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Realizing potential savings of energy and emissions from efficient household appliances in India

Kirit S. Parikh *, Jyoti K. Parikh

Integrated Research and Action for Development (IRADe), C 80, Shivalik, Malviya Nagar, New Delhi 110017, India

HIGHLIGHTS

- Estimates the stock of selected household appliances with 20 classes of rural and urban households in the years 2030 in India.
- Assesses the economics of energy efficient appliances.
- Estimates spread of selected energy efficient appliances.
- Assesses savings in energy consumption and CO_2 emissions in four alternative scenarios.
- Suggests policies to promote energy efficient appliances.

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ABSTRACT

The paper projects households' stock of four major electricity consuming appliances till 2030 and explores policy options to accelerate adoption of more energy efficient appliances. India's rapid economic growth has enabled the growing middle class to buy household appliances in increasing numbers. The consequent rise in energy consumption and GHG emissions can be significantly reduced if consumers are motivated by awareness and options in the market to buy energy efficient appliances. India has introduced a star rating scheme for appliances, and even without incentives consumers purchase star-rated appliances. The stock of household appliances is projected using the data of a national sample survey of household consumption, observed sale of star-rated appliances and projected consumption distribution.

Estimated savings in households' electricity consumption from just four appliances, ACs, refrigerators, TVs, and ceiling fans, for which data were available, range from 52 bKwh to 145 bkwh in 2030, reductions of 10–27%. The corresponding reduction in CO_2 emissions will be between 42 Mt and 116 Mt in 2030. With policies of finance and bulk procurement to reduce costs, emissions reduction can be 128 Mt in 2030, a reduction of 30%.

1. Introduction

India's rapid economic growth has enabled the growing middle class to buy household appliances in increasing numbers. The consequent rise in energy consumption and GHG emissions can be significantly reduced if consumers are motivated by awareness and options in the market to buy energy efficient appliances, (Parikh et al., 2014; Banerjee, 2005). The paper projects appliance ownership by households, their adoption of energy efficient appliance models based on economic considerations, assesses the saving in electricity consumption and carbon emissions from them and explores policy options to accelerate adoption of more energy efficient appliance models.

Currently, due to low income levels, the appliance use is comparatively small. Thus, a very high growth in the ownership, often in double digits, is expected to continue for most of the high-energy-consuming appliances in the coming decades. For example, air conditioner (AC) ownership in 2009 was 1% in urban areas and less than 0.1% in rural India compared to 85% in USA in 2010 (EIA, 2011), more than 100% in Urban China in 2010 (Zhou et al., 2012) and 85% in South Korea in 2000 (McNeil and Letschert, 2008). As incomes increase, electricity consumption by appliances used in households can become quite large. For example, in the US, in 2009, the residential sector consumed 32.4% of the gross electricity generated not counting the 6.2% consumed by air conditioning. In 2009, a US household used 11,320 kWh of electricity;

* Corresponding author.
E-mail addresses: kparikh@irade.org (K.S. Parikh), jparikh@irade.org (J.K. Parikh).

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of which 45% was for space heating and the rest for water heating, air conditioning, appliances and lighting (US Energy Information Administration website: http://www.eia.gov/consumption/residential/). It is, therefore, important to project energy use by appliances and the energy conservation by the use of more energy-efficient appliances in India.

In India, the Bureau of Energy Efficiency (BEE), set up by the government, has initiated programmes to promote energy efficiency (BEE website: http://www.beeindia.in). One of these is the labelling and star rating of appliances (http://beestarlabel.com). A 5-star-rated appliance is the most energy efficient. This has created awareness as well as markets for energy efficient appliances by providing information on performance with gradation from 1 to 5 stars. The BEE provides data on electricity consumption per unit by different star-rated appliances. Also, after introducing the star rating system for appliances in 2007, it has commissioned annual assessments by an independent agency, National Productivity Council (NPC, 2007 to 2011). These assessments provide data on the sales of different star-rated appliances.

To project energy savings from the use of star-rated appliances in the year 2030, we project the use of appliances by the households of different expenditure classes and assess what proportion of these would be energy-efficient appliances assuming that consumers will buy energy-efficient appliance models that are economically justified. The study estimates the energy savings from the star rating of four major appliances, air conditioners (ACs), refrigerators, TVs and fans. The paper addresses the following questions:

- What is the stock of household appliances with rural and urban households in India in 2009?
- What will be the stock of appliances in 2030 and electricity consumption by them?
- What will be the uptake of energy efficient appliances by consumers on their own without any subsidy and what would be their spread?
- How much savings of electricity and emissions will result?
- What pro-active policies can increase spread of energy efficient appliances over the normal rise and how much electricity and emissions savings can result?

Energy savings by efficient appliances have been highlighted by India's Low Carbon Strategy for Inclusive Growth (Parikh, et al., 2014). A number of papers have projected ownership and energy use for selected appliances; e.g. air conditioners (Sivak, 2013; McNeil and Letschert, 2008; Auffhammer and Maximilia, 2011; Phadke et al., 2014); fans, televisions (TVs), and refrigerators, etc. (Rathi et al., 2012); a World Bank (2008) study provides a detailed analysis of residential electricity consumption in India. It projects appliance ownership by households till 2030 and estimates energy savings under alternate efficiency scenarios.

Our study is different in that it uses data of a more recent survey, accounts for income distribution in rural and urban areas and projects adoption of energy efficient appliances based on economic rationality the importance of which was brought out by Chatterjee and Singh (2012).

Parikh et al. (1994) examined the potential gains from specific measures to improve energy efficiency and found that barriers prevent industries from adopting energy-efficient equipment, even those with a very low payback period. It is therefore important to base our projection on the observed behaviour of households. Further, it helps to design programmes to incentivize consumers to purchase more energy-efficient appliances, as shown by Parikh and Banerjee (1994).

We also compare our results with other studies. Palmer et al. (2013) assessed the household-level electricity savings for the UK and Hubacek, Guan, and Barua (2007) compared appliance ownership in China and India. Sanchez et al. (2008) have assessed energy savings from USA's ENERGY STAR program and METI (2015) examines the impact of Japan's "Top Runner" program. IEA (2015) provides an assessment of energy efficient end-use equipment in different countries.

Section 2 describes the available data on household appliances in India, our approach and the methodology used. Section 3 discusses the ownership of appliances. Section 4 deals with the economics of different star-rated appliances and examines policies to accelerate adoption of more efficient appliances. Section 5 presents the use of star-rated appliances and the corresponding energy and emissions savings. *For simplicity of exposition, we use the terms ownership, use, and possession interchangeably*.

2. Available data, approach and methodology

Our approach to projection is based on the available empirical evidence.

2.1. Available data

In India the National Sample Survey (NSS) in its household survey carries out household consumption expenditure survey regularly since 1950. The sample size in recent surveys exceeds 200,000 households. This data is a valuable source of any analysis of how the standard of living and consumption patterns are changing. Apart from consumption expenditure it also provides data on the possession of appliances by households belonging to different per capita monthly expenditure classes. Since income data are considered unreliable in India, we use consumption expenditure in its place. The National Council of Applied Economic Research (NCAER) also periodically carries out more detailed household surveys but with a much smaller sample size than NSS. We have also used these data for our analysis. Data from BEE (2015) is used to assess the electricity consumption of various star rated models of the selected appliances.

The NSS is a quinquennial survey of consumer expenditure. The 66th round data (April 2009–March 2010; henceforth, we refer to this period as 2009) provides the number of households possessing an appliance per 1000 households for the year 2009. The population is divided into 10 decile classes of monthly per capita consumer expenditure (MPCE). The survey generates estimates of average MPCE by households and its distribution over households and persons.

2.2. Approach and methodology

Thus, we take the following step by step approach:

a) Total appliance ownership in the base year: Using the data of the 66th round (2009) of the household consumption survey by the National Sample Survey Organisation (NSSO, 2011) provide appliances possessed by households belonging to different decile classes of per capita consumer expenditure.
b) Income distribution of appliance ownership – urban and rural: Appliance ownership depends on household income or total per capita consumption expenditure. For a particular appliance we can stipulate that

$$X_{ij} = f(c_j) \quad (1)$$

Where X_{ij} = appliance i used by a household of per capita consumer expenditure class j
And c_j = total per capita consumption expenditure of

household class j.

Also these relationships will differ for rural and urban consumers and are separately established for different appliances to get X_{ijr} and X_{iju} for rural and urban households respectively.

c) Projecting per capita consumption expenditure for rural and urban areas: To project appliance stock we project per capita consumption expenditure for 10 different expenditure classes each for rural and urban households. This is done by projecting total national level aggregate consumption at constant 2009-10 prices. This is distributed to rural and urban consumers assuming a parity ratio between rural and urban per capita consumption and exogenously provided rural and urban populations based on projections by the Registrar General of Census in India.

Aggregate consumption at constant 2009-10 prices in 2030, C_{30} is projected by assuming an annual growth rate of 7% from 2010. Thus $C_{30}=C_{10}\,(1.07)^{20}$. Per capita consumption, c, will be $c=C_{30}/P_{30}$, where P_{30} is population in 2030. In the social accounting matrix for 2007-08 used for this study, the urban rural per capita consumption parity ratio was 2.5. Given the rural and urban populations. P_r and P_u, and a parity ratio of 2.5, so that $c_u=2.5c_r$, we can obtain the average per capita consumptions in rural and urban consumers, c_r and c_u respectively by the following.

$$C = P_u c_r R + P_r c_r \tag{2}$$

d) Distribution of consumption expenditure by different classes: To distribute the rural and urban populations to different expenditure classes we use separate log normal distributions of per capita consumptions in rural and urban areas i.e. if c_r and c_u are per capita consumption expenditure in rural and urban areas respectively, then $\log_n c_r$ and $\log_n c_u$ are normally distributed.

e) Log normal distributions of consumption expenditure have been observed to be quite stable over time (Ghosh et al., 2011) and we assume that it will remain so till 2030. It can be described by two parameters, mean income and standard deviation as follows.

$$h = N\,(log_n c :\ \mu, \sigma) \tag{3}$$

where h is the proportion of households with per capita consumption expenditure c, μ is mean of $\log_n c$ and σ is standard deviation. Our estimated σs from NSS survey are

$$\sigma_r = 0.7\sigma_u = 1.0$$

Thus

$$N_r(log\ c_r{:}\ \mu_r,\ 0.7)$$
$$N_u(log\ c_u{:}\ \mu_n,\ 1.0)$$

Thus $_{Hjr}$ proportion of households in expenditure class j of rural population is given by

$$h_{jr} = \int_{jl}^{ju} \mathrm{N}(\log c :, 0.7)dc \tag{4}$$

where h_{jr} is the proportion of households in class j with lower limit of per capita concumption jl and upper limit ju and similarly for h_{ju}.

f) Stock of appliances: Based on this, the numbers of households in consumption expenditure class j are obtained as $H_{ju}=h_{ju}{}^*$ U and $H_{jr}=h_{jr}{}^*$R, where U and R are the total number of urban and rural households. We assume that in future also the proportion of households belonging to the same level of monthly per capita consumption expenditure at constant prices will possess a particular appliance at the same rate as was observed in the survey of 2009. The total stock of appliance $_i$ is then given by

$$X_i = X_{iju}{}^*H_{ju} + X_{ijr}{}^*H_{jr} \tag{5}$$

This gives us the stock of appliances by different expenditure classes in rural and urban areas for 2030.

g) Economic attractiveness of different star rated models: In order to assess the penetration of star rated appliances, we examine the cost difference and energy savings between a star-rated appliance and the lowest rated appliance and assess the economic attractiveness of it under alternative policies. We assume that a consumer will purchase the star rated appliance if the present discounted value of annual saving in electricity charges over the life of the appliance exceeds the initial cost difference over a base rated appliance. Thus if the initial cost difference between a 1 star-rated and a 3 star-rated appliance is K, annual saving in cost of electricity is E, life of the appliance is L and discount rate as a fraction is d, then a consumer will buy a 3 star-rated appliance instead of a 1 star-rated appliance if

$$E[(1+d)/d][1-(1/(1+d)^{\wedge L})] > K \tag{6}$$

h) Projecting share of star rated models and savings in electricity consumption: Based on this, we project the number of different star rated appliances the household will have and the likely savings in energy consumption at a prescribed price of electricity that will result by 2030. We assume that poorer households have a higher discount rate than richer households.

3. Results and discussion: projection of household ownership of appliances

We first estimate the stock of appliances owned in 2009 by rural and urban households. Then, we relate the demand for various appliances to MPCE. Next, appliance ownership for 2030 is projected.

3.1. The stock of appliances in 2009

Data for various household appliances and durable goods that are possessed by rural and urban households according to their monthly per capita consumption expenditure (MPCE) decile class for the all-India level in the year 2009 are obtained from NSSO survey. NSSO data provide information on the possession of air conditioners (ACs) and coolers together. To obtain data only for

Table 1
Estimated number of appliances owned by households (millions) and number per 1000 persons in 2009.

	Rural	Urban	Total	Rural	Urban	Total
MPCE (INR)	**1054**	**1856**	**1290**	**1054**	**1856**	**1290**
Appliance	**Millions**			**Number per 1000 persons**		
Electric fan	157	135	292	187	386	246
Television	64	63	128	77	181	107
Refrigerator	9	27	36	11	76	30
Air conditioner	0.5	3.6	4	0.6	10	3.4

Notes: The authors' estimates are based on NSS data and the number of appliances per household assumed to match other evidence. Population (in millions) in 2009: Rural 840; Urban 350; Total 1190, which with a household size of around five persons give 163 million rural, 68 million urban and 231 million total households. MPCE is monthly per capita consumption expenditure. INR is Indian Rupees. The PPP exchange rate in 2009 was INR 13 per one US $.

ACs, we have taken the NCAER (2014) data for ACs owned by rural and urban households.

The NSS survey collects data on whether the household possesses the appliance or not but does not collect how many units of the appliance are possessed by the household. We have assumed that in the first few deciles, each household has only one unit of the appliance, whereas on average, the higher deciles would have more than one unit of some appliances. The assumed number of units of an appliance per appliance-owning household is taken as 1 for all households except for fans. In the case of fans, the number of units owned by the households of the top 6th to 9th deciles is taken as 2 and that for the top decile is taken as 3 in rural areas, whereas for urban households, the number of fans owned is taken as 2 for the top 4th to 9th deciles and 4 for the top decile. Further, for urban households, the number of refrigerators, TVs, and ACs owned per household is taken as 2 for the top decile.

Based on the above assumptions, we have calculated the number of units of appliances owned by rural and urban households in 2009. These results are presented in Table 1 along with the number of units owned per 1000 persons. The projected number of units is more or less consistent as compared to the NCAER data for the year 2010–11. In fact, the assumptions of the number of units per household were made in order to obtain estimates that match the NCAER estimates of the number of units of various appliances with households.

It is emphasized that the appliances considered are household appliances only and do not include appliances owned by and used in the commercial private sector and public sector institutions, which own significant number of certain appliances.

The data show that electric fans are the most widespread in both urban and rural areas. While 90% of urban households own at least one electric fan, only 55% of the rural households do so because of the lack of electricity access in many rural areas. If one accounts for the differences in electricity access, the relative preferences for different appliances of rural and urban households look comparable.

3.2. Relating appliance ownership and monthly per capita consumption expenditure (MPCE) of the household

We have plotted the possession of appliance data against MPCE. Since MPCE will increase substantially in the future, the 2009 NSS data have to be extended. Figs. 1 and 2 show the graphs for different appliances for rural and urban households, respectively. For each appliance line, there are twelve points, the first 10 points, the portions up to around Indian Rupees (INR) 14,400 MPCE for rural areas and around INR 23,100 MPCE for urban consumers, correspond to the deciles of NSSO and NCAER surveys.

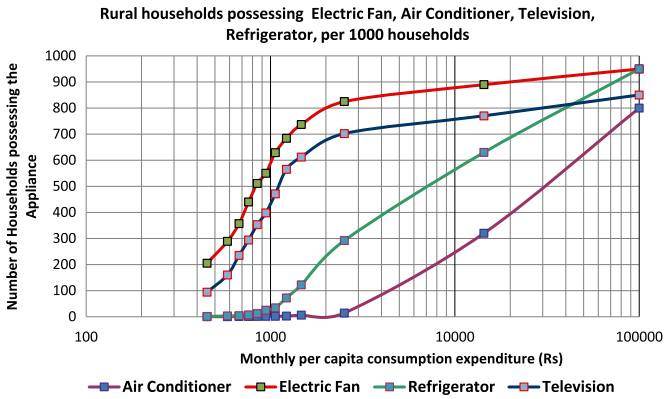

Fig. 1. Rural households' ownership of appliance and monthly per capita consumption expenditure (MPCE) of the household.

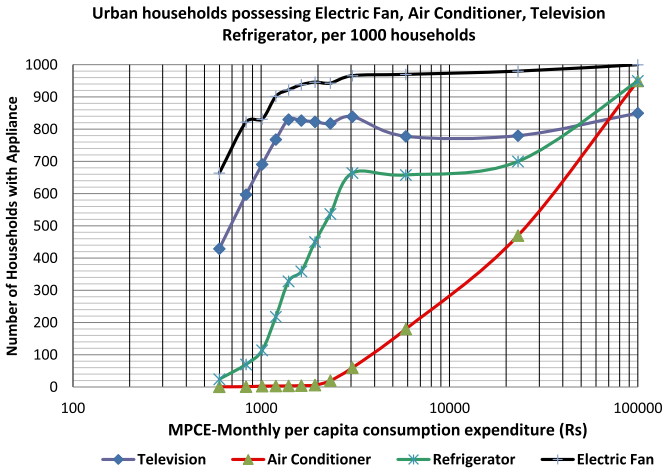

Fig. 2. Urban households' ownership of appliance and monthly per capita consumption expenditure (MPCE) of the household.

Table 2
Appliance and vehicle ownership of the richest 100 households in the NSS survey.

	Rural households	Urban households
Average MPCE (INR)[a]	14,383	23,108
Electric fan	89	95
Television	77	76
Refrigerator	63	70
Air conditioner	32	47

The PPP exchange rate in 2009 was INR 13 per US $.

[a] Monthly per capita consumption expenditure in Indian rupees.

To assess appliance use by households with much larger MPCE, we tabulated appliance possession by the richest 100 households in rural and urban areas in the NSS survey (see Table 2). This gives us the 11th point. It may be noted that in our projections we do not go beyond the 11th point for rural households and only slightly beyond that for urban households. The last point corresponding to MPCE of Rs 1,00,000 is obtained by extending the trend of the first eleven points. The extensions are made on heuristic considerations based on the trends of the survey data, the rate at which some of the appliances have grown in China where air conditioners in urban households grew from 30% in 2000 to more than 100% in 2010 (Hubacek et al., 2007) and saturation levels that seemed reasonable. It may be noted that the highest level of MPCE, shown in Figs. 1 and 2, of INR 1,00,000 per person per month corresponds to an expenditure of USD 80,000 per person per year in purchasing power parity terms. At this level, saturation for many appliances seems reasonable.

We reiterate that in the figures above higher appliance levels are reached with increased consumption expenditure levels and not automatically simplistically? with time. However as income growth takes place, the amounts available for consumption expenditure also increase. Thus, there is a linkage with time but it depends on economic growth. In the next section we show projections for 2030.

3.3. Projection of consumption expenditure, its distribution, and appliance ownership for 2030

Assuming an annual growth rate of private consumption of 7% from 2009 to 2030 and the ratio of urban to rural MPCE as 2.5 on the basis of the social accounting matrix of 2007–08 (Pradhan and Sharma, 2013) we have calculated distribution of households in different consumption expenditure classes using the method

Table 3
Projected rural and urban population distribution for different expenditure classes based on MPCE at constant prices.

Class	Rural MPCE (INR)	Rural population %	Rural MPCE (INR)	Rural population %	Urban MPCE (INR)	Urban population %	Urban MPCE (INR)	Urban population %
	2009	2009	2030	2030	2009	2009	2030	2030
1	453	**10**	350	0.1	599	10	735	0.2
2	584	**10**	588	0.3	831	10	833	1.5
3	675	**10**	1125	4.2	1012	10	2158	12.6
4	761	**10**	1668	5.8	1196	10	3811	10.8
5	848	**10**	2154	7.2	1398	10	5289	9.8
6	944	**10**	2990	18.6	1633	10	7478	15.8
7	1063	**10**	4168	16.1	1931	10	10,502	11.3
8	1221	**10**	5448	14.1	2330	10	13,968	10.3
9	1470	**10**	7094	13.1	3051	10	17,865	6.5
10	2517	**10**	12,958	20.5	5863	10	40,184	21.2
All	1054	**100**	**5882**	**100**	1856	**100**	**14,702**	**100**

Table 4
Projected number of appliances owned by households (in millions) and its increase over 2009.

Appliances	Millions			Per 1000 households			Ratio of total stock to 2009
	Rural	Urban	All	Rural	Urban	All	
Electric fan	594	342	936	2495	2713	2564	3
Television	211	125	336	889	992	922	3
Refrigerator	130	105	235	547	833	644	7
Air conditioner	14	55	69	59	437	189	17
Population (Millions)	950	503	1453	950	503	1453	1.22
Households (Millions)	238	126	365	238	126	365	1.53

(Authors' Projections).

described in Section 2.

The projected MPCE and population proportions are given in Table 3. Total rural, urban and total populations were determined exogenously on the basis of the projections by India's Registrar General of Census to be 950, 503 and 1454 million in 2030 respectively. Household size is projected to reduce from 5 in 2009 to to 4.0 in 2030.

We also assume that the number of each appliance owned by households owning the appliance will change as with higher income, households will have multiple units of the same appliance. Thus, the number of electric fans will increase from 2 per household in poorer classes to 5 per household in the richest class. The promise to bring 24/7 "electricity to all by 2018" in the budget speech of the finance Minister on feb 29th 2016 (MOF-Ministry of Finance, 2016) makes this a reasonable assumption.

Using Table 3 and Figs. 1 and 2, we have projected the total number of the four selected appliances owned by the households according to their expenditure class for the year 2030. These projections are summarized in Table 4.

It can be seen that up to 2030, it is the upper expenditure classes that will drive appliance growth because of two factors: more people will move to this class and more purchases will be made per 1000 persons. This is so for both rural and urban classes. On the other hand, the lower expenditure classes will have fewer people than before, but as they will be relatively better off, the number of appliances owned by them will also increase. The main drivers of the number of appliances owned will be the increase in income and the shift of people to higher expenditure classes. This is seen in Table 3 that while 60% of rural population had MPCE bellow INR 1065 and 10% above INR 2000 in 2009, in 2030 only 0.4% of rural population is projected to have MPCE below INR 1100 and more than 80% had MPCE above INR 2500. Similar movements also take place among urban population.

Table 5
Comparison of stock estimates by the authors and the World Bank.

Appliances (millions)	World Bank (2008) Study 2031	Authors' projection 2030	Authors'/World Bank estimate 2030/2031
Electric fan	1092	936	0.91
Television	296	337	1.14
Refrigerator	201	235	1.17
Air conditioner	48	69	1.44

The number of appliances owned increases rapidly with an assumed growth rate of per capita consumption expenditure of more than 7% per annum. This is the kind of growth rate India aspires to and is feasible for it to achieve. With an average household size of 4.0 persons, by 2030, every household will have electric fans, mobile phones, and one TV. 70% of the households will have a refrigerator. However, the ownership of ACs will be limited to only 18% of the households.

In Table 5, we compare our stock projections with projections by World Bank for India. The World Bank estimates made in 2008 are based on the NSS surveys of 2004–05, whereas ours are based on the more recent survey of 2009–10. Over this period, the appliance sales boomed as the Indian economy registered an annual growth rate of around 9% during these 5 years. Also in the World Bank study appliance use depends on percentile classes of consumers whereas in our study it depends on consumption expenditure levels. Moreover, in our study spread of energy efficient appliances is based on economic attractiveness for consumers. In Table 5, we see that in 2030 our estimates are larger than the World Bank's, excepting for electric fans. Our estimate for 2009 of the number of electric fans owned is 280 million units and is consistent with the NCAER survey of 2011–12, which estimated the number to be 310 million after two years of growth. Compared to that the World Bank estimates 354 million fans for the period 2011–12.

4. Spread of star-rated appliances

Having estimated the appliance stock, we come to the question of how many of the four major energy consuming appliances, namely air conditioners, refrigerators, TVs and fans will be star-

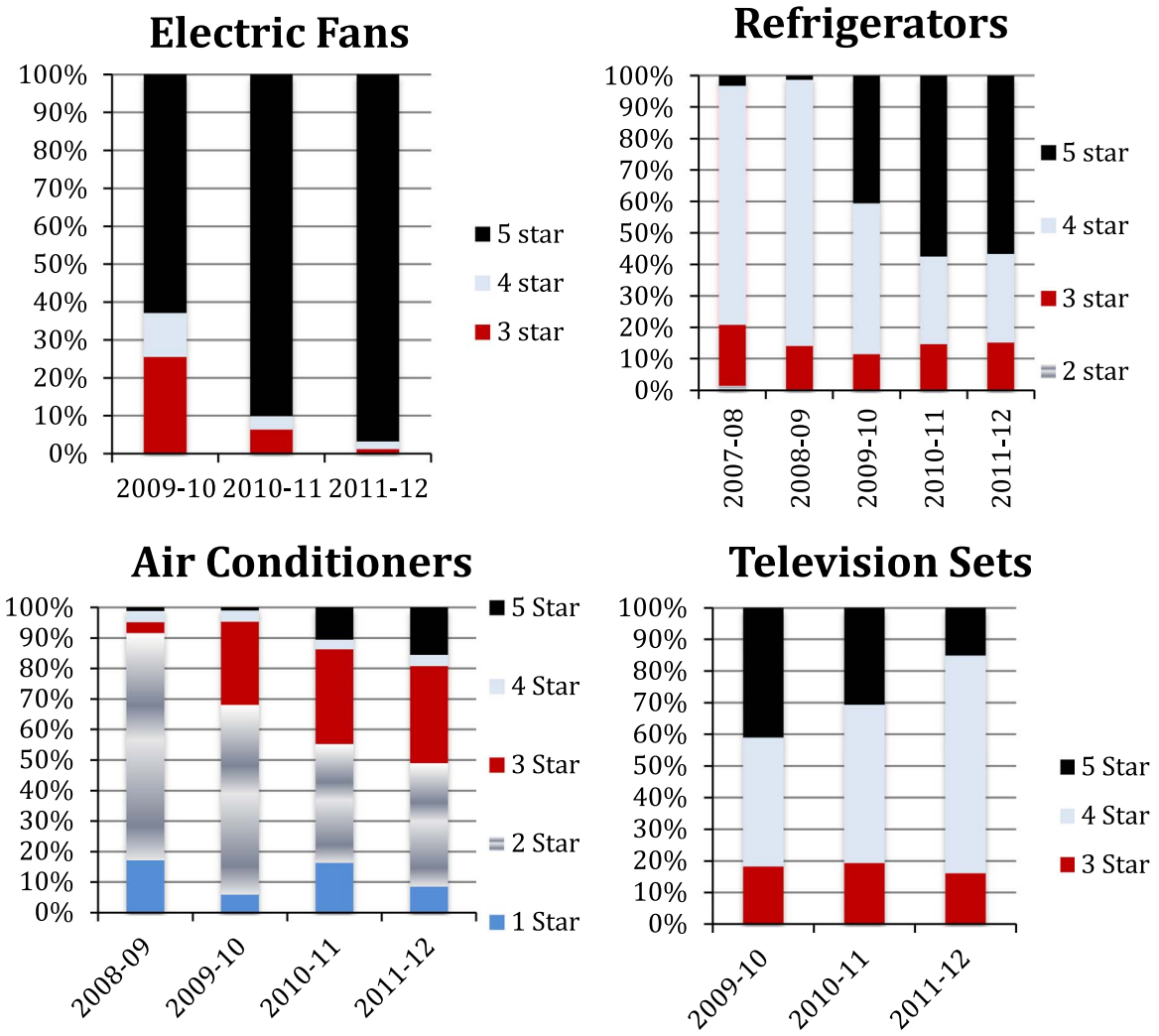

Fig. 3. Shares of rated appliances sold from 2007 to 08-2011–12.

rated appliances of different ratings and the resulting saving in electricity consumption and CO2 emissions.

BEE started its appliance labelling program in 2006. Every year, an independent evaluation is carried out by National Productivity Council (2010), which assesses the penetration of the starred products. Using the data from the evaluations downloaded from the BEE website, penetrations of different starred products are worked out. These data are shown in Fig. 3.

It can be seen that there is a wider shift to 5-star-rated appliances for cheaper and frequently used items such as fans compared to expensive items like ACs and refrigerators.

These data refer to annual sales and do not differentiate between consumer classes. We can conclude that consumers are buying higher star rated energy-efficient appliances on their own, even though they cost more, and no subsidy is given for the purchase of these appliances and there are no regulations mandating such purchases. However, Parikh and Banerjee (1994) argue that if financed, the promotion of these appliances will be considerably more effective. This is supported by the analysis in the next section where it is shown that if consumers are to buy the most energy efficient appliance that is economically attractive additional savings might result.

4.1. Economic analysis of rated appliances

A consumer will buy a more expensive and higher star-rated product if the value of the energy savings exceeds the initial cost. This will depend on the expected life of the appliance, electricity cost, the discount rate at which future savings in the electricity bills are valued. The energy consumed by an appliance depends on the size, rate of use and the type such as direct cool (DC) or frost free (FF) refrigerator, window or split air conditioner (AC), CRT or LCD television and also on the star rating. Higher rated appliance saves electricity but costs more. An appliance may be considered economically attractive to a consumer if the present discounted value (PDV) of the savings in electricity bill over the life time of the appliance exceeds the additional cost of star rated appliance.

To identify economically attractive models, we assume that the poorer classes will have a higher discount rate of 20% compared to richer classes with a discount rate of 10%. These may be considered their opportunity costs in terms of what the rich may earn otherwise or what the poor may have to pay for consumption loans. Since the electricity tariff is usually a step function and increases by slabs, we have considered the electricity tariff to be Rs 4/kWh for the poorest classes, 5 urban and 6 rural, and Rs 6/kWh for the richer classes. As of 2012, the tariff for consumers consuming 0–200 kwh per month, the tariff is INR 4/unit (including surcharge of 8%) and for those consuming more than 400 units it was INR 6.9 per unit (DERC, 2012).

For ease of presentation, the households are grouped into two classes, namely poor and rich, depending on their MPCE. Rural households with MPCE of less than INR 4,000 (bottom 6 classes)

Table 6
Air conditioners: initial cost, energy consumption and economic attractiveness.

Star rating	Cost (INR/ unit)	Energy consum. (kwh/ year)[a]	Energy saving over 1* (kwh/ year)	PDV of saving @ INR 4/kwh and discount rate of 20%	PDV of saving @ INR 6/kwh and discount rate of 10%
Window Acs: (1.5 Tonne, operated 1200 h per year, life 10 years)					
1	18,190	2258	0	0	0
2	19,000	2101	157	3159	6367
3	24,990	2061	197	3964	7989
4	27,000	2004	254	5111	10,301
5	30,000	1856	402	8090	16,303
Split Acs: (1.5 Tonne, operated 1200 h per year, life 10 years)					
1	23,000	2100	0	0	0
2	26,000	1981	119	2395	4826
3	29,000	1926	174	3502	7056
4	31,500	1849	251	5051	10,179
5	33,500	1786	314	6319	12,734

[a] From BEE rated data for 148 window and 309 split ACs of 1.5 T, (BEE, 2015).

Table 7
Refrigerators: Initial Cost, Energy Consumption and Economic Attractiveness.

Star rating	Cost (INR/ unit)	Energy consum. (kwh/ year)[a]	Energy saving over 2* DC and 1* FF (kwh/ year)	PDV of saving @ INR 4/kwh and discount rate of 20%	PDV of saving @ INR 6/kwh and discount rate of 10%
Direct cool (DC) refrigerators (175–225 litres, life 10 years)					
1	0				
2	9000	419	0		
3	10,500	322	96	1661	3085
4	13,000	258	161	2786	5173
5	16,000	207	211	3651	6780
Frost free (FF) refrigerators (235–265 litres, life 10 years)					
1	9000	500	0		
2	11,000	400	100	2012	4055
3	14,000	310	190	3824	7705
4	17,500	240	260	5232	10,544
5	20,000	190	310	6238	12,572

[a] From BEE rated 305 DC and 175 FF models (BEE, 2015) of these capacities.

Table 8
Colour TV: initial cost, energy consumption and economic attractiveness.

Star rating	Cost (INR/ unit)	Energy consum. (kwh/year)[a]	Energy Saving over 1* (kwh/ year)	PDV of saving @ INR 4/kwh and discount rate of 20%	PDV of saving @ INR 6/kwh and discount rate of 10%
CRT televisions – 55 cm screen size- operating hours 2190 per year- life 10 years					
1	7800	235	0	0	0
2	8200	208	27	543	1095
3	8500	188	47	946	1906
4	10,000	167	68	1368	2758
5	13,500	140	95	1912	3853
LCD televisions – 55 cms screen size- operating hours 2190 per year- life 10 years					
1	16,500	158	0	0	0
2	17,000	135	23	463	933
3	17,500	108	50	1006	2028
4	18,500	92	66	1328	2677
5	23,000	71	87	1751	3528

[a] From BEE rated models (BEE, 2015) of 55 cms.

Table 9
Ceiling fans, minimum air delivery 210 cubic metre/minute, operating hours 3600, Life 10 years.

Star rating	Cost (INR/ unit)	Energy consump.[a] (kwh/year)	Energy saving over 2* (kwh/ year)	PDV of saving @ INR 4/kwh and discount rate of 20%	PDV of saving @ INR 6/kwh and discount rate of 10%
1	0	0	0	0	0
2	1600	222	0	0	0
3	1750	209	13	**266**	**535**
4	1900	197	25	**503**	**1014**
5	2100	180	42	**845**	**1703**

[a] From BEE rated 138 models (BEE, 2015) of this capacity.

and urban households with MPCE of less than INR 5,500 (bottom 5 classes) are classified as poor households. The rest are treated as rich households.

Tables 6–9 show the costs, characteristics and economic attractiveness of the most common models of the four selected appliances. The energy consumption of the appliances are taken from the star rated models by BEE of these appliances (BEE, 2015). The number of operating hours are based on communications by BEE. Also the life time assumed are not the life time of equipment but the number of years over which consumers may take in to account the saving in electricity bills. The lightly shaded bold cells show economically attractive models.

It can be seen that at the higher discount rate and the lower electricity price that the poorer households have, 5* product is purchased only for a relatively low initial cost item such as electric fan. On the other hand, we can assume that most people who buy air conditioners are likely to be richer and pay a price of Rs 6/kwhr, for them 5* air conditioner would be economical. Yet if we see in Fig. 3, consumers purchase ACs with 2*,3*, 4* and 5* ratings. This may be an outcome of liquidity constraint as ACs cost substantial amount per unit. The penetration of 5* ceiling fans is nearly 100 per cent as can be seen in Fig. 3 as the unit cost of a ceiling fan is much less compared to that of an AC. *Thus, financing will increase the adoption of higher star-rated items of relatively more expensive items.*

5. Estimation of energy and emissions savings from star-rated appliances

5.1. Energy savings

After estimating the stock and share of start rated appliances, we now come to Energy savings. They are estimated for the year 2030 for the poorest 5 urban and 6 rural classes and the richest 5 urban and 4 rural classes. We generate a number of scenarios to get a range of likely saving that may occur. In scenario 1 to obtain a lower bound we assume that households will purchase the lowest star rated appliance that is economical. The saving in billion kwh (bkwh) and percentage terms from the electricity consumption in the base star rated models are shown in Table 10 for this scenario.

The adoption of the lowest star rated economical models leads to a saving of 52046 million kwh of electricity per year which is 13% of the consumption by the base rated models of these four appliances. 2* ACs save only 6–7% of electricity whereas 2* FF refrigerator saves 20–22%. 2* colour TV saves 11–15%.

Three more scenarios are developed with adoption of progressively higher star rated models. The savings in these scenarios are worked out in the same way as in Table 10 taking the data from Table 9. All the four scenarios are summarized in Table 11.

Table 10
Energy saving through star-rated appliances – scenario 1.

Poorest classes	Units owned (Millions)	Star rated	Energy saving (kwh/unit/year)	Energy saving by star rated appliances (million kwh)	Energy consumed by base product (kwh/unit/year)	Energy consumption in base product (Million kwh)	Energy saved over of base energy (%)
1	2	3	4	5=2*4	6	7=2*6	8=100*5/7
Poorest classes (6 rural+5 urban)							
AC	4	2* Window	157	673	2258	9683	7
Refrigerator	49	3* DC	96	4714	419	20,576	23
Colour Tv	98	2* CRT	27	2643	235	23,001	11
Ceiling Fans	198	3*	13	2573	98	19,395	13
Richer classes (4 rural+5 urban)							
AC	65	2* Split	119	7764	2100	137,005	6
Refrigerator	186	2* FF	100	18,596	500	92,981	20
Colour Tv	239	2* LCD	23	5491	158	37,723	15
Ceiling Fans	738	3*	13	9592	98	72,305	13
All Classes				52046		412,668	13

Table 11
Energy saving under different scenarios: economically attractive star rated appliances in different scenarios.

	Lowest-1	One higher-2	highest-3	All 5*-4
Poorer Classes				
AC	2* Window	2* Window	2* Window	5* Window
Refrigerator	3* DC	3* DC	3* DC	5* DC
Colour Tv	3* CRT	3* CRT	4* CRT	5* CRT
Ceiling Fans	4*	4*	5*	5*
Richer Classes				
AC	3* Split	3* Split	5* Split	5* Split
Refrigerator	3* FF	3* FF	5* FF	5* FF
Colour Tv	3* LCD	3* LCD	4* LCD	5* LCD
Ceiling Fans	4*	4*	5*	5*
Saving (bkwh)	52	92	151	165
Saving (%)	13	22	37	40

Scenario 2 saves 92 bkwh or 17% electricity whereas scenario 3 saves 151 bkwh or 37%. Scenario 4 assumes every one uses 5* products even when they are not economically attractive. It saves 165 bkwh or 40% over the base rated models. This is an upper bound of saving that can be made with existing models and assuming government policies or technical progress either brings down the cost of 5* models or provides incentive such as cheap finance. The scenarios also reflect what can happen if learning by doing reduces the cost or efficiency of models. In which case consumers will find higher star rated models economically attractive.

It may be noted that we have not considered super-efficient fans, which have been introduced into the market in 2015 but are relatively quite expensive. It seems that the government needs to actively promote the purchase and use of fans, which are high energy-consuming appliance because of numbers and hours of use.

What these show is that substantial savings in 2030 in the energy consumption by the four appliances can result as a result of the labelling program.

5.2. Reduction in emissions

CO_2 emissions reduce over the baseline due to reduction in electricity consumption due to greater uptake of energy efficient appliances. The emissions of CO_2 per kilowatt hour in India's electricity generation mix of 2013–14 were around 0.82 kg/kWh (CEA, 2014). Based on this, the emissions from the use of these four appliances would be 338 Mt of CO_2 in 2030 with base rated appliances. With higher star rated appliances, the reductions in emissions due to these four appliances alone would be between 43 and 124 Mt of CO_2 per year in 2030. With policies to push 5* models it could be 135 Mt with existing models. With development of more energy efficient models and reduction in initial price, larger savings can be obtained.

5.3. Comparision with other countries

We now compare these results with experience in other countries of appliance labelling programmes.

The USA's "energy star" is a voluntary energy efficiency labelling program started in 1992. Sanchez et al. (2008) estimated a projected saving over 1992–2015 of 203 Mt of CO_2. IEA (2015) shows that in 2013 this program saved 380 bkwh of electricity and 294 Mt of CO_2 in the USA. The USA's residential electricity consumption in 2013 was around 1400 bkwh. The saving thus is around 27.5% of residential consumption. IEA also shows saving in household electricity consumption of 10% in 2012 for New Zealand and Australia and a projected saving of 25% in 2020 for EU, which is much more proactive than many other countries. The IEA estimates compare with our estimates of 13–40% saving in the year 2030 from appliances in the household sector alone.

Japan's "Top Runner" program (METI, 2015) has concentrated on manufacturers of appliances who are set targets for energy efficiency by given dates. The goal is to have the world's most energy efficient appliances. The target over 2005–2010 for energy efficiency improvement for ACs (wall mounted) and refrigerators were 22.4% and 21% respectively. The actual improvements were 16.3% for ACs and 43% for refrigerators. For LCD/Plasma TV the improvements over 2008–2012 was 60.1% compared to the target of 37%. These numbers are comparable to enrgy savings between 1* rated model and 5* rated models. Table 6 shows a saving of 15–18% for 5* ACs, Table 7 shows improvements of 50–60% for refrigerators and Table 8 shows that a 5* LCD TV saves 55% of electricity over a 1* TV.

Thus our estimates of how much enrgy India can save from energy efficient household appliances are comparable to what other countries have achieved.

6. Policy implications

It can be noted that the estimates in the previous section are only for households, and commercial and government purchases are not included in them. The savings are obtained without any incentive provided by the government. We consider here some policies that can accelerate adoption of more energy efficient appliances. We deal with them below.

6.1. Increasing effectiveness of labelling

Households on their own do buy energy efficient star rated products as seen in Fig. 3. The labelling program created awareness among consumers of possibilities of saving electricity. The effectiveness in creating awareness can be increased by designing labels specific to different states. Davis and Metcalf (2015) have shown that state specific labels can be effective in the USA.

6.2. Public sector and government procurement

Households and private commercial enterprises are driven by economic consideration and opt for more energy-efficient appliances on their own. On the other hand, public sector procurement is based on the lowest initial cost basis and the Government of India has mandated that public-sector enterprises and government departments buy only 5-star-rated appliances. Thus these would be procured regardless of their performance superiority over lower star rated appliances. This could jack up the price of 5-star-rated appliances. Though this policy is easier to implement, it compromises competition between different star-rated products. A better policy would have been to announce a price preference for different star-rated appliances so that 5-star-rated appliance manufactures would have an incentive to compete with lower-priced products.

6.3. Impact of financial incentives

Households will opt for even more energy-efficient appliances with financial incentives. The impact of the policy of providing finance that leads consumers both rich and poor to opt for higher star rated models is seen in Table 11. Going just one star above increases savings from 13% to 22%. If all are incentivised to go for only 5* models the savings could be 40%.

Finance can be provided by electricity distribution companies (DISCOMs) and government can provide them interest subsidy to provide consumers low interest loans. Also, energy service companies (ESCOs) can be encouraged by the government to promote more energy efficient appliances, particularly for replacing or retrofitting older equipment.

6.4. Bringing down the cost of appliances

Another way to promote adoption of energy efficient appliances is to bring down their costs. Bulk procurement by the government through competitive bidding for a 5-star-rated appliances can be an effective way not only to bring down the price of the appliance but also to facilitate public sector and government departments to buy such an energy efficient appliance at lower cost. If a consolidated tender is floated for a large number of units of a particular appliance, its price can be brought down. For example, to promote faster diffusion of light-emitting diode (LED) lamps for lighting, India's Bureau of Energy Efficiency (BEE) has floated periodically, competitive tenders to buy a large number of LED bulbs. This has provided scope for manufacturers to exploit the economies of scale, and the price of LED bulbs has decreased from few hundred rupees just two years ago to less than INR 100 (see Fig. 4). A similar measure can be followed for other appliances.

Source: personal communication from BEE.

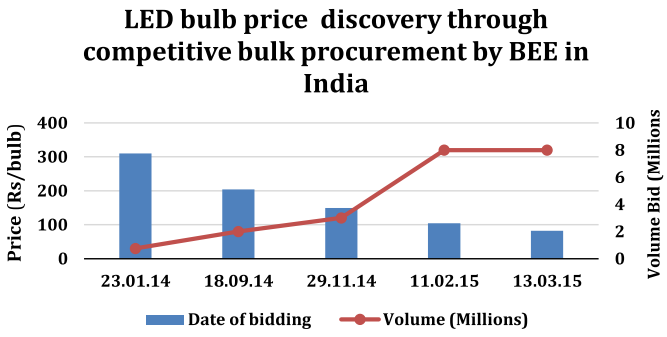

Fig. 4. Price Reduction of LED Bulbs through competitive bulk procurement. *Source*: personal communication from BEE.

6.5. Appropriate pricing of electricity and reduction in cost of appliances

We have assumed the price of electricity to remain constant at Rs 4/kWhr for the poorer classes and Rs 6/kWhr for the richer classes. Since consumption expenditures are projected at constant prices, electricity prices are also kept fixed. This seems reasonable to do. Higher electricity tariff would encourage consumers to buy more energy efficient appliances. Removing subsidies especially in the residential and commercial sectors will lead to appropriate price. However, this may reduce the total number of a particular appliance purchased and increase the cost of the appliance. Also raising electricity price for poorer classes is politically difficult to do. Any increase in relative price of electricity will lead most likely to larger energy savings. Similarly if appliances become cheaper in future, and the cost differences between star-rated appliances get reduced, higher star-rated appliances will become economically attractive. Thus larger energy savings will take place. Thus our projection may be taken as providing a lower bound on energy savings.

7. Summary and conclusions

In this paper, we have taken the NSSO 66th round decile class-wise expenditure data for different monthly expenditure deciles for the year 2009. When appliance ownership classes for decile groups according to consumption expenditure levels are examined, we find higher ownership at higher expenditure levels. For 2030 we projected class-wise populations and consumption expenditures assuming a 7% economic growth rate per year in the aggregate consumption in the country. Based on these extensions and projections, we have estimated the number of appliances that will be owned by households for the year 2030.

We have considered star-rated products direct cool refrigerators, frost-free refrigerators, colour TVs, window ACs, split ACs and ceiling fans, and water heaters.

We see that the stock of household appliances will grow manifold compared to 2009. Although the population in 2030 will be only 22% higher than in 2009, the stock of fans will be higher by a factor of 3; TVs by a factor of 3; and refrigerators by a factor of 7. Expensive item like ACs with a very low ownership in 2009 will show the stocks increase to 17 times by 2030. Even then, the stock in urban households in 2030 would be lower than what prevailed in China in 2010 for AC and TV and comparable for refrigerator (Zhou et al., 2012).

We have assumed that all the appliances owned by households will be the ones that are economically attractive star rated ones as reflected in Tables 10 and 11 as the production of the less energy efficient appliances would have stopped by then.

The capital cost were obtained from BEE. The average energy consumption for each star-rated appliance was obtained from the list of star rated models by BEE.

The availability of finance or technical progress may be particularly important for faster adoption of higher star-rated high cost appliances such as AC and refrigerators, which also consume more energy.

We estimate that electricity savings from just four appliances, namely AC, refrigerator, colour TV, and ceiling fan, for which data were available, will reduce electricity consumption of households from 52 to 151 bkWh in 2030, a reduction of 13% and 37%, depending on the spread of star rated models even without financing. With policies to reduce cost and low cost financing the saving in 2030 could be 165 bkWh, a reduction of 40%.

The corresponding reduction in CO_2 emissions in the absence of financing will be between 43 million tonnes to 124 million tonnes in 2030, assuming the same mix of electricity generation as in 2009 from coal, hydro, and nuclear sources. With policies it would be 135 Mt in 2030. This is 40% savings.

Improving efficiency should be a never-ending pursuit and a way of life. Hopefully, increasingly energy-efficient appliances will be available in the near future, leading to energy savings exceeding the above estimates. The move towards more energy-efficient rated products could be accelerated by fiscal incentives. From the country's point of view, this may be desirable as well. However, incentives should be given in a manner that they do not become a perpetual fiscal burden but stimulate competition and reduce costs.

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