Assessing the social benefits from a small-scale biomass stove program

A case study from Guizhou Province

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PROJECT MANAGER'S PREFACE

This report is the Master Thesis in economics of Han Xianyu, which was approved September 22, 2010. Han Xianyu wrote the thesis while being a Research Assistant at Vista Analysis. It is a contribution to the project *Indoor air pollution – A neglected poverty related cause of globall ill health – implications for public health and society of promoting clean household fuels in China*, which is implemented by CICERO and Vista Analysis on behalf of the Norwegian Research Council.

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Haakon Vennemo

Project Manager Vista Analysis AS

Content

AUTHOR'S PREFACE

First of all, I would like to express my sincerest gratitude to my supervisor, Dr. Haakon Vennemo, I am extremely grateful for his guidance in my studies and the great offer for me to participate in the project 'Indoor air pollution. A neglected poverty related cause of global ill health'. I must make grateful acknowledgement to the financial support from Vista Analyse for this thesis. I would like to thank Haakon Vennemo, for his patient help, simulating suggestions and insightful comments that guide me throughout the writing of the thesis. Without his invaluable help in all respects, this thesis would never have been completed.

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Xianyu Han

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ABSTRACT

This thesis uses a cost-benefit analysis to compare the benefits and costs generated from the implementation of new biomass project in rural of Guizhou. The benefited population is mainly the user of traditional and old improved stoves. Base on the epidemiologic studies, the results of the simulation demonstrated that for these two types of users, there is significant reduction of the excess mortality risk from Cardiopulmonary Diseases (CPD). This health improvement is even larger for the traditional stove users. From the results of the cost-benefit analysis, there are positive net benefits for both cases which mean the stove project is advisable. Consistent with the health improvement, users of the traditional stoves will be benefited more from this intervention compared with the households using old improved stoves. These results support the approval of the stove project for mitigating the indoor air pollution.

The results of the sensitivity test also demonstrate that the emphasis should be put on the standardization of the stove production and setting up the criteria of new biomass stove. Since the implementation of the intervention will be more beneficial with the efficient and suitable biomass stoves.

LIST OF ABBREVIATIONS

ALRI – Acute Lower Respiratory Infections

CAREI – China Association of Rural Energy Industry

CB – Chronic Bronchitis

CEIHD – Center for Entrepreneurship in International Health and Development

CICERO – Center for International Climate and Environmental Research – Oslo

COPD – Chronic Obstructive Pulmonary Diseases

CPD – Cardiopulmonary Diseases

CVD – Cardiovascular Diseases

DD – Daily Dose

LPG – Liquefied Petroleum Gas

NBS – National Bureau of Statistics of China

RD – Respiratory Disease

R&D – Research and Development

TCE – Ton of Standard Coal Equivalent

USEPA – U.S. Environment Protection Agency

VSL – Value of Statistical Life

WTP – Willingness to pay

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1 Introduction

Macro-economists usually treat health and life expectancy as major proxies for qualifying national economic development. After 30 years economy opening, China has already gotten abundant achievements in economy growth and the living quality improvement along with the imbalanced developments across the country. The urbanization process has been carried out for more than 20 years and still continuing, the rural population still shares more than half of the total population, which is about 54.3% in 2008 (NBS, 2009), this fraction is even higher in the western provinces. Figure 1.1 exhibits the proportion of rural population and income level per person for each province.

It is reported that more than 90% of the households have access to the clean energy such as electricity or liquefied petroleum gas (LPG) among this category of population, but the problem still exists. Since in some remote areas, the electricity is only enough for lighting, but the energy for cooking or heating cannot be met by electricity; most of the residents still follow the tradition from generations using poorly ventilated stoves and rely on the biomass and coal (combined called solid fuel) as the main resource for cooking and heating ((Rural Survey Organization) NBS, 2008).

Both global and Chinese studies in terms of the health burden demonstrate that indoor air pollution has been an important factor affecting the health of people living in the rural and remote areas of developing countries. The annual report from WHO using fuel-based method shows that approximately 0.42 million premature deaths per year occurred in China are related to the use of solid fuels (J. J. Zhang and K. R. Smith, 2007). However this result has been suspected to be considerably conservative by some other researchers. It is possible to obtain a more detailed assessment of exposure according to different groups of population and types of fuel use based on an alternative method, named pollutant-based method, instead of fuel-based approach. The estimated premature deaths using pollutant-based method may reach to 8 times more than WHO estimation, with a lower bound of 0.82 million. It also indicates that through the practical interventions, the huge health improvement can be achieved (H. E. S. Mestl et al., 2007).

The government started to conduct national improved stove program in 1980s in the rural area of several provinces. This stove plan is aimed at improving the efficiency of traditional stoves for the residents in the rural area. A precise valuation of this stove program including the type of fuel used and the performance of the improved stoves has been published; it also provides the measurement of the exposure for each category of stoves (Smith K. Sinton J., Peabody J, Liu YP et.al., 2004). From the reviewing of the papers published between 1994 and 2006 regarding of the indoor air pollution intervention, the epidemiological studies have provided the evidences for the benefits from the improved stove and combined educational and behavioral interventions, mainly concerning the coal stove, but only few of the biomass stove (Zhang J.L Liu L., Jiang F.X., 2007).

The objective of this thesis is to evaluate the benefits of a better ambient or indoor air quality, thus the relevant linkages between pollutant emissions and the significant health damage must be determined first, and then through quantifying these effects, the benefits can be monetarily valued. Epidemiological evidences clearly indicate that the solid fuel combustion is associated with higher incidence for certain diseases in the population exposed, such as lung cancer, obstructive pulmonary disease etc., which can be defined as a potential effect matrix (William H. Desvousges et al., 1998). Based on the epidemiology evidences, WHO has also done plenty of works to determine and estimate the health burden relating to the indoor air pollution, the main method involved in addressing the potential damage caused by combustion of the solid fuel is the fuel-based approach (M Desai et al., 2004) .

When it comes to practical part, there still exist difficulties even though the risk factors have been determined, since the uncertainty involved in the data collection, complex emission composition and living ambient of the population may not be fully captured or explained by the model. By disaggregating the associated effects, I hope to derive a precise image of the benefits from the air quality improvement, such as the relative risk reduction of acute lower respiratory infections (ALRI) in the group of children less than 5 years old.
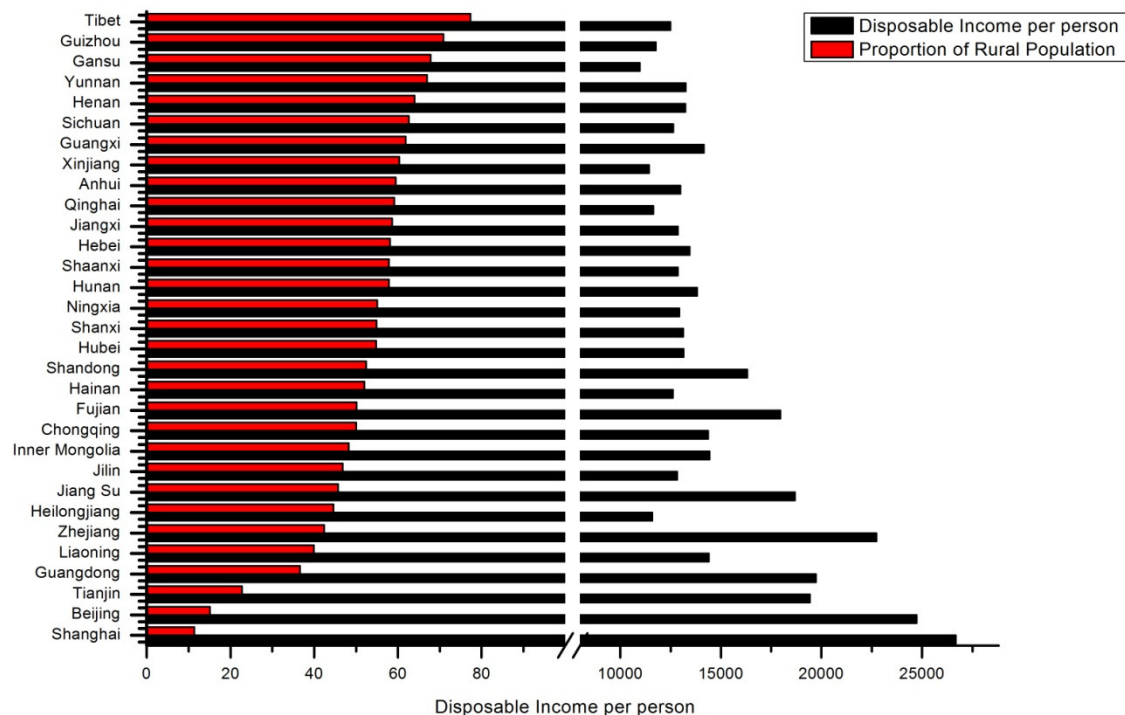
Figure 1.1 this figure illustrates the disposable income per person in each household and the proportion of the rural population for corresponding province. It is ranked according to the share of rural population. Guizhou and the other provinces in western China have larger share of rural population and lower disposable income per person compared with the southeast coastal provinces such as Zhejiang, Jiangsu, Fujian and Shandong. Source of data: (NBS, 2009)

The benefits can be scaled up if the stove program would be promoted among a large scale of population, for instance, the rural area of Guizhou province.

Different from the south-east coastal provinces, the population of Guizhou province has the similar proportion as the other provinces in western China: more than half of the whole population dispersed in the rural area, the GDP per capita is ranked last among all provinces. The special geological condition and incomplete infrastructure are seemed to be the main reasons to hinder the economic growth in these remote areas in Guizhou. Most residents in remote rural areas, including ethnic minority people, are still relying on the traditional open stoves for cooking, room heating or drying chili and corns. The use of open stoves, solid fuel with high content of sulfur, arsenic and fluoride, low thermal efficiency and incomplete combustion of the stove have been causing great

damage to the people especially the women and children who spend longer time in the kitchen (He G.Y. An D., et al, 1995). Meanwhile, in the southeast coastal areas, clean energy, including electricity and LPG, has already dominated the household cooking and heating energy consumption market. In order to mitigate the IAP in rural area in China, switching from traditional heavily polluting stove to the new environment-friendly stove is an alternative way. In this thesis, I want to estimate if it is beneficial to implement this stove project from the perspective of health improvement.

Recently, the rapid growing stove manufacturers provide more available choices for the indoor air pollution interventions. The main reason might be the legislation of the Renewable Energy Law (2005) and the vigorous promotion of the newly improved biomass stove by the government. Compared with the traditional stoves, the new biomass stove is more energy-efficient and environmental-friendly (B. Zhou, 2009). If the government carries out the biomass stove projects and help the local residents to install new biomass stoves, will the health benefits totally cover the cost of the stove, that is, will this project be beneficial from the perspective of health improvement?

Some cost-effective analysis has already been done for the national improved stove program conducted in 1980s. It is reported that national stove program is the most cost–effective measure from the aspect of the rural energy conservation (Y. Lu, 1993). Some researchers place emphasis on the 'technology- behavior interventions', which indicating that the effects can be achieved from the better designed technological intervention (Y. Jin et al., 2006). Also many papers are concerned about the health improvement from the reduction of pollutant emission (R. D. Edwards et al., 2007, G. He et al., 2005, H. E. Mestl et al., 2007).

The purpose of this thesis is to focus on net benefit generated from the potential health improvement that can be obtained from the new biomass stove project. A cost-benefit analysis will be conducted to compare the total potential benefits with the costs. The results of this analysis will give some answers to the importance of the switch from the old stove to the new stove and whether there has enough incentives for the implementation of the stove program in Guizhou.

To investigate the net outcome from implementing a new biomass stove project in Guizhou province, I set up a cost-benefit analysis to compare the cost and benefit

generate within a household unit. The quantification of health improvement follows the impact pathway method: two scenarios are suggested for evaluating the health improvement after the intervention, which are divided according to different types of stoves used. The first scenario represents the household living in the heaviest polluted indoor air quality with using of the traditional stoves. The second scenario refers to the moderate level of indoor air pollution while the old improved stove is the main choice for the household in this category. In order to evaluate the damage from the indoor air pollution for these two scenarios, the significant risk factors are determined first, and then based on the epidemiology studies, we can quantify the possible health improvement for the corresponding improved air quality and finally this quantified improvement can be monetized.

The main results of the thesis are as follows: with respect to the two scenarios mentioned before, if the indoor air quality can be significantly improved after the intervention, the monetized health improvement will cover the cost of the implementation of the new stove project. The health improvement is mainly from the reduction of mortality risk from cardio-pulmonary diseases. The results of simulation show that the households using traditional stove will obtain the health improvement almost twice as much as the households using old improved stove. With respect to the results of the cost-benefit analysis, both scenarios end with the positive net benefits, although the second scenario has lower health improvement. Therefore, it supports the approval of the new stove project aiming at tackling the damage from the combustion of biomass fuel. However, the result from the sensitivity test indicates that the net benefits can also come down to negative value with more uncertainties involved in the simulation. With analyzing the parameters separately, I derive the exact threshold level for each parameter that leads to the negative net benefits. These can be supplement guidelines for the selection of the new biomass stoves with respect to costs, concentration level and life expectancy.

The method used in this thesis is mainly a combination of epidemiology studies and cost-benefit analysis. The data source of concentration level and epidemiology-related data is based on a project conducted by Center for International Climate and

Environmental Research-Oslo (CICERO)[1]. Numerical analysis and Monte Carlo simulation are performed in Excel.

The reminder of the thesis is as follows. The first chapter is the part of introduction: illustrate the main purpose of the thesis. The second chapter aims to provide the background of the routine of energy consumption transition in rural China and the soc-economic situation in Guizhou province. The third chapter reviews the research achievement from both china and abroad and the extension work need to be done. The fourth part of the paper explains the model and the methodology to evaluate the improvement of the health and compare the benefits with the cost. Chapter 5 illustrates the results of the model, the determination of valuation of statistical life and a sensitivity test of the results will be presented. The last chapter is conclusion and the recommendations for the future work.

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[1] The ongoing project 'Indoor air pollution in China- NEGLECT (GLOBVAC)' is conducted by CICERO, the updated data for mortality risk and pollutants concentrations are both kindly provided by Kristin Aunan and Heidi Elizabeth Staff Mestl. See the homepage for the project:
http://www.cicero.uio.no/projects/detail.aspx?id=30238&lang=en

2 Background

2.1 The overview of the biomass energy utilization in china

From the view of the financial support activities, the government is the biggest supporter for the use of renewable energy. In order to alleviate the conflicts resulted in energy shortages in rural areas; the government has put lot of effort to promote renewable energy development and utilization. According to the report of 2000-2015 New Energy and Renewable Energy Development Plan[2], the available rural energy capacity is presented as follows: first of all, biomass resource in rural China is abundant, annual yield of straw is about 700 million tons, while more than 280-350 million tons of total yield can be used as direct source of rural energy. Secondly, reasonable amount of firewood harvesting is assumed around 158 million tons while the current actual amount of harvesting is estimated over 182 million tons, which is at least 15% more than the recommended level. Therefore, it means that certain proportion of available biomass energy has been wasted or not fully developed in rural China. Furthermore, if this firewood over-harvesting continues, it may lead to serious consequences such as land deterioration or soil erosion.

The part of this new development plan for 2015 also focuses on air quality improvement: the amount of new energy and renewable energy consumption substituted for fossil fuel will be equivalent to 43 million tons of standard coal equivalent (TCE)[3], which equals to annual saving of 60 million tons of coal; 30 million tons of carbon emissions reduction; 2.1 million tons total emission reduction of SO2, NO_X and Particle Matters (PM). The realization of the whole plan requires a total investment of about 89 billion Yuan with annual investment of more than 5 billion.

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[2] 2000-2015 New Energy and Renewable Energy Development Plan elements (2000 version 4) is published by Resource Conservation and Comprehensive Utilization of State Economic and Trade Division. Webpage: http://www.envir.gov.cn/info/2000/9/921307.htm (In Chinese)

[3] Tonne of Standard Coal Equivalent (TCE) is a statistical term used for uniform energy criterion in China, one ton of high-quality coal generating a standard calorific value of 7000Mcal is defined as tce. 1 ton of raw coal generates only 5000 Mcal. 1 ton of coal equivalent (tce) = 29.3 GJ (net calorific value) = 7000 Mcal

Table2.1 Strategic Goals of Rural Biomass Energy Development

Priority Area for Development	Technologies	2010	2015	2020
Priority 1: Household heating and cooking	Household biogas digesters (million)	40	60	80
	Straw biogas plants	100	500	1000
	Straw briquette/pellet fuel (million tons)	1	20	50
	Medium-to-large biogas plants	4000	not available	10000
Priority 2: Bioethanol/biodiesel	Energy crop planting area (million ha)	1.66	not available	3.33
Priority 3: Biomass-powered electricity	Straw power generation(GW)	3	not available	6

GW = Gigawatt, ha = hectare.   Source of data: Modified from (Q. Zhang et al., 2010) based on MOA's 2015 goals and the central government's long-term development plan for renewable energy for 2020[4].

Asian Development Bank recently published report indicates that: in the next 10 years China will need 413.5 billion Yuan to carry out the overall renewable energy projects, of which 314.3 billion Yuan will be allocated as benefits to farmers, 16.5 million for construction of community or central gas station projects, 82.7 billion will be used for biomass power generation and liquid fuel production, in addition, 1.5 billion will be allocated as funds for research and development (R&D), demonstration and pilot. Recently, most of the ongoing biomass projects are implemented in small scale. This is mainly because most of China's new energy and renewable technology development is far behind foreign countries, while investments mostly either rely on state investment, or other limiting financing channels (Q. Zhang, M. Watanabe, T. Lin and et.al., 2010).

2.2 Previous undertaken biomass stove programs

In 1990s China began to implement the policy of reducing the use of wood fuel in order to protect the local forest resources, but some studies also indicate that after the implementation of these policies, the demand for coal and other fossil fuel has increased substantially, particularly in the coal-rich areas. Since the residents have limited energy choices for cooking and heating, the switch to the unwashed coal and the use of

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[4] Long-term development plan for renewable energy is released by National Development and Reform Commission (NDRC) in 2007.
Download: http://www.sdpc.gov.cn/zcfb/zcfbtz/2007tongzhi/W020070904607346044110.pdf(in Chinese)

inefficient traditional stoves will lead to potential health risks for local residents. (Q. Xiang, 2006).

Since the Renewable Energy Law released in 2005 officially supports the use of biomass energy, the number of biomass stove manufacturers has a remarkable growth year by year; even the traditional coal stove business enterprises emerge gradually as developing a variety of emission-reduction and high-efficiency biomass stoves. This emerging stove market provides the biases of the promotion of the new biomass stoves.

2.2.1 Sino-Dutch Program

The project is financial supported by the Shell Foundation, approved by relevant departments of the Ministry of Agriculture and completed accompanied by China Association of Rural Energy Industry (CAREI) together with Center for Entrepreneurship in International Health and Development (CEIHD). The aim of the project is to select leading Chinese and international high-efficiency and low-emission household biomass stoves and promote technological innovation projects. The project was divided into three steps, which lasted nearly two years, began from June 2005, ended in March 2007 (F. Hao, 2007a).

During the beginning of the project, experts from CAREI and CEIHD jointly constituted testing standards on China's biomass stoves performance (Table 2.1). The significant difference to tell the new biomass stove from the traditional wood stove is the high thermal efficiency, which can be 15%-20% higher compared with the old stoves (F. Hao, 2007b). The stove with the best performance in the test won the competition.

Table2.1 the standard criteria for high-efficiency and low-emission stoves

Thermal efficiency	≥35%
Smoke and dust emission concentration	≤ 70mg/m^3
Indoor CO average concentration	≤10mg/m^3

Ringelmann Smoke [5]	≤ level 1

Source (F. Hao, 2007b)

2.2.2 Biomass stove dissemination project in western China

This project is funded by U.S. Environment Protection Agency (USEPA) and implemented by both China's Rural Energy Industry Association (CAREI) and the U.S. Center for International Health and Development Entrepreneurs (CEIHD), it started from Oct.1.2007, ended until Sep 30, 2009.

The aim of the project is to reduce indoor air pollution and improves human health, especially women and children's health. At the same time, the project will vigorously promote the winning stove of the sino-dutch competition in rural western China. Therefore the project will help the market-oriented stove enterprises develop more rapidly. The biomass stoves are disseminated mainly in Chongqing, Yunnan, Guangxi, Shanxi and Tibetan areas in Sichuan (Aba).

The important message we can tell from the winning stoves is that the stove companies have been paying more attention to practicality and meeting local residents' living habits, such as one stove is specially designed for the people live in Tibetan area, since it can use many different combination of fuels such as dung and firewood. In addition to cooking, the stove can be used as a heater in the winter, which is very important for the people live in that severe weather condition. Also for each stove, there are often two or three cookers to adapt to Tibetan's cooking habit---cooking several pots at the same time. It makes cooking more convenient than the old ones.

2.3 Scio-economic condition in Guizhou Province

We are witnessing the severe imbalance development of economy in China from the recent twenty years especially the income inequality in terms of rural and urban areas. The main income resources of central and western provinces rely on agriculture, or locally available minerals and forestry resources. Urbanization of the southeast coastal provinces has transferred the problems of environmental pollution, ecological degradation, water pollution, air pollution and other problems to nationwide,

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[5] Ringelmann Smoke Chart: use the shades of gray to compare the different density of smoke rising from the stack. See: http://www.cdc.gov/niosh/mining/pubs/pdfs/ic8333.pdf

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meanwhile the western provinces still experience the consequences of less developed economy, such as the indoor air pollution from biomass fuel in rural Guizhou.

Guizhou is located in the mountainous region in southwest China while the eco-zones are mainly located in the transition terrain, but there are still some ethnic minorities living in mountainous areas, such as Miao. It is reported that in Guizhou province rural population accounts for 70% of the province's population; in 2007 the per capita GDP is only over one-third of the national level along with the extremely frail ecological environmental conditions (NBS, 2008, Q. Xiang, 2006). As presented in Figure2.1, the total areas of soil erosion in Guizhou province have a significant growth from last 1950s. Until 1990s, the trend of growth was brought under control. From the report published by Guizhou government; it will take at least 70 years to tackle this severe problem (D. Zhang et al., 2001).

Figure 2.1 Percentage of soil erosion areas in Guizhou Province
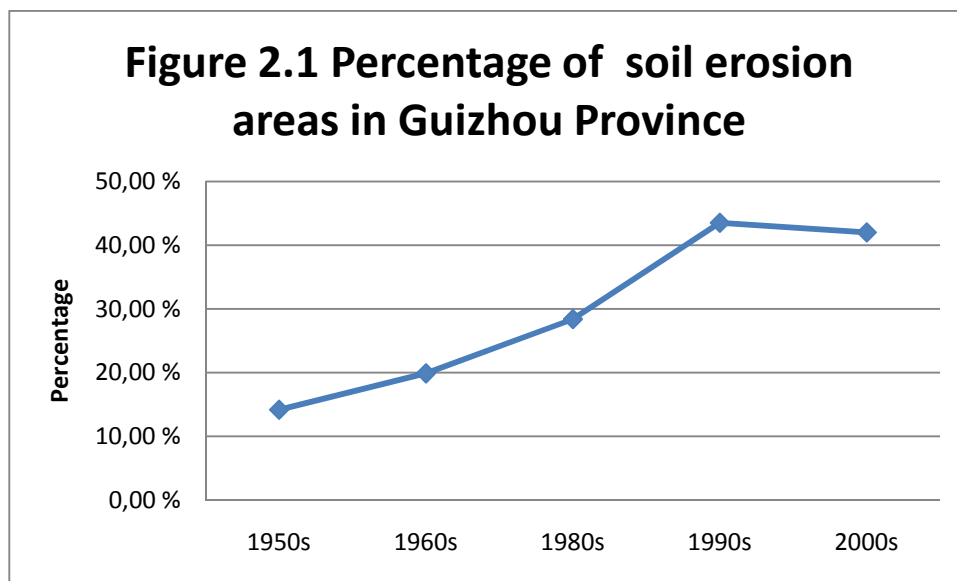
Source of data: (D. Zhang, Z. Ouyang and S. Wang, 2001)

Figure2.2 exhibits the development of rural energy in Guizhou. Compared with the promotion of firewood and coal saving stove, the annual promotion of biogas container is growing steadily. The peak of the stove promotion in 2004 is mainly related to the World Bank stove project in Guizhou to tackle the indoor air pollution with fluorosis and arsenic poisoning. In Guizhou province, the local government also has been promoting the biogas program in the villages as both an important environmental policy to mitigate the indoor air pollution and energy saving project. Biogas promotion project is greatly

supported by the central and local government. Combined with implementing the biogas container, the

Figure 2.2 The firewood saving stove and biogass digester projects implemented in rural Guizhou
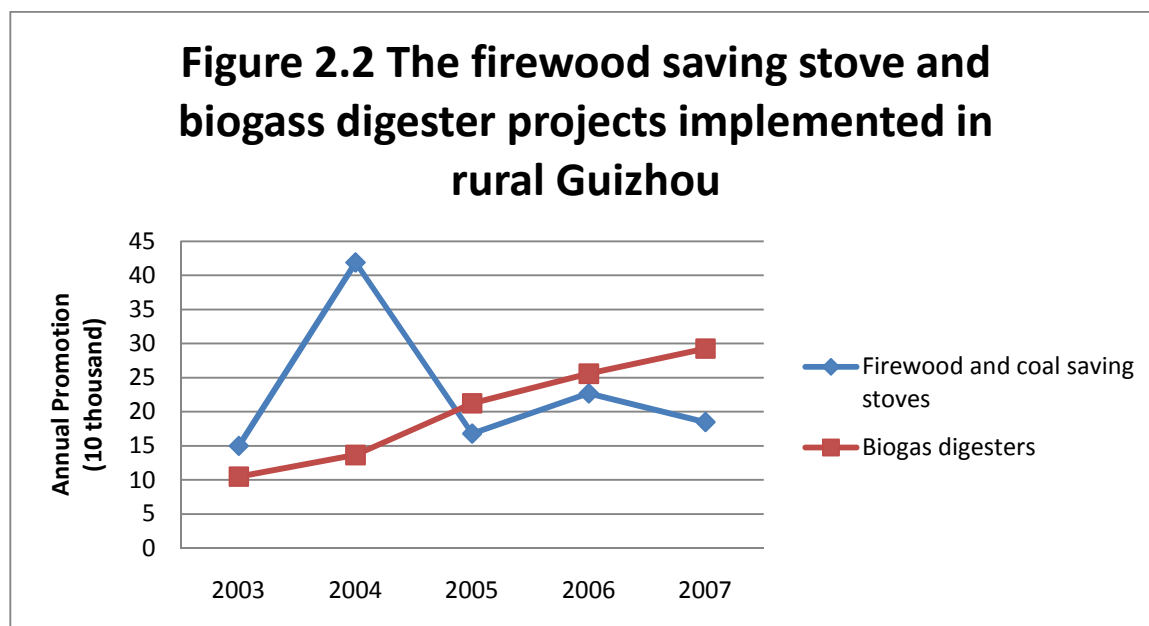
Source of data: (NBS, 2005, 2008)

local government also assisted the residents to reconstruct the toilets which give extra by-products of indoor air quality improvement.

Electricity transmission from West to East China project[6] in Guizhou also leads to closing-down of the some small coal mines. In order to eliminate inefficient production capacity, large number of small coal mines were shut down, which has sent coal prices soaring since these small coal mines used to cover the household energy demand. Farmers turn to choose traditional firewood. However, the implementation of conceding the land to forestry may also cause the limited supply of firewood fuel for farmers. The old-fashioned firewood stove are often used as heating stove in rural area with the shortcomings as large demand for the consumption of firewood along with low thermal efficiency, meanwhile it will cause heavily air pollution. The estimations indicates that from switching to the firewood and coal saving stoves, each household can save more than 1000 KG of firewood annually and protect $0.03hm^2$ area of forest (Q. Xiang, 2006).

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[6] Electricity transmission from West to East China project launched from 2003, the aim of the project is to ease the energy shortage in the coastal southeast province, by building the power station in western province where the coal mine is abundant.

Small hydropower station pilot project is also one of the alternatives for switching from solid fuel to new energy. In Puan county (Guizhou province), the annual cost of fuel spent by each household is reduced to nearly one hundred Yuan after the completion of small hydropower station with 3100kw installed capacity. The total investment of the project is 17 million Yuan and more than 3000 households will switch from the firewood stove to the clean and cheap electricity power with bearing the cost less than 0.2yuan per KWh[7]. The annual cost of coal saved per household is estimated more than 800 Yuan without mentioning the other benefits from improved environment. It is expected that the installed capacity of small hydropower stations will reach to 1mkv in 2020[8] and a large scale of population in rural and remote areas will be benefited.

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[7] The source of the data: http://power.nengyuan.net/2008/0111/1808.html (in Chinese)
[8] Energy Development Plan in Guizhou Province was released in 2007, webpage: http://www.lrn.cn/basicdata/elseplan/200711/t20071120_169483.htm (in Chinese)

3 Literature Review

The long-term exposure to the indoor firewood smoke may cause various severe health outcomes; most of previous epidemiology studies show that the main diseases referring to the solid fuel combustion can be: morbidity and mortality from respiratory disease (RD), chronic bronchitis (CB), and cardiovascular diseases (CVD). But it is difficult to monitor the pollution level and quantify the exact health outcomes from certain amount of pollutants (G. He, B. Ying, J. Liu, S. Gao, S. Shen, K. Balakrishnan, Y. Jin, F. Liu, N. Tang, K. Shi, E. Baris and M. Ezzati, 2005). After obtaining the evidences from epidemiology studies regarding the solid fuels combustion damage, the next step for processing the cost-benefit analysis is to estimate the economic value of the quantified health hazard. The core part involved in this step is the determination of the monetary valuation of statistical life in China.

3.1 Concentration of pollutants

From the 1990s, the researchers began to evaluate the effects of the national stove program launched from 1980s and provided plenty of detailed measurements of both traditional stove and the improved stove. However, as indicated in many papers, '*the analysis of improved stoves was complex*' (R.D. Edwards et al., 2004). The reasons for this problem can be diverse. Not only the using of complex combination of the fuel affects the results of analysis, the seasonal changes of fuel option combination also make the estimation more ambiguous. It was mentioned as 'misclassification', since the standard of the improved stove has not been defined clearly yet. According to the data collected for the national stove program, the seasonal PM_4 concentration level for almost all households was higher than the national standard[9] except in the summer, which varied from $200\mu g/m^3$ to over $300\mu g/m^3$. Through the comparison of the performance across several stoves using different fuel type, the purpose is to carefully examine the varied pollutant products from the stoves combustion process. There also rise the concerns for the global warming attributed to these pollutants(R.D. Edwards, K.R. Smith, J. Zhang and Y. Ma, 2004).

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[9] The national standard level of PM_{10} is $150\mu g/m^3$. PM_4 concentration of $200\text{-}300\mu g/m^3$ implies that PM_{10} concentrations are at least as high as PM_4. Since PM_4 denotes particles less than 4 micrometers in diameter, while PM_{10} denotes particles less than 10 micrometers in diameter.

Since the evaluation of the improved stove is such a complex process, some researchers plan to disaggregate the exposure level according to living places and time activity and other endogenous factors (S. Dasgupta et al., 2004, H. E. Mestl, K. Aunan, H. M. Seip, S. Wang, Y. Zhao and D. Zhang, 2007). From examining the demographic and indoor air pollution data collected from the households in four poor provinces in western China, included Guizhou province as well, the results demonstrate that Guizhou province obtains the lowest awareness of the health hazard caused by respirable matters. The main reason is most of the traditional or improved stoves are poorly ventilated in the rural area of Guizhou province, it is hardly to call the stoves are improved. Although most of the coal stoves with the chimney, almost 90% of them are 'ending in the attic' in order to dry chili or corns with the flue gas, which leads to a heavily polluted indoor air quality (Y. Jin, X. Ma, X. Chen, Y. Cheng, E. Baris and M. Ezzati, 2006).

3.2 Epidemiology Studies

The estimation from WHO studies demonstrated that the use of solid fuel could cause great damage to human health and the case can be even worse combined with open stove; poor ventilated condition or housing condition. The experts try to unify the systemic analysis of risk factors attributed to certain health outcomes; as a result, the baseline description for health burden and associated risk factor needs to be clarified clearly. Based on the primary data of mortality and morbidity together with the previous papers studies related to the health hazard and disease casualty, the meta-analysis can give significant risk factors attribution: ALRI in children less than 5 years, COPD, cataracts, tuberculosis, asthma and lung cancer from using biomass for cooking or heating (M. Ezzati et al., 2002b). The estimated main health burden from the use of solid fuel includes: lower respiratory infections (more than one third of the total mortality from this disease), chronic pulmonary disease (about 22% of the total mortality from this disease) and 1.5% of total mortality cases from lung cancer, tuberculosis cataracts and asthma may be also associated with the indoor air pollution (G. H. Brundtland, 2002).

WHO introduces the attribution fractions to explain the relative risk of the population exposed associated with indoor pollutants concentration; therefore the excess health burden for counterfactual scenario can be calculated compared with the guideline

pollutants exposure level. According to WHO air quality guidelines[10], it is clear that the concentration of PM_{10} or $PM_{2.5}$ for the household using traditional stove is usually 10 times more than the guideline level, which will pose greater health risk for the people living in this air quality. (M Desai, S Mehta and Smith K., 2004, A. Rodgers et al., 2004, WHO, 2000).

A study in Taiyuan, where the major energy consumption is coal, gives the evidence for the linkage between the morbidity of respiratory diseases (RD) and the exposure from the combustion of solid fuel. The estimation from multivariate logistic regression analysis shows that the odds rate[11] of respiratory symptoms associated with one additional unit of PM10 and PM2.5 logarithm increasement are 1.67 and 1.79 respectively. After changing to COPD as dependent variable in the multivariate Logistic regression model, relative risk of being afflicted with COPD associated with one additional unit of PM10 and PM2.5 logarithm increasement are 1.51 and 1.68 respectively. The three scenarios in this study are divided according to the different levels of concentration exposure. Consistent with most previous reports from abroad studies, the area with highest exposure level obtains the highest relative risk of COPD and RD (Y. Jin et al., 2001).

Some papers also focus on analyzing the health burden caused from mainly 'poisonous' coal in remote rural area in China. By reviewing of the main data resources about the exposure data comes from the paper relating to the three stove programs conducted in China: the national stove program, World Bank project and Sino-Dutch project, the results of meta-analysis support the results from WHO research and relating epidemiologic studies. The excess health burden includes: lung cancer, respiratory illnesses, acute respiratory infection and COPD. One recommended intervention is to use the less poisonous fuel such as washed coal (J. J. Zhang and K. R. Smith, 2007).

The economists are interested in monetizing the value of the interventions for mitigating the indoor air pollution and the energy shortage. The mainly used method is the cost-benefit analysis. The comparison between implementing stove program and

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[10] Annual mean concentration level of $PM_{2.5}$ is $10\mu g/m^3$, PM_{10} is $20\mu g/m^3$

[11] Odds rate is used to assess the risk of particular outcome associated with certain level of exposure concentration or other influence factors taking place.

biomass power plant indicates that the stove program has greater potential of increasing the income of local residents and the CO2 emission reduction. The benefits from generated social welfare will cover the cost of the stove program. Thus the stove program is recommended for the rural and remote community with possible financial support and backup stove technology (L. Gan and J. Yu, 2008). A cost-benefit analysis conducted for assessing potential measurement indicates that implementing theses interventions in Shanxi province for mitigating the PM_{10} exposure and other polluting emissions will generate large profits in a socio-economic sense with only including the benefits from the CO_2 abatement (K. Aunan et al., 2004).

4 Methodology

In this section we will introduce the cost-benefit analysis model. I use this model to assess the cost and benefits of implementing a new stove dissemination program in rural Guizhou. This method is adopted in order to make suggestions and recommendations for the policy makers or stakeholders. The implementation of the stove program is considered advisable, if and only if

$B > C$

In this cost-benefit analysis, we use B to stand for gains or benefits through new biomass stove project; C represents the total cost for implementing this project. As conducting a cost-benefit analysis, we calculate the benefits generated from the project based on the purpose of the project that we are particularly interested. Since the main purpose that we promote the new stove project is to mitigate the indoor air pollution and reduce the mortality risks of residents in rural Guizhou, therefore the major direct benefits we concerning from the stove project is the health improvement. The net benefits of the project could be scaled up if the intervention could potentially be introduced to a population of household P for instance rural area in Guizhou, the total benefit to society is

(B-C)*P

A benchmark scenario will be established in the cases of the emission level of old stove. Since the stove company introduces a new technology or innovation, the pollutant concentration of using the new stove can be reduced to a lower level compared to the old stove, this reduction will lead to a corresponding reduction in the mortality rate for the certain risk factors. Many of previous epidemiological studies provide reliable theoretical basis for quantify the health improvement related to certain pollutant concentration reduction. The commonly used method is using the dose-response relation to determine the mortality and morbidity risks associated with exposure to PM, CO or other pollutant (C Arden Pope III et al., 2009, L. Zhong et al., 1999). Although many studies have shown that the higher the concentration of pollutants will lead to more serious health damage, when it comes to the specific quantitative results, there is still certain existence of uncertainty.

4.1 The calculation of benefits, B

4.1.1 Conceptual Model
In a stove intervention, the starting point is a new stove that hopefully has a lower emission factor than the previous stove, and at least it ventilates emissions better. The next step is to determine how indoor air quality is affected. Therefore it needs to be determined firstly how household exposure is affected. Then we need to transfer the affected exposure to the associated health outcomes. Finally the changes in health outcome are valued. If we consider the stove will be disseminated using household as a

unit, the benefit can be calculated for the representative household. Thus in this conceptual model, the indoor air quality IAP is assumed as a function of concentration level $e_1...e_N$ for all household stoves,

$$IAP = IAP\ (e_1..e_i..e_N) \quad i=1, ... , N \tag{1}$$

e_i is defined as the concentration of the traditional stove for specific household stove *i.*

After the intervention, if all households have been equipped with new stoves, the IAP is

$$IAP = IAP\ (e_0^1..e_i^1..e_N^1) \quad i = 1, ... , N \tag{2}$$

We expect that after the intervention, the combustion and thermal efficiency of the new stove *i* will be improved and the concentration level for the new stove will be down to e_i^1. Then intake fractions IF is introduced to mapping between exposure and indoor air quality

$$IF = IF\ (IAP) \tag{3}$$

The IF function should be different for each category of family members, i.e. the three types of the health impact will be calculated: women, men and children, the effects could change if the females bear most of the cooking work.

In some papers, the different health conditions are described as a univariate scale of '*health state*'. From introducing this health-state index, it allows researchers to assign flexible values to the specific health effects (William H. Desvousges, F. Reed Johnson and H. Spencer Banzhaf, 1998). Health status H is a function of IF but also on factors like smoking s. Smoking can be considered as a behavioral trait which is exogenous to the stove program. When we calculate the possible health improvement from the stove program, we should separate the exogenous smoking effect from the total health burden.

$$H = H\ (IF; s) \Longrightarrow dH = H'dIF \tag{4}$$

Finally we will value health status and the theoretically consistent way of doing that is through the utility function. The utility gain from the stove project can be interpreted as the value of the declining risk factors for the cleaner air quality.

$$U = U (H) \tag{5}$$

Combing the equations (1) – (4), the full conceptual model to calculate the net benefit is suggested as below,

$$B = U^1 - U^0 \tag{6}$$

For small interventions B approximates to

$$B = U' \, dH = U' \, H' \, IF' \, dIAP \tag{7}$$

U' equals willingness to pay (WTP), H' is improvement in health status with respect to the specific exposure reduction, IF' is changes in exposure. The determination of dIAP depends on the emission reduction.

$$dIAP = IAP' \, de \tag{8}$$

4.1.2 Practical Computing Model- Pollutant-based method

Transformation from conceptual model to the practical computing model needs more information to establish the mapping of exposure and excess mortality risks. The studies of epidemiology provide the basis of calculation, the commonly used methods include fuel-based and pollutant-based (M Desai, S Mehta and Smith K., 2004, H. E. S. Mestl, K. Aunan and H. M. Seip, 2007). Mestl and Edwards (in press) collects the data of the emission factors in three provinces in China and the estimation of the data gives the updated version of dose-response function in rural areas of China, we will continue to use these equations for both calculation and Monte Carlo simulation. I conduct the Monte Carlo simulation in Excel: the first step is to determine the varying range of the certain parameters in the model, then Excel can perform random draws on normal distribution for simulation, here in the data sheet, 6000 random draws are generated. This is fairly not a large sample population, but it is enough for me to process the calculation or statistical analysis based on the distributions of the draws. To estimate the relative risk (RR) for cardiopulmonary and cardiovascular diseases, the exposure metric which gives significant health outcomes is determined as PM2.5,

$$DD = PWE{\times}V \tag{9}$$

DD is the daily dose, which indicates the actual intake level of certain pollutants for a person, corresponding to equation (3). PWE is population weighted average $PM_{2.5}$ exposure. V is inhalation rate, which is estimated as average 18 m^3 per day for adults (C Arden Pope III, Richard T. Burnett, Daniel Krewski, Michael Jerrett, Yuanli Shi, Calle Eugenia E. and Thun Michael J., 2009).

The mapping of RR and DD is represented as a logarithmic relationship for cardiopulmonary diseases (CPD) (Heidi ES Mestl and Rufus Edwards, In press), given as below:

$$RR=0.1083*\ln (DD) +1.37 \qquad R^2=0.87 \tag{10}$$

Relative risk[12] for CPD includes risk factors of both CVD and pulmonary diseases (COPD and ALRI). Since the CVD and COPD are the common diseases among the adults while ALRI only exists in the group of children less than 5 years old, therefore we can use equation (10) to calculate the excess mortality risks for COPD, ALRI and CVD with respect to the corresponding daily dose level for each sub-population category. When processing the computing of the relative risk and excess mortality risks, I assume a family as a representative household according to the statistical data (NBS, 2008). The excess mortality risk or premature mortality risk from the risk factors is estimated from the equation below,

$$Mp = \frac{PWE*M*(RR-1)}{1+PWE*(RR-1)} \tag{11}$$

Mp is defined as the premature mortality risk for each population category while M is the total mortality risk subtracted by the part of mortality risk attributed by smoking. The population weighted exposure and relative risk are differed across the category of family members, the exposure to women and children is assumed to be the same, but for men, the risk factors could be lower since men probably spent less time in the kitchen and be exposed not as heavily as women and children. The exposure ratio for men and women is estimated between 0.69 and 0.82, I choose to use the exposure ratio as 0.69 in the calculation (Heidi ES Mestl and Rufus Edwards, In press).

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[12] Relative risk refers to the odds rate mentioned before.

Based on the model I introduce above, the benefits from the new stove can be valued from the less exposure level which will finally leads to the reduction of the excess mortality risk, in other words, the excess health hazard that can be avoided from the intervention.

$$M_G = M_p^0 - M_p^1 \qquad (12)$$

M_G is the gap of excess mortality risk between the baseline and the intervention scenarios.

As the problem of quantifying the excess mortality risk reduction obtained from the stove project is solved, the next step is to monetize this health improvement. The appropriate way to interpret this improvement is the WTP for certain changes of risk factors.

$$WTP = VSL * M_G \qquad (13)$$

In this equation, VSL is the value of statistical life. According to United States Environmental Protection Agency (US EPA), VSL is defined as the monetary valuation placed on the elimination of premature mortality risk[13]. Finally the benefits for the representative household are available for comparison with the costs that will be paid.

4.2 The calculation of costs, C

As mentioned before, the costs C represents the total cost of implementing the project. It includes: sum of purchase and installation cost, transportation cost and the shared price of other supporting facilities, such as the pellets machine or chopping machine which can sustainably provide the most suitable fuel for the new stove (Haakon Vennemo, 2010).

4.3 Comparison with present value of benefits and costs

$$B = \sum_0^T \frac{B_t}{(1+d)^t} \qquad (14)$$

And the formula to calculate present value of net benefit is

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[13] A formal definition of VSL can refer to the webpage from USEPA:
http://www.epa.gov/oaqps001/benmap/basic.html

$$NB = \sum_0^T \frac{B_t}{(1+d)^t} - C \tag{15}$$

Where B_t and C_t are annual benefits and costs for the intervention respectively, d is the discount rate; here we use interest rate subtracted by WTP growth to define the discount rate.

$$NB = \sum_0^T \frac{B_t}{(1+d)^t} - C$$

5 Simulation analysis

In this section, first of all, I will calibrate parameters related to the model, which includes demographic data of rural households to capture the characteristics of the household in rural Guizhou, relevant manufacture data for new biomass stoves and the updated indoor air pollution-related data collected in rural Guizhou for the baseline scenarios. I will also answer the substantial questions involved for calculating the benefits, such as the determination of the WTP. The health effect with regarding to the different level of indoor air pollution will be explained precisely with respect to each category of the household. The mortality rate of the CVD is explained by the corresponding relative risk generated by different level of pollutant. Using Monte Carlo simulation, the cost-benefit analysis can be conducted for alternative interventions targeting different levels of pollution. It will be also interesting to test whether the changes of the situations may alter the results. In the Monte Carlo simulation, the basis for processing the simulation in Excel is the sets of randomly generated numbers within a certain interval. All sequences of randomly generated numbers follow a uniform distribution.

5.1 Calibration

I calibrate the model using the data from Guizhou Statistical Yearbook (NBS, 2008) and CICERO.

Table 5.1 Parameters calibration

Discount Rate	Time	Number of family members	Cost	Value of statistical life
0.025	8	4.42	400	600000

The discount rate is an important part for the cost-benefit analysis, if it is set too low, some projects which cannot generate adequate social welfare can still pass the cost-benefit analysis. In contrast, if the discount rate is too high, some feasible projects might still not be able to pass the cost-benefit analysis. In the simulation, we use the interest

rate subtracted by WTP growth rate to represent the discount rate which is set to be around 0.025.

Some manufacturers guarantee the lifetime of the stove lasting for 8 years (B. Zhou, 2009) while others claim either the guarantee of 5 years or 10 years. The variation of stove lifetime seems in a certain range. Here I choose the median point indicating that stove can be used for 8 years. To establish a representative household for rural area in Guizhou province, I use the average members in the rural household and the members of labor force for adults in each family, and the ratio between female and male to construct the each category of family members. And therefore, the numbers of female and male are estimated at 1.39 and 1.51 respectively. This simplification will bring out convenience when we calculate the mortality risks that each household faces before and after the intervention (NBS, 2008). The retail price of the stove can be varied among a large range based on the investigation from the biomass market in China. The price can range from 200 to almost 700 Yuan (See Table 5.2). We select C = 400 in our base case simulation as choosing the stoves with median price including other shared cost of transportation and pellet machines[14]. In the simulation, an interval for possible cost values will be set for sensitivity test.

Table 5.2 Pricelist of biomass stoves

Company	Daxu	Heluo	Liangqi	Jin Qilin	Guang Lei	Sheng Chang
Price (¥)	650	520	400	400	400	200

Source: modified from CAREI 2007 and Zhou 2009 (CARIE, 2007)

The next major problem is to determine the value of statistical life (VSL) in rural China. This is also an important component of cost-benefit analysis since the valuation of risk is through VSL. The commonly used method is contingent valuation but there is uncertainty and other endogenous factors which may affect the estimation. From reviewing of the papers referring to this subject (Table 5.3), the estimations using contingent valuation or hedonic method have show great variations across the different

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[14] The introduction of pellet machine is to provide the most suitable fuel for the new stove and maximize the effectiveness of the new stoves.

regions or population differing in income levels. Thus we need to be more cautious in determining the VSL for the household members in rural Guizhou.

Table 5.3 Summary of the publications used for estimating VSL in China

Reference	Valuation Method	Area	VSL(million ¥)	Notes
(J. K. Hammitt and Ying Zhou, 2006)	Contingent Valuation	Rural area	0.701	mean value
		Anqin	0.26	
		Beijing	0.45	
(X. Deng, 2006)	Human Capital Approach	Beijing	0.735	The figure finally adopted for is 735000
	Per Capita of GNI conversion	Beijing	0.72	
(H. Wang and J. Mullahy, 2006)	Contingent Valuation	Chongqing	0.3-1.25	Annual income in this region is ¥3430 per capita
(X. Zhang, 2002)	Contingent Valuation	Beijing	0.24-1.7	Estimation from lower-bound Turnbull
(X. Guo, 2006)	Contingent Valuation	Chengdu and national	0.14-0.42	Annual income is set around 6720
(WorldBank, 2007)	Willingness to Pay approach	Shanghai	1.4	Also 1 million is used in the estimation
		Chongqing	Lower than 1.4	
(R. Mead and V.	Contingent	national	0.675-2.87	With a low bound of

Brajer, 2006)	Valuation			287700
(V. Brajer et al., 2008)	Comparison	national	0.88	No age adjustment
(H. Wang et al., 2008)	Contingent Valuation	national	0.18- 0.51	Risk of underestimation exists
(K. Aunan, J. Fang, Haakon Vennemo, O. Kenneth and M.S Hans, 2004)	Comparison	China	100*per capita GDP	

Based on the conservative reading of literatures regarding of the VSL in China, it is clear that we can hardly adopt a uniform national VSL level since people evaluate the mortality risks differently based on their regional income level, the living quality or other elements. In particular, when we determine the VSL, ethical issue will be one of the main concerns. Take this stove program as an example, the main objective is to improve the indoor air quality in the rural area in Guizhou. Thus the VSL should reveal the tradeoff that people will make between the mortality risks and the benefits. If we choose to use a VSL that is too high to afford, the program may pass the cost-benefit analysis even that it is unadvisable and vice versa. That is why the VSL that suggested by US EPA could be much higher than the VSL estimated for China which is $4.8 million(34 million Yuan) (US-EPA, 1997).

The regression-based estimation approach in Miller (2000) captures the relationship between the VSL and per capita income based on the review of previous VSL estimations studies and the corresponding soc-economy characteristic of studied population, but the samples of VSL are mainly from developed countries. The result of the regression indicates that VSL is around 120 multiplied by per capita income. When transferring this study to developing countries such as China, some adjustment may be required. It is recommended as 100 times per capita GDP in Aunan et.al (2004) in the environmental cost model to represent VSL in Shaanxi, which is another province in China. Compared

some results of contingent valuation, it seems quite reasonable to adopt this ratio times per capita GDP since it is consistent with the results of contingent valuation in table 5.3. As the survey of the VSL in Guizhou is not available, I choose to follow ratio which is recommended in Aunan et.al (2004) to determine the VSL in Guizhou province.

It is reported that the net income level of rural residents in Guizhou is more than 3000 Yuan, while the provincial level per capita GDP has reached to 9000 Yuan (NBS, 2009)[15]. In From the perspective of ethical concerns, I will choose 0.3 million as the lower bound and 0.9 million as the higher bound for the VSL in Guizhou province in the sensitivity test. In the calibration, I choose to use the median level as 0.6 million for the calculation since 0.3 million is a fairly low VSL level even for Guizhou province.

5.2 The epidemiology data

Figure 5.1 Impact Pathways Analysis.
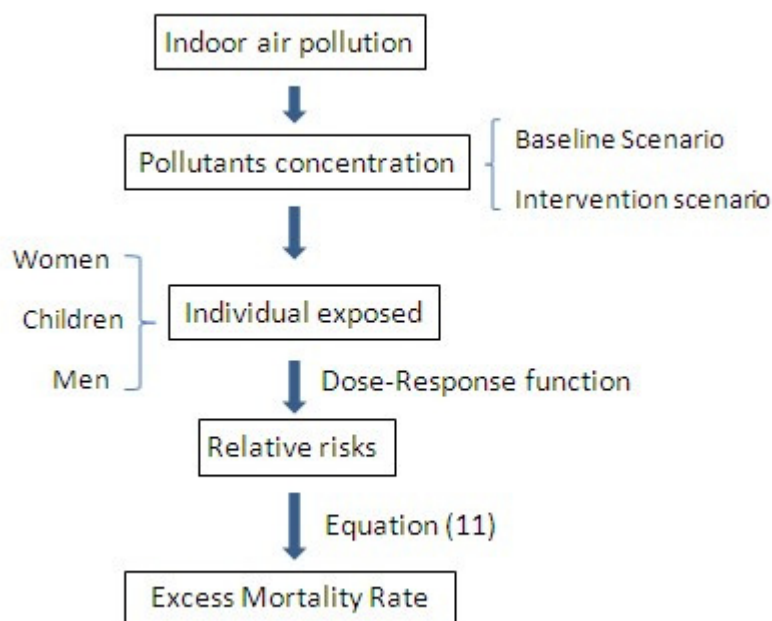
As shown in the impact pathway analysis, the process of quantifying the health risk is based on system of different components. This process is set up according to the data

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[15] The recently released statistical report from NBS indicates that per capita GDP in Guizhou is 10258 Yuan ($1502). See webpage:
http://www.stats.gov.cn/was40/gjtjj_detail.jsp?searchword=%B9%F3%D6%DD&channelid=6697&record=23
(in Chinese)

available[16] and mathematical tools or statistical method which can be adopted (P. Bichel and R. Friedrich, 2001). The data used in this analysis is collected from three sample villages in rural Guizhou and the using-fuel are biogas, biomass (mainly firewood) and coal respectively. Here in this thesis I only target the improvement of households using biomass. The reason for that is the mortality risk from attribution risk factor is lung cancer for the household using coal. The types of biomass stoves differ across the villages. $PM_{2.5}$, the size of particular matters down to 2.5 micrometer in diameter, is used as the only indicator of risk to health from indoor combustion of biomass according to the suggestion from WHO (WHO, 2006).

In the baseline scenario, the concentration of $PM_{2.5}$ is set as $269\mu g/m^3$ of the indoor air pollution level using the tradition stoves and $191\mu g/m^3$ for women and kids using the old improved stoves. The determination of these concentration levels is based on the data collected from the project launched by CICERO mentioned in the previous sections. It illustrates that the pollutants emission of the old improved stove is less than traditional stove. A new biomass stove with lower emission will bring the improvement for the indoor air quality. The setup of the concentration level after intervention is $100\mu g/m^3$ along with an interval based on the WHO guideline suggestion(WHO, 2005).

Here we consider that the exposure level for each family member varies, and furthermore, the corresponding health outcome varies too. This proposition will be adopted throughout the process of quantifying the mortality risk. Combining equation (10) and (11), it gives that the relative risk associated with the concentration $269\mu g/m^3$ is 1.54 for women and kids while the relative risk is 1.5 for men. It indicates that risk of dying from CVD under such circumstance is 54% higher than women and kids living in clean air environment. This relative risk will lower to 1.43 when the corresponding $PM_{2.5}$ concentration reduces to $100\mu g/m^3$. The baseline mortality risk from COPD and CVD subtracted by the risk attributable to smoking is approximately 0.57% and 0.63% for men and women respectively in rural China (D. Gu et al., 2009, Colin Mathers et al., 2008). It is noticeable that after the removal of the mortality risk attributable to smoking, women still have higher mortality risk from COPD and CVD than men. Different from the adults, the mortality risk for the children (mainly under 5 years old)

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[16] The data is kindly provided by Mestl H. and Aunan K. from CICERO.

is from ALRI, which is the main cause of death for the children. The baseline of mortality risk for children from ALRI is set as 0.06%.

5.3 Health improvement and Net benefits

To estimate the health outcomes and the monetized valuation, the method adopted here is to run a Monte Carlo simulation in Excel. Since the original concentration level has already been collected, we only allow the estimates of the concentration level after intervention to vary from $80\mu g/m^3$ to $120\mu g/m^3$ with a mean of $100\mu g/m^3$. In the sensitivity test, we will adopt different values for comparison. The results of the simulation concentrate mainly on the possible mortality risk reduction corresponding to different stoves. It will be affected by both stoves used before and new replaced stoves which distributed by the project. The random-generated sample size of the underlying concentration level is 6000. Combining the set of equation (9)-(15) and 6000 draws from the generated sample, the Monte Carlo simulation gives the quantification of the health outcome with uncertainty and variability.

The simulation is classified into two cases: distinguished by the types of stoves that are used before the implementation of new biomass stove project. Figure 5.2 and Figure 5.3 display the results of cost-benefit analysis for the household using traditional stove and old improved stove respectively. The histograms reveal the potential gain from the stove project under each scenario and provide a visually clear distribution of the monetary valuation. It is obvious to notice that the net benefits are positive in both cases, indicating the benefits from health improvement brought by the project are sufficient to offset the cost. Furthermore, the lower excess mortality risk reduction implies less net benefits created.

From comparison between Figure 5.2 and 5.3, it illuminates that the amount of net benefits in two cases is different in terms of the corresponding generated health improvement. The variation of the net benefits is within a considerable large range. The maximum net benefits for both cases can reach to over 800 Yuan and 500 Yuan, respectively. Figure 5.3 also exhibits some degree of the volatility compared with the well-distributed decline displayed in Figure 5.2. However, simultaneous the trend lines in both graphs exhibit the downward sloping which indicates that logarithmic relation between daily dose and the relative risk affects the distribution of the simulation. The

lower marginal relative risk reduction will be associated with the higher initial concentration level. Therefore the net benefits curve also inherits this concavity.

Figure 5.2 The net benefits for the household using traditional stove after intervention
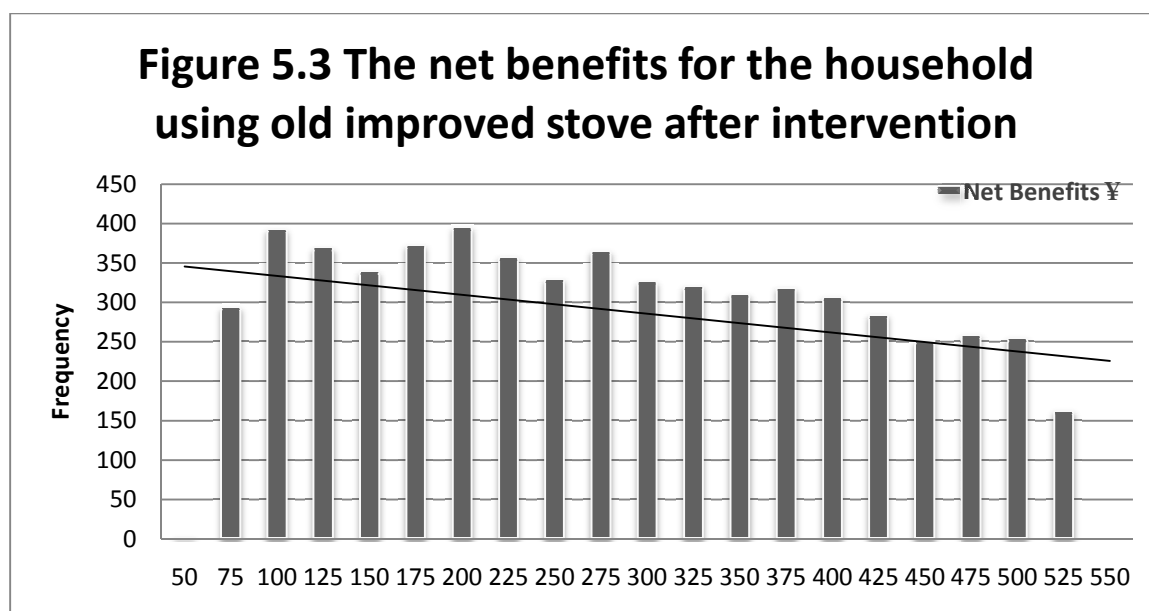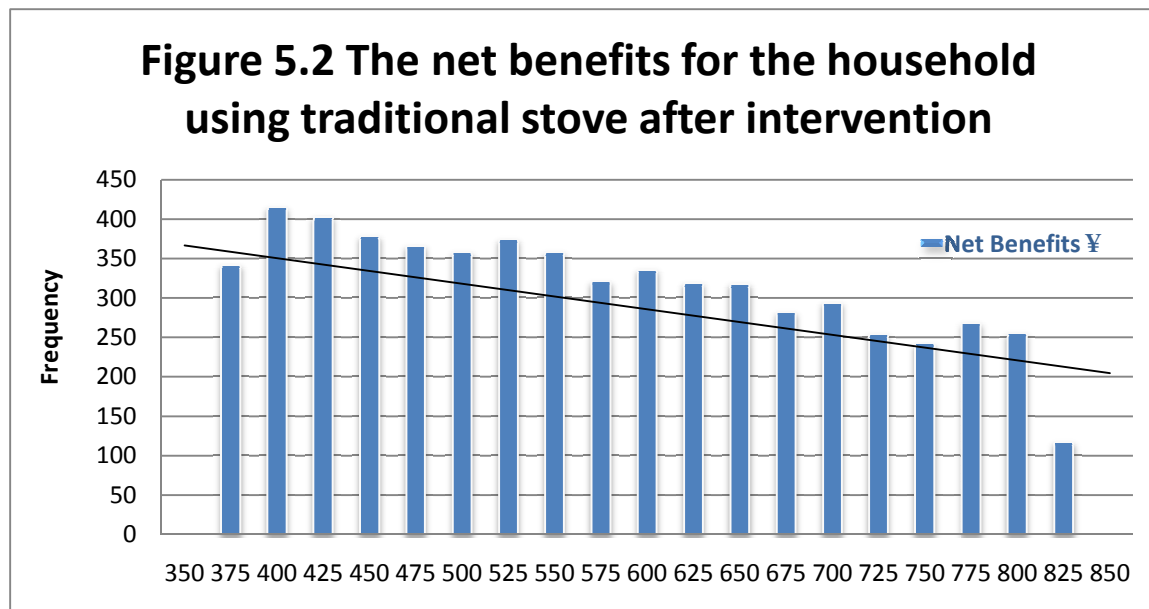
From the simulation, I can also derive the potential health gain for both cases: As presented in Table 5.4, the mean health improvement of the combined values from all draws together is calculated as 0.00022, therefore switching from traditional stove to new biomass stove can bring an excess mortality risk reduction from CPD equal to 22

cases per 0.1 million population. The mean of net benefits is almost 570 Yuan for each household. Meanwhile, for the second case, switching from old improved stove to the new biomass stove, there is an apparent reduction of health improvement from the implementation of the project compared with the first case. From the statistical analysis of excess mortality risk reduction estimated from all of 6000 draws together, the reduced health burden from CPD is estimated as 15 per 0.1 million population. Accordingly, the net benefits fall to one-third of the first case. But still these results give the evidence for the approval of the new stove program in terms of the positive health benefit; the main requirement is the performance of the new stove can lower the concentration of $PM_{2.5}$ to approximately around $100\mu g/m^3$. In the sensitivity test, from adding the uncertainty into the estimation, we will assess if there exists other alternatives.

Table 5.4 Summary of statistical results

| Two cases	Mean of Reduced excess mortality risk		Mean of Net Benefits per household	
	Mean Value	Standard Error	Mean Value	Standard Error
From tradition stove to new stove	0.00022	3.96E-7	￥564	1.7
From old improved stove to new stove	0.00015	3.95E-7	￥265	1.7

5.4 Sensitivity test

In the previous sector, I set up the simulation using several calibrated parameters. This allows us to avoid the consideration of variation and uncertainty in the calculation. As demonstrated in the Table 5.5 below, all the parameters in the model are set up along with a variation interval expect the baseline epidemiology data. When I use these parameters with some degree of uncertainty, the results of the estimation is displayed as in Figure 5.4. The mean of the mortality risk reduction is approximately 0.00024 which is slightly higher than the estimation result of the first case and the mean net benefits is

610 Yuan, which is higher than the mean health improvement for two cases. In addition to these, one more thing need our attention is that the net benefit from the intervention will not be positive for sure, the probability of the positive net benefits is 94.9%. It demonstrates that the assumptions made for the parameters will affect the approval of the project.

Table 5.5: The setup of Parameters for likely impact estimation

Parameter	Nominal	Min	Max
Interest rate less WTP growth (d)	0.025	0.02	0.03
Lifetime(t)	8	5	11
Original Concentration Level (e^0)	250	315	185
Improved Concentration Level (e^1)	100	80	120
VSL (P) (¥)	600000	300000	900000
Cost (C) (¥)	400	200	600
Total mortality of women and kids	0.009625		
Total mortality of Men	0.008622		
Total mortality per household	0.018247		

Figure 5.4: Estimation of net benefits under uncertainty
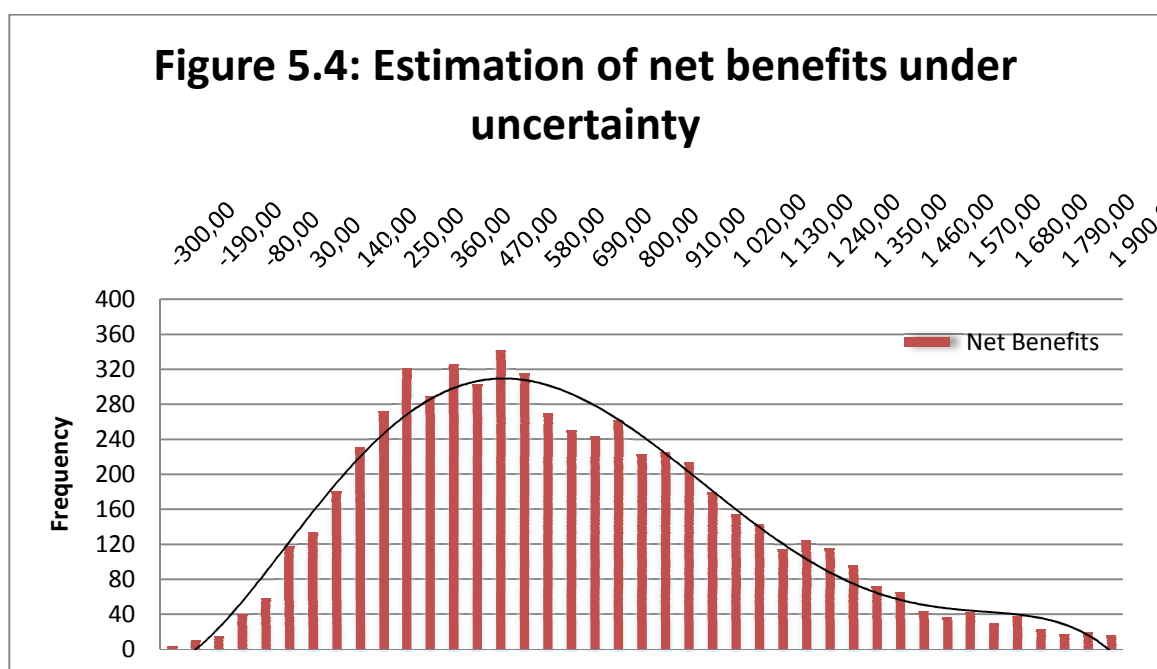
After the estimation with the combination of parameters varied in certain range, I will examine how the results will be sensitive to the variation of each parameter. As discussed in the previous sector, the health improvement for the second case is lower than the first case; I conclude that the first case dominates the second. Through varying the parameters in the simulation, we can examine if there exists the threshold limit value for the positive net benefits. The skewness value of this distribution is 0.66 indicating that tail on the right side is longer. To clarify the impact from each parameter in the sensitivity test, we examine each parameter separately in the simulation; the result of the threshold value that will lead to the negative net benefits is detailed in Table5.6.

Table 5.6 Sensitivity of estimation results to several parameters.

Parameters	Likely impact on results
Interest rate subtracted by WTP growth (d)	Higher discount rate will lead to lower net benefits. If the discount rate is increasing to 15%, the corresponding net benefits will be negative.
Lifetime(t)	The net benefits are very sensitive for a few alteration of this parameter. If the lifetime of the new stove is less than 4.5 years, the stove project will not be considered as a beneficial intervention from the perspective of health improvement.
Improved Concentration Level (e^1)	The threshold annual concentration level for the new biomass stove is recommended at $125\mu g/m^3$. Thus the interval of [80,120] which I suggest for the implemented stove can be considered as reasonable.
VSL (P) (¥)	VSL is also a significant factor affecting the net benefits. If the VSL is down to 360000 Yuan, a remarkable low value, the net benefits can hardly stay positive.

Cost (C) (¥)	The estimated net benefits is quite sensitive to the varying of the cost, the maximum cost that can be afforded is at 650 in terms of the corresponding benefits generated.

6 Conclusions

6.1 Remarkable conclusions

This thesis aims at evaluating the health improvement from implementing the new biomass stove project in rural of Guizhou. The benefited population is mainly the user of traditional and old improved stoves. I analyze the potential health improvement generated from the intervention for the users of these two stoves.

A representative household is assumed in the model according to the demographic data of Guizhou province. Base on the epidemiologic studies, the results from the computing model demonstrated that for both cases, there is significant reduction of the excess mortality risk from CPD. This health improvement is larger for the traditional stove users. From the results of the cost-benefit analysis, there are positive net benefits for both cases which mean the stove project can pass the cost-benefit analysis. Nevertheless, the uncertainty with regard of the concentration level after the intervention is also included in the calculation. Consistent with the health improvement, users of the traditional stoves will be benefited more from this intervention compared with the households using old improved stoves. These results support the approval of the stove project for mitigating the indoor air pollution.

The results of the sensitivity test also demonstrate that the emphasis should be put on the standardization of the stove production. Since both the lifetime expectancy and the performance of the new biomass stove have a significant impact on obtaining the positive net benefits. It also demonstrates the importance of setting up the criteria of new biomass stove and gives the suggestions for stove manufacturers to produce the suitable stoves for implementing the intervention.

6.2 Discussions

The cost-benefit analysis conducted in this thesis mainly focus on the health improvement with regard to the excess morality risks reduction from CVD, while the potential outcome from the intervention can also be the reduced morbidity risks from attributable risk factors without mentioning the external impact from other environmental benefits. It is possible that the benefits I derive in this thesis may be underestimated to some extent especially under such fragile geologic environment in Guizhou province.

The baseline scenarios I considered in this model is mainly focusing on the traditional biomass stove, this assumption does not take full account of the different types of stoves used all over the rural Guizhou, while the coal stove is also the common type of stove and the corresponding health hazard is lung cancer. Therefore the third scenario can be the case of switching from coal stove to the new biomass and the net benefits can be also discussed following the same process in this thesis.

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