# Long term building energy demand for India: Disaggregating end use energy services in an integrated assessment modeling framework

Vaibhav Chaturvedi[1], Jiyong Eom[1], Leon E. Clarke[1], Priyadarshi R. Shukla[2]

## Abstract

Building and residential energy demand consists of more than 45% in India's final energy consumption. With increasing population growth, income, and urbanization, it can be reasonably expected that meeting the energy service demands for the building sector will be a huge challenge for energy policy in the country. The present study uses a technologically detailed, service based building energy model nested in the long term in the long-term, global, integrated assessment framework, GCAM. After presenting an aggregate picture of long term energy demand in the Indian building sector, it analyses the urban and rural household energy demand in the business as usual scenario. The analysis reveals that by end of century, energy for cooking, appliances, and cooling will take a high share of final energy for India around at 35%, 30% and 25% respectively. Space heating and cooling demand will grow at the fastest rate though because of the low base space heating share will be just above 1% in 2095. Electricity and LPG would be the dominant fuels with the combined share of about 90% by 2095, though there will be some penetration of delivered gas and commercial biomass as well. The evolution of future energy system and end use energy technologies would be significantly different for rural and urban India with different growth rate and penetration of various building energy services and fuels. Climate policy can be expected to have only small effect in reducing final energy consumption in the Indian building sector. Finally the study discusses some policy implications for India from the present analysis.

JEL classification: Q470, Q480, O130, O180, O530, O210

[1] Joint Global Change Research Institute, College Park, MD, USA
[2] Indian Institute of Management Ahmedabad, Gujarat, India

## 1. Introduction

India's energy consumption and resultant emissions have been an important agenda in the global climate change mitigation discussions. Though per capita emissions in this region have been less than one-eighth of most of the developed nations, because of its high population India is the fifth largest greenhouse gas emitter in the world (Pew Centre on Global Climate Change, 2008). Current per capita energy consumption is one of the lowest in the world and stood at less than 150 kgoe in 2005, compared to 250 kgoe for China and 640 kgoe and 915 kgoe for Europe and North America respectively (WRI, 2010). With almost 44% households having no access to electricity, low income households have to meet their energy needs with expensive choices (Shukla et. al., 2007). Access to electricity varies dramatically across various Indian states.

The current energy mix of India is dominated by fossil fuels, with thermal power contributing to 65% of India's electricity requirements in 2010, and hydro power taking almost 25% (Ministry of Power, GoI; 2010). With more than 8% average economic growth rate for next 20 years (GoI, 2006), driven primarily by productivity growth (Poddar and Yi, 2007), India's overall commercial energy consumption is expected to increase to more than 1500 Mtoe in 2032 (GoI, 2006)**,** and more than 2500 Mtoe in 2050 and 5500 Mtoe in 2095 (Shukla and Chaturvedi, 2011). In terms of final energy consumption in 2005, transportation sector consumed 10%, industrial sector consumed 28%, while the highest share was taken by the building sector at 47%, including both residential and services sector (IEA, 2007). The future energy consumption trajectory suggests that the share of residential sector in final energy consumption will decrease while both transportation sector and industrial sector share will rise (*ibid.*). This can be expected to happen predominantly because the traditional biomass usage will decline significantly in the future. However, rapid urbanization and income growth will lead to significant increase in the overall building and household energy service and its implications for energy consumption are not well understood.

The urban and rural building energy consumption profiles present a contrasting picture. In the rural sector, traditional biomass supplies energy for most of the household energy requirements and 668 million people depend on fuel-wood, cow-dung and agriculture residues for meeting their cooking energy needs (IEA, 2007). Urban building sector is predominantly dependent on electricity. The high reliance of traditional biomass in the rural sector is not because of consumer preference, but due to the lack of access to commercial fuels like liquefied petroleum gas (LPG) and electricity. The per capita energy consumption trend for India between 1980 and 2005 reflects the aggregate statistics in terms of shares of various fuels in residential energy use. In rural India, biomass use per capita increased slightly, though there was a ten-fold increase in electricity use per capita. In the urban households, rapid substitution of biomass by electricity and LPG was observed between 1980 and 2005, leading to decline in the per capita energy consumption across years (Pachauri and Jiang, 2008).

Rural electrification has been one of the priority areas for Indian energy policy. Scenarios for electricity generation from renewable energy, grid and diesel suggest that renewable energy based end uses could save 35% of primary energy in 2030 compared to BAU, but would be more costly if electric end-use devices are predominantly used (Urban et. al., 2009). End use energy technology choices in households hence become an important determinant for the future evolution of energy system in India.

With rising incomes and increasing urbanization, the residential and commercial building sector energy service demands are expected to expand at a high rate. The present paper focuses on the long term evolution of energy consumption in the building sector for India, focusing on disaggregating the end-use urban and rural residential and commercial energy services within an integrated assessment modeling framework. Detailing end use energy service demands are important for India as it can be reasonably expected that different services will grow at different rates over the century which will guide the evolution of end use energy technologies for meeting building energy service demands. Disaggregating services can allow endogenous determination of fuel choices in the building sector over the century. Detailed competing technologies have been identified for providing five different end use energy services (space cooling, space heating, lighting, cooking and water heating, and appliances) in the urban household, rural household and commercial building sectors. Long term energy demand scenario has been constructed for analyzing the pathways for detailed end-use energy consumption for the Indian building sector till century end. The present study also incorporates the effect of climate change feedbacks on the heating and cooling energy demands through information on heating and cooling degree days for India.

## 2. Methodology

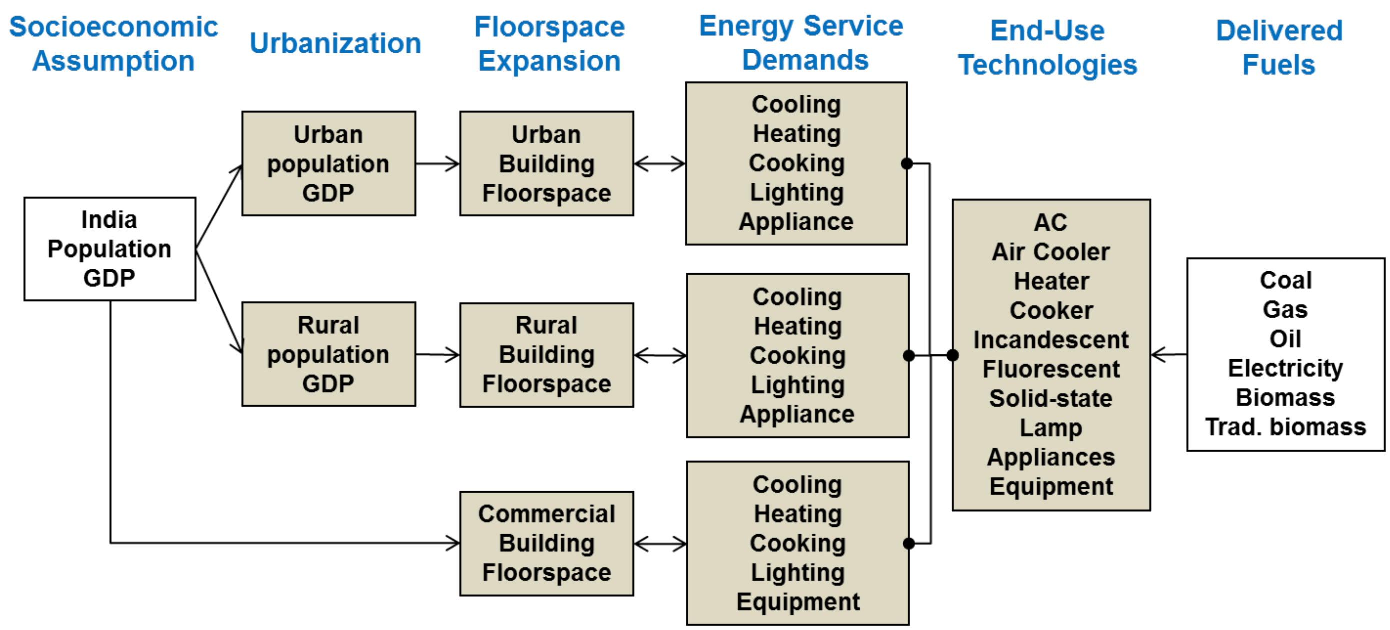
The study uses Global Change Assessment Model (GCAM) for modeling long term building energy demands for India. The economic and demographic assumptions have been adjusted to reflect the projections of the Indian government. GCAM is an energy sector focused partial equilibrium integrated assessment model incorporating complex interactions between the energy and climate systems. The model is global in scale and comprises of 14 aggregate world regions and models energy and emissions in 15 year time steps from 1990 to 2095. GCAM has been extensively used for scenarios regarding long term energy consumption and emissions, energy technology strategy analysis, land-use change and emissions, bio-energy, etc. for details regarding the model, please refer Edmonds and Reilly (1983), Edmonds *et al.* (1996), Clarke and Edmonds (1993), Clarke *et al.* (2007), and Clarke *et al.* (2008).

## 2.1 Modeling building sector energy demands

Indian building sector consists of the household sector and the commercial sector. Given the significant differences in lifestyle as well as energy usage patterns of rural and urban households, these two need to be modeled and analyzed separately to gain better insights into the evolution of the household building sector. The commercial sector for India includes government buildings, schools, hospitals and buildings of other similar institutions along with commercial offices, retail outlets, malls, etc.

The current paper broadly follows the detailed buildings model provided in Eom et al. (2011) with some modifications in end-use technologies for a better representation of the Indian buildings sector energy scenario. The building energy model framework developed by Eom et al. (2011) is characterized by (1) urbanization and the resulting changes in population and income in urban and rural areas; (2) the expansion of floorspace in urban, rural, and commercial buildings; (3) the increase in the demand for building energy services; and (4) the competition of end-use technologies consuming different fuels at the price endogenously determined by GCAM (see Figure 1). In the rest of this section, these four major components of the framework are discussed in the specific context of Indian buildings sector.

Figure 1: Building energy model framework




## 2.2 Urban and Rural Socioeconomics in India

Urbanization and the associated separation of population and GDP are taken into consideration because the pattern of household energy consumption is substantially different in the rural and urban areas and the future growth in household energy demands would be different between these. This setting allows us to represent urban and rural household building energy services separately along with commercial building energy services.

Future rural and urban per capita income trajectories for India have been estimated based on assumptions about future GDP and population projections, urbanization rate, and urban-rural per capita income ratio. Future GDP forecast for India is based on an average annual growth rate of 8% between 2007-2032 as assumed by the planning commission in the integrated energy plan (GoI, 2006). Population projections are based on UN long range forecast for medium scenario (UN, 2004). Urbanization rate till 2050 has been taken from the UN urbanization forecasts[3]. Post 2050 urbanization rate has been extrapolated on the basis of regression of urbanization rate on per capita GDP, with the maximum urbanization rate held at 86%. Urban-rural income ratio has been projected to decrease from the 2005 value of 3.18 to 2.95 in 2035 based on 2030 urbanization and GDP forecast by the McKinsey

[3] http://esa.un.org/unup/

Global Institute (MGI, 2010). Post 2035, the ratio is assumed to decrease at a constant rate to reach unity by 2200. The following table presents economic and demographic assumptions used in this study.

Table 1: Economic and demographic assumptions

| | GDP | Population | Population share | | Per Capita GDP | |
|---|---|---|---|---|---|---|
| | 2005 Tr USD | Total (Bn) | Urban (%) | Rural (%) | Urban (2005 USD) | Rural (2005 USD) |
| | | | | | | |
| 2005 | .807 | 1.13 | 28.7 | 71.3 | 1089 | 342 |
| 2020 | 2.63 | 1.31 | 34.3 | 65.7 | 3256 | 1064 |
| 2035 | 7.31 | 1.45 | 44.2 | 55.8 | 7993 | 2710 |
| 2050 | 17.85 | 1.53 | 55.2 | 44.8 | 17112 | 6400 |
| 2065 | 33.49 | 1.55 | 63.1 | 36.9 | 29518 | 12181 |
| 2080 | 51.78 | 1.53 | 69.9 | 30.1 | 42691 | 19438 |
| 2095 | 74.71 | 1.47 | 75.1 | 24.9 | 58857 | 29568 |

## 2.3. Expansion of Building Floor space

The growth of each building sector over the century is represented by the expansion of per capita building floorspace. Floor-space expansion is assumed to be dependent on per capita GDP and population. Per capita demand for a building [$m^2$/capita] in time period *t* is given by

$$q_{B,t} = k_D \cdot P_{B,t}{}^{\alpha} \cdot i_t{}^{\beta}$$

where $P_{B,t}$ and $i_t$ are building price per unit of floorspace and per capita income in period *t*, and $\alpha$ and $\beta$ are the price and income elasticities of the demand for building, respectively. Unobserved effects are captured in the calibration parameter $k_D$. Here, the building floorspace price also includes the price of energy services delivered to the floorspace. Floor space supply has been also considered and assumed to be a function of current year as well as one year lagged values of floor space prices. [4]

[4] Income and price elasticity values with which these demand and supply relationships are solved have been estimated from yearly cross-sectional data of 15 Indian states for a period between 2001 and 2008 taken from NSSO (2002, 2003a, 2003b, 2005a, 2005b, 2008a, 2008b, 2010). Since income elasticity values estimated from the data were giving high value of per capita floor space requirement after 2050, this value was lowered to arrive at a

## 2.4. Representation of Energy Service Demands

Demands for building energy services are constructed to allow for a satiation with energy service comfort (or, equivalently, a bliss point), so that the magnitude of the income and price effects declines as income grows. There are two main elements constituting the demands: satiated demand and economic choice. The satiated demand term is specified to represent the maximum that consumers might demand as a function of technical parameters. We then incorporate the economic choice term as a function of income and service prices. End use energy service demands have been modeled for five energy service categories- space cooling, space heating, cooking and water heating, lighting, and appliances. Demands per unit of floorspace for space heating service, space cooling service, and other services (e.g., cooking, lighting, appliance, and others) are represented as follows:

$$d_H = k_H \cdot (HDD \cdot \eta \cdot r - \lambda_H \cdot IG) \cdot \left[1 - \exp\left(-\frac{\ln 2}{\mu_H}\frac{i}{P_H}\right)\right]$$

$$d_C = k_C \cdot (CDD \cdot \eta \cdot r + \lambda_C \cdot IG) \cdot \left[1 - \exp\left(-\frac{\ln 2}{\mu_C}\frac{i}{P_C}\right)\right]$$

$$d_j = k_j \cdot \overline{q_j} \cdot \left[1 - \exp\left(-\frac{\ln 2}{\mu_j}\frac{i}{P_j}\right)\right]$$

where the first coefficients are the usual calibration parameters, the second aggregate terms represent the satiated demands, and the third aggregate terms represent the economic adjustment for space heating service, space cooling service, and other services. Regarding the satiated demand term, *HDD* and *CDD* are heating and cooling degree days [hr $^{o}$C], $\eta$ is thermal conductance [GJ/m$^2$ hr $^{o}$C] representing the extent to which indoor air temperature is susceptible to outdoor weather, $r$ is building floor-to-surface area ratio representing the size of building shell exposed to outdoor temperature, *IG* is the amount of building internal gains [GJ/m$^2$], and $\lambda_H$ and $\lambda_C$ are internal-gain scalars accounting for the potential mismatch of the time when space conditioning is required and the time when the internal gains are produced. Thus, with the internal gains, space heating demand decreases, whereas space cooling demand increases. The satiated demands for other services are held fixed in this study. Regarding the economic choice term, $i$ is per capita income, $P_j$ is the price of an energy service, $\mu_j$ is referred to as saturation impedance of the service. The saturation impedance represents the extent to which the saturation of an energy service is impeded, given the affordability of the service, $i / P_j$ in the

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reasonable projection of floor space requirement, largely comparable to the per capita floor space in developed countries.

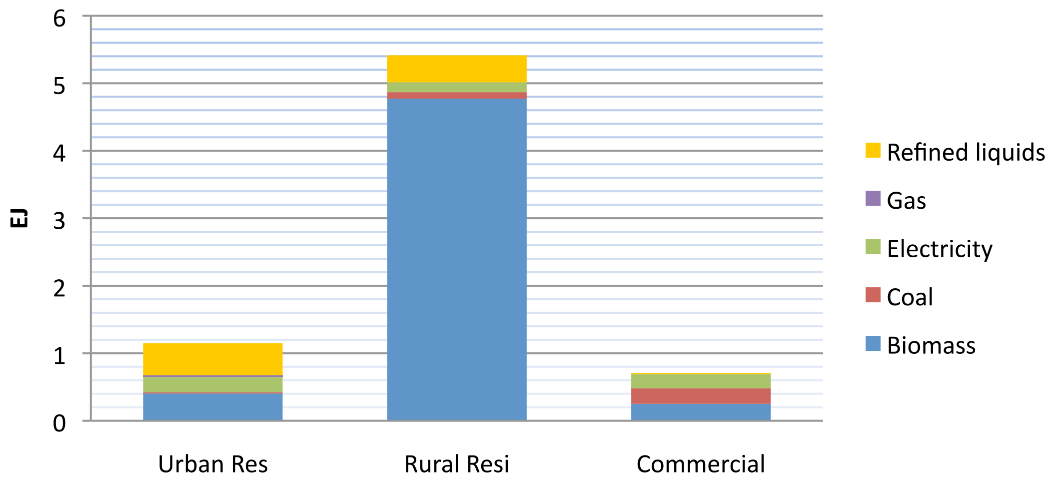
process of prioritizing various energy services within the budget. Given the same affordability, the higher the level of saturation impedance for the energy service, the lower the level of the energy service delivered. Technically, $\mu$ is equivalent to the level of affordability required to achieve half the satiation demand. This relationship captures the two desired characteristics: attenuation in the responsiveness of energy service demand to income and price and ultimate service demand satiation.

The saturation impedance for each energy service is calibrated based on energy service delivered to India buildings in 2005 combined with the energy service delivered to US building sector in 2005. This assumes that at the current level of energy services delivered to the USA have reached their satiation and hence these can be regarded as appropriate benchmark for India. The heating and cooling energy services in the building sector are modeled as being dependent on the heating and cooling degree days (HDD/CDD). Details regarding method for calculating HDD and CDD can be found in Zhou et al. (2011). In brief, as GCAM's emissions pathway in the BAU scenario is largely consistent with SRES A2 scenario, we chose A2 temperature run simulated by CCSM as our reference, and employed "globally downscaled climate database" established by Maurer et al. (2009) to calculate population-weighted heating and cooling degree days during the century.

## 2.5 Building Energy Technologies in India

The final component of the building energy modeling framework relates to the choice of end-use technologies to deliver energy services. The technologies currently present in the Indian buildings sector are predominantly determined by the type of fuel available to deliver the energy service demands. Lack of access to uninterrupted and reliable electricity supply, especially in the rural areas, has lead to predominance of traditional biomass in fulfilling energy service demands. Energy for cooking in urban areas is largely met through liquefied petroleum gas and biomass along with kerosene to some extent. Cooling and appliance services are dependent on electricity. The following graph exhibits the 2005 share of various fuels in the final energy consumption for the Indian buildings sector.

Figure 2: Final energy consumption by fuel for Indian building sector (Source: IEA (2007) and assumptions based on NSSO dataset)




India falls in the tropical region with the weather throughout the country, ranging from warm to hot for most of the months. Winter days are comparatively fewer, which is a major difference as compared to most of the developed regions of the world (e.g., USA, Europe, and Japan) as well as to China. Hence the technology options modeled for India buildings have been chosen after consideration of Indian weather conditions, present distribution of technologies, as well as other technologies which may penetrate the market in the future. The following table exhibits the technologies modeled for the five energy service categories specified in this study and their fuel types.

Table 2: Disaggregated end use technologies for various energy services in the building sector

| **Service** | **Technology** | **Fuel** |
|---|---|---|
| Space Cooling | Air conditioner | Electric |
| | Air cooler | Electric |
| Space Heating | Room heater | Electric |
| | Building heater | Electric |
| Cooking and Water Heating | Gas cooker | Liquefied Petroleum Gas |
| | Gas cooker | Natural Gas |
| | Electric cooker | Electric |
| | Coal cooker | Coal |
| | Biomass cooker | Commercial biomass |
| | Traditional biomass cooker | Traditional biomass |
| | Kerosene stove | Kerosene |

| | | |
|---|---|---|
| Lighting | Incandescent bulbs<br>Fluorescent bulbs<br>Solid state lighting<br>Oil Lamp | Electric<br>Electric<br>Electric<br>Kerosene |
| Appliances | Generic appliance technology | Electric |

## 3. Data Sources and Building Energy Disaggregation

Base-year energy consumption data for the model is calibrated to the 2005 IEA energy balances (IEA, 2007). The IEA gives fuel wise energy consumption for the three building sectors- urban residential, rural residential, and commercial (see Figure 2). Apart from electricity and oil, all other fuels are associated with only one technology for each type of energy service, e.g. one traditional biomass technology, coal technology, and natural gas technology for cooking. Information regarding cooking and lighting for Indian households has been taken from NSSO (2007). While LPG is only used for cooking, kerosene is used for cooking as well as lighting. Refined petroleum use for cooking and lighting has been divided into 'liquefied petroleum gas (LPG)' and kerosene usage on the basis of findings of earlier studies (Rue du Can, 2009). Electricity consumption for an energy service has been further disaggregated into specific technologies on the basis of assumptions regarding the wattage of these technologies and their usage, along with Indian national sample survey data regarding ownership rates of various technologies (NSSO, 2008a; TERI, 2008). For the commercial sector, kerosene and traditional biomass technologies have been assumed to be unavailable. Similarly building heater technology is available only to the commercial sector while room heater is available to the urban and rural residential sector. It has been assumed that traditional biomass as well as kerosene used in cooking will not be consumed after 2065 due to their many negative health effects. Cost for traditional biomass include the cost of collecting fuelwood and is based on estimates of time spent in fuelwood and biomass collection by Saxena (1997). The typical traditional biomass use efficiency varies from 5-15%, while for the other fuels it can be even four times higher or more. The following table shows the assumptions on the basis of which electricity use has been allocated among various end use technologies-