Socio-economic impacts of energy poverty alleviation in rural areas of developing countries

Makoto Kanagawa and Toshihiko Nakata

Tohoku University
Department of Management Science and Technology
Graduate school of Engineering

September 25, 2006

Energy Access

- Sustainable use of electricity and LPG at affordable price.

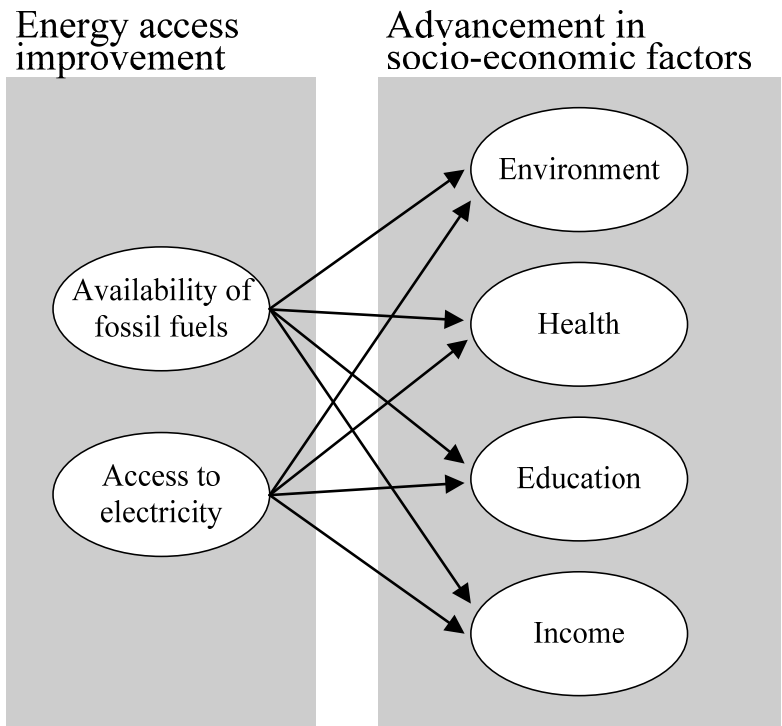
[person]

Population	2000	2030
Depending on traditional biomass	2.4 billion	2.6 billion
Without electricity access	1.6 billion	1.4 billion

Source: IEA, 2002. Energy and poverty In: World Energy Outlook 2002.
Mkoka, 2004. Fueling Malawi's environmental challenges.
Garner, 2006. Night-time women's literacy class in rural Mali.

Energy access and poverty alleviation

- Recently, poverty alleviation is assessed not only from economic aspects (e.g. income) but also from social aspects (e.g. health and education).
- Improvement of energy access can contribute for poverty reduction from various aspects.



Literature review

- Enables practical policy evaluation.
- However, there is few study assesses socio-econo empirical study
- Researches on policies or programs (Bastakoti, et al., 2003).
- Discussions are limited in objective areas.

- Experimental study
  - Experiments of energy appliances or energy consumption (Bhattacharya, et al., 2002).
- Analytical study
  - Numerical analysis by models (Howells, 2005).
  - mix impacts of energy access improvement.

Objectives of this study

- Provide analytical framework for assessment of energy access improvement and its socio-economic impacts.
- Analyzed areas for case study:

  Villages of Assam state, India.
  - Cooking demand: RPSM exposure
  - Lighting demand: Literacy rate
- Studying period: year 2004 to 2012
- Economic optimization of energy demand and supply by META-Net.

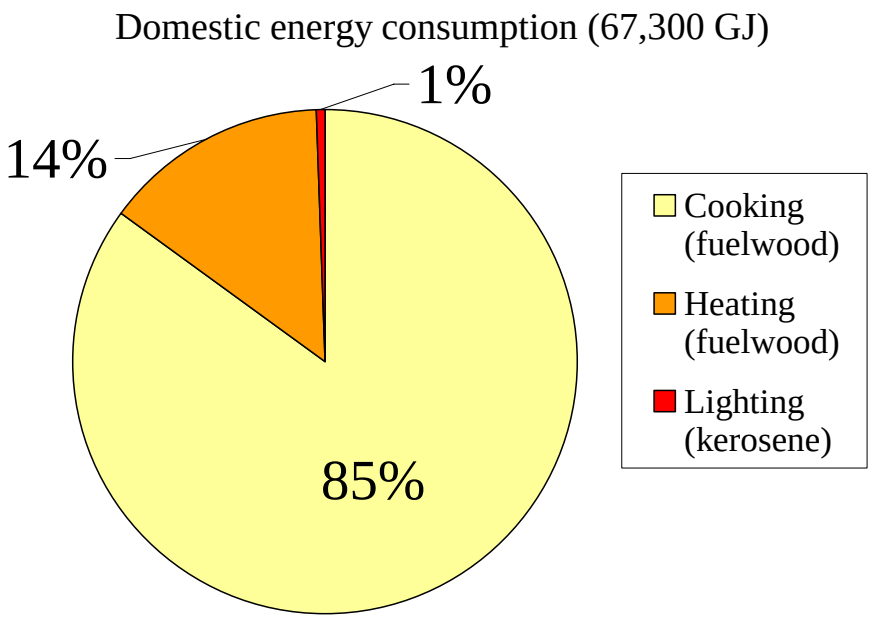
Assam state in India

		Assam	India	Japan
Population	Total	26,655,528	1,028,610,328	127,291,000
	Rural	(87.1%)	(72.2%)	-
Gross Domestic Products per capita [US$]		161	281	44,834
Literacy rate		63.3%	64.8%	>99.0%
Electricity consumption per capita [kWh]		20.36	75.18	7,601.91
Electrification rate	Total	24.9%	55.8%	-
	Rural	16.5%	43.5%	-

Source: Central Electricity Authority, 2005. All India electricity statistics 2005: general review.

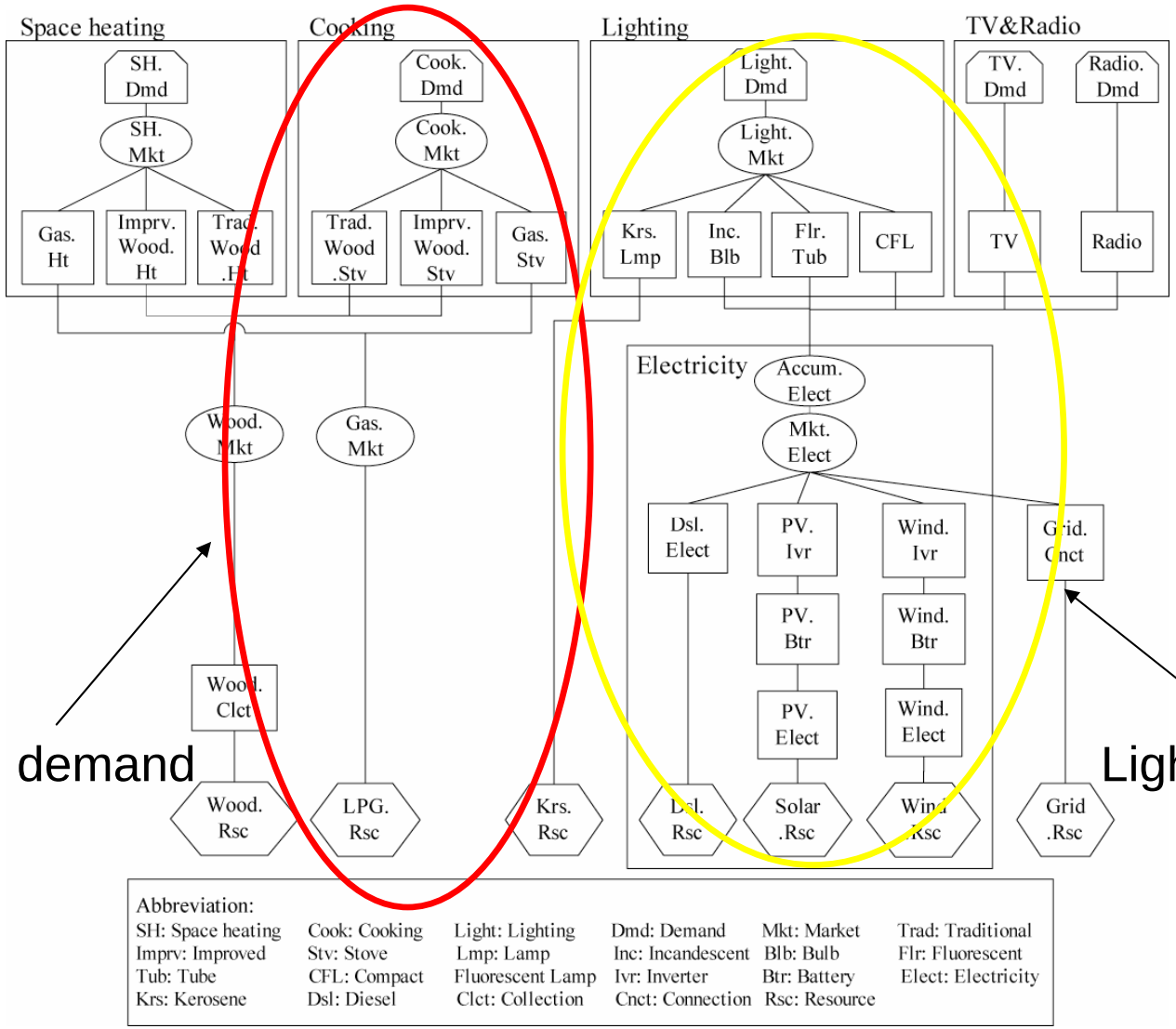
Rural areas of Assam state

- Population: 5,958 (485 households)
- Cooking demand
  - depends on direct combustion of wood fuels.
- Lighting demand
  - Kerosene lamps are used.



Source: Sarmah et al., 2002. Energy profiles of rural domestic sector in six un-electrified villages of Jorhat district of Assam.

Energy access model



Cooking demand

Lighting demand

Parameters required for cooking demand analysis

- Adoption of LPG in the area is analyzed through dissemination of gas stoves instead of using wood fuels.
- Opportunity cost
  - extra time due to collecting fuelwood and cooking with a stove.
- Respirable Suspended Particulate Matter (RSPM) exposure

Methodology of cooking demand analysis

- Calculate women's opportunity cost and RSPM* exposure as a parameter of health damage.
- Design an energy economic model in analyzed area, then evaluate the possibility of utilization of gas stoves.
- Estimate reduction of RSPM exposure through utilization of gas stoves.

Improvement of energy access on cooking demand means the transition of energy source from wood fuel to LPG.

RSPM (Respirable Suspended Particulate Matter)
A kind of particle pollutants. It arises from combustion process of biomass, and is regarded as cause of respiratory disorder.

Opportunity cost

- Opportunity cost by use of wood stoves

Women's opportunity cost with fuelwood [US$/GJ]

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

[hour]

	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

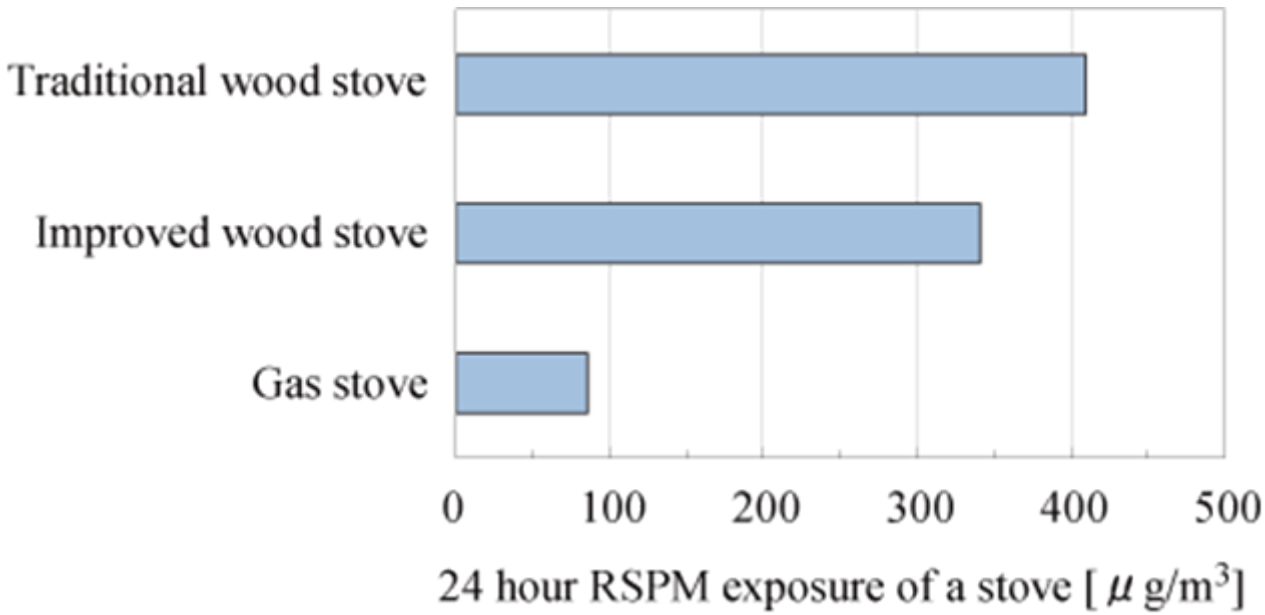
Source: UNDP/ESMAP, 2004. The impact of energy on women's lives in rural India.

Calculation of RSPM exposure

- Rural households depending on traditional wood stove are exposed to indoor air pollution.

$$\text{Average RSPM exposure of a stove } [\mu g/m^3]$$

$$= \sum \left(\text{24 hour RSPM exposure of a stove } [\mu g/m^3] \times \text{Adoption rate of a stove } [\%] \right)$$



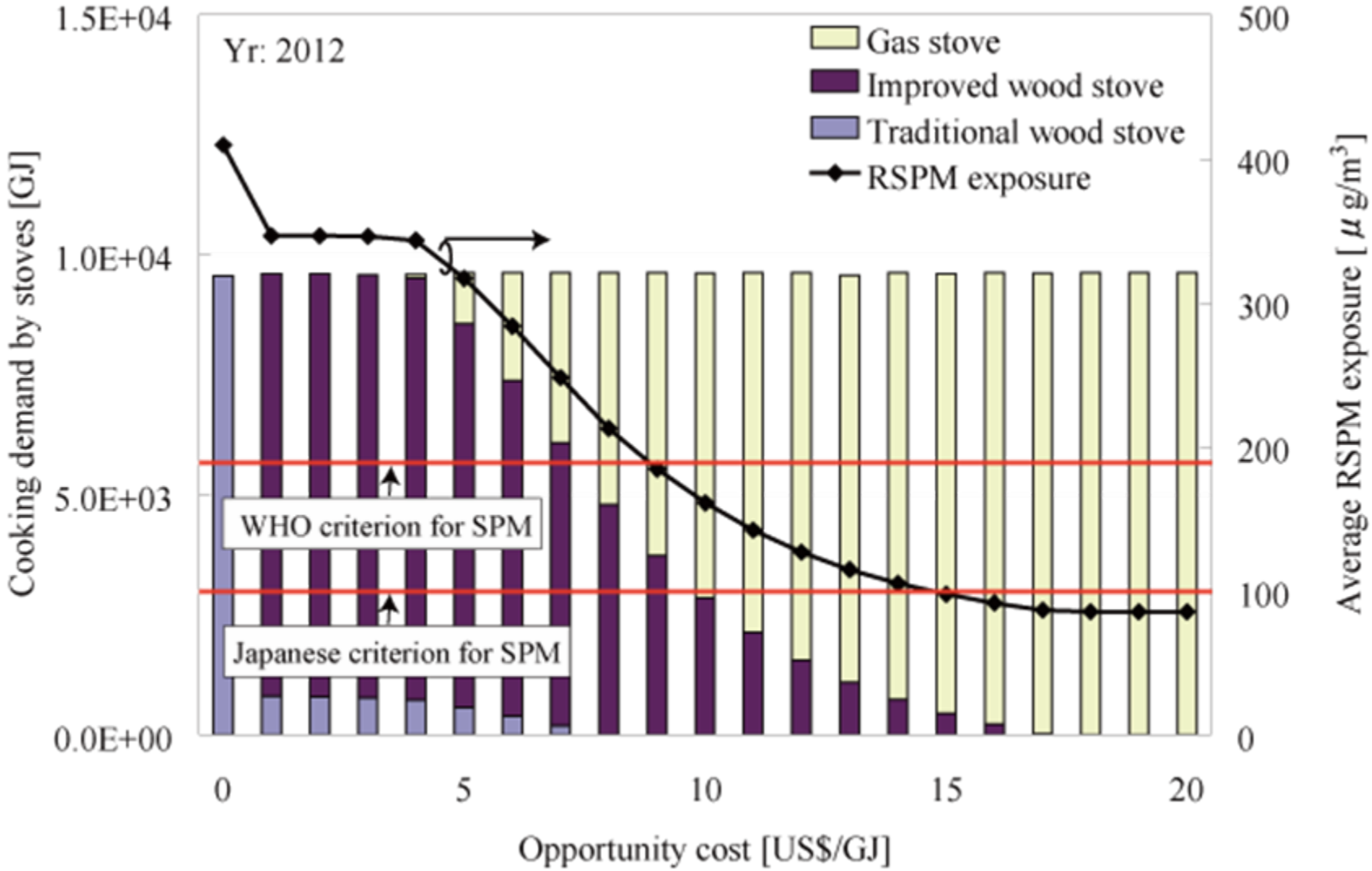
Source: UNDP/ESMAP, 2002. India: household energy, indoor air pollution, and health.
UNDP/ESMAP, 2004. The impact of energy on women's lives in rural India.

Cost parameters of cooking devices

	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

Source: Jungbluth et al., 1997. Life cycle inventory for cooking: some results for the use of liquefied petroleum gas and kerosene as cooking fuels in India.
Rubab and Kandpal, 1996. Biofuel mix for cooking in rural areas: implications for financial viability of improved cookstoves.
Subramaniam, 2000. Whose interests? Gender issues and wood-fired cooking stoves.
TERI et al., 1999. Potential for use of renewable sources of energy in Asia and their cost effectiveness in air pollution abatement.

Cooking demand and RSPM exposure



Result of analysis

- Traditional cooking stoves are continuously used without considering the opportunity cost.
- Gas stoves are adopted when the opportunity cost is included in price of traditional wood stoves.
- For the opportunity cost of US$9/GJ, the average RSPM exposure reaches 185 [μg/m^3], below WHO criterion (54.9% reduction from BAU case).

Methodology of lighting demand analysis

- Expect relationship between energy demand and literature rate by multiple regression analysis.
- Design the energy economic model in analyzed areas, then evaluate the possibility of utilization of electric lighting appliances.
- Estimate improvement of literature rate through utilization of electric lighting appliances.
  - Incandescent bulbs
  - Fluorescent tubes
  - Compact Fluorescent Lamps (CFL)

Selection of explanatory variables

- Decide explanatory variables based on stepwise criteria.
  - Test reliability of variables at 5% of statistical significance level.

$$Y_i = \beta_1 + \beta_2 \times X_{2i} + \beta_3 \times X_{3i} + \beta_4 \times X_{4i} + \ldots$$

Economic factor	Log of Gross Domestic State Production (GSDP) per capita.	2000-01
Educational factor	Log of the number of primary schools per 1,000 people in state.	2002-03
Geographical factor	Log of road density per 1,000km^2	1998-99
Socio-cultural factor	Sex ratio (Female/Male)	2001
	Population rate of particular caste in state	2001
	Population rate of Hindus in state	2001
Electrical factor	Electrification rate	2001

Source: Office of the Registrar General. http://www.censusindia.net.

Result of multiple regression analysis

- After the multiple regression analysis, electrification rate, sex ratio and the log of road density were selected as explanatory valuables of literature rate.
- At increase of 1 point of electrification rate, literature rate will improve to 0.166 point.

$$\text{Literacy rate above 6 years old} = -0.489 + \underset{(0.040)^{**}}{} \quad 0.166 \times \text{Electrification rate}_{(0.004)^{**}}$$

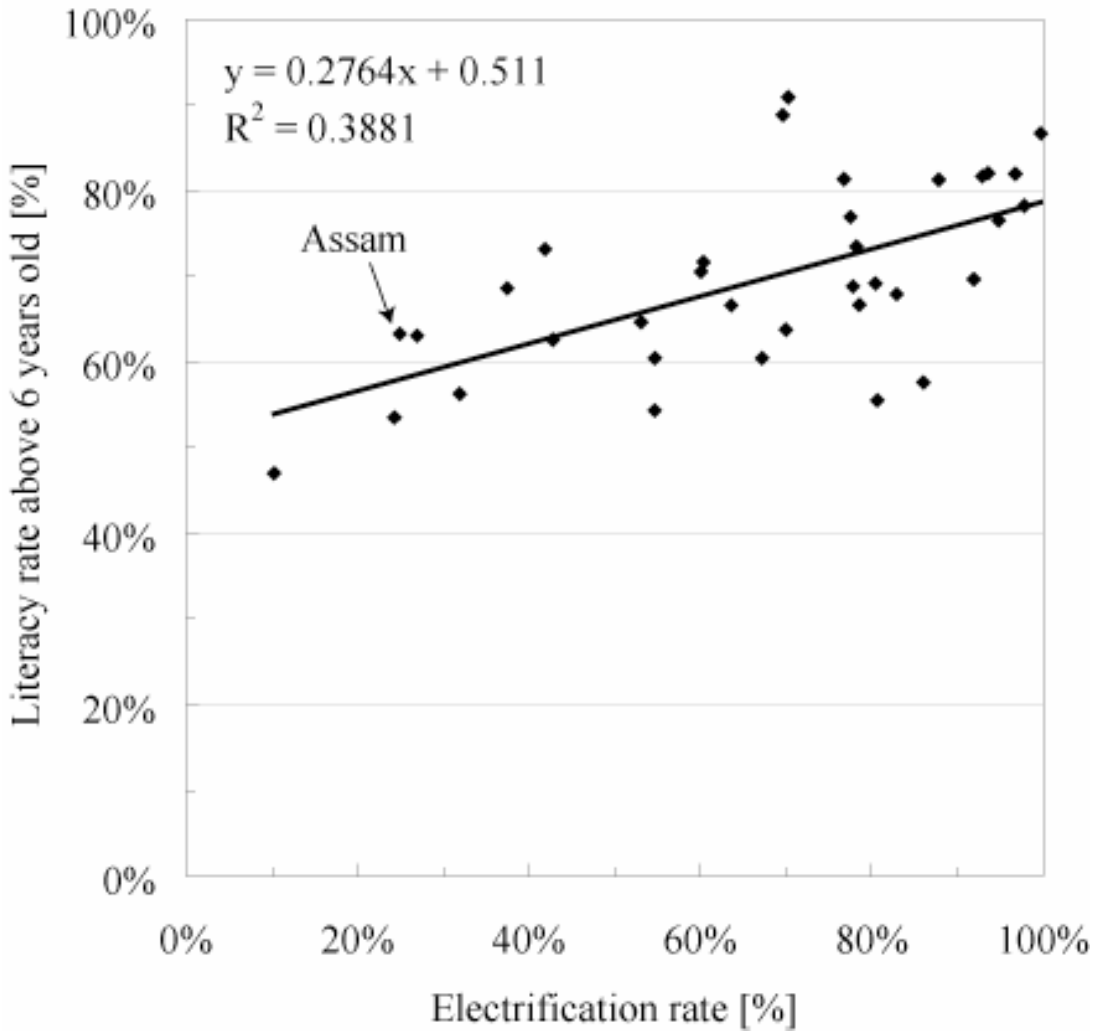
$$+ \underset{(<0.001)^{*}}{0.143 \times \text{Log (Road density)}} + \underset{(0.003)^{**}}{0.683 \times \text{Sex ratio}}$$

Note: Value in the parenthesis is p value

* 1% significant.

** 5% significant.

Relations between electrification rate and literacy rate



Statistically significant at 95% level

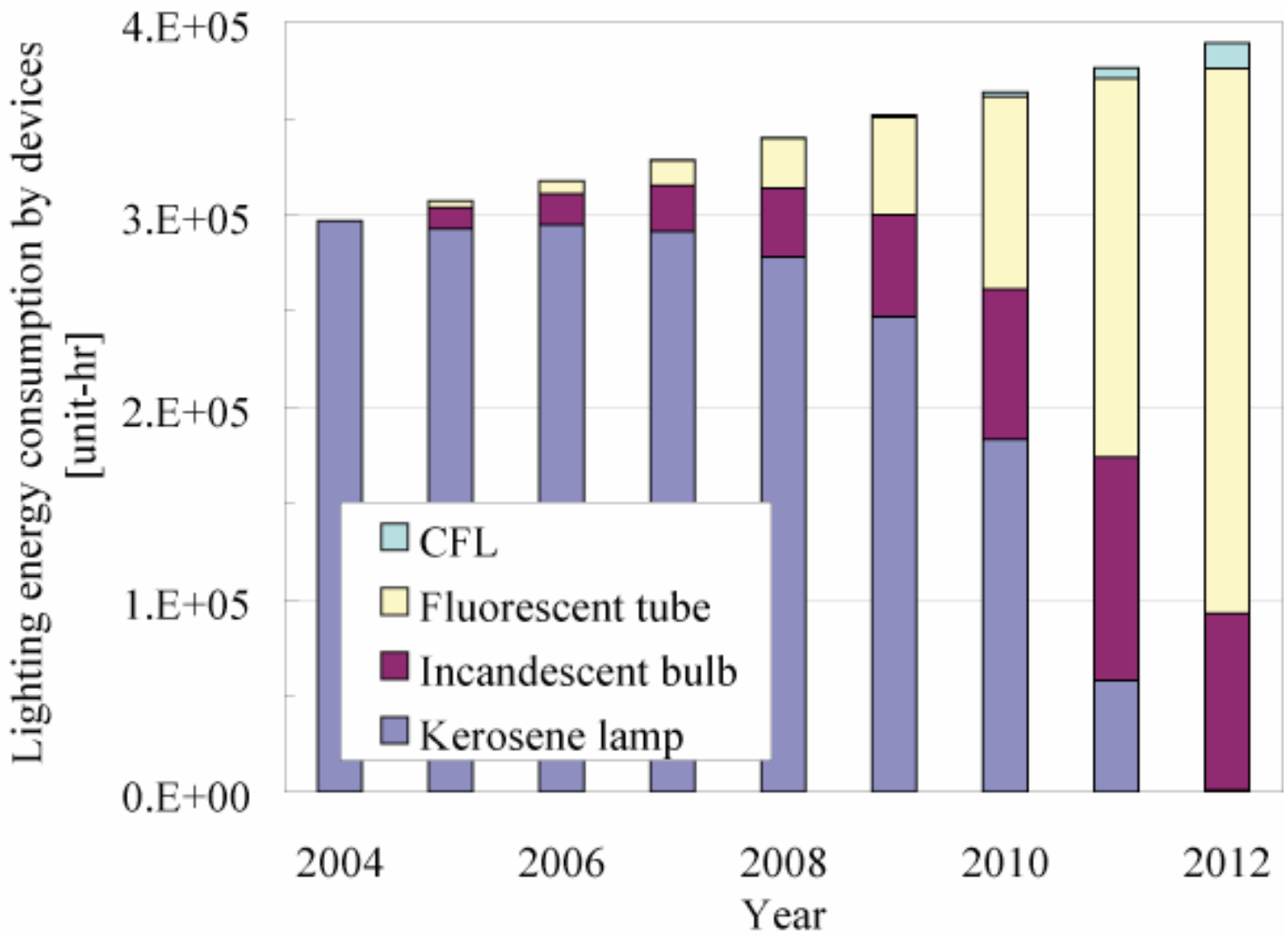
Cost parameters for lighting devices

- Lighting

	Equipment cost [US$]	Unit cost [US$]	Life [hour]	Energy consumption per unit-hour [kWh]
Kerosene lamp	0	0.602	5*	0.400
Incandescent bulb	0.736	0.241	1,000	0.060
Fluorescent tube	6.024	1.205	10,000	0.040
CFL**	0.736	4.819	10,000	0.011

* Life for kerosene lamp is in year.
** CFL: Compact Fluorescent Lamp.

Model simulation of lighting demand



Result of analysis

- Assume that same results will be achieved in the rest of rural areas of Assam, 96.3% of households in the entire state attain electricity access.
- Application of regression analysis and model simulation reveals improvement of literacy rate from 63.3% to 74.4%.

$$\text{Literacy rate above 6 years old} = -0.489 + 0.166 \times \text{Household electrification rate} + 0.143 \times \text{Log (Road density)} + 0.683 \times \text{Sex ratio}$$

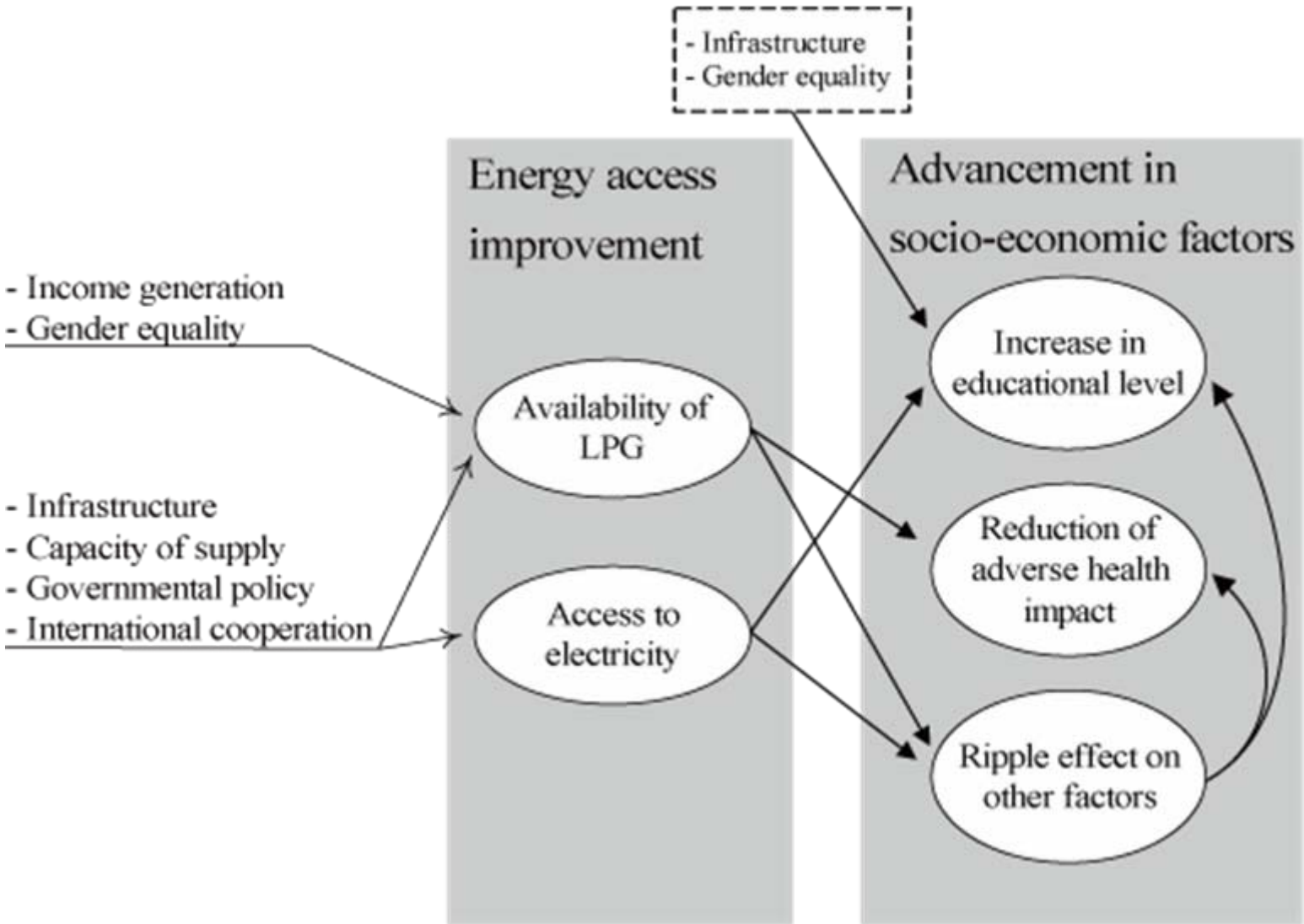
$$= -0.489 + 0.166 \times 0.963 + 0.143 \times 3.039 + 0.683 \times 0.935$$

$$= 74.4\ [\%]$$

Discussion

- Preconditions on the study
  - Supply side: steady supply of energy resources
  - Demand side: selection of devices based on NPV
- In reality, some constraints should be considered;
  - Supply side: infrastructure, ability to supply
  - Demand side: initial investment on devices
- Utilization of government policies, international cooperation and institutions enable to encourage improvement of energy access.
  - Supply side: subsidy, market liberalization, ODA
  - Demand side: micro credit, subsidy

Summary of this study



Conclusion

- In the study, we have proposed analytical framework combining an energy economic model with the regression analysis of socio-economic impacts.
- Energy access improvement in cooking demand
  - At the opportunity cost of US$9/GJ, gas stoves are utilized in 61% of total households. Then, RSPM exposure are largely reduced.
- Energy access improvement in lighting demand
  - Until year 2012, electric lighting appliances are utilized in every households. As a result, average literacy rate is expected to increase from 63.3% to 74.4%.