Coping with residential electricity demand in India's future – How much can efficiency achieve?

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Abstract
The time when energy-related carbon emissions come overwhelmingly from developed countries is coming to a close. China will soon overtake the United States as the world's leading emitter of greenhouse gas emissions. Meanwhile, India also seems to be on track to experience rapid long-term economic expansion. With this growth will surely come continued massive growth in energy demand. This paper explores the dynamics of that demand growth for one sector – residential electricity – and the realistic potential for coping with it through efficiency. Currently, only 60 % of Indian households use electricity, and 12 % own a refrigerator, but sales of appliances are booming. Air conditioning sales are growing at 20 % per year. This paper forecasts ownership growth of each product using econometric modeling. Products considered explicitly -– refrigerators, air conditioners, fans, lighting, electronics, and water heating – account for about 80 % of current household electricity consumption.

Using this method, we determine the trend and dynamics of demand growth and its dependence on economic scenarios at a level of detail not accessible by models of a more aggregate nature. In addition, we present scenarios for reducing residential consumption through efficiency measures defined at the product level. The research takes advantage of an analytical framework developed by LBNL (BUENAS) which integrates end use technology parameters into demand forecasting and stock accounting to produce detailed efficiency scenarios, which allows for a technologically realistic assessment of efficiency opportunities specifically in the Indian context.

Introduction and Methodology
The past decade has seen rapid economic growth in Asia. India and China, each with populations over 1 billion are a critical interest of study to energy researchers. China has seen energy consumption grow faster than its GDP, and its carbons emissions will soon be larger than those of the United States. It is expected that India is likely to follow a similar path. What, then, will India's energy consumption be like in 10 or 30 years? China's energy consumption has been studied closely at LBNL for years[1] and is relatively well understood, unlike India's, for which it is hard to find energy projections at the end use level in the residential sector.

Many studies have been conducted (A.K.N.Reddy, 1994, B.Sudhakara Reddy, 2003, 2006) on the matter of fuel use and shift in India for lighting, cooking and water heating. These studies show that Indian households go from cheap or free but inefficient fuel to commercial fuels like electricity and LPG. The studies also propose some energy efficiency solutions. Our focus, on the other hand, is on electricity only, but considers all electricity end uses. The paper proposes a projection of electricity consumption in the residential sector to 2030 based on household appliance ownership rates parameterized according to econometric variables. The analysis takes advantage of the ownership-based model to design efficiency scenarios at the

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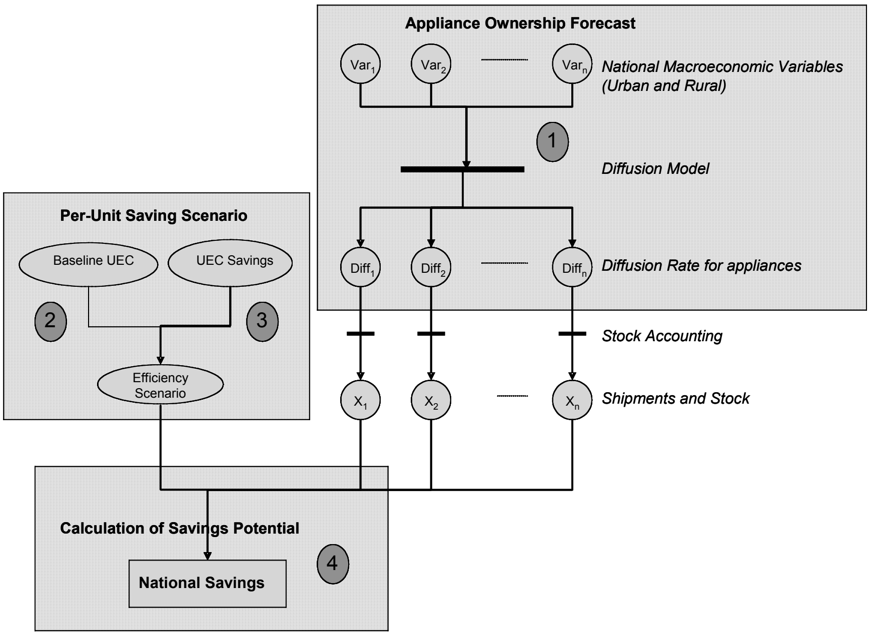

Figure 1 BUENAS Flowchart

appliance level[2] and to evaluate the extent to which efficiency measures may be applied to mitigate the expected energy consumption growth. Energy consumption and savings estimates are calculated according to an analysis package developed at LBNL called the Bottom Up Energy Analysis System (BUENAS).

The analysis consists of 4 steps shown in Figure 1. Step 1 of the BUENAS Model models appliance ownership as a function of macroeconomic variables. In the current application of the model, the list of appliances considered covers total household electricity consumption[3]. The shipments and stock turnover for all these appliances are then derived from first purchases (due to increase in ownership and population growth) and replacement of old appliances.

The second step of the analysis is to gather the best estimates of the average baseline unit energy consumption (UEC). Step 3 is to estimate the unit energy savings achievable through energy efficiency policies, (e.g. standard or labelling programs). Total savings are then calculated in Step 4 where appliances sold in each year of the Base Case or Efficiency scenario are combined with the stock accounting model to arrive at total national end use energy consumption in each case.

Appliance Ownership Model

In developing countries, growth in residential energy consumption is mainly driven by growth in appliance ownership. The diffusion model relates national income and electrification variables to ownership of appliances in households, through the use of micro level data[4]. To do so, several sets of data from household surveys have been studied.

2. A previous study has been carried for refrigerators only in the residential sector (McNeil, 2006)

3. The model can also be used in a single enduse mode covering multiple countries, as in (McNeil, 2006)

4. We use the term "diffusion" instead of "saturation" to specify rates that can exceed 100 % in the case of multiple appliances.

HOUSEHOLD SURVEYS

NSSO Survey (55th Round)

The National Sample Survey Organization (NSSO) carried out its 55th survey in 1999/2000. This survey contains detailed data on energy use and durable goods possessed by Indian households. The results were gathered by monthly per capita expenditure (MPCE) class, and are given separately for urban and rural areas. We use MPCE as a proxy for per capita income.

The appliance saturation, which is the percentage of households possessing at least one appliance of a given type, is given for each category of income. Household electricity consumption is based on the number of appliances per household, however, which can be greater than one. The survey provides the average diffusion for 1 000 households, so the saturation data points can be corrected to diffusions assuming that the ratio between diffusion and saturation is a linear function of income:

$$Diff_i = Sat_i \times K(Inc_i)$$

where $Diff_i$ is the diffusion in the income bin i, Inc_i is the average MPCE, and Sat_i is the saturation in the income bin i. K varies between 1 and X from the poorest category to the richest, X being the number of appliances per household in the richest category of the sample. The weighted average diffusion is then given by

$$Diff = \frac{\sum_{i=1}^{N} Sat_i \times K(Inc_i) \times Pop_i}{\sum_{i=1}^{N} Pop_i}$$

A conversion between saturation and diffusion was made in cases where there is a significant difference between average saturation and average diffusion. This was the case for fans, and TVs. In all other cases, K is equal to 1 in all income categories.

Energy use in three Indian Cities

This survey was carried out in 1989 in 3 Indian cities Pune, Ahmednagar and Talegaon (Kulkarni, 1994). It also provides some relations between appliance diffusion and income. This dataset was helpful in modeling lighting patterns, because it provides the breakdown between incandescent bulbs and fluorescent tubes, and the number of each per household as a function of income. The household sample seems to be more affluent overall than the average urban population, but since the data were disaggregated by income level, a parameterization could be applied to all households.

End Uses of Electricity in Households of Karnataka state

This survey was conducted in Karnataka state in 1994/95, by the International Energy Initiative (IEI) in collaboration with the Karnataka Electricity Board (KEB) covering both urban and rural areas in 4 districts (Bangalore, Bijapur, Tumkur, Uttara Kannada). Households are categorized according to type of connection load available. The category AEH (All Electrified Household with 15-amp limit corresponding to a 3.5 kVA connected load) was characterized as urban since 88 % of the sample lives in urban areas but the non AEH (5-amp limit category corresponding to a 1.15 kVA load) consists of a mix of urban and rural households. We assume that AEH are the wealthiest households, and generally use this sample to characterize consumption in the highest income bin of the NSSO survey (MPCE higher than 1200 Rs). This appears to be a reasonable assumption since only 20 % of the electrified households are AEH.). This data was used to model ownership of the richest category of household or for average UEC when there is no other reliable data available.

MODEL URBAN/RURAL

Differences in development between rural and urban areas are large in India. The data show us that even if the diffusion is corrected for electrification, there is still a big difference between urban and rural areas for the same level of income. Therefore, these two sub-populations were modeled separately.

Electrification and Lighting

Modelling electrification serves two purposes. First, diffusion is modelled on the subset of electrified households only and it acts as a scaling parameter in the forecast. Second, electrification is used to forecast lighting use, with the assumption that all electrified households use electric lighting.

The NSSO provides data on use of electric lighting for each category of MPCE in urban and rural areas. We parameterize the relation between electricity use and income according to a Gompertz function:

$$\mathrm{Elec} = \exp(\gamma \times (\exp(\beta \times Inc)))$$

The Gompertz function can be linearized and the parameters γ and β determined through a linear regression:

$$\ln(\ln(\frac{1}{\mathrm{Elec}})) = \ln(-\gamma) + \beta \times Inc$$

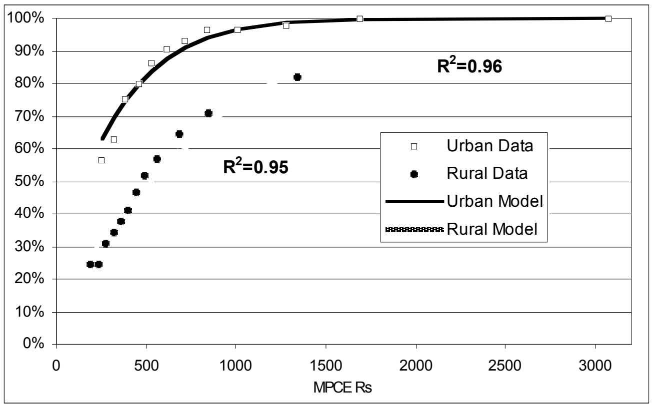

Figure 2 Electrification Regression Results for Urban and Rural Areas

Figure 2 shows the results of the regression. The correlation between the model and the data is very good, as indicated by the high values of R^2.

Using the data from Pune, Ahmednagar and Talegaon, (Kulkarni, 1994) the number of bulbs is modeled as a linear function of income.

It was found that:

IL=0.00037 x Income + 0.2011 (R^2=0.85), and
FL= 0.0019 x Income + 0.5333 (R^2=0.97)

Where *IL* and *FL* are the number of incandescent bulbs and fluorescent tubes per household, respectively, and *Income* is the monthly per capita income in 2000 Rs.

Fans, Washing Machines, TV

Diffusion data were parameterized in two steps, by first considering electrified households only for rural and urban areas, and then applying electrification rates. As in the case of electrification, the Gompertz functional form was used for all of the above appliances.

$$Diff = Elec \times \alpha \times \exp(\gamma \times \exp(\beta \times Inc))$$

This equation can be transformed to a form that allows linear regression to find γ and β for each appliance for urban and rural sub-populations:

$$\ln\left(\ln\left(\frac{\alpha}{Diff} \times Elec\right)\right) = \ln(-\gamma) + (\beta \times Inc)$$

α is set to 1 except for fans (where we assumed 3.5). The parameters resulting from the regression are given in the following paragraph in Table 1. The table shows the generally good agreement between the data and the model with very high R^2 and low *P*-values for all the parameters.

Refrigerators and Air Conditioning

The relationship between income and ownership for refrigerators and air conditioning proceeded in a similar way to the other appliances, but with a modification to the Gompertz functional form. Upon taking the logarithm twice, the relationship

Table 1 Regression Results for Urban and Rural Areas

Urban		*Coefficients*	*Standard Error*	*P-value*	*Rural*		*Coefficients*	*Standard Error*	*P-value*
Refrigerator	ln γ	3.289	0.124	1.4E-10	**Refrigerator**	ln γ	3.169	0.056	2.0E-09
R Square = 0.96 α=1	β	-3.1E-01	1.9E-02	1.4E-08	R Square = 0.99 α==1	β	-2.7E-01	8.7E-03	7.3E-08
Air Conditioner	ln γ	4.690	0.273	9.3E-09	**Air Conditioner**	ln γ	3.114	0.323	2.2E-06
R Square = 0.97 α=1	β	-7.4E-01	4.1E-02	5.7E-09	R Square = 0.88 α=1	β	-4.6E-01	5.3E-02	5.9E-06
Washing Machine	ln -γ	1.787	0.088	1.8E-09	**Washing Machine**	ln -γ	1.959	0.050	2.9E-12
R Square = 0.90 α=1	β	-7.1E-04	7.3E-05	2.0E-06	R Square = 0.85 α=1	β	-6.4E-04	8.4E-05	1.8E-05
Fan	ln -γ	0.688	0.054	1.7E-07	**Fan**	ln -γ	1.152	0.084	8.7E-08
R Square = 0.98 α=35	β	-8.9E-04	4.5E-05	2.2E-09	R Square = 0.90 α=35	β	-1.3E-03	1.4E-04	2.9E-06
TV	ln -γ	-0.322	0.177	9.9E-02	**TV**	ln -γ	0.940	0.106	4.9E-06
R Square = 0.58 α=1	β	-5.5E-04	1.5E-04	3.9E-03	R Square = 0.89 α=1	β	-1.6E-03	1.8E-04	4.8E-06
Water Heater	ln -γ	1.797	0.088	1.7E-09	**Water Heater**	ln -γ	1.900	0.057	1.4E-11
R Square = 0.95 α=1	β	-9.7E-04	7.3E-05	1.1E-07	R Square = 0.85 α=1	β	-7.2E-04	9.5E-05	1.7E-05

deviated from a straight line, and instead followed a power law. Therefore, the parameter β in the above equation appears as an exponent rather than a coefficient below. Secondly, we assume that ownership for these products has a maximum of 100 %. Because of this, the model represents saturation rather than diffusion. The resulting functional form is:

$$Sat = \mathrm{Elec} \times \alpha \times \exp(-\exp(\gamma \times Inc^{\beta})$$

Its linearized form is:

$$\ln\left(\ln\left(\ln\left(\frac{\alpha}{Diff} \times Elec\right)\right)\right) = \ln\gamma + \beta \times \ln\left(Inc\right)$$

The use of this form resulted in a better fit to the data (higher R^2) for these two products, especially at higher income levels.

In addition, AC usage scales with income in a complex way, because wealthier households may have multiple units, larger units, or use AC more often. For this reason, air conditioner UEC grows over time, according to assumptions presented below. The growth in UEC includes ownership of multiple units, which are not given explicitly by the saturation relationship.

Water heating

From the NSSO survey it appears that the use of electricity for cooking/water heating was negligible in rural but also in urban areas, where people use LPG, kerosene or wood. The use of electricity might be neglected because the survey investigates the *main* source of energy for cooking/water heating[5]. An important number of studies mentioned high saturation of geysers in some cities like Pune (Kulkarni, 1994), or Bangalore (Reddy, 1998). We judged that these high numbers - higher than refrigerator saturation in some urban areas would apply to the wealthiest urban households in the NSSO survey (with an average MPCE of 3075Rs.). In order to determine saturation for other incomes, we assume that the ownership trends of a geyser have the same form as washing machines, due to its cost and status as a luxury item. Accordingly, we scaled diffusion in each income category by the ratio between the geysers and washing machines for the highest income category, which was 1.5 in the NSSO survey. In other words, households in each category have on average 1.5 more geysers than washing machines. From those data points, we determined a new set of parameters for water heaters using the Gompertz equation. Table 1 shows the results of the regression analysis for all appliances modeled.

5. If a household uses more than one of the sources given in the questionnaire then the one having major use has been assigned to the household (NSSO Report No. 464, 2001).

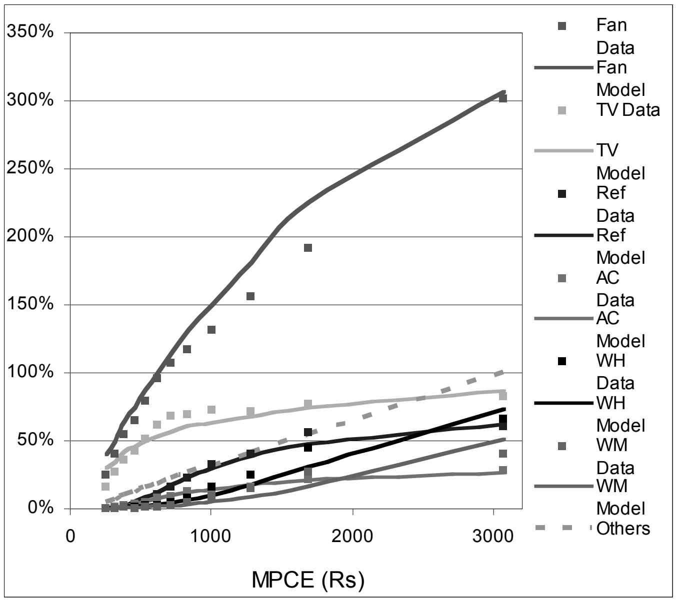

Figure 3 Appliance Diffusion vs MPCE – Urban Households

Other End Uses

We use the Karnataka survey to model the category of 'other' end uses, assuming that the wealthiest category of the NSSO survey is similar to the AEH category in Karnataka, defining 'diffusion' of this category in terms of percentage of energy consumption of the Others category in Karnataka (298 kWh). We then assume that consumption in lower income households scales simply with income and electrification. This category may seem high for poor households, but many appliances in the Others category are small and affordable, such as radios, irons, grinders, etc.

Figure 3 shows the appliance diffusion rates as a function of MPCE for urban households. The appliance ladder appears pretty clearly here; after lighting, households use electricity for fans, then a TV, and then if the connection load allows it, a refrigerator, a water heater, an air conditioner and a washing machine. For low income it is interesting to note the gap between the TV and the first "major" appliance. It is only for the richest category of income that every household have both. The results are shown for all households (electrified or not)

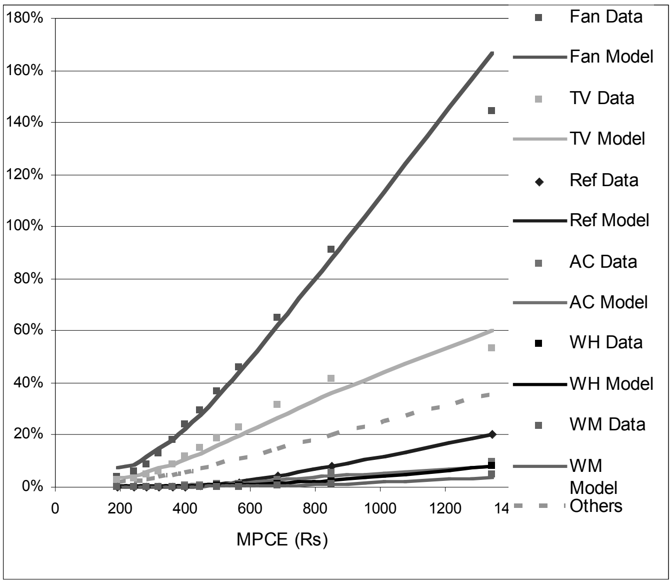

Figure 4 Appliance Diffusion vs MPCE – Rural Households

Figure 4 shows the same appliance ladder that we found in urban areas but in a more dramatic gap between each level of ownership. Virtually only the richest category of household possesses white goods.

PROJECTIONS OF APPLIANCE OWNERSHIP

The back extrapolation (1990-2004) of MPCE is based on per capita GDP statistics from the World Bank. The forecast (2004-2030) of MPCE is based on an assumption of a constant 4.7 % economic growth rate, according to IPCC SRES economic scenarios B2 (for the non-centrally planned Asia region). Diffusion and electrification is calculated for each income bin and then the average is calculated using the income distribution from the survey. Each bin is projected assuming that the ratio between the bin and the average income is constant[6]. Number of households and urbanization projections are from the UN.

Figure 5 shows the results for urban, rural and all households for all appliances except light bulbs and fans because they are out of scale compared to other appliances.

CALCULATION OF SHIPMENTS AND STOCKS

Calculation of shipments and stock turnover is essential in understanding the rate at which products enter the household population and thus impact the overall energy consumption. This shipments rate impacts both the base case and efficiency scenarios. After the standard is passed, savings come from the households acquiring the appliances for the first time but also from the stock which is gradually replaced by efficient products. Shipment and stock accounting is combined with unit efficiency scenarios in Step 4 of the BUENAS model.

Shipments are calculated as the sum of the first purchases and replacements. The first purchases are the increase in appliance stock from one year to the next, where stock is the product of number of households and diffusion rate. Replacements are calculated based on the age of the appliances in the stock

6. We take in account that part of the economic growth is due to urbanization growing and then apply the ratio to calculate each income bin.

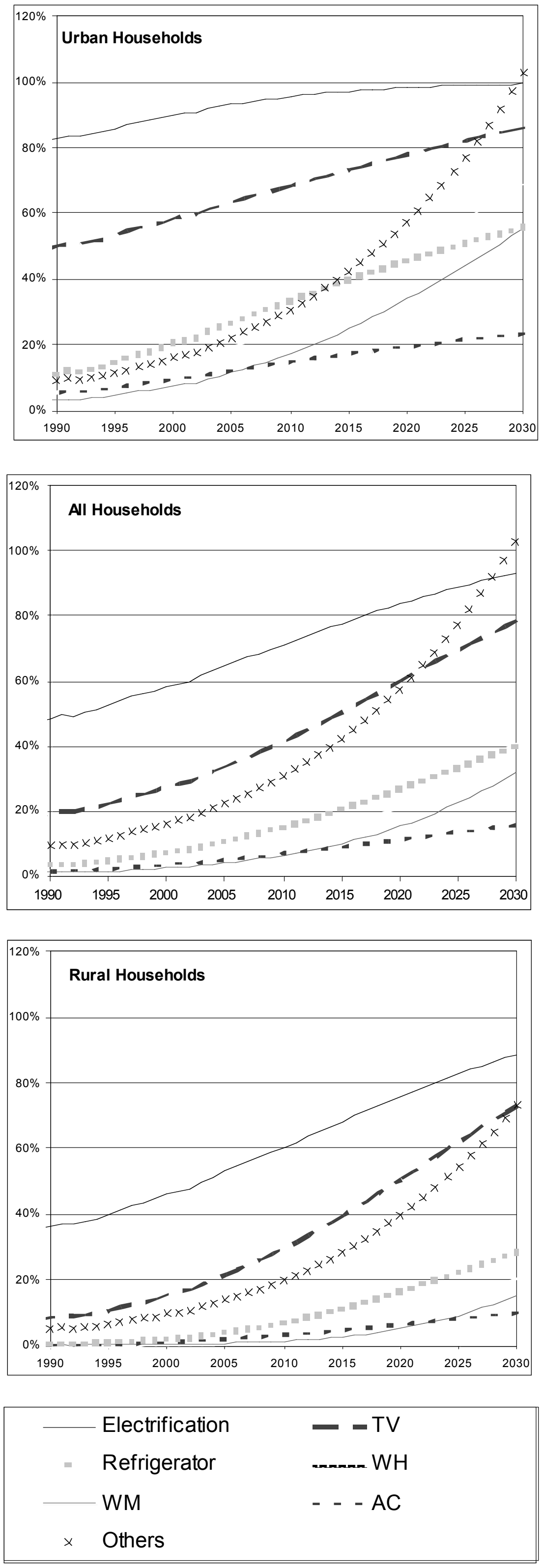

Figure 5 Appliance Diffusion Projections to 2030, Urban Households, Rural Households and All Households

and a retirement function that gives the percentage of surviving appliances in a given vintage. The incremental retirement function is a normal distribution around the average lifetime. We assume an average lifetime of 15 years for all appliances, except for incandescent lamps (1 year) and fluorescent tubes and CFLs (5 years). Table 2 shows the evolution of shipments

Table 2 Appliance Shipments in 2000, 2030, and Growth Rate

	Shipments in Millions		Growth
	2000	2030	Rate
Refrigerator	1.8	10.8	6.1%
AC	1.0	4.3	5.1%
Washing Machine	0.7	10.7	9.6%
Fan	13.9	66.4	5.3%
TV	5.3	19.6	4.5%
Water Heater	1.2	13.0	8.4%
Fluorescent Tubes	32.5	260.3	7.2%
Incandescent Bulb	114.7	1,192.2	8.1%

Table 3 Baseline UEC for all end uses in 2000 and 2030.

	UEC (kWh)		Reference/Assumption	
	2000	2030	2000	2030
Refrigerators	494	657	LBNL Estimates	LBNL Estimates
Air Conditioners	2,160	4,620	LBNL, based on RAMA estimates	Hong Kong in 1996 (Lam,2000)
Washing Machines	190	190	Euromonitor, 2003 and Sanchez, 2006	Euromonitor, 2003 and Sanchez, 2006
Fans	145	145	Karnataka Survey	Karnataka Survey
TV	150	150	Karnataka Survey	Karnataka Survey
Water Heaters	617	591	Reddy, 1995	Reddy, 1995
Fluorescent Tube 40W	58	58	4 hrs a day	4 hrs a day
Incandescent Lamp 60W	88	88	4 hrs a day	4 hrs a day
Others	298	298	Karnataka Survey	Karnataka Survey

between 2000 and 2030. Notably, most of the growth rates are much higher than the economic growth rate.

Base Case Scenario for the Residential Sector

BASELINE UEC

Table 3 presents a summary of our assumptions and references used to determine the average UEC of Indian appliances. Per unit UEC are assumed constant over time in the Base Case, with three exceptions: refrigerators, air conditioners and water heaters. Refrigerator consumption is expected to grow due to the growing market share for larger models, two-door refrigerator freezers, and frost-free units. Air conditioner UEC growth includes the use of multiple units, increase in unit cooling capacity, and increase in hours of use. Air conditioner UEC in 2000 is based on estimates made by India's Refrigeration and Air conditioning Manufacturers Association (RAMA) provided to the Indian Bureau of Energy Efficiency (BEE) in 2006. Air conditioning use in 2030 is based on current use patterns in Hong Kong. Water heater UEC is supposed to slightly go down during the forecast period due to the projected decrease of the number of persons per household.

BASE CASE CONSUMPTION SCENARIO

Multiplying household appliance ownership by the unit energy consumption for each year, and accounting for each end use, we obtain the country electricity consumption projection for the residential sector.

Figure 6 shows the evolution of the electricity consumption for all households. According to the projection, the average household will consume 6 times more in 2030 than in 2000. Urban household consumption rises from 990 kWh in 2000 to 4000 kWh in 2030, while rural rises from 280 to 2450 kWh. Per household rural consumption grows twice as fast as urban. Rural households see a higher growth because they transition from low access to electricity (48 % in 2000), and very low appliance ownership to a situation where almost all households are electrified, and a significant portion can afford at least the main appliances.

Figure 7 shows the combination of diffusion projections (urban and rural), UEC assumptions, and population growth. National residential electricity consumption in the year y (REC_y) is given by.

$$REC_y = \frac{Pop_y}{HHSize_y} \times \sum_i Diff_{y,i} \times UEC_{y,i}$$

where $Diff_{y_i}$ is the average diffusion of the appliance i, in the year y, UEC_{y_i} is the average UEC of the appliance i in the year y, Pop_y and $HHSize_y$ are the population and the average household size in the year y.

Modeled national residential electricity consumption by enduse is shown in figure 7. In 2002, the Tata Energy Research Institute published a projection of electricity demand across sectors as part of their Report on the Coal Industry in India (TERI, 2002). The projections from this study are shown in figure 7 for comparison with our model. The modelled (backcast) totals between 1990 and 2005 agree well with actual demand statistics in this time period. The 2005-2020 forecast for the two models are comparable, but our model shows somewhat higher consumption.

On average, between 2000 and 2030, the per capita energy consumption grows at a rate of 8.2 % a year, which is almost twice the assumed rate of economic growth. Relative to 2005, consumption will have doubled by 2013 in our projections (by 2014 according to TERI), and will be 7 times higher by 2030.

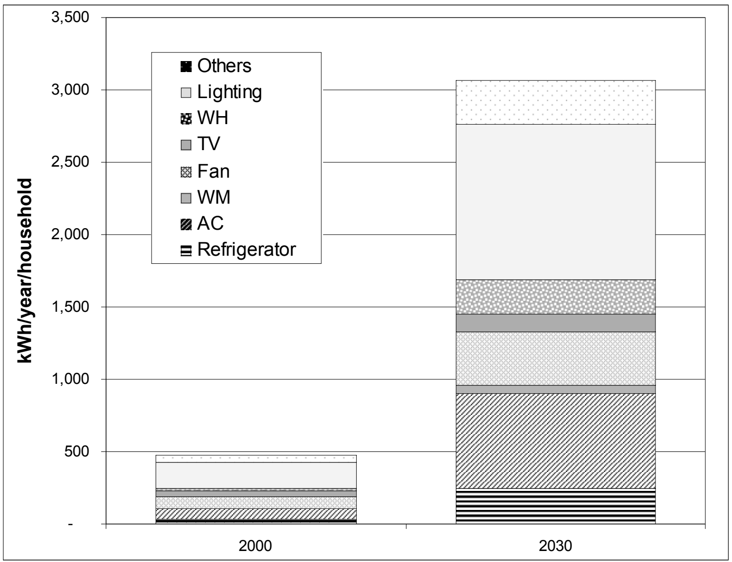

Figure 6 Household Electricity Consumption in 2000 and 2030 (urban and rural)

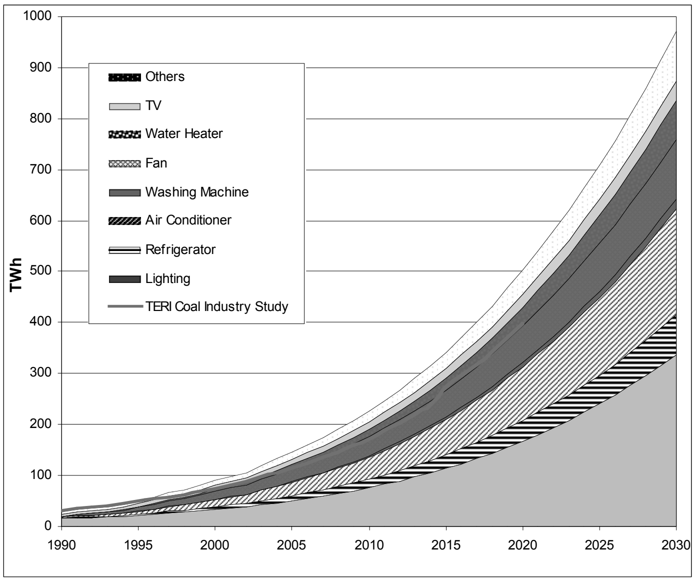

Figure 7 Modeled Residential Electricity Consumption by End Use 1990-2030

Energy Efficiency Scenarios

The expected growth in energy consumption in India is a result of demographic and economic changes likely to occur in that country. The Base Case adopts an assumption of "frozen efficiency", that is, continued use of appliances utilizing a generally low level of efficiency technology. In this section we explore the opportunity of minimizing consumption growth through energy efficiency measures applied to each end use.

TARGETS ACHIEVABLE THROUGH EFFICIENCY PROGRAMS

The BUENAS model uses a set of end-use efficiency scenarios in order to evaluate potential energy (and emissions) savings. Once the appliance ownership forecast is established, BUENAS combines these with a timeline of efficiency levels for new products in order to track the average unit energy consumption of products entering the stock. This is then combined with a stock accounting methodology which tracks the overall consumption of the national stock in both the base case efficiency case, designated at Case 1 and Case 2. Target efficiencies are those which we judge to be reasonable targets for minimum efficiency performance standards (MEPS). This is not the only possible policy which could achieve the target efficiency levels, however, nor do we exclude considerations which may make such targets unfeasible. The targets are generally those shown to be technically achievable in the past. In Case 2, we assume that the efficiency targets are achievable by 2010, which is an optimistic scenario.

Efficiency Scenarios

As detailed above in Table 3, the UEC of all end uses have been evaluated specific to India in this case study. To the degree possible, target efficiencies are also developed considering the Indian context. Specifically, we used performance parameters specific to Indian appliance models for refrigerators, air conditioners and water heaters. Parameters from other countries (described in detail below) were used as a proxy for lighting, fans and washing machines.

Refrigerators

The potential for efficiency improvement in Indian domestic appliances is best defined for two of the products with highest UEC, refrigerators and air conditioners. This is due to the work of India's Bureau of Energy Efficiency. BEE has established a scheme which combines a labeling program and MEPS, for both of these products.

Currently, direct cool, single-door refrigerators account for 82 % of shipments in India (IMRB 2004), but larger 2-door frost free refrigerator/freezers are increasing in market share. Single door units use about 359 kWh per year[7]. Frost free units were found to use about twice as much energy according to test data gathered by BEE. The market weighted UEC of refrigerators grows in time according to the assumption that the frost-free market will grow to 50 % by 2030.

A recent analysis by LBNL (McNeil, 2005) found that efficiency improvements of up to 45 % would be cost effective for Indian residential consumers. Therefore, we assume that new refrigerator consumptions will ramp down from the current level to 55 % of that level by 2012.

Air Conditioners

The current baseline level of efficiency for new air conditioners sold in India is about 2.34 W/W (7.8 Btu/Wh)[8]. A life-cycle cost analysis based in cost data and efficiency improvement due to specific design options suggests that a level of 2.81 W/W (9.6 Btu/Wh) would be cost effective to consumers, representing an improvement of 17 %.

Fluorescent Lamp Ballasts.

Fluorescent lamp ballasts efficiencies are well-defined, in terms of wattage losses. According to a recent study (VOICE 2004), "magnetic ballasts typically have losses of 8-12 watts per lamp. Less than 1 % of the ballasts sold in India have losses below

7. LBNL Estimate based on market wattage data and methodology of (Harrington 2004).

8. For window units, BEE estimate based on industry data.

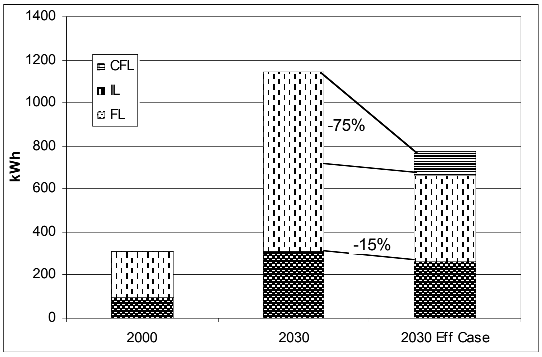

Figure 8 Household Lighting consumption by bulb type, in 2000 and in 2030, base case and policy case

8 watt." However, the survey indicates that sales of electronic ballasts are growing, and that a wide variety of models are available. In some regions, the use of electronic ballasts is similar to the use of magnetic ones (Bangalore). The savings scenario therefore assumes that the baseline (average) losses are 10 W per lamp, and that the efficient scenario will include 100 % penetration of electronic ballasts, with a loss of 4 W, yielding a 6 W per lamp savings, which represent 15 % savings on the most common fluorescent lamps, in agreement with estimates of 10-15 % savings (VOICE 2004).

CFLs

Sales of CFLs are currently extremely low in India-600,000 per year in 2000 (Kumar, 2003). Therefore, we assume no significant baseline market before 2010. In the high efficiency scenario, we assume that each household buys an additional CFL every 5 years starting in 2010. In 2030, each household has 5 CFLs that have replaced 5 incandescent bulbs, leaving 4 remaining incandescent lamps and 5 fluorescent tubes. Figure 8 shows the results on the lighting consumption. We can see that even if more than half of the stock of incandescent lamps is replaced by CFLs they remain the largest contributor to lighting consumption.

Water Heaters

The newsletter of the Indian consumer advocacy organization *Consumer Voice* (January 2002 issue[9]) reports a wide variation in efficiency for electric storage tank water heater (geysers). The range of equivalent products tested was found to be from 0.79 to 1.45 kWh per day, representing a difference in over 50 %[10]. We therefore conservatively assume that a 25 % improvement is achievable.

Fans

Potential fan efficiency improvement is based on studies in the U.S. targeting ceiling fans. U.S. ceiling fans often are fitted with lighting fixtures, and both the mechanical and lighting energy are considered for efficiency by the USEPA Energy Star program. For India, we consider only mechanical efficiency. Cost effective efficiency potential from improved blade design and motor efficiency improvement is estimated at 30 % (USDOE, 2004). The maximum technology potential indicates a fractional savings of over 60 %. We assume that an efficiency improvement of 30 % for all fan types is within reach with existing technologies.

9.Available at http://www.tribuneindia.com/2003/20030113/biz.htm#4

10. A similar range was found for European 75 liter water heaters in (Sakulin, 2000)

Washing Machines

Currently, semi-automatic washing machines are dominant in the Indian market, with about 80 % of the market share (Euromonitor 2003). Of the automatic washing machine market, about a third are front-loading units, which are more expensive, but use less energy (and water). Data regarding energy consumption and potential efficiency improvement for Indian washers are absent. Therefore, we use international data as a proxy. The Mexican government set efficiency standards for washing machines, including both semi- and fully-automatic units in 1995. For semi-automatic washers, tested models improved in efficiency between by 63 % 1995 and 2005. We use the Mexican UEC for 1995 and 2005 to represent the improvement for semi-automatic washers through an aggressive program in India. For automatic washers, we use a recent EU analysis to evaluate improvement potential. The 2001 study (Novem, 2001) found that design options resulting in a 22 % efficiency improvement minimized the life-cycle cost of the appliance. We assume this level to be achievable in India, with the implicit assumption that the technologies used in Indian automatic washing machine in 2010 will be similar to the European baseline in 2001.

Table 4 summarizes the UEC for each targeted equipment type in Case 1 and Case 2, and shows the relative efficiency improvement.

ENERGY SAVINGS

The calculation of the total electricity savings in Indian households is the last step of the analysis (step 4 of BUENAS). The Base Case projection is described in the previous section. The Efficiency Scenario is developed with the assumption of a shift to high efficiency products in 2010. In the Efficiency Scenario, the efficiency of the stock gradually increases as modeled by the shipments forecast. Savings in each year is the difference in total consumption between the 2 cases. Figure 9 shows the Efficiency Scenario consumption by end use, compared with the Base Case total.

By 2030, most of the stock is made of efficient products, which translate into a 26 % electricity savings for that year, compared to the base case (237 TWh saved in 2030).

Table 4 Summary of Baseline and High Efficiency UEC

Product	Base case UEC 2010	High Efficiency Case UEC 2010	Efficiency Improvement
Refrigerators	528	237	55%
Air Conditioners	2980	2473	17%
Ballasts	10 W per fixture	4 W per fixture	6 W
CFLs	40W	15W	75% per replacement
Water Heaters	607	455	25%
Fans	145	100	30%
Washing Machines			
Semi-Automatic	125	46	63%
Automatic	452	325	28%

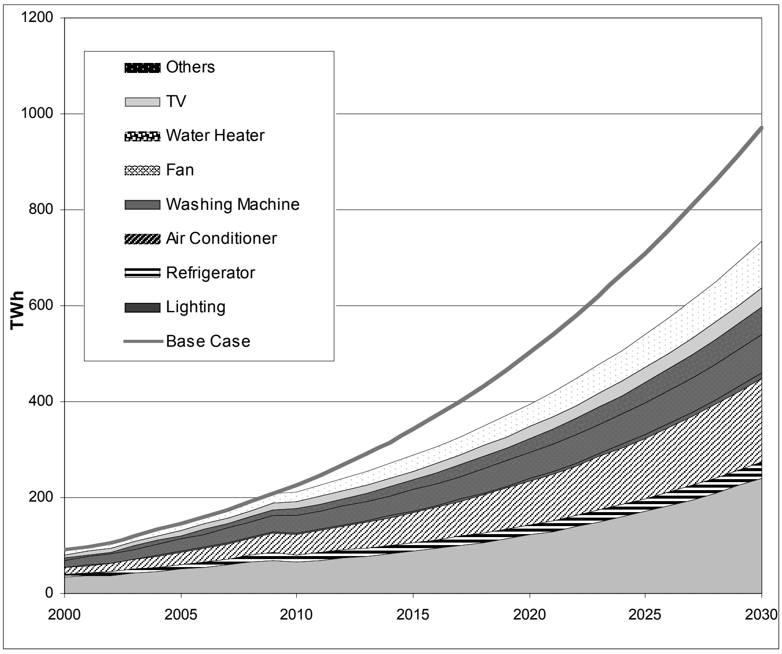

Figure 9 Total Electricity Consumption, Base Case and High Efficiency Case.

Table 5 Electricity consumption, Base Case and High Efficiency Case in 2030, per end use

	Base Case Consumption	High Efficiency Case Consumption	Savings	Savings
	TWh	TWh	TWh	%
Lighting	338	241	97	41%
Refrigerator	77	35	42	18%
Air Conditioner	208	173	35	15%
Fan	116	81	35	15%
Water Heater	78	58	19	8%
Washing Machine	19	10	9	4%
TV	37	37	0	0%
Others	97	97	0	0%

Table 5 shows the amount of savings per end use, lighting shows by far the highest potential for energy savings, followed by refrigerators, air conditioners and fans. These products represent 88 % of the potential savings.

Finally, electricity consumption and savings are converted to source energy, or primary energy which is the equivalent of the input energy. The heat rate we use (2.89) is based on the fuel mix given by the International Energy Agency and some rough estimations of each type of generation heat rate. We use 29 % for Transmission and Distribution losses[11]. The CO_2 emissions are calculated with the IEA estimation of carbon factor of 926 g/kWh. Table 6 shows the savings between the base case and the high efficiency case for each year, along with cumula-

11. A revised estimation from the Planning Commission for the year 2001-2002 (Planning Commission 2002) gives transmission and distribution losses state by state for state electricity boards (SEBs) and electricity departments (EDs). Sales of power are used to weight the average. (McNeil, 2005)

Table 6 Electricity Consumption in both Cases and Savings in the high efficiency case in 2030

Year	Base Case Consumption	High Efficiency Case Consumption	Savings	Cumulative Primary Energy Savings	Cumulative CO_2 Mitigation
	TWh	TWh	TWh	Mtoe	Mt (CO_2)
2005	146	146	0	0	0
2010	226	212	15	14	54
2015	342	287	54	70	266
2020	503	395	108	206	784
2025	710	539	171	444	1,689
2030	970	733	237	792	3,016

tive primary energy savings and CO_2 emissions avoided. By 2030, India will have saved 792 Mtoe and 3016 Mt of CO_2.

Conclusion

We hope that this paper serves two purposes. Fist, it demonstrates the application of a flexible analysis system (BUENAS) to a country study, whereas it was previously used to analyze the worldwide efficiency potential for a single appliance (McNeil 2006). Secondly, it provides a look at possible future of consumption in one large developing country, and by extension, says something about the impact of rapid growth in developing countries.

The forecast of appliance ownership growth is remarkably high. This is essentially an effect of diffusion threshold. With economic growth rates of about 5 % (i.e. high, but slower than the current growth rate), average income will increase by about a factor of four by 2030. The model predicts that a large fraction of households will own most major appliances. This will lead to an enormous growth in consumption, because diffusion rates are currently so low. This will not be surprising if we believe that the average Indian household will in 25 years time have the consumption power that the middle-class currently do. If, on the other hand, the great majority of households remain poor, our model will likely overestimate future consumption. An important next step in studies of India and other developing countries may be to more fully utilize what is known about distribution of wealth as countries grow.

Significant improvement in efficiency in the Indian residential sector should be possible. For instance, we expect that lighting and refrigeration will continue to hold large shares of household consumption, and both of these end uses show the potential for large improvements. In our high efficiency scenario, the improvement in lighting efficiency is mostly due to CFLs as shown in figure 8, even with the moderate assumption that each household buys only one additional CFL bulb every 5 years. Even so, lighting is by far the largest single contribution to savings in the long term. This suggests the significant opportunity for CFLs as a target technology for India to manage the growth of the residential sector electricity in a highly cost effective way from the consumer perspective.

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