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## Solid Fuel Use in Rural China and Its Health Effects

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**Abstract:** Solid fuels such as firewood and coal are widely used for cooking and heating in the developing countries, which result in serious indoor air pollutions and health effects. Governments and international organizations have been devoted to addressing this issue for a long time. Based on the micro survey data from 1989–2011, this paper quantitatively investigate the situations and evolutions of cooking fuel using and its health effects in rural China. We have four findings: (i) most rural households still rely on solid fuels for cooking in modern China. ii) the cooking fuels are slowly diversifying in the last two decades, (iii) there are considerably geographical differences in cooking fuel using across China, and (iv) those resident usually using solid fuel have lower levels of self-assessed health and higher prevalence of respiratory diseases. We then draw some policy implications to reduce cooking fuel use.

**Keywords:** rural residents; solid fuel; indoor air pollution (IAP); cooking; health

## 1. Introduction

Indoor air pollution (IAP) induced by solid fuel using in the rural daily life is usually ignored [1, 2]. Solid fuel generally includes traditional biomasses (wood, animal dung, agricultural residues, etc.) and coal, which is widely used for cooking and heating in developing countries. IAP, sometimes called household air pollution, has serious adverse effects on residential health [3]. According to a worldwide estimation by the World Health Organization (WHO) [4], the IAP produced by solid fuel using leads to 35.7% of all lower respiratory infections, 22% of the chronic obstructive pulmonary disease, 1.5% of tracheal, bronchial, and lung cancer, and 2.7% of the loss of disability adjusted life years (DALYs). The most recent Global Burden of Disease (GBD) project [5] estimated that there about 3.55 million people in 2010 prematurely died of household air pollution caused by solid fuel using. Moreover, this team found that IAP is the world third largest disease burden (just preceded by hypertension and smoking). The World Bank [6] data showed that there about 2.8 billion people worldwide used solid fuels for daily cooking and heating in 2013, of which rural population accounted for 78%. The wide use of solid fuels and unavailability of modern clean fuels, as manifestations of energy poverty, are important issues need to address around the world, especially in the developing countries [7-11].

Incomplete combustion of solid fuels in a simple/traditional stove (refers to those without chimney or grate) produces a large amount of harmful material, including carbon monoxide, oxides of nitrogen and sulfur, hydrocarbons, and inhalable particulates, etc. As the main components of IAP, these harmful pollutants have serious adverse effects on household health. Smith et al. [12] have continuously studied the IAP for decades. Usually, women are responsible for most of the cooking, and children often accompany their mothers during cooking. Therefore, women and children are possibly in higher health risk.. WHO [4] reported that indoor smoke resulted in 2.8% of the loss of DALYs for women, which was higher than that for men (2.5%). WHO data [13] showed that indoor air pollution accounts for more

than 50% of Children's deaths to pneumonia in children less than five years of age.

Though China has achieved great success on universal household electricity access and become one of the upper-middle-income countries (according to World Bank Classifications), there about 59% and 17% of rural households still mainly use firewood and coal for cooking in 2010, respectively [14]. Some researchers have studied the cooking fuel situation in China. Tang and Liao [14] investigated the energy poverty and solid fuels use based on national population census (statistical) data. Sinton et al. [15] and Edwards et al. [16] examined stove improvements in China's rural households. Zhang and Smith [17] reviewed more than 200 Chinese and English papers relating to household solid fuel use and connection with health. However, most historical and current researches are focused on a specific county, town or village, which are not the representative sample of China. In addition, these studies usually employ one year or short term data, which fails to find the evolutions of cooking fuels and health effects in the long term. In this paper, we try to address this issue using a large-scale longitudinal household survey dataset. In section 2, we will describe the dataset and methodology in detail.

## **2. Data and methodology**

All the data used in this study was sourced from the China Health and Nutrition Survey (CHNS). The CHNS is a large-scale social health survey jointly conducted by the University of North Carolina at Chapel Hill and the Chinese Center for Disease Control and Prevention. The survey questionnaires include variables about household, nutrition, health, adults, children, and community, etc. and the data files that link longitudinally households and individuals are easy to statistically analysis. The survey has been conducted for 9 times (in 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, and 2011) and will be continued. According to the survey introduction, CHNS covers nine provinces (Liaoning, Heilongjiang, Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi, and Guizhou), which substantially vary in geography, economic development, natural resources (see Fig. 1). They are the representatives of China to some

extent. The multistage, stratified and random cluster sampling was used to draw the villages and townships samples in each province. For more details about the sampling process, please see the website <http://www.cpc.unc.edu/projects/china>. After excluding the households with missing or abnormal values, we get the valid samples by year ( Fig. 2)<sup>1</sup>.

<Insert Fig. 1 here>

<Insert Fig. 2 here>

Though CHNS has a large panel dataset (about 4,400 households with 19,000 individuals), there are few variables related to cooking fuel selection and impacts. In addition, most of these variable are 0-1 ones. It is difficulty to use econometrical methods. Therefore, in this paper we will mainly employ the descriptive statistics to investigate the cooking fuel evolution and its health effects. First, we analyze the static situations of cooking fuel use in 2011 (the latest survey). Subsequently, we examine the evolutions of cooking fuel in 1989-2011. Based on the historical trend, we calculate a Markov transition matrix and forecast the future household distribution in cooking fuel using. Finally, we investigate the health effects especially the respiratory disease burden possibly related to indoor air pollution induced by solid fuel use.

CHNS questionnaire divides the cooking fuels into 8 sub-groups: 'coal', 'electricity', 'kerosene', 'liquefied petroleum gas (LPG)', 'natural gas', 'charcoal', 'wood, sticks and straw', and 'others'. In this paper, 'charcoal' is combined with 'wood, sticks and straw', and referred to as 'traditional biomass' or 'biomass' in brief. In addition, since only few rural households use kerosene for cooking in the sample (possibly data record mistakes), we include kerosene into 'others'. Therefore, cooking fuels in this study

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<sup>1</sup> According to the CHNS, rural households / residents refer to those residing in village areas (Cun or Xiang) and townships (Zhen). Urban Site includes urban (or city) and suburban neighborhoods (Shi and Jiaoqu). With this definition we consider a household / resident to be rural or urban.

has 6 types: coal, traditional biomass, natural gas, LPG, electricity, and others. In the cases where no special explanation is required, the term 'solid fuel' in this study merely refers to coal and traditional biomass.

The questionnaire requires answering two kinds of fuel for cooking: the most often used is referred to the primary cooking fuel, and the second most often used is referred to the secondary cooking fuel. If a household only uses one cooking fuel, then that fuel is the primary cooking fuel and there is no secondary cooking fuel. Therefore, we divide the cooking fuels into four combinations: 'solid fuel + solid fuel (S + S)', referring to the primary and secondary fuels are both solid ones (or merely use solid fuel), 'solid fuel + non-solid fuel (S + N)', 'non-solid fuel and solid fuel (N + S)', and 'non-solid fuel + non-solid fuel (N + N)'. The explanations of the latter three are similar to the first one..

### **3. Cooking fuel use in 2011**

#### **3.1. Fuel choice**

Fig. 3 shows the proportions of rural residents by cooking fuel choice in 2011 (without distinguishing between primary and secondary cooking fuels). There respectively 25% and 35% rural residents use solid fuel (coal and biomass) for cooking. Residents using electricity and liquefied petroleum gas account for 69% and 48%, respectively (some household use both of them). However, the data implies that about 55% of the residents are still using solid fuels (coal and biomass) for cooking and so rural residents are still strongly dependent on these fuels<sup>2</sup>.

[<Insert Fig. 3 here>](#)

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<sup>2</sup> Considering that some residents simultaneously use coal and biomass for cooking, the figure cannot be simply obtained by summing the population proportions.

### **3.2. The relation between cooking fuel choice and income**

China has made great achievement on increasing the residential income in the last three decades. More and more residents are affordable for modern clean and commercial fuels. As a result, they have substituted solid fuels with clean fuels for cooking. Fig. 4 shows the relations between fuel type choice and income in 1989-2011 by province. Cross sectional analysis shows that provinces with higher household income have lower proportion of households using solid fuels. Longitudinal analysis show that about 94% households using solid fuels for cooking in 1991, while this figure has dramatically dropped to 58% in 2011. During this period, household income has increased from 2,596 Yuan to 12,352 Yuan. We may safely predict that the roles of solid fuels will continually decreasing in the future due to the rising income.

[<Insert Fig. 4 here>](#)

### **3.3. Provincial differences on rural cooking fuel use**

Cooking fuels significantly vary in provinces. Except for the household income, the geography and natural endowment account for the cooking fuel choice. As indicated in Fig. 5, In Guizhou, a southwestern province in China, and rich in coal resource, 22% and 40% of the rural residents use coal as primary and secondary cooking fuel, respectively. While in Jiangsu, a eastern province in China, 62% and 85% of the residents use electricity and liquefied petroleum gas for cooking, respectively. However, in Heilongjiang, more rural residents use biomass for cooking as they are rich in firewood resources. Thanks for the central government's effort on significantly increasing electricity access and dramatically reducing electricity price in rural China, electricity is more and more widely used for cooking in all provinces. In Liaoning, more than half of the rural residents rely mainly on electricity for cooking. According to the government's ambitious



target, it is expected that by the end of 2015, all the residents in China will have access to electricity [18].

In addition to electricity, liquefied petroleum gas is also selected by a number of residents for cooking in each province. In Chongqing, Shandong, and Guangxi, etc., there many residents use natural gas (biogas) for cooking.

<Insert Fig. 5 here>

#### **4. Cooking fuel transition from 1989 to 2011**

##### **4.1. The diversification of cooking fuels**

Thanks to the increasing fuel alternatives especially the commercial fuels such as electricity, liquefied petroleum gas, household cooking fuels in rural China are becoming diversified. More and more rural residents have simultaneously adopted two or more fuels for cooking (See Fig. 6). Before 1993, most of the household could only select coal and biomass. Almost all the rural resident did not use electricity for cooking in earlier years. In 1998, due to the overcapacity of power generation induced by the economic recession, the central government has launched a large project of upgrading the rural power grid, aiming to improve the electricity universal service and reduce the electricity price. This project was accomplished in 2002. As a result, electricity access is dramatically increased and much more reliable than before, and the rural electricity price significantly declined by about 30-40% and was equal to the urban. Since then more and more electric facilities have been equipped in the cooking room. For example, electric rice cooker ownership increased considerably according to the survey data of 2000 and 2004 (See Fig. 7).

<Insert Fig. 6 here>

<Insert Fig. 7 here>

#### 4.2. Provincial comparisons

The evolution of cooking fuel choice varies in economic development, energy resource endowment and price, and residential habits. Fig. 8 and Fig. 9 show the evolution of coal and biomass use by province in the 22 years. As shown in Fig. 8, the proportion of rural residents that use coal for cooking peaks in Guizhou, followed by Henan and Hunan. And that, the proportions in all three provinces present annually decreasing trends. In other provinces, the proportions are smaller in comparison.

<Insert Fig. 8 here>

Consistent with the trend in coal use, the proportion of rural residents that used biomass as a cooking fuel also decreased slightly year-on-year, as shown in Fig. 9. However, the provinces with high coal use (Guizhou, Henan, and Hunan), show a relatively lower proportion of rural residents using biomass as cooking fuel. Excluding these three provinces, there are a large number of rural residents using biomass as cooking fuel in other provinces, especially in Jiangsu and Heilongjiang.

<Insert Fig. 9 here>

With the continuous decrease in solid fuel use, the use of electricity in rural areas presents a constantly rising trend (Fig. 10). The proportion of electricity choice in rural has rapidly increased since 1997. In 2011, nearly 90% of the rural residents in Guizhou Province used electricity for cooking. Unfortunately, the proportion of rural residents using electricity is still low in some provinces. For

example, this figure is only 30% in Shandong in 2011.

<Insert Fig. 10 here>

#### **4.3. The transition matrix of cooking fuel choice**

Cooking fuel transitions is driven by income, education, employment, technology, and infrastructure access, and fuel price. As Zhang and Hassen found that, higher coal price is associated with a lower probability of using coal, but a higher probability of using liquefied natural gas or firewood for cooking [19]. In addition, since rural residents have become more concerned on the health effects, they have been more likely to use clean fuels for cooking (liquefied petroleum gas and electricity, etc.). Fig. 11 is the transition matrix of the primary cooking fuel used by rural households from 1989 to 2011.

<Insert Fig. 11 here>

As shown in Fig. 11, 46.7% (summing all the figures in the first row) and 23.5% (summing all the figures in the second row) of the rural resident respectively used coal and biomass as primary cooking fuels in 1989. 10.6% of the households used coal as their primary cooking fuel in 1989, and didn't change their cooking fuel choice in 2011. The other 2.3%, 9.5%, 2.8%, and 20.9% of the households surveyed used coal in 1989, but in 2011 they chose biomass, liquefied petroleum gas, natural gas, and electricity as their primary cooking fuel, respectively. Meanwhile, 3.9% and 9.6% of the households surveyed that used biomass in 1989 chose liquefied petroleum gas and electricity as the primary cooking fuel in 2011, respectively. In other words, more than 2/3 of the households surveyed using coal and biomass (solid fuel) in 1989 chose liquid gas, natural gas, and electricity (clean fuels) as their primary cooking fuel in 2011.

Considering the importance of secondary cooking fuels used for rural households, we combine both of them and analyze the transitions. Fig. 12 displays the transition matrix from 1997 to 2011. Only 8.8% households that used solid fuels for cooking in 1997 sustained their choice in 2011. The other 20.3% used solid fuels in 1997, while in 2011 they converted to completely using non-solid fuels for cooking. In general, most of the rural households tended to choose clean and efficient cooking fuels. According to this transition matrix, if in the next 14 years the transition rate is the same with that in the past 14 years (1997-2011), we can figure that there will be 65.6% rural household use non-solid fuel for cooking in 2025. This is not an optimistic figure. It means that the government should continue to make the efforts on improve the residential cooking fuel use.

<Insert Fig. 12 here>

## **5. The health effects of household solid fuel use**

The foregoing analysis shows that there were, and still are, a large number of rural residents using solid fuels (biomass and coal) as their primary cooking fuels in rural areas of China. Solid fuels give rise to copious amounts of poisonous emissions and inhalable particulates when burned in stoves without chimney or grate, and this leads to serious IAP. As a result, solid fuels have become one of the major health risk factors. In addition, as women are mainly responsible for cooking activities, they suffer the most serious hazards.

### **5.1. Household solid fuel and resident health status**

We investigate this issue using residential self-assessed health data collected by the CHNS. The questionnaire asks that *'right now, how would you describe your health compared to that of other people your age'*, and the respondents can choose only one answer from the five choices: *'excellent', 'good', 'fair',*

'poor', and 'unknown'. Since the question was excluded from the survey after 2006, we only employ health data in 2006. Considering the relatively the hysteresis of the effects, we apply tracking data from 2000 to 2006. The aim is to analyze the health statues of the adult (i.e. those aged 18 years or older in 2000) in 2006 considering whether they used solid fuels or not in 2000.

#### **5.1.1. Solid fuel, gender and health status**

We have a sub-dataset of 4773 observations with health related information. The rural residents that used 'solid fuel + solid fuel (S + S)', 'solid fuel + non-solid fuel (S + N)', 'non-solid fuel and solid fuel (N + S)', and 'non-solid fuel + non-solid fuel (N + N)' for cooking amounted to 2,499, 964, 628, and 682 in 2011, respectively.

As shown in Fig. 13, the residents who only used solid fuel for cooking present a relatively poorer health condition compared to those who did not solely use solid fuel. Of the 1,202 male residents using entirely solid fuel for cooking, only 12% considered that their health condition was 'excellent' and 45% expressed 'good'. These two figures are both lower than those for male residents using other fuel type. As is the case with the male, female relying on solid fuel for cooking have inferior health compared to those using non-solid fuels.

[<Insert Fig. 13 here>](#)

In addition, among the household using various kinds of fuels for cooking, the proportions of males indicating their good and excellent health conditions are all higher than those of females. One possible reason for this lies in the fact that the females in rural areas are more frequently engaged in cooking activities than the males. Therefore, females are more exposed to the IAP than males. The health condition of the females is thereby inferior to that of the males. The data in 2000 suggests that more than

80% of adult females bear the responsibility for the family's cooking duties. This figure is dramatically higher than that of males (only about 20%).

### **5.1.2. Exposure level and health status**

We further analyze the correlation between the degree of exposure to IAP and the residents' health condition. As shown in Fig. 14, those performing cooking activities show a significantly poorer health condition compared with the residents that do not. Of the rural residents that only used solid fuels and carried out cooking services, 6% and 41% considered themselves to have 'excellent' and 'good' health conditions, respectively. And for those that merely used solid fuels but did not engage in cooking activities, these figures increase to 13% and 45%, respectively. For the residents using other fuel types, the relative health conditions also show the same characteristics. This result further evidence that those residents performing cooking services (and thus being exposed to IAP for longer time) suffer higher hazards caused by solid fuel use.

<Insert Fig. 14 here>

### **5.1.3. House sanitation and health status**

Studies have shown that poor housing sanitation has a negative health effect [20-22]. As Fig. 15 shows, whichever cooking fuel is used, on the whole, the health status of rural residents living in favorably sanitized conditions is slightly higher than that in poor ones. Of the residents only using solid fuels for cooking, 54% of those living in favorably sanitized conditions considered that they had 'excellent' and 'good' health. This figure is significantly higher than that in poorly sanitized conditions. However, among the residents only using non-solid fuels for cooking, the health condition of residents living in poor conditions unexpectedly is superior to that of those living in good sanitary conditions. A possible reason

for this is that there are probably other factors influencing the sanitation state..

<Insert Fig. 15 here>

## 5.2. Household solid fuel use and respiratory disease

Since IAP from solid fuel exerts a significant effect on adults as well as the hysteresis of such effects, we employ tracking data from 2000 to 2011. The aim is to analyze the prevalence of respiratory disease among adult rural residents (i.e. those aged 18 years or older in 2000) in 2011 considering whether they used solid fuel or not in 2000. After processing the data, we have a sample containing 3982 rural adults. In this sample, 2154, 800, 505, and 523 adults used 'solid fuel + solid fuel (S + S)', 'solid fuel + non-solid fuel (S + N)', 'non-solid fuel and solid fuel (N + S)', and 'non-solid fuel + non-solid fuel (N + N)' for cooking, respectively. Fig. 16 shows the incidence of respiratory disease among the rural adult residents using the various types of cooking fuel.

As shown in Fig. 16, residents using solid fuels for cooking have a higher rate of prevalence of respiratory disease compared to those using non-solid fuels. In the 4 weeks before the survey, 35 residents developed respiratory system diseases per 1,000 residents using solid fuels as PRIMARY cooking fuels. This figure is similar to that ONLY using solid fuels (32 per 1,000 residents). This result shows that the health conditions of residents mainly using solid fuels are slightly different to those exclusively using solid fuels. However, there 20 and 18 residents have respiratory diseases per 1,000 residents when 'N+N' and 'N+S' were used for cooking, respectively. These two figures are significantly lower than those of the residents using 'S+S' and 'S+N'. Therefore, solid fuel use is closely correlated with incidence of respiratory system disease. Therefore, IAP caused by solid fuel combustion may be one of the key factors inducing respiratory system disease.

<Insert Fig. 16 here>

Consistent with the self-rated health conditions, female has a lower health level than the male. As shown in Fig. 16, except for the female using 'N+N', the prevalence rates of respiratory disease among females using 'S+S', 'S+N', and 'N+S' for cooking are significantly higher than that for males. In particular, among residents using 'S+S' for cooking, the disease prevalence rate for female is almost twice that for male. Therefore, the higher respiratory system disease prevalence rate in female (compared with that in males) is possibly and partly due to the adverse effects of the polluted air induced by the solid fuel combustion.

Fig. 17 further illustrates the close connection between exposure of the residents to polluted air and the prevalence rate of respiratory diseases. In the household using 'solid fuel' for cooking, during the 4 weeks before the survey, there about 2.3% resident suffered respiratory diseases among those not performing cooking activities. While this figure is just half that of the residents that used 'solid fuel' for cooking and did perform cooking activities. In addition, the morbidity rate among the residents that used 'solid + non-solid' and 'non-solid + solid' appears to the same difference. That is, among the residents that used 'solid fuel' for cooking, those that performed cooking services has a higher morbidity rate.

<Insert Fig. 17 here>

The analysis above implies that there many health effects due to solid fuel use and these effects are correlated to many other factors such as cooking equipments and habits, the health preferences of residents, etc. A simple descriptive statistical analysis can, however, only yield limited and simple



conclusions. It is our intention that the causal effect between solid fuel and health will be more rigorously investigated in future research.

## **6. Conclusions and policy implications**

### **6.1. Conclusions**

#### **6.1.1. The cooking fuel are diversifying and more clean in rural China**

In 1997, only about 42% of rural residents used two or more different kinds of cooking fuel. While by 2011, the proportion had grown to over 80%. In addition, the cooking fuel is transiting to the clean ones such as electricity, liquid petroleum gas due to the increasing accessibility and affordability. The proportion of households that use solid fuel fell from 93.6% in 1991 to 57.5% in 2011. Solid fuel use varies in provinces due to differences in resource endowment and economic development. There is still a long way to improve the cook fuel in rural China.

#### **6.1.2. Solid fuel results in negative health effects on resident**

Of the 2499 rural residents who only used non-solid fuels for cooking, those considering themselves to be in 'excellent' and 'good' health condition accounted for 9% and 43%, respectively. These two figures are both lower than those for residents using other cooking fuel types. In addition, residents using solid fuels for cooking are more likely to have respiratory diseases.

### **6.2. Policy implications**

#### **6.2.1. Improve modern energy services varied in local conditions**

The IAP produced by the solid fuels combustion has great harm to the human health [3-5]. Electricity is universal access in rural China. However, due to the diet culture such frying, quick and hard fire is welcome in China's household cooking. Therefore, electricity is suitable for staple food cooking such as rice and steamed bun, but not for vegetable or meat cooking. If the household has liquid petroleum gas (LPG) or natural gas access, this may be helpful to transit from solid fuels. Due to the restrictions of

geography and resource endowments, LPG may be the potential alternative in many rural area.

### **6.2.2. Promote clean stoves and improve health education concerning IAP**

There still a large number of rural households use simple traditional biomass and coal stoves (and even open fires) for cooking in rural China [15]. There is much potential to improve the stoves and teach the resident use them correctly. However, a research report from World Bank pointed out, in addition to subsidy limitations and products of poor quality, etc., a lack of public awareness of the benefits of clean stoves is the biggest obstacle to such a promotion [23]. Due to their ignorance of the health risks associated with IAP and the important role of clean cook-stove, many residents lack the enthusiasm to invest and adopt improved stoves. The health education associated with indoor air pollution and solid fuel use is necessary.

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**Figures**



Fig. 1. The distribution of the provinces involved in the survey.

**Notes:** This figure is just for illustration; it does not represent an accurate measurement of the administrative divisions.

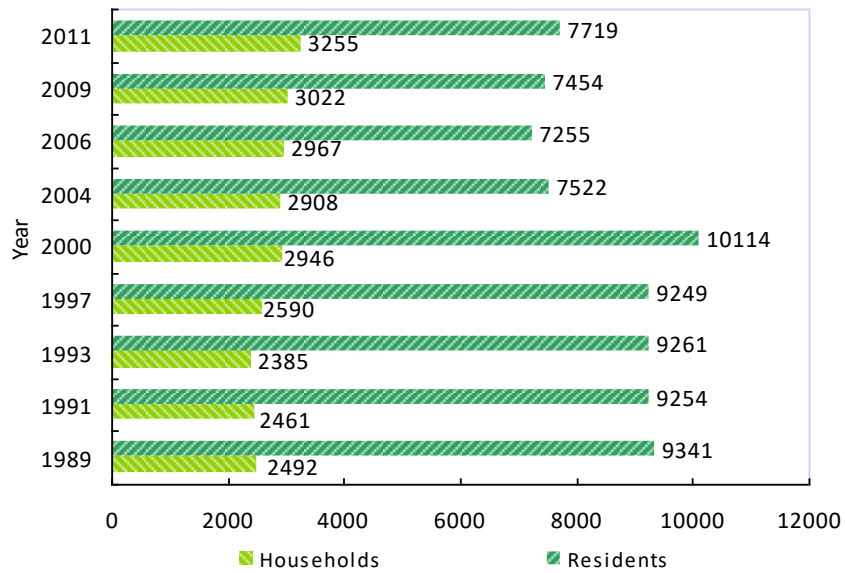


Fig. 2. Sample sizes of rural households and residents of the survey.

**Notes:** The 1997 data excludes the Liaoning Province and that in 1989, 1991, and 1993 excludes Heilongjiang Province. The 2011 data includes the rural resident population of Chongqing but excludes those in Beijing and Shanghai.

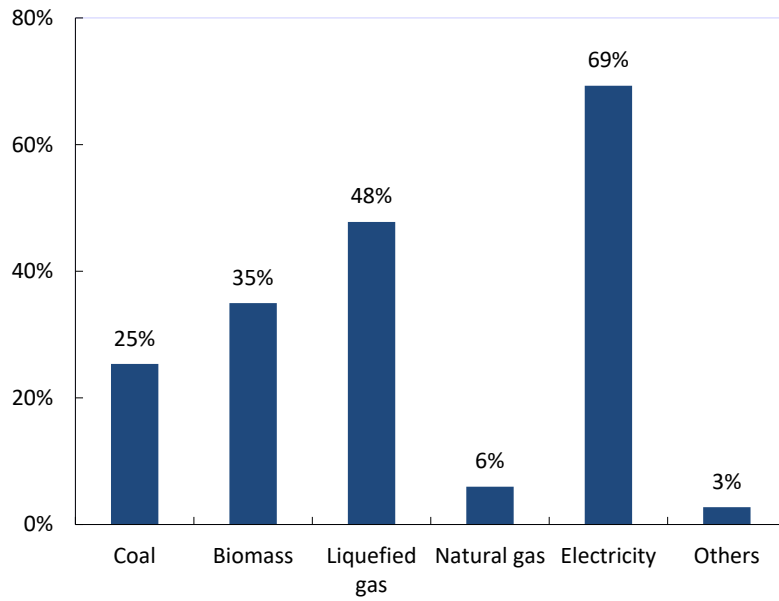


Fig. 3. The proportion of residents using various types of cooking fuels (in 2011).

**Notes:** It does not distinguish between primary and secondary cooking fuels. That is, residents using various fuels as primary or secondary cooking energy are considered.

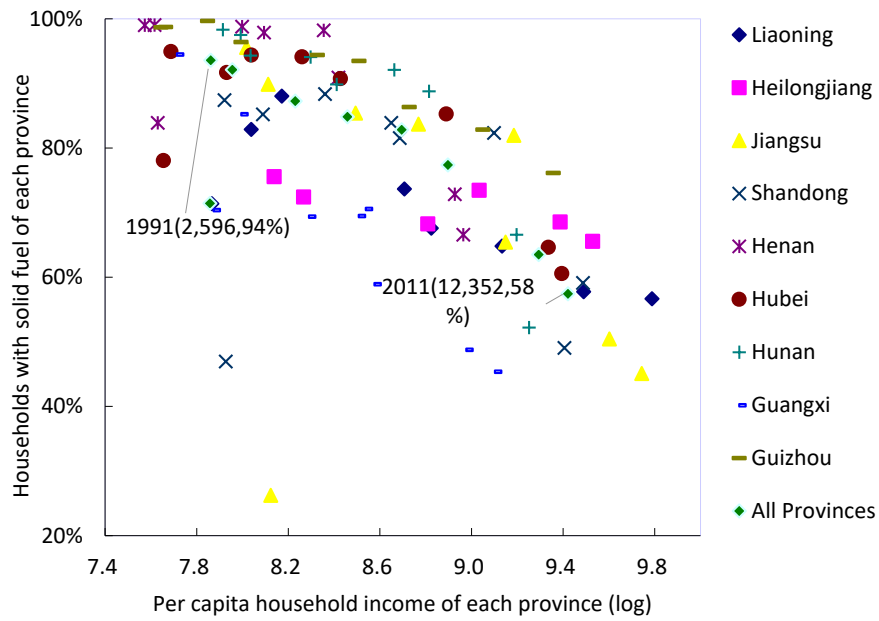


Fig. 4. Rural household selection for solid fuel and their income.

**Notes:** Households using solid fuels as primary or secondary cooking energy are considered. The 'All Provinces' data points reflect the overall situation of the 9 provinces in the survey. The per capita household income was real income that calculated by inflation index on the base period of 2011 and the nominal per capita household income year, which was obtained directly from the CHNS.



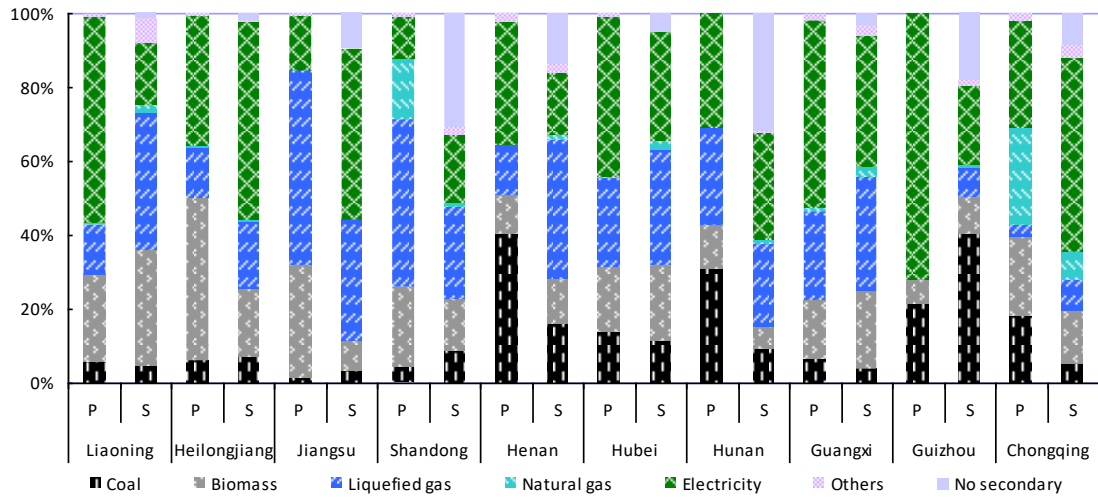


Fig. 5. The proportion of residents using various types of cooking fuels in 2011, by province.

**Notes:** The terms 'P' and 'S' in this figure refer to the primary and secondary cooking fuel used by the rural residents, respectively.

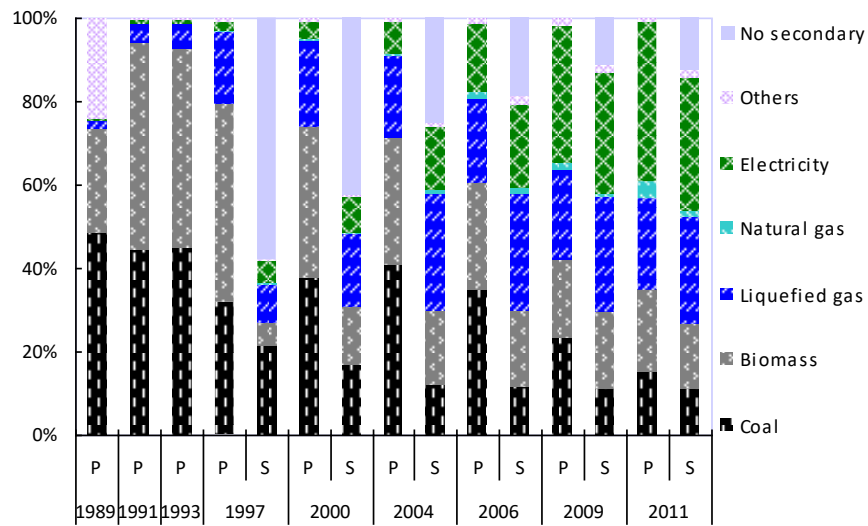


Fig. 6. The proportion of residents using various types of cooking fuels in each year of the survey.

**Notes:** In 1989, 1991, and 1993, secondary cooking fuels were not investigated. Therefore, this figure does not display data concerning secondary cooking fuel used by the rural residents in these three years.

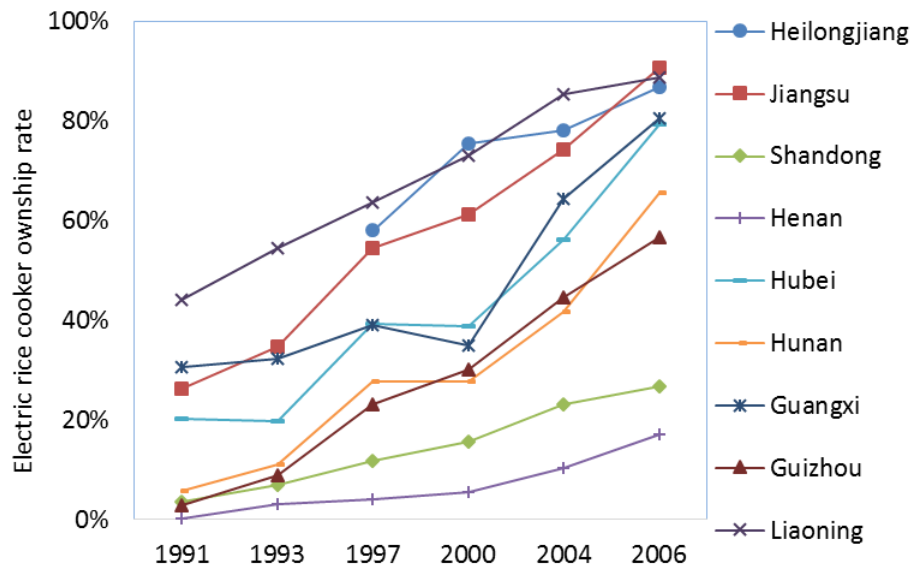


Fig. 7. Electric rice cooker ownership rate in rural household by province

**Note:** CHNS did not collect the data in 1989, 2009 and 2011.

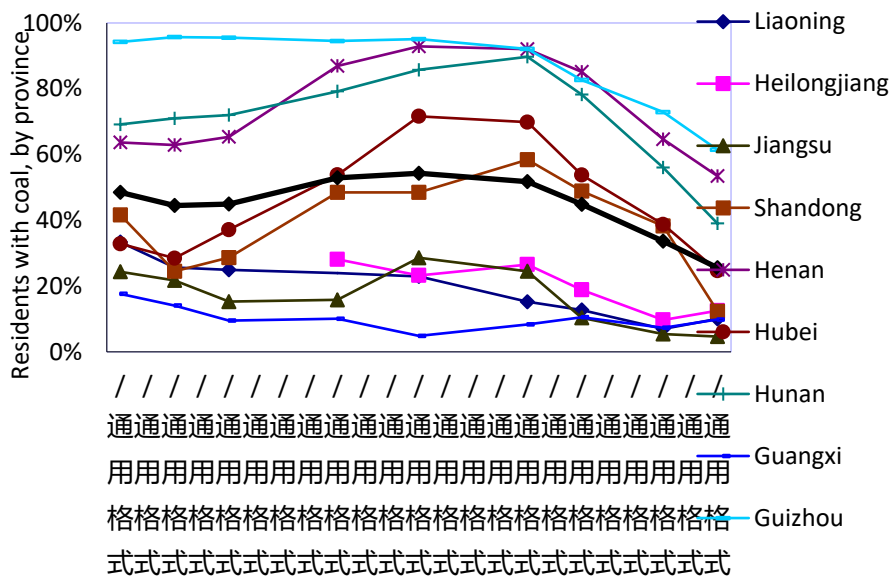


Fig. 8. The variation in the proportion of residents using coal during 1989–2011.

**Notes:** In 1997, Liaoning Province was excluded from the survey; in 1989, 1991, and 1993, Heilongjiang Province was excluded. Therefore, there are no data points for these two provinces in these years. Residents using coal as primary or secondary cooking energy are all taken into consideration.

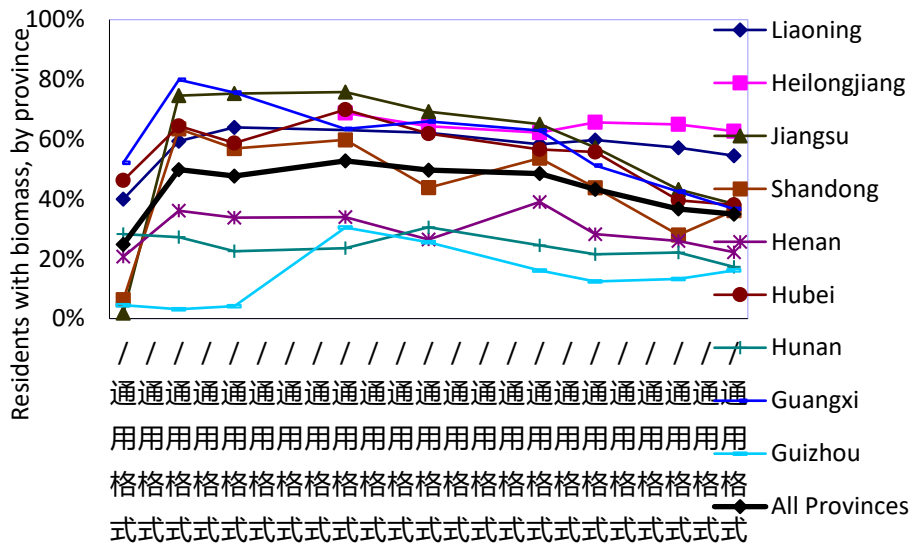


Fig. 9. The variation in the proportion of residents using biomass during 1989–2011.

**Notes:** Residents using biomass as primary or secondary cooking energy are all taken into consideration.

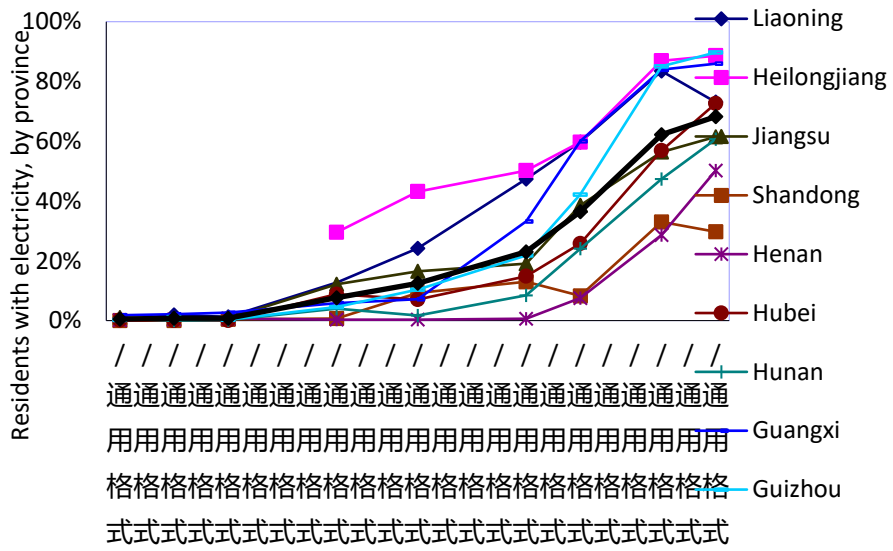


Fig. 10. The variation in the proportion of residents using electricity during 1989–2011.

**Notes:** Residents using electricity as primary or secondary cooking energy are all taken into consideration.

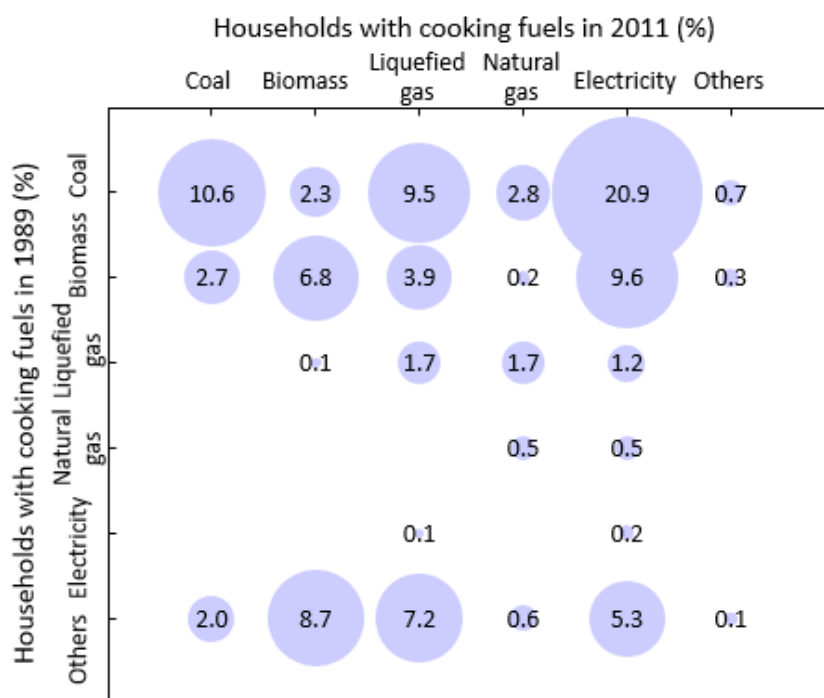


Fig. 11. Transition matrix showing the household selection changes for the primary cooking fuels (%).

**Notes:** The data was obtained by CHNS from 2,094 rural households tracked from 1989 to 2011. The abscissa and ordinate represent the various cooking fuels used by rural households in 2011 and 1989, respectively. The data represents the rural households using certain kinds of primary cooking fuel in 1989 and 2011 as a percentage of the total number of rural households surveyed (2,094). The areas of the bubbles are proportional to the corresponding percentages.

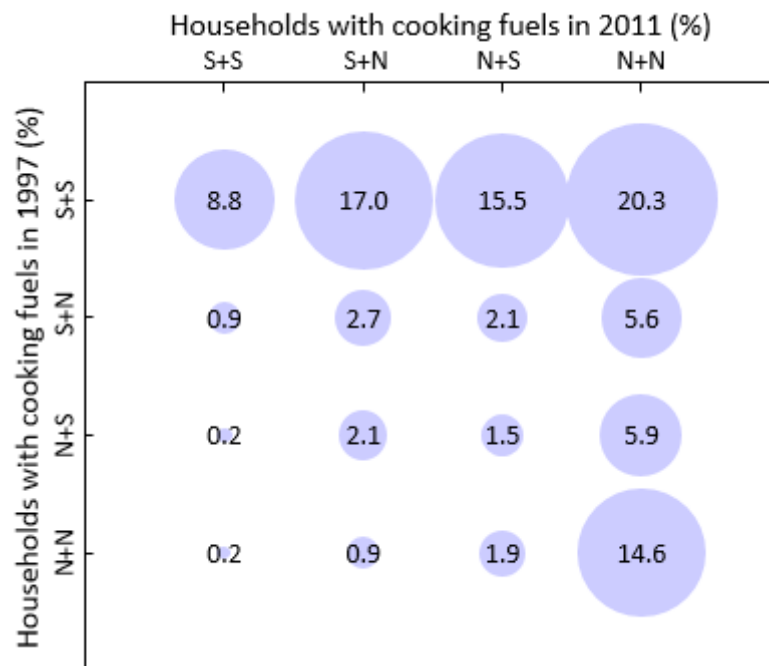


Fig. 12. Transition matrix showing the household selection changes for cooking fuels (%).

**Notes:** The data was obtained by CHNS from 2,522 rural households tracked from 1997 to 2011. The abscissa and ordinate represent the various cooking fuels used by rural households in 2011 and 1997, respectively. The data represents the rural households using certain kinds of fuel for cooking in 1997 and 2011 as a percentage of the total number of rural households surveyed (2,522 households). The areas of the bubbles are proportional to the corresponding percentages.



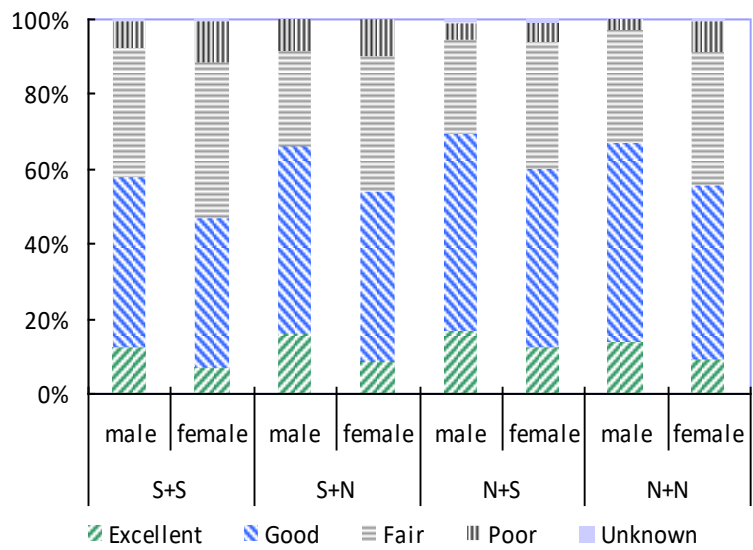


Fig. 13. The gender differences of residents' health status.

**Notes:** The data is composed of the use of cooking fuel data for rural adult residents in 2000 and the self-rated health condition of these residents in 2006.

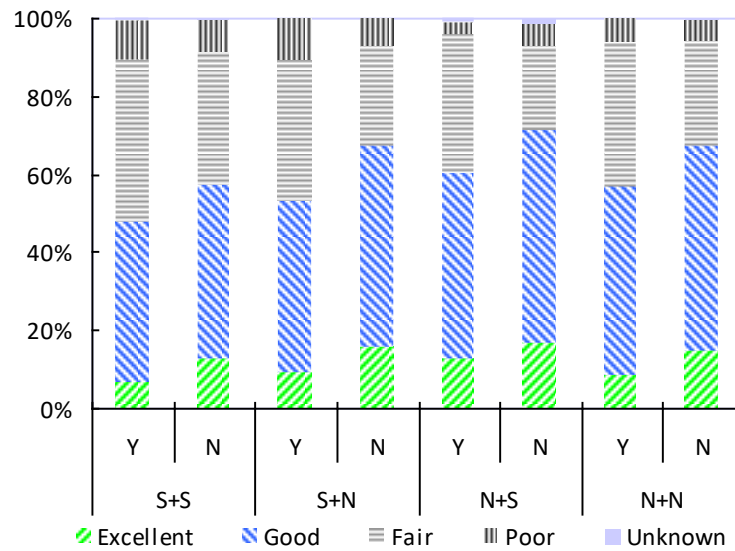


Fig. 14. The health status of residents in different exposure levels.

**Notes:** The data is composed of the use of cooking fuel and cooking activity data for rural adult residents in 2000 and the self-rated health assessments of these residents in 2006. The term 'Y' in this figure refers to a resident engaging in cooking activities, and the term 'N' refers to a resident does not engage in cooking activities.

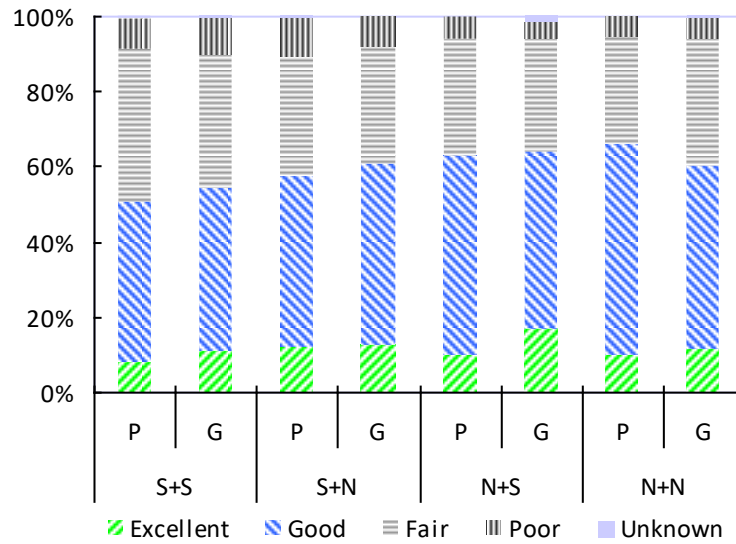


Fig. 15. The health status of residents in different house sanitation.

**Notes:** The data is composed of the use of cooking fuel and house sanitation data for rural adult residents in 2000 and their self-assessed health condition data from 2006. Residents with excreta around their dwelling place (rarely, some, or much) are classified as the households living in poor house sanitation ('P'); those without excreta around their dwelling place are classified as living in good house sanitation ('G').

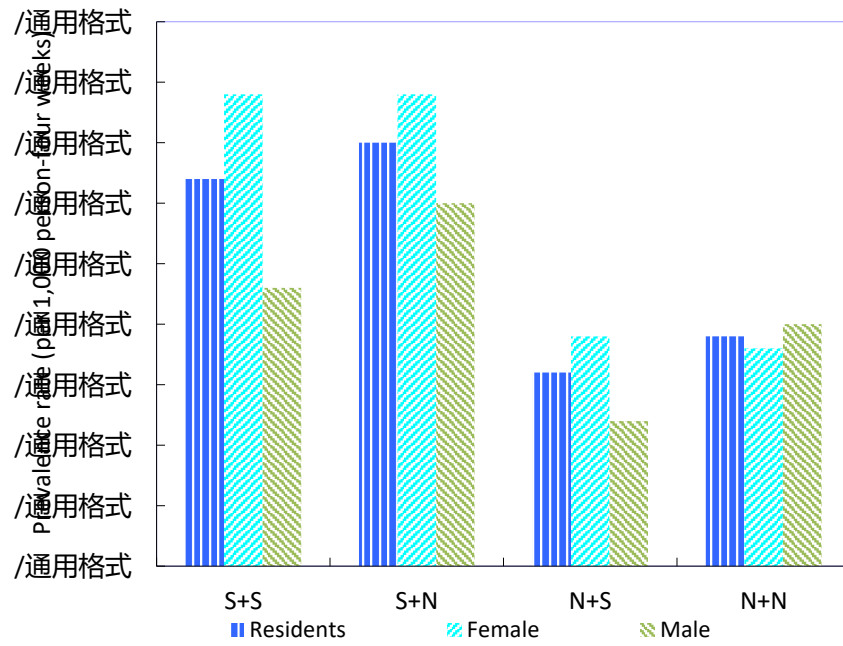


Fig. 16. The prevalence of respiratory disease of residents using various types of fuels.

**Notes:** The data was compiled using cooking fuel use data from 2000 (for rural adult residents aged 18 or older) and respiratory disease data from 2011.

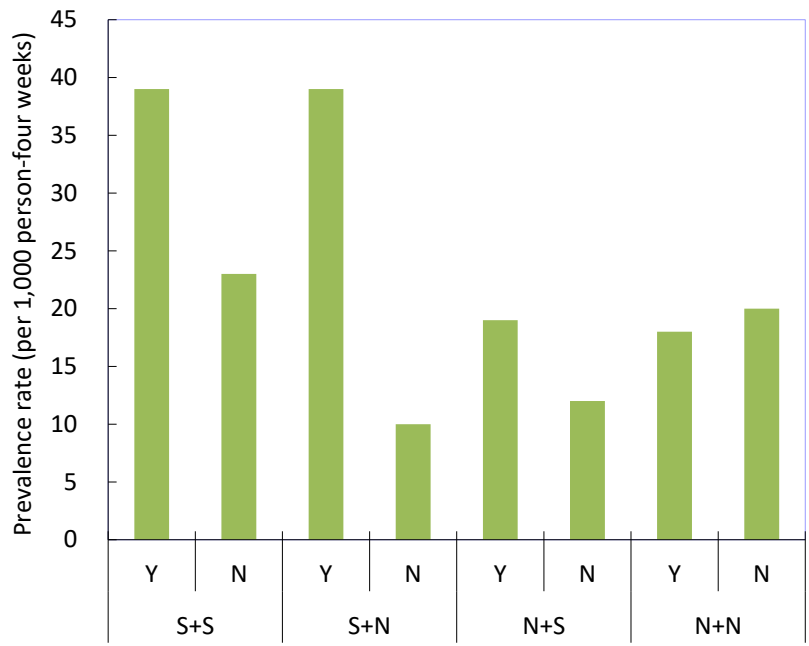


Fig. 17. The prevalence of respiratory disease in different exposure levels.

**Notes:** The data is compiled from cooking fuel use data from 2000 (for rural adult residents aged 18 or older) and the prevalence rate of respiratory diseases from 2011.