and remote areas, but also as means of improving the environment and generating economic opportunities.

1. OVERVIEW OF RURAL ENERGY DEVELOPMENT

This article does not pretend to provide a complete in-depth assessment of rural energy in China. However, it is hoped that through a historic summary of the development in past 50 years and analysis of some relevant aspects, this discussion will contribute to a better understanding of the current situation and future challenges.

1.1 Rural Energy Path

Generally, the development of rural energy and rural energy policy in China can be divided into three stages.

1.1.1 Energy Shortage and the Development of Biogas, Small Hydro, and Local Coal Mines (1950–1979)

Despite the high level acknowledgement of the situation, rural energy shortage was severe throughout these three decades. By the end of 1979, the energy consumption per capita in rural areas was 19% of that in urban cities. Seventy percent of rural households lacked cooking fuel, among which 47% had no fuel for more than 3 months per year. Promotion of biogas for cooking and lighting and utilizing local coal resources were strategic decisions from the top since the 1950s; however, not until the late 1970s were specific institutional arrangements and policy measures clarified for a biogas program, with allocation of financial and human resources. Although large-scale biogas projects have been carried out, most digesters failed to perform soon after installation (1 to 3 years of average life time) due to insufficient technical, managerial, and financial support. Because of this long period of lacking of alternative cooking fuels, regional deforestation, and excessive utilization of agricultural residues, among other factors, have contributed to serious degradation of rural ecological environment, which, in turn, has hampered the rural economic development. The impacts were felt well into the next stage.

1.1.2 *Satisfaction of Energy Needs and Development of Policies and Regulations (1980–1990)*

After the first national seminar on rural energy in 1980, series of energy policies and regulations have been announced focusing on reforestation, improvement of energy efficiency in both rural industries and households, and the development of renewable energy. The principle of integrated rural energy strategy was defined as developing all possible local alternative resources of energy while rationally utilizing the current sources. Nation wide programs have been carried out in this context, and most of them continuously constitute the current rural energy activities. Thus, it is worth while to have a detailed discussion on the following main results from this period:

Fuelwood Forest. As one of the five forest categories, the main products of the fuelwood forest are wood fuels. Reforestation plans were conceived according to local surveys on fuelwood supply and consumption. From 1981 to 1995, approximately 5 million hectares of forest have been established as fuelwood forest, which, in total, reached 6 million hectares and generated 20 to 25 million tons of wood as fuel per year. However, due to the decline of fuelwood demand, it is expected that the financial viability of these reforestation projects will be highly challenged. Technology optimization and standardization ensuring a diversified and reliable range of products are essential to improve the economic performance. Further more, flexible management and involvement of the private sector are crucial to gradually moving away from subsidies to a market-based operation.

Improved Cook Stoves and Energy Efficiencies in Rural Industries. From 1983, large-scale promotion of improved cooking and heating stoves has been carried out all over the country. By the end of 1999, it was reported that approximately 189 million rural households had been equipped with improved stoves. Generally the efficiency of these stoves, using coal and solid biomass as fuel, has improved by 20 to 40%, which enables energy saving of more than 30 million TCE (ton of coal equivalent) per year. However, to what extend these stoves have been used is not known. Rural industries have experienced a similar process. Improved boilers and kilns, mainly used in tea processing, tobacco drying, and brick and cement producing industries, could have brought about 2 million TCE per year energy saving, as well as significant quality improvement and control in production.

Rural Coal Mining. By the end of the 1970s, coal production from the mines developed at town and county level had already taken a significant role in the energy supply in China. The production of coal from these mines shared 18% of the national total in 1980. The continuous encouragement in collective and private coal mining has tripled their production to nearly 390 million tons and shared 36% of the coal production. Such increase climaxed in the year 1995–1996 when the production shared 45% of national total coal output. Despite low-efficient equipment and technologies and a poor safety record, the rural coal mines have contributed to the rural economy in three ways: easing the energy shortage, ensuring rural productivity, and improving rural employment. While majority of the coal produced from these mines has served market demand locally and from neighboring provinces, a small portion of the product, usually of better quality, has been transferred to the eastern coastal region. To a certain extent, replacing fuelwood with coal has also contributed to forest conservation. The low production and combustion efficiency of coal, however, has had adverse impact on rural environment and health. These effects have also been aggravated by the poor quality of coal in China and the fact that only a small amount has been processed. A case study on Xuan Wei County, Yunnan Province, showed that indoor air pollutants caused by coal combustion was the main health risk factor responsible for the high rate of lung cancer cases in the county.

Rural Electrification. Development of small hydropower has been the dominant strategy for rural electrification in China. In the late 1970s, several policy measures, including subsidy schemes, were adopted to promote small hydro, which resulted in a large increase in generation capacity from an average of 58,000 KW per year in the 1960s to more than 1 million KW in 1979. In the 1980s, local grids and local electricity companies have emerged, which has helped to overcome the disadvantages of standalone systems and also enhanced the rational utilization and distribution of electricity at county level. The improvement of grid connection continues in the 1990s while the expansion moves toward cross-county connection. Establishment of hydroelectricity enterprises are further encouraged by introducing, among others, a private stockholder scheme. Per capita rural electricity consumption increased 7 times in 40 years and by the end of the year 2000, 28 million people (around 5 million households) in rural areas had no access to electricity, comparing to 450 million in 1978 (nearly half of the total population and 57% of rural population at that time).

1.1.3 Sustainable Energy Development and Market-Oriented Policy and Strategies (1990–2000)

Since the beginning of the 1990s, environmental policy has become one of the principle national development policies in China. As in many other developing and developed countries, renewable energy and energy efficiency have become more prominent in the energy agenda. Several rural energy policies have been published to address renewable energy and sustainable development, energy and environment, and rural energy technology in poverty alleviation. With the deepening rural economic reform since the mid-1980s, energy has been advocated as an integrated component of the rural development and rural market economy. The need for commercialization of conservation technologies, utilization of new and renewable energy resources, and the provision of energy services have been given great emphasis. Progresses in some of these aspects mentioned earlier are detailed in the following discussion:

Renewable Energy (RE). Direct combustion of biomass has gradually decreased both in share and absolute terms, while the utilization of solar, biogas, small and pico hydro, and biomass gasification have increased. Energy policies in addressing environmental problems in the country have set favorable conditions to RE. In particular, several financial measures, such as subsidies, low- or zero-interest loans, taxes, and so on have been essential in renewable energy development. Since 1987, the state council has financially supported more than 500 RE projects in the form of low-or zero-interest loans (more than 400 million RMB, e.g., approximately US$50 million). From 1990 to 1996, more than 1 million US$ subsidy was given to training and demonstration of RE technologies, while between 1996 and 2000, subsidies of about 7 million U.S. dollars were given to research and development of RE technologies and implementation. As a result, in 1998, renewable energy utilization, excluding traditional biomass, was 35 million TCE, accounting to more than 2% of the China's total energy consumption (including commercial and noncommercial sources).

Rural Energy Enterprises. Rural energy enterprise emerged with the promotion of biogas in the late 1970s to provide technical services and after build services. Under the strong support from the government on efficiency technologies, various types of devices and equipment have become commercialized. Into the 1990s, different renewable energy technologies have been demonstrated and promoted and, along with it, a more diverse rural energy industry has emerged. By the end of 1998, there were about 4300 rural energy enterprises, 1660 of which were in the industrial sector, manufacturing energy devices for rural users, such as solar water heater, PV, biomass gasifiers, and so on, and more than 2630 were in the service sector, providing technical, marketing, sales, and other services. Compared to 1997, the number of both types of enterprises increased by 8% and 18%, respectively, although the number of total employment has stayed roughly the same (approximately 42,000 to 43,000). Until 2000, such yearly increases have been consistent. However, data show that before 1996, enterprises and employment had been declining in the rural energy sector, and a relatively sharp decrease occurred to the collectively and state-owned enterprises. This short period of decline reflects the further market opening up in rural China, making many inefficient and less flexible state enterprises go bankrupt. Nonetheless, the rural energy industry has yet to mature and favorable policy environment is still essential, since its benefits to overall rural sustainable development have not been integrated and valued fairly (see also Section 3).

The development of rural energy, particularly in the past 20 years, has brought significant changes in the sector in terms of policy, structure, management, technology, and economy. Rural energy consumption increases at a steady rate of 4% per year from 330 million TCE in 1980 to 670 million TCE in 1998. Several comparisons of changes are listed in Table I, while the changes of rural energy structure are presented in Fig. 1.

The fall of rural energy consumption in 1996 is mainly due to the large decrease in the use of noncommercial energy sources (e.g., fuelwood and straw), while the use of coal and oil increased with the latter nearly doubled comparing to 1995.

TABLE I

1980–1998 Rural Energy Development in China

	1980	1998
Rural population (million)	796	869
Average rural income per person (RMB)	191	2162
Total energy consumption (million TCE)	330	670
Average energy consumption per capita (Kg CE)	420	770
Total electricity, consumption, including household and rural industry (billion KWh)	13	129
Average household electricity consumption per capita (KWh)	8	68
Population without electricity (million)	450	60
Clean fuel for cooking (electricity, LPG, coal gas, biogas, producer gas, solar, etc.) (million households)	3.7	56.3

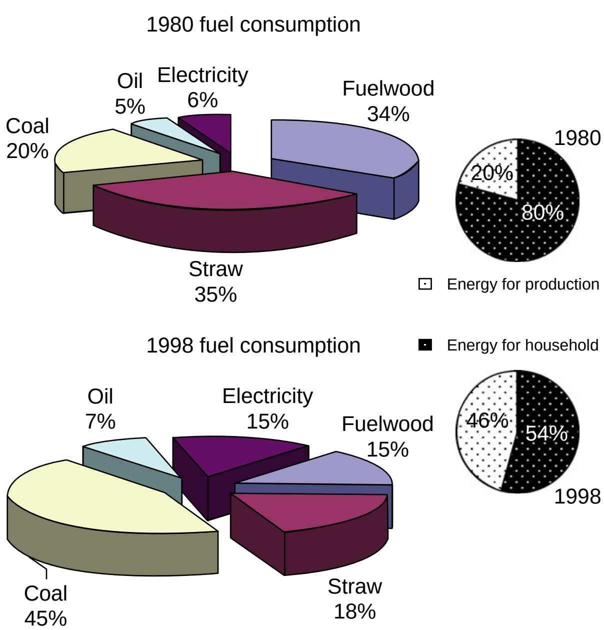

FIGURE 1 Fuel consumption structure changes in rural China 1980–1998.

Decrease in residential electricity consumed in 1996 was uncertain. Official figures from the Ministry of Agriculture show that the consumption was 29 million TCE, which was two-thirds of that in 1995 and, although increasing in the following years, it has not regained the level of 1995. However, according to the statistics from Department of Rural Electricity of the National Electricity Power Bureau, no such decrease has been observed. Nevertheless, energy

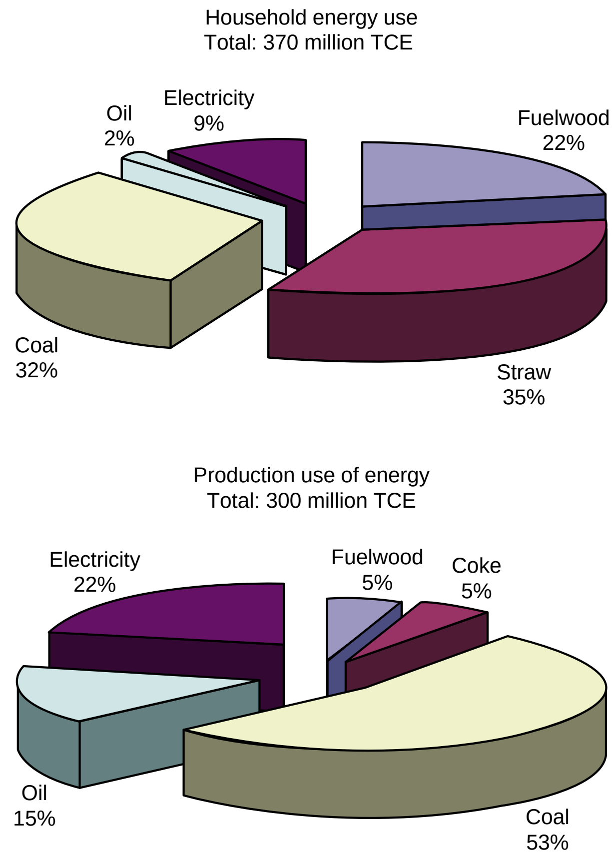

FIGURE 2 Rural energy consumption, 2000.

consumption in rural households has been grown in slow pace since 1995, if not decreased, mainly due to the closure of small coal mines and power producers. In the same period, rural productivity use of energy grew about 16% despite the successful efficiency program in rural industries nationwide. This has significantly contributed to higher income and improved livelihood in many rural areas in China.

1.2 Rural Energy Today

Since 2000, rural energy has accounted to approximately 45% of the total energy consumption and 35% of total commercial energy consumed (e.g., excluding fuelwood and straw). The total rural energy consumption was 670 million TCE in 2000 (see Fig. 2). The majority of rural households still use solid fuel for cooking and heating, while 84% of urban households are using gaseous fuels (LPG, natural gas, and coal gas). China has undergone series of reforms in the energy sector in the past 10 years, and the reform is being extended into rural power grid. The long-term goal of the power sector is the establishment of a unified national grid. It would require a modern power market in which small and large plants are able to sell electricity to the grid at market-determined price. It would also require a well-defined regulatory role of the government. In the short to medium term, many rural areas will stay with local grid or isolated (village) grid, where renewable energy sources are most promising.

1.2.1 Energy Efficiency

As already mentioned, energy efficiency has been improved tremendously in the past years. However, comparing to national and international averages, rural industries still consume more energy per product unit as shown in Table II, and a significant difference exists between the western and the eastern regions, where efficiency is in general much higher. Because the out-of-date technologies and machinery still prevail in agricultural activities, energy consumption for mechanical power is very high, accounting for nearly half of the diesel used in the country. The current energy efficiency program, focusing on the modification of old equipment and technologies, results in diesel saving of 300,000 tons per year. However, the demand and consumption of diesel in agricultural sector will continuously increase since mechanical power is only responsible for approximately 50% of the productivity.

TABLE II

Energy Efficiency of Selected Rural Industries

Type of product (energy consumption/unit)	Average of rural industries	National average	International average
Brick (kgce/10,000 pieces)	1093	780	780
Cement (kgce/t)	161	133	94
Coke (tce/t)	1.56	1.1	1.1
Pulp and paper (tce/t)	1.55 ~ 1.7	1.25	0.51
Electricity (from coal, gce/kWh)	450 ~ 550 (< 50 MW)	320 ~ 350 (300 MW)	329 (Japan)

1.2.2 Clean Energy

With the stabilized balance between demand and supply of energy, China has been moving forward to clean and modern energy and technologies. The demand for clean fuel (electricity, LPG, coal gas, and modern renewable fuels) from rural households has five-fold in the past 10 years, and this trend will continue. Currently, renewable energy and modern renewable energy (including small hydroelectricity) account for 19.8% and 2.3%, respectively, in the total national consumption, as shown in Fig. 3.

A detailed breakdown of the use of renewable energy resources in 1998 is presented in Table III, which shows that all new renewable energy (excluding traditional biomass and all hydroelectricity) constitutes 0.3% of total national energy consumption (i.e., 5.4 Mtce). According to national planning on renewable energy development, this figure is expected to reach 2% by the year 2015, which indicates that total consumption of new renewable energy would have to reach approximately 60 Mtce in 15 years, which may require hundreds of millions of U.S. dollars, as subsidies from central government. Thus, the commercialization of renewable energy and technologies, with a well-performing rural energy service sector, would be crucial. The existing rural energy industry covers almost all renewable energy technologies; however, their stage of development and commercialization varies greatly and are presented in detail in Section 3.

Although domestic coal meeting the demand will still be the strategy in rural energy development in the foreseeable future, coal combustion, particularly at the small scale, has been and will be unavoidably having a negative impact on rural environment and health. Modern renewable fuels, such as solar water

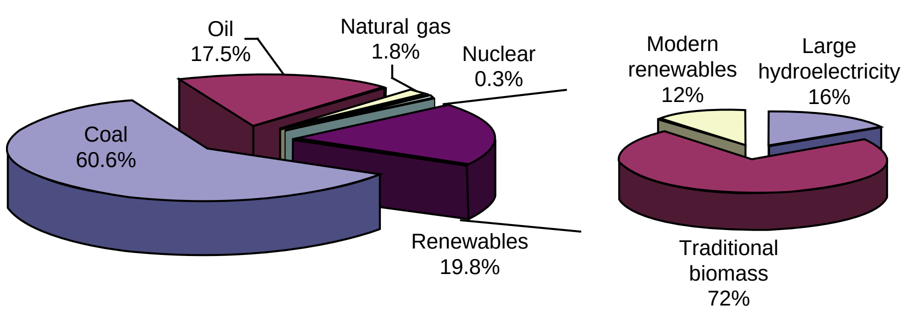

FIGURE 3 Renewable energy consumption in China.

TABLE III

Utilization of Renewable Energy Resources in China (1998)

Resources	Utilization	Mtce
Hydro electricity — small hydro[a]	208 billion kWh, 80 billion kWh	77.6, 29.84
Biomass	221.98 Mtce	221.98
Biogas	2.36 billion M^3	1.73
Bagasse for power	800 MW/2000 GWh	0.75
Geothermal for heat	0.4 Mtce	0.4
Geothermal for power	27.8 MW/110 GWh	0.05
Solar water heater	15 million M^2	1.8
Solar homes	15 million M^2	0.37
Solar cooker	244,000	0.04
Solar PV	13 MW/28.7 GWh	0.01
Wind	242 MW/641 GWh	0.24
Total		305

[a]Note: Micro hydro not included.

heaters, biogas, producer gas from agricultural residues, and electricity from wind and microhydro, could provide some viable alternatives for rural and remote areas. They have the potential in competing with the high cost of LPG and coal gas and meanwhile improving indoor air quality (see also Section 2).

A number of new and renewable energy projects, under the Tenth Five-Year Plan, are currently being carried out at nation wide. Since these projects are and will be of significance to the long-term development of the rural energy sector, it would deserve some discussions.

1.2.2.1 The "Brightness" Project By the end of the last century, about 7 million households, accounting for 3.55% of total rural households, have yet to be electrified. Most of these households are located in the western region and the majority of them are of minority origins. To address this situation, the "Light" project was initiated by the national Planning Committee and supported by several other countries [e.g., Japan, Germany, the Netherlands, the United States, and the United Nations Development Programme/Global Environment Facility (UNDP/GEF).] The 10-year target of the project is to provide electricity, in average 100W/person, to 23 million people in remote areas with renewable technologies such as wind and solar PV. The first period of the project (from 2000 to 2005) will install 1.78 million sets of household systems and 2000 sets of village systems, which will require, approximately, a total of US$1.2 billion. It is expected that the majority of the investment will come from the users themselves, while only 6.7% will be provided by the central and local government by means of subsidies, especially for the village systems and service networks. The project, in its first period, will focus on the development of domestic industries of wind generators and solar PV; the establishment of sales and a after sale service network; technical training on installation, optimization, repair and maintenance; standardization; and quality control mechanisms.

1.2.2.2 Biomass Gasification Demonstration Project With 65 million rural Chinese without electricity, 70 million are in shortage of cooking fuel. As shown in Fig. 2, agricultural residues, mainly straw, account for 35% of rural household energy use. The average efficiency of straw directly used for cooking is just 5 to 8%; however, after gasification, the overall efficiency reaches about 35 to 45%. Most of all, converting solid fuel to gaseous fuel could bring huge environmental, social, and economic benefits, such as improved indoor air quality and health, reduced of load of house work for women, the sense of modernization of rural communities, and reduced greenhouse gas emissions. However, these externalities are not internalized financially; thus, in average the daily expense on fuel in terms of producer gas is 7 to 8% higher than that in terms of coal gas. One of the first demonstration projects was initiated in Shangdong province with a gasification system and a village gas pipe line installed in 50 villages. It brought significant benefits to those villages in terms of reducing smoke and liberalizing women from the drudgeries of fuel handling. From 1999 to 2000, the national planning committee budgeted 12.5 million RMB ($\sim$US$1.5 million) for wider dissemination of the technology in seven other provinces. It is expected that 53,900 households would be using producer gas for cooking. Standardization and commercialization of gasifiers and gas stoves are key issues to be addressed, along with the demonstration projects (see Fig. 4; see also Section 2).

Modern energy is the main engineer of economic growth. Meanwhile, national policies and measures to promote such growth have a profound impact on sustainable energy development. One of the strategic developments focuses is the current Western Development Plan. Through rational and efficient exploration, distribution, and utilization of resources, the development plan aims at stimulating

FIGURE 4 Biomass gasifiers manufactured and used in Yunnan, China.

economic growth in the West and minimizes the social and economic disparities between the western and eastern regions. Western China is rich with both renewable and conventional energy resources. However, the demand of energy mainly comes form the Eastern coastal areas. Two major programs under the development plan are to transfer both natural gas and electricity (generated from coal) from the western to the eastern region. Mostly energy resources are located in rural areas and the pipe line and network will be most likely constructed along remote villages and rural towns, thus, it is hoped that these programs would enable those rural households to access clean energy services. These programs would also encourage the growth and development of energy service industries in the western region, which could provide employment and income generation opportunities.

The previously discussed rural energy development in China has had a profound impact on the sustainable development in all of its three dimensions (i.e., environment, economy, and society). The impacts are complex and interrelated. The following sections exam several characteristic issues in each of the three dimensions, and through that, the challenges and possibilities in advancing rural energy development are discussed.

2. ENERGY AND RURAL ENVIRONMENT

Small-scale coal mining has caused serious environmental problems in rural China. As mentioned in the previous section, these mines are mostly collectively or privately owned by the counties; little capital was invested in technology and equipment. The average efficiency of coal production (e.g., resource recovery)

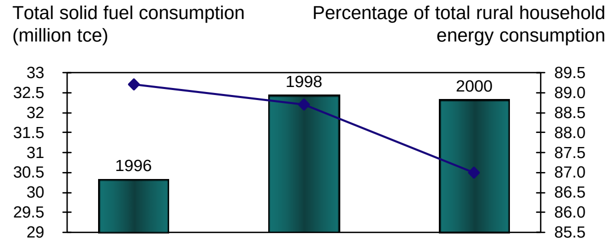

FIGURE 5 Reduced solid fuel consumption in rural household.

is much lower than 50%. Most of the mines are very labor intensive and some have the productivity as low as 1t/labor. Few environmental control measures have been adopted in these mines, and only a small portion of coal produced has been further processed with, for instance, de-sulfur technology. From the end user side, rural households and industries are the main consumers of the low-quality coal from the small mines. Rural industries are known to have outdated equipment with low efficiency (as presented in Table III). This situation has worsened as many high pollutant and energy intensive industries have moved to rural areas. In average, the brick, cement, paper, coking, and casting industries in rural areas shares 8% of the total production of the country, while they account for more than 50% of the total energy consumption in these industries. For rural households, since the late 1990s, the consumption of solid fuels (e.g., biomass and coal) has increased only marginally and their share in the total household energy use started decreasing, as shown in Fig. 5. This indicates that with the promotion of improved technologies, efficient stoves, coal, and biomass energy intensity decreased and resulted in energy saving and, consequently, emission reduction both indoors and outdoors. However, it is difficult to assess the actual changes and effects due to the lack of detailed data.

Overexploration of fuelwood still persist in some rural areas despite the relatively successful reforestation program since the 1970s. From the 1990s, fuelwood supply and consumption has been roughly kept in balance due to mainly improved energy efficiency and promotion of coal replacing fuelwood; however, statistics show that fuelwood consumption is higher than the sustainable supply at various degrees in more than ten provinces. For example, Yunnan Province, located in the Southwest of China, has relatively successful solar heating and biogas programs. However, data in 1999 show that fuelwood consumption was about 32 million M^3 while the total sustainable supply from all type of forest was only about 14 million M^3. Several counties in Yunnan province are located upstream of, among others, the Yangtze and Mekong River. Years of over exploration of the forest for timber and fuel in these areas have resulted in soil erosion and degradation.

In 1998, agricultural plantation generated approximately 600 million tons of residues, of which 27% was utilized mainly as animal feed and for industries, 15% was returned to the field as natural nutrients, and 47% was used as fuel. On one hand, the declined consumption of agricultural residues as fuel has made the returning of residues back to the field possible. On the other hand, this has led to about 65 million tons of residues left for disposal. Since decomposing stem residues is a rather long process, most of it is burned openly to prepare the field for the next crop. In many areas of central China, this has become a serious seasonal environmental problem.

2.1 Rural Energy and Emission Reduction: The Potential of Biomass Gasification

Analysis has confirmed that China actually has reduced its greenhouse gas emissions, even as its economy has grown rapidly (as shown in Fig. 6). However, due to lack of data from monitoring and evaluation, it is difficult to analyze the share of the emissions from rural energy consumption. Estimates of all energy efficiency projects claim more than 32 million tce energy saving capacity (30 million tce from the improved fuel/stove projects in rural homes) per year, which would be responsible for about 70 million tons CO_2 avoided, that is, two-thirds of the CO_2 reduction from coal in 1998–1999 and twice of the total CO_2 reduced of the year. The steeper CO_2 reduction from coal indicates higher coal efficiency (comparing with coal consumption) and the increases of CO_2 emission from other sources.

As discussed previously, biomass gasification provides a promising alternative in replacing solid fuels for cooking and heating in rural areas. The amount of agro-residue available for energy use in 1998 was about 350 million tons (possible losses already taken into account), 58% of the total residues generated. Since 285 millions tons of the residues are already used as fuel, it could be assumed that all the available residues could be gathered and transported without imposing any major changes to practices and workload. Assuming 350 million tons of residues could be converted to gashouse fuel for rural cooking and heating, their contribution to emission reduction can be estimated. The average emission factors of coal and biomass fuel for household applications are shown in Table IV.

Based on technical specifications of producer gas in China, it is assumed that gas production rate is 2 M^3/kg residues and 1 M^3 of producer gas would replace 0.25 kgce; thus, 350 million tons of residues would generate 700 billion M3 of gas and equal to 175 million tce.

When producer gas replaces all the residues used for fuel (285 million tons) and partially replaces fuelwood (i.e., 32 million tce), it could avoid, in total, 109 million tons of CO_2; this is about the total emission reduction from coal in 1998–1999. When producer gas replaces all the residues (285 million tons) and partially replaces coal (32 million tce), it could avoid, in total, 167 million tons of CO_2.

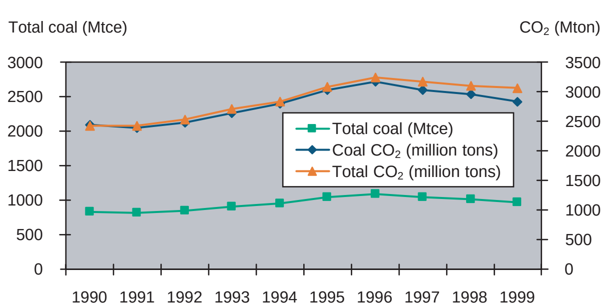

FIGURE 6 China CO_2 trends.

2.2 Rural Energy and Health: A Possible Win-Win Strategy

The simple household solid-fuel stoves commonly used in rural areas do not obtain high combustion efficiency. They emit a substantial amount of fuel carbon as byproduct of incomplete combustion (PIC)—such as carbon monoxide (CO), methane (CH_4), and total non-methane-hydrocarbons (TNMHC)—as well as sulfur dioxide (SO_2) and

TABLE IV

Average Missions Factors of Household Fuels in China

Fuel	Overall efficiency (%)	g CO_2/kg fuel	g CH_4/kg fuel	Total g CO_2/kg fuel[a]
Crop residues	14	1130	5	311
Wood	23	1520	5	311
Coal	35	2280	3	2466

[a] Note that wood and residues are assumed to be CO_2 neutral. And in a 20-year time horizon, the Global Warming Potential (GWP) of one CH_4 molecule is 22.6 time higher than that as CO_2.

particulates. Some of these PICs are hazardous to health when inhaled under the concentrations commonly found in homes using unvented biomass or coal stoves. As discussed, China has carried out, in the past 20 years, efficient cooking stove dissemination programs, which claims that the various technologies have benefited 184 million households by the end of 1998, and this figure is increasing at 2.2% per year. However, again, no monitoring and evaluation data are available to exam the true effect of the stove program, particularly in terms of health improvement. With improved efficiency, carbon emissions could be reduced as discussed in the previous section. It could also result in fuel saving, if more energy is actually delivered in less PICs or if more carbon is converted to CO_2. Table V presents data from site analysis of Chinese stoves. The data show that improved efficiency does not necessarily accomplish emission reduction. However, processed and high-quality fuel is always preferable.

A study of the health benefits from emissions reduction in China has given some further interesting results. It was found that greenhouse gases (GHG) reductions resulting from changes in energy use are generally accompanied by substantial short-term health benefits. However, the degree of health benefits varies greatly with the choice of energy technologies and sectors. The variation appears to be larger when shifting between sectors rather than between technologies, and the largest benefit can be obtained in the household sector. Even conservative estimates show, for example, that the health benefits of one tonne reduction in particulates emission from household stoves are at least 40 times larger than those from coal-power plants. This study also shows that although GHG reduction itself is usually accompanied by increasing costs, when the economic benefits of improved health are counted, there is a net economic benefit for those household energy options, involving a shift from traditional use of coal and biomass. This strongly suggests that emission reduction in the household sector can be a real win-win strategy for China.

TABLE V

Health Hazardous Emissions — Improved Fuel/Stove

Fuel/stove	Efficiency	g PIC/MJ delivered	g NO_x/MJ delivered	g SO_2/MJ delivered
Unprocessed coal	37%	4	0.2	0.02
Coal briquette	14%	24	0.04	0.04
Wood/improved	24%	20	0.1	—
Wood/brick	13%	12	0.2	—

PIC = CO + CH_4 + TNMHC-C (carbon in total none-methane hydrocarbons) + TSP (total suspended particulates).

3. ENERGY AND RURAL ECONOMY

As essential to industries, modern energy services are prerequisites for rural economic development. Most rural industries and agro-product processes have been limited to solid fuel (biomass and coal) with outdated equipment as main energy input. This, as already discussed, has resulted in unnecessary waste of energy and constraints to productivity improvement and products diversification. Figure 7 is a simplified diagram showing the inter linkages of lack of energy services and its impact on agriculture and local economy, which is complex and dynamic.

By no means, this section could provide a comprehensive overview of such complexities in rural China. Rural energy production, supply, and services as part of the rural economy have also undergone tremendous changes in terms of market potential and development, and the following will exam this aspect in detail.

3.1 Rural Energy Business

As discussed before, since 1996, the number of rural energy enterprises, as well as their market value and employment, has been increasing consistently. The current rural energy industry covers almost all renewable energy technologies; however, their stage of development and commercialization varies greatly. According to China Rural Energy Industry Association, the technologies and products are grouped in six categories and are under the mandate of six committees in the association. The market situation of these technologies/products is resented with some details.

Solar heating—including Solar Water Heater (SWH), Solar Cooker, Green House and Solar Homes—has been developed rapidly in the past 20 years in China and has become the main product of the sector. There are two main types of SWH on the market (flat-panel and vacuum tube), with an average heat production efficiency of 100 ~ 150 kgce/M^2. The total sale of the two types was 5 million M^2 in 1999, which was an increase of 25% from 1998. Total installed capacity of SWH has reached

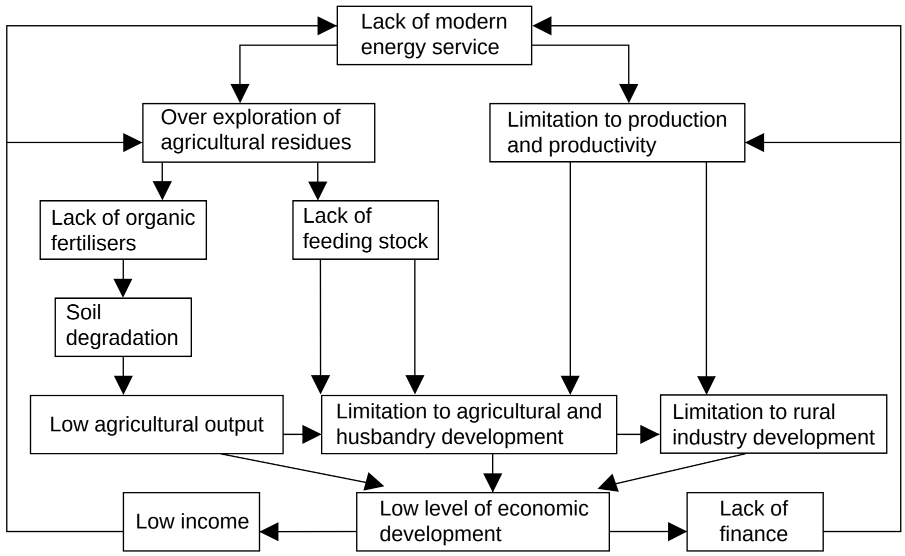

FIGURE 7 Example of energy shortage and its impact on rural economy.

20 million M^2, of which more than 50% is in rural areas. There are nearly 1000 factories with annual production capacity of 6 million M^2, which values more than US$600 million. In total, 20,000 people are employed by these enterprises. By the end of 1998, solar home system (SHS) construction reached 15 million M^2 in total, from which 6.5 million M^2 is located in rural areas. The rate of growth for SHS was 54% per year in the past 10 years. On average, SHS could accomplish 75 to 90% fuel savings on heating. Figure 8 shows a flat-panel solar water heater.

Although there is wide range of products in the energy-efficient cooking devices sector, only two have achieved a large market share. One is the drinking water heater, with a yearly production and sale of more than 300,000 and a value of more than US$12 million. There are more than 1000 factories, mainly small- and medium-sized enterprises (SMEs). The other one is coal-saving stoves. There are five factories reaching an annual production of more than 10,000 stoves.

There are more than 2600 biogas enterprises all over the country with nearly 18,000 employees. The service provided includes digesters (both large scale and household scale) and its design, necessaries, and end use devices, technologies, construction, consultation, repair maintenance, and so on. In total, about 7.6 million digesters have been installed in rural China. Still in technology demonstration stage, there are 740 large and 49,000 medium digesters installed in large farms, industries, and small cities. Although small in size, the market for household biogas systems could be promising. Every year 300,000 new digester are being built, and another 100,000 need to be replaced, which implies approximately US$70 million per year. However, one of the key issues in commercializing small digesters is standardization. Semiconstructed digesters have been developed to secure consistent quality as well as reduce the time needed for construction.

FIGURE 8 Flat-panel solar water heater, Yunnan province.

Another technology is solid biomass conversion equipment, including briquetting, direct high efficiency combustion, gasification, liquadization, and carbonization equipment and facilities. Although these products are still in the stage of research and development and demonstration, some 50 factories have already been in production and their products are sold in several provinces. A study of the market potential of a village scale biomass gasification system shows that the average income level of a village affects the current market of the technology. In the case study, it is shown that when yearly household income reaches 10,000 RMB (about US$1200), residues as fuel are abandoned and the financial implication of gasification is more acceptable.

A new type of liquid fuel/stove presents yet another technology. The liquid fuel in this category is mainly referring to methanol and ethanol from the waste of oil and chemical industries. There are about 600 research and production enterprises in this sector, among which several are more than $1 million enterprises. Although the technology is yet to be standardized and further improved, it has already reached more than 300,000 households.

Small-scale electricity production makes up another category. This sector includes small wind, solar, and hydropower industries. More than 50 enterprises are engaged in small wind power research and development and equipment production. Currently, the production of small wind turbines is about 20,000 units per year. Products range from 100W to 5 KW, of which the 100 to 300W types are most in demand. The technology has matured in the past 5 years and production quality has been stable. Solar PV industry has been commercially established. There are more than ten solar PV production lines in China, each with 4.5 MW per year capacity. The annual production has been around 2 MW. In total, 12 MW has been installed, of which 5 MW in rural areas. In average, the system cost is around US$10 to $12 per watt at peak and electricity could be generated at 30 U.S. cents/KWh. Other products associated with the systems include lighting appliances, batteries, and pumps. More than 100 enterprises are engaging in their production, mainly located in Gansu and Qinghai provinces. A small hydro industry has been developed to a relatively large scale with approximately 1 million employees. Meanwhile, the mini hydro industry is in expansion with annual sales of 15,000 systems, mainly in the Southwest provinces.

The development of these industries depends largely on the economic viability of these technologies in reality, which is influenced by several factors: the abundance of the energy resources, the demand and willingness to pay by end users, system configuration and performance, system costs, and financial and policy scenarios. Under these factors, the following specific and direct limitations have been identified based on past project experiences in rural China: There are no unified technical standards. Thus, it is difficult to guarantee the product quality with different standards in different regions. In some cases, markets and consumers are confused with bogus products of low quality; most of the companies are inexperienced in getting loans from banks. Therefore, the shortage of capital is a major barrier for companies to expand their sales and improve after-sales services. With China joining the WTO, increasing domestic and international competition is expected, especially for the PV and wind sectors due to their relatively low level of production technology. Markets need to be closely examined and regulated with proper financial means in order to sustain and develop rural energy enterprises, as well as to reflect their true economic benefits.

3.2 Rural Energy and Income Generation: The Biogas and Eco-Farm Model

As mentioned, biogas technology, for providing cooking and lighting fuel for rural households, was disseminated in the 1950s. However, due to the immaturity of the technology and lack of management and maintenance skills, most of the digesters failed to perform soon after being installed. Similar failures were experienced in the 1970s. More than 7 million units were built in just a few years. Despite the potential environment and health benefits of biogas technology, its economic performance was recognized as a key to success. Two variations of biogas system in combination with eco-farming model have been gradually developed in the past 20 years, the Southern model and the Northern model. The Southern model focuses on the utilization of the sludge from the digester as fertilizer, thus, animal stable, a biogas digester, and fruit/vegetable plantation have become components of one "eco farm." On average, production cost per hectare was reduced by US$360. Financial payback of the system is about 4 years. Due to low temperature, biogas use in the north had been limited. In the Northern model, animal stable, toilet, biogas digester, and green house are built on one spot to ensure sufficient and better temperature for animal growth and anaerobic reaction. The initial investment of the Northern model is about US$480 and the payback time is usually within 2 years. According to survey, households installing the Northern model were benefited with US$380 increased income per year. Currently, 210,000 and 81,300 households have adopted the Northern and Southern models, respectively. They produced more than 4 million tons of fruit and vegetable without using chemicals in 1998. By the end of 1999, 6.7 million households were provided with digesters, and their total gas production is around 2 billion M^3 annually.

4. *ENERGY AND RURAL SOCIETY*

Economic reform is changing the social structure and lifestyle of rural population. As part of the overall development in rural communities, the increasing availability of improved energy services has contributed to improved living and working conditions, better education facilities, saved time for other activities and leisure.

4.1 Rural Energy and Gender Equity

Based on the law of China, women and men are equal. While this has greatly increased the social significance of women in the cities, such development in rural areas has been lagging behind. Rural women have been, for centuries, taking care of household duties. They are not only responsible for the well-being of children and other members of the family, but also for the basic daily livelihood, such as food, cooking, feeding, and washing, in addition to helping in the field. With the broadening of economic reform in rural China, mobility and business opportunities largely increased, which led to more and more agricultural laborers, particularly men, transferring to nonagricultural sectors and working in peri-urban and urban factories. As a result, more responsibilities fell upon women. Thus, unless the household burden is alleviated, there will be little chance for true gender equality in rural society. For many rural women, fuel for cooking and heating has been drudgery in terms of time and labor spend on fuel collecting and smoke irritation from fuel burning. A typical rural family of five would require 3000 kg of firewood per year, which would need 80 days to collect, an average of 5 hours per day. Plus another few hours to cook food and feed, many have to work at least 15 hours a day. Women as users have deeply realized the benefits of improving their fuel situation and have been actively initiating and participating in rural energy projects.

The Forest Research Institute of Yunnan province in Southwest China has carried out a comprehensive research on women and rural energy based on case studies in nine different counties in the province. (In Yunnan province, the Forest Department of the provincial government is in charge of rural energy development.) The findings of the study show that although the form and type of technologies vary from project and region, several common achievements can be identified as follows:

- The energy project has brought great benefits to women in terms of health and living environment. The physical workload has been reduced, and in many cases less fuel consumption resulted in savings and more time available for increased opportunities for other activities.
- Decision making on fuel and household expenditures in rural China mostly relies on women. Thus, knowledge about energy technologies and related issues is as essential as active participation in energy projects. These energy projects have provided opportunities of training and self-improvement for many women, which in turn have ensured the success of project/technology promotion and implementation.
- Engaging women in energy projects has been seen as one of the means to increase their self-confidence in taking part in community development and getting involved thereafter in all other fields of rural development, some even becoming a leading force in rural economic reform.

4.2 Rural Energy and Community Development

The lifestyle of rural communities links closely to energy production and use. Issues discussed in previous sections all have a profound and complex impact on rural communities. The availability of modern energy services, such as electricity, heated water, and liquid cooking fuel, has affected rural life as it has in urban areas. It has contributed to the modernized agriculture and rural industries, improved the indoor air quality, enriched life with new information and opportunities, increased the speed of daily rhythm, and changed traditional habits and ideas. Closure of rural coal mines unavoidably seriously affected employment and income generation, directly and indirectly, since these coal mines employed more than 3 million rural laborers and were the main source of fuel for most rural industries where more than 20 million were employed. Moreover, coal has been the economic foundation of half of the coal-producing counties. The communities in these regions are in transition. Social security and training for reemployment are main issues of concern, among others.

Meanwhile, evolution of rural society, such as reduced family size and improved living standards, has in turn challenged the energy supply, technology, and policy. Stove programs in the past have helped millions of households to build stoves for large multigeneration families. Many of them are not used regularly, particularly when gaseous fuels became available and affordable. It is often observed that various types of fuel are used in rural household due to mainly economic and security reasons. More and more agro-residues have been left unused when better quality fuel was available and higher living standard was achieved. The ban of open burning of residues would have to be combined with control and enforcement, which is rather costly. Also it does not provide alternatives to utilize the materials. As already discussed, gasification technology has been demonstrated to be a viable solution. One of the key issues on village scale application is the management of a gasification system. Village communities should be mobilized to either direct management or cooperation with service providers. Fuel supply policies, financial incentives, and energy market should be designed with these issues in mind.

5. LOOKING FORWARD

China's Tenth Five-Year Plan (2000–2005) has set several targets in relation to rural energy. By the year 2005, annual modern renewable energy utilization is expected to reach 13 Mtce (excluding hydroelectricity and traditional biomass). This would avoid 10 million tons of CO_2 and 600,000 tons of SO_2 and particulates emissions. It would also electrify 5 million to 6 million people and provide employment for 200,000 people. Annual production capacity and total installation of solar water heaters are expected to be 11 million M^2 and 64 million M^2, respectively, and for PV, 15 MW, and 53 MW, respectively. Wind power installation is expected to reach 1.2 million KW. Annual production of equipment would be equivalent to $150 \sim 200$ MW capacity. Finally, large-scale biogas application in industries and husbandry and biomass gasification are expected to provide 2 billion M^3 fuel gas.

Compared to energy use in 1998, modern renewable energy utilization will more than double. Although consumption of modern renewables has been increasing fast, financial support remains crucial given the current immature development of the market and business environment. Experiences show that government plays an essential rule in this respect as an enabler rather than a controller. Financial support from all levels of government offices should be rightly focused, catalytic in nature with no distortion of the market, and costs and benefits truly reflected in economic values.

Traditional energy resources in many rural areas have been considered free. This concept does not only undermine the importance of energy efficiency, but also hinders the promotion of clean fuels, such as biogas and producer gas from gasification. Commercial utilization of biomass resources will be an important step toward better resource management, which is essential for sustainable rural development.

With the increasing gap in income and living standards among different rural regions, energy demand varies greater and greater from area to area. Income for farmers without any other source of income, accounting for 68% of total rural households, has been decreasing in 1999 and 2000, while the national average of rural income has increased 2%. Lower income households, most likely, will still rely on traditional biomass fuel, whereas, higher income farmers will demand modern and clean energy services. Rural energy policy and technology will need to be diverse and locally customized.

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