Assessing the Cost-Effective Energy Saving Potential from Top-10 Appliances in India

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Abstract

Given rising incomes and falling appliance prices, demand for residential, commercial, and industrial appliances in India has been growing rapidly over the last few years. Over the next 15-20 years, peak electricity demand from the top ten most electricity consuming appliances and equipment such as air-conditioners, chillers, refrigerators, TVs, ceiling fans, lights, electric water heaters, agricultural pumps, motors, and distribution transformers is projected to be more than 300GW or 60-70% of the projected total peak load by 2030 or so. Such growth in the appliance demand poses serious energy security, equity, and environmental challenges. In this paper, we assess the total energy efficiency improvement potential and assess its cost-effectiveness for top-10 energy consuming appliances in India. We find that 20% of the appliance energy (and ~25% of their peak load contribution) could be saved cost-effectively by enhancing their efficiency. This translates to a potential energy saving of 300 TWh/yr at bus-bar, a peak load reduction of over 70 GW, and avoided CO_2 emissions of 200 million tons/yr by 2030. This potential saving is equivalent to avoiding the construction of 150 new power plants of 500 MW each. In order to realize this large cost-effective potential, a coordinated approach of market push (standards) and market pull (awards, labels, and incentives) is needed.

Assessing the Energy Saving Potential by Improving the Efficiency of Top-10 Appliances in India

Nikit Abhyankar, Nihar Shah, Virginie Letschert, and Amol Phadke

1 Introduction

Given rising incomes and falling appliance prices, demand for residential, commercial appliances in India has been growing rapidly over the last few years. Over the next 15-20 years, peak electricity demand from the top ten most electricity consuming appliances and equipment such as air-conditioners, refrigerators, TVs, ceiling fans, lights, electric water heaters, agricultural pumps, motors, and transformers is projected to be nearly 300GW or ~60-70% of the projected total peak demand [1]–[3]. This is equivalent of the output of nearly 600 large power plants. Such growth in the appliance demand poses serious energy security, equity, and environmental challenges. Energy efficiency offers a cost-effective way of meeting the electricity demand i.e. it is much cheaper to invest in energy efficiency programs and reduce the future demand than building new power plants [4], [5]. It can also play a crucial role in India's climate mitigation plan.

Given that most (more than 80%) of the appliance stock is yet to be purchased in India, leapfrogging to super-efficient and smart solutions offers a real opportunity to meeting the rising electricity demand in a cost-effective and sustainable manner. The objectives of this paper are to: (a) assess the energy efficiency improvement potential in the top-10 energy consuming appliances in India by 2030, (b) estimate the total energy, peak load, and emissions impact of the appliance efficiency improvement, and (c) evaluate the cost-effectiveness of appliance efficiency improvement in India. We conduct the analysis by assessing how the appliance efficiency and minimum energy performance standards (MEPS) have been improving historically. For each appliance, we identify the globally best commercially available technology (BAT) and its incremental cost. We then assess the energy, peak, and emissions reduction potential for each appliance up to 2030 by assuming that all new appliance sales from 2017 onward would be replaced by the current (2016) BAT. Using the incremental cost estimates, we also assess the cost-effectiveness of the BAT from consumers as well as utility's perspective. We conclude the paper by discussing high level policy and programmatic recommendations for aggressive improvement in the appliance efficiency.

The remainder of the paper is organized as follows. Section 2 gives an overview of the appliance market and efficiency policies in India. Section 3 summarizes our key assumptions and method. Section 4 shows key results followed by the discussion and policy recommendations in section 5.

2 Status of the Appliance Market and Efficiency in India

The Energy Conservation (EC) Act 2001 provides the legal and institutional framework for the Government of India to promote energy efficiency across all sectors of the economy. The Bureau of Energy Efficiency (BEE) was created under the Ministry of Power to implement the EC Act.[1] The Standards and Labeling (S&L) Program was launched by BEE in May 2006 as a voluntary scheme with an overarching agenda to reduce the energy intensity of electrical appliances used in the country. The label provides a comparative 5-star rating system based on annual or daily energy consumption. The star labeling scheme combines comparative star labels with Minimum Energy Performance Standard (MEPS); products that pass the minimum energy efficiency requirements specified by BEE are awarded 1-star while the consumption norm specified by the five star level is the most stringent, awarded to only the most efficient products available on the market. BEE typically revises the rating criteria every few years.

Appliance labeling is mandatory for several key appliances while it is still voluntary for several others. Currently (2017), fixed speed room air conditioners, refrigerators (frost free and direct cool), fluorescent tubelights, distribution transformers, electric water heaters, and TVs were covered under the mandatory program. Variable speed ACs, agricultural pumps, ceiling fans, and industrial motors are covered under the voluntary labeling program. By 2018, variable speed ACs will be included in the mandatory labeling program.

Beyond BEE's labeling program, only a handful utilities and ESCOs have run appliance efficiency programs; such programs have seen mixed success. One of the most notable programs is the UJALA LED program by the Energy Efficiency Serviced Limited (EESL). Between 2015 and 2017, EESL has distributed over 200 million LED lamps across the country and has built the critical momentum for full market transformation. With demand aggregation and global competitive bidding, EESL was also able to reduce the procurement cost of LEDs by over 80% in two years. Currently, EESL is undertaking similar programs for other key appliances such as LED tubelights, ceiling fans, super-efficient ACs, Agricultural pumps, albeit at a small or pilot scale. Utilities in Mumbai and Delhi did implement pilot consumer rebate programs for the purchase of 5-star room ACs. Few other state utilities like Kerala, Pondicherry, and Maharashtra implemented CFL programs a few years ago. But apart from these, no large scale appliance efficiency programs have been implemented by utilities yet.

[1] EC Act amended in 2010 to empower BEE to accredit energy auditors and to hire its own staff, and the Central Government to issue energy savings certificate.

2.1 Air conditioners

Mainly driven by rising incomes, room AC (RACs) sales, which is the most common type of AC used in India, have been growing at a Compounded Annual Growth Rate (CAGR) of about 12.5% per year between 2005 and 2016, with total annual sales reaching over 4.5 million units in 2016 [6]. The Room AC market is increasingly dominated by split ACs (split-packaged non-ducted units) [2]. Rooms ACs are primarily used in the residential, and small and medium commercial sector; the current market trends indicate that share of the residential sector is increasing faster than that of the commercial sector [7].

Under the labeling program, Historically, BEE has been revising the efficiency performance criteria and the energy efficiency ratio (EER) for star levels every two years (see Table 1), and has done so about two years in advance of implementation to give the AC industry time to adjust their supply.

Table 1: BEE star rating levels for split ACs effective January 2012 and January 2014

	Star Levels for Split ACs (1 Jan 2012 - 31 Dec 2013)	
	Minimum EER (W/W)	Maximum EER (W/W)
1-Star	2.50	2.69
2-Star	2.70	2.89
3-Star	2.90	3.09
4-Star	3.10	3.29
5-Star	3.30	

	Star Levels for Split ACs (1 Jan 2014 - 31 Dec 2015)	
	Minimum EER (W/W)	Maximum EER (W/W)
1-Star	2.70	2.89
2-Star	2.90	3.09
3-Star	3.10	3.29
4-Star	3.30	3.49
5-Star	3.50	

Source: [8], [9]

Since June 2015, BEE adopted a voluntary label for split inverter ACs with a one-star level of 3.1 and a 5-star level of 4.5 in the newly adopted Indian Seasonal Energy Efficiency Ratio (ISEER) metric, based on the ISO 16358 standard with an India-specific temperature distribution.[2] This is shown in Table 2.

[2] ISO 16358 was adopted by the ISO in 2013 to provide an international standard to rate fixed-speed and inverter (or variable speed) ACs under the same metric. This metric (Cooling Season Performance Factor/Heating Season Performance Factor or Annual Performance Factor) allows a weighted average to be calculated based on a country or region-specific temperature bin, but has the added advantage of using the same test points as ISO 5151 rating standard for ACs, thus making for a smoother transition to rating of inverter and fixed speed ACs under the same metric while also capturing the benefits of the part load savings available under a seasonal metric. For cooling only operation, this metric is known as the cooling season

Table 2: BEE star rating levels for inverter ACs effective June 2015 through December 2019

	Star Levels for Inverter ACs (29 June 2015 - 31 Dec 2019)	
	Minimum ISEER	Maximum ISEER
1-Star	3.1	3.29
2-Star	3.3	3.49
3-Star	3.5	3.99
4-Star	4.0	4.49
5-Star	4.5	

Source: [11]

Note that the ISEER metric credits the efficiency improvement to a variable speed drive used in RACs, known as inverter ACs. The ISEER metric and the star labels shown in Table 2 are due to become mandatory for all ACs (fixed-speed and inverter ACs) in 2018. It can been seen from Table 1 and Table 2, Minimum Energy Performance Standard (one-star label) for room ACs has increased by about 32% between 2006 and 2016, i.e. about 3% per year (**Error! Reference source not found.**). Market average RAC efficiency has typically been slightly higher than the one star level and has improved similarly; historically, market average efficiency has been close to 2-3 star level. Our previous assessments have shown significant efficiency improvement potential in RACs using more efficient compressors, variable speed drives, and expansion valves etc. [6], [10].

2.2 Refrigerators

Residential refrigerator is another appliance that has witnessed rapid growth in the last decade or so. In 2016, the total refrigerator sales (residential as well as commercial) were over 13 million units a year increasing at over 12-15% per year [12]. While majority of the current residential refrigerator sales (>50%) are direct cool, the share of frost-free refrigerators is increasingly rapidly. Therefore, going forward, we have considered only frost-free refrigerators in our analysis. Frost-free (as well as direct cool) refrigerators are covered by the mandatory labeling program and BEE has been revising them aggressively. Using the BEE's regulations, the following table shows the total estimated annual energy consumption in kWh for 1 through 5-star levels across multiple years. The energy consumption is estimated assuming the refrigerator size to be 260 liters (208 liters fresh food capacity and 52 liters freezer capacity).

performance factor (CSPF). In 2015, BEE has adopted ISO 16358 but modified the temperature bin distribution to account for the hotter weather in India to calculate the Indian SEER (ISEER) metric for fixed speed and inverter ACs. BEE has adopted the ISEER metric to measure the performance of Room ACs in India in the future [10].

Table 3: BEE star rating levels for frost-free refrigerators between 2010 and 2018 (assuming 208 lit fresh food and 52 lit freezer capacity)

	2010 - 2011		2012-2013		2014-2015		2016-2018	
	Max	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**
1-star	1014	811	811	649	519	415	415	332
2-star	811	649	649	519	415	332	332	266
3-star	649	519	519	415	332	266	266	212
4-star	519	415	415	332	266	212	212	170
5-star	415	0	332	0	212	0	170	0

Note: All numbers in the table are kWh/yr unless specified otherwise.
Source: [13]

Between 2010 and 2018 (announced), efficiency of the 1-star level (de-facto MEPS) as well as five-star level for refrigerators has improved by over 11% per year. With more efficient compressors (DC compressors or variable frequency drives), better insulation (such as increased wall thickness and vacuum insulation panels), and optimized gaskets, the overall efficiency could be improved by over 85% relative to the current market average [14].

2.3 Televisions

Television sales have been growing at a CAGR of over 15%; in 2011, the total TV shipments were 15.6 million units/yr. TVs are part of BEE's mandatory labeling program; however the program has created three categories for CRT, LCD/Plasma, and LED TVs respectively. Over the last few years, LCD TV sales have overtaken those of all other technologies (expected to reach as high as 95% of total market in 2017 per [15]); therefore, going forward we have only considered efficiency improvement opportunities in LCD TVs. Also, within the LCD TV market, the share of CCFL backlit TVs is dropping and that of LED backlit TVs is increasing rapidly. The following table shows the annual energy consumption for LED backlit TVs per BEE's labeling program - assuming one of the most popular screen size (diagonal) of 32 inches and an aspect ratio of 16:9.

Table 4: BEE star rating levels for LED backlit TVs between 2010 and 2017 (assuming screen size of 32 inches and aspect ratio of 16:9)

	2010-2014	**2014-2015**	**2016-2017**
1-star	426	171	87
2-star	388	156	79
3-star	349	141	72
4-star	311	125	64
5-star	273	110	56

Note: All numbers in the table are kWh/yr unless specified otherwise.

Source: [16]

Between 2010 and 2017, efficiency of the 1-star level (de-facto MEPS) as well as five-star level for LED backlit TVs has improved by about 20% per year. Studies have shown that reflective polarizer and backlight dimming can reduce the on-mode power consumption of standard LCD/LED TVs further by nearly 40% [15].

2.4 Distribution Transformers (DTs)

Distribution transformers are covered under the mandatory labeling program. The following table shows the total losses for each star rating for the most commonly used distribution transformers in India (25 kVA, 63kVA, and 100kVA).

Table 5: BEE star rating levels for Distribution Transformers (25 kVA, 63kVA, and 100kVA rated capacity)

Rated capacity	**1 star**		**2 star**		**3 star**		**4 star**		**5 star**	
kVA	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)
25	290	785	235	740	210	695	190	635	175	595
63	490	1415	430	1335	380	1250	340	1140	300	1050
100	700	2020	610	1910	520	1800	475	1650	435	1500

Note: All numbers in the table are kWh/yr unless specified otherwise.
Source: [17]

The efficiency levels for star labels for DTs have not changed since 2007. In 2014, the total installed capacity of all transformers in India was about 400 GVA, up from 180 GVA in 2009 [18]. Nearly 60% of this capacity is distribution transformers [18].

2.5 Electric Water Heaters

There are two types of electric water heaters sold in India – instant electric geysers (with no storage) and stationary storage type heaters. In this paper, we assess instant geysers, which are significantly more popular than the storage type heaters. Instant geysers are not covered by the labeling program. Since 2016, the storage type water heaters are covered by the mandatory labeling program.

2.6 Industrial Motors

The industrial sector (large and small) together consumes about 40% of the total electricity in India and industrial motors are responsible for a substantial share in this consumption [5], [19]. Industrial motors are covered by the voluntary labeling program. For all motor types, BEE's star labels are aligned with the IEC's efficiency levels as shown in the following table.

Table 6: BEE star rating levels for Motors (assuming 15kW rating with 2poles at 100% loading)

Star Rating	**Motor Efficiency Class**	**Nominal efficiency for 15kW motor with 2 poles at 100% loading**
1 Star	≥IE2&<IE2(+)	90.3%
2 Star	≥IE2(+)&<IE3	91.1%
3 Star	>= IE3 &<IE3(+)	91.9%
4 Star	>=IE3 (+) &< IE3(++)	92.7%
5 Star	≥IE3(++)	93.4%

Source: [20]

Currently, most of the motors sold in India have the efficiency of IE2 or below [19], [21].

2.7 Ceiling Fans

Ceiling fans are one of the most commonly used household appliance in India with annual sales of about 29 million/yr in 2009 growing at 10% [22]. They are covered by the voluntary labeling program. The most popular ceiling fans are single phase induction motor type and consume about 75W at full speed [4]. Also, the labels are applicable only a single product category (1,200 mm blade sweep) and does not vary by air delivery (or fan speed). The label as well as the market average efficiency has not changed since 2010. Several studies have shown that permanent magnet / brushless DC motors are about 15-20% more efficient than the single phase induction motors typically used in the residential and commercial ceiling fans. Additionally, better blade design can enhance the fan efficiency further by 15-20% [4].

2.8 Irrigation Pumps

The agricultural sector consumes about 25% of the total electricity in India and most of the electricity consumption is due to irrigation pumpsets. It is also one of the key sectors where the electricity prices are highly subsidized as well as cross-subsidized. Many connections are not even metered. In 2013, total new irrigation pump sales were 1.4 million units and they have been growing at 6-7% per year [23]. Irrigation pumps are covered by the voluntary labeling program. However, pump sales are dominated by the non-labeled products (95% market share) and their market average efficiency has been fairly low for the past several years (20-30% overall) [23]. The most typical irrigation pumps used in India are 3-phase induction motor pumps with a rated capacity of 5 hp (about 3.7kW) or 7.5 hp (5.6kW) [23]–[25]. Similar to the fans, with brushless DC motors and better piping system design, the conventional pump efficiency can be improved by over 50% [26].

2.9 Lighting

There are two major sources of lighting in India – incandescent lamps/CFLs/LEDs and Tubular Fluorescent Lamps (TFLs). Out of these, the incandescent lamp market has already started transforming rapidly with Energy Efficiency Services Limited's (EESL) UJALA LED program, which is the largest in world with nearly 210 million LEDs distributed in 18 months since its launch in October 2015. In the same period, EESL's LED prices have fallen from $3-4/unit to nearly $0.5/unit. EESL's program has a target of replacing the entire incandescent bulb market (770 million) by 2019.

For TFLs, the typical products sold are the T-12 (40W), T-8 (36W), and T-5 (32W) tubes. Given the clear advantage of the LED based lighting products in terms of their lumen efficiency (lumens per Watt), there is significant efficiency improvement potential in the TFL market. EESL launched a program for TFLs in 2016, which, however has not scaled yet. TFLs are covered by the mandatory labeling program and the efficiency levels are shown in the following table.

Table 7: BEE star rating levels for Tubular Fluorescent Lamps (Lumens/Watt)

	1-star	2-star	3-star	4-star	5-star
Lumens per Watt at 0100 hrs of use	<61	>=61 & <67	>=67 & <86	>=86 & <92	>=92
Lumens per Watt at 2000 hrs of use	<52	>=52 & <57	>=57 & <77	>=77 & <83	>=83
Lumens per Watt at 3500 hrs of use	<49	>=49 & <54	>=54 & <73	>=73 & <78	>=78

Source: [27]

These labels have not changed since 2010. Also, only 3-star or 5-star TFLs are available on the market and all have the same input power rating of 36W. Currently, LEDs are covered under a voluntary labeling program, while CFLs are not covered under any labeling program.

3 Key Assumptions and Method

With this background, we now describe our key assumptions and method for estimating the energy saving potential by 2030.

3.1 Scenarios for analysis

We create two scenarios for the appliance efficiency levels in 2030, as described below. For each scenario, we assess the peak load and electricity consumption impact, and also conduct a cost-benefit analysis for enhancing the appliance efficiency.

(a) ***Business as Usual (BAU)***: In this scenario, we assume that the appliance efficiency continues to improve between now and 2030 per the historical trajectory.

(b) ***Efficient Future***: In this scenario, we assume that all new appliance sales between 2017 and 2030 are replaced by the current (2016) globally best available technology (BAT).

The following table summarizes our assumptions on the appliance Unit Energy Consumption (UEC) in the BAU as well as Efficient Future scenarios.

Table 8: Assumptions on UEC for BAU and Efficient Future Scenarios

Appliance	Business as Usual (BAU)			Efficient Future Scenario		Sources
	What is BAU and expected improvement	UEC 2016 (kWh/yr)	UEC 2030 (kWh/yr)	What is the Current BAT?	UEC (kWh/yr)	
Lamps	Incandescent / CFL moving to LED (~120 lumens/W)	72	10	LED	9	[28]
FTLs	T-8+magnetic choke moving to T5+electronic choke, LED	95	44	LED tubelight	16	[28]
Fans	Single phase induction motor ceiling fan	120	120	BLDC fan with efficient blade design	48	[4]
TV	Old stock is CRT; new sales are mostly LCD/LED.	83	39	LED backlit w/ reflective polarizer & dimming	33	[15]
Water Heaters	Electric geysers	240	146	Natural Gas/LPG water heaters	0	[28]
Refrigerators	Direct Cool/ frost free; significant efficiency gain through efficient compressors and gaskets	399	69	Thicker insulation, VIPs, efficient compressor, gasket	60	[28]
AC	Old stock is fixed speed; moving toward inverter ACs	1992	1269	Inverter AC with efficient compressor, VFD, bigger heat exchanger, electrostatic expansion valve	797	[6]
Motors	IE 1 or IE 2 motors	9196	9196	IE 3++ (or IE5) motors	8910	[1], [21], [29]
AG Pumps	Standard mono-block / submersible pumps	5914	5914	Brushless DC pump and efficient piping system	3593	[25], [30]
Distribution Transformers	Standard DT	2186	2186	Reduction in no load as well as load losses using better material and cooling	905	[29], [31]

3.2 Estimating the Appliance Stock

We used the Bottom-Up Energy Analysis System (BUENAS) to estimate the total appliance market in India up to 2030. The bottom-up approach allows for a detailed accounting of the appliances and modeling of saturation effects. In BUENAS, we use a combination of sales forecast, income, urbanization, weather related parameters such as cooling degree-days, and to assess the total penetration / saturation and stock of a particular appliance. A detailed description of the general BUENAS methodology is available in [32]. Based on recent sales data, and using BUENAS stock turnover analysis, we estimate the following appliance stocks up to 2030. Note all stock numbers are in millions.

Table 9: Total appliance stock (millions) up to 2030

	2015	2020	2025	2030
Lamps	954	1199	1524	1965
FTLs	276	347	441	569
Fans	341	399	451	497
TV	205	288	387	503
Water Heaters	42	61	87	126
Refrigerators	65	99	144	199
Room AC	24	38	69	124
Motors	20	28	41	59
Agricultural Pumps	21	26	36	49
Distribution Transformers	4.8	6.5	8.6	11.4

3.3 Other Assumptions

The following table summarizes our other key assumptions for assessing the energy and peak impact of appliances as well as incremental cost of BAT over BAU in 2016.

Table 10: Other key assumptions for each appliance

	Hours of use/yr	Peak Coincidence Factor*	Incremental Cost of BAT over BAU (2016) Rs	BAT Appliance Life (years)	Sources
Lamps	1825	0.5	40	5	[28]
FTLs	1825	0.5	50	5	[28]
Fans	1600	0.7	840	10	[4]
TV	1825	0.7	540	7	[15]
Water Heaters	120	0.25	500	5	[28]
Refrigerators	3329	0.38	4,652	10	[28]
Room AC	1200	0.7	54,401	7	[6]
Motors	2296	0.25	7,000	20	[1], [29]
Agricultural Pumps	1577	0.25	10,000	20	[25], [30]
Distribution Transformers	8760	0.25	20,000	25	[29], [31]

* Note: Summer evening peak coincidence

Peak load contribution of an appliance is estimated by multiplying the connected load of that appliance by the peak coincidence factor. We estimate the peak load (and energy consumption) at transmission bus-bar by assuming the transmission and distribution (T&D) loss of 15%. Also, all peak load numbers imply concurrent peak during evening periods in the summer (i.e. around 8 PM in April-May 2030), unless stated otherwise.

3.4 Grid emission factors

Currently, India's electricity generation is dominated by coal and the average grid emission factor in 2015 was 0.82 kg CO2 per kWh generated [33]. However, the country has planned significant investments in renewable energy which will likely reduce the grid emissions factor by nearly 20% to 0.67 kg CO2/kWh by 2030 [34].

4 Results

In this section, we show the impacts of the Efficient Future scenario on total energy consumption, national peak load, CO2 emissions and discuss the impact of rebound effect. We also assess the cost of conserved electricity for such efficiency improvement and evaluate the total cost-effective efficiency improvement potential.

4.1 Total Electricity Consumption and Peak Load

The following chart shows the total energy consumption (at bus-bar) due to top-10 appliances for both scenarios. By 2030, under the BAU scenario, the appliance energy consumption becomes as high as 1473 TWh/yr or about 60% of the total electricity consumption in that year. Under the Efficient Future scenario, the top-10 appliance energy consumption could be reduced by nearly 300 TWh/yr at bus-bar without compromising any service provided by these appliances. This is equivalent to the total energy generation from nearly 180 GW of solar PV capacity.

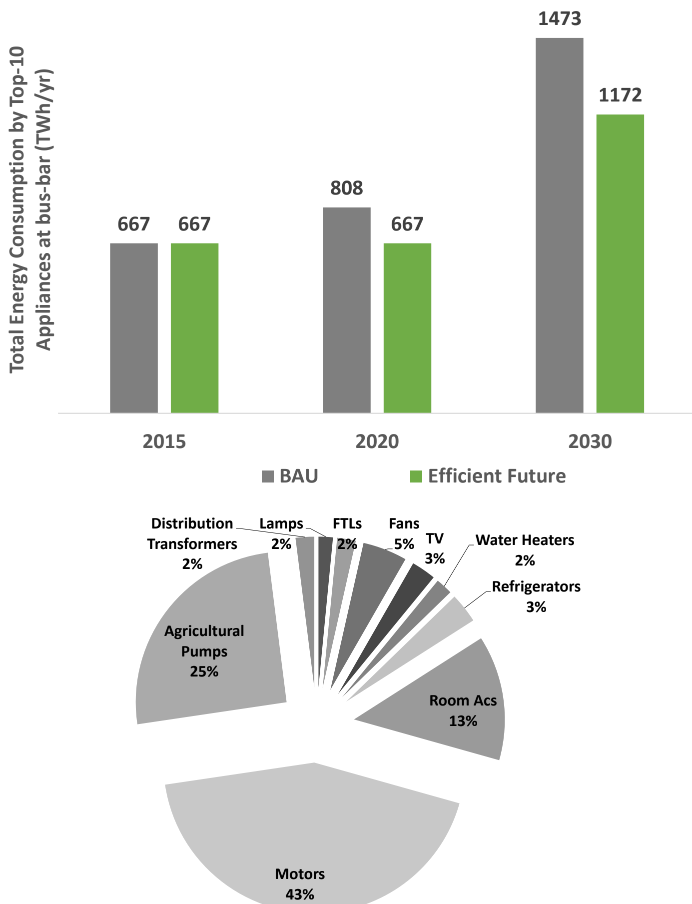
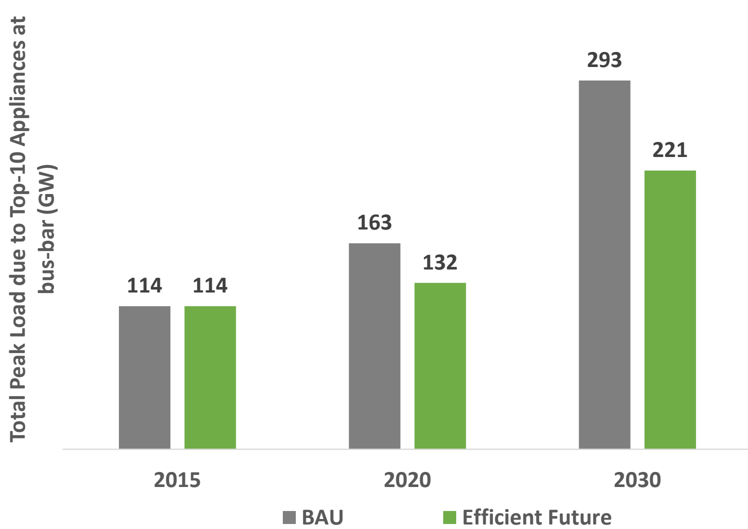


Figure 1: Total Annual Energy Consumption by Top-10 Appliances at bus-bar and Share of Each Appliance in 2030

The pie chart shows the share of each appliance in the total energy consumption in 2030 for the BAU scenario. Note that Motors, Agricultural Pumps and Room ACs together are responsible for over 85% of the appliance energy consumption in the BAU scenario. This is because of two reasons: first, these three appliances are extremely energy intensive. Second, the BAU efficiency improvement in other residential and commercial appliances is significantly higher than these three; as a result, their consumption drops substantially by 2030.

The following chart shows total peak load (summer evening concurrent peak at 8 PM) due to top-10 appliances for both scenarios. Certain appliances such as fans, room ACs, lamps, TVs etc are major contributors to the peak load while motors, refrigerators etc contribute very little, especially to the evening peak load. In the BAU scenario, top-10 appliances will add over 290GW to the peak load (summer evening concurrent peak) by 2030, which is as high as 70% of the projected peak load in that year. In the Efficient Future scenario, the total peak load from top-10 appliances could be saved by over 70GW by 2030. This is equivalent to avoiding building of 150 new coal power plants of 500 MW each.



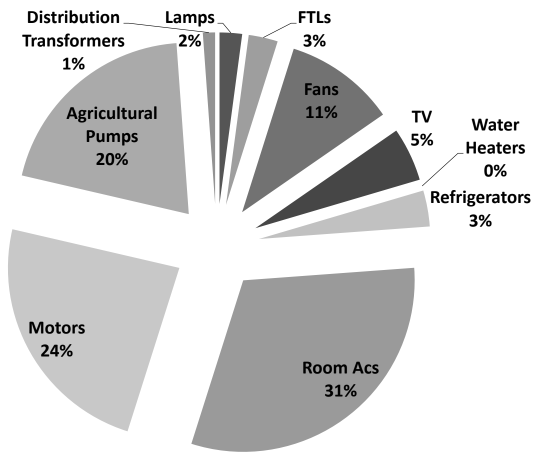


Figure 2: Total Peak Load (Summer Evening Concurrent Peak) by Top-10 Appliances at bus-bar and Share of Each Appliance in 2030

The pie chart shows the share of each appliance in the total peak load (summer evening concurrent peak) in 2030 for the BAU scenario. Note that residential appliances, particularly, room ACs and fans have significant peak load contribution (over 40%); their share in the top-10 appliance energy consumption was only 15%.

4.2 Energy and Peak Load Saving

Efficient Future Scenario can potentially save over 300TWh/yr at bus-bar by 2030. This is equivalent to the total generation from 180GW of solar PV plants. The following chart shows the breakdown of the potential energy saving in 2030.

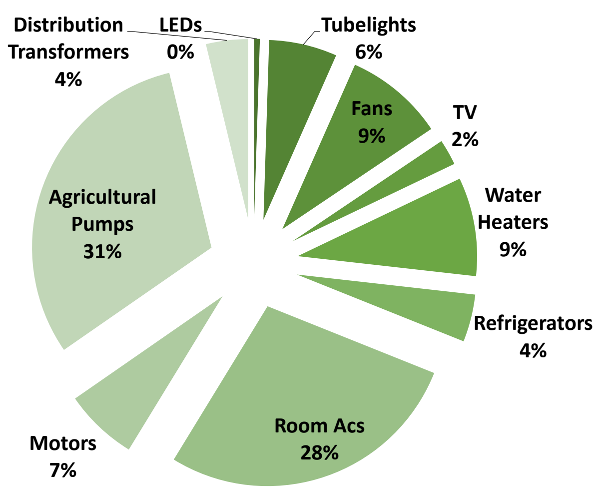


Figure 3: Breakdown of the total energy saving in the Efficient Future scenario in 2030 (total saving = 301 TWh/yr)

The energy saving potential in Agricultural pumps (93 TWh/yr by 2030) and room ACs (83 TWh/yr by 2030) together is nearly 60% of the total saving showing that the BAT is significantly more efficient than the BAU. Note that although motors consume a large portion of the total electricity, their saving potential is small as most of the motor sales are already efficient. What is noteworthy is the small energy potential from the lighting sector (20 TWh/yr by 2030 or 7% of total). This is primarily because the lighting market has already started shifting towards LEDs and by 2030, even in the BAU trajectory, majority of that market would already be transformed. Similarly, the BAU efficiency improvements in the TVs and Refrigerators have been fairly aggressive and thus their share in the total saving is small as well. However, in the TV and the refrigerator market, consumers have started preferring bigger size appliances. Therefore, The BAU efficiency improvement, when adjusted for the changing appliance size, may not be as aggressive as presented in Table 8. In our analysis, we have assumed that the consumer preferences for appliance size do not change over time; so, this estimate should be taken as a conservative energy saving potential.

Efficient Future Scenario can potentially reduce the peak load (summer evening concurrent peak) by over 70GW at bus-bar by 2030. This is equivalent to avoiding nearly 150 power plants of 500MW each. The following chart shows the breakdown of the potential peak load reduction in 2030.

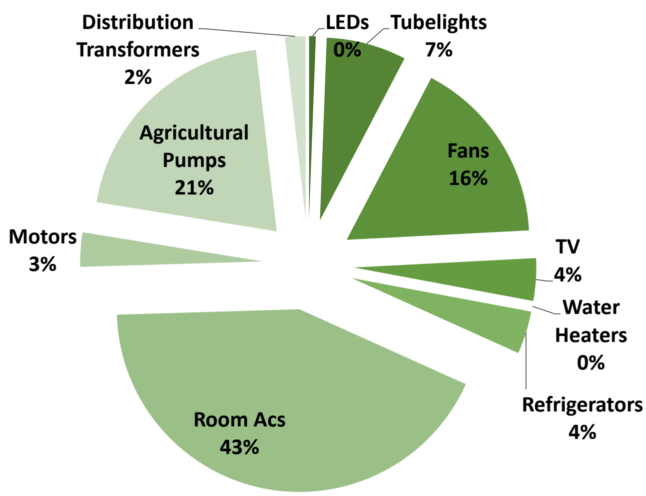


Figure 4: Breakdown of the peak load reduction in the Efficient Future scenario in 2030 (total reduction = 71GW)

As expected, room ACs (31GW), fans (12GW), and agricultural pumps (15GW) together can avoid nearly 50GW of peak load (summer evening concurrent load at 8PM) – or about 70% of the total peak load reduction. Given the BAU efficiency improvements in lighting and refrigerators, their contribution in the peak load saving is small.

4.3 Cost Effectiveness of Efficiency Improvement

We assess the cost effectiveness of efficiency improvement in the Efficient Future scenario by comparing the cost of conserved electricity (CCE) for each options with the consumer tariffs or

Long Run Marginal Cost (LRMC) of supplying electricity. CCE is estimated by dividing the incremental cost of the efficient by the incremental energy saving due to the efficiency gain.

$$CCE = \frac{Annualized\ incremental\ cost\ of\ efficient\ appliance}{Annual\ electricity\ saved\ by\ efficient\ appliance}$$

If the CCE is lower than the consumer tariff, it will be cost-effective for consumers to invest in the efficient appliance. Note that when consumers install efficient appliances, they avoid the consumption from the highest tariff block. Therefore, CCE should be compared with the marginal consumer tariff and not average. To be conservative, we assume the marginal tariff for residential, commercial, and industrial sectors to be Rs 6/kWh, increasing at 5% per year (average long term inflation rate for India) [6].[3] Agricultural electricity consumption is highly subsidized and their marginal tariff is around Rs 1.5 - 2/kWh [5].

If the CCE is lower than the long run marginal cost of electricity, investing in an appliance market transformation program would be cost-effective relative to building new power plants and transmission/distribution infrastructure. Based on the historical trends, we use the long run marginal cost of power supply Rs 5.2/kWh (including the transmission and distribution costs), increasing at 3% per year [5], [35]–[37].

The following chart shows the CCE for each appliance against the total energy saving potential by that appliance in 2030. This is called the energy efficiency supply curve. It also shows the marginal consumer tariff and LRMC. As shown in the chart, CCE for all appliances is lower than the consumer tariff as well as the utility LRMC. For agricultural consumers, the CCE for enhancing the agricultural pump efficiency (Rs 0.6/kWh) is lower than their tariff (Rs 1.5-2/kWh). This implies that the entire energy saving potential in the top-10 appliances in India is cost-effective for utilities as well as for consumers. This makes a strong case for setting aggressive MEPS for these appliances as well as a strong utility driven market transformation program.

[3] This implies that the real electricity costs (adjusted for inflation) are assumed to stay almost constant as the rate of their increase equals the inflation rate. This is also a highly conservative assumption since real costs are actually rising.

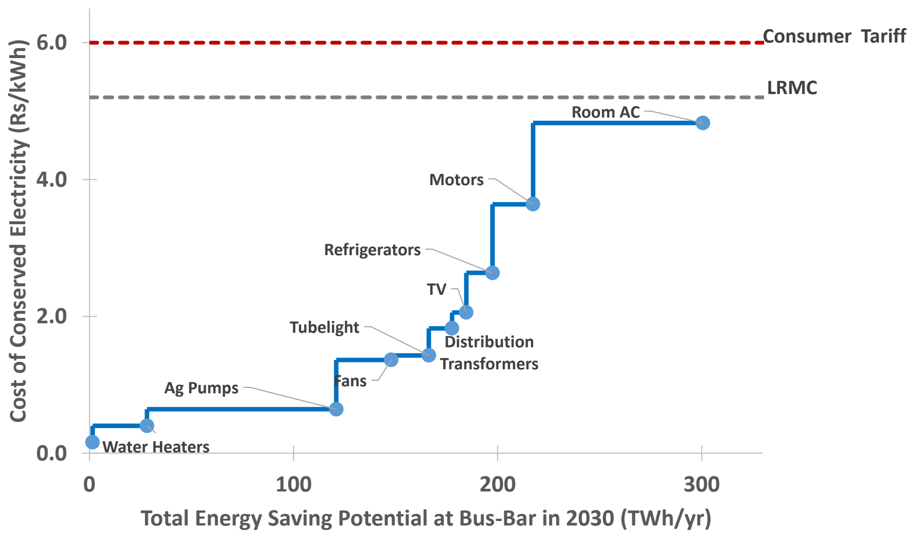


Figure 5: Cost of Conserved Electricity and Cost-effective Energy Saving Potential by 2030

The weighted average CCE for the entire appliance portfolio is Rs 2.3/kWh. For utility programs, this highlights the importance of high potential-low cost programs such as water heaters and agricultural pumps for absorbing the impact of high cost programs such as motors and room ACs. Note that the cost estimates shown here only include the economic costs and do not consider significant transaction costs of implementing an efficiency program as well as consumer behavioral issues. Significant additional work would be needed to assess those costs.

4.4 Emissions

Given that the entire appliance efficiency potential is found to be cost effective for utilities, the CO_2 emissions abatement cost for the appliance efficiency measures would be negative. The following table shows the total CO_2 emissions abatement potential by 2030 and the average abatement cost in US $/ton.

Table 11: Total Emissions Abatement Potential (million tons/yr) and Cost ($/ton)

	Emissions Abatement Cost $/Ton	Avoided Emissions by 2030 Million Tons/yr
LED Lamps	-111	1
LED Tubelights	-83	12
Fans	-84	18
TV	-69	5
Water Heaters	-105	18
Refrigerators	-56	9
Room AC	-8	56
Motors	-34	13

Agricultural Pumps	-100	62
Distribution Transformers	-74	8
Total	**-65**	**201**

By 2030, with appliance efficiency improvement, more than 200 million tons/yr of CO_2 emissions could be avoided at an average abatement cost of -$65/ton.

4.5 Rebound Effect

One of the common concerns when assessing the validity of cost-benefit estimates from any appliance efficiency improvement is the rebound effect. The direct rebound effect (increase in the energy use as a result of the effective rise in the disposable income of consumers due to increased energy efficiency) is found to be 8-12% for most appliance efficiency improvements in developed countries in the short and medium run [38], [39]. In emerging economies, direct rebound effects on electricity consumption are observed higher than the developed countries; they tend to vary over a wide range between 12 and 46% [38]. However, the consumption patterns in emerging economies change rapidly and thus estimating the short term demand elasticities and thus the rebound effect accurately is very hard. Also, note that rebound effect implies an increase in the consumption of energy services and thus an overall increase in consumer welfare. The Indirect rebound effect (increase in the consumption of other commodities due to the reduction in the energy expenditure) is hard to predict and typically small [38], [39]. Note that the rebound effect will likely have little impact on peak load saving. This is because even if appliances are used for more hours, their peak coincidence will likely remain unchanged. The other impact of the rebound effect may be increasing appliance penetration. If the net consumer benefit of efficient appliances (electricity bill saving minus the incremental cost) is very high (especially if the efficiency improvement does not have any impact on the appliance prices), the appliance penetration may increase i.e. consumers that would not have purchased an appliance in the BAU scenario may now purchase one. This would reduce the overall energy and peak load saving numbers. However, that would also substantially increase consumer welfare due to increased energy service.

4.6 Sensitivity Analysis

We understand that our analysis is based on significant assumptions. In this section, we test the sensitivity of our results on some of the key assumptions and parameters such as appliance sales growth (and stock), hours of use, peak coincidence factor, BAU efficiency improvement rate etc. We change these parameters from their base case values by +/- 25% and show impact on energy saving, peak load reduction, and CCE in the Efficient Future scenario in the following table.

Table 12: Sensitivity of the Results on Key Parameters

	Base Case	Sensitivity on Appliance Sales Growth		Sensitivity on hours of use		Sensitivity on Peak Coincidence Factor		Sensitivity on BAU Efficiency Improvement	
Appliance sales growth	Base	**Low**	**High**	Base		Base		Base	
Hours of use/year	Base	Base		**Low**	**High**	Base		Base	
Peak Coincidence Factor	Base	Base		Base		**Low**	**High**	Base	
BAU Efficiency Improvement	Base	Base		Base		Base		**Low**	**High**
Total Energy Saving at bus-bar in 2030 (TWh/yr)	301	225	376	225	376	301	301	392	259
Total Peak Load Reduction at bus-bar in 2030 (GW)	71	53	89	71	71	53	89	93	61
Appliance Portfolio CCE (Rs/kWh)	2.3	2.3	2.3	3.0	1.8	2.3	2.3	2.3	2.3

Overall, by 2030, the total energy saving potential will range between 225 to 392 TWh/yr and the peak load reduction will range between 53 and 93GW. CCE of the appliance portfolio will likely vary between Rs 1.8 to 3 per kWh, significantly below the utility LRMC.

5 Discussion and Conclusion

In this paper we assess the total energy efficiency improvement potential and assess its cost-effectiveness for top-10 energy consuming appliances in India. Due to the Standards and Labeling policies as well as global market trends, the appliance efficiency in India has been improving over the last decade. While the efficiency improvement in some appliances such as TVs or Refrigerators has been very aggressive, efficiency improvement in certain other appliances such as Agricultural pumps or fans has been very slow. Going forward, we find that the overall appliance penetration in India is expected to grow rapidly and by 2030, the top-10 appliances would likely contribute nearly 290-300 GW to the peak load (about 70% of the total peak load) assuming that the efficiency continues to improve per historical trajectory. We find that 20% of the energy consumed by the top-10 appliances (and ~25% of their peak load contribution) could be saved cost-effectively by enhancing their efficiency. This translates to a potential energy saving of 300 TWh/yr at bus-bar or a peak load reduction of over 70 GW by 2030. This potential saving is equivalent to avoiding the construction of 150 new power plants of 500 MW each. Note that rebound effect may reduce the financial benefit but it would not affect the overall consumer welfare benefit. Also, accelerated efficiency improvement will likely strengthen the capacity of Indian manufacturers to compete in the global market.

In order to realize this large cost-effective potential, a coordinated approach of market push (standards) and market pull (awards, labels, and incentives) is needed. First, India's existing standards and labeling program is not mandatory for certain energy intensive appliances such as agricultural pumps, industrial motors, fans etc; these appliances should be covered under the mandatory labeling program. Second, the stringency level of the labels need to be revised significantly especially for energy intensive appliances such as room ACs. Also, the test procedures should fully recognize the efficiency gains due to certain technologies e.g. test procedures for ACs or Refrigerator labels should recognize the full extent of the energy saving due to operation at partial loads, made possible by variable speed drives. For ensuring long term industry support and compliance of the labeling program, a long/medium term target should be specified. Such target provides a broader policy direction, which informs setting and revision of the interim targets. This approach has been successfully used in Japan for its Top-Runner program. An example of the long term target could be setting today's best available technology in India can be the target for market average efficiency level by 2022 or making today's globally available best commercial technology the market average by 2030. Once such long term targets are specified, BEE may ratchet up MEPS in the interim years. One of the options for an accelerated ratchet up is widening the spread of the star labels which incentivizes more efficient products to be sold on the market. Third, given that the appliance demand reduction is cost-effective from consumer as well as utility perspective, ratepayer funds can be used to undertake bulk procurement and incentive programs that can address the first cost barrier for uptake of efficient appliances. Given the governance challenges in the utility sector, the appliance programs could be undertaken by a third party such as Energy Efficiency Services Limited (EESL). EESL has been successfully running the largest LED program in the world (distributing 210 million LED lamps in 18 months) and has been able to bring the LED process down from $3-4/unit in 2015 to about $0.5/unit in 2017.

Note that for aggressive efficiency improvement, such programs would be crucial for complementing the standards revision by pulling up the top of the market. For example, increasing the market share of today's five-star appliances will allow an easier transition to the same efficiency level being characterized as MEPS few years down the line. Incentive and bulk procurement programs can be used in bringing super-efficient (e.g. global best) products to the market. However, design of such programs is crucial to ensuring the overall benefits are maximized because of the "freerider" effect (i.e. consumers using incentives when they would have purchased the appliance without it or with a lower incentive level). See for example Boomhower & Davis [40], where they show examples from Mexico's residential refrigerator replacement program of 2009 and argue that most households would have participated even for much lower subsidy amounts.

Finally, because the peak load contribution of the top-10 appliances could be significant, standards for making the appliances demand-response (DR) ready or "smart" are recommended. Smart appliances could be used in conjunction with utility DR programs to reduce / shift peak load and also integrate variable renewable energy generation in a cost-effective manner. Several countries such as Australia, Korea, Japan, USA etc. have adopted or are considering adoption of

DR readiness requirements for various appliances including ACs, refrigerators, water heaters, and pumps etc. It is also important to pursue complementary efforts to reduce or delay the electricity demand from appliances. For example, improved building design and cool roofs to reduce or postpone the AC demand.

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