RESIDENTIAL CONSUMPTION OF ELECTRICITY IN INDIA

DOCUMENTATION OF DATA AND METHODOLOGY

Background Paper

India: Strategies for Low Carbon Growth

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CONTENTS

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Acronyms and Abbreviations

CFL	Compact fluorescent light
CRT	Cathode ray tube
EEUL	Electrical energy usage for lighting
GDP	Gross domestic product
GWh	Gigawatt-hours
kWh	Kilowatt-hours
LCD	Liquid crystal display
MCEH	Monthly consumption of electricity per household
MMHE	Mean monthly household expenditure
MPCE	Mean monthly per capita expenditure
MW	Megawatts
NCAER	National Council of Applied Economic Research
NSS	National Sample Survey
PCEG	Per capita expenditure growth

Residential Consumption of Electricity in India - Documentation of Data and Methodology

1.0 Introduction

This paper describes the methodology used for the electricity consumption section of the household module of the *India Low Carbon Growth* Study and presents preliminary results. The module is used to project the numbers of electric appliances in use in the residential sector in India to fiscal 2031–32. Currently, lighting accounts for approximately 30 percent of total residential electricity use, followed by refrigerators, fans, electric water heaters, and TVs. Approximately 4 percent of total residential electricity used is for standby power—the apparently small amount of power that many modern appliances consume when they are not actively turned on. Appliance penetration, particularly of refrigerators and air conditioning units, is expected to be the main driver for the growth of residential energy demand by 2020 (McKinsey Global Institute 2007). The paper describes all the assumptions for scenario 1, the first scenario to be modeled in the study. Scenario 1 models the absorption of the appliances currently on sale in India into the appliance population. Many of these are more efficient than those historically sold—and currently used—in the country. The paper also describes an alternative (scenario 2) with higher energy efficiency. It is important to point out, however, that neither scenario takes the rebound effect into account.[1] As a result, the results will under-estimate the amount of electricity consumed and should be taken only as a (most likely unachievable) lower bound on power consumption. The methodology presented in this paper needs to be expanded in a future version to include limited modeling of direct rebound effects by incorporating price elasticities (see an accompanying paper, "Cost-effectiveness assessment of greenhouse gas mitigation options: A proposed methodology"). Other scenarios and sensitivity analysis will also be described in a future version of this paper. Unless indicated otherwise, all sources for tables and figures in this paper are World Bank staff calculations.

2.0 Brief Review of Literature

There exists an extensive literature on electricity demand projection, and different approaches are found. This section provides a brief review of those that have focused on India's electricity demand. One approach makes use of aggregate macro data at the country or sub-national/state level (for example, Bose and Shukla 1999, CEA 2007a). Essentially, this approach aims to estimate the income elasticity of electricity consumption by econometric analysis of the relationship between electricity consumption and its key determinants, such as gross domestic product (GDP) per capita and electricity price, over a relatively long period of time.

Another approach uses micro-level data that reflects individual and household behaviour; this may be referred to as a microeconomic approach. This approach enables analysis across different heterogeneous household sub-groups and takes into account a number of household characteristics. Examples include Pachauri (2004), Filippini and Pachauri (2004), and Tiwari (2000). These authors estimate price and income elasticities of electricity demand in the residential sector using household survey data. Filippini and Pachauri (2004) regressed

[1] The energy savings realized in practice almost always fall short of engineering estimates based on energy efficiency improvements, because energy efficiency improvement lowers the effective cost of using energy and encourages greater consumption. When direct and indirect rebound effects are considered, there could even be a net increase in energy consumption rather than energy savings. An excellent overview of the rebound effect can be found in UKERC (2007).

household electricity consumption on household expenditure (as a proxy for income), the average prices of electricity and other fuels, and a set of other geographic (regional dummies) and socio-economic (such as household size and the age of the household head) variables. The elasticities used to project electricity demand are based on future income and price scenarios.

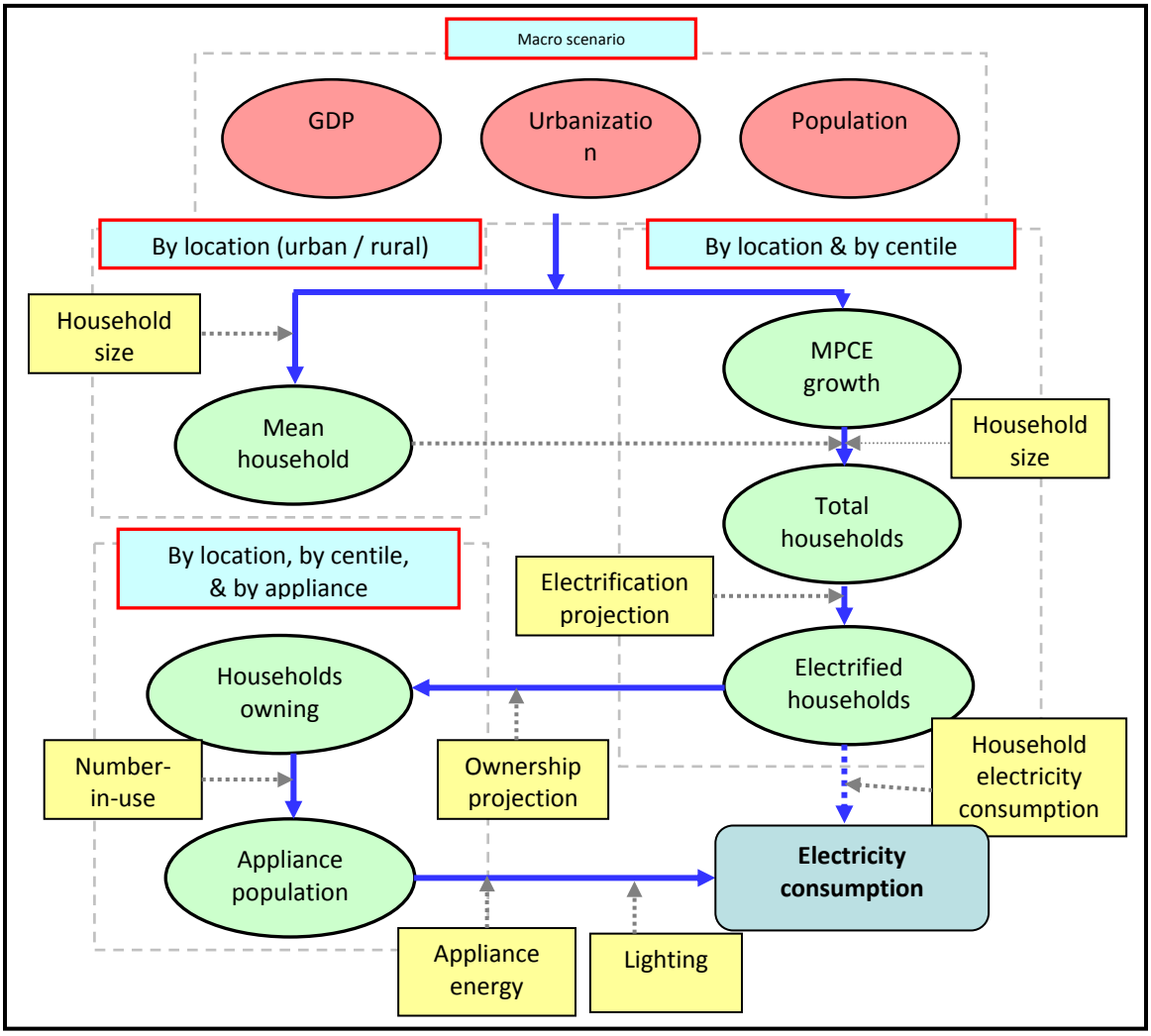
The approach used in this study is a variant of the microeconomic approach and is sometimes referred to as an end-use or bottom-up approach. As with the microeconomic approach, the end-use approach makes use of micro-level data. While the former aims to analyze income-electricity demand relationship through a reduced-form equation, the latter examines the ownership and the use of household electricity-consuming devices and considers efficiency scenarios from an engineering point of view, as opposed to micro-economic/econometric.

A key advantage of end-use over other approaches is that it allows the assessment of efficiency scenarios for electrical appliances, their usage, and electricity conservation as well as the impact of other economic (GDP growth, prices), demographic (population growth, urbanization), and geographical (e.g., rural/urban and regional/state dummies) factors. Kadian, Dahiya, and Garg (2007) used this approach to examine mitigation opportunities in the residential sector in Delhi. Letschert and McNeil (2007) projected India's residential electricity demand based on six appliances from the 55th round of the National Sample Survey (NSS) conducted in 1999–2000.

3.0 Methodology & Data

Figure 1 depicts the modeling framework adopted in this study. The *India Low Carbon Growth* study is developing a bottom-up model that covers the electricity supply, residential, non-residential buildings, transport, industry, and agricultural sectors. The model projects supply and demand and greenhouse gas emissions on an annual basis between fiscal 2005–06 and the last fiscal year of the 15th Plan, 2031–32 (referred to as 2005 and 2031, respectively, hereafter).

Figure 1: Modeling Framework: Household Module



Household electric appliance ownership is assumed in this study to depend only on household income, for which household expenditures are used as a proxy. This simplifying assumption is made because, while ownership is a function of other explanatory variables such as the education level of the head of the household, projecting the distribution of education levels of heads of households, etc., to 2031 would involve many bold assumptions. Making many such assumptions would not necessarily improve accuracy and could potentially even increase, rather than decrease, uncertainties.

There are four main steps in forecasting household electricity consumption. The first is to project numbers of households and their expenditures in urban and rural areas. The second is to identify households that are electrified. The third is to forecast ownership of appliances among electrified households. The last step computes electricity consumption. The sub-steps are described below.

I Projecting the distribution of household size, household expenditure, and household number
Analysis of household survey data suggests that ownership of electric appliances depends on household income. Household size and per capita income projections can be combined to forecast household income, using household expenditures as a proxy. The steps are as follows:

(1) GDP growth, urbanization, and population growth rates are exogenous and taken from government and other sources.

(2) The mean household size is projected using a methodology adopted by the United Nations that correlates the number of households with the population in the 15–64 age group. Dividing the total population by the number of households gives the average (national) household size.

(3) The urban household size is computed assuming that the number of urban households increases at the same rate as urbanization, as described below. The rural household count is computed by taking the difference between the numbers of total and urban households. The rural household size is calculated by dividing the rural population by the number of rural households.

(4) The data from the 61st round of the NSS (NSS Round 61 hereafter), conducted in July 2004–June 2005, are used to create 100 quantiles (referred to centiles hereafter) based on monthly per capita expenditures (MPCE) in urban and rural areas, respectively, with each centile containing approximately the same number of individuals. Each centile, however, contains a different number of households. NSS data give different population and household counts from the Census of India. How the differences are accounted for is explained in more detail below.

(5) The exogenous parameters in step (1) are used to calculate rates of growth in MPCE, taking into account rural-urban migration. MPCE is projected annually by centile and by location.

(6) The number of households in each centile and location is computed, taking mean (location-level) household size projections and household size distribution across centiles as given. The distribution of household size by location and centile is adjusted (by applying in each year an adjustment factor to all centiles in each location) such that the weighted mean household size of the centiles is the same as the mean (location-level) household size projection.

(7) Based on MPCE and the mean household size, the average monthly household expenditure (MMHE) is computed for each centile.

II Projecting electrified households

(8) The electrification rate is projected by location as a function of MPCE, and the number of electrified household is computed.

III Projecting appliance ownership

(9) Appliance ownership is estimated for each appliance in each location and centile as a function of MMHE and electrification. This yields the number of households that own at least one unit of a given appliance.

(10) The number of appliances in use is projected for certain appliances where data yielded meaningful modeling results. Combing this with the information on the number of appliance-owning households gives the total number of appliance in use.

IV Projecting electricity consumption

(11) Electricity consumption from lighting is modeled using data from a survey of 600 households.

(12) Electricity consumption from appliance use is modeled by assuming different levels of energy efficiency. Although the rebound effect is not taken into account in this

paper, price elasticities may be used to model the direct rebound effects in future papers.

4.0 Population and Urbanization

The Census of India provides population and urbanization projections to March 2026 (Census of India 2006). This study extends the series to 2031, extrapolating the trends given by the Census of India in 2006 (Table 1). More details are provided in Appendix 1.

Table 1: Population and Urbanization, 2006-2031

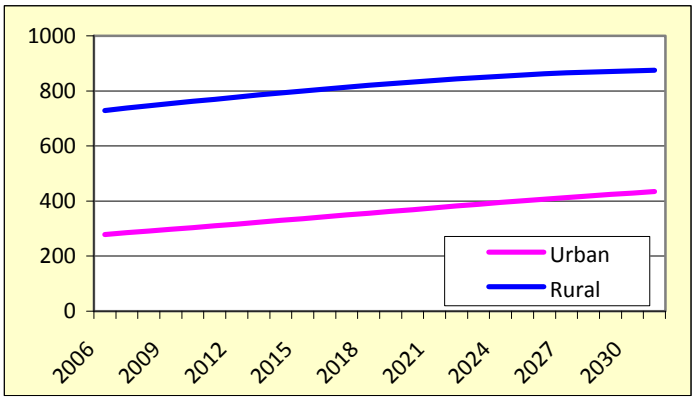
Year	Population ('000 persons)	Urbanization (% of urban population to total)
2006	1,112,186	28.9
2007	1,128,521	29.1
2008	1,144,734	29.3
2009	1,160,813	29.6
2010	1,176,742	29.8
2011	1,192,506	30.0
2012	1,208,116	30.2
2013	1,223,581	30.5
2014	1,238,887	30.7
2015	1,254,019	30.9
2016	1,268,961	31.1
2017	1,283,600	31.4
2018	1,298,041	31.6
2019	1,312,240	31.8
2020	1,326,155	32.1
2021	1,339,741	32.3
2022	1,352,695	32.5
2023	1,365,302	32.8
2024	1,377,442	33.0
2025	1,388,994	33.2
2026	1,399,838	33.4
2027*	1,409,991	33.7
2028*	1,419,472	33.9
2029*	1,428,303	34.1
2030*	1,436,507	34.4
2031*	1,444,110	34.6

Sources: Data for 2006–2026 are from Census of India, Population Projection for India and States 2001-2026, December 2006, and all projections are effective 1 March of each year
*denotes the projections made by the study.

According to the Census of India, India's total population will reach 1.4 billion by 2026. This study projects that the total population will continue to increase at a declining rate and reach about 1.44 billion by March 2031. The urbanization rate is projected to rise from 29 percent in 2006 to 33 percent in 2026. Extrapolating this trend gives an urbanization rate of 35 percent by 2031. Figure 2 shows urban and rural population projections to 2031. The 2031 urbanization rate

in India is low compared with those in other countries with current per capita income close to India's in 2031.

Figure 2 : Rural and Urban Population, 2005-2031



4.1 Annual Growth Rate of GDP and Per Capita Expenditure

The recently published 2006 GDP growth figure of 9.4 percent is used in this study (MoSPI 2008). GDP growth in scenario 1 is the government's target of 8 percent between 2010 and 2021, and then falls to 7.5 percent in 2022-2026 and to 7.0 percent in 2027-2031. GDP growth rates used in scenario 1 are presented in Table 2.

Table 2: GDP and MPCE Growth in Scenario 1

Fiscal year	GDP growth	Per capita expenditure growth
2006/7	9.6%	7.8%
2007/8	9.0%	7.3%
2008/9–2009/0	7.6%	5.9%†
2010/1–2021/2	8.0%	6.5%†
2022/3–2026/7	7.5%	5.6%†
2027/8–2031/2	7.0%	4.9%†

Sources: http://mospi.nic.in/press_release_7feb08.pdf for 2006/7, GoI's 8% target to 2021. Economist Intelligence Unit projection Apr 8th 2008 to 2008/9.
† denotes average value over the years.

Total household expenditures are assumed to grow at the same rate as GDP. However, because of increasing urbanization, per capita expenditure grows more slowly than GDP. The table also presents the per capita expenditure growth used during the projection period. Per capita expenditure growth, *PCEG*, in year *t* can be computed from the variables in the same year and urban and rural populations in year *t+1* using the following equation:

(**Equation 1**)
$$PCEG_t = \frac{\sum_k MPCE_{k,t} \cdot POP_{k,t}(1+GDPG_t)}{\sum_k MPCE_{k,t} \cdot POP_{k,t+1}} - 1$$

where $k \in (\text{rural}, \text{urban})$, *POP* denotes population with the same subscripts, and *GDPG* is the annual rate of GDP growth. Appendix 2 provides the derivation of equation 1.

4.2 Household Size Projection by Location

Household size is a determinant of both the total number of households and household expenditure. This study adopts the United Nations' methodology in projecting household size to 2031. The United Nations bases projections on past trends of *the ratio of the number of households to population between 15–64 years of age.*[2] Census of India 1991 and 2001 provides data on the number of household and 15–64 age-group population (Table 3). The ratio is increased every year by 0.0011 (average annual rate of increase between 1991 and 2001 in the table) to 2031. The households considered here are what the Census of India calls "normal" households. The other two categories are houseless households and institutional households. For the purpose of calculating residential electricity consumption, the latter two categories were omitted. Because the total and age 15–64 population figures were available only for the entire country, and not excluding those associated with houseless and institutional households, the total population figures, and not those that pertain only to those living in "normal" households, were used in estimating the number of normal households.[3]

Table 3: Summary of Data for Household Size Projection

National	1991	2001
(a) Number of household	153,440,588	192,671,808
(b) population (15-64)	494,843,370	614,792,265
Ratio (a/b)	0.310	0.313
Total population	846,302,688	1,028,610,328
Household size	5.52	5.34

Sources: Census of India and World Bank calculations

Electric appliance ownership patterns and the distribution of household expenditures are derived from NSS Round 61 household survey data. However, NSS and census give different population and household counts. For example, as of 1 March 2001, the Census of India reports 1.02 billion people and 193 million "normal" households in India, 742 million people and 137 million households in rural India, and 286 million people and 282 million households in urban India, whereas linearly interpolating NSS Round 55 and NSS Round 61 yields only 0.79 billion people and 164 million households in India, 594 million people and 119 million households in rural India, and 200 million and 45 million households in urban India. These differences become smaller if NSS Round 61 results are compared with the population projections by the Census of India linearly interpolated to 1 January 2005 (midpoint of the NSS Round 61 survey period), but NSS results continue to under-estimate. The study projects household expenditures and numbers based on NSS Round 61 using growth rate projections from the Census of India, and scales the calculated numbers of households by a constant factor in urban and rural areas separately to match the Census of India projections.

The number of households is projected as follows:

[2] This is based on the conversation with Prof Ram (International Institute for Population Sciences).

[3] The 1991 census, unlike that in 2001, did not include Jammu and Kashmir . It is also not clear whether the number of households in Assam was included in the total number of households. As such, coverage of the population and the number of households was greater in 2001, introducing an additional source of error in the interpolations carried out in this study.

(1) The number of households and the size of the 15–64 age group population (which is available from the Census of India for 1991 and 2001) were used to determine this ratio and the annual rate of change of this ratio in the intervening years (that is, between 1991 and 2001). By linearly extrapolating the ratio for each year up to 2031 and combining with the projections of the total population (available from the Census of India to 2026 and extended by this study to 2031) the numbers of households across India in the study years were calculated.

(2) The fraction of households in urban areas is computed by taking the census data in 2001 and increasing the fraction of households in urban areas by the same rate as the growth of urbanization. Multiplying the fraction of total households in urban areas by the total population gives the number of urban households. The number of rural households is computed from the difference between the total number of households in the country and the number of urban households.

(3) The annual change in household size for urban and rural households is computed from the projections made with the census data. This is applied to the urban and rural household sizes determined in the NSS Round 61 survey to project household sizes.

(4) Combining the rural/urban household number and size projections allows the numbers of the households and of people inhabiting these households in urban and rural areas separately to be computed to 2031. All numbers are corrected to be representative of the 1st of October of each year, this being the mid-point of each Indian fiscal year (Table 4). The household sizes shown in the table, based on NSS data, are markedly smaller than those estimated using the Census of India projections. The number of individuals in each centile is adjusted by a common factor to yield the numbers of households consistent with the census data.

Table 4: Household Size Projection and Household Urbanization, 2006-2031

year	person per household		% of urban household to total	year	person per household		% of urban household to total
	urban	Rural			Urban	rural	
2006	4.3	4.8	27.5	2019	3.9	4.4	30.4
2007	4.2	4.8	27.7	2020	3.9	4.4	30.6
2008	4.2	4.7	27.9	2021	3.9	4.4	30.8
2009	4.2	4.7	28.1	2022	3.9	4.4	31.0
2010	4.1	4.6	28.4	2023	3.9	4.4	31.2
2011	4.1	4.6	28.6	2024	3.9	4.3	31.5
2012	4.1	4.6	28.8	2025	3.9	4.3	31.7
2013	4.0	4.5	29.0	2026	3.9	4.3	31.9
2014	4.0	4.5	29.2	2027	3.8	4.3	32.1
2015	4.0	4.5	29.5	2028	3.8	4.2	32.4
2016	4.0	4.5	29.7	2029	3.7	4.2	32.6
2017	4.0	4.4	29.9	2030	3.7	4.2	32.8
2018	3.9	4.4	30.1	2031	3.7	4.1	33.0

The most recent U.N. Habitat's Global Report on Human Settlements (2007) projects India's national average household size in 2030 to be 4.48 persons, quite a bit higher than 4.0 estimated in this study for those households represented in the NSS. A Deutsche Bank Research study

(Just, Vath, and Chin, 2006) regressed current average household size on household size in 2003, fertility, urbanization, per capita GDP, and life expectancy in 27 (mainly industrialized) countries. The model predicted that India's average household size will decline to between 3.7 and 4.7 persons by 2030.

4.3 Projection of MPCE by Centile and Location

The evolution of MPCE and its distribution affect household size (which generally declines with increasing income), the electrification rate, and appliance ownership. The study divides the population into urban and rural, and creates centiles—each containing the same number of individuals—based on MPCE. For this purpose, total expenditures found in NSS Round 61 are used. The lowest expenditure group spent slightly over Rs 850 per month in rural areas and Rs 1,482 in urban areas, while the highest expenditure is just over 10,300 rupees in rural areas and slightly over 19,000 rupees in the urban areas. Annex 1 provides the distribution of monthly household expenditures by centile and location.

Scenario 1 assumes uniform growth across rural and urban centiles. Alternatives include growing certain centiles faster than others, and differentiating urban and rural growth rates. Scenario 1 projects MPCE to 2031 by centile for both rural and urban households by setting MPCE in year $t+1$ to equal

(**Equation 2**) $$MPCE_{ik,t+1} = MPCE_{ik,t} \cdot (1 + PCEG_t)$$

where i denotes the i^{th} centile and k is rural or urban. Population is similarly assumed to grow uniformly across all centiles and at both locations:

(**Equation 3**) $$POP_{ik,t+1} = POP_{ik,t} \cdot (1 + POPG_{kt})$$

where $POPG$ denotes the annual growth rate of population.

4.4 Projection of Household Size by Centile

A snapshot of NSS Round 61 reveals evidence of significant variation in household size across expenditure groups (see Annex 1). The distribution of household size across MPCE groups is captured through a linear regression. Table 5 reports the results. The dependent variable is the logarithm of the household size, and explanatory variables are the logarithm of MPCE and a dummy that is 1 for the first centile and 0 otherwise.

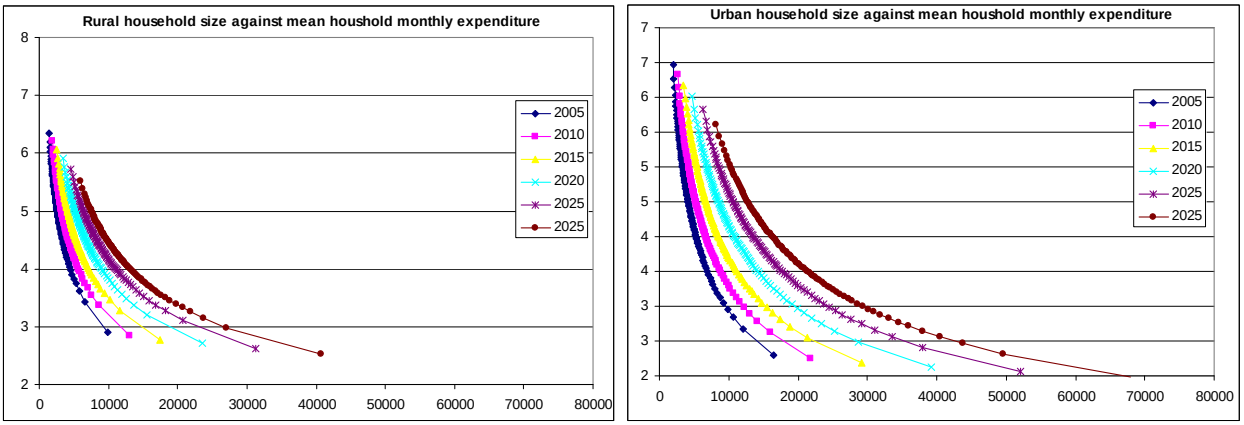
Table 5: Linear Regression on Household Size

Independent variable	Rural	Urban
log of mpce	-0.2882	-0.329
	(0.00017)	(0.0003)
dummy for 1st centile	-0.3977	-0.291
	(0.0011)	(0.00188)
constant	3.394	3.728
	(0.0011)	(0.00207)
R^2	0.9732	0.9637

Note: standard errors in parentheses

The relative distribution of household sizes in NSS Round 61 is assumed to hold in the future projection years. Adjusting household size as a function of household expenditure using the regression results contained in Table 5 would lead to household sizes that are too small in the future years. Taking MPCE growth and mean household size projections as given, the household size distribution pattern from NSS Round 61 is projected forward by adjusting the constant in Table 5 to match the weighted average of household sizes across centiles with the location-level mean household size projection. Figure 3 shows the projection of mean household monthly expenditure for various household sizes by centile to 2031. Household size estimates enable calculation of the number of households in each centile to 2031.

Figure 3 : Household Size Distribution, Rural (left) and Urban (right) against Mean Household Expenditure



5.0 Projection of Electrification Rate

This study uses NSS Round 61 to compute the percentage of electrified households in 2004–05. A household is considered electrified if it reported (1) positive expenditures on electricity, *or* (2) electricity as the primary source of lighting. The second group was not a subset of the first, and if a household satisfied either or both of the two conditions, it was assumed to be electrified. The rate of electrification in both rural and urban location is closely related to MPCE (Figure 4). As MPCE increases, the proportion of electrified households increases until it reaches a saturation level. A three-parameter Gompertz function is suitable for approximating such an uptake curve. The rate of electrification is estimated by Equation 4:

(**Equation 4**)
$$\text{Electrific ation}_{\text{i, k, t}} = \beta_{k1} \cdot e^{-e^{-\{\beta_{k2} \cdot (\text{MPCE}_{\text{i,k,t}} - \beta_{k3})\}}}$$

where $electrification_{i,k,t}$ is defined as the percentage of total households that are electrified in the i^{th} expenditure centile, location k, and in year t, $MPCE_{i,k,t}$ is similarly defined, and β_1, β_2 and β_3 are the three Gompertz function parameters. Parameter β_1 can be interpreted as the current saturation level of the electrification rate, whereas parameter β_3 can be interpreted as the MPCE level above which the rate of electrification increases at an increasing rate (point of inflexion). The higher the value of β_2, the more rapid the turn of the curve to saturation. The three parameters are location-specific.

The estimated coefficients are all highly significant at 1 percent and are reported in Table 6. The Gompertz curves based on the estimated parameters are shown in Figure 4. Multiplying the

predicted electrification rate by the total number of households yields the number of electrified households by location and centile. Figure 5 shows the projection of electrified households between 2005 and 2031.

Figure 4: Electrification Rate, Rural and Urban Area

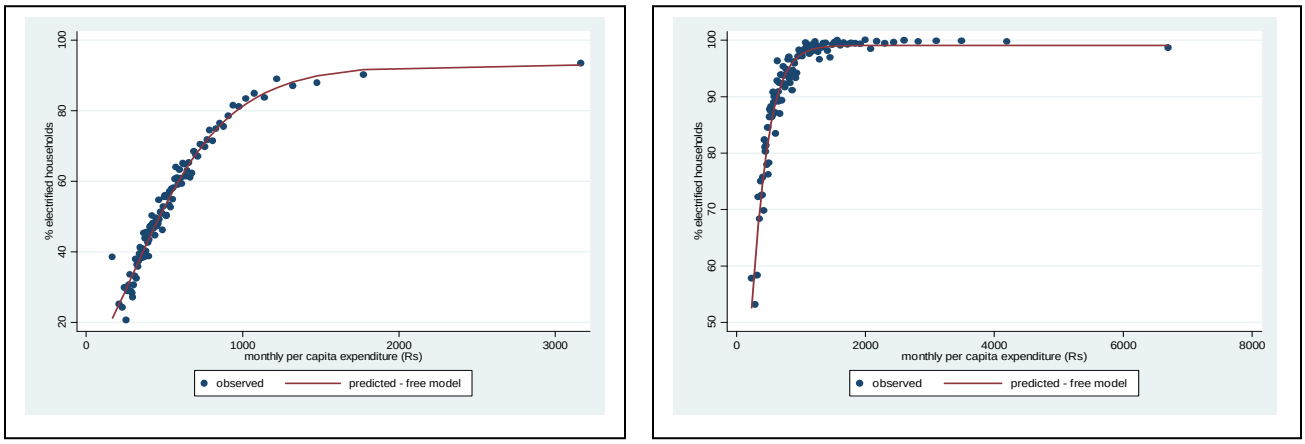
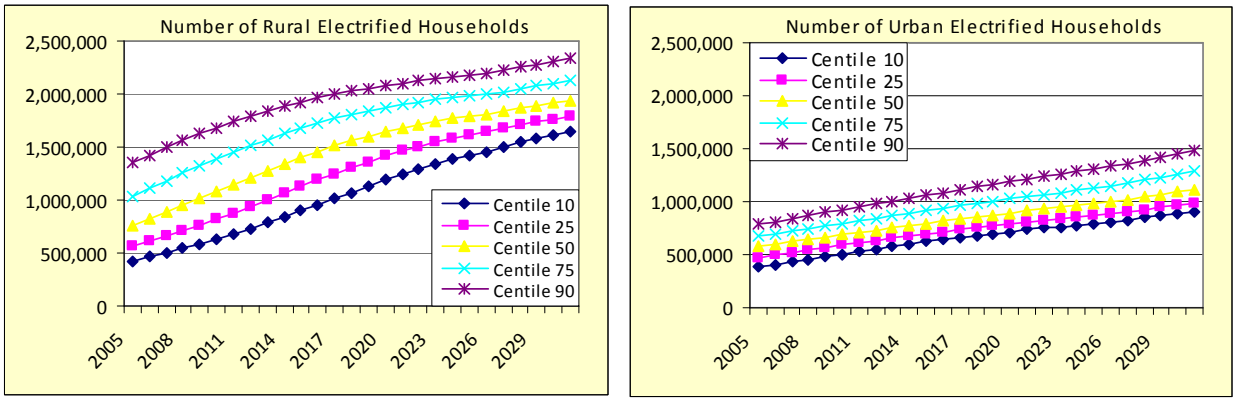


Table 6: Non-linear regression: Gompertz—Electrification against MPCE

coefficient	Rural	Urban
β1	93.004	99.090
	(1.5732)	(0.4141)
β2	0.002876	0.004735
	(0.00013)	(0.00023)
β3	303.1154	134.0101
	(6.93288)	(12.77578)
R^2	0.997	0.999

Note: standard errors in parentheses

Figure 5 : Electrified Households by Centile, Rural and Urban



Note: Projections based on Gompertz curve fitting. 10, 25, 50, 75, and 90 refer to the 10th centile, 25th centile, etc.

The analysis also allows for scenarios with target electrification rates. An exogenous future electrification rates may be set, and the model uses an automated "goal seek" function in Excel to adjust the distribution of electrified households such that it gives the weighted mean electrification equal to the targeted levels in all years (*t)*.

6.0 Appliance Ownership Projection

Consistent with evidence elsewhere, appliance ownership as a function of household expenditure in India follows an S curve. A three-parameter Gompertz function is used to model ownership patterns. For this purpose, only electrified households are considered, and they are divided into centiles in urban and rural areas according to monthly household expenditures, with the same number of persons in each centile. The Gompertz formulation for appliance ownership uses monthly household expenditure (MMHE) as the independent variable as shown in Equation 5:

(**Equation 5**) $$\text{Ownership}_{\text{i, j, k, t}} = \beta_{i,j1} * e^{-e^{-\{\beta_{i,j2}*(\text{MMHE}_{\text{i,k,t}}-\beta_{i,j3})\}}}$$

where *ownership* is defined as the percentage of households in the ith expenditure centile who own appliance *j* in year *t*; *MMHE* is the average monthly household expenditure with the same subscripts, and *betas* are Gompertz parameters. *β1* can be interpreted as the saturation level of the appliance penetration, *β2* determines the rate at which the curve turns to saturation, and *β3* can be interpreted as the MMHE level above which the rate of penetration increases at an increasing rate (point of inflexion). The three parameters are location- and appliance-specific.

This study makes use of the ownership of appliances reported in (*i*) NSS Round 61, (*ii*) NSS Round 58, (*iii*) the results of the 2004 survey conducted by the National Council of Applied Economic Research (NCAER) and (iv) the results of a survey of 600 households conducted by DSCL. Table 7 shows which source was used for each appliance. The estimated coefficients obtained using Gompertz functions for a total of 16 electrical appliances are reported in Table 19 (urban) Table 20 (rural) in Annex 2. Two cases are considered, termed free and forced saturation. In the free model, all three parameters are estimated to provide the best overall fit; in the forced saturation mode, β_1 is forced to improve the fit of the saturation level at the high end of expenditure. This is only reported for those cases were a noticeable improvement could be obtained. The reason for seeking a better fit at the high expenditure end is that future expenditure groups will move up because of rising income, and hence matching each Gompertz equation at that end is more important for projecting ownership patterns in the coming years than seeking the best overall fit. Annex 3 provides the predictions of ownership using the estimated coefficients.

Table 7: Appliances by Source of Data

Appliance	Source of Data
Fan	NSS Round 61
AC	NSS Round 61
Cooler	NSS Round 61
Fridge	NSS Round 61
Radio	NSS Round 61
TV	NSS Round 61
Washing Machine	NSS Round 58
CD Player / tape recorder	NSS Round 58
DVD / VCR	NSS Round 58
Computer	NCAER/Maryland
Lighting	DSCL Household Survey

Electric Water Heater	DSCL Household Survey
Oven	DSCL Household Survey
Toaster	DSCL Household Survey
Microwave	DSCL Household Survey
Booster Pump	DSCL Household Survey

The NCAER/Maryland survey data (2004/5) were used to model the ownership of computers as a function of mean household expenditure. Whilst this dataset contains other appliances, the more extensive NSS data was used wherever possible.

A household survey was undertaken as part of the *India Low Carbon Growth* study by DSCL. The survey consisted of 600 households in 12 cities and 5 climatic zones where the annual electricity consumption and ownership of appliances in each household was recorded. This small survey was not necessarily proportionally representative of urban and rural households in India and exhibits considerable scatter even when the 600 data points are divided into only 15 groups. Thus the data should be used with caution as an indicative approximation for patterns of appliance ownership and electricity used in lighting. The expanded uncertainty associated with the sampling error of each data point could be significative and since the data collected in this survey allows appliance ownership and electricity used in lighting to be related only to total household electricity consumption this could introduce an additional survey bias.

The survey did not collect data on household expenditure. It did, however, collect detailed information on average monthly consumption of electricity per household (MCEH). Data on lighting was collected on the number, rating and type of light bulbs per household. The collected information covered incandescent and compact fluorescent (CFL) light bulbs and fluorescent tubes (with magnetic and electronic ballasts). An estimated usage factor for each lighting unit of 2.5 hours per day allowed electrical energy usage for lighting (EEUL) to be calculated for each household in the survey. A nonlinear regression was fitted to this using monthly total electricity consumption in kilowatt-hours (kWh) as the independent variable as shown in Equation 6 using data grouped into 15 quantiles ordered by monthly total electricity consumption and where $EEUL_{i,k,t}$ is defined as the fraction of total electricity consumption used for lighting in households that are electrified in the i^{th} expenditure centile, location k, and in year t, $MCEH_{i,k,t}$ is the average monthly consumption of electricity per household and is similarly defined, and β_1, β_2 and β_3 are the three function parameters. This function is valid only for monthly electricity consumptions over 19 kWh where electrical lighting equates to a single bulb.

(**Equation 6**) .

$$\mathrm{EEUL}_{\mathrm{i,\ j,\ k,\ t}} = \beta_{i,j1} \times \left(\frac{100}{\mathrm{MCEH}_{\mathrm{i,k,t}}} - \beta_{i,j2} \right) + \beta_{i,j3}$$

For the other appliances in the DSCL dataset, appliance ownership was modeled as with the NSS data but as a function of monthly total electricity consumption.

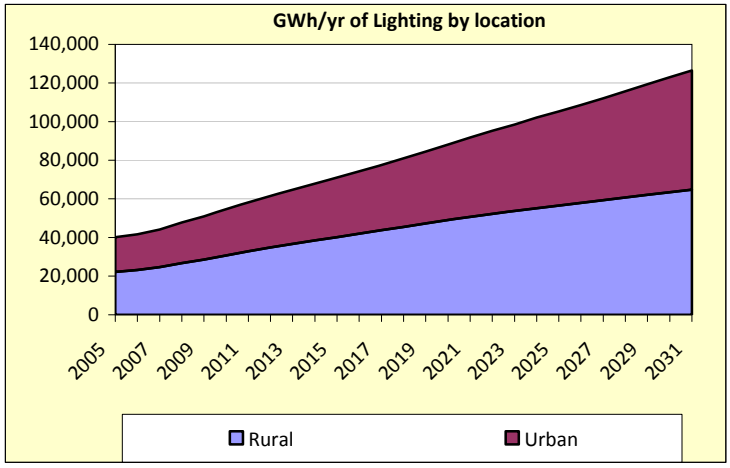
Monthly consumption of electricity per household was first modeled for each location and centile from 2005 to 2031 under an assumption that no changes occur to the 2005 “base case” consumption condition. This is known as the “status quo forecast” where household energy consumption varies by year, location and centile due only to changes in demographics and household expenditure. The status quo forecast was then used as the basis for the projection of

electricity consumption used for lighting (in kWh per month per household) and for the ownership patterns of the additional appliances from the DSCL dataset. A three-parameter Gompertz function is used to model ownership patterns using Equation 7 where $Ownership_{i,k,t}$ is defined as the percentage of electrified households in the i^{th} expenditure centile who own appliance j at location k (urban or rural) in year t; and β_1, β_2 and β_3 are the three function parameters. Results of these projections are in graphically presented in Annex 4**.** It is recommended that these numbers be reviewed based on a more extensive survey in which appliance ownership and usage can be directly related to total household expenditure.

For illustrative purposes, Figure 6 below provides the projection of electricity usage for lighting in both the rural and urban sectors.

(**Equation 7**) $$\text{Ownership}_{\text{i, j, k, t}} = \beta_{i,j1} * e^{-e^{-\{\beta_{i,j2}*(\text{MCEH}_{\text{i,k,t}}-\beta_{i,j3})\}}}$$

Figure 6 : Projection of Electricity Usage for Lighting - Rural and Urban



7.0 Projection of Number in Use

The foregoing projections indicate how many households own at least one unit of each appliance. For items such as electric fans, many households own more than one. To estimate the number of units owned, this study uses information on the number of appliances in use provided in NSS Round 58. For the number in use, a Gompertz function, with the intercept set equal to 1, as described in Equation 8, is applied to households owning the appliance in question:

(**Equation 8**) $$\text{Number}_{\text{i, j, k, t}} = 1 + \beta_{ij1} * e^{-e^{-\{\beta_{ij2}*(\text{MMHE}_{\text{i,k,t}}-\beta_{ij3})\}}}$$

where *number* is the number of appliance j in use for the i^{th} expenditure centile at location k and in year t. The three *betas* are location- and appliance-specific. MMHEs from NSS 58 were adjusted using CPI in India to express them in constant 2004-05 rupees. This provided the linkage between the DSCL dataset appliance ownership and lighting (associated with total electricity consumption) and total electricity consumption associated with monthly household expenditure through the NSS data.

For certain appliances—electric fans, televisions sets (in both urban and rural areas), and air coolers in urban areas—the number in use is positively correlated with MMHE. Other appliances were also examined but no meaningful correlation between the number in use and MMHE could be found. Annex 3 provides the projection of the number of appliances in use in these categories over time and across key centiles.

Table 8 reports the statistics obtained from fitting the above modified Gompertz equation. The number-in-use prediction for each appliance is applied to the ownership projection obtained in the preceding section to arrive at the total number of units owned by centile and location. These are then aggregated to yield the total number of units owned for each appliance in the country.

Table 8: Non-linear Regression: Gompertz function - Number-in-use and MMHE

Round 58	Rural				Urban			
	β1	β2	β3	R^2	β1	β2	β3	R^2
Fan	2.285	0.0003736	4573.094	0.996	4.068	0.0002177	6761.317	0.993
	(0.094)	(0.000021)	(143.474)		(0.145)	(0.000012)	(218.65)	
Air Cooler/Air Cond					1.897	0.0001082	14653.19	0.988
					(0.325)	(0.000018)	(1938.359)	
TV	0.0693	0.0004194	7931.514	0.999	0.3576	0.0001431	16280.15	0.999
	(0.006)	(0.00007)	(349.002)		(0.028)	(0.000015)	(790.208)	

Note: standard errors in parentheses. All coefficients are statistically significant at 1 percent level.

8.0 Projection of New Appliance Sales

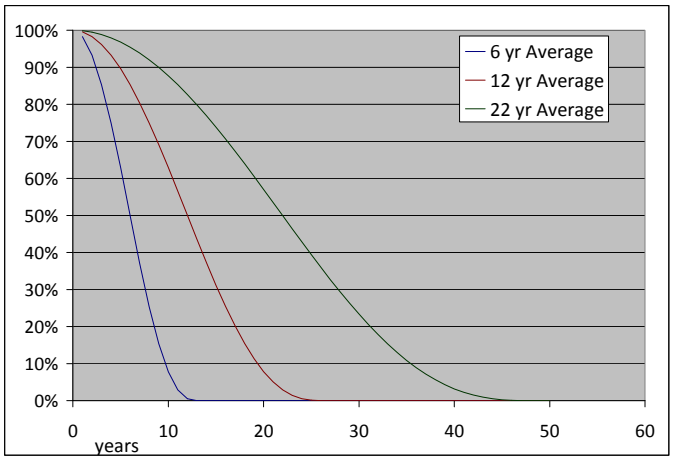
The appliance ownership calculation by centile and location, combining the number of households owning each appliance with the number of appliances per household, yields a total active population (or parc) for each appliance per year of the study. New appliance sales are derived from (i) the growth in this parc from one year to the next, and (ii) the replacement of appliances in service that have been scrapped during that year.

Appliance mortality is calculated using a Winfrey S3 survival curve as shown in Equation 9, where $mortality_{i,,t}$ is defined as the percentage of the parc of appliance i that needs to be replaced in year t, $m = 3$ and a is adjusted such that $\left(1-\frac{Y_t^2}{a^2}\right)^m$ gives 50 percent when t is equal to the average age of retirement of appliance i.

(**Equation 9**)
$$mortality_{i,t} = \left(1-\frac{Y_{t-1}^2}{a^2}\right)^m - \left(1-\frac{Y_t^2}{a^2}\right)^m$$

Figure 7 shows the form of typical Winfrey S3 survival curves for average operation life years of 6, 12 and 22.

Figure 7 : Typical Winfrey S3 Survival Curves



The average age of retirement for all appliances is assumed to be 15 years except:

1. Lighting where the assumed mean useful operational life is
    a. 1,250 hours of operation for incandescent light bulbs
    b. 10,000 hours for fluorescent tubes
    c. 5,000 hours for CFL light bulbs
2. Computer where the assumed mean useful operational life is 5 years.

Appliance mortality is calculated separately for each year's sales of appliances during the modeling period. For those appliances already in existence in 2005 an average age of the parc (historic parc configuration) of each appliance is assumed to be 4 years in all cases except for computers (2 years) and lighting. The total appliance mortality in each year, which represents the number of appliances that have to be replaced via new appliance sales, is the sum of the mortalities calculated from historic sales data in the preceding years.

In the case of lighting, the DSCL survey gave a sample of the parc by type of light bulb. The average age of historic parc configuration was estimated from sporadic sales using the mortality calculation to generate the parc mix obtained in the DSCL sample. This resulted in average age of the parc in 2005 of

a. 0.5 years for incandescent light bulbs
b. 3.7 years for fluorescent tubes
c. 1.8 years for CFL light bulbs.

9.0 Appliance Unit Power Consumption

The power consumed by each appliance during the year depends on, amongst other factors:

a. The average watts per hour consumed by the appliance when in active use. For many appliances, this is not the same as the rated power consumption of the appliance since most do not normally operate continuously at their rated energy consumption.
b. The number of hours in active use of each appliance per year.
c. The power consumed by the appliance (standby power) when it is not in active use.

The mean power consumed by each appliance will also depend on the year in which it was sold the following and other factors affect power consumption:

a. The market mix of the appliances sold in that year (size, technology, supplier)
b. The mean energy efficiency of those appliances both in operation and standby.

For TVs, for example, many countries have enacted voluntary efficiency standards and are considering mandatory minimum standards, but gains from efficiency standards are easily offset by the shift to less energy-efficient technology (from cathode ray tubes to liquid crystal displays and to plasma) and to larger screen sizes.

Much work still has to be performed to forecast technological and marketing pathways over the modeling timeframe to 2031 and thus define scenarios giving different levels of effort with their corresponding energy efficiency improvements. Annex 5 provides illustrations of data used in the model's working.

10.0 Total Household Appliance Ownership and Annual Sales

The total household appliance ownership and annual sales of appliances were calculated on an annual basis using the assumptions and calculations provided in Annex 5. A summary of the appliance population sizes resulting from these calculations are shown in Table 9 to Table 11.

Table 9: Population of Entertainment Appliances (millions)

Entertainment		2006	2011	2016	2021	2026	2031
Radio	Urban	23.1	31.1	40.3	50.0	59.1	68.7
	Rural	28.7	43.3	60.0	75.4	85.7	94.6
	Total	51.8	74.4	100.3	125.4	144.8	163.3
CD Player	Urban	21.6	32.6	46.4	61.4	74.8	87.9
	Rural	18.8	31.6	48.2	65.1	77.0	86.3
	Total	40.4	64.2	94.6	126.5	151.8	174.3
TV	Urban	51.3	66.9	82.5	97.8	113.7	133.6
	Rural	46.0	72.7	103.4	130.7	147.8	162.2
	Total	97.3	139.6	185.9	228.5	261.5	295.8
DVD / VCR	Urban	2.7	5.5	10.8	19.5	30.6	42.5
	Rural	0.9	2.1	4.6	8.0	10.9	12.9
	Total	3.5	7.6	15.4	27.6	41.5	55.4
Computer	Urban	1.5	3.1	6.0	11.0	17.3	24.2
	Rural	0.1	0.3	0.6	1.3	2.0	2.7
	Total	1.6	3.3	6.6	12.2	19.3	26.9

Table 10: Population of Kitchen Appliances (millions)

White Appliances		2006	2011	2016	2021	2026	2031
Refrigerator	Urban	26.0	41.4	59.4	76.1	88.8	101.1
	Rural	7.3	16.2	32.6	57.0	81.0	100.3
	Total	33.3	57.6	92.0	133.1	169.8	201.4
Washing machines	Urban	7.5	14.3	25.5	41.2	58.1	74.4
	Rural	1.0	2.2	4.7	9.5	16.7	25.3
	Total	8.5	16.5	30.2	50.7	74.8	99.7
Electric Oven	Urban	5.8	9.2	14.4	21.8	30.6	40.2
	Rural	0.0	0.0	0.0	0.0	0.0	0.0
	Total	5.8	9.2	14.4	21.8	30.6	40.2
Toaster	Urban	3.6	6.9	12.6	21.1	30.9	40.6
	Rural	0.0	0.0	0.0	0.0	0.0	0.0
	Total	3.6	6.9	12.6	21.1	30.9	40.6
Microwave	Urban	8.1	12.5	19.3	28.9	40.1	52.3
	Rural	0.0	0.0	0.0	0.0	0.0	0.0
	Total	8.1	12.5	19.3	28.9	40.1	52.3

Table 11:Population of Heating / Cooling Appliances (millions)

Heating / Cooling		2006	2011	2016	2021	2026	2031
Electric Water Heater	Urban	27.0	38.9	55.7	78.1	103.9	132.4
	Rural	0.0	0.0	0.0	0.0	0.0	0.0
	Total	27.0	38.9	55.7	78.1	103.9	132.4
Fans	Urban	123.1	179.7	254.7	344.7	435.5	527.3
	Rural	105.8	174.2	270.3	384.3	482.4	564.3
	Total	228.9	353.9	525.0	729.1	917.8	1,091.7
Air cooler	Urban	17.6	28.3	43.1	61.8	83.2	107.8
	Rural	4.9	10.1	19.5	33.5	48.2	61.1
	Total	22.5	38.5	62.6	95.3	131.4	168.9
Air-conditioning	Urban	1.7	4.0	8.9	17.5	28.5	40.0
	Rural	0.3	0.6	1.3	2.6	4.8	8.0
	Total	2.0	4.7	10.2	20.1	33.3	48.0

Table 12 shows a summary of the Annual sales projection of each appliance, while **Annex 6** provides details with graphical projections of annual sales for each category of appliance.

Table 12: Annual Sales of Appliances (millions)

	2006	2011	2016	2021	2026	2031
General						
Lighting	310.5	522.9	673.3	837.5	978.7	1,127.1
Entertainment						
Radio	7.9	11.0	13.6	15.3	17.0	18.8
CD Player	5.5	7.4	10.0	11.6	11.9	13.0
TV	11.0	13.9	17.2	19.1	19.9	22.3
DVD / VCR	0.7	1.2	2.3	3.6	4.3	5.0
Computer	0.4	0.9	1.7	2.9	4.3	5.6
White Appliances						
Washing machines	1.5	2.4	4.1	6.2	7.8	9.1
Refrigerator	5.2	7.4	10.8	13.5	14.3	15.5
Electric Oven	0.7	1.1	1.7	2.5	3.1	3.7
Toaster	0.6	1.0	1.7	2.6	3.1	3.6
Microwave	1.0	1.5	2.3	3.2	4.0	4.7
Heating / Cooling						
Electric Water Heater	2.8	4.1	6.0	8.2	10.0	11.7
Fans	28.6	40.2	57.4	72.4	77.9	85.6
Air cooler	3.4	4.9	7.6	10.7	12.8	15.0
Air-conditioning	0.4	0.8	1.7	2.9	3.9	4.8

11.0 Household Appliance Power Consumption and Operating Time

Table 13 to Table 15 show mean per-unit figures for the population of each appliance for different years. Annex 7 provides details of the parc average for unit power consumed in the various categories.

Table 13: Parc Average Operating per-Unit Power Consumption

		2006	2011	2016	2021	2026	2031
General							
Lighting	W/hr	37	39	38	38	39	38
Entertainment							
Radio	W/hr	11	11	11	11	11	11
CD Player	W/hr	35	35	35	35	35	35
TV	W/hr	77	92	113	127	135	139
DVD / VCR	W/hr	40	35	32	31	30	30
Computer	W/hr	116	71	64	64	64	64
White Appliances							
Washing machines	Wh/load	101	112	130	149	163	174
Refrigerator	kWh/Unit	705	568	473	431	417	418
Electric Oven	W/hr	960	1,088	1,193	1,248	1,271	1,279
Toaster	W/hr	800	1,031	1,182	1,246	1,270	1,278
Microwave	W/hr	1,080	1,080	1,080	1,080	1,080	1,080
Heating / Cooling							
Electric Water Heater	kWh/Unit	609	591	575	566	562	561
Fans	W/hr	39	38	37	37	37	36
Air cooler	W/hr	250	241	235	232	231	230
Air-conditioning	W/hr	1,973	1,883	1,834	1,817	1,811	1,809

Table 14: Parc Average Standby per-Unit Power Consumption

		2006	2011	2016	2021	2026	2031
General							
Lighting							
Entertainment							
Radio	W/hr	1.7	1.3	1.1	1.0	1.0	1.0
CD Player	W/hr	1.7	1.4	1.2	1.1	1.0	1.0
TV	W/hr	5.8	4.2	2.7	1.8	1.3	1.0
DVD / VCR	W/hr	4.2	3.6	3.2	3.1	3.0	3.0
Computer	W/hr	6.8	4.3	3.9	3.9	3.9	3.9
White Appliances							
Washing machines							
Refrigerator							
Electric Oven							
Toaster							
Microwave	W/hr	4.2	3.7	3.3	3.1	3.0	3.0
Heating / Cooling							
Electric Water Heater							
Fans							
Air cooler							
Air-conditioning	W/hr	0.6	0.4	0.3	0.2	0.2	0.2

Table 15: Parc Average per-Unit Annual Operating Time

		2006	2011	2016	2021	2026	2031
General							
Lighting	Hrs/Year	913	913	913	913	913	913
Entertainment							
Radio	Hrs/Year	2190	2190	2190	2190	2190	2190
CD Player	Hrs/Year	1460	1460	1460	1460	1460	1460
TV	Hrs/Year	1460	1460	1460	1460	1460	1460
DVD / VCR	Hrs/Year	156	156	156	156	156	156
Computer	Hrs/Year	803	803	803	803	803	803
White Appliances							
Washing machines	Loads/Year	364	364	364	364	364	364
Refrigerator	Hrs/Year	8760	8760	8760	8760	8760	8760
Electric Oven	Hrs/Year	91	91	91	91	91	91
Toaster	Hrs/Year	91	91	91	91	91	91
Microwave	Hrs/Year	37	37	37	37	37	37
Heating / Cooling							
Electric Water Heater	days/Year	140	140	140	140	140	140
Fans	Hrs/Year	2520	2520	2520	2520	2520	2520
Air cooler	Hrs/Year	1440	1440	1440	1440	1440	1440
Air-conditioning	Hrs/Year	575	575	575	575	575	575

12.0 Total Power Consumed by Appliances

The Total power consumed by household appliances in key years is shown in Figure 8. For more detailed changes by category and time see graphs in Annex 8.

Figure 8: Total Power Consumed by Appliances

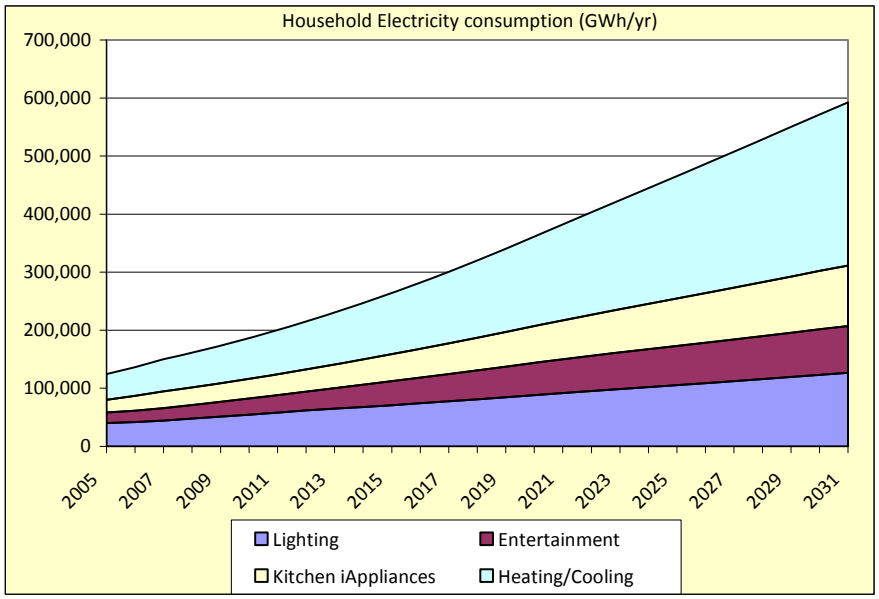
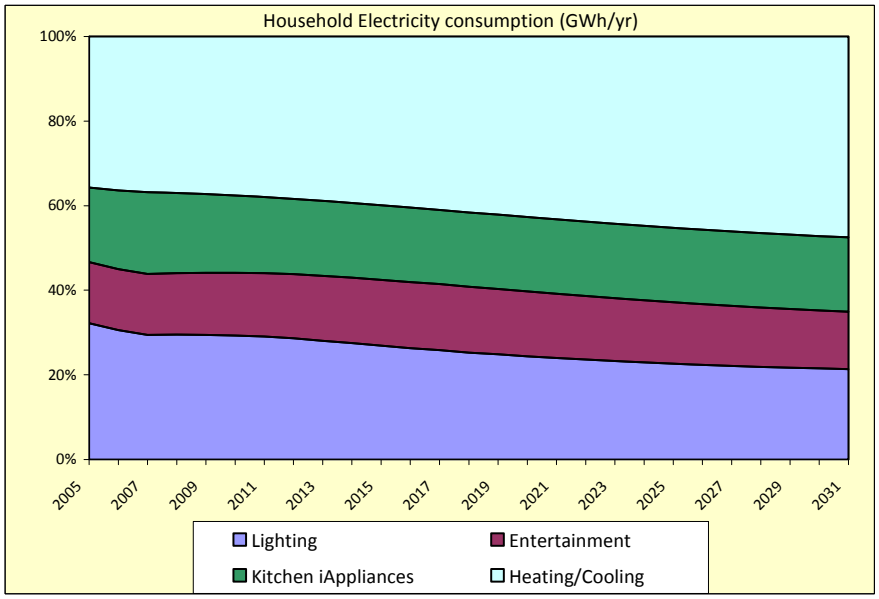


Figure 9: Distribution of Power Consumed by Appliances



12.1 Scenario 2: Modified Assumptions

An additional scenario, scenario 2, illustrates the working of this module. In this scenario the only changes introduced are higher efficiency new appliance sales starting in 2012 and in 2015 using the assumptions contained below. All other assumptions remain unchanged. The details of the changes in these efficiencies are provided in Annex 9.

13.0 Scenario 2: Total Power Consumption

Table 16 shows the difference in the total household power requirement due to the efficiency measures implicit in scenario 2. It can be seen that by 2031 the difference amounts to 135,240

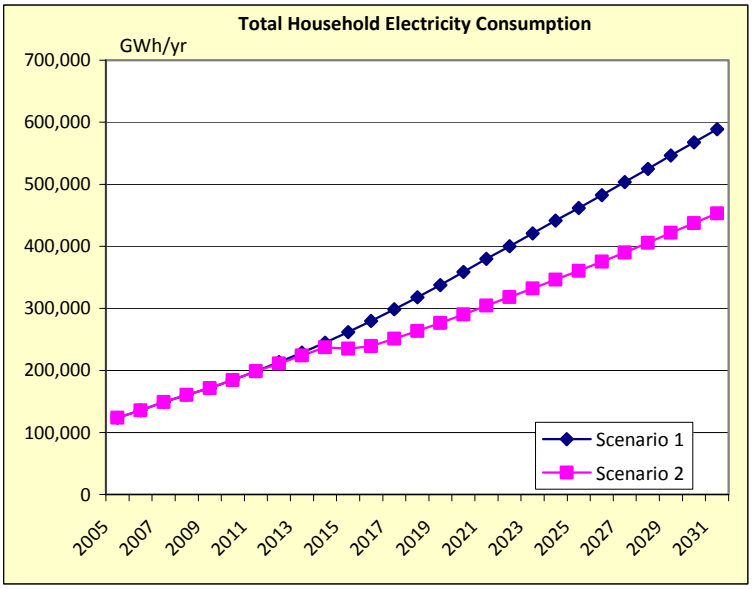
GWh/year, equivalent to the total output of approximately thirty eight 500MW power stations. However, the rebound effect has not been included in either scenario. Although the context is different, one study in rural India found the combined direct and indirect rebound effect for lighting to be 100 percent—that is, there were no net energy savings, although the lighting program brought considerable welfare benefits to the villagers (Roy 2000).

Scenario 2 represents savings of 23 percent grid supplied power for households in 2031 when compared to Scenario 1. As can be seen from Figure 10, the divergence begins in about 2012 and after 2014 the rate of increase in consumption reduces appreciably.

Table 16:Difference in Total Power Requirement between Scenarios 1 and 2

Scenario 2		2006	2011	2016	2021	2026	2031
Lighting	GWh/yr	41,440	57,786	48,874	53,656	60,618	70,073
Entertainment	GWh/yr	19,596	29,874	38,351	46,639	53,083	59,718
Kitchen iAppliances	GWh/yr	25,189	35,835	41,375	47,356	54,188	62,620
Heating/Cooling	GWh/yr	49,420	75,310	110,717	156,846	207,428	260,413
Total	GWh/yr	135,646	198,807	239,317	304,497	375,318	452,824
Scenario 1		2006	2011	2016	2021	2026	2031
Lighting	GWh/yr	41,440	57,786	73,676	91,092	107,890	125,601
Entertainment	GWh/yr	19,596	29,874	43,767	57,845	69,196	79,989
Kitchen iAppliances	GWh/yr	25,189	35,835	49,152	66,905	85,064	103,435
Heating/Cooling	GWh/yr	49,420	75,310	112,931	164,011	220,472	279,449
Total	GWh/yr	135,646	198,807	279,526	379,854	482,622	588,474
Difference		2006	2011	2016	2021	2026	2031
Lighting	GWh/yr	0	0	(24,801)	(37,437)	(47,272)	(55,528)
Entertainment	GWh/yr	0	0	(5,416)	(11,207)	(16,112)	(20,271)
Kitchen iAppliances	GWh/yr	0	0	(7,777)	(19,548)	(30,876)	(40,815)
Heating/Cooling	GWh/yr	0	0	(2,214)	(7,165)	(13,044)	(19,036)
Total	GWh/yr	0	0	(40,209)	(75,356)	(107,304)	(135,650)

Figure 10: Total Energy Consumption of Scenarios 1 and 2



It can be seen in Table 17 that the largest differences between scenarios—those with the greatest savings in 2031—come from:

(i)	Lighting	55,528 GWh
(ii)	Refrigerators	39,310 GWh
(iii)	Televisions	17,839 GWh
(iv)	Air Conditioning	13,347 GWh
(v)	Fans	5,689 GWh

Table 17: Differences between Scenarios 1 and 2 by Type of Appliance

General		2006	2011	2016	2021	2026	2031
Lighting	GWh/yr	0	0	24,801	37,437	47,272	55,528
Entertainment							
Radio	GWh/yr	0	0	119	220	282	322
CD Player	GWh/yr	0	0	162	341	492	613
TV	GWh/yr	0	0	4,899	10,015	14,272	17,839
DVD / VCR	GWh/yr	0	0	157	443	767	1,081
Computer	GWh/yr	0	0	79	187	299	416
White Appliances							
Refrigerator	GWh/yr	0	0	7,677	19,078	29,916	39,309
Washing machines	GWh/yr	0	0	100	470	960	1,505
Electric Oven	GWh/yr	0	0	0	0	0	0
Toaster	GWh/yr	0	0	0	0	0	0
Microwave	GWh/yr	0	0	0	0	0	0
Heating / Cooling							
Electric Water Heater	GWh/yr	0	0	0	0	0	0
Fans	GWh/yr	0	0	895	2,627	4,274	5,689
Air cooler	GWh/yr	0	0	0	0	0	0
Air-conditioning	GWh/yr	0	0	1,319	4,537	8,770	13,347
Total Savings	GWh/yr	0	0	40,209	75,356	107,304	135,650

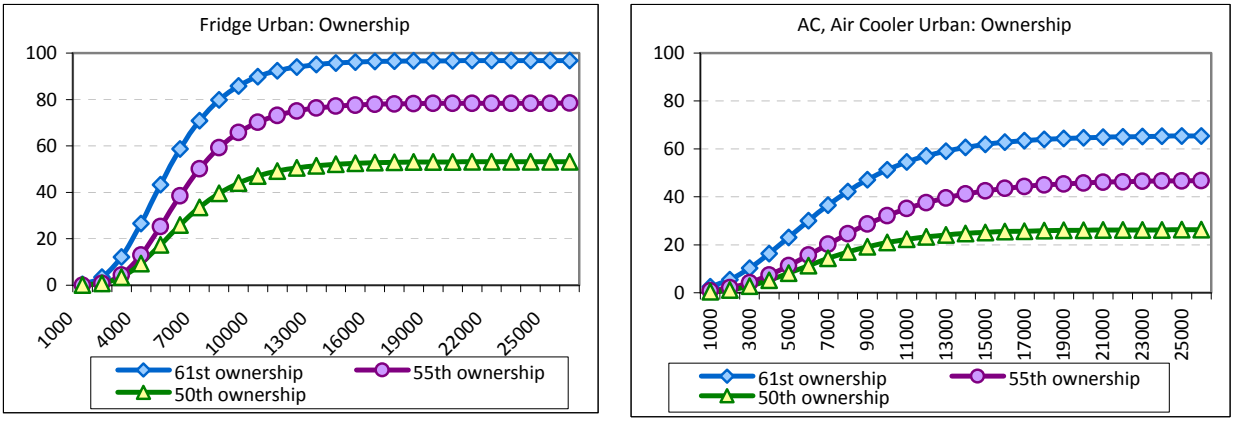
14.0 Conclusions

The Household electricity sector module is a tool kit that allows any number of scenarios to be investigated and run. The novel approach used in this model examines the ownership and the use of household electricity-consuming devices. To demonstrate its operation, two scenarios have been selected. The first is based on the currently achievable efficiency levels of appliances available in India in 2008. The second has higher energy efficiency and computes reductions in electricity consumption based solely on engineering assumptions. The difference in the terminal year of modeling is considerable. In practice, however, the rebound effect would cancel out some of the potential savings.

It is interesting to note that, in Scenario 1, whilst GDP grows at an annual average rate of 7.8 percent over the modeling period from 2005 to 2031, household electricity usage grows by an annual average rate of 5.8 percent, or 74 percent of GDP growth. Because of declining household size, this means that income elasticity is even smaller when households are taken as consuming units. The introduction of more efficient (2008) appliances no doubt helps to contain the growth of residential power consumption. However, rebound may drastically reduce this apparent saving. These findings need to be examined further by sensitivity analysis and other means.

One issue is the effect of popularity and technology. For most appliances, an analysis of different rounds of NSS data reveals increasing ownership at the same household expenditure level. Figure 11 demonstrates this effect for two appliances with analyses from the 50th, 55th and 61st rounds.

Figure 11: Increasing Ownership Across Rounds



Note: household expenditures are in 2004 rupees

It can be seen that at all mean household expenditure levels the percent of electrified households with the appliance has increased over time. NSS Round 50 was conducted shortly after India embarked on liberalization, and as such appliance availability might have been an issue, explaining low uptake. Between NSS Rounds 50 and 61, prices of many electric appliances declined in real terms. Price reductions, easier access to consumer credit, and greater availability of appliances likely all contributed to rising ownership at the same income level.

Annex 1 : Population and Urbanization: Extension from 2026 to 2031

Table 18: MMHE and Number of Households by Centile based on NSS Round 61

	monthly mean household expenditure (Rs)		Number of Households (in thousands)			monthly mean household expenditure (Rs)		Number of Households (in thousands)	
centile	rural	urban	rural	urban	centile	rural	urban	rural	urban
1	857	1,482	1,566	427	51	2,728	4,741	1,428	486
2	1,501	2,291	1,120	339	52	2,749	4,793	1,437	491
3	1,596	2,438	1,146	351	53	2,770	4,847	1,431	499
4	1,661	2,546	1,170	363	54	2,791	4,902	1,441	487
5	1,714	2,637	1,180	363	55	2,813	4,955	1,445	497
6	1,761	2,721	1,198	370	56	2,837	5,013	1,452	502
7	1,802	2,788	1,205	376	57	2,860	5,071	1,453	503
8	1,836	2,848	1,228	380	58	2,884	5,131	1,460	505
9	1,865	2,906	1,212	382	59	2,907	5,194	1,467	512
10	1,892	2,956	1,233	393	60	2,930	5,255	1,466	509
11	1,920	3,002	1,239	382	61	2,955	5,312	1,474	515
12	1,945	3,051	1,245	396	62	2,980	5,366	1,479	519
13	1,971	3,099	1,248	391	63	3,003	5,427	1,488	520
14	1,998	3,150	1,260	401	64	3,029	5,492	1,486	523
15	2,020	3,196	1,265	399	65	3,057	5,554	1,497	528
16	2,043	3,243	1,267	406	66	3,085	5,614	1,499	530
17	2,065	3,288	1,276	405	67	3,113	5,689	1,507	529
18	2,084	3,327	1,280	409	68	3,141	5,762	1,509	536
19	2,106	3,365	1,286	415	69	3,169	5,841	1,517	540
20	2,128	3,402	1,293	413	70	3,200	5,912	1,525	545
21	2,148	3,443	1,301	414	71	3,228	5,988	1,526	543
22	2,169	3,485	1,294	420	72	3,258	6,060	1,537	551
23	2,189	3,532	1,307	423	73	3,294	6,130	1,541	551
24	2,208	3,577	1,307	422	74	3,327	6,205	1,543	559
25	2,228	3,623	1,319	428	75	3,364	6,290	1,555	557
26	2,246	3,666	1,318	428	76	3,403	6,388	1,561	563
27	2,265	3,706	1,324	432	77	3,445	6,475	1,571	569
28	2,283	3,746	1,327	433	78	3,486	6,573	1,576	570
29	2,302	3,788	1,337	438	79	3,529	6,686	1,584	577
30	2,321	3,835	1,337	437	80	3,573	6,806	1,589	583
31	2,341	3,874	1,336	441	81	3,623	6,915	1,603	585
32	2,362	3,913	1,348	443	82	3,672	7,034	1,608	589
33	2,381	3,951	1,352	447	83	3,725	7,156	1,620	597
34	2,400	3,989	1,353	446	84	3,780	7,300	1,631	600
35	2,419	4,024	1,359	449	85	3,841	7,466	1,639	608
36	2,439	4,063	1,364	452	86	3,905	7,624	1,649	616
37	2,457	4,109	1,369	463	87	3,979	7,794	1,662	621
38	2,476	4,151	1,379	448	88	4,059	7,998	1,677	631
39	2,494	4,191	1,370	459	89	4,147	8,220	1,691	636
40	2,513	4,232	1,385	463	90	4,244	8,440	1,707	646
41	2,533	4,280	1,382	460	91	4,347	8,672	1,724	656
42	2,553	4,322	1,391	466	92	4,463	8,937	1,743	663
43	2,572	4,369	1,390	467	93	4,607	9,279	1,766	677
44	2,590	4,414	1,399	472	94	4,781	9,649	1,789	690
45	2,611	4,461	1,405	471	95	4,988	10,079	1,823	705
46	2,631	4,510	1,403	475	96	5,227	10,640	1,858	722
47	2,651	4,554	1,412	479	97	5,540	11,329	1,906	747
48	2,670	4,597	1,414	479	98	5,993	12,280	1,958	776
49	2,689	4,647	1,420	481	99	6,830	13,884	2,070	826
50	2,708	4,690	1,421	485	100	10,306	19,018	2,444	960

Figures 12 and 13 show MPCE growth path of select centiles for the two locations.

Figure 12: Rural MPCE path

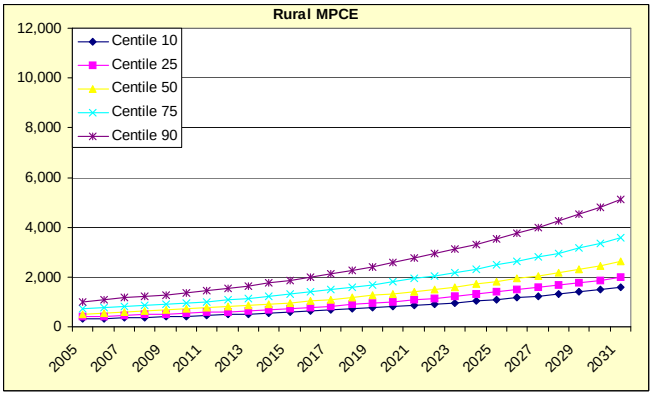
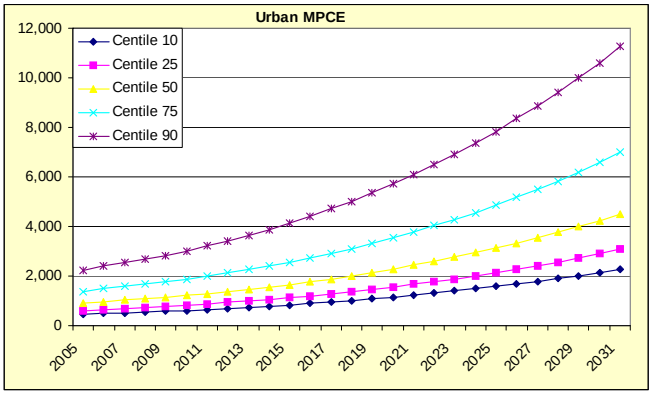


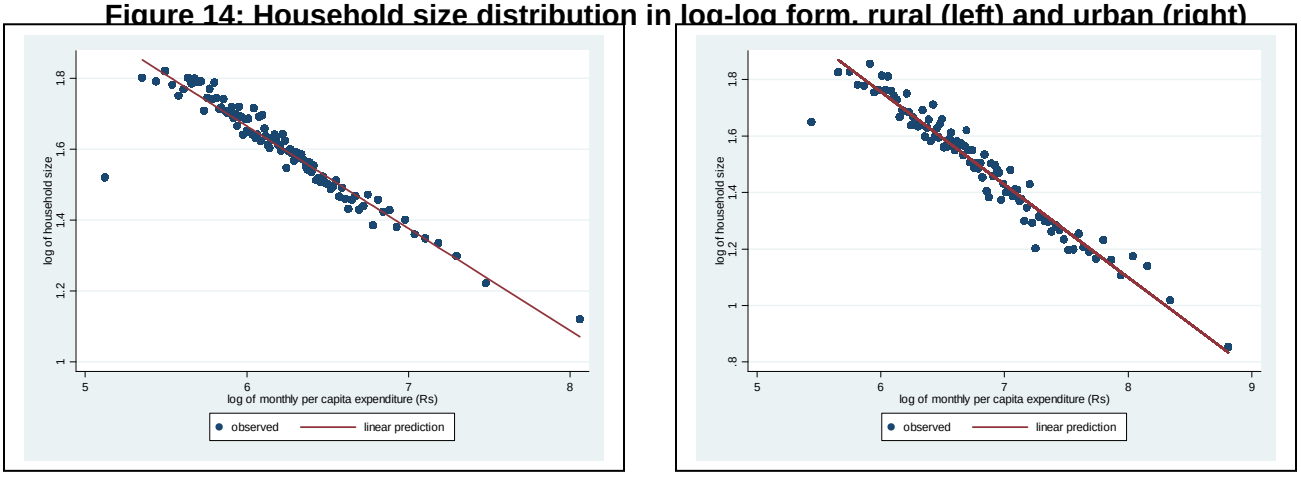
Figure 13: Urban MPCE path



Projection of household size by centile

Figure 14 shows a scatter-plot of the logarithm of household size against the logarithm of MPCE by centile in each location.

Figure 14: Household size distribution in log-log form, rural (left) and urban (right)



Annex 2 : Ownership of Appliances with Increasing Mean Household Monthly Expenditure

Table 19: Non-linear Regression: Gompertz function—Ownership and MMHE (urban)

Parameter	Free model				Forced saturation			
Round 61	**β1**	**β2**	**β3**	**R^2**	**β1**	**β2**	**β3**	**R^2**
Fan	95.617	0.001048	542.5894	0.999	98.256	0.000844	391.4801	0.999
	(0.354)	(0.000046)	(51.961)			(0.000035)	(72.444)	
AC	44.452	0.0002383	11299.22	0.964				
	(1.654)	(0.000015)	(236.416)					
Cooler	45.036	0.0004606	3988.36	0.982				
	(1.182)	(0.000031)	(94.889)					
Fridge	87.981	0.0005223	4407.953	0.997				
	(0.923)	(0.000014)	(35.881)					
Radio	61.9478	0.00021	1748.535	0.987				
	(2.575)	(0.000024)	(214.824)					
TV	92.282	0.0008993	1768.146	0.998	96.78	0.000751	1784.456	0.997
	(0.618)	(0.000034)	(30.474)			(0.000025)	(39.14)	
Round 58	**β1**	**β2**	**β3**	**R^2**	**β1**	**β2**	**β3**	**R^2**
washing machine	73.89	0.00024	8401.728	0.954				
	(3.505)	(0.000018)	(284.494)					
tape recorder/CD player	79.174	0.000282	4476.566	0.961				
	(3.875)	(0.000029)	(236.724)					
VCR/VCP	49.105	0.000186	11164.43	0.913				
	(3.196)	(0.000017)	(490.517)					
NCAER (2004)	**β1**	**β2**	**β3**	**R^2**	**β1**	**β2**	**β3**	**R^2**
Computer	28.452	0.0001799	11426.44	0.991				
	(1.359)	(0.000014)	(409.947)					
Generator set	22.1507	0.000157	12004.31	0.989				
	(1.368)	(0.000013)	(575.396)					
DSCL data (vs monthly KWh)	**β1**	**β2**	**β3**	**R^2**	**β1**	**β2**	**β3**	**R^2**
Water heater	96.8664	0.006434	94.1237	0.978				
	(9.422)	(0.00179)	(21.95)					
Oven	57.3248	0.006162	204.3647	0.977				
	(4.632)	(0.001049)	(19.419)					
Toaster	45.7499	0.010887	181.2516	0.905				
	(7.204)	(0.004345)	(26.666)					
Microwave	74.5924	0.005955	200.373	0.959				
	(8.171)	(0.00138)	(26.851)					
Booster pump	74.10715	0.005331	135.5106	0.974				
	(7.522)	(0.001316)	(25.658)					
DSCL data (percent consumption vs monthly KWh)	**β1**	**β2**	**β3**	**R^2**	**β1**	**β2**	**β3**	**R^2**
Lighting	0.176879	0.4033	0.152					

Parameter	Free model	Forced saturation

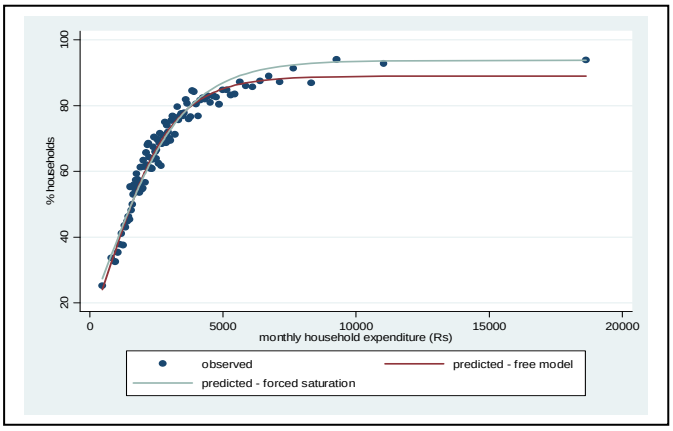
Note: standard errors in parentheses. All coefficients are statistically significant at 1 percent level. Generator set is not considered an electrical appliance, but its ownership pattern is also reported here.

Table 20: Non-linear Regression: Gompertz function - Ownership and MMHE (Rural)

Parameter	Free model				Forced saturation			
Round 61	**β1**	**β2**	**β3**	**R^2**	**β1**	**β2**	**β3**	**R^2**
Fan	88.947	0.0007484	822.4175	0.998	93.756	0.0006164	800.5217	0.998
	(0.852)	(0.000033)	(36.531)			(0.000019)	(43.88)	
AC	15.6524	0.0001109	15910.22	0.873				
	(4.129)	(0.000019)	(2531.955)					
Cooler	36.64	0.0003414	5635.664	0.978				
	(1.191)	(0.000016)	(131.637)					
Fridge	57.049	0.0004212	5376.33	0.993				
	(0.953)	(0.000011)	(58.142)					
Radio	48.748	0.0004961	1522.989	0.991				
	(1.331)	(0.000038)	(70.645)					
TV	79.921	0.0007012	2035.027	0.995	83.048	0.0006464	2095.493	0.995
	(1.222)	(0.000029)	(33.088)			(0.000018)	(24.512)	
Round 58	**β1**	**β2**	**β3**	**R^2**	**β1**	**β2**	**β3**	**R^2**
washing machine	23.118	0.0002081	9431.079	0.772				
	(3.615)	(0.000035)	(981.24)					
tape recorder/CD player	44.947	0.0005149	2834.183	0.923				
	(3.163)	(0.000077)	(185.474)					
VCR/VCP	6.933	0.0005969	4988.45	0.761				
	(0.738)	(0.000122)	(285.887)					
NCAER/Maryland survey	**β1**	**β2**	**β3**	**R^2**	**β1**	**β2**	**β3**	**R^2**
Computer	1.6927	0.0003983	6704.679	0.980				
	(0.079)	(0.000041)	(230.476)					
Generator set	5.410081	0.0002134	7875.152	0.973				
	(0.451)	(0.000027)	(583.805)					

Note: standard errors in parentheses. All coefficients are statistically significant at 1 percent level. Generator set is not considered an electrical appliance, but its ownership pattern is also reported here.

Figure 15: Ownership of Electric Fans - Rural and Urban



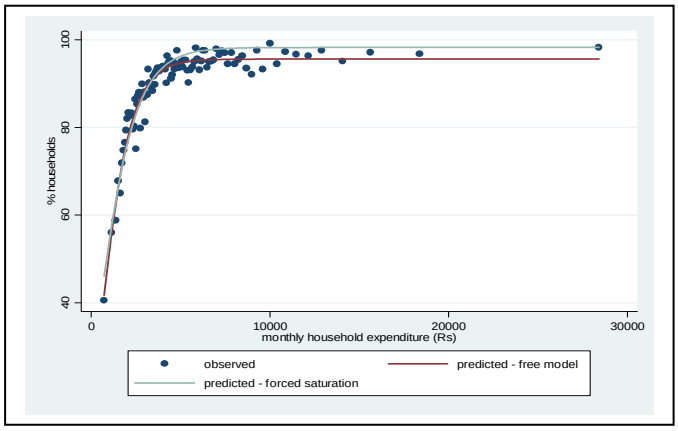
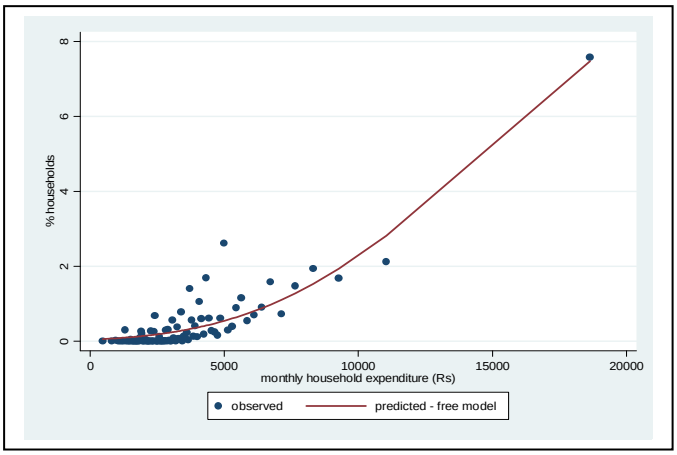


Figure 16: Ownership of Air conditioning Units - Rural and Urban



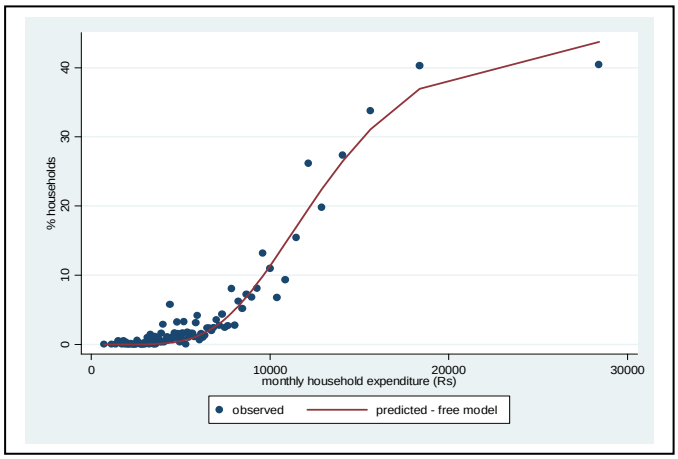
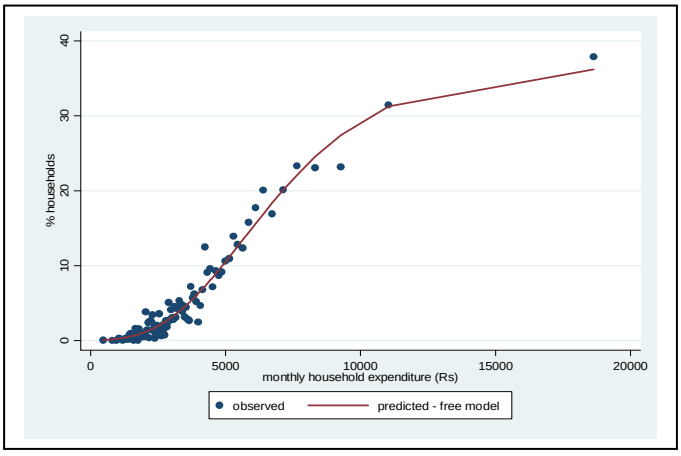


Figure 17: Ownership of Air coolers - Rural and Urban



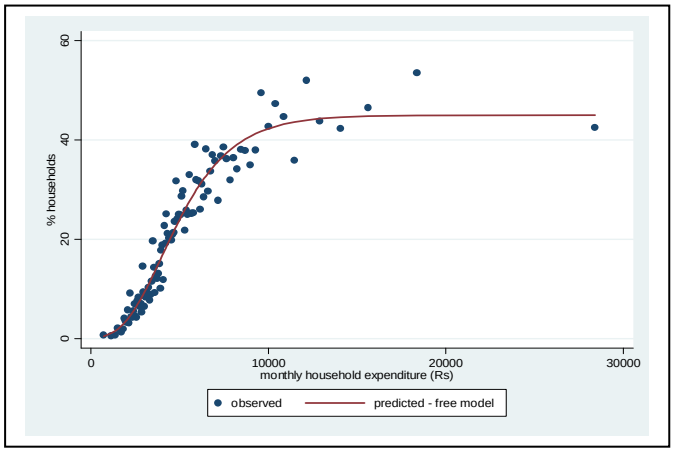


Figure 18: Ownership of Refrigerators - Rural and Urban

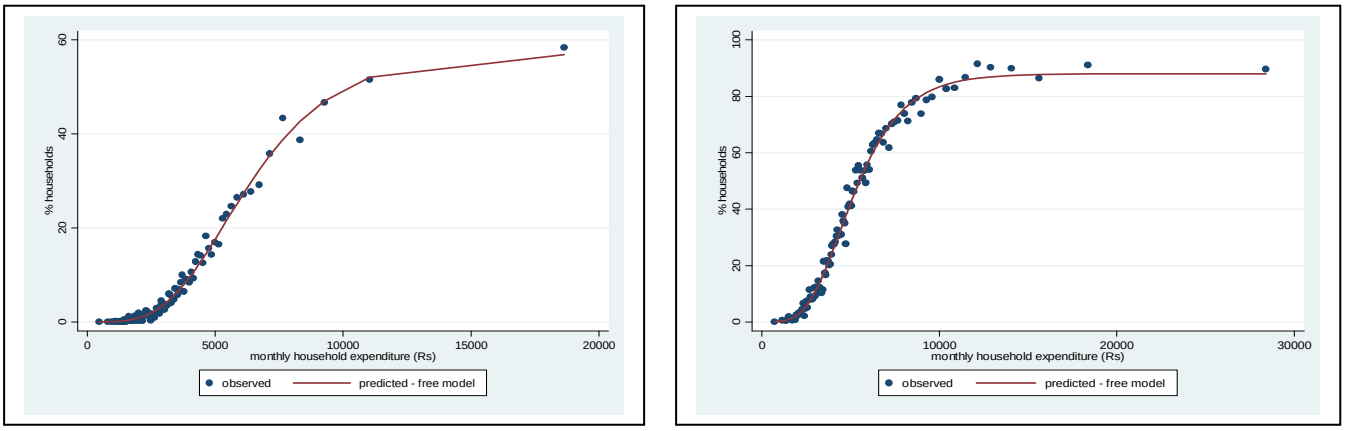


Figure 19: Ownership of Radios - Rural and Urban

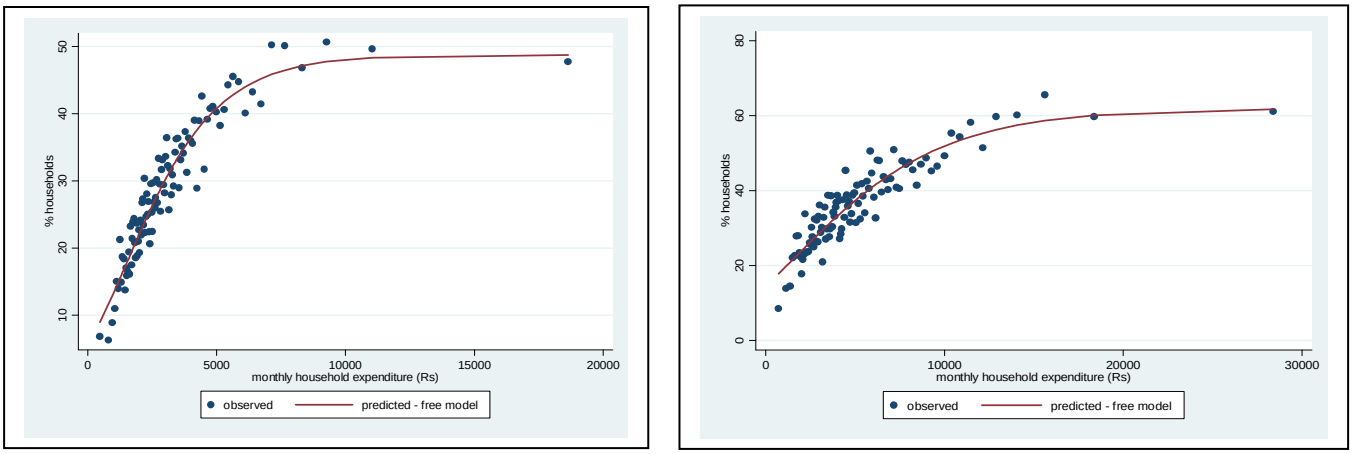


Figure 20: Ownership of Television sets - Rural and Urban

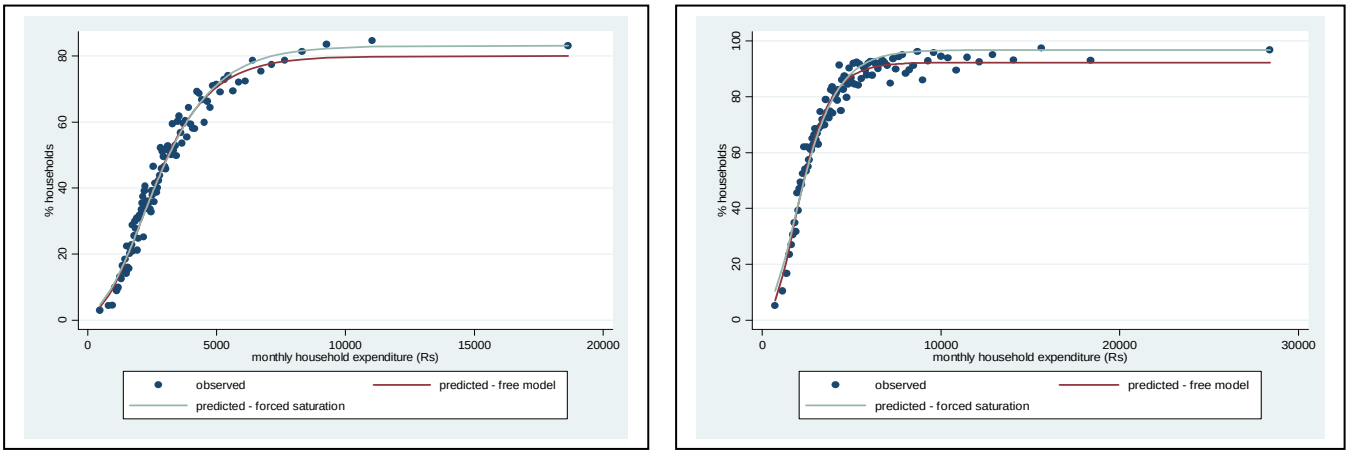
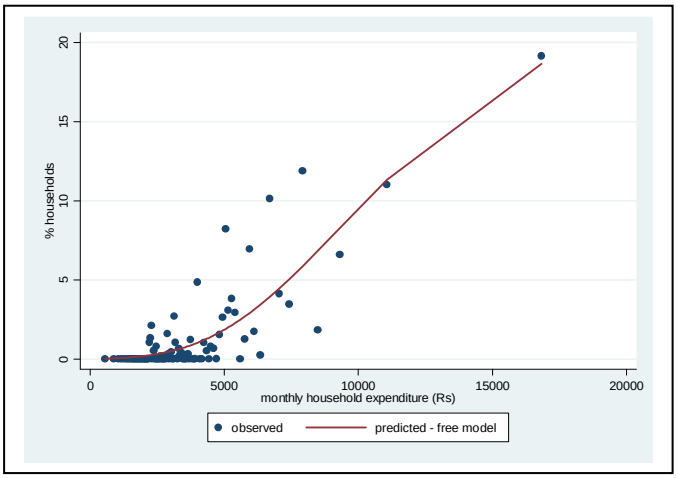


Figure 21: Ownership of Washing machines - Rural and Urban



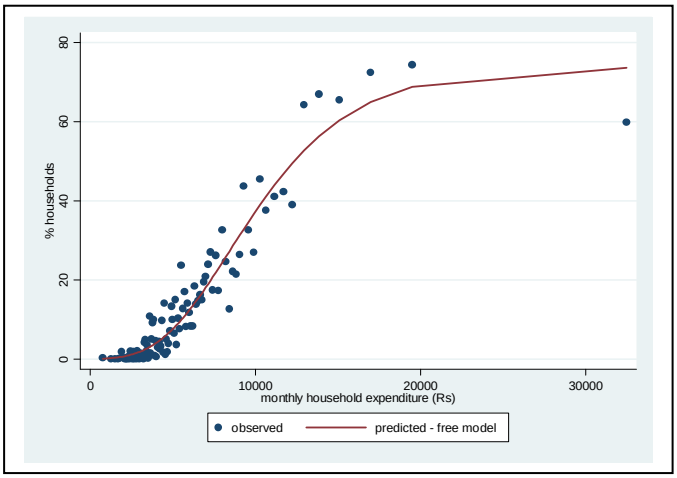
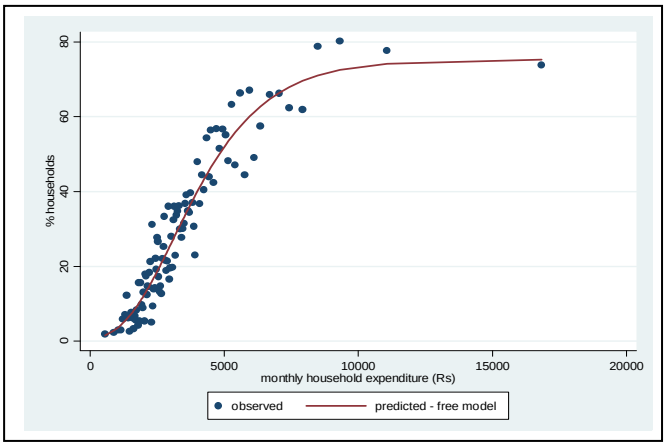


Figure 22: Ownership of Pressure cookers/pans - Rural and Urban



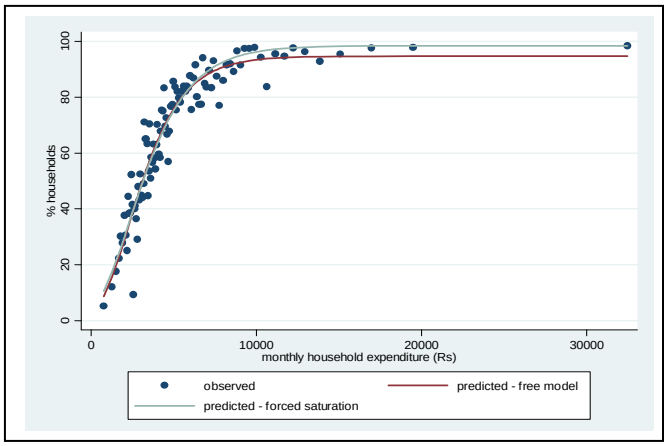
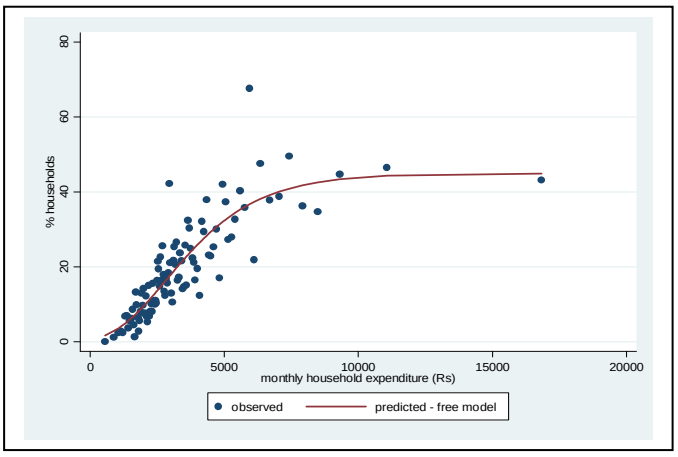


Figure 23: Ownership of Tape recorders/CD players - Rural and Urban



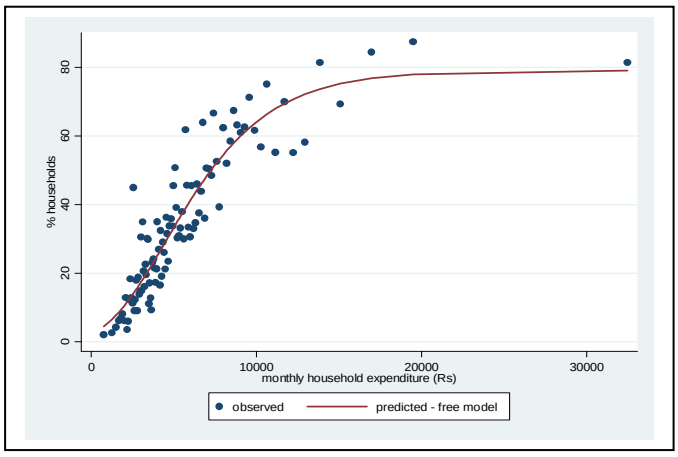


Figure 24: Ownership of VCR/VCP - Rural and Urban

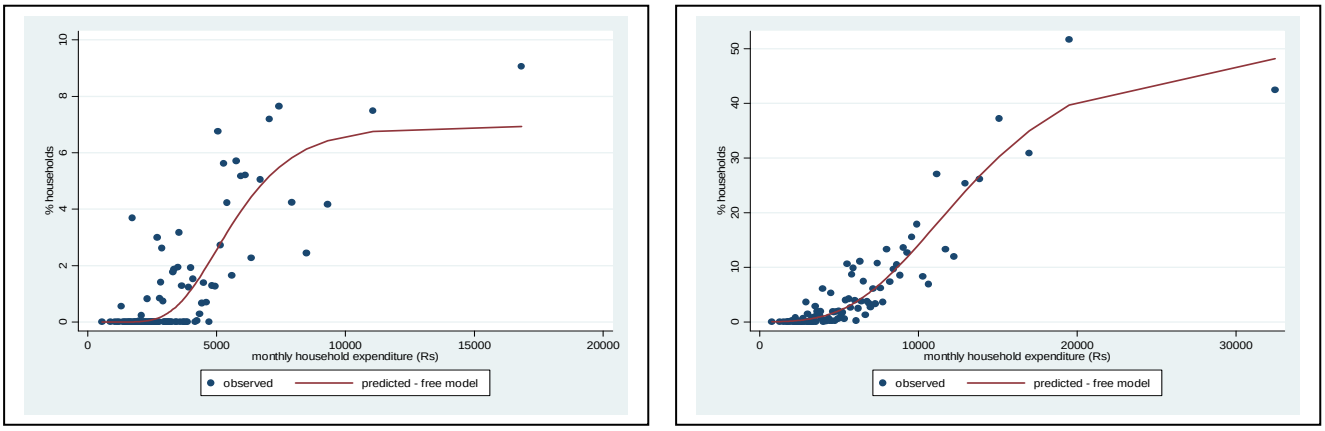


Figure 25: Ownership of Computers - Rural and Urban

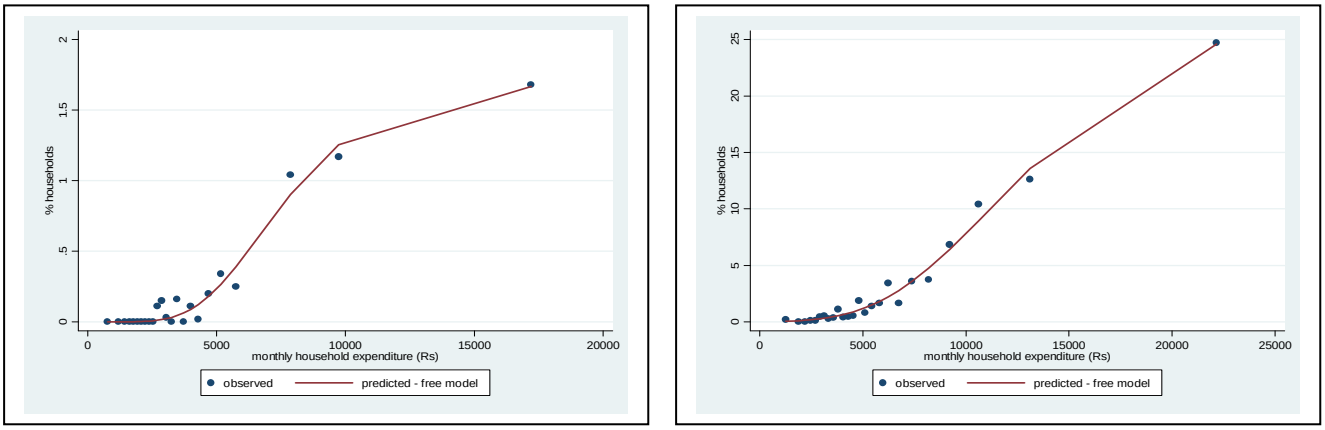


Figure 26: Ownership of Generator sets - Rural and Urban

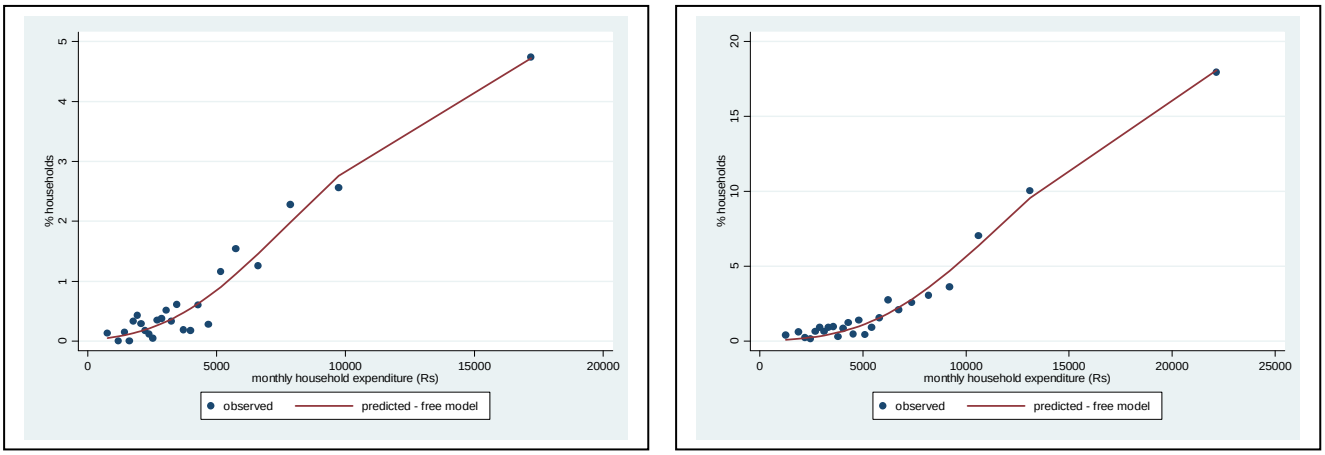


Figure 27: Ownership of Water heaters - Urban

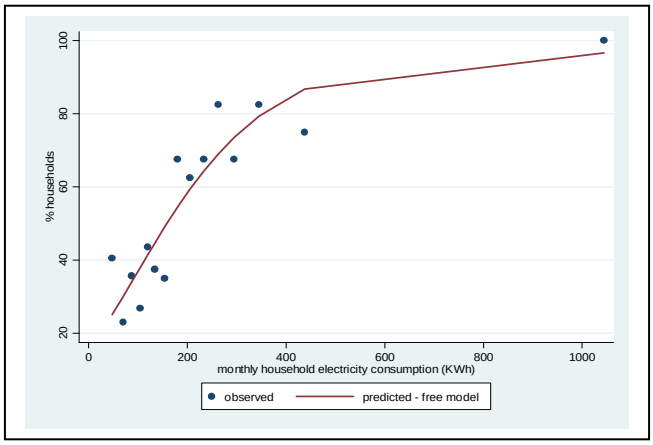


Figure 28: Ownership of Electric ovens - Urban

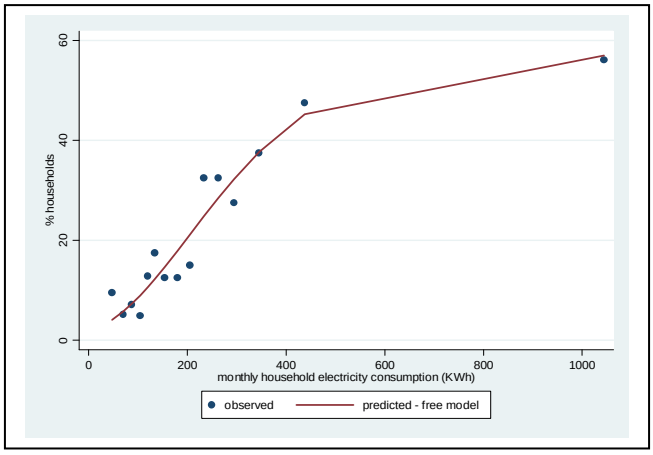


Figure 29: Ownership of Electric toasters - Urban

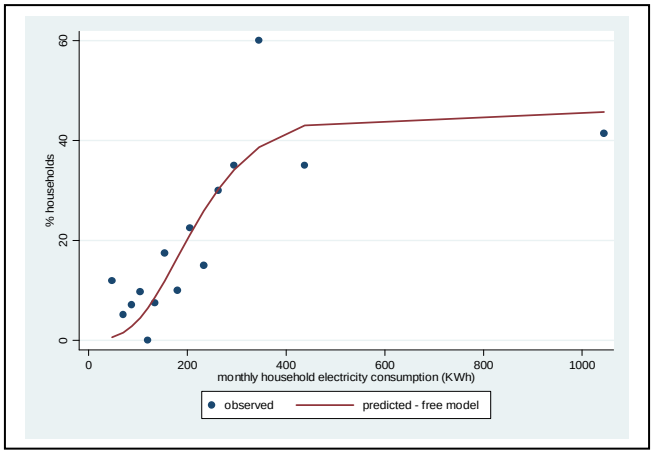


Figure 30: Ownership of Microwave - Urban

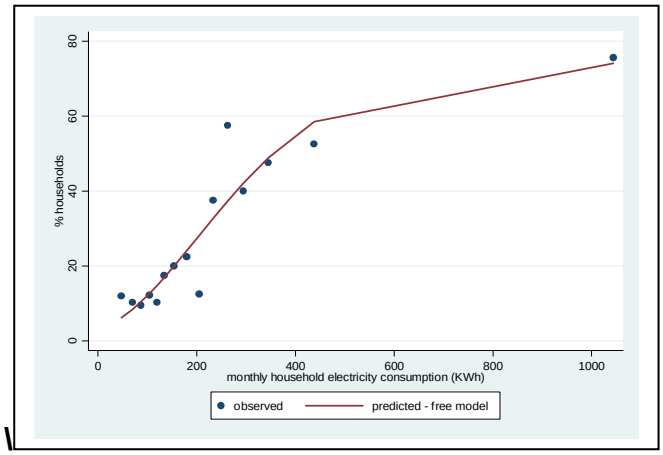


Figure 31: Ownership of Booster pump - Urban

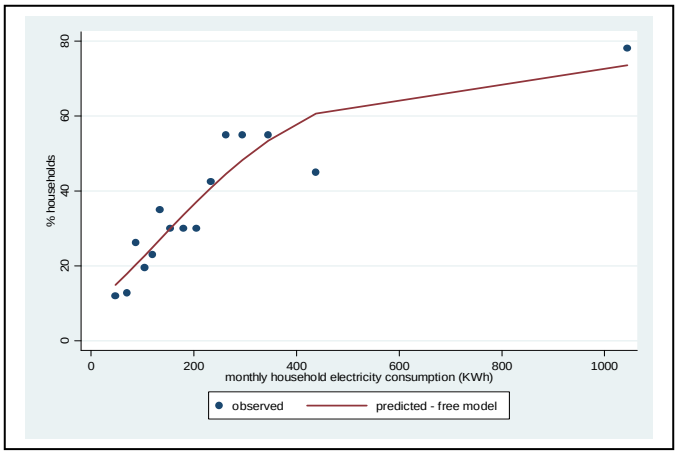
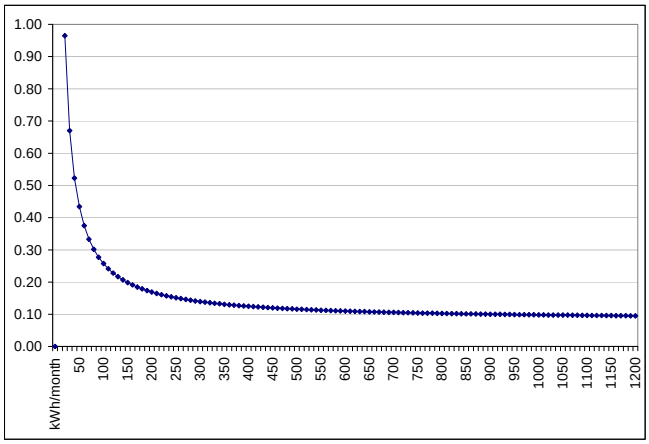
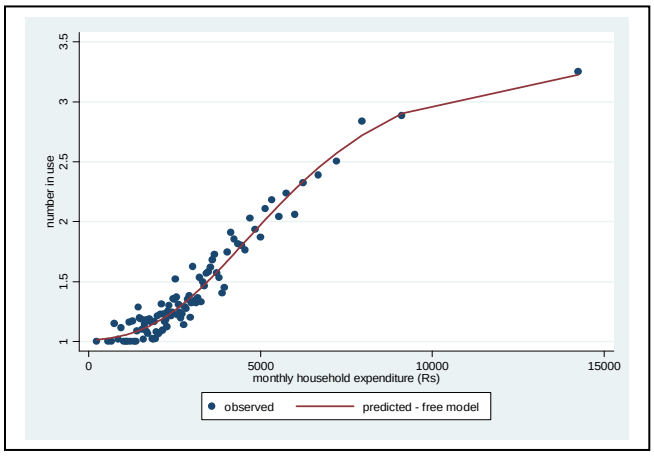


Figure 32: Lighting as percentage of Total Electricity Consumption



Annex 3 : Correlation of Specific Appliance Use and MMHE and Projections for Selected Appliance Use

Figure 33: Number of Electric Fans in Use - Rural and Urban



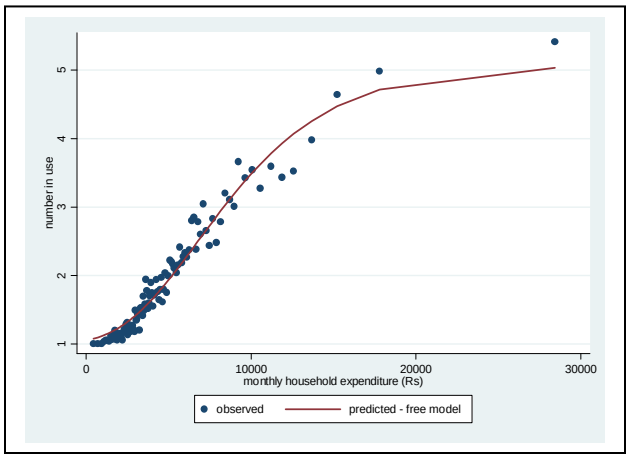
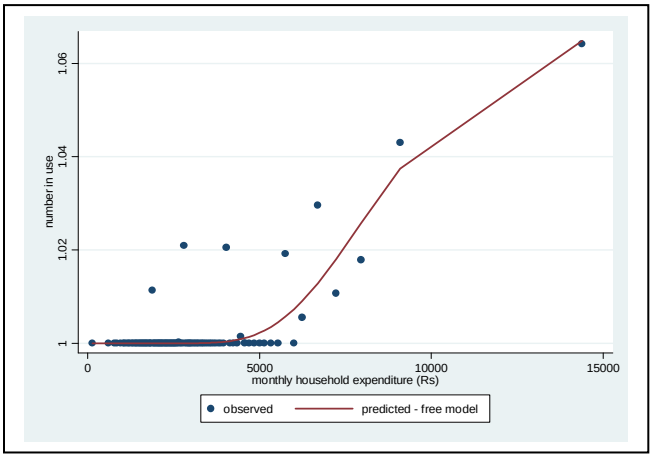


Figure 34: Number of Television sets in Use - Rural and Urban



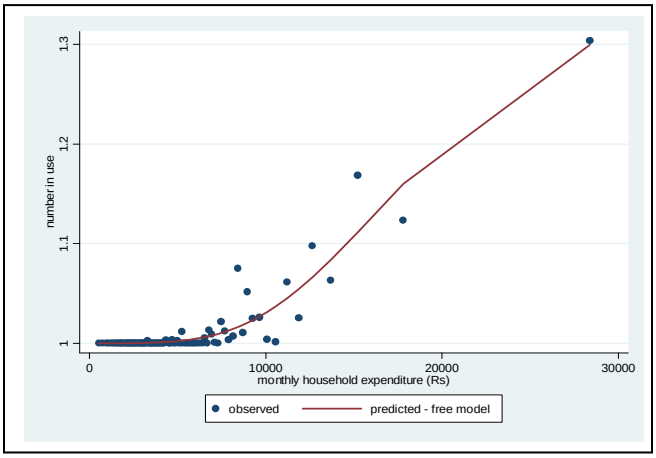


Figure 35: Number of Air coolers in Use - Urban

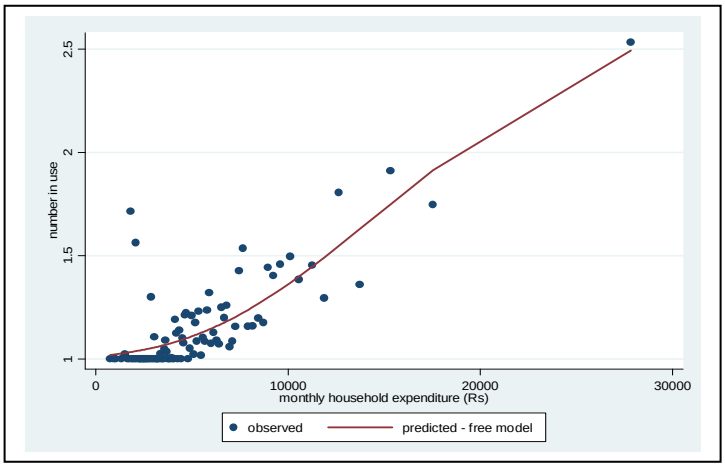


Figure 36: Number of Electric Water heaters in Use per Household - Urban

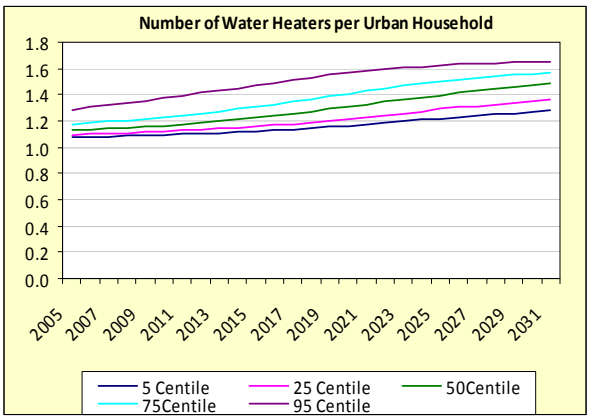


Figure 37: Number of Fans in Use per Household - Rural and Urban

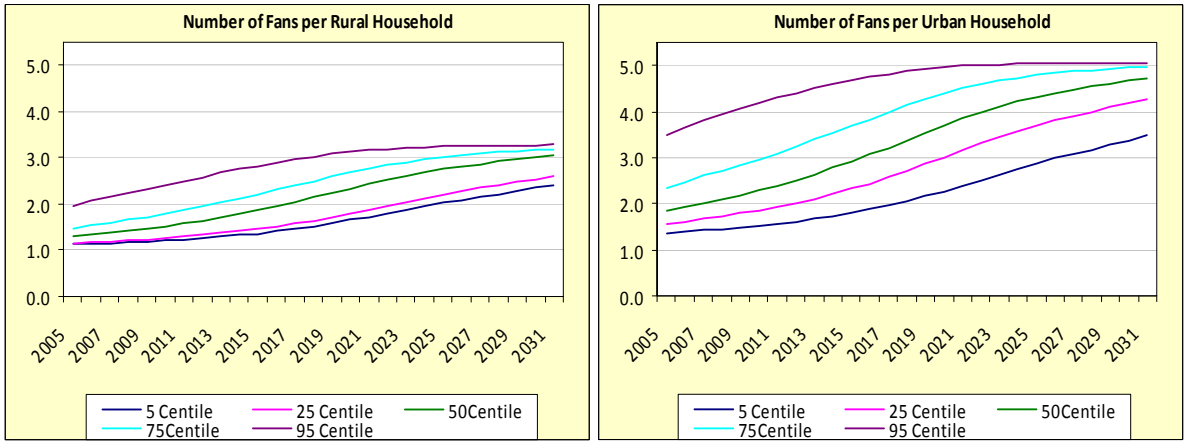


Figure 38: Number of Air Coolers in Use per Household - Urban

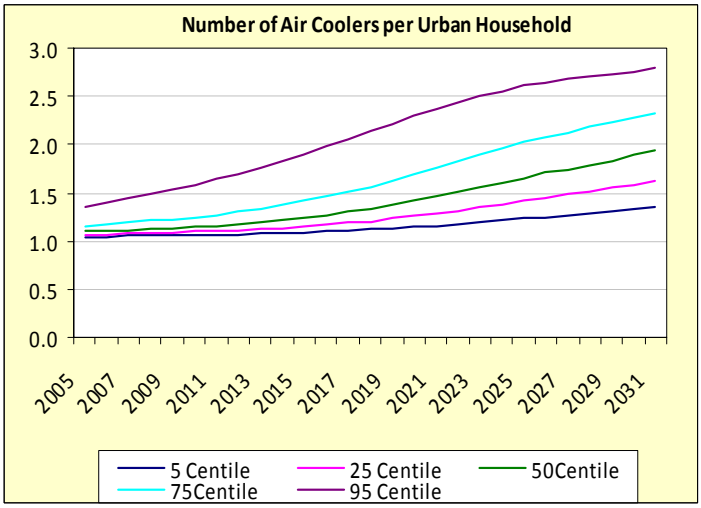
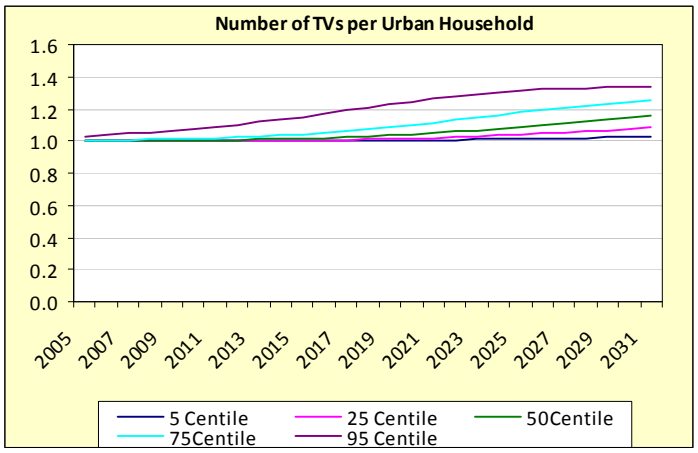


Figure 39: Number of TVs in Use per Household - Urban



Annex 4 : Ownership of the Household Appliances by Centile and Year

Figure 40: Projection of Ownership of Radios in Selected Centiles - Rural and Urban

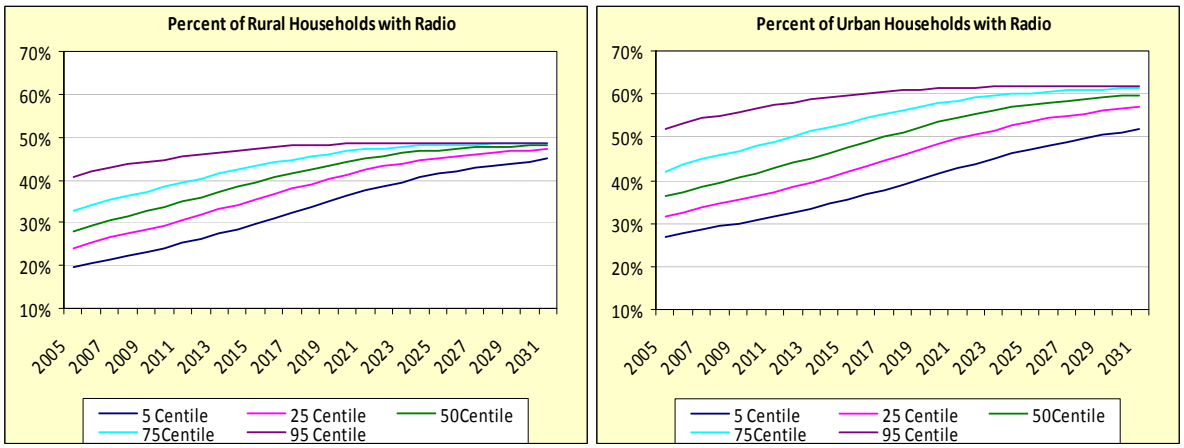


Figure 41: Projection of Ownership of CD Players in Selected Centiles - Rural and Urban

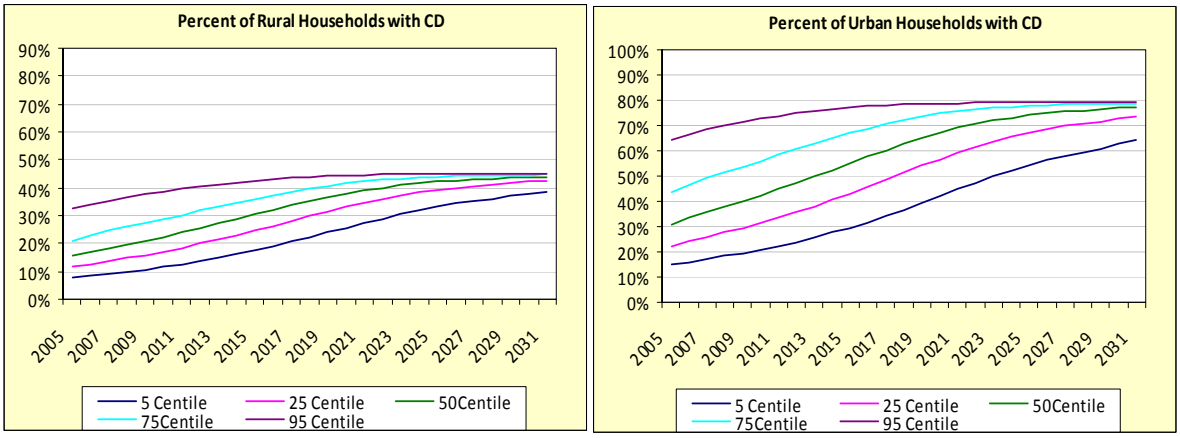


Figure 42: Projection of Ownership of TVs in Selected Centiles - Rural and Urban

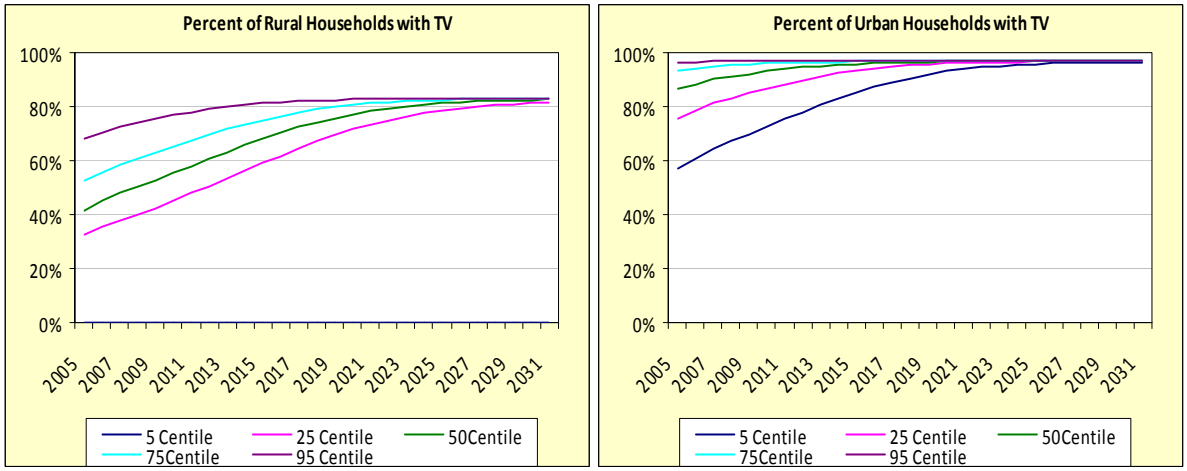


Figure 43: Projection of Ownership of DVD Players in Selected Centiles - Rural and Urban

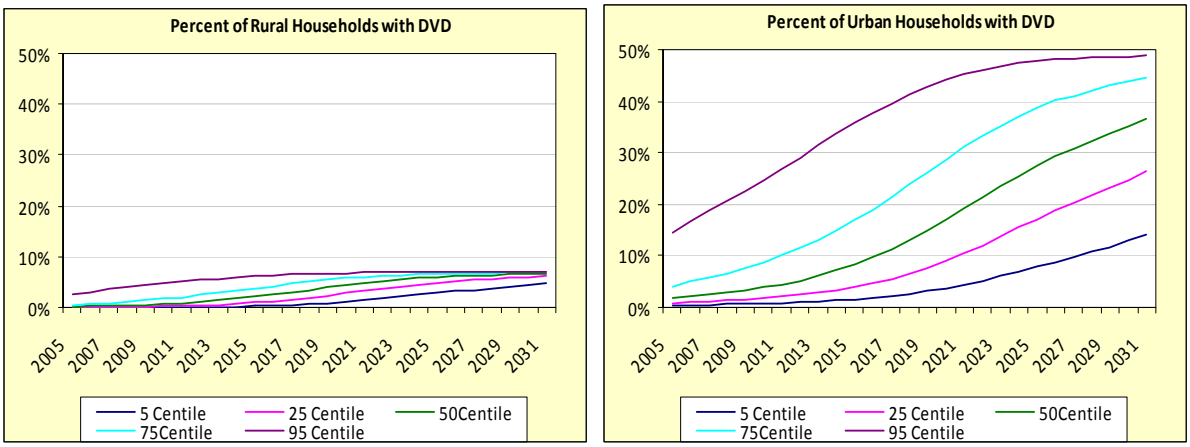


Figure 44: Projection of ownership of Computers in Selected Centiles –R\ural and Urban

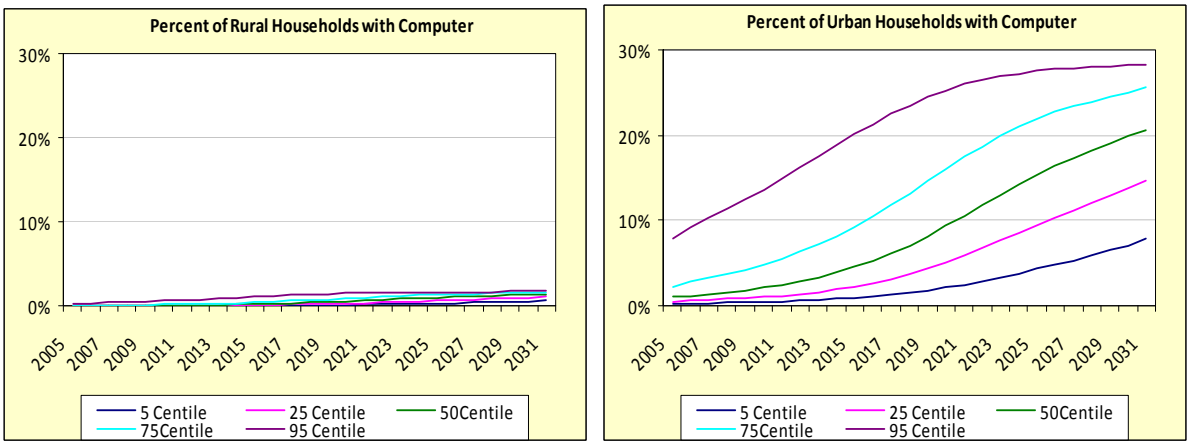


Figure 45: Projection of Ownership of Washing Machines in Selected Centiles —Rural and Urban

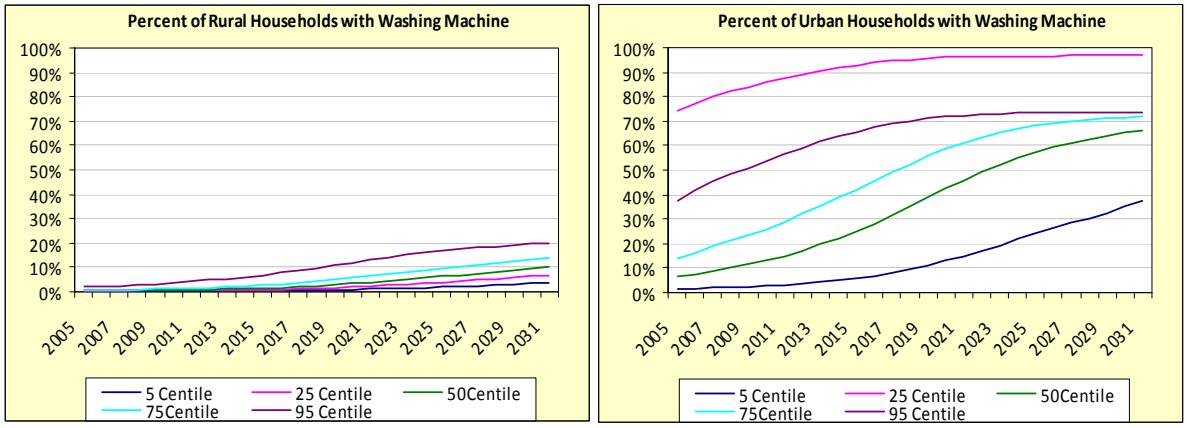


Figure 46: Projection of Ownership of Fridges in Selected Centiles - Rural and Urban

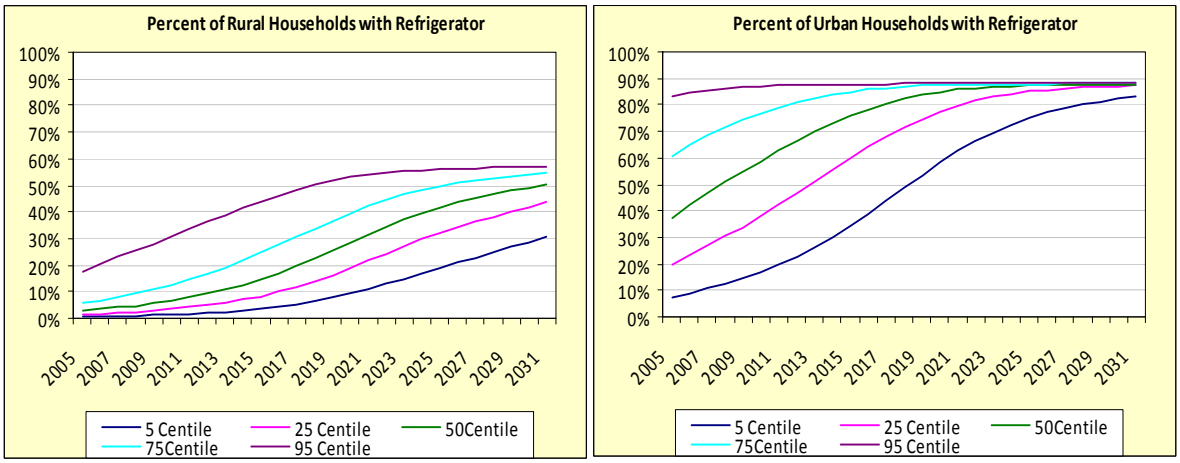


Figure 47: Projection of Ownership of Electric Ovens in Selected Centiles - Urban

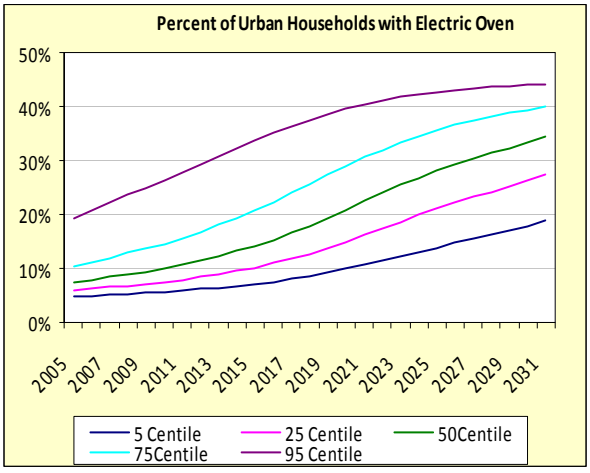


Figure 48: Projection of Ownership of Electric Toasters in Selected Centiles - Urban

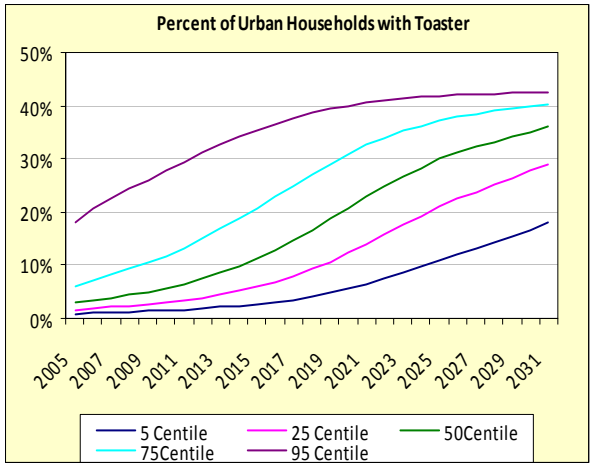


Figure 49: Projection of Ownership of Microwaves in Selected Centiles - Urban

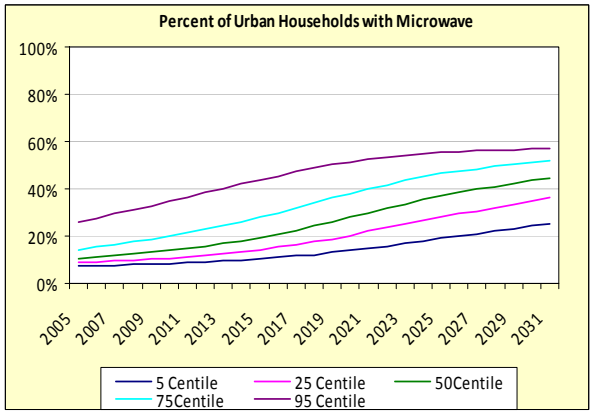
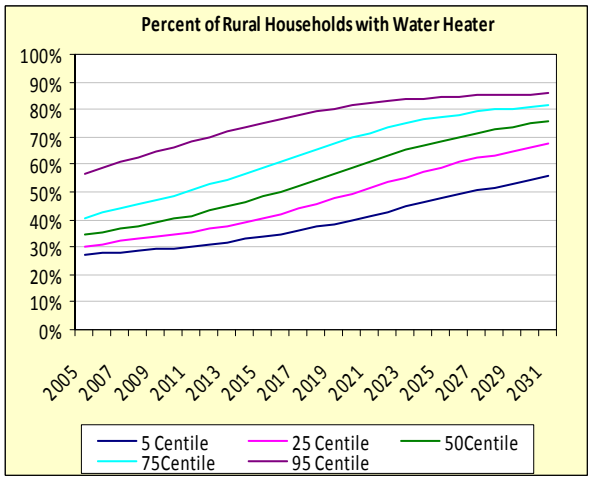


Figure 50: Projection of Ownership of Electric Water Heaters in Selected Centiles - Rural and Urban



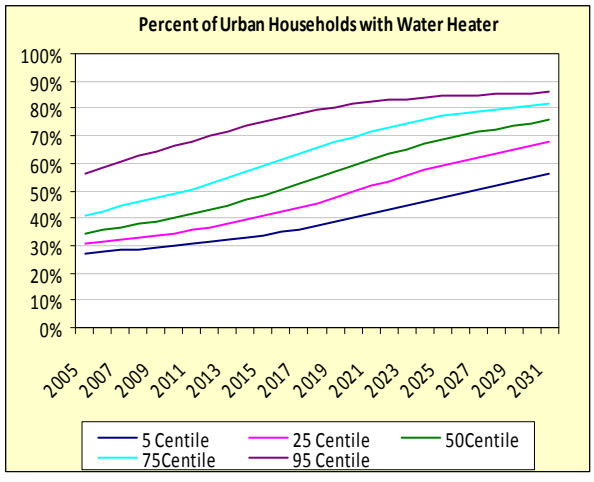


Figure 51: Projection of Ownership of Fans in Selected Centiles - Rural and Urban

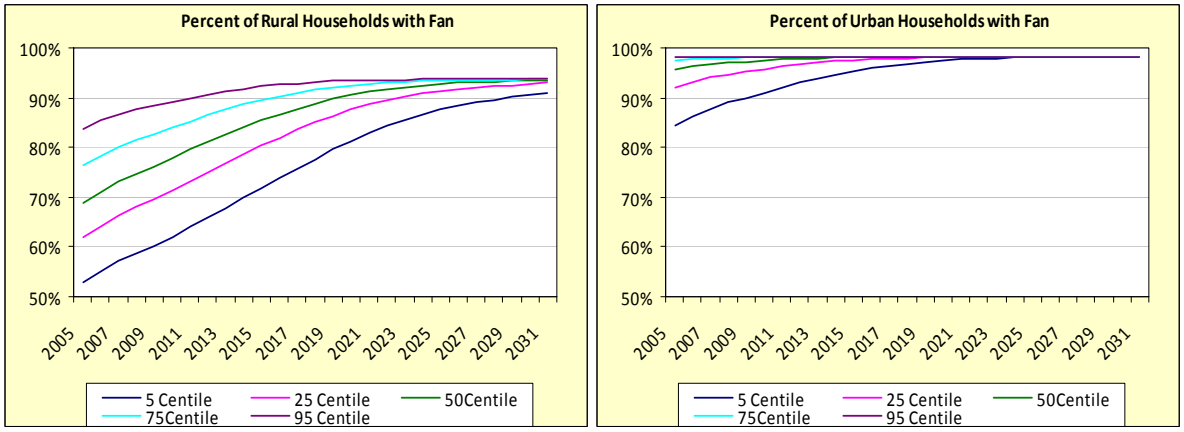


Figure 52: Projection of Ownership of Air Coolers in Selected Centiles - Rural and Urban

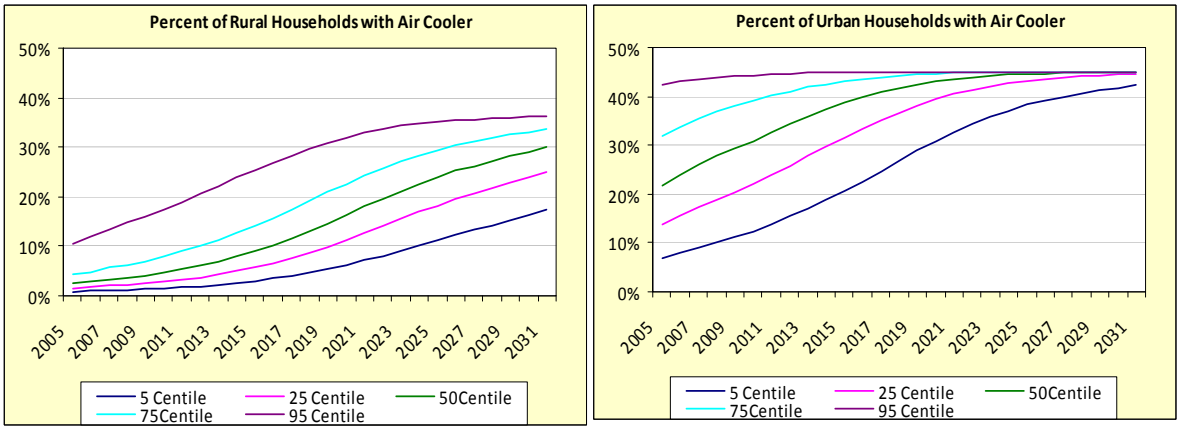
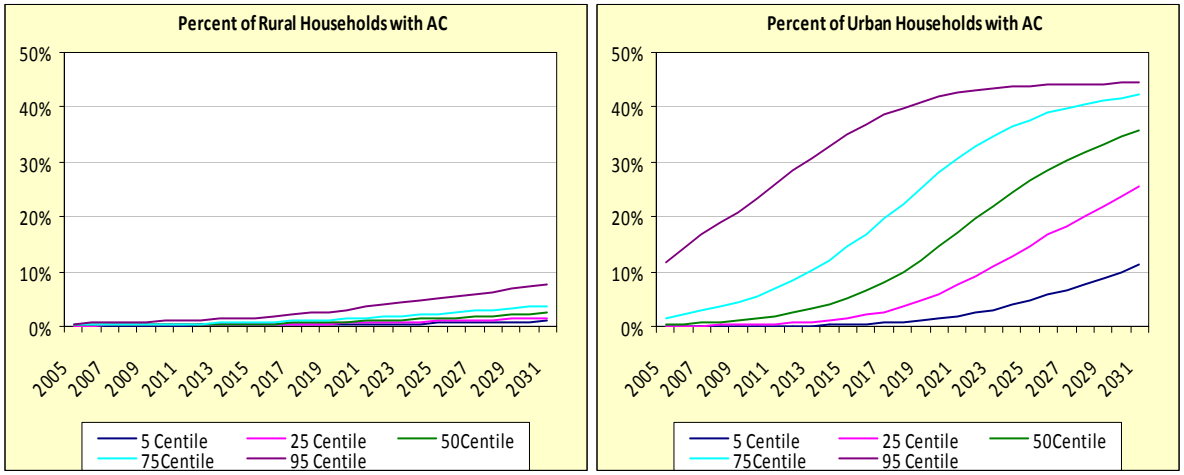


Figure 53: Projection of Ownership of Air Conditioners in Selected Centiles - Rural and Urban



Annex 5 : Illustrative Data used in Scenario 1 to Demonstrate the Working of the Model

Television

Average usage 4 hour/day

Table 21: TV Power and Standby

Type	Size	Power		Standby	
		Historic	2008	Historic	2008
CRT	18 or less	70	47	5	3.1
normal	19-20	75	68	6	5.1
	25-27	125	90	6	4.9
	30-36		114		5.3
CRT	18 or less				
widescreen	19-20		111		1
	25-27		149		1
	30-36		168		1
LCD	18 or less		60		1
	19-20		83		1
	25-27		140		1
	30-36		180		1
	37-43		247		1
	44 or above		350		1
Plasma	18 or less				
	19-20				
	25-27				
	30-36				
	37-43		355		1
	44 or above		500		1

Table 22: TV Sales Mix

Type	Size	Parc	Sales Mix		
		2005	2010	2020	2030
CRT	18 or less	22%	4%		
normal	19-20	72%	5%		
	25-27	6%			
	30-36				
CRT	18 or less				
widescreen	19-20		45%		
	25-27		10%		
	30-36				
LCD	18 or less		6%	15%	15%
	19-20				
	25-27		17%	45%	45%
	30-36		10%	32%	32%
	37-43				
	44 or above				
Plasma	18 or less				
	19-20				

Type	Size	Parc	Sales Mix		
		2005	2010	2020	2030
	25-27				
	30-36		3%	6%	6%
	37-43			3%	3%
	44 or above				

Washing Machine

Average usage 7 loads/week

Table 23: Washing Machine Power Consumption per load

Type	Size	Power Wh/load	
		Historic	2008
Semi-Automatic	5	75	67
Automatic	5	235	210

Table 24: Washing Machine Sales Mix

Type	Size	Parc	Sales Mix		
		2005	2010	2020	2030
Semi-Automatic	5	85%	61%	31%	16%
Automatic	5	15%	39%	69%	84%

Air Conditioning

Average usage 575 hours/year

Table 25: Air Conditioning Power Consumption

Type	Size	Power		Standby	
		Historic	2008	Historic	2008
Window	1 ton	1500	1342	0.0	0.0
	1.5 tons	2200	1982	0.0	0.0
	2 tons	2600	2557	0.0	0.0
Split	1 ton	1500	1238	2.7	1.0
	1.5 tons	2000	1857	2.7	1.0
	2 tons	2500	2489	2.7	1.0
Whole House	10 tons	15384	15384	0.0	0.0

Table 26: Air Conditioning Sales Mix

Type	Size	Parc	Sales Mix		
		2005	2010	2020	2030
Window	1 ton	45%	45%	45%	45%
	1.5 tons	22%	22%	22%	22%
	2 tons	10%	10%	10%	10%
Split	1 ton	12%	12%	12%	12%
	1.5 tons	6%	6%	6%	6%
	2 tons	4%	4%	4%	4%
Whole House	10 tons	1%	1%	1%	1%

Cooler

Average usage	1440 hours/year
Power	
Historic	250 W
2008	230 W

Fan

Average usage	2520 hours/year
Power	
Historic	39.4 W
2008	36.4 W

Fridge

Average usage continuous

Table 27: Fridge Power Consumption

Type	Size	Power kWh/yr	
		Historic	2008
Direct Cool		669	343
Frost Free	<300 L	763	490
	>300 L	1130	587

Table 28: Fridge Sales Mix

Type	Size	Parc	Sales Mix		
		2005	2010	2020	2030
Direct Cool		83%	76%	63%	51%
Frost Free	<300 L	12%	16%	25%	33%
	>300 L	5%	8%	12%	16%

Electric Water Heaters

Hot water per Unit	60 liters/day
Temperature out	55 deg C
Temperature in	5 deg C
Average usage	140 days per year

Unit Sales Mix by Type		Efficiency Factor (ER)	
		Historic	2008
Storage Geyser	68.1%	0.80	0.87
Instant Geyser	18.4%	0.82	0.89
Immersion Rod	11.3%	0.78	0.85
Solar Thermal	2.1%	1.60	2.18

Electric Oven

Average usage	15	min/day
Power		
Historic	960 W (1200 W @ 80%)	
2008	1280 W (1600 W @ 80%)	

Electric Toaster

Average usage	15 min/day
Power	
Historic	800 W
2008	1280 W (1600 W @ 80%)

Microwave

Average usage 6 min/day
Power
Historic 1080 W
2008 1280 W (1600 W @ 80%)
Standby Power
Historic 4 W
2008 3 W

Computer

Average usage 2.2 hours/day

Table 29: Computer Power Consumption

Type	Operating (Idle)		Standby	
	Historic	2008	Historic	2008
Desktop	157	106	9	6
Laptop	27.5	22.0	2.1	1.7

Table 30: Computer Sales Mix

Type	Parc	Sales Mix		
	2005	2010	2020	2030
Desktop	75%	50%	50%	50%
Laptop	25%	50%	50%	50%

DVD / VCR

Average usage 156 hours/year
Power
Historic 40 W
2008 30 W
Standby
Historic 4.2 W
2008 3 W

Radio

Average usage 2190 hours/year
Power
Historic 11 W
2008 11 W
Standby
Historic 1.7 W
2008 1 W

CD Player

Average usage 1460 hours/year
Power
Historic 35 W
2008 35 W
Standby
Historic 1.7 W
2008 1 W

Lighting

Table 31: Lighting Power Consumption

Type	Size	Power	
		Historic	2008
Flourescent	Electronic Ballast	41.3	41.3
	Magnetic Ballast	47.3	47.3
CFL	20W	20	20
	16W	16	16
	11W	11	11
	5W	5	5
Incandescent	100W	100	100
	60W	60	60
	40W	40	40
	25W	25	25
	15W	15	15

Table 32: Lighting Sales Mix

Type	Size	Parc	Sales Mix		
		2005	2010	2020	2030
Flourescent	Electronic Ballast	14%	14%	100%	100%
	Magnetic Ballast	86%	86%	0%	0%
CFL	20W	23%	23%	23%	23%
	16W	37%	37%	37%	37%
	11W	23%	23%	23%	23%
	5W	17%	17%	17%	17%
Incandescent	100W	15%	15%	15%	15%
	60W	46%	46%	46%	46%
	40W	21%	21%	21%	21%
	25W	7%	7%	7%	7%
	15W	11%	11%	11%	11%

Annex 6 : Annual Sales Projections for Various Appliances

Figure 54: Annual Sales of Light bulbs

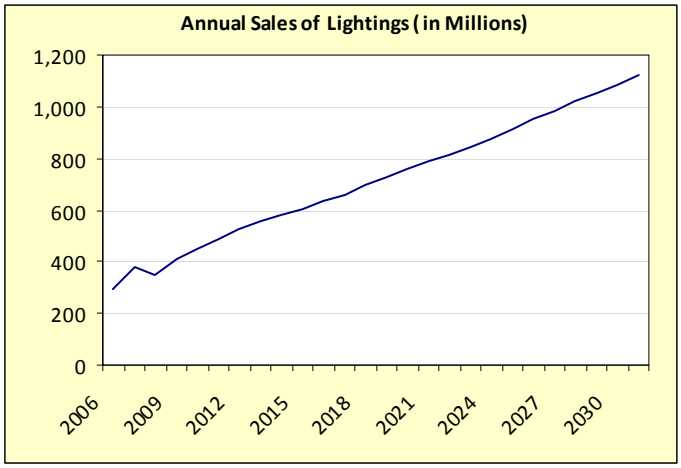
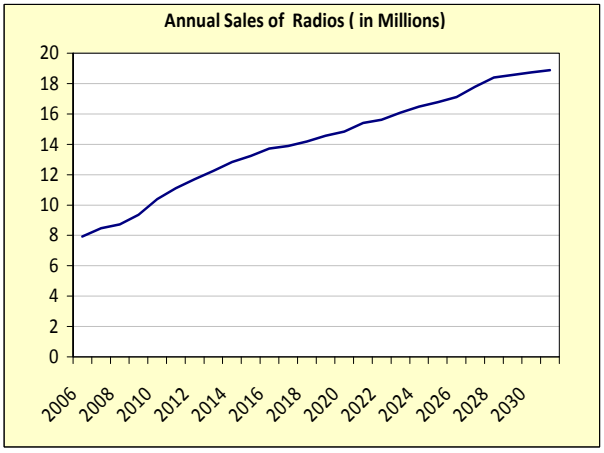


Figure 55: Annual Sales of Radios and CD Players



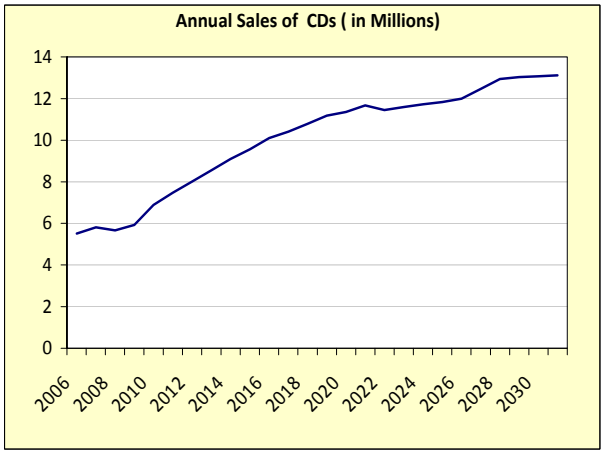


Figure 56: Annual Sales of DVD Players and TVs

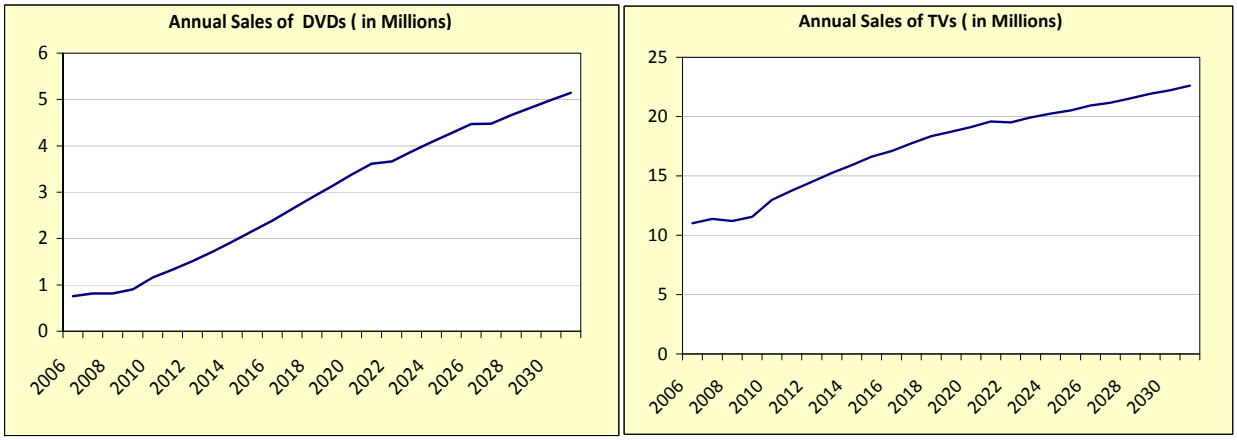


Figure 57: Annual Sales of Computers

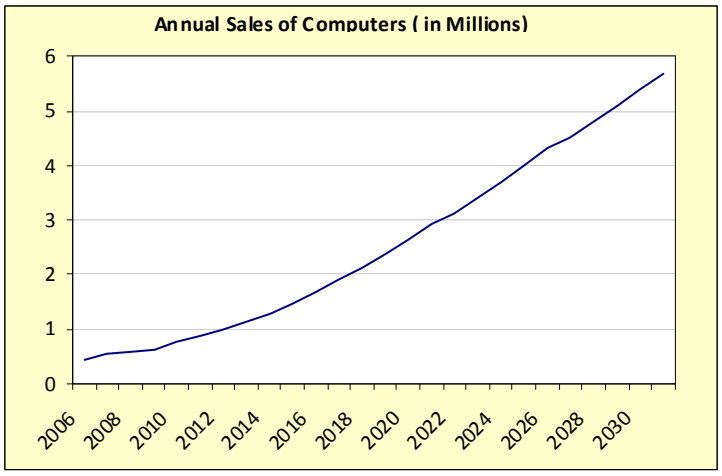


Figure 58: Annual Sales of Microwaves and Fridges

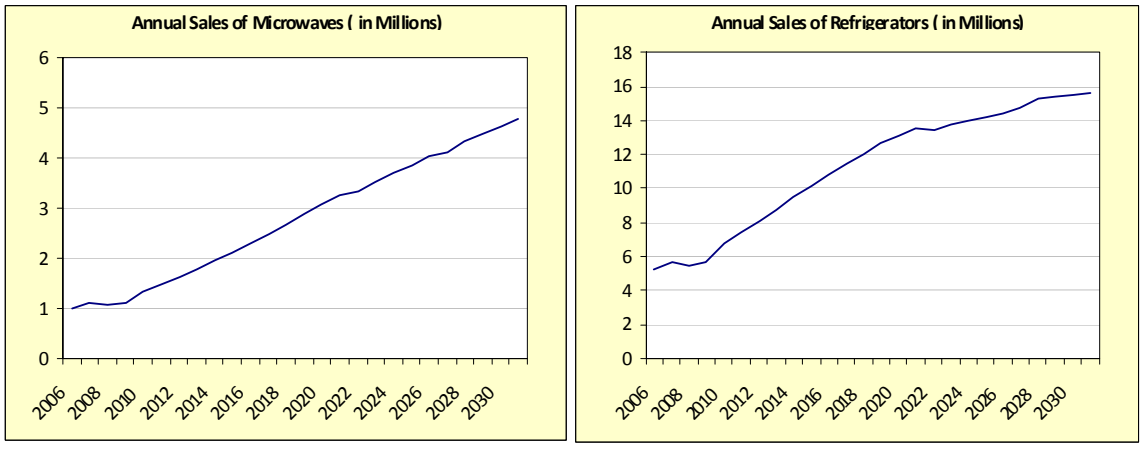


Figure 59: Annual Sales of Electric Ovens and Toasters

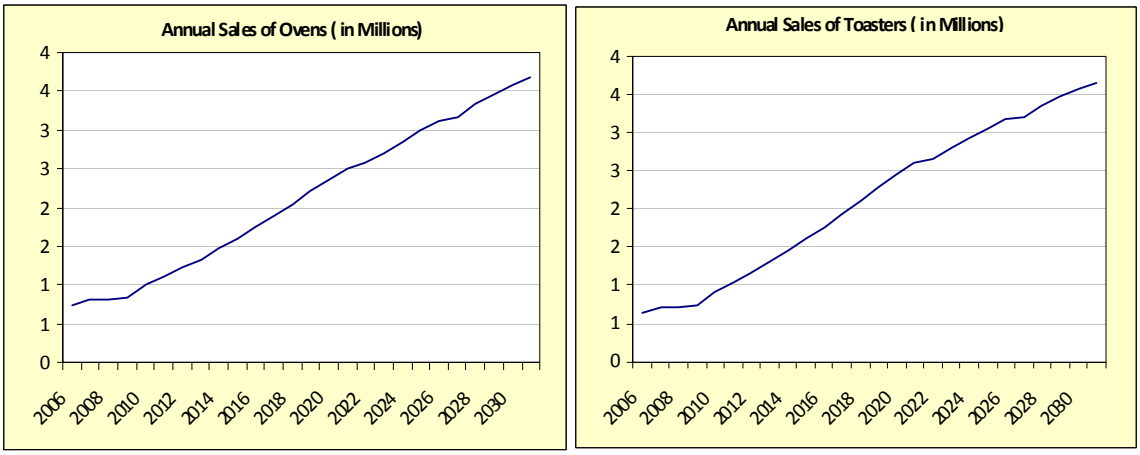


Figure 60: Annual Sales of Washing Machines

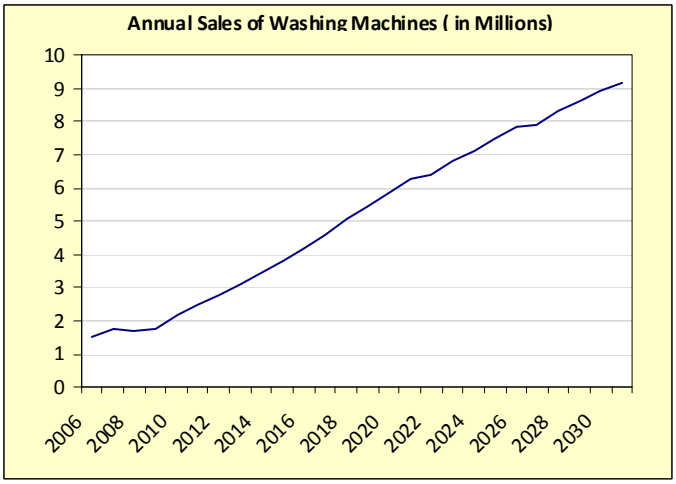


Figure 61: Annual Sales of Electric Water Heaters and Air Conditioning

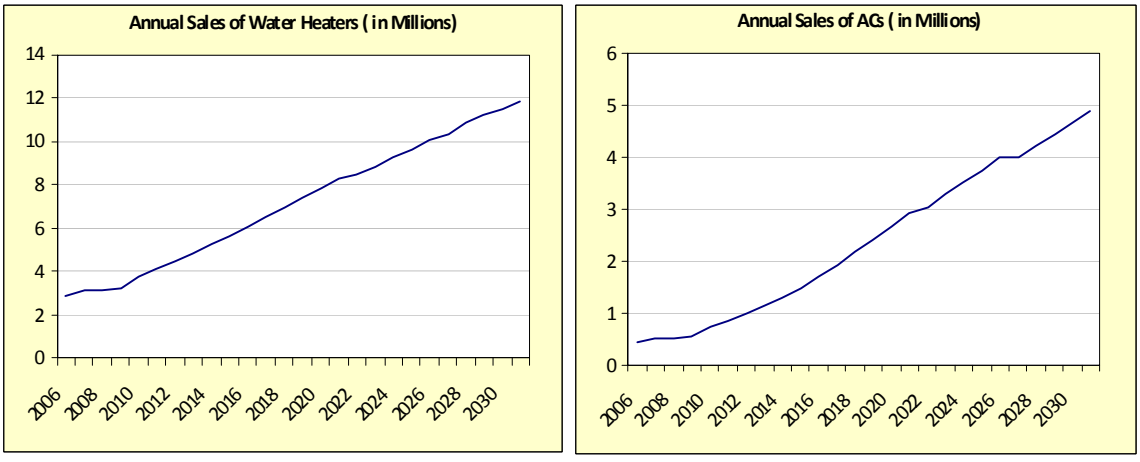
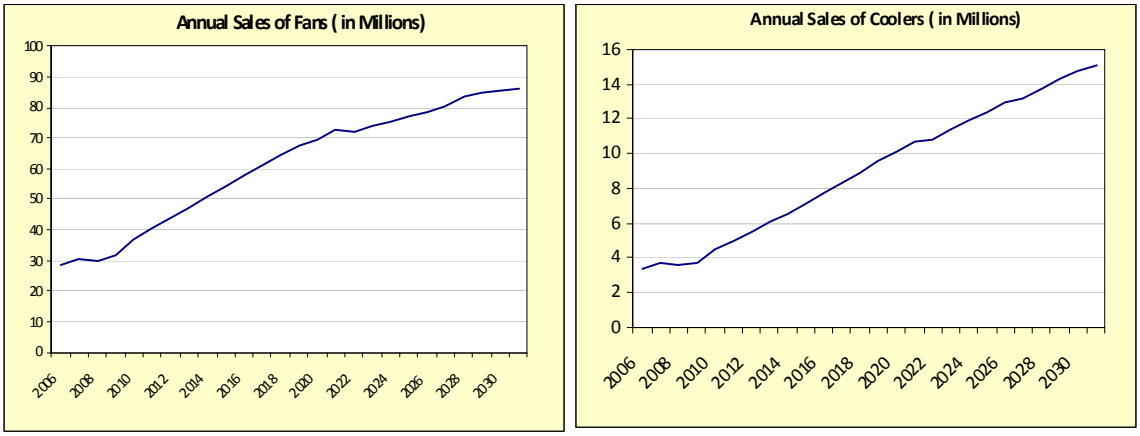


Figure 62: Annual Sales of Fans and Coolers



Annex 7: Average per unit Power Consumed for Various Categories of Devices

Table 33: Parc Average Per Unit Power consumed by Lighting

Lighting			2006	2011	2016	2021	2026	2031
	Operating	kWh/yr	33.7	35.2	35.0	35.1	35.2	35.0

Table 34: Parc Average Per Unit Power consumed by Entertainment Appliances

Entertainment			2006	2011	2016	2021	2026	2031
Radio	Operating	kWh/yr	24.1	24.1	24.1	24.1	24.1	24.1
	Standby	kWh/yr	11.2	8.8	7.1	6.6	6.6	6.6
	Total	kWh/yr	35.3	32.9	31.2	30.7	30.7	30.7
CD Player	Operating	kWh/yr	51.1	51.1	51.1	51.1	51.1	51.1
	Standby	kWh/yr	12.4	10.4	8.8	7.9	7.5	7.3
	Total	kWh/yr	63.5	61.5	59.9	59.0	58.6	58.4
TV	Operating	kWh/yr	111.7	134.8	164.5	185.3	197.3	202.9
	Standby	kWh/yr	42.1	30.4	19.6	12.9	9.2	7.7
	Total	kWh/yr	153.9	165.2	184.1	198.2	206.5	210.6
DVD / VCR	Operating	kWh/yr	6.2	5.4	4.9	4.8	4.7	4.7
	Standby	kWh/yr	36.1	30.8	27.6	26.4	26.0	25.8
	Total	kWh/yr	42.4	36.2	32.5	31.2	30.7	30.5
Computer	Operating	kWh/yr	92.8	57.3	51.5	51.4	51.4	51.4
	Standby	kWh/yr	54.1	34.1	30.7	30.6	30.6	30.6
	Total	kWh/yr	147.0	91.5	82.1	82.0	82.0	82.0

Table 35: Parc Average Per Unit Power consumed by Kitchen Appliances

White Appliances			2006	2011	2016	2021	2026	2031
Refrigerator	Operating	kWh/yr	704.6	567.7	472.7	431.1	417.4	418.4
	Standby		0.0	0.0	0.0	0.0	0.0	0.0
	Total		704.6	567.7	472.7	431.1	417.4	418.4
Washing machines	Operating	kWh/yr	36.6	40.7	47.5	54.1	59.3	63.5
	Standby		0.0	0.0	0.0	0.0	0.0	0.0
	Total		36.6	40.7	47.5	54.1	59.3	63.5
Electric Oven	Operating	kWh/yr	87.6	99.3	108.9	113.9	116.0	116.7
	Standby		0.0	0.0	0.0	0.0	0.0	0.0
	Total		87.6	99.3	108.9	113.9	116.0	116.7
Toaster	Operating	kWh/yr	73.0	94.1	107.9	113.7	115.9	116.6
	Standby		0.0	0.0	0.0	0.0	0.0	0.0
	Total		73.0	94.1	107.9	113.7	115.9	116.6
Microwave	Operating	kWh/yr	39.4	39.4	39.4	39.4	39.4	39.4
	Standby	kWh/yr	36.6	32.5	29.1	27.3	26.5	26.2
	Total	kWh/yr	76.1	72.0	68.5	66.7	65.9	65.6

Table 36: Parc Average Per Unit Power Consumed by Heating/Cooling Appliances

Heating / Cooling			2006	2011	2016	2021	2026	2031
Electric Water Heater	Operating	kWh/yr	602.9	584.1	568.0	559.0	554.9	553.6
	Standby		0.0	0.0	0.0	0.0	0.0	0.0
	Total		602.9	584.1	568.0	559.0	554.9	553.6
Fans	Operating	kWh/yr	99.3	96.4	93.9	92.6	92.0	91.8
	Standby		0.0	0.0	0.0	0.0	0.0	0.0
	Total		99.3	96.4	93.9	92.6	92.0	91.8
Air cooler	Operating	kWh/yr	360.0	347.6	338.4	333.9	332.0	331.3
	Standby		1.0	6.0	11.0	16.0	21.0	26.0
	Total		361.0	353.6	349.4	349.9	353.0	357.3
Air-conditioning	Operating	kWh/yr	1,134.4	1,082.8	1,054.4	1,044.5	1,041.3	1,040.4
	Standby	kWh/yr	4.9	3.2	2.3	1.9	1.8	1.8
	Total	kWh/yr	1,139.2	1,086.0	1,056.7	1,046.5	1,043.1	1,042.2

Annex 8 : Total Power Consumed by Appliances

Table 37: Total Power Consumed by Appliances

		2006	2011	2016	2021	2026	2031
Lighting	GWh/yr	41,440	57,786	73,676	91,092	107,890	125,601
Entertainment	GWh/yr	19,596	29,874	43,767	57,845	69,196	79,989
Kitchen Appliances	GWh/yr	25,189	35,835	49,152	66,905	85,064	103,435
Heating/Cooling	GWh/yr	49,420	75,310	112,931	164,011	220,472	279,449
Total	GWh/yr	135,646	198,807	279,526	379,854	482,622	588,474
Operating	GWh/yr	129,947	192,491	273,147	373,151	475,330	580,143
Standby	GWh/yr	5,699	6,316	6,379	6,703	7,293	8,331
Total	GWh/yr	135,646	198,807	279,526	379,854	482,622	588,474

Figure 63: Distribution of Power Consumed by Appliances

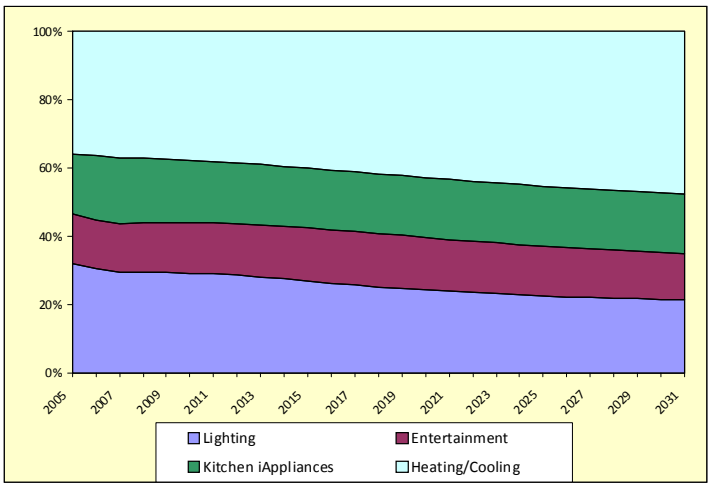


Figure 64: Total Power consumed by Lighting

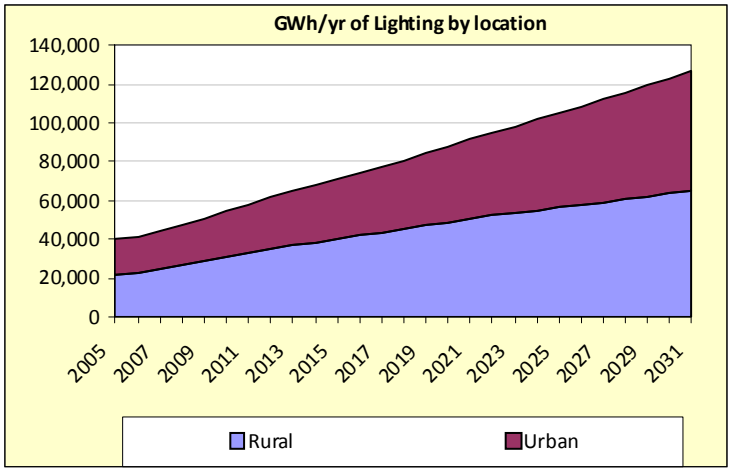


Table 38: Total Power Consumed by Lighting

Lighting			2006	2011	2016	2021	2026	2031
	Operating	GWh/yr	41,440	57,786	73,676	91,092	107,890	125,601

Figure 65: Distribution of Power Consumed by Entertainment Appliances

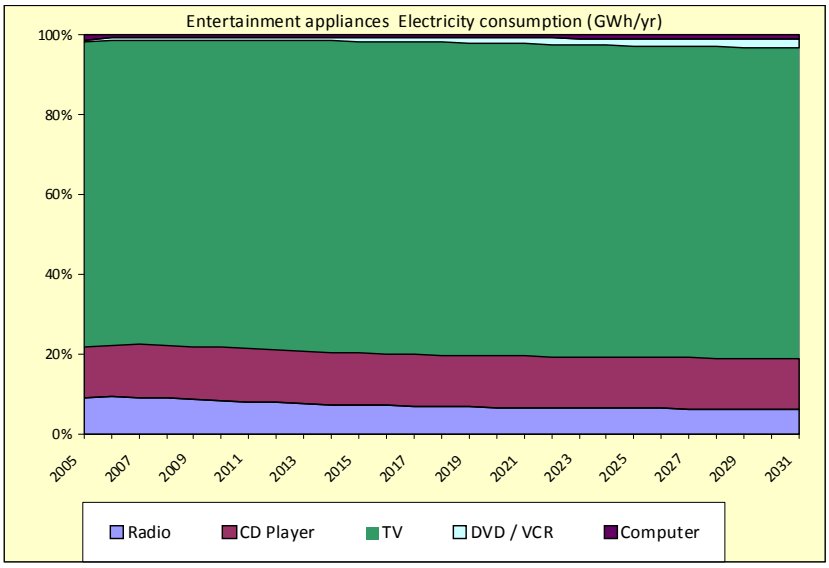


Table 39: Total Power Consumed by Entertainment Appliances

Entertainment			2006	2011	2016	2021	2026	2031
Radio	Operating	GWh/yr	1,248	1,792	2,416	3,021	3,488	3,934
	Standby	GWh/yr	578	654	712	832	951	1,073
	Total	GWh/yr	1,826	2,446	3,128	3,853	4,439	5,006
CD Player	Operating	GWh/yr	2,063	3,281	4,834	6,462	7,757	8,904
	Standby	GWh/yr	501	666	830	1,002	1,139	1,278
	Total	GWh/yr	2,564	3,947	5,665	7,464	8,896	10,183
TV	Operating	GWh/yr	10,870	18,867	30,646	42,353	51,584	60,015
	Standby	GWh/yr	4,099	4,224	3,622	2,942	2,408	2,265
	Total	GWh/yr	14,969	23,091	34,269	45,295	53,992	62,280
DVD / VCR	Operating	GWh/yr	22	41	76	131	195	260
	Standby	GWh/yr	128	235	425	727	1,079	1,432
	Total	GWh/yr	150	277	501	859	1,274	1,692
Computer	Operating	GWh/yr	0	1	1	2	3	4
	Standby	GWh/yr	86	113	204	374	592	824
	Total	GWh/yr	86	114	205	376	595	828

Figure 66: Distribution of Power Consumed by Kitchen Appliances

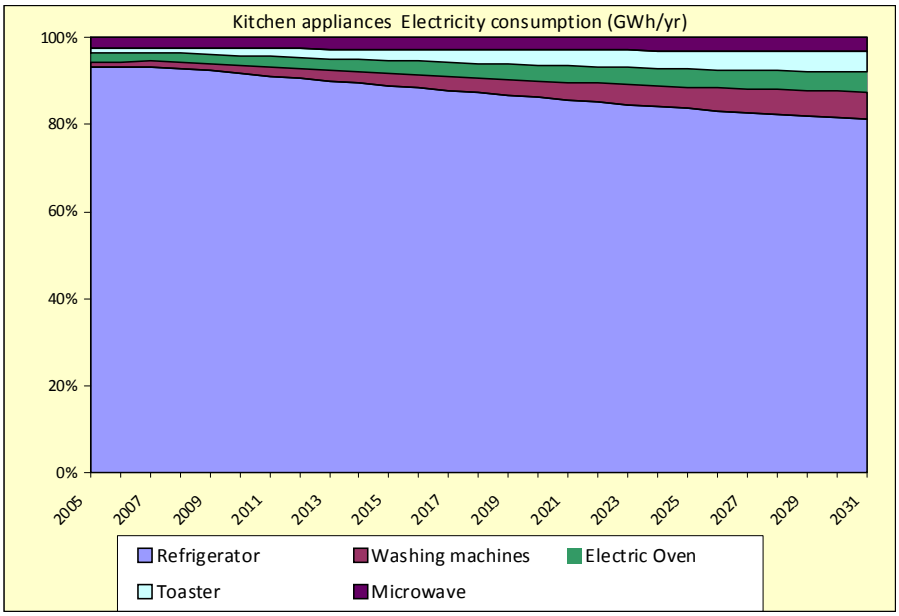


Table 40: Total Power Consumed by Kitchen Appliances

White Appliances			2006	2011	2016	2021	2026	2031
Refrigerator	Operating	GWh/yr	23,490	32,706	43,472	57,349	70,844	84,244
Washing machines	Operating	GWh/yr	312	672	1,433	2,742	4,439	6,328
Electric Oven	Operating	GWh/yr	509	909	1,564	2,484	3,553	4,687
Toaster	Operating	GWh/yr	261	646	1,359	2,404	3,583	4,742
Microwave	Operating	GWh/yr	320	495	761	1,138	1,582	2,063
	Standby	GWh/yr	297	408	562	787	1,062	1,372
	Total	GWh/yr	617	903	1,323	1,925	2,644	3,434

Figure 67: Distribution of Power Consumed by Heating/Cooling Appliances

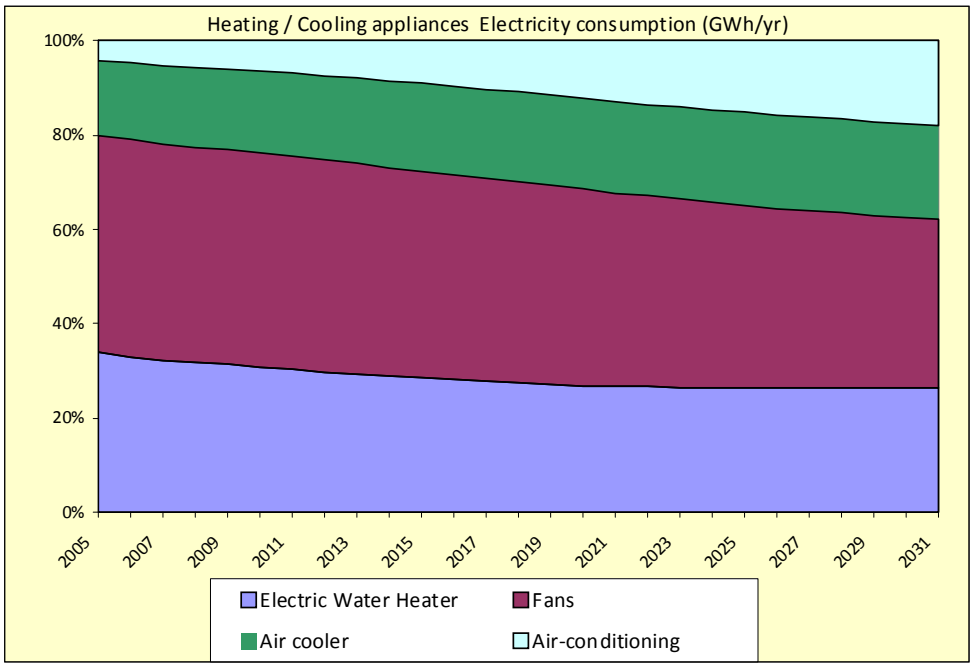


Table 41: Total Power Consumed by Heating/Cooling Appliances

Heating / Cooling			2006	2011	2016	2021	2026	2031
Electric Water Heater	Operating	GWh/yr	16,298	22,738	31,628	43,657	57,668	73,289
Fans	Operating	GWh/yr	22,724	34,100	49,310	67,521	84,441	100,185
Air cooler	Operating	GWh/yr	8,091	13,373	21,186	31,828	43,626	55,975
Air-conditioning	Operating	GWh/yr	2,298	5,084	10,783	20,966	34,675	49,913
	Standby	GWh/yr	10	15	23	39	61	87
	Total	GWh/yr	2,308	5,099	10,806	21,005	34,737	50,000

Annex 9 : Improved Energy Efficiency Assumptions for Various Appliances Used in Scenario 2

Television

Table 42: TV Power and Standby

Type	Size	Power		Standby	
		2012	2015	2012	2015
CRT normal	18 or less	42	42	1	0.8
	19-20	48	48	1	0.8
	25-27	64	64	1	0.8
	30-36	84	84	1	0.8
CRT widescreen	18 or less	57	57	1	0.8
	19-20	66	66	1	0.8
	25-27	90	90	1	0.8
	30-36	120	120	1	0.8
LCD	18 or less	57	57	1	0.8
	19-20	66	66	1	0.8
	25-27	90	90	1	0.8
	30-36	120	120	1	0.8
	37-43	183	183	1	0.8
	44 or above	246	246	1	0.8
Plasma	18 or less	57	57	1	0.8
	19-20	66	66	1	0.8
	25-27	90	90	1	0.8
	30-36	120	120	1	0.8
	37-43	183	183	1	0.8
	44 or above	246	246	1	0.8

Washing Machine

Table 43: Washing Machine power consumption per load

Type	Size	Wh/load
		2015
Semi-Automatic	5	60
Automatic	5	155

Air Conditioning

Table 44: Air Conditioning Power consumption

Type	Size	Power		Standby	
		2012	2015	2012	2015
Window	1 ton	1157	959	0.0	0.0
	1.5 tons	1743	1444	0.0	0.0
	2 tons	2134	1768	0.0	0.0
Split	1 ton	1187	1012	1.0	1.0
	1.5 tons	1831	1475	1.0	1.0
	2 tons	2197	1821	1.0	1.0

Whole House	10 tons	12172	10375	0.0	0.0

Cooler

Power

2012 230 W

Fan

Power

2012 35.6 W

2015 34.2 W

Fridge

Table 45: Fridge Power Consumption

Type	Size	Power kWh/yr	
		2012	2015
Direct Cool		219	175
Frost Free	<300 L	320	255
	>300 L	370	296

Electric Water Heaters

Table 46: Water Heater Efficiency Factors

Type	EF
	2015
Storage	0.93
Instant	0.95
Immersion	0.91
Solar	2.79

Electric Oven

No change

Electric Toaster

No change

Microwave

No change

Computer

Table 47: Computer Power consumption

Type	Operating (Idle)		Standby	
	2012	2015	2012	2015
Desktop	97	85	3.3	2.6
Laptop	19	17	1.4	1.3

DVD / VCR

Power

2012 20 W

2015 12 W

Standby

2012 1.5 W

	2015	1 W
Radio		
Power		
	2012	11 W
Standby		
	2012	0.7 W
CD Player		
Power		
	2012	35 W
Standby		
	2012	0.5 W

Lighting

Prohibit sales of Incandescent lamps and magnetic ballasts from 2015

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Appendix 1: Population and Urbanization: Extension from 2026 to 2031

The extension of the Census of India's population projection is carried out to 2031. Figure A1.1 shows the trend of percent change in the annual population growth rate between 2007 and 2026. A linear regression is used to estimate the change in the growth rate between 2026 and 2031. As reported in Figure A1.1, the linear slope predicts that there will be a 0.0019 percentage point drop per annum in the annual rate of population growth. As a result, it is projected that population growth will decline from 1.5 percent per annum in 2006 to 0.53 percent per annum in 2031.

Figure A1.1

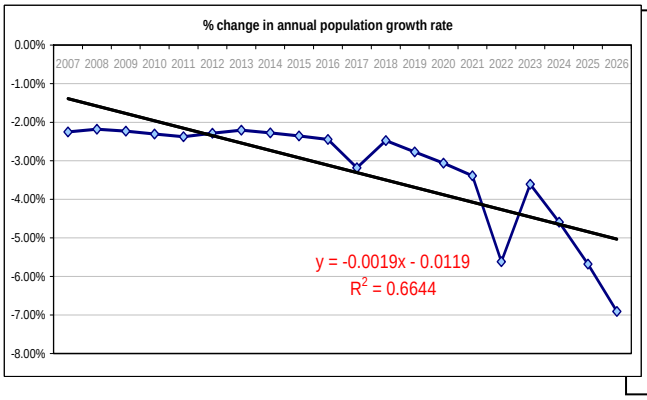
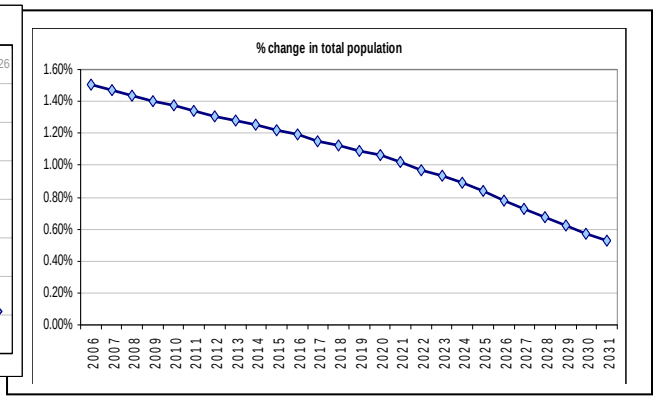


Figure A1.2



The urbanization rate projected by the Census of India to 2026 is also extended to 203. In 2026, the percentage change in urbanization rate is 0.9 percent. This study assumes that this rate of change is maintained through 2031, and predicts that the urbanization rate will reach 34.6 percent by 2031 (Figure A1.4). Assuming approximately a five-fold increase in household income by 2031, 48.9 percent urbanization rate is at the lower bound of what a cross-country analysis would predict (Figure A1.3)

Figure A1.3

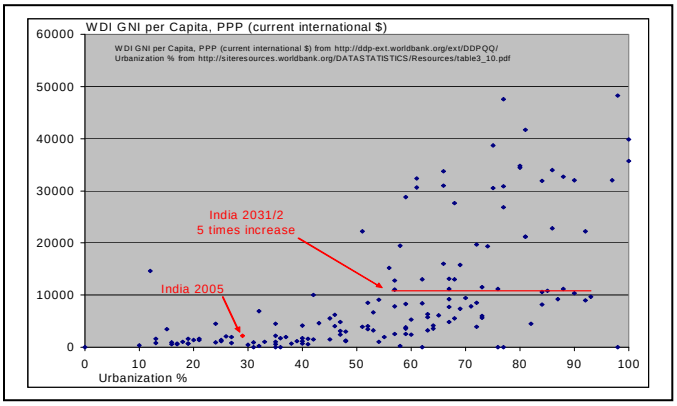
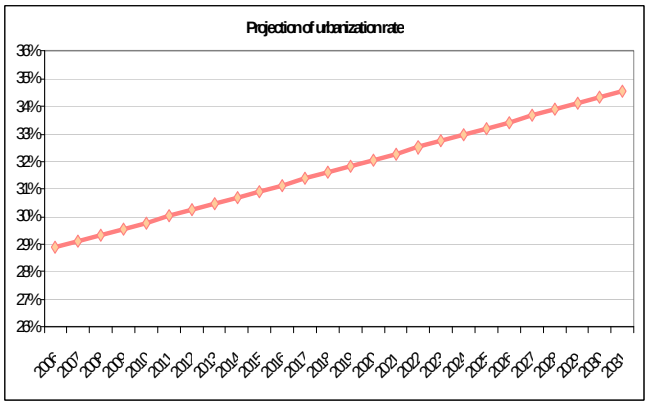


Figure A1.4



Note: a plot of 2005 GNI per capita PPP current international for all countries vs percent urbanization

The projection of population in the 15-64 age group is also undertaken using the same approach. The Census of India reports projections at five-year intervals (see Table A1.1), and in this study they are linearly interpolated to provide annual figures. Figure A1.5 shows the trend of percentage change in the 15-64 age-group, linearly extrapolated from 2026 to 2031. Figure A1.6 shows the projection between 2006 and 2031, based on the estimated slope from Figure A1.5.

Table A1.1 Projected Population by Age Group in India ('000 persons)

age group	2001	2006	2011	2016	2021	2026
15-64	613,156	699,051	779,498	850,457	907,965	956,571

Source: Census of India, Population Projection for India and States 2001-2026, May 2006 (projection as on 1st March 2006)

Figure A1.5

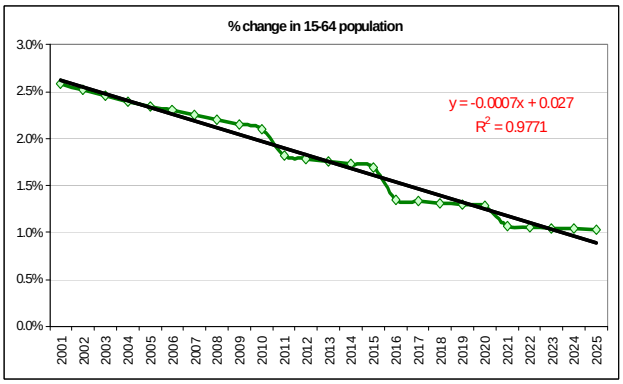
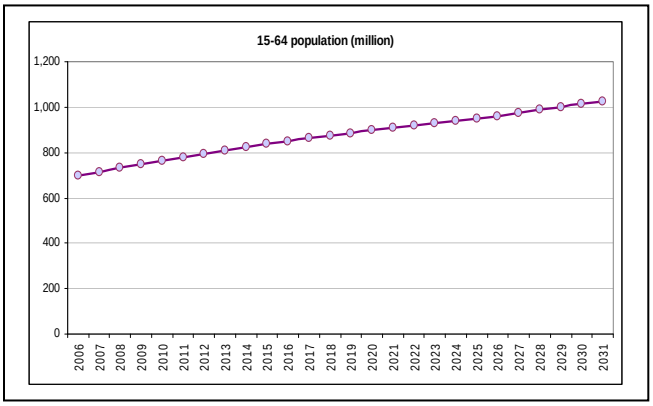


Figure A1.6



Since recent Census of India data corresponds to March 1st of the sampled year, linear interpolation is used to convert all the population, household and household size data to the mid-point of the fiscal years used in this study.(Indian fiscal years run from the 1st of April until the 31st of March with a mid-point corresponding to 1st of October).

Appendix 2: Derivation of Equation 1

First, total expenditures TE are computed from the NSS 61st round.

$\mathrm{TE}_{04/05} = \sum_{\mathrm{k}} MPCE_{\mathrm{k},04/05} \cdot POP_{\mathrm{k},04/05}$, $\mathrm{k} \in (\text{rural}, \text{urban})$, and TE_t is assumed to grow at the same rate as $GDPG_t$, the rate of GDP growth.

(Equation A.1) $$TE_{t+1} = TE_t(1 + GDPG_t)$$

(Equation A.2) $$TE_{t+1} = MPCE_{r,t}(1 + PCEG_t) \cdot POP_{r,t+1} + MPCE_{u,t}(1 + PCEG_t) \cdot POP_{u,t+1}$$

Substitute equation A.1 into A.2 and solving for per capita expenditure growth, $PCEG_t$, yields

$$PCEG_t = \frac{\sum_k MPCE_{k,t} \cdot POP_{k,t}(1 + GDPG_t)}{\sum_k MPCE_{k,t} \cdot POP_{k,t+1}} - 1$$