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ANALYSIS

Analysis of the energy access improvement and its socio-economic impacts in rural areas of developing countries

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ABSTRACT

Access to modern energy is one of the most basic requirements for development. In rural areas of developing countries, there are a large number of people who do not have access to LPG and depend on traditional biomass such as wood, crop, and dung for cooking. In addition, energy has numerous and complex links with poverty reduction. Therefore, it is important to estimate the impacts of energy access improvement on socio-economic situation in the rural areas of developing countries quantitatively. This study focuses on socio-economic impacts of cooking demand through changes in stoves adopted by the rural households. We have developed an energy-economic model of rural areas in India to analyze the links between energy, income, and health hazard, applying both opportunity cost for using fuelwood and exposure to Resipirable Suspended Particulate Matter (RSPM). As a result of the analysis, there is a positive relation between the opportunity cost and the average RSPM exposure of women in the rural areas. Following to increase in the opportunity cost, that is, income, the cost of an improved wood stove becomes relatively lower first than that of a traditional wood stove, and then a gas stove attains price competitiveness. It is achieved that the average RSPM exposure is below the WHO and Japanese criteria for Suspended Particulate Matter (SPM), 190 and 100 [$\mu g/m^3$], at the opportunity cost of US$9 and 15/GJ, respectively.

1. Introduction

Poverty is a major obstacle for sustainable development of not only developing countries but also the entire world. It has been the main target of the international donor community such as the World Bank Group and other development banks. Historically, the main actors of development issues have been development economists, and the major focus of their study is to demonstrate factors that largely affect on further development of developing countries. However, as the international donor community found that issues of the development are extremely complicated, it has begun to involve other professionals in such field as engineering, gender, and public health.

Energy plays an important role for development in terms of poverty reduction, and the Energy Sector Management Assistance Programme (ESMAP) of the World Bank has vigorously taken initiatives on the poverty from the energy field. There has also been strong attention to reducing poverty through energy access improvement among international organizations. Recently, IEA has been focusing on the poverty reduction through

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the improvement of energy situation in developing countries, and devoted a chapter to explain roles of energy for the development in its World Energy Outlook 2002 (IEA, 2002). It is mentioned that there is one forth of the world population, about 1.6 billion people, who do not have access to electricity, and some 2.4 billion people depend on traditional biomass such as wood, agricultural residues, and dung for their cooking and heating demand. In addition, most of them are in rural areas of developing countries. It is estimated that 1.4 billion people will not have the electricity access and 2.6 billion people will not improve their energy situation for cooking and heating in 2030. The lack of energy access also causes serious adverse effects on socio-economic condition of rural people. Therefore, achieving energy access improvement has huge impacts on lives of people in the rural areas of the developing countries.

There are some works coping with developmental issues from the field of energy, for example, technological comparison of cooking stoves or possibility of electrification in remote villages. These can be mainly divided into three categories; data and factor analysis, economic and technological analysis, and model analysis. Characteristics and references of these studies are the following.

- Data and factor analysis: It surveys data of energy demand and expenditure in rural areas of developing countries; collects information that is difficult to obtain, such as sectorwise disaggregate energy consumption data; conducts case studies and develops a method to analyze a factor for measurement of energy poverty (Pachauri et al., 2004; Ramachandra et al., 2000; Rehman et al., 2005).
- Economic and technological analysis: It evaluates cooking stoves using fuelwood and LPG or power generation technologies such as a diesel generator, wind turbine, and photovoltaic in terms of cost-effectiveness and environmental effects; compares technological performance among traditional wood, improved wood, and gas stoves (Banerjee, 2006; Edwards et al., 2004; Ezzati and Kammen, 2002; Wijayatunga and Attalage, 2002).
- Model analysis: It applies an analysis tool to estimate energy demand and supply structure in a village, nation, or region, based on economic and technological efficiency; incorporates factors associated with energy consumption profile such as greenhouse gas emissions. (Bailis et al., 2005; Biswas et al., 2001; Howells et al., 2005).

There are a large number of studies for the economic and technological analysis as well as the data and factor analysis. Although these studies are greatly detailed and accurate, quantitative impacts of changes of energy supply and demand structure, such as the introduction of new technologies, are not considered in the studies. In contrast, there is not enough number of researches categorized as the model analysis, and, in particular, few researches incorporate socio-economic effects into the analyses. Because nowadays poverty is defined as low attainment of social condition, for example, education, health, and nutrition in addition to economic deprivation, it is indispensable to include these socio-economic factors in the analysis. Therefore, we have developed an energy-economic model of rural areas in India in order to clarify the possibility of the energy access improvement, including socio-economic impacts on the areas.

2. Relation between energy and poverty reduction

Recently, the international donor community has been increasingly focusing on software of development, for example, institutional development, empowerment, and human development, instead of hardware, that is, large infrastructure. This means that it highly regards socio-economic aspects, such as education, health, and gender as the most fundamental components of the development. These components of development are intricately connected with each others as shown in Fig. 1.

Energy has a great potential to influence on such components. Although small-scale energy programs, for example,

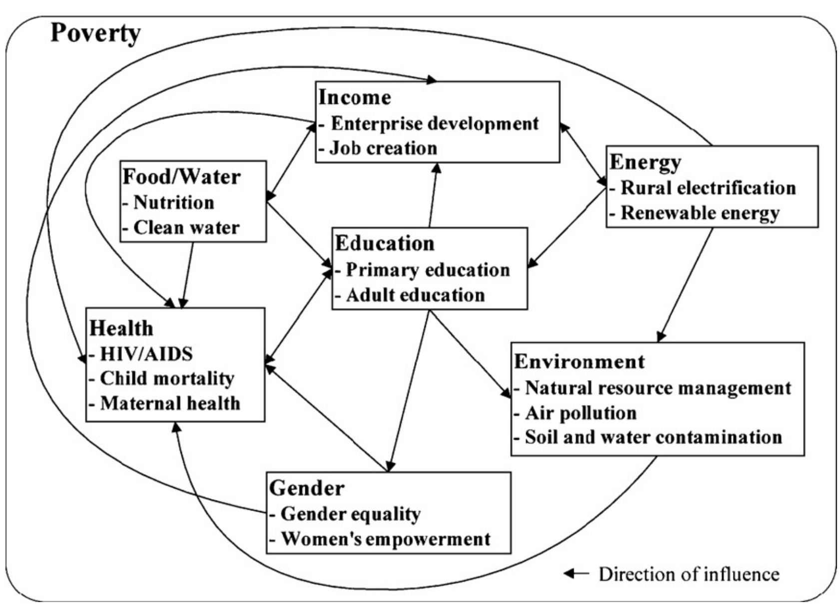

Fig. 1 – Components of poverty and their links.

introduction of efficient stoves, have enough impacts on socio-economic aspects of areas implemented, it has not been paid much attention. Rather large-scale projects such as construction of several hundreds mega-watt class hydropower plants have had a priority in the past, considering their economic efficiency alone.

There are complex and numerous links between energy and poverty. The World Bank Group's Energy and Mining Sector Board point out the links through social and economic development such as productivity, income growth, health and education, gender, social impacts of energy extraction, and human development, as well as through macroeconomic stability and governance (Energy and Mining Sector Board, 2001). It is explained that, expanding access to modern energy services, drudgery such as collecting fuelwood can be alleviated and polluting fuels like wood and dung can be replaced. On the other hand, the Department for International Development (DFID) of the United Kingdom mentions links to the Millennium Development Goals (MDGs), classifying into direct and indirect contributions (DFID, 2002). For one of the MDGs, gender equality and women's empowerment, the energy access improvement directly contributes to freeing up women and girls from gathering fuelwood, fetching water, and cooking with an inefficient stove. In addition, it has indirect contributions for women's enterprises through utilization of energy services.

Fig. 2 illustrates the links between energy and other components with the influence of energy on the others. The energy access improvement in rural areas of developing countries strongly contributes to the alleviation of time consuming labor mentioned above and adverse impacts on health. In addition, because mostly women attain those benefits, the improvement of energy access is favorable from the viewpoints of gender issues. Moreover, it creates time and opportunity of women for income generating activities, and, consequently, increased income, which results in higher opportunity cost for drudgery, creates further demand for the modern energy.

In the study, we have taken into account the opportunity cost to estimate the links between energy and health impacts quantitatively.

3. Areas of the analysis

There are over 1 billion people in India, and about 75% of the total population is in rural areas. According to prospects of the UN agency, in spite of rapid urbanization, 818 million people of total population of 1.24 billion still live in the rural areas (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2005). With respect to the economy, India is one of the most successful developing countries in terms of economic growth, and, in fact, its GDP has rapidly risen at an annual growth rate of 4.6% from the year 2001 to 2002. Energy use and electric power consumption in the country have also increased steadily to 22,540.4 [PJ] and 576.5 billion [kWh] in 2001 at annual growth rates of 3.6% and 6.5% from 1990 to 2001, respectively. However, population living on less than $1 a day and $2 a day are 34.7% and 79.9%, respectively, and thus there is serious inequality in the country (World Bank, 2004). From the viewpoints of energy, IEA's World Energy Outlook 2002 estimates that there are 585 million people who depend on traditional biomass and the population will increase to 632 million in 2030. In addition, Regional Wood Energy Development Programme (RWEDP) of Food and Agriculture Organization (FAO) reports that biomass represents 54% and woody biomass shares 29% of the total energy consumption in India. In the country as a whole and the rural areas, fuelwood contributes 62% and 59% of the total energy used for cooking, respectively (RWEDP, 2005).

In the field of energy, the Government of India has launched several projects. For power sector development, the Ministry of Power of the Government of India has set "Mission 2012: Power for All," which includes complete household electrification as well as power supply to achieve

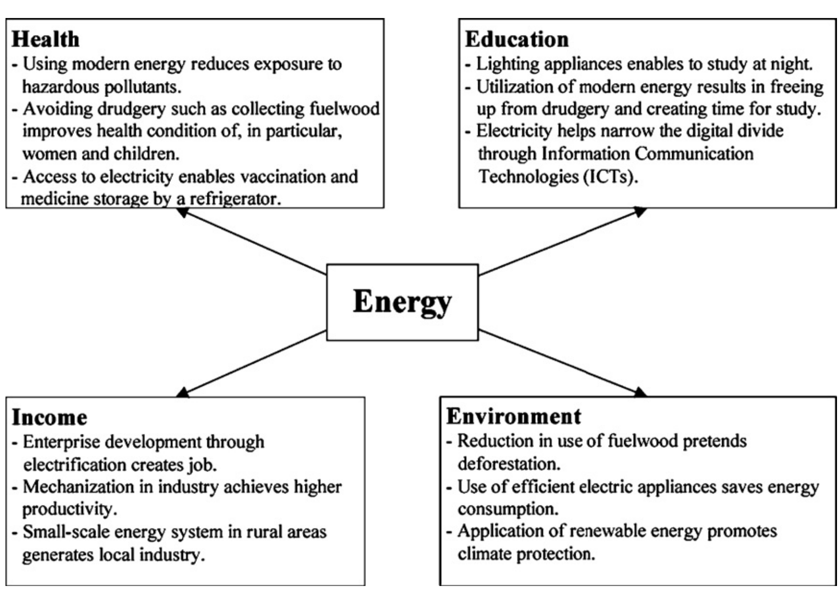

Fig. 2 – Influence of energy on the other components.

Table 1 – Description of the analyzed areas (CIA, 2005; Sarmah et al., 2002)

Population [–]	5958
Male	(54%)
Female	(46%)
Population growth	1.4%
Energy consumption [GJ]	67,267
Cooking and water heating (fuelwood)	(85%)
Space heating in winter (fuelwood)	(14%)
Space lighting (kerosene)	(1%)

continuous economic development of the country. Furthermore, the Rural Electrification Supply Technology (REST) Mission was also adopted in 2002, and its purpose is to complete electrification of all villages and households by the year of 2012 with renewable energy sources, decentralized technologies, and grid expansion. For cooking stoves, on the other hand, the government has also initiated programs, for example, utilization of biogas under the National Biogas and Manure Management Programme as well as dissemination of energy-efficient wood-burning cookstoves, improved Chulhas. Thus, it aims to introduce cleaner cooking devices and fuels into cooking demand of the rural households.

For the analysis, we have targeted villages of the Jorhat district of Assam in India, where fuelwood consists of approximately 85% of total energy consumption and access to electricity is not established (Sarmah et al., 2002). Table 1 summarizes the size and energy consumption patterns of the areas. Although the areas analyzed are strictly specified, the framework of the analysis, as well as concepts of estimation of both the opportunity cost and average RSPM exposure is applicable to other rural areas in developing countries.

4. Method of the analysis

4.1. *Energy-economic model*

For the analysis, we have developed an energy-economic model of rural areas in India, the energy access model, based on both economic and technological parameters of energy conversion processes, and adopted a nonlinear optimization tool. The energy access model is shown in Fig. 3. The model

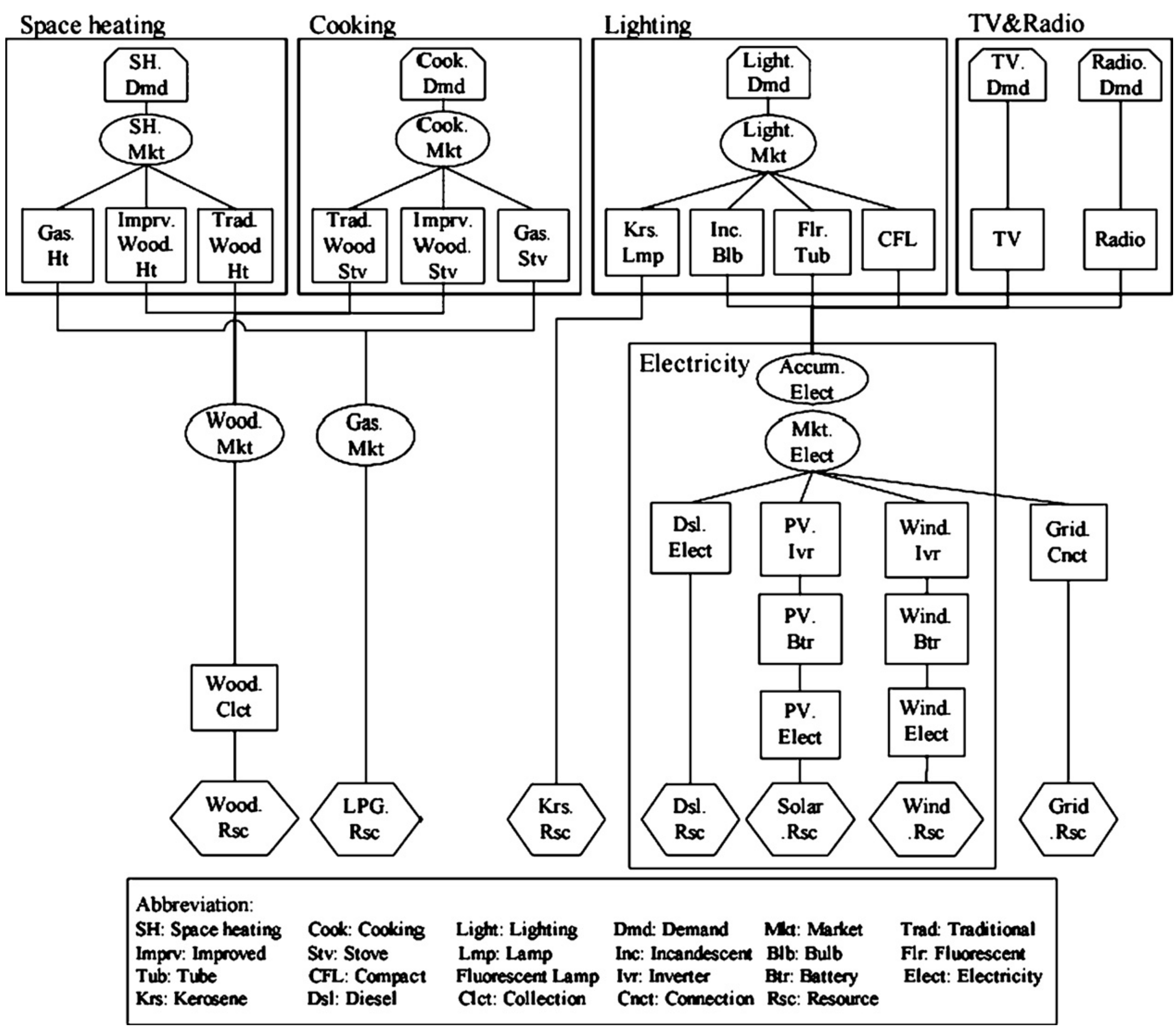

Fig. 3 – Schematic of an energy access model.

Table 2 – Costs of cooking stoves (Jungbluth et al., 1997; Rubab and Kandpal, 1996; Subramaniam, 2000; TERI et al., 1999)

	Cost* [US$/unit]	Life [Year]	Efficiency [–]
Traditional wood stove	0.24	2	0.150
Improved wood stove	1.20	3	0.260
Gas stove	24.10	5	0.541

* US$1=41.6 [Rs.].

consists of 40 nodes; 5 end-use nodes (cooking demand, lighting demand, etc.), 28 technological conversion nodes (traditional wood stove, improved wood stove, gas stove, etc.) including 7 market nodes (heat market for cooking, electricity market etc.), and 7 resource nodes (fuelwood, LPG, etc.). We have applied the META·Net Economic Modeling System jointly developed by Nakata laboratory at Tohoku University and Lawrence Livermore National Laboratory, USA, as an analysis tool (Lamont, 1994). This analysis tool has been already used to analyze energy systems of national and regional levels, and is also compatible with a local level without any particular modification.

The META·Net is categorized as a bottom-up model, which deals with disaggregate process of energy production and conversion process by network of nodes. In addition, it is a partial equilibrium model, based on technological and economic characteristics of technologies, for example, electric power generation in an electricity sector or heating and electric equipments in an industry sector. The modeling approach is characterized as the network modeling. It represents the economy as a network of nodes, and each node models actual actors in the economy such as end-users, conversion technologies, and resources. Among these entities, signals of price and quantity are sent and received. As iterations proceed, price and quantity reach to an equilibrium condition with the convergence process and share of technologies is calculated based on the costs to end-users. Therefore, it has advantages for analyzing introduction of a new technology though it does not estimate impacts on economic activities in areas analyzed. Further explanation of the details is available in the previous studies (Kanagawa and Nakata, 2006; Nakata, 2004). The periods of the analysis are set from the year 2004 to 2012.

In this type of analyses, there are several key assumptions for simplification. It is assumed that total energy demand in the areas increases linearly during the analysis periods according to population growth of the areas referred to the annual growth rate of India, 1.4% (CIA, 2005). There is another assumption that other demographic parameters, for example, average number of people in a household, are constant as well as there is no outflow of the rural population due to urbanization. In addition, because the Government of India decided phase-out of subsidy for fossil fuels in 2002, LPG price rises from subsidized price in the beginning of the analysis to actual market price in the end. Moreover, since, in most of rural areas of developing countries, fuelwood is collected freely at nearby forest instead of being purchased in the market, the cost of fuelwood is set at zero. Finally, economic and technological parameters of cooking stoves are shown in Table 2.

4.2. *RSPM exposure*

Rural households in developing countries are highly dependent on fuelwood, burning it with an inefficient wood stove. As a result, women, who are mostly responsible for cooking, are exposed to high concentrations of hazardous pollutants such as Resipirable Suspended Particulate Matter (RSPM), carbon monoxide (CO), and nitrogen oxide (NOx). RSPM is Suspended Particulate Matter (SPM) whose size is defined below 3 [μm]. It is capable of penetrating the adult lung and causes serious respiratory affection of women in the rural areas of developing countries. In the study, we have estimated changes in the average RSPM exposure of women in the rural households as an indicator for the socio-economic aspects of the energy access improvement.

In order to estimate the emissions and exposure of RSPM, we have referred to joint works by UNDP and ESMAP in India (UNDP/ESMAP, 2002, 2004). Based on the studies, time allocation of women in rural households and RSPM concentrations during cooking or non-cooking time in a kitchen, living area, and outdoors are shown in Table 3, considering efficiency of stoves.

The average RSPM exposure is calculated by the following equations.

$$24-\text{h RSPM exposure of stove } [\mu g/m^3] = \frac{\sum(\text{RSPM concentration in an area } [\mu g/m^3]) \times \text{Time allocation in an area } [h])}{24[h]} \quad (1)$$

$$\text{Average RSPM exposure } [\mu g/m^3] = \sum(24-\text{h RSPM exposure of stove } [\mu g/m^3] \times \text{Adoption rate of a stove}) \quad (2)$$

The adoption rate of a stove indicates the share of the stove in cooking energy demand. It illustrates, as gas stoves are adopted by the rural households, the average RSPM exposure, which might result in alleviating adverse effects on women's health.

4.3. *Opportunity cost*

An opportunity cost is the idea that the use of limited resources such as money and time loses opportunities for alternatives. In the analysis, the opportunity cost is taken into account as an input parameter, in order to incorporate time spent for collecting fuelwood and extra time for cooking with a wood stove in monetary terms. Table 4 shows the extra time by using a wood stove. We have assumed that women in the rural areas could spend an average of 8 h a day on income

Table 3 – Time allocation and RSPM concentrations (UNDP/ESMAP, 2002, 2004)

	Cooking period		Non-cooking period		Outdoors
	Kitchen	Living area	Kitchen	Living area	
Time allocation [h]	3.6	1.3	1.7	12.4	4.8
RSPM concentration [μg/m^3]					
Traditional wood stove	2,150	767	265	262	87
Improved wood stove	1,353	565	265	262	87
Gas stove	122	132	65	62	114

generating activities, which account for more than 2000 h labor annually. In addition, as UNDP has pointed out, it is assumed that women contribute to 53% of household's income (UNDP, 1995).

Based on the above assumptions, the opportunity cost of women for using fuelwood in the rural areas is calculated, based on following equations.

$$\text{Women's opportunity cost with fuelwood [US\$/GJ]} = \frac{\text{Women's opportunity cost [US\$/h]}}{\text{Daily energy consumption [GJ/day]}} \times \text{Extra time with fuelwood [h/day]} \quad (3)$$

where,

$$\text{Women's opportunity cost [US\$/h]} = \frac{\text{Women's contribution to household's income [US\$/year]}}{\text{Hours of labor [h/year]}}$$

$$\text{Women's contribution to household's income [US\$/year]} = 0.53 \times \text{household's income [US\$/year]}$$

From the equations, due to increase in household's income, the opportunity cost of women also rises up. Thus, it appreciates the cost of fuelwood, and LPG price becomes relatively lower. For example, from the calculation, women's opportunity cost of the poorest household in West Bengal, which is geographically close and whose households are hardly electrified similarly to those of Assam, is estimated to be US\$0.02/GJ. On the other hand, the opportunity cost of US\$16/GJ is equivalent to the highest income of a rural household in Himachal Pradesh, one of the richest states in India.

Table 4 – Extra time by using a wood stove [h] (UNDP/ESMAP, 2004)

	Wood stove	Gas stove	Extra time for a wood stove
Wood collection	0.67	–	0.67
Cooking	2.73	2.3	0.43
Total extra time by using a wood stove	–	–	1.10

5. Result of the analysis

In this section, results of the analysis are shown. First, for a fundamental analysis, several results without considering the opportunity cost that is equal to the opportunity cost of US\$0/GJ are provided as the BAU case. Then, the opportunity cost is introduced into the analysis.

Fig. 4 shows the changes in total energy consumption in the rural areas of India from the year 2004 to 2012 in the BAU case. It is revealed that all of energy consumption for space heating and cooking in the rural areas is provided by traditional wood heaters and stoves. Improved devices such as improved wood heaters and stoves as well as gas heaters and stoves are not adopted by the rural households during the analysis periods, because of their higher unit costs compared to those of traditional devices.

For cooking energy demand, the result of the analysis is shown in Fig. 5. Similar to the total energy consumption, traditional wood stoves share 100% of energy demand for cooking without the opportunity cost. Improved wood and gas stoves are not used by the households from 2004 to 2012 because their costs are higher than that of traditional wood stoves. In particular, the cost of gas stoves is prohibitively higher in terms of both unit and fuel costs as shown under the condition of the BAU case. As for the fuel cost, it is because LPG is purchased in the market, on the contrary to fuelwood, which is collected by the households without any monetary cost.

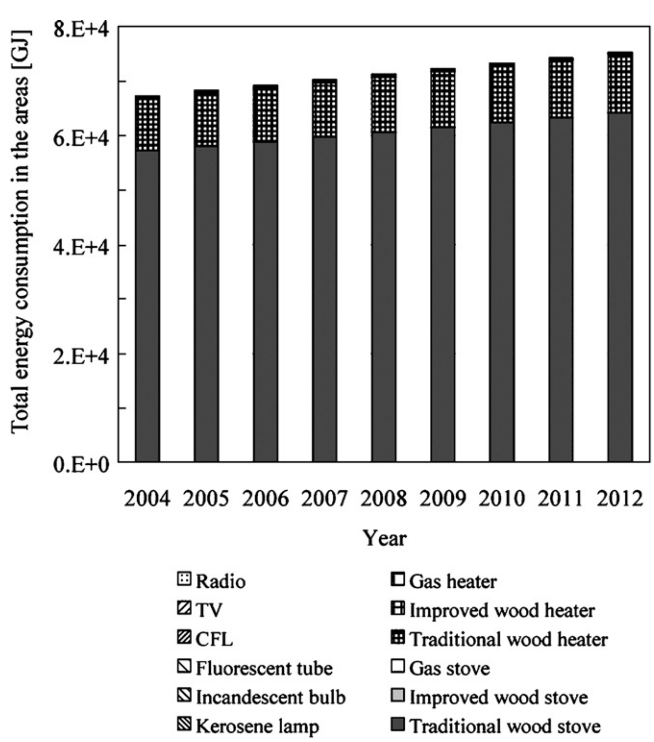

Fig. 4 – Energy consumption in the rural areas for the BAU case.

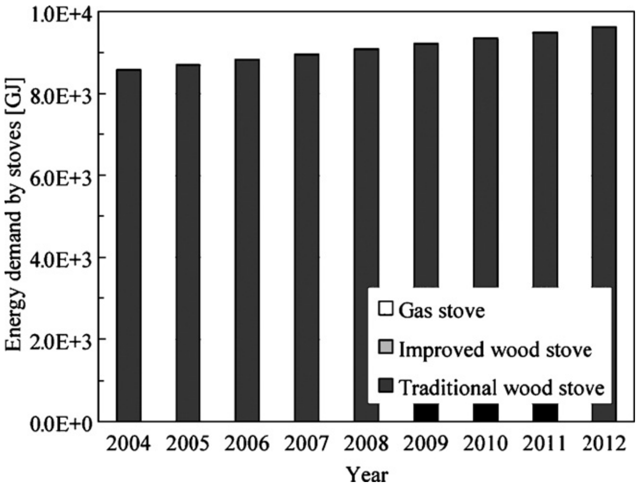

Fig. 5 – Energy demand for cooking in the areas for the BAU case.

In order to take into account socio-economic aspects of the energy access improvement, we have considered the opportunity cost for consuming fuelwood for cooking in the analysis. Then, we have also estimated the average Resipirable Suspended Particulate Matter (RSPM) exposure of women in the rural areas, applying the calculation shown in the previous section.

Considering the opportunity cost, additional costs generate for drudgery of collecting fuelwood and extra time of cooking with a wood stove. The cost of wood stoves is escalated according to combustion efficiencies, and it results in that the price escalation of a traditional wood stove is higher than that of an improved wood stove. On the other hand, the cost of a gas stove remains constant because the gas stove does not incur the opportunity cost. Fig. 6 shows the cost comparison among stoves with opportunity costs. Compared to the cost of a gas stove, the cost of a traditional and improved wood stove becomes double and equivalent, respectively, for the opportunity cost of US$10/GJ. Furthermore, for the opportunity cost of US$20/GJ, the cost of an improved wood stove reaches US $76.9/GJ, which is approximately twice as much as that of a gas stove. Thus, the cost of a gas stove becomes relatively lower as the opportunity cost increases, and the stove is adopted in the rural areas.

The relation between the energy demand by cooking stoves, opportunity cost, and average RSPM exposure is shown in Fig. 7. The WHO environmental health criterion for Suspended Particulate Matter (SPM), 190 [μg/m] as well as the Japanese environmental criterion for SPM regulated by the Ministry of Environment of Japan, 100 [μg/m] (Ministry of Environment of Japan, 2005) is shown in the figure. Although the WHO concluded that there are not enough surveys for SPM, it suggested the criterion for 24-h exposure to SPM, 150–230 [$\mu g/m^3$] with a 20% range (WHO, 1979). As a result of the analysis, for the opportunity cost of US$0/GJ, that is, the BAU case, traditional wood stoves share 100% of the energy demand for cooking in the areas. The average RSPM exposure exceeds 400 [$\mu g/m^3$], which is two and four times more than the WHO and Japanese criteria, respectively. Taking the opportunity cost into account, even for the opportunity cost of US$1/GJ, improved wood stoves greatly penetrate into cooking energy demand because of their higher efficiency of wood consumption than traditional ones. However, gas stoves are still higher and are not introduced in the areas. Even though the average RSPM exposure is reduced by 15.3% from 410 to 347 [$\mu g/m^3$], the level of the exposure is still high, compared to the international and Japanese standards. This trend continues to the opportunity costs of US$3/GJ. Thereafter, as the opportunity cost increases, gas stoves are widespread in the rural households steadily and the average RSPM exposure also decreases continuously. For the opportunity cost of US$9/GJ, it is achieved that the average RSPM exposure reaches 185 [$\mu g/m^3$], below the WHO criterion, resulting in the 54.9% reduction from the BAU case. Moreover, for the opportunity cost of US$15/GJ, the average RSPM exposure attains 98 [$\mu g/m^3$], reduced by 76.2% compared to the BAU case, and accomplishes the Japanese criterion. The opportunity cost of US$15/GJ is equivalent to the income gained by

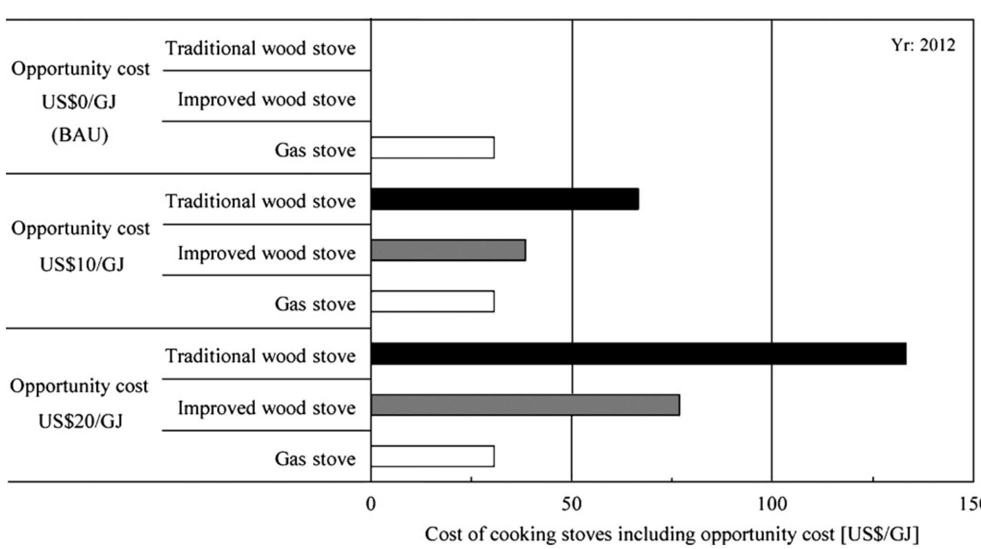

Fig. 6 – Cost comparison of cooking stoves with opportunity costs.

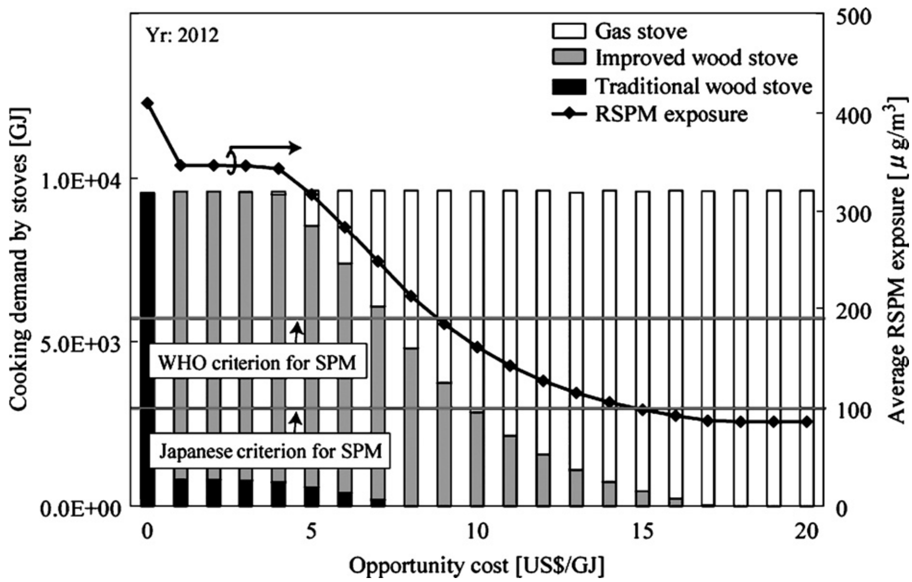

Fig. 7 – Changes in energy demand and average RSPM exposure in the areas.

women in one of the richest rural areas in India, Himachal Pradesh. It is achieved that, for the opportunity cost of US$18/GJ, the gas stoves prevail in the areas, sharing 100% of the cooking energy demand, and the average RSPM exposure results in 86 [μg/m^3]. Therefore, it can be interpreted that the rural areas in India have the possibility to meet the health criteria of the international organization and developed country, following to the increase in the income and energy access improvement.

Table 5 shows the summary of the analysis. First, for the energy consumption, the energy consumption for cooking in the rural areas of India decreases because efficient gas stoves are widely used by the households instead of wood stoves. Fuelwood consists of 100%, 57.0%, and 9.3% of the cooking energy consumption in the areas for the opportunity cost of US$0/GJ, US$9/GJ, and US$15/GJ, respectively. Compared to the BAU case, wood consumption for the opportunity cost of US$9/GJ and US$15/GJ decreases by 77.4% and 97.3%, respectively. It might mitigate in the local deforestation in rural areas. Second, as the opportunity cost increases, the total expenditure of the rural households for cooking energy from 2004 to 2012 rises remarkably. Almost all of the expenditure represents the fuel cost of LPG. It is explained that, for the BAU case, the households obtain fuelwood freely at the price to their time allocation for the drudgery. However, due to the increase in the opportunity cost, the households become able to pay for the cost of LPG and a gas stove. Finally, the average RSPM exposure is reduced by 54.9% and 76.2%, and attains to 185 and 98 [μg/m^3] for the opportunity cost of US$9/GJ and US$15/GJ, respectively, achieving the WHO and Japanese criteria for SPM.

Table 5 – Comparison of the energy consumption, total household expenditure, and average RSPM exposure in the three opportunity costs

	Opportunity cost US$0/GJ (BAU)	Opportunity cost US$9/GJ	Opportunity cost US$15/GJ
Energy consumption for cooking [GJ]	6.38E+4	2.53E+4	1.86E+4
Fuelwood	(100.0%)	(57.0%)	(9.3%)
LPG	(0.0%)	(43.0%)	(90.7%)
Total household expenditure[a] [US$]	6.56E+1	4.68E+5	9.51E+5
Capital cost	(100.0%)	(0.2%)	(0.2%)
Fuel cost	(0.0%)	(99.8%)	(99.8%)
Average RSPM exposure [μg/m^3]	410	185	98
RSPM reduction ratio compared to BAU	–	(54.9%)	(76.2%)

[a] Total household expenditure for cooking is calculated by adopting the interest rate of 10%, from 2004 to 2012.

6. Discussion

This section provides the discussion of energy access improvement in cooking demand in rural areas of developing countries. We argue three points; pollutants related to cooking, policy implementation by the Government of India, and income generation.

The result of the analysis shows the significant reduction of RSPM exposure because of the replacement of wood stoves by a gas stove. It results in alleviating adverse impacts on health in areas, where households rely mostly on burning wood for their cooking demand. In particular, women, who are mainly responsible for such daily chores, and sometimes children are the beneficiary for the replacement. In addition, developing countries are huge inventory of greenhouse gases, and their residential sector can potentially reduce the gases as a result of the replacement of the stoves. Although biomass is regarded as carbon neutral resource it is not sustainable and largely contributes the global warming when burnt incompletely. Bhattacharya et al. (2002) have measured emission factors for

CO, CO_2, CH_4, Total Non-Methane Organic Compounds (TNMOC), and NOx, examining a number of traditional and improved biomass stoves used in Asian developing countries (Bhattacharya et al., 2002). The study has concluded that, as the efficiency of the cookstoves increases, the emission factors in gram per useful energy used for all pollutants decline. Furthermore, in another study, the emission factors of the pollutants from more various cooking stoves – coal, kerosene, and LPG as well as biomass – have been examined in order to construct the database (Smith et al., 2000). Because CO and TNMOC are not included in the global warming commitments by IPCC, as a result of the study, some biomass stoves indicate less GHG emission than a LPG stove under the renewable harvesting assumption if only CO_2, CH_4, and N_2O are taken into account. However, including CO and TNMOC emitted due to the incomplete combustion, as well as the pollutants shown above, LPG attains lower emission factors because of its higher thermal efficiency and fuel composition.

Therefore, dissemination of gas stoves in rural areas of developing countries contributes not only improvement of the health condition in the habitants but also mitigation of environmental burden. This implies that energy access improvement in the rural areas has huge impacts on socio-economic situation of both local and global levels.

The Government of India has assisted the introduction of an improved biomass stove, launching the National Programme on Improved Chulhas (NPIC) since the year 1986–1987 (Ministry of Non-Conventional Energy Sources of the Government of India, 2005). Subsidizing the capital cost of the stove, it aims to preserve fuelwood and other biomass, remove smoke from a kitchen, check deforestation and environmental upgrade, reduce drudgery of women and girls, mitigate health hazards, and provide employment opportunities in rural areas. As a result, up to the end of March 2003, cumulative introduction of the stove has reached 35 million units. However, this number is far less than estimated potential. In addition, as shown in the results of our analysis, adoption of improved wood stoves has limited impacts on the improvement of health condition of rural households.

It is necessary to disseminate LPG in order to alleviate adverse health impacts substantially. The number of LPG customers has increased to 82.3 million at the beginning of the year 2005, and most of them are in urban areas (Ministry of Petroleum and Natural Gas of the Government of India, 2005). Due to the liquidation of LPG connection in urban areas, oil marketing companies have started to focus on rural areas, expanding the distribution network. In order to facilitate the adoption of LPG by low income households in rural areas as well as the transportation to hilly areas, Public Sector Undertakings (PSU) Oil Companies have provided a 5 kg cylinder of LPG. On the other hand, as the results of our analysis indicate, it is essentially inevitable to generate income in the areas to achieve continuing purchase of LPG.

Income generation is directly related to poverty reduction, and is one of the targets of the MDGs. In fact, international donor community has extensively been making implementation of the creation of income generating activities in rural areas of developing countries.

In the analysis, we have considered possibility of the income generation as an exogenous factor. Rather, the results of the analysis have shown the consequences of the income generation; the changes in adoption rate of a traditional wood stove, improved wood stove, and gas stove as well as the health impacts of energy access improvement in rural areas of developing countries. It is indispensable for the donor community to estimate how much economic and social impacts a project will have, and how much cost should be spent to conduct the project cost-effectively. For this purpose, the analysis proposes desirable amount of expenditure on a project in rural areas of developing countries, illustrating socio-economic impacts of energy access improvement due to the income generation quantitatively.

Recently, the international donor community has increasingly paid attention to software of the development and equity in a developing country including gender equality. Improving energy situation through the dissemination of a gas stove provides rural households the basic opportunity to avoid detrimental effects on their health and to educate children, freeing up from drudgery. It will result in the mitigation of socio-economic conditions between urban and rural areas in developing countries. Taking into account more various socio-economic factors, this analytical method will evolve into the framework of energy access improvement including socio-economic impacts on rural households in developing countries. The framework will greatly help the donor community invest and implement development projects cost-effectively, for example, through the Official Development Assistance (ODA).

7. Conclusion

Energy is a fundamental requirement for development and one of the most influential components of poverty reduction in developing countries. Although the energy access improvement has significant impacts on the socio-economic aspects in the rural areas, it is not achieved under the BAU condition. In order to reveal the links between energy, income, and health hazard, we have introduced the opportunity cost of women in the rural areas of India for collecting fuelwood and cooking with a wood stove, as well as the estimation of average RSPM exposure. The introduction of the opportunity cost results in the cost appreciation of fuelwood according to the income level of the rural households.

In the BAU case, that is, the opportunity cost of US$0/GJ, the total energy consumption and cooking energy demand in the rural areas are completely supplied by traditional wood heaters and stoves, respectively. Improved wood and gas devices are not adopted by the rural households during the analysis periods because of their high unit cost. In addition, gas heaters and stoves consume LPG bought in the market, and the cost of LPG is prohibitively expensive for the rural households. Thus, in the BAU case, the households collect fuelwood freely at the expense of the drudgery such as collecting fuelwood, instead of purchasing LPG.

Considering the opportunity cost, composition of energy demand for cooking is drastically changed. Even for a small amount of the opportunity cost, improved wood stoves are adopted by most of the rural households. However, gas stoves are not used because the opportunity cost is not enough for the households to replace wood stoves, until the opportunity cost of US$3/GJ. This level of income is equivalent to the maximum income in rural areas of Andhra Pradesh, one of the poorest states in India. Subsequently, as the opportunity cost increases, gas stoves penetrate into the cooking energy demand steadily. Because the opportunity cost reflects to the income of the rural households, it means that the households can afford to pay for the cost of LPG, as the income increases. It is difficult that rural households adopt gas stoves instead of wood stoves at hand. However, in the future, because of economic development in rural areas, it is likely to occur that gas stoves are widely purchased by rural households in developing countries.

As the improved wood and gas stoves are widely used by the households, the average RSPM exposure of women is reduced. The dissemination of the improved wood stoves does not have enough effects on the reduction of the average RSPM exposure, compared to the WHO standards for SPM. However, as the gas stoves are increasingly adopted by the rural households, the level of the exposure decreases rapidly. As a result, the average RSPM exposure attains the level well below the WHO criteria.

Based on the analysis, we can draw the following conclusions:

- Without income generation, which is reflected by the opportunity cost, the rural households do not adopt improved wood and gas devices. In particular, focusing on the income of women is important in terms of gender equality and women's empowerment. Further research is needed for precise data collection of both income and energy consumption of the rural households.
- As the opportunity cost increases, improved wood and gas stoves will be used for cooking energy demand. Increased income might result in changes in patterns and amounts of energy consumption in the rural households. Thus, it is important to take into account emerging energy demand as well as additional energy demand for daily activities of the households.
- Following to the increase in the opportunity cost, the average RSPM exposure is reduced to the level set by the international organization and developed country. It results in the improvement of socio-economic aspects in the rural areas of developing countries. It is expected that other socio-economic aspects of development be incorporated in further study, such as education, natural environment, and labor.

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