Potential Savings from Selected Super-Efficient Electric Appliances in India

A Discussion Paper

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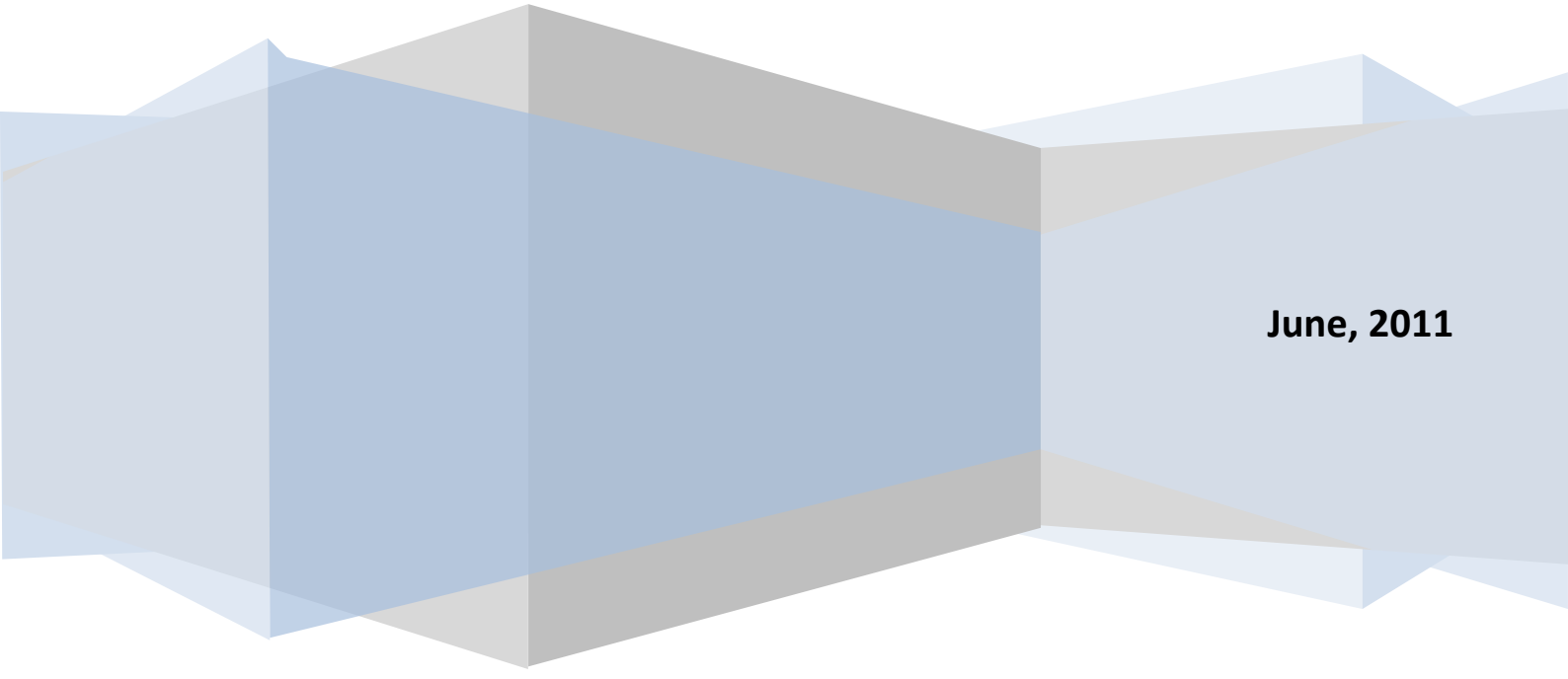

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Abstract

India's continued high economic growth is likely to result in booming sales of electrical appliances in both residential and commercial sectors, placing a tremendous burden on the already resource-strained power sector. Policies that encourage energy efficiency have the unique advantage of meeting demand through existing capacity at a lower cost than that of building additional capacity. We present a case for promoting super-efficient appliances (SEA) as a step beyond India's current standard and labelling (S&L) program. We considered four most popular mass-market electrical appliances, namely room air conditioners, refrigerators, television sets, and ceiling fans, and found that compared to a moderate S&L program, a shift to super-efficient models of these appliances in the next decade can save three times as much electricity as that possible through the aggressive S&L program proposed by Bureau of Energy Efficiency clearly pointing out the urgent need to go beyond the S&L program. We estimate the total savings from SEA in 2020 at 60 TWh avoiding about 48 million tonnes of CO_2 equivalent. An estimated 20,000 MW of peak capacity will be avoided as a result of these savings.

Keywords: electrical appliances, energy efficiency, saving potential, India

Introduction

India's high economic growth has resulted in booming sales of electrical appliances in both residential and commercial sectors, placing a tremendous burden on the already resource-strained power sector. Limited supply of the resources required for power generation such as land, fuel, and water and rising concerns about the impacts of power generation on the global environment pose serious challenges to building new power plants. Energy efficiency measures have the unique advantage of meeting demand through existing capacity at a lower cost than that of building additional capacity. For example, more energy-efficient models of such long-lasting electrical appliances as room air conditioners and refrigerators offer long-term savings in electricity.

The Bureau of Energy Efficiency (BEE), a nodal agency to implement energy efficiency policies in India, has been carrying out a standards and labelling (S&L) program for different electrical appliances since 2006. The program is mandatory for some appliances and voluntary for others. Every model is rated for its energy efficiency and the rating is given in the form of stars, a model earning a 5-star rating being the most energy-efficient. Appliances for which the program is mandatory must earn at least 1 star before they can be marketed. This program has boosted the sales of more efficient models in India (National Productivity Council, 2010). Super-efficient appliances (SEA) are even more efficient than those that have earned a 5-star rating in India. For example, a power rating of 60 W or less is enough for a 21" LCD TV set to earn a 5-star rating in India whereas an efficient model of

32" LCD TV set available in USA consumes only 32 W.[1] A super-efficient model does not necessarily use the best possible conceptual technology to improve its energy efficiency; rather, it uses a technology that has already been commercialized and available in the market. A market shift to such SEA models has the potential to maximize the savings that can be achieved from any appliance efficiency program.

Need to look beyond S&L

Ratcheting up the current S&L program to the SEA level can be slow and is unlikely to bring about the desired market shift. The Bureau of Energy Efficiency had initially planned to tighten the standards in 2008 but could not do so, probably because of resistance from appliance manufacturers. On the one hand, high-efficiency models are usually expensive and hence may not find buyers in the price-sensitive Indian market; on the other, manufacturers are hesitant to make the required additional investments to manufacture energy-efficient products due to uncertainty in the demand. Therefore it is necessary to develop new policies to achieve rapid market transformation.

The benefits of such market transformation over and above the S&L program needs to be quantified. In this paper, we estimate the possible savings in electricity consumption from the sale of SEA in four most popular categories, namely room air conditioners (RAC), refrigerators, television sets, and ceiling fans. We have considered sales of new appliances – not those of pre-owned or retrofitted appliances – to residential and commercial sectors in the next decade.

Previous work

Several recent studies have forecast the energy consumption from newly sold appliances in India. Two studies, one by the World Bank (World Bank, 2008) and one by the Lawrence Berkeley National Laboratory (LBNL) (Letschert & McNeil, 2007), predict appliance ownership up to 2030 based on the increase in income levels due to GDP growth using the National Sample Survey Organization (NSSO) data for 2000, 2002, and 2004. However, the sales projected for 2010 in the two reports differ significantly from actual sales reported by various industry sources and market research reports (CRISIL and Euromonitor). McNeil et al. 2008; Boegle, Singh and Sant, 2010; and Sathaye and Gupta, 2010 forecast electricity consumption based on actual sales data and predicted growth in the number of appliances sold. All the reports use sales data available before 2007, and none of them evaluates savings from BEE's S&L program.

Increased efficiency can lower the operating cost of an appliance, which may lead to increased use of that appliance. Also, a consumer may spend the savings from efficient

[1] http://www.toptenusa.org/ . Accessed on 14th March, 2011.

appliances on other energy-consuming activities. In calculating savings due to energy efficiency measures, such rebound effects on consumption are widely accepted to be significant. However, for appliances other than RAC, rebound effects are usually smaller (Sorrell, 2007), mainly because these appliances do not consume as much energy: consumers seldom worry about electricity costs while watching TV. In the case of RAC, rebound effects are significant. A review (Sorrell, 2007) estimated that the rebound effect in the case of space heating in USA and Europe can be as much as 30%. These effects have not been quantified in India and are beyond the scope of this study. However the impact of the rebound will be on both S&L and SEA program and hence it will not significantly change the conclusions of the paper.

Approach

Projections of sales and savings are always fraught with uncertainty. Further, in such developing countries as India, collecting and compiling data on production, sales, efficiency, ownership, and usage pattern of appliances is a challenging task. The data may vary widely from source to source. Although we cross-checked the data from multiple sources, our objective in this paper is to give not so much the precise figures of potential savings as a general idea of their magnitude.

We have used market research reports (CRISIL, 2010) and (Euromonitor, 2010) and various industry sources to project the sales of appliances for the current decade (2010 to 2019). Details of the assumptions made in projecting the sales are given in Annexe A. The consumption of each appliance depends on its size, type, and use. A single representative size and a single representative type were identified for each appliance based on their popularity in the market. For example, 90% of all the TV sets sold in 2009 were cathode ray tube (CRT) models with 21" being the most preferred screen size (Euromonitor, 2010). Sales figures for models of different star ratings from a report by the NPC (National Productivity Council, 2010) and the usage patterns reported by Boegle et al. were then used to compute the weighted unit energy consumption (UEC) of each appliance (Annexe B). Table 1 summarizes the sales and the weighted UEC for each of the four categories of appliances in 2010 as well as projected growth in sales for the current decade.

Table 1: Total (commercial + residential) sales and energy consumption

Appliance	Weighted UEC in 2010 (kWh)	Units sold in 2010 (millions)	Sales CAGR, % (2010–2020)
Room air conditioners	1242	3.1	12.5
Refrigerators	416	8.8	6.0
Television sets	175	14.9	10.0
Ceiling fans	71	30.0	6.0

We estimated electricity consumption under three scenarios, namely Moderate S&L, Aggressive S&L, and super-efficient appliances program (SEAP). The savings were then calculated as the difference in consumption between the scenarios.

Moderate S&L: Moderate S&L is the baseline scenario and assumes that BEE pursues its S&L program at its current pace but without any aggressive push. Mandatory labelling and ratcheting up the standards are two main actions that can influence market penetration of high-efficiency models. BEE plans to tighten the standards every 2 years starting 2012. However, the Bureau needs to push these changes aggressively to overcome the resistance from manufacturers. In the Moderate S&L scenario, we assume that BEE tightens the standards every four years instead of every two years, putting the efficiency improvements closer to the market-driven path without aggressive intervention. As BEE's reach widens, a number of small manufacturers may start applying for the labelling program, thereby increasing the market penetration of efficient models. We assume a gradual phase-out of the current unlabelled appliances to account for this effect. One of the major assumptions is that the proportions of appliances with different star ratings in the total number of labelled appliances sold remain the same as those in 2009. With time, the share of efficient appliances is expected to increase. But as the standards tighten and as appliances with higher ratings become more expensive, buyers may shift to appliances with lower ratings. Both these effects, have opposite impacts, but are not easy to estimate and have been assumed to nullify each other.

Aggressive S&L: The scenario of Aggressive S&L assumes tightening of the standards every two years as proposed by BEE. At present, BEE's schedule of implementation extends to 2016 for room air conditioners and refrigerators and 2012 for televisions and ceiling fans. Post schedule, we assume the unit energy consumption to fall at a constant annual rate determined by BEE's tightening rate and a feasible limit to technology improvement. The assumption leads to a 25% fall in unit energy consumption in 2020 over its 2010 values for all the appliances except for refrigerators where it is 60% due to wide scope of improvement. All other assumptions remain the same as those for the Moderate S&L scenario.

SEAP: The SEAP scenario assumes gradual introduction of SEA starting with a market share of 20% in 2012, which doubles every year and levels off at 80%. In any given year, sales of non-SEA of different star ratings are assumed to be in the same proportions as those for the other two scenarios. Table 2 summarizes the technology assumed for different categories of appliances (details in Annexe C). We assume the efficiency of SEA to improve over time at a modest annual rate such that the unit energy consumption in 2020 is 25% lower than its 2010 values for all appliances. This is very likely as appliances more efficient than the one assumed for 2020 exist even today.

Table 2: Technologies and efficiency levels of super-efficient appliances

Appliance	Unit	Efficiency level of a 5-star rated appliance in 2010	Efficiency level of an SEA[1] in 2010	Decrease in UEC[2] (%)	Technology assumed for SEA
Room air conditioners	EER[3]	3.1	4.86	36	The most efficient grade 1 AC (1.5 T capacity) in China (Source: Top 10 China, 2010)
Frost-free (FF) refrigerators	kWh / year	411	128	69	The most efficient grade 1 215-litre FF refrigerator in China (Source: Top 10 China, 2010)
Television sets	W	62	36	41	A 32" LCD TV set in USA with LED back-lighting and auto brightness control (Source: Top 10 US, 2010)
Ceiling fans	W	51	35	32	A brushless direct-current (BLDC) motor

[1]super efficient appliances [2]unit energy consumption, kWh/year [3]energy efficiency ratio

Detailed computations of electricity consumption in the three scenarios are in Annexe D.

Potential savings

Energy consumption in 2020 from cumulative sales of the four categories of appliances under the three scenarios is shown in Figure 1. The consumption in the SEAP scenario is about 115 TWh as compared to 154 TWh in the Aggressive S&L scenario and 175 TWh in the Moderate S&L scenario. Total savings due to the shift to SEA over the Moderate S&L scenario are approximately 60 TWh in 2020, three times as much as those in the Aggressive S&L scenario. For comparison, total electricity consumption in the residential sector (including lighting and all other end-uses) in 2007/08 was 120 TWh (Central Electricity Authority, 2009).

Figure 1: Annual total electricity consumption (TWh) due to cumulative sales of four categories of appliances up to 2020

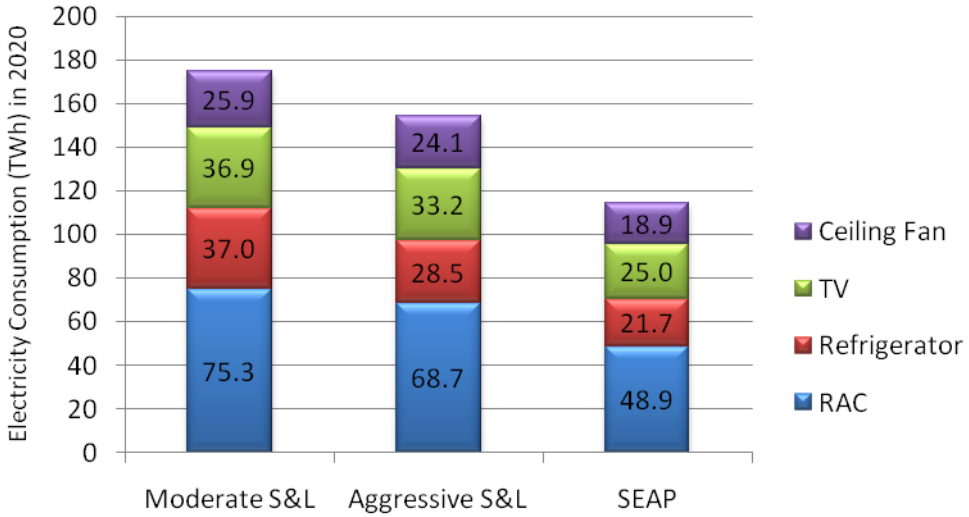
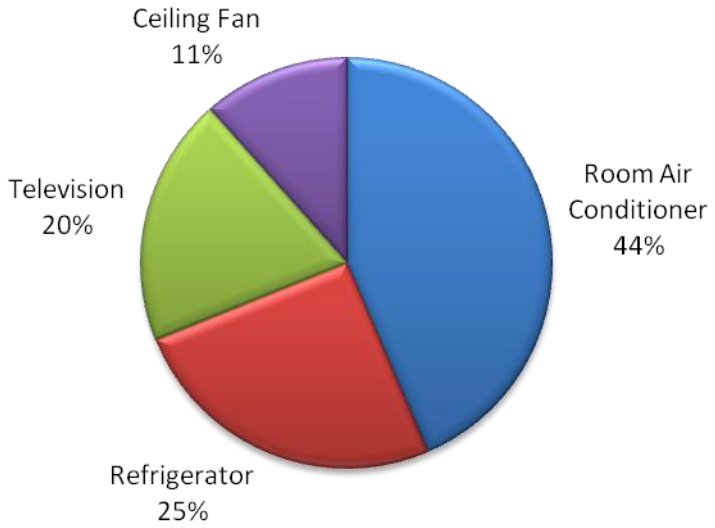


Figure 2: Contribution of different categories of SEA to annual savings in 2020



The contribution of different categories of SEA to the total savings in electricity consumption in 2020 is shown in Figure 2. The room air conditioner is a major contributor (44%) to the savings because of its high sales and high UEC: even a minor fractional gain in the efficiency of a RAC leads to significant savings in consumption. Refrigerators represent the greatest increase in savings because currently available refrigerators in the SEA category are about 69% more efficient than the 5-star-rated models in India at present. In the case of TV sets and ceiling fans, the large number of appliances added in the decade results in substantial cumulative savings.

Avoided peak capacity due to the savings is calculated by using the assumptions made in (Boegle, Singh, & Sant, 2010)[2]. Promoting SEA (Scenario 3) can reduce the additional peak capacity required in 2020 by about 20,000 MW over the Moderate S&L scenario and 15,000 MW over the Aggressive S&L scenario. Annual savings in consumption in 2020 due to SEA (Table 3) can reduce emissions of carbon dioxide by about 48 million tonnes[3] over the Moderate S&L scenario and 32 million tonnes over the Aggressive S&L.

Table 3: Avoided peak capacity additions and cumulative reductions in CO_2 emissions over the Moderate S&L

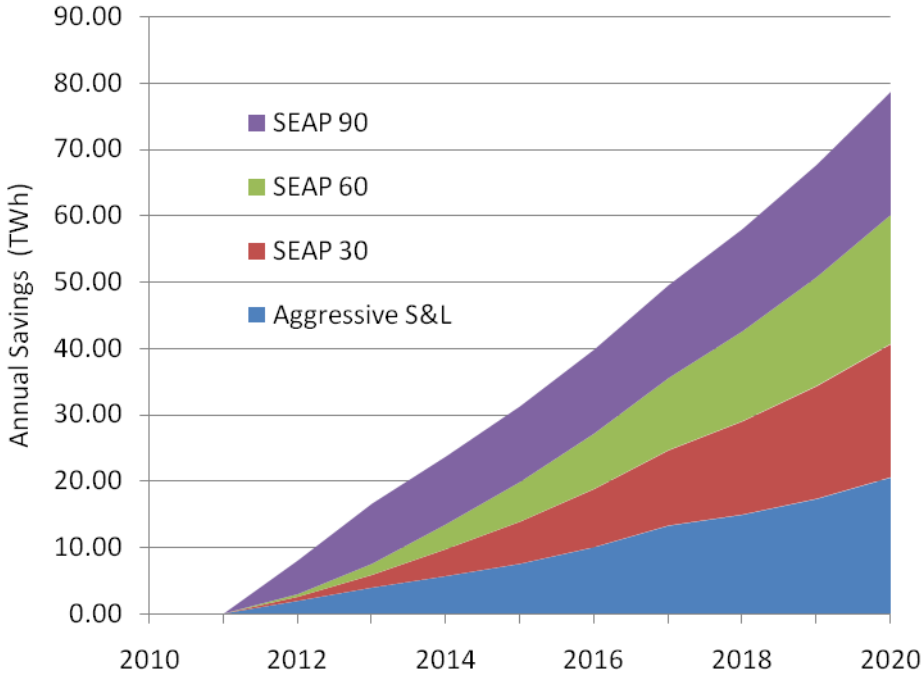
Scenario	Annual savings (TWh) 2020	Avoided peak capacity in 2020 (MW)	Avoided emissions in 2020 (million tonnes of CO_2)
Aggressive standards and labelling (S&L)	20.6	7,023	16.7
Super-efficient appliances program (SEAP)	60.7	21,620	47.9
SEAP over Aggressive S&L	40.1	14,597	31.7

A sensitivity analysis estimates the extent to which market penetration of SEA affects savings. The gradual shift towards SEA assumed in the SEAP scenario assumes that the SEA capture about 60% of the market for all appliances sold from 2010 to 2020. We also evaluated two additional scenarios, assuming the market share of SEA sold in next decade would be 30% and 90% by 2020. The resultant savings can be seen in Figure 3. Even a 30% share can save about 41 TWh over the Moderate S&L scenario—a 90% share takes the figure to a staggering 78 TWh.

[2] Transmission and distribution losses: 15%; Average availability of new capacity: 90%; Peak Coincidence Factor - RAC: 0.4, Refrigerator: 0.33, TV: 0.75, Ceiling fan: 0.5.

[3] The current rate of CO_2 emissions of 0.87 tonne of CO_2 per generated MWh is expected to decrease to 0.79 tonne of CO_2/MWh in 2020 because of more efficient thermal plants (McNeil, Iyer, Meyers, Letschert, & McMohan, 2008).

Figure 3: Annual electricity savings for different levels of market penetration of SEA



Need for Policy push for SEA

Looking at the past experience, there is likely to be a substantial effort to implement the BEE announced S&L program (referred to as aggressive program in the paper). We show that a very large potential for saving electricity exists even beyond the aggressive S&L program. The costs of the SEAs have not been discussed in this paper. But the costs of SEAs are a function of their production. Hence, it becomes a chicken and egg syndrome – where real costs are not revealed unless production increases. In most situations, the higher costs of SEAs are much less than the cost of expanding coal based generation plants and far lower than some other green energy sources like solar.

The market transformation towards SEAs needs radically different policy initiatives, which can reduce the opposition of manufacturers and barriers on consumer side. One such option is to offer support to manufacturers for initial period to off-set the cost of shifting manufacturing lines, and encourage them to carry out more R&D (Prayas Energy Group, 2010). This is conceptually similar to the high tariff we offer to the producers of wind and solar energy. As the costs of SEAs reduce, the S&L program can then be ratcheted up locking the saving.

Conclusion

A policy push to a market transformation towards super-efficient models of room air conditioners, refrigerators, TV sets and ceiling fans in the next decade can save three times as much electricity as saved by the aggressive standards and labelling (S&L) program proposed by the Bureau of Energy Efficiency, compared with the moderate S&L program. Savings due to the super-efficient appliances (SEA) program in 2020 are estimated at 60 TWh and 40 TWh over the moderate and aggressive S&L program respectively with corresponding avoided peak capacity additions of 20,000 MW and 15,000 MW. Annual savings in 2020 can reduce the emissions of CO_2 48 by and 32 million tonnes over the moderate and aggressive S&L program respectively. Room air conditioners are a major contributor to the savings because of their high sales and high unit energy consumption. Refrigerators also contribute substantially to savings because the super-efficient models currently available are almost 70% more efficient than the 5-star-rated models in India at present. The estimated potential savings due to SEA therefore present a strong case for implementing policies to promote a shift to SEA. One such policy is a national-level incentive program for manufacturers to develop and sell SEA. A logical next step is to try the national program of SEA for a set of appliances to establish its cost and benefits.

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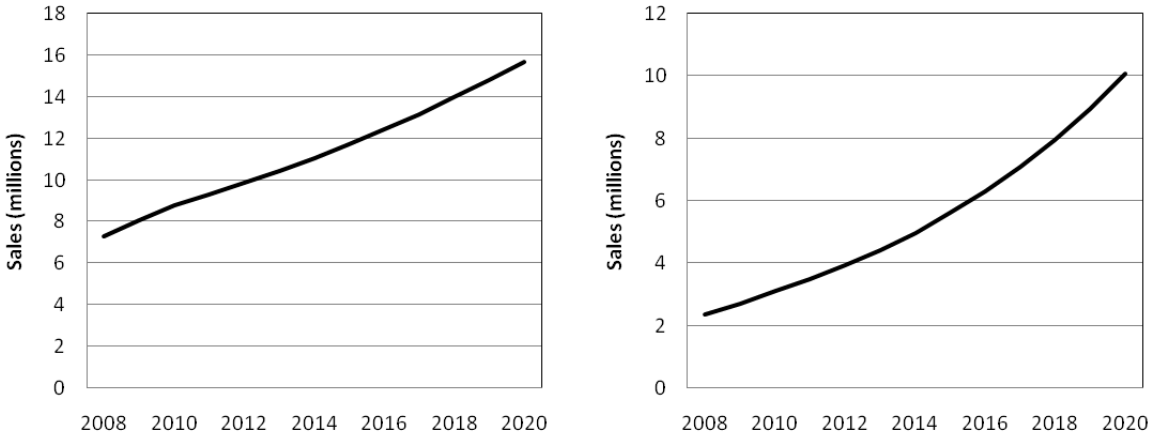
Annexe A: Assumptions about sales

Room air conditioners

India is a country with a warm climate, which supports good sales of air conditioners. Traditionally, an air conditioner has been considered a luxury item affordable only to commercial customers and a small number of wealthy households in large cities. However, a combination of rising summer temperatures, rising income levels, easy finance, and a rise in rural buyers has resulted in booming sales of air conditioners. The room air conditioner (both window and mini-split) is the most popular segment of AC sales with a preferred size of 1.5 T. 2.7 million RAC were sold in 2009 with a 15.9% CAGR during the five preceding years (Euromonitor, 2010). Euromonitor, as well as CRISIL, forecast a CAGR of about 15% for 2010–2014, although we have considered a conservative figure of 12.5% for the next decade (Figure A1). According to various industry sources, almost a third of the RAC sold in 2010 were in the residential sector; the current market trends (Euromonitor, 2010) indicate that share of the residential sector is increasing faster than that of the commercial sector.

Figure A1: Sales (millions of units) of room air conditioners and refrigerators



(a) Room air conditioners **(b) Refrigerators**

Refrigerators

Refrigerators are common in Indian households both urban and rural. Rising income levels, consumer awareness, and a variety of new energy-efficient high-end models are driving the sales of refrigerators: 8 million were sold in 2009 with a CAGR of 12.4% in the preceding five years (Euromonitor, 2010). CRISIL forecasts a CAGR of 8.0% for 2010–2014 while Euromonitor puts the figure at 6%, which is what we have considered (Figure A1). Refrigerators in India are commonly offered in two types, direct-cool (DC) refrigerators with manual defrosting and frost-free (FF) refrigerators with in-built automatic defrosting; DC refrigerators are usually smaller, cheaper, and consume less energy. The most common sizes

are 180 litres in DC refrigerators and 250 litres in FF refrigerators. Frost-free refrigerators had a market share of 31% in 2009 and the share is expected to grow to 40% in 2014 (CRISIL, 2010). We have assumed that the trend will continue with the share of FF refrigerators reaching 54% in 2020. The residential sector dominates refrigerator sales, with an estimated share of 85% in terms of the number of refrigerators sold (The Energy and Resources Institute, 2006).

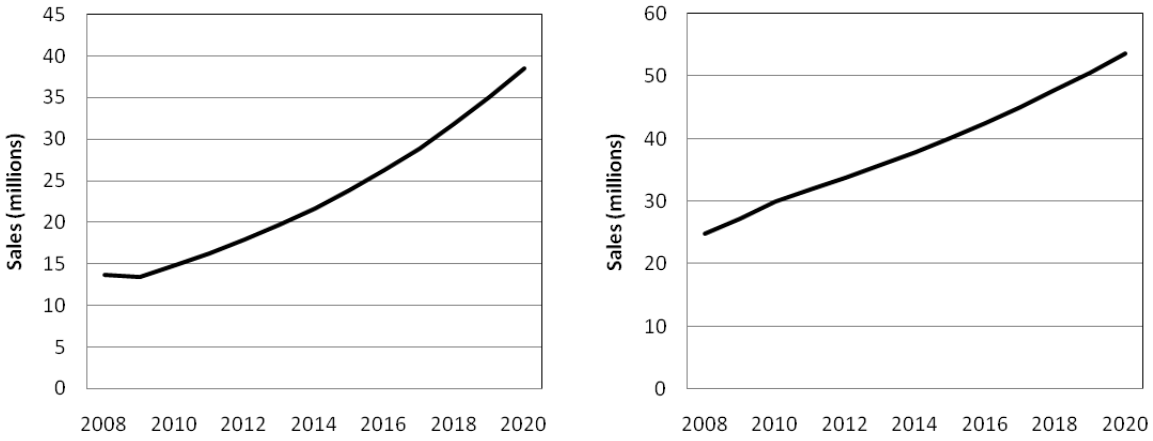
Television sets

Television sets are quite commonplace today. In 2004-2009, sales were sluggish, posting a CAGR of approximately 4.4% (Euromonitor, 2010). However the increasing popularity of satellite TV and falling prices of LCD TV sets are expected to boost sales. In 2009, about 13 million TV sets were sold: the majority (90%) were CRT models, with 21" being the most preferred size (Euromonitor, 2010). Although LCD models currently have only a small share, it is expected to grow by 63% annually during 2009–2014, with a number of households replacing their old CRT sets with LCD models. Euromonitor expects TV sales to grow by 16% annually while CRISIL puts the figure at 14.5% for 2009–2014. We have assumed a conservative figure of 10% for the next decade (Figure A2). The residential sector dominates the sales and, as with refrigerators, we assume that the sector will have a market share of 85%, the commercial sector contributing the rest (Boegle, Singh, & Sant, 2010).

Ceiling fans

The ceiling fan is indispensable to Indian households for providing relief from the warm, tropical climate. Almost every urban electrified household has 2–3 ceiling fans. The market for fans is divided into three segments: eight leading brands with a share of 60% in terms of the numbers of fans sold, about a hundred lesser-known brands with a share of 25%, and a large number of very small manufacturers with a share of 15% (Singh, Barve, & Sant, 2010). Given the predominance of the unorganized sector in the market, sales data for fans are scarce and available estimates differ widely. The Indian Fans Manufacturers Association estimated the size of the fan market in 2007 at 30 million fans with an annual growth rate of 10%. We have assumed that the growth over the decade would be around 6%. Additionally, we have assumed that table fans and pedestal fans have a 20% share, exports account for 10%, and ceiling fans account for the rest (Singh, Barve, & Sant, 2010) (Figure A2).

Figure A2: Sales (millions of units) of television sets and ceiling fans



(a) Television sets **(b) Ceiling fans**

Annexe B: Energy consumption

Data on unit energy consumption (UEC) of appliances with different star ratings are available on BEE's website[4]. UEC is computed by estimating the number of annual hours of usage for each appliance. Table B1 lists the assumptions of equivalent annual usage hours after accounting for the partial load running though a scaling factor (Boegle, Singh, & Sant, 2010).

Table B1: Equivalent Annual usage hours for appliances

Appliance	Equivalent annual usage hours
Room air-conditioner	630
Television	2190 (On mode) + 4380 (Standby)
Ceiling Fan	1080

BEE has also published a report on the savings achieved by the S&L program in 2009/10 (the findings were verified by the National Productivity Council). The report gives the shares of appliances of different star ratings, which we have used to compute the weighted UEC for each category as follows:

[4] http://220.156.189.25:8080/beeLabel/index.jsp. Accessed on 14th March 2011.

$$\text{WUEC} = \sum_{k=1}^{5} (\omega_k * \text{UEC}_k)$$

where

k = star rating of model

ω_k = percentage of sales of k^{th} star models

UEC_k = unit energy consumption of k^{th} star model.

Values of the UEC and the shares of different star ratings for each category of electrical appliances are given in Table B2.

Table B2: Unit energy consumption (kWh) and shares (%) of appliances in terms of numbers of units sold with different star ratings (for energy efficiency): 2009/10

Rating (no. of stars)	UEC (kWh)	Sales* (%)		Rating (no. of stars)	UEC (kWh)	Sales (%)
Room air conditioners						
1	1388	16		The share of unlabelled room air conditioners is negligible.		
2	1281	39				
3	1189	31				
4	1110	3				
5	1072	11				
Direct-cool refrigerators				**Frost-free refrigerators**		
Unlabelled	748	20		Unlabelled	—	0
1	598	0		1	903	0
2	478	0		2	723	0
3	383	19		3	579	11
4	306	25		4	463	48
5	272	35		5	411	41
TV sets				**Ceiling fans**		
Unlabelled	180	88		Unlabelled	73	90
1	199	0		1	69	0
2	181	0		2	65	0
3	162	2		3	61	3
4	143	5		4	58	1
5	134	5		5	55	6

*Source: BEE report (National Productivity Council, 2010)

Annexe C: Super-efficient appliances

Room air conditioners

Improving the efficiency of the compressor significantly improves the efficiency of air conditioners. High-efficiency reciprocating and scroll compressors are commonly used in efficient RAC, and the inverter-type RAC use a variable-speed compressor to improve efficiency further. Traditional RAC with a single-speed compressor always operate at peak power; electronically controlled variable-speed compressors, on the other hand, match the compressor speed to the cooling needs, thus reducing consumption. Other efficiency improvements are associated with surface area of the heat exchanger, the fan system, and the expansion valve. According to Top 10 China, (Top 10 China), the best first-grade 1.5 T RAC available in China with the variable compressor speed technology has an Seasonal Energy Efficiency Ratio of nearly 5.4. There is no direct comparison between SEER and EER but we have assumed a 10% reduction to give an EER of 4.9. We have considered this as the SEA technology in our analysis.

Refrigerators

Large frost-free models are widely popular in China, Europe, and USA; a similar trend is being observed in India. A number of measures including reducing leakage of heat through the gasket, using high-efficiency compressors, and increasing the evaporator and condenser area can improve efficiency (McNeil, Iyer, Meyers, Letschert, & McMohan, 2008). In the case of FF refrigerators, we considered the most efficient refrigerator in China, with a unit energy consumption of 128 kWh/year (Top 10 China), which is nearly 70% more efficient than a 5-star rated FF in India. We also considered a DC refrigerator 65% more efficient than the current 5-star rated refrigerator in India.

Television sets

The liquid crystal display (LCD) technology is the most efficient technology for television sets. Features such as back-lighting with light-emitting diodes (LED) and auto brightness control increase the efficiency further. These features are being widely adopted because they also improve picture quality. A few other options such as improvements in the light-dispersing film, which have the potential to reduce electricity consumption by as much as 20%–30%, are unlikely to become mainstream in the near future (Phadke & Sathaye, 2010). We have considered a 32” LCD-LED TV set with auto brightness control, one of the most efficient TV sets in USA (Top 10 USA), as the SEA. The set consumes 36 W of electricity with

a standby power of 0.1W whereas the current 5-star-rated TV set in India consumes as much as 60 W.

Ceiling fans

Ceiling fans currently popular in India use induction motors and can be made more energy-efficient by increasing the height of the stator and the rotor stack (which requires greater quantities of iron), by making the wires thicker (more copper), and by using a smaller, that is a lower-value, capacitor to reduce the top speed of the fan (Singh, Barve, & Sant, 2010). The efficiency can be improved further by using alternative technologies such as brushless DC (BLDC) motors, which are more efficient because they are lightweight and minimize rotor losses. Our interactions with fan manufacturers confirm that a fan using a BLDC motor will operate at a peak power of 35 W compared to the current value of 75 W. We have considered this as the SEA technology for ceiling fans.

Annexe D: Electricity consumption

We computed electricity consumption in 2020 for the three scenarios using the following equation:

$$E_{SCN,n} = \sum_{t=1}^{n} \left[\sum_{i=1}^{m} \left(S_{i,t} * WUEC_{i,t} \right) \right]$$

where

$E_{SCN,n}$ = annual electricity consumption in the year n due to cumulative sales of all appliances up to that year in scenario SCN

i = type of appliance (RAC, refrigerator, TV set, ceiling fan)

$S_{i,t}$ = sales volume of i type of appliance in year t.

$WUEC_{i,t}$= weighted unit energy consumption of i type appliance in year t and is given by the equation

$$WUEC_{i,t} = \sum_{k=1}^{z} \left(\omega_{i,k,t} * UEC_{i,k,t} \right)$$

where

k = category of appliance (unlabelled, star-rated, or SEA)

$\omega_{i,k,t}$ = percentage of sales of k^{th} category of i type appliance in year t

$UEC_{i,k,t}$ = unit energy consumption of k^{th} category of i type appliance in year t.