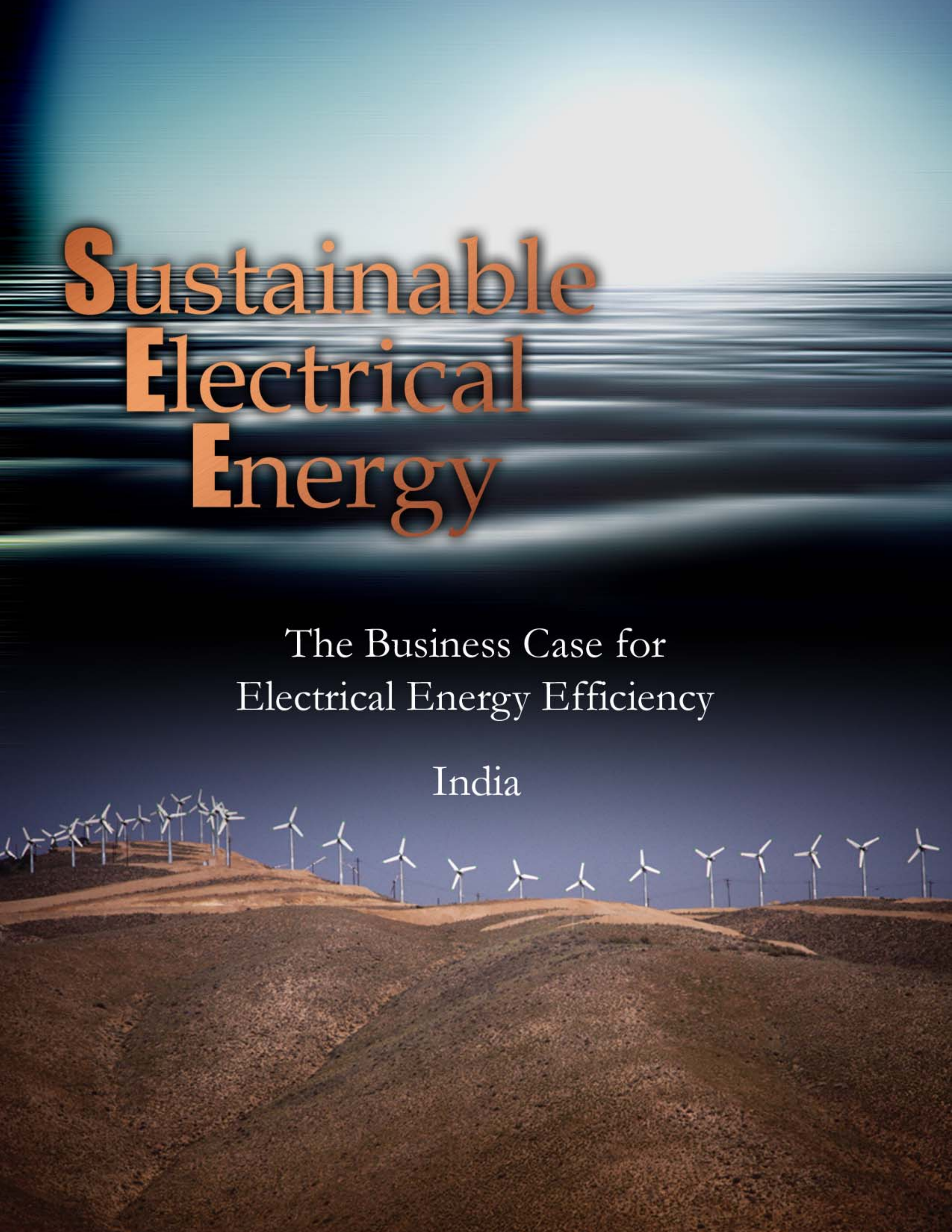

Sustainable Electrical Energy

The Business Case for Electrical Energy Efficiency

India

Potential Net Benefits from Improved Energy Efficiency of Key Electrical Products: The Case of India, with Extension to South Asia, the Middle East, and Africa

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ABSTRACT

The goal of this project is to estimate the net benefits that cost-effective improvements in energy efficiency can bring to developing countries. The study focuses on four major electrical products in the world's second largest developing country, India. These products – refrigerators, room air conditioners, electric motors, and distribution transformers – are important targets for efficiency improvement in India and in other developing countries. India is an interesting subject of study because of it's size and rapid economic growth. Implementation of efficient technologies here, would save billions of dollars in energy costs, and avoid hundreds of megatons of greenhouse gases. India also serves as an example of the kinds of improvements opportunities that could be pursued in other developing countries. Therefore, the study extends the findings to rough estimates of potential impacts in the rest of South Asia, the Middle East, and Africa.

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1. Executive Summary

There is a strong, profit-based business case for investing in more energy-efficient products and designs. Energy efficiency, however, is often viewed as something that businesses and individuals "should" do to as good citizens. The reality is that using energy ***inefficiently*** is like walking past money on the ground - - - money that could be put to far better use than paying electricity bills. Investing in energy efficiency creates economic value.

The study described in this report employed the methodologies of life-cycle cost analysis and national energy and environmental impact accounting in order to provide detailed estimates of the potential benefits of equipment efficiency programs in India. In addition, it extended the findings of the Indian case to nine other countries in South Asia, the Middle East and Africa.

The equipment studied include: household refrigerators, room air conditioners, industrial and agricultural motors and distribution transformers. These products were chosen based on three criteria:

1. Contributions significant to national electricity consumption in India.
2. Opportunity for efficiency increases through cost-effective design improvement ranging from 2% to 62%.
3. Sufficient engineering and market data available to afford rigorous technical evaluation.

These products do not represent an exhaustive set of equipment for which efficiency programs may be attractive. Instead, they are best seen as examples which may demonstrate the cost-effectiveness and scale of impacts of such programs in general. Together, these four products are projected to consume 165 TWh in 2010, accounting for about 25% of electricity consumption in that year. There are other products that use significant amounts of electricity and which afford the possibility of efficiency improvement. The most obvious of these are lighting products, water heaters electric fans and laundry appliances. Because detailed technical data were not available for these products, they are not included here. Therefore, the reader should keep in mind throughout that summary results represent only a subset of the potential for efficiency improvement. In addition, we note that, while the current study covers motors, the analysis is limited to energy savings gained from motor equipment improvements. There are significant additional opportunities for improvement in motor system efficiency, but a detailed evaluation of these was not within the scope of this study.

Major conclusions for India are:

- The products studied – domestic refrigerators, room air conditioners, industrial and agricultural motors and distribution transformers -- all represent attractive candidates for efficiency programs in India, in terms of potential electricity savings.

- Substitution for baseline models of these equipment by high-efficiency models is highly cost effective from a consumer perspective, given current estimates of incremental equipment prices and the projected future price of electricity.

- Substitution of baseline equipment in India with high-efficiency models that minimize consumer costs over the lifetime of the equipment would result in an average per-unit fractional electricity consumption reduction of:
    - 56%-62% for distribution transformers
    - 45% for domestic refrigerators
    - 20 - 39% for industrial motors (percent reduction in losses)
    - 12% for agricultural motors (percent reduction in losses)
    - 6% for room air conditioners

- Efficiency programs implemented in 2010 would impact a large number of units, as sales of identified products are growing rapidly. In the period between 2010-2020, product sales are expected to total:
    - 77 million domestic refrigerators
    - 47 million room air conditioners
    - 18 million motors
    - 5 million distribution transformers

  For a total of 147 million units for the four selected products.

- Assuming that an efficiency program achieves target levels in India for all products shipped between 2010 and 2020, energy savings and avoided carbon dioxide emissions will accrue over the lifetime of products shipped between these years. Resulting cumulative savings are given in Table 1.

Table 1. Estimated Cumulative Primary Energy Savings and Avoided CO_2 Emissions in the High Efficiency Case for products shipped between 2010 and 2020

Product	MTOE	Million tons CO_2
Refrigerator	77	259
Distribution transformer	45	153
Room air conditioner	23	78
Motor	14	47
TOTAL	159	538

- Assuming that full market transformation occurs in 2010, by 2020, most of the stock of targeted products will use high efficiency technology. Base case delivered (site) electricity consumption and savings in 2020 are shown in Table 2. Savings in this year account for 2.5%, or about 9 days worth of projected electricity consumption for that year.

Table 2. Estimated Base Case Consumption and Savings for High Efficiency Case in 2020

Product	Consumption (TWh)	Savings (TWh)
Refrigerator	45	16
Distribution transformer	25	7

Room air conditioner	56	5
Motor	151	4
TOTAL	276	31

- Electricity ratepayer cost savings, additional product costs and Net Present Value (difference between electricity bill reductions and increased first costs discounted to present year) are given in Table 3.

Table 3. Estimated Present Value of Costs and Benefits to Indian Consumers of the High Efficiency Case ($ billion)

Product	Additional Product Costs	Electricity Cost Savings	NPV
Distribution transformer	0.7	3.2	2.5
Refrigerator	0.6	1.9	1.3
Room air conditioner	0.1	1.3	1.2
Motor	0.2	0.7	0.5
TOTAL	1.5	7.0	5.5

- Aside from financial benefits gained by consumers, significant benefits could be gained from efficiency programs in India by avoidance of power outages currently experienced throughout the country as a result of loads that exceed system capacity.

In addition to providing detailed results for products in India, the study made a rough estimate of potential impacts in nine other countries for refrigerators, motors and distribution transformers (market data for air conditioners was not available for these countries). The countries studied are: Pakistan, Bangladesh, Saudi Arabia, Iran, Israel, Egypt, Algeria, South Africa and Nigeria. These countries were chosen because:

- They are located in South Asia or adjacent regions, and therefore may be the most similar to the Indian case in terms of technologies utilized.
- They are the largest economies in their respective regions and therefore may represent the largest overall savings potential.

The results provided for these countries are probably not specific enough to directly persuade policymakers to implement efficiency programs for these products. They may, however, serve as a tool to engage country representatives in consideration of programs, and demonstrate the value of the methodologies employed. Ideally, these results will lead to a further level of analysis which will utilize engineering and market data appropriate to each country, in order to provide estimates at a level of detail achieved by the current study for the Indian case. Major findings for the nine extension countries are summarized in Table 4.

Table 4 – Impacts of Improved Efficiency for Refrigerators, Motors and Distribution Transformers shipped between 2010 and 2020

Country	Site Energy Savings	Avoided Emissions	NPV
	TWh	MT(CO_2)	$Billions
India	482.0	460.1	4.31
Pakistan	29.6	14.0	0.25
Bangladesh	13.3	8.7	0.13
Saudi Arabia	48.8	31.5	0.57
Iran	85.0	51.0	0.49
Israel	23.5	20.7	0.25
Egypt	49.3	22.1	0.55
Algeria	17.8	13.3	0.17
South Africa	99.6	89.7	0.78
Nigeria	10.1	4.1	0.09
Total (non-India)	377.0	255.2	3.28

- This analysis shows that, although no single country studied would receive as much energy savings as India, there is significant potential for savings. In particular, South Africa and Iran are predicted to consume large amounts of electricity with equipment for which efficiency improvement has been demonstrated to be highly cost-effective.

- In summary, we believe that the extension of the Indian results to other developing countries in adjacent regions identifies countries where governments may consider implementation of efficiency programs including standards and labeling and/or other market transformation programs.

2. Introduction

The goal of this project is to estimate the net benefits that cost-effective improvements in energy efficiency can bring to developing countries. The study focuses on four major electrical products in the world's second largest developing country, India. These products – refrigerators, room air conditioners, electric motors, and distribution transformers – are important targets for efficiency improvement in India and in other developing countries. After characterizing the net benefits of these cost-effective efficiency improvements in India, we extend the findings to the rest of South Asia, the Middle East, and Africa.

India is a major energy consumer. Its energy consumption growth is rapid and continual. Efficiency policies have a particularly important role to play since so much new equipment is entering the stock. Cost-effective efficiency measures will save consumers money, but they also address other important issues as well. India is currently unable to generate enough electricity to meet demand. To do so, it will have to expend capital to increase generation capacity and reduce system losses. Improved efficiency has the additional benefits of increasing the number of customers served by existing generation and reducing the investment necessary to meet demand, thus allowing for a re-allocation of capital to other projects and/or other sectors of the economy.

While India is unique, many aspects related to efficiency there are common to other developing countries. In many countries, economic growth will drive energy demand through increases in energy-intensive industrial production, growth of the service sector, and entry of an increasing number of people to a level of income that allows for ownership of major energy-consuming appliances. Building the generation capacity necessary to meet this demand is a continuing concern throughout the developing world.

This report estimates potential efficiency savings for a few important products. Thus, the estimated benefits represent only a part of the total that might be realized through a comprehensive program of efficiency improvement applied to a larger set of energy-using products. Our focus is to provide the most specific and technically accurate analysis available. For this reason, we do not consider likely opportunities where solid technical data is not yet available.

3. Approach

The study combines a bottom-up engineering-economic analysis of specific technologies with a projection of the market evolution for each product.

Technology Cost-Efficiency Analysis

For each product, we first study key characteristics (including efficiency level) for specific product classes. Each product is represented by two or more product classes. For refrigerators, for example, we consider single-door manual defrost and two-door auto-defrost models. We estimate the typical user purchase cost of each product class. The characteristics of the most common current product establish the baseline, for which we gather data on purchase price and energy-use characteristics. Efficiency improvements and their costs are estimated relative to this baseline.

We estimate the energy savings and additional purchase cost associated with specific technologies that enhance efficiency. The fundamental component of the purchase cost is the per-unit manufacturing cost. To this cost we apply markups for manufacturers and distributors that result in the purchase price.

Taking typical product utilization and equipment lifetime into account, we calculate the Life-Cycle Cost (LCC) of owning and operating a product at alternative efficiency levels for a typical user. The LCC accounts for the electricity costs paid by the consumer or, in the case of transformers, the costs of electricity generation. The price of the electricity that is saved at the margin is based on current tariff structures. Future prices are based on projections of electricity prices or avoided costs for product users.

We calculate LCC values using discount rates appropriate for each type of user. The typical user is a household in the case of refrigerators, a household or commercial enterprise for room air conditioners, an industrial firm or agricultural operation in the case of motors, and an electric utility in the case of transformers. We based the discount rates on Indian conditions.

For each product, we identify the efficiency level with the lowest LCC, which represents the most economically justifiable design for the consumer. Of course, policy makers will consider other important factors besides consumer LCC in reaching their decisions about target efficiency levels, including impacts on manufacturers

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Market Projection

The approach for estimating the sales of each product for each year in the 2010-2020 period involves use of historical shipments data (for estimating replacement sales), sales forecasts by a market research firm, and consideration of the key drivers for growth of each product. For appliances in a growing market, new installations account for the majority of sales, rather than replacement of retired equipment.

Potential National Impacts with High-Efficiency Products

Our estimate of impacts considers the outcome if all products installed in the 2010-2020 period embody the identified cost-effective efficiency level. The benefits of this High Efficiency scenario are measured against a Base Case in which the efficiency of each product remains at current levels. This Base Case is not a forecast of what is likely to happen, as efficiency will likely improve to some degree due to market forces. Since the extent of this market-driven improvement is very uncertain, we chose not to incorporate estimates of such improvement in the Base Case.

The impacts for each year consider the accumulated stock of products sold in the 2010-20 period. We count impacts through 2030.

We calculate the total benefit to consumers as the difference between total energy cost savings and additional first costs for higher-efficiency products in each year. Depending upon the product, we multiply the electricity savings in each year by the projected marginal electricity price for households or industries or commercial enterprises, or by the projected marginal price of electricity supply for utilities. To arrive at a cumulative benefit, we discount the net benefit or cost in each future year to the present using discount rates appropriate for each type of user.

In estimating national benefits, we consider impacts assuming that the current situation of electricity shortages is greatly relieved by 2010 (as envisioned by government plans). Thus, reduced electricity consumption from higher efficiency products is expected to have an effect on generation at the margin. We calculate the present value of the net national benefits using an appropriate national discount rate for India.

We also consider how the benefits would differ if shortages continue in the 2010-2020 period. In this case, much of the electricity saved through higher efficiency could be sold to consumers whose demand would otherwise not be met. This consumption would allow for additional economic output or would provide services to households.

Based on savings of energy at the consumer level, we calculate the associated reduction in national electricity generation and primary energy consumption using estimates of future transmission and distribution losses and generating efficiency. We calculate the associated reduction in emissions of carbon dioxide based on per-kWh emissions factors.

Extending India Results to Other Regions

Once a detailed analysis is completed for India, expected impacts of efficiency programs are extended to a regional level. Regional analyses rely on extension of the results of the individual countries, using available market data.

4. Technology Cost-Efficiency Analysis

For each considered product, we estimated the incremental consumer cost of technologies providing higher energy efficiency relative to a specific baseline technology, as well as the associated reduction in annual energy use.

Refrigerators

There are two main product classes for residential refrigerators in India: direct cool (manual defrost) and frost-free. Nearly all of the direct-cool models are one-door type, with a small freezer compartment within the same cabinet area as the fresh-food compartment. Likewise, the frost-free units are entirely two-door units, with two isolated compartments connected by an air passage. Traditionally, direct cool units have dominated the market, but frost-free units are gaining ground. According to a recent survey of Indian refrigerator manufacturers (IMRB 2004), direct-cool units command

82% percent of the market, with 18% held by frost-free. While sales of refrigerators are currently growing at about 6% per year, one source indicates, however, that frost-free sector growing at 20% per year.[1], indicating a strong market trend towards this product class (Euromonitor 2003).

The parameters necessary to assess the cost effectiveness of improved refrigerator efficiency are taken from an engineering analysis (Bhatia 1999), which evaluated the characteristics of a baseline refrigerator model and utilized a simulation software package in order to determine efficiency benefits. This analysis used cost estimates reported by Indian refrigerator manufacturers.

Table 5 shows data collected for direct-cool refrigerators of 165-liter capacity. This capacity of refrigerator class continues to be the most popular sold. We assume that the relationship between cost increase and efficiency improvement is still generally applicable to the baseline unit on the market today.

In order to more accurately estimate energy savings of current Indian refrigerators, we estimated the daily electricity consumption from a survey of the current market (IMRB 2004). This dataset is comprehensive in terms of models currently sold, but does not have consumption data for many models. Therefore we adopt the methodology of a recent report (Harrington 2004), which estimated a compressor activation rate of 38% for Indian refrigerators currently on the market. Using this, in combination with the wattage ratings provided for current models (weighted by sales), we determine that the baseline refrigerator uses an average of 0.98 kWh per day. Annual unit energy consumption for the baseline model is 0.98 kWh/day x 365 days = 359 kWh.[2]

Frost-free models, almost all of which are two-door models in India, are more than twice as energy intensive. According to a sample of models tested by manufacturers, the average consumption of a frost-free model is roughly 2.4 kWh/day, or 876 kWh per year.

Table 5. Efficiency Improvement and Incremental Manufacturer Cost for Refrigerator Design Options (direct-cool refrigerator of 165 liter capacity)[3]

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[1] STAT-USA Industry Sector Analysis – Refrigeration and Air Conditioning Equipment - India

[2] Although refrigerators may not be operational during every hour of the day due to unreliability of the power supply, we assume, however that any compressor run time lost during a power outage is compensated for by the increased cooling necessary when power is restored.

[3] Baseline design assumed to have (1) Gasket heat leak rate of 8.0 W/m – 100°C, (2) Compressor EER of 3.41, (3) Wall and door insulation thickness 4.00 cm (4) Evaporator area 0.488 m^2 and (5) Condenser area 0.63 m^2; from Bhatia (1999).

	Design	Energy				Manufacturer Cost		Incremental Price	
		Unit Savings		UEC		∆ Cost	Cum	Price	Cum
		kWh/day	%	kWh/day	kWh/yr	$	%	$	
0	Baseline			**0.98**	359			**$184**	$0.00
1	Gasket Heat Leak Reduction 25%	0.05	5%	0.94	341	$2	1.3%	$186	$2.39
2	Higher EER(4.13) compressor	0.23	23%	0.76	276	$7	3.9%	$191	$7.17
3	Increase insulation thickness in door and wall by 50%	0.45	45%	0.54	196	$19	10.3%	$203	$18.94
4	Increase Evaporator area by 33%	0.46	47%	0.52	190	$23	12.7%	$207	$23.36
5	Increase condenser area by 50%	0.49	50%	0.49	179	$32	17.4%	$216	$32.00

Source: Bhatia, Pankaj "Development of Energy-Efficiency Standards for Indian Refrigerators" ASHRAE Transactions: Research 1999
Baseline Energy Consumption calculated from currently available models, using rated Wattage, in combination with methodology used in Harrington (2004).

The incremental costs shown in the table represent direct material and labor expenses to the manufacturer, and are not indicative of the additional price paid by the consumer, which also includes distributor and retail markups. In order to estimate these, we scale the percentage manufacturer incremental costs according to an estimate of baseline retail price. The baseline retail price for a 165-liter direct-cool (single-door) refrigerator are taken from a survey of a comparison-shopping website in India (www.compareindia.com). Price data are from a sampling of retail outlets, and therefore we judge them to be competitive and potentially more representative of actual prices paid than manufacturers' suggested retail prices. The average of a sample of 17 models between 165 and 175 liters is $184 at current exchange rates (45.45 Rs/$).

For frost-free models, the baseline is around 220 liters, with about half of sales for units within the 220 to 250 liter range. To estimate the baseline price for frost-free models, we used a sample of 18 models from the same retail source, and found an average price of $311 for units between 220-235 liters.

Air conditioners

As in the case of refrigerators, there are two main classes of room air conditioners common in India, but one of them dominates the market. Indian businesses and residences use both window-mounted and split air conditioning units, but window units enjoy 83% of production, according to a recent survey of air conditioner manufacturers (IMRB 2004). The market share of split units shows some indication of gaining ground on window units, however. Central air conditioning is still relatively rare in India.

Traditionally, large commercial enterprises dominated the purchase of air conditioning equipment, but residential consumers are entering the market. We estimate that by 2010, half of the purchases will be made by residential customers.

Detailed engineering data for air conditioners particular to the Indian market are not available as they were for refrigerators. Air conditioner designs tend to be similar among countries, however, so that design option parameters from the U.S. market may be used as a proxy.

Baseline capacity, retail price and efficiency are estimated from a combination of production data, and model data from www.compareindia.com. Market shares of each cooling capacity category are taken from manufacturer production estimates. The most common capacity class is 1.5 ton (12,000 Btu/hr) cooling capacity, with one and two-ton units making up most of the remainder of the market. The market-weighted average capacity is 1.5 tons, or 18,000 Btu/hr, well within the range of the units covered in the product class analyzed for U.S. DOE minimum efficiency standards (Table 6). The market-weighted average price of the online models is $497, and the average efficiency level (EER) is 9.1. Since the baseline efficiency considered by the DOE analysis was 9.0 EER, the average retail price of these models should be reasonably representative of the baseline price.

Table 6. Room Air Conditioners in India: Capacity, Retail Price and Efficiency

Capacity (in Tons)	% Market	Price (Rs)	Price ($)	EER
0.75	0.1%	12870	$283	9.2
0.8	1.0%	15725	$346	9.3
1	10.3%	20587	$453	8.7
1.25	0.6%	19993	$440	9.4
1.5	**78.3%**	**22561**	**$496**	**9.3**
2	8.7%	26045	$573	9.0
2.2	0.1%	N/A		
3	0.5%			
4	0.3%			
Weighted Average				
1.50	99.9%	22567	$497	9.1

Table 7 shows the changes in EER and equipment cost estimated for various room AC efficiency levels in the U.S. DOE's analysis (USDOE 1997). The annual energy consumption in India is estimated using assumptions about utilization by residential and commercial users.[4] The efficiency increase with design 1 implies a 7.2% reduction in energy consumption, reducing annual use from 1191 kWh to 1105 kWh.

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[4] The regions in India where AC is common (North) have a six month cooling season. We assume that commercial users (assuming these are mostly office buildings) use AC 8 hours a day, 20 days a month, and that residential users use AC 4 hours a day, 30 days a month. This gives 960 hours per year for commercial users, and 720 hours for residential. We assume that by 2010, residential sales (and therefore affected stock) will be equal to commercial, so we take a simple average and get 840 hours per year.

Table 7. Efficiency Improvement and Incremental Manufacturer Cost for Window Air Conditioners With Louvered Sides – 14,000 to 19,999 Btu/hr Capacity

Design Number	Design	EER	Energy Savings			Equipment Price		
			Unit Savings		UEC	Inc.	Total	Delta
			kWh/yr	%	kWh/yr	%	$	
0	Baseline	9.0			**1191**	0%	**$497**	$0
1	0 + Incr Compressor EER to 10.8	9.7	86	7.2%	1105	4%	$514	$17
2	1 + Condenser Grooved Tubes	10.0	117	9.8%	1074	5%	$520	$24
3	2 + Add Subcooler	10.2	135	11.3%	1056	6%	$527	$31
4	3 + Increase Evap/Cond Coil Area	10.7	193	16.2%	998	36%	$674	$178
5	4 + Incr Compressor EER to 11.3	11.1	224	18.8%	966	46%	$723	$227
6	5 + Incr Compressor EER to 11.4	11.2	232	19.5%	958	50%	$746	$250
7	6 + BPM Fan Motor	11.5	259	21.7%	932	74%	$865	$368
8	7 +**Variable Speed Compressor	12.8	351	29.5%	839	119%	$1,089	$592

Source: U.S. Dept. of Energy. Technical Support Document for Energy Conservation Standards for Room Air Conditioners. Sept. 1997.

Incremental costs to manufacturers to implement each design option are assumed to be the same in percentage terms in India as in the United States, and we expect these costs be passed on proportionally to the consumer. For example, an increase in efficiency from the 9.0 EER baseline to a level of 9.7 (design 1) is expected to add 4% to direct material and labor expenses to the manufacturer. Therefore, the retail price of this model is expected to be 4% higher than the current average of $497, or $514.

Split-system air conditioners are not considered separately for the engineering analysis. Savings and costs for these units are assumed to follow the same pattern as window air conditioners. Considering the small market share of these units, this creates only a small inaccuracy in evaluation of national impacts.

Motors

Electric motors represent a distinct case from refrigerators and air conditioners, for several reasons. In general, motors are relatively efficient products when they are run at design loads (80-90%). High-efficiency motors reduce losses in both the windings (joule losses) and in the magnetic material of the core, most directly through the use of high-quality materials. The reduction of annual energy consumption from these measures is generally of the order of a few percent, or equivalently, a reduction of losses on the order of 10-40%. Such an efficiency improvement can be highly cost-effective due to the extensive operating hours in many agricultural or industrial applications. Operating hours are highly variable, however, producing a large degree of variability in energy savings. We consider two sectors for motor efficiency improvement: agricultural (irrigation pump) applications, and industrial (manufacturing) applications. Smaller motors (less than 10 HP) are used across all sectors, often as a component in other equipment, such as household appliances. In this case, motor efficiency improvement is a design option that may be considered by manufacturers in order to meet overall product efficiency goals. We do not consider component motors as a separate class of products in this report, however.

Incremental manufacturing costs for motors are generally a closely-held trade secret, and are thus difficult to obtain. Therefore we rely on retail price estimates provided by a recent study performed in a cooperation between International Institute for Energy Conservation and the International Copper Promotion Council India (IIEC 1999). Cost and energy consumption parameters are summarized in Table 8.

Table 8. Per Unit Efficiency Improvement and Incremental Manufacturer Cost for Motor Design Options

AGRICULTURAL - 5 HP						
Design	Energy			Equipment Price		
	UEC	Losses	Loss Reduc.	%	$US	$US
	kWh/year	kWh/year	%	Inc	Price	Inc
83% Efficiency	5837	992	0	0	$190	**0**
85% Efficiency	5720	875	12%	**15.0%**	$219	**$28.50**
INDUSTRIAL - 15 HP						
Design	Energy			Equipment Price		
	UEC	Losses	Loss Reduc.	Inc	Price	Inc
	kWh/year	kWh/year	%	%	$US	$US
89% Efficiency	37079	4079	0	0	$648	**0**
91% Efficiency	36264	3264	20%	**15.1%**	$746	**$97.86**
INDUSTRIAL - 20 HP						
Design	Energy			Equipment Price		
	UEC	Losses	Loss Reduc.	Inc	Price	Inc
	kWh/year	kWh/year	%	%	$US	$US
89% Efficiency	50562	5562	0	0	$561	**0**
93% Efficiency	48387	3387	39%	**21.0%**	$678	**$117.81**

The prototype agricultural motor is a 5 HP (3.8 kW) unit typically used as part of an irrigation pump set. The efficiency improvement offered by a high efficiency motor of this capacity is 2%. The improvement in efficiency from 83% to 85% amounts to a 12% reduction in losses, and requires an increase of 15% in retail price, or an additional $27. We assume that pumps are run 1700 hours per year at 75% of their rated capacity (Banerjee 1993).

We consider the example of industrial motors of 11kW (15 HP) and 15 kW (20 HP) capacity as representative of the class of motors between 11 HP and 50 HP, which represents roughly 10% of unit sales of low-tension squirrel cage (LTSC) motors (IIEC 1999) in India. While smaller motors dominate the market, these are less-likely to be used in high-intensity industrial applications, and actual use patterns are more difficult to estimate. Motors over 50 HP hold a very small market share. Therefore, the 10-50 HP segment is the most likely to provide a relevant and accurate assessment of cost effectiveness.

The representative case of 11kW and 15kW show somewhat different levels of efficiency improvement. Efficiency improvement for a 11 kW (15 HP) motor is 2.2% (20% reduction in losses), while for a 15 kW (20 HP) motor it is 4.5% (39% reduction in losses). Correspondingly, the percentage increase in price is higher for the larger motors (21% for 15 kW vs. 15% in the 11 kW case). Operating hour assumptions for industrial motors are considerably higher than in the agricultural case. Assuming that a typical industrial application has motors running 250 days per year for 2 eight-hour shifts per day, we arrive at an estimate of 4000 hours. We expect this is a typical load, but realize that there is a large amount of variability in operating hours, since some industrial facilities will operate for one shift per day, while others may be operating continuously (3 shifts).

The levels of efficiency assumed in this analysis are meant to represent those typically available in India rather than conform to a particular set of standards. It is useful, however, to compare these levels to common international practices. Therefore, we note that baseline efficiencies for India are all lower than the current minimum levels set by the U.S. Department of Energy, which are 89.5%, 90.2% and 90.2% for 3.8kW, 11kW and 15 kW respectively (USDOE 1999). The high efficiency case for agricultural motors still lies below the US minimum. For industrial motors, the high efficiency case exceeds the US minimum, and is equal or greater than the voluntary ‘premium’ level set by NEMA, which is 91% for both 11kW and 15 kW motors.

Distribution transformers

In general, efficiency improvement of distribution transformers in the Indian context is highly cost-effective. For this reason, and for simplicity, we consider only the ‘best technology’ case, that is, transformer models that would receive the highest rating under the current rating scheme. We use the star rating as proposed by the Bureau of Energy Efficiency (BEE), India, based on survey data they collected in support of efficiency programs. The baseline is set at the current purchase practice conforming to the current standard (IS-1180). The losses for the baseline are set at 50% load condition. Total power loss ratings for the BEE Star rating plan used in the analysis are given in Table 9.

Table 9 – Power loss ratings for BEE Star Plan

Rating	25 kVA	63 kVA	100 kVA	160 kVA	200 kVA
	Maximum Losses at 50% Load in Watts				
1 Star	290	490	700	1000	1130
2 Star	235	430	610	880	1010
3 Star	210	380	520	770	890
4 Star	185	330	440	670	780
5 Star	160	280	360	570	670

Source: Indian Bureau of Energy Efficiency

The high efficiency level chosen for distribution transformers is well-understood in the Indian context, since we used levels already defined by BEE as voluntary rating levels. These levels can also be compared to levels defined by the National Electrical

Manufacturers Association (NEMA) in the United States. NEMA's TP1 standards are defined as percentage efficiency at 50% load, and assuming a power factor of 1.0. The levels are 98.7%, 98.6%, 98.8%, 98.9% and 99.0% for 25 kVA, 63 kVA, 100 kVA, 160 kVA and 200kVA respectively. The Indian 1 star level falls below this for all transformer sizes. Efficiency levels for 5 star transformers are 98.8%, 99.2%, 99.4%, 99.3% and 99.4%. These levels therefore exceed the TP1 standard by a significant margin.

There are two major components of energy loss incurred by distribution transformers: *no-load losses*, and *load losses*. The first of these occurs whenever the transformer is active, and is not significantly dependent on the transformer load. These losses are related to the transformer core. The other type of loss takes place in the coil, and is proportional to the square of the power passing through the unit at any given time. Load losses are calculated as the square of root-mean-square (RMS) loading adjusted for load growth. Average energy consumed per unit capacity for affected stock therefore varies from year to year due to load growth effects. The annual unit energy consumption for distribution transformers for affected stock is given by

$$UEC = E_{NL} + E_{LL} \times \left(L_{RMS}\right)^2 ,$$

where E_{NL} and E_{LL} are energy loss constants, L_{RMS} is the root mean square of the load as a fraction of rated transformer capacity. The energy loss parameters E_{NL} and E_{LL} are given in turn by multiplying the power loss factors P_{NL} and P_{LL}, respectively, by the number of hours in a year (8760) divided by 1000, to yield kWh.

Engineering data was provided by manufacturers in the form of energy loss ratings at 100% load. In order to estimate installed UEC, actual load levels must be taken into account. Transformer capacity is determined according to the maximum (peak) load they will carry, but on average, the load is much lower than the rated capacity. Table 10 gives engineering parameters and estimated equipment prices provided by manufacturers for baseline (1 Star) units and high-efficiency (5 Star) transformer models. Power loss ratings are given at 50% load in order to correspond to the BEE ratings.

Table 10. Per Unit Efficiency Improvement and Incremental Manufacturer Cost for Distribution Transformers by Capacity Class

25 kVA								
Rating	Energy						Equipment Price	
	P_{NL}	P_{LL} @ 50%	P_{TOT} @ 50%	E_{NL}	E_{LL}	UEC	Price	Δ Price
	Watts	Watts	Watts	kWh	kWh	kWh	$US	$US
1 Star	86	166	252	753	284	1036	$670	
5 Star	27	122	148	232	208	441	$1,007	**$337**
63 kVA								
Rating	Energy						Equipment Price	
	P_{NL}	P_{LL} @ 50%	P_{TOT} @ 50%	E_{NL}	E_{LL}	UEC	Price	Δ Price
	Watts	Watts	Watts	kWh	kWh	kWh	$US	$US
1 Star	151	299	450	1323	511	1834	$1,218	
5 Star	50	210	260	438	359	797	$1,678	**$460**
100 kVA								
Rating	Energy						Equipment Price	
	P_{NL}	P_{LL} @ 50%	P_{TOT} @ 50%	E_{NL}	E_{LL}	UEC	Price	Δ Price
	Watts	Watts	Watts	kWh	kWh	kWh	$US	$US
1 Star	216	427	643	1889	731	2619	$1,446	
5 Star	76	236	312	664	404	1068	$1,951	**$505**
160 kVA								
Rating	Energy						Equipment Price	
	P_{NL}	P_{LL} @ 50%	P_{TOT} @ 50%	E_{NL}	E_{LL}	UEC	Price	Δ Price
	Watts	Watts	Watts	kWh	kWh	kWh	$US	$US
1 Star	316	578	894	2768	989	3757	$2,438	
5 Star	103	439	542	902	751	1653	$2,741	**$303**
200 kVA								
Rating	Energy						Equipment Price	
	P_{NL}	P_{LL} @ 50%	P_{TOT} @ 50%	E_{NL}	E_{LL}	UEC	Price	Δ Price
	Watts	Watts	Watts	kWh	kWh	kWh	$US	$US
1 Star	425	740	1165	3723	1266	4989	$2,976	
5 Star	113	519	632	991	888	1880	$3,789	**$813**

Source: *Determination Analysis of Standards and Labeling Program for Distribution Transformers,* Indian Bureau of Energy Efficiency (BEE).

Total annual energy consumption is calculated from power losses assuming that the transformer is operating at all times. Therefore, for no-load losses, we simply multiply Watt losses by 8760 hours per year and divide by 1000 to arrive at kWh. For load losses, the consumption is given by

$$E_{LL}\ x\ (L_{RMS})^2,$$

Where L_{RMS} is the average root mean squared load of each transformer, given by

$$L_{RMS} = \sqrt{\sum_t \left(L(t)/Capacity(t)\right)^2}$$

We estimate the current RMS loading of the system according to the current average load (in terms of percentage of rated transformer capacity) and the current load factor (average load divided by peak load). The current average load is calculated by dividing the total load of the system by the total installed transformer capacity. According to Central Electricity Authority, the country registered a total load of 65036 MW in 2003 and recorded a total installed transformer capacity of 310496 MVA (CEA 2003-2004). This calculation yields an average load L_{AVE} of 21% of capacity. The average load factor LF defined as the ratio of average load to peak load, is 0.47 according to BEE. The relationship between average load, load factor and RMS load is strongly dependent on the variability in load over time. Unfortunately, load shape data for India are not readily available. Therefore, we rely on estimates of the relation between parameters estimated for the United States. According to (USDOE 2004), the relationship is given empirically by

$$L_{RMS} = (1+1.4 \times \exp(-7*LF))* L_{AVE},$$

This calculation results in an RMS loading of 0.22

Retail prices are estimated according to data provided by manufacturers to BEE. BEE asked the manufacturers to submit the loss and price data for the lowest cost transformer they could design for a set of specifications. The prices submitted through this process reflected the FORD, or the Free on Railway Destination price. This price is close to what can be considered the manufacturer's selling price as it includes sales tax, excise duty, shipping and packaging charges.

5. Consumer Impacts Analysis

To estimate the per-unit impacts of more efficient products on consumers, we used payback period, life-cycle cost (LCC) analysis, cost of conserved energy, and return on investment.

The payback period is the time required for savings in operating costs to equal the extra initial cost of a more efficient product.

The LCC is given by the following formula:

$$LCC = P + \sum_{n=1}^{L} \frac{OC}{(1+DR)^n}$$

where P is the equipment retail price, OC is the annual operating cost (electricity bill), and DR is the consumer discount rate. The sum ranges over the lifetime of the appliance. The denominator in the sum accounts for the fact that future operating cost savings are valued less by the consumer ("discounted") than immediate first costs.

We calculated the LCC for each design option considered for each product using the data from the technology cost-efficiency analysis, and discount rates for each sector. We interpret the design option with the lowest LCC to be the most cost efficient, and therefore an appropriate target for government efficiency programs, pending evaluation of other impacts.

Another indicator of cost-effectiveness is the Cost of Conserved Energy (CCE). Cost of conserved energy is the annualized increase in equipment costs divided by the value of annual energy saved through efficiency. These costs can be compared to the marginal price of electricity in order to assess the benefit to the consumer.

Finally, we also present the return on investment (ROI), which is the discount rate at which operating cost savings from the efficiency 'investment' equal the incremental first cost.

Marginal Electricity Prices

The consumer impacts analysis uses marginal energy prices to calculate the reduction in consumer energy costs associated with higher efficiency. Marginal energy prices are the prices paid for the last unit of energy used in a given billing period. Since marginal prices reflect a change in a consumer's bill associated with a change in energy consumed, such prices are appropriate for determining energy cost savings associated with efficiency.

For the LCC analysis we use estimated current marginal electricity prices. In all likelihood, the marginal prices in the 2010-2020 period will be higher than current prices, especially for residential and agricultural sectors. Thus, the use of current prices is a conservative assumption, since higher electricity prices will yield larger energy bill savings.

There is considerable sectoral cross-subsidization in the sale of electricity in India, with large industrial and commercial consumers paying the highest rates, and residential and especially agricultural consumers paying below the cost of production. There is, however, a block structure by which the marginal cost increases with consumption. This is generally true for all sectors but agriculture, where marginal cost increases are low or nonexistent in most states.

To estimate the current residential and commercial marginal electricity price, we obtained and analyzed the prevalent tariff structures. Most Indian residential and commercial consumers purchase electricity from State Electricity Boards (SEBs), so we based our estimates on their published tariffs. Table A-1 shows the rates at a usage of 100 kWh/month for each state for which data were available (a household with a refrigerator would likely be in the 100 kWh/month range).[5] We arrived at a national average rate of 5.9 cents per kWh by weighting each state's rate by its urban population (those households likely to have refrigerators). Average marginal commercial rates were obtained using the same methodology, and by assuming a nominal monthly consumption of 500 kWh for commercial enterprises. We arrived at a national average rate of 10.7

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[5] We chose a household consumption level of 100 kWh/month as provided by a study in Karnataka state by Murthy et al. (2001). More representative national household consumption data were not available. With the current tariff structures, we find that marginal rates would vary by less than 10% for household consumption within the 50 kWh/month to 200kWh/month range.

cents per kWh by weighting each state's rate by total commercial electricity consumption.

The price of electricity for agricultural consumers is currently 3.2 cents per kWh. This low price is only a fraction of the estimated cost of electricity production, and is highly subsidized, partially via higher rates for customers in other sectors. We assume that by 2010 prices will increase to 3.8 cents per kWh in accord with government policy on tariff reform, which requires that tariffs cover at least half of the cost of production. More detail on this assumption is given in the section on benefits to consumers below.

Industrial rates are currently close to the cost of production, and marginal rates are similar to average rates. We estimate the price of electricity to industrial customers to be 7.6 cents per kWh.

For distribution transformers, the cost to utilities of energy losses in distribution transformers is calculated according to estimates of the per unit energy cost, rather than in terms of retail electricity price. We use the Availability Based Tariff (ABT) to represent the marginal cost of electricity supply or generation (see discussion below).

Consumer Discount Rates

Consumers value immediate savings more than future savings. The time value of money is typically accounted for by discounting future savings using a discount rate.

There is limited data on which to base consumer discount rates in India. The rate currently used by utilities for their investment in demand-side efficiency programs is 10%. We assume that rates used for other sectors will be somewhat higher, with residential consumers discounting deferred savings by the largest factor. The sector discount rates are 15% for residential consumers. The rates used for other sectors are as follows: commercial – 12%, industry – 12%, agriculture – 15%, utilities --10%.

Life-Cycle Costs

Refrigerators. Given a unit energy consumption (UEC) of 359 kWh per year and a price of 5.9 cents/kWh, the annual operation of a baseline direct cool refrigerator (design 0) would cost about $21. As shown in Table 11, each subsequent combination of design options results in a lower UEC, with an accompanying increase in retail price.

For all of the design option combinations, payback to the consumer is less than three years, and all of them lower the LCC. Design option 3, which incorporates a reduction of heat leakage through the gasket, a more efficient compressor, and moderate insulation in the walls and door of the cabinet, has the lowest LCC. We estimate a discounted net savings of about $38 over the life of the appliance for this unit. For the design options analyzed, CCE ranges from 1.5 to 3.0 cents per kWh, well below the relevant electricity price. Return on investment to the consumer ranges between 33% and 68%, consistent with payback periods of a year or two. Based on the LCC analysis, we chose design option 3 as the policy target in calculating national impacts.

Table 11. Consumer Financial Indicators for Direct-Cool Refrigerators

Design Number	UEC	Retail Price	Annual Electricity Bill		Payback Period	Life-Cycle Cost		Cost of Conserved Energy	Return on Investment
			Total	Change		Total	Change		
	KWh/yr	$US	$US		Years	$US		$US/kWh	Per Annum
0	359	$184	$21.31	$0.00	0.00	$308	$0.00	$0.000	
1	341	$186	$20.24	-$1.07	2.24	$305	-$3.84	$0.023	44%
2	276	$191	$16.39	-$4.91	1.46	$287	-$21.54	$0.015	68%
3	196	$203	$11.64	-$9.67	1.96	$271	**-$37.58**	$0.020	51%
4	190	$207	$11.29	-$10.01	2.33	$273	-$35.20	$0.024	43%
5	179	$216	$10.61	-$10.69	2.99	$278	-$30.52	$0.030	33%

Assumed lifetime: 15 years[6]

Comparison of refrigerator efficiency levels with international practices is difficult, due to differences in product design, climate, use patterns and test procedures. Nevertheless, some indication of the efficiency of baseline and high-efficiency Indian refrigerators can be inferred by comparison to EU refrigerator standards passed in 1999. For the product class containing no freezer compartment, EU regulations require an annual energy consumption of no more than 252 kWh for a 165 liter appliance (European Commission 2000). The baseline UEC in India of 359 kWh is well above this level, and in fact corresponds roughly to the estimated baseline of European refrigerators before standards took effect there. The EU standard falls between design numbers 2 and 3 in our analysis. Design 3 uses 22% less energy than the EU standard, and would therefore correspond to an ‘F’ rating, where ratings run from A to G, A being the best and G barely passing the minimum.

For frost-free units, we assume that incremental equipment costs and energy savings will scale with the direct-cool analysis. The estimated discounted savings for design option 3 is about $106 over the life of the appliance (Table 12). For the design options analyzed, CCE ranges from 1.0 to 2.1 cents per kWh. Return on investment to the consumer ranges between 48% to 99%, consistent with payback periods of one to two years.

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[6] Estimate by Tata Energy Research Institute, Delhi – http://www.teri.res.in/teriin/news/terivsn/issue3/newsbrk.htm. Last Accessed Jan 10, 2005.

Table 12. Consumer Financial Indicators for Frost-Free Refrigerators

Design Number	UEC	Retail Price	Bill		Payback Period	Life-Cycle Cost		Cost of Cons. Energy	Return on Investment
			Total	Delta		Total	Delta		
	KWh	$US	$US		Years	$US		$US/kWh	Per Annum
0	876	$311	$51.94	$0.00	0.00	$615	$0.00	$0.000	
1	832	$315	$49.35	-$2.60	1.56	$603	-$11.15	$0.016	64%
2	674	$323	$39.97	-$11.97	1.01	$557	-$57.89	$0.010	99%
3	479	$343	$28.38	-$23.56	1.36	$509	**-$105.78**	$0.014	74%
4	464	$350	$27.53	-$24.42	1.62	$511	-$103.29	$0.016	62%
5	436	$365	$25.88	-$26.07	2.07	$516	-$98.35	$0.021	48%

Assumed lifetime: 15 years

Air conditioners. Traditionally, most air conditioner sales in India have been to commercial customers, but rapid economic growth and the rise of a burgeoning middle class is a large driver of new sales. We therefore assume that in 2010, half of sales will be to residential consumers. Therefore, the relevant marginal energy price for air conditioners is taken to be the simple average of the residential marginal rate (estimated at 5.9 cents/kWh) and the commercial marginal rate (estimated at 10.6 cents/kWh)

Given a unit energy consumption (UEC) of 1063 kWh per year and a marginal price of 8.3 cents/kWh, the annual operation of a baseline room AC (design 0) is estimated to cost about $99.

For the first three design option combinations, payback to the consumer is less than three years (Table 13). In order to reach an EER level above 10.2, however, the incremental retail price increases significantly, because the design options required to achieve higher levels of efficiency would incur significant redesign and retooling costs for manufacturers[7]. For this reason, the LCC is lower than the baseline only for the first 3 levels. Design option 3, which achieves 10.2 EER, has the lowest LCC. In calculating LCC for air conditioners, we use a discount rate of 13.5%, which is the average of the residential discount rate of 15%, and the commercial discount rate of 12%. We estimate a discounted net savings of about $35 over the life of the appliance for this unit. For this design option, the CCE is 3.9 cents per kWh, well below the relevant electricity price. Return on investment to the consumer for this level is 36%, consistent with a payback period of 2.8 years. Based on the LCC analysis, we chose the 10.2 EER design option as the policy target in calculating national impacts. For comparison, the US Department of energy required a minimum efficiency of 8.8 EER for this product class in it's 1990 rulemaking. Standards effective in 2000 raised this minimum efficiency level to 9.7 (USDOE 1997a).

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[7] These design options would require enlargement of the air conditioner cabinet.

Table 13. Consumer Financial Indicators for Room Air Conditioners

Design Number	EER	UEC	Retail Price	Annual Electricity Bill		Payback Period	Life-Cycle Cost		Cost of Cons. Energy	Return on Investment
				Total	Change		Total	Change		
		KWh	$US	$US		Years	$US		$US/kWh	Per Annum
0	9.0	1191	$497	$99	$0	-	$1,078	$0	$0.000	
1	9.7	1105	$514	$92	-$7	2.45	$1,053	-$24	$0.034	41%
2	10.0	1074	$520	$89	-$10	2.46	$1,044	-$33	$0.035	40%
3	10.2	1056	$527	$88	-$11	2.76	$1,043	**-$35**	$0.039	36%
4	10.7	998	$674	$83	-$16	11.11	$1,161	$84	$0.157	4%
5	11.1	966	$723	$80	-$19	12.20	$1,195	$117	$0.172	3%
6	11.2	958	$746	$79	-$19	12.97	$1,214	$136	$0.183	2%
7	11.5	932	$865	$77	-$21	17.16	$1,320	$242	$0.242	-2%
8	12.8	839	$1,089	$70	-$29	20.32	$1,498	$421	$0.286	-4%

Assumed lifetime: 12.5 years

Motors. As shown in Table 14, our analysis shows that efficiency measures for larger motors and motors used in industrial applications are highly cost-effective, especially for the larger motor. The CCEs are 2.5 cents per kWh for the 11 kW motor and 1.1 cents per kWh for the 15 kW motor. Both CCEs are much below the industrial electricity price.

The high-efficiency motor used in agricultural applications has an estimated CCE of 5.1 cents per kWh, which is above the current price but below the cost of production of 7.7 cents per kWh. Correspondingly, the life cycle cost of the high efficiency option is higher than that of the baseline model. Thus, unless tariff reforms bring agricultural tariffs close to the cost of production, this application will not be cost-effective from the point of view of the ratepayer. This analysis, however, does not consider the benefits of efficiency to utilities, who may have the incentive to subsidize the purchase of high-efficiency motors. This issue is addressed below in the section on utility impacts.

Table 14. Consumer Financial Indicators for Motors

AGRICULTURAL - 5 HP									
Design	UEC	Retail Price	Annual Electricity Bill		Payback	LCC		CCE	Return on Investment
			Total	Delta	Period	Total	Delta		
	kWh/year	$US	$US	$US	Years	$US	$US	$/kWh	Per Annum
83% Efficiency	5837	$190	$224.82	$0.00		$1,263	$0.00		
85% Efficiency	5720	$219	$220.30	-$4.51	6.32	$1,270	$6.97	$0.051	8%
INDUSTRIAL - 15 HP									
Design	UEC	Retail Price	Annual Electricity Bill		Payback	LCC		CCE	Return on Investment
			Total	Delta	Period	Total	Delta		
	kWh/year	$US	$US	$US	Years	$US	$US	$/kWh	Per Annum
89% Efficiency	37079	$648	$2,824	$0.00		$21,290	$0.00		
91% Efficiency	36264	$746	$2,762	-62.07	1.58	$20,934	-$356	$0.025	63%
INDUSTRIAL - 20 HP									
Design	UEC	Retail Price	Annual Electricity Bill		Payback	LCC		CCE	Return on Investment
			Total	Delta	Period	Total	Delta		
	kWh/year	$US	$US	$US	Years	$US	$US	$/kWh	Per Annum
89% Efficiency	50562	$561	$7,584	$0.00		$28,708	$0.00		
93% Efficiency	48387	$678	$7,258	-$326.21	0.71	$27,616	-$1,093	$0.011	277%

Assumed lifetime: 9 years for agricultural, 15 years for industrial

Distribution transformers. Estimates of financial benefits to electric utilities as a result of purchasing high efficiency transformers are calculated using the same methodology as for other equipment, with two important exceptions. First, as power delivery grows over time, each transformer is likely to experience some increase in load over its lifetime. Load growth occurs when new equipment, appliances, or additional activities occur on the circuits served by the distribution transformer. Load growth has the impact of increasing the load losses relative to the losses that we estimate during the first year of installation. The load is assumed to increase at a constant rate of 1% per year over the life of each transformer. For example, a transformer with initial load at 50% of capacity will face growth to about 55% load in 10 years, and roughly 60% load after 20 years. The unit energy consumption of the transformer in each year of its life is therefore given by

$$UEC_y = E_{NL} + E_{LL} \; x \; (1.01)^{2y}$$

Second, the cost to utilities of energy losses in distribution transformers is calculated according to estimates of the per unit energy cost, rather than in terms of retail electricity price. We use the Availability Based Tariff (ABT) to represent the marginal cost of electricity supply or generation. ABT unbundles the availability charge from the energy charge. This availability charge is payable by all those State Electricity Boards who have either contracted for capacity creation with the generator or to whom capacity has been allocated. The availability charge comprises all fixed costs that have been prudently incurred by the generator as a consequence of installing capacity. Its recovery is linked to a target availability.

The average generation cost of 7.7 cents/kWh is estimated based on historical (2001) data from the Planning Commission's Annual Report on the working of State Electricity Boards and Electricity Departments.

The other component of ABT is Unscheduled Interchange (UI) charges. UI is the variation between actual generation or actual drawal and scheduled (allocated) generation or scheduled drawal. For a generating station, it is equal to its actual generation minus its scheduled generation. UI for a beneficiary is equal to its total actual drawal minus its total scheduled drawal. The UI charges as an add-on to the average generation cost can therefore be viewed as the price of generating an additional unit of electricity over the allocated quota. Table 15 provides the UI charge calculation for the country for the year 2003/04.

Table 15 – Unscheduled Interchange (UI)Charges by Region

Frequency	paise/kWh	Northern	Western	Southern	Eastern & N-Eastern
>50.5 Hz	0	5.8	2.4	0.4	1.1
49 - 50.5 Hz	215.3	89.4	94.8	97.3	96.1
<49 Hz	570	4.76	2.7	2.3	2.89
Electricity Generation	%	28.1	32.9	27.3	11.8
Weighted UI	**220.8**	219.7	219.7	222.5	223.2
cents/kWh	**4.91**				

Source: Calculations based on frequency data from regional load dispatch centers.

The table indicates that most of the power delivered by State Electricity Boards was at a frequency below 50.5 hertz, and therefore incurred UI charges. The UI charge can be viewed as a marginal cost that is currently paid on most energy delivered, but which provides an incentive for SEBs to reduce load, and therefore frequency distortion. The weighted-average UI charge for all regions is 4.9 cents per kWh. Adding this to the average generation charge yields a total marginal cost of electricity of 12.6 cents/kWh.

As shown in Table 16, installation of high efficiency transformers provides a significant financial benefit to utilities. Even though increased incremental costs are large in percentage terms, the reduction in terms of losses is also large. Since transformers incur losses at all times they are in operation, the cumulative energy savings are substantial. As a result, payback period ranges from 4.5 years for the smallest capacity ratings to around 1 year for the 160 kVa class. Cost of conserved energy ranges from 1 to 5.2 cents per kWh, well below the cost of electricity delivery. For the larger capacity transformers, which are the most common, the installation of high efficiency equipment could save the utility thousands of dollars per unit installed.

Table 16. Consumer (Utility) Financial Indicators for Distribution Transformers

25 kVA									
Design	First Year UEC	Retail Price	Cost of Losses		Payback Period	LCC		CCE	ROI
			First Year	Average		LCC	ΔLCC		
	kWh	$US	$US	$US	Years	$US	$US	$/kWh	Per Annum
1 Star	1036	$670	$131	$161		$2,101			
5 Star	441	$1,007	$56	$68	4.49	$1,615	**-$485**	$0.052	19%
63 kVA									
Design	First Year UEC	Retail Price	Cost of Losses		Payback Period	LCC		CCE	ROI
			First Year	Average		LCC	ΔLCC		
	kWh	$US	$US	$US	Years	$US	$US	$/kWh	Per Annum
1 Star	1834	$1,218	$231	$284		$3,750			
5 Star	797	$1,678	$101	$124	3.51	$2,779	**-$971**	$0.041	26%
100 kVA									
Design	First Year UEC	Retail Price	Cost of Losses		Payback Period	LCC		CCE	ROI
			First Year	Average		LCC	ΔLCC		
	kWh	$US	$US	$US	Years	$US	$US	$/kWh	Per Annum
1 Star	2619	$1,446	$331	$406		$5,062			
5 Star	1068	$1,951	$135	$166	2.58	$3,426	**-$1,636**	$0.030	38%
160 kVA									
Design	First Year UEC	Retail Price	Cost of Losses		Payback Period	LCC		CCE	ROI
			First Year	Average		LCC	ΔLCC		
	kWh	$US	$US	$US	Years	$US	$US	$/kWh	Per Annum
1 Star	3757	$2,438	$474	$583		$7,625			
5 Star	1653	$2,741	$209	$256	1.14	$5,024	**-$2,601**	$0.013	89%
200 kVA									
Design	First Year UEC	Retail Price	Cost of Losses		Payback Period	LCC		CCE	ROI
			First Year	Average		LCC	ΔLCC		
	kWh	$US	$US	$US	Years	$US	$US	$/kWh	Per Annum
1 Star	4989	$2,976	$629	$774		$9,863			
5 Star	1880	$3,789	$237	$291	2.07	$6,384	**-$3,479**	$0.024	49%

Assumed lifetime: 22 years

6. Forecast of Product Sales

For each product, we developed a forecast of sales in each year in the 2010-20 period. The approach and data used are described in each section below.

Refrigerators

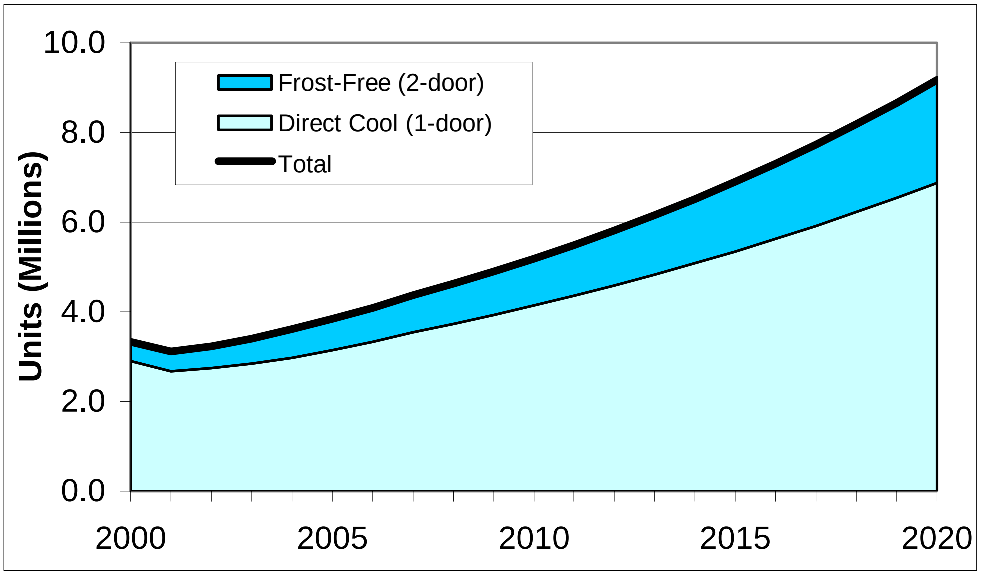
Currently, between 3 and 4 million refrigerators are sold in India each year. The great majority of these are produced in India by Indian firms, or by firms representing a joint venture with a North American or East Asian company. Foreign multinationals have traditionally had only a small presence in India, but now command a large share of the market. Direct imports from other countries are small. Furthermore, there is a strong trend towards consolidation, with the unorganized sector losing market to the bigger players and prices of units declining.

Although the market does contain a component due to replacements of old refrigerators, growth is dominated by the entrance of households to the expanding middle class. As of 2002, only 12% of households nationwide owned a refrigerator (Appliance Magazine), with very low levels of saturation in rural areas and among the poor, roughly half of whom do not have access to electricity.

Total sales of refrigerators in the years 1997-2002 was taken from a recent report (CLASP 2003). For 2003-2008, we relied on a forecast for sales provided by Euromonitor, a marketing research firm. These two sources combined indicate a ten-year average growth rate of 5.9% per year. We assume that this rate of total sales will continue throughout the forecast period. Our forecast shows sales growing from roughly 3.5 million units in 2002 to around 9 million in 2020 (Figure 1). A more precise forecast is inhibited by the large uncertainties in predicting the number of households that will be able to afford refrigerators.

The current market split is 82% direct-cool and 18% frost-free units. As mentioned previously, the frost-free sector continues to gain market share. We assume that it will gradually increase until it reaches 25% share by 2020, perhaps a conservative assessment.

Figure 1 – Unit Refrigerator Sales, 2000-2020



Air conditioners

The new and increasing residential customer base for air conditioners has caused dramatic growth in the industry in recent years at rates of more than 20% per annum.[8] There is still great potential for growth in the residential sector, as household saturation rates are still around the 1% level. A further impetus for sales growth has been the lowering of value-added tariffs.

In line with a general trend towards manufacturing industry consolidation, the unorganized sector, which once was dominant in air conditioner manufacturing, has given way to large firms, including multinationals, which now control about 80% of the market. We forecast sales only for the organized sector, as we assume that it would be more difficult to implement efficiency measures in the unorganized sector. Sales in the organized sector totaled 660,000 units in 2002, a dramatic increase from only 264,000 in 1998 (a 17% per annum growth rate). Growth in air conditioners is expected to be even larger during the 2002-2007 period, reaching 25% per annum (Euromonitor 2003). We assume that the growth rates will level to 15% between 2008 and 2010, and remain constant at 10% throughout the period 2010-2020, as saturation effects become significant. We assume that the share of split-system air conditioners remains constant at 17% throughout the forecast period.

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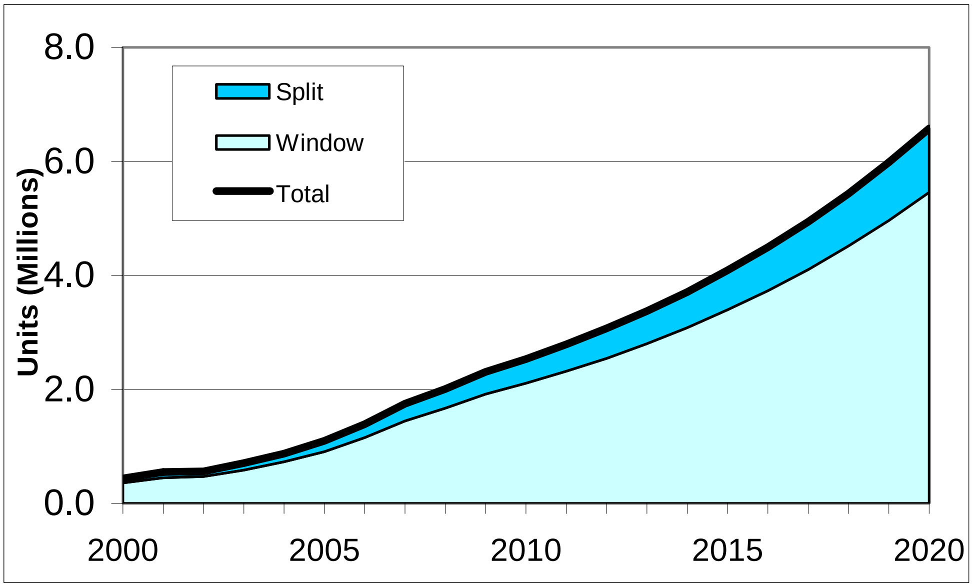
[8] Source: Euromonitor

Figure 2 – Unit Room Air Conditioner Sales, 2000-2020

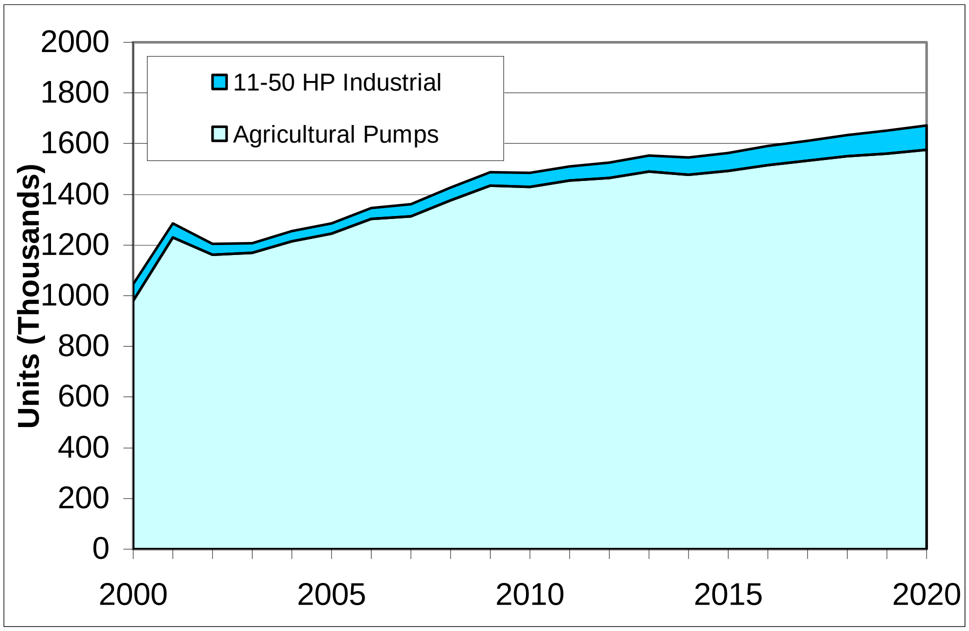


Motors

India possesses an enormous number of irrigation pump sets in its rural areas. Recent estimates indicate that, as of 2002, over 13 million pump sets were energized throughout India (Planning Commission 2002). The same report estimates the total potential for pump-sets at just under 20 million. Recent increase in the number of energized pump sets implies new sales of pump sets on the order of 400,000 to 500,000 per year, with a sales growth of about 3.3% in recent years (1995-2001). At this rate, the total potential of 20 million will be approached around 2020. As the sector becomes saturated, energization growth rates are likely to slow, and the market will be replacement-dominated. We forecast a smooth approach to market saturation, with energization rates continuing to grow at 1% per year until 2010, but thereafter dropping off proportional to the remaining potential in each year. Throughout the forecast, replacements are expected to grow according to the retirement function applied to past shipments.

According to IEEMA production statistics, domestic production of low-tension squirrel cage (LTSC) motors in the organized sector grew from 467,000 in 1992 to 620,000 in 1997, with a high of 715,000 in the intervening years (1994) (IIEC 1999). In addition, there were a large number of imports. 90% of the LTSC motors are less than 10 HP (a large fraction of which are accounted for by agricultural pump sets). The remaining 10% are over 10 HP. Between 1998 and 2003, production of 10-50 HP motors is assumed to scale with IEEMA production indices in terms of total motor capacity (IEEMA 2003). After 2003, since motor use is such an integral contributor to industrial production, we assume that motor sales will increase with forecasts of growth in industrial production. These are 5.3% in the period 2004-2010 and 5.7% in the period 2010-2020 (Planning Commission 2002).

Figure 3 – Unit Motor Sales, 2000-2020



Distribution transformers

Distribution transformer sales are primarily driven by increases in the total generation capacity of the power system. Generation increased at an average rate of 6.7% from 1990-2000. According to energy sector researchers in India, high growth rates are expected to continue through the coming decades, with annual growth rates ranging between 5 and 7% (Planning Commission 2004).

Between 1970 and 1994, total transformer capacity in MVA is given by ASI Production indices[9], scaled to 1995 production values for transformers. From 1995 to 2002, manufacturer estimates (IEEMA 2003) are used. After 2002, the stock of transformers is expected to scale with generation capacity. Once the total transformer capacity shipments are determined, shipments of each capacity class are calculated according to estimated market shares of each class.

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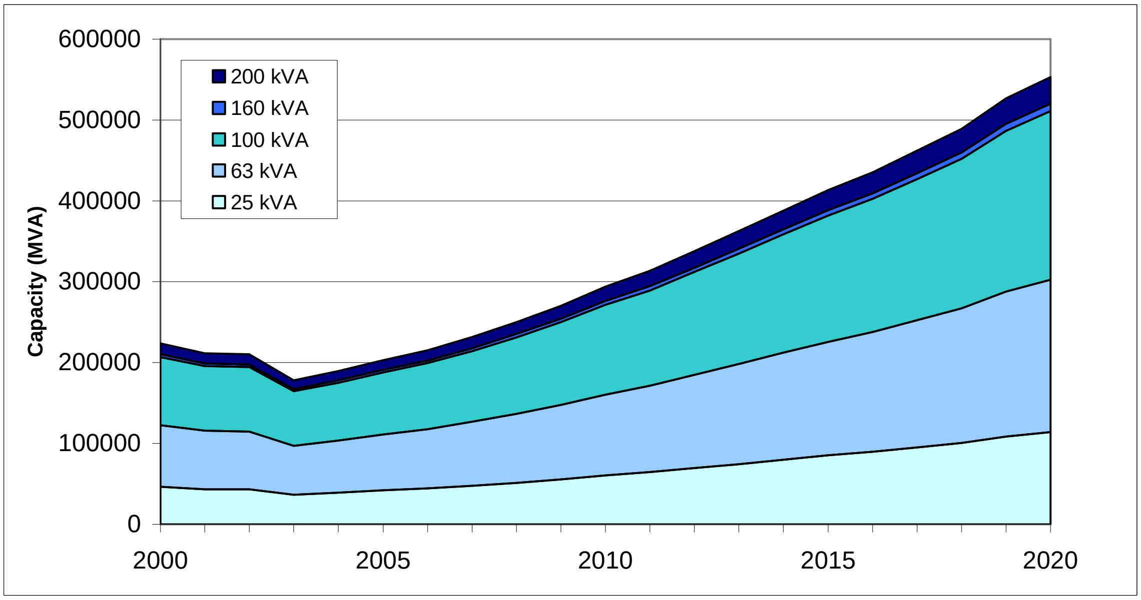
[9] Index for Electrical Machinery Apparatus and Appliances

Figure 4 – Distribution Transformer Sales in MVA, 2000-2020



7. National Impacts of the High Efficiency Case

The Base Case provides a reference against which we measure the potential impacts of the High Efficiency Case. The Base Case employed assumes no improvements in the baseline efficiency, and no change in the (inflation adjusted) retail price of the baseline units.

The High Efficiency Case assumes that a mixture of market forces and policy initiatives result in a situation in which the average efficiency of products sold in 2010 and thereafter meets the efficiency of the design option that provides the minimum LCC. This assumption corresponds to achievement of the full cost-effective potential of efficiency improvement. A lack of data on historical trends in efficiency makes it difficult to assess to what extent efficiency of the considered products may improve in India due to market forces.

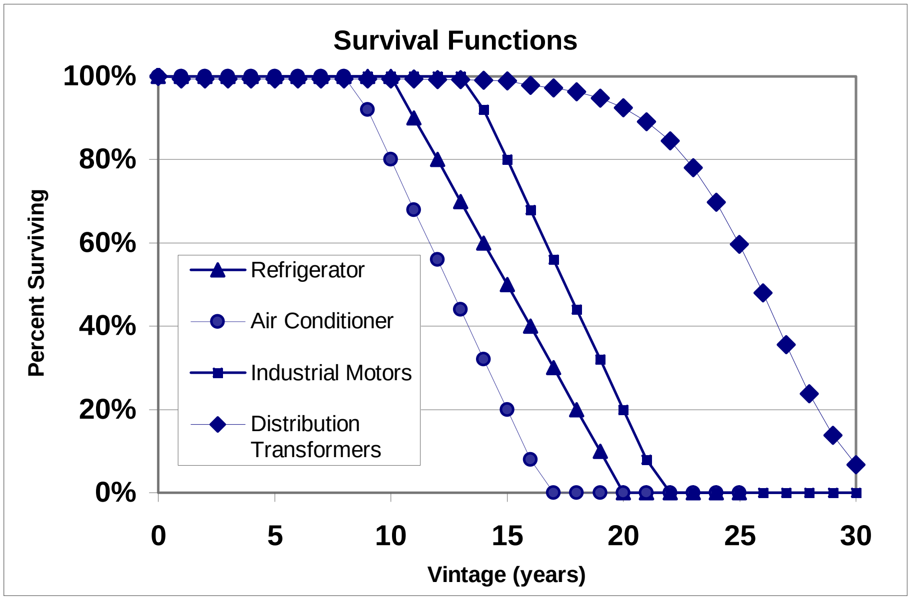
All sales of products during the 2010-20 period are affected by the policy, and savings are estimated from these products only. Sales that occur after 2020 do not affect national savings; however, lifetime savings due to units that remain in the stock after this time are included in the net present value. We calculate energy and cost savings until the last unit shipped in 2020 is retired from the stock.

Stock Forecast

The total stock and vintage of appliances in any given year is needed in order to calculate national energy consumption and savings. The stock is calculated using a straightforward accounting method that takes each year's sales as input. For each year, some fraction of the cohort installed in previous years remains, according to a survival function. For the purposes of this analysis, the survival function is a simple curve based on the average lifetime.

Figure 5 shows the survival function for refrigerators and air conditioners. According to this function none of the refrigerators are retired before 10 years (2/3 of the mean lifetime of 15 years), and all of them are replaced by 20 years (4/3 of the mean lifetime). Between these limits, the probability of retirement is a straight line. The survival function for air conditioners is of the same form, but uses a mean lifetime of 12.5 years, as estimated by the U.S. Department of Energy in its technical analysis of proposed standards. For motors, we assume the same general retirement function shape as with refrigerators and air conditioners, but with a 9 year mean lifetime.

Figure 5 – Survival Function for Refrigerators and Air Conditioners



Stock and shipments of distribution transformers are related, as in the case of the other types of equipment covered in this report, through a retirement and replacement model, according to the mean lifetime of 22 years. The lifetime is given by a Weibull function of the form

$$Survival(age) = e^{-(age/a)^b} \times \left(1 - F_{Const}\right)^{age} \times \left(1 - F_{Corrosion}\right)^{age-15}$$

The constant failure rate, F_{Const} is 0.65% per year. After the transformer is 15 years old, there is an additional corrosion failure rate $F_{Corrosion}$ of 0.65% per year (ORNL 1995). The parameters *a* and *b* were adjusted for the Indian case, so that the mean lifetime of the equipment corresponds to the value reported by the Indian Bureau of Energy Efficiency.

Energy Consumption by Consumers

Total annual energy consumption by consumers in the Base Case and the High Efficiency Case is calculated by multiplying the remaining stock from each cohort by the unit energy consumption (see Appendix B for equations).

We consider that some changes in average product size and/or features are likely between today and 2020. Such change will affect the UECs. For example, the market share of frost-free refrigerators is increasing. It is also likely, however, that frost-free refrigerators will become larger. We therefore apply a UEC growth rate of 1% for frost-free units over the forecast period. We assume that this rate of increase will be accomplished through improved manufacturing processes and economies of scale, and will therefore impose no price increase. No increase in average capacity over time is assumed for room air conditioners.

In calculating national energy impacts of a high efficiency policy for air conditioners, we take into account that roughly 5% of the models available on the retail website surveyed (www.compareindia.com) were above the target efficiency level of 10.2 EER. We assume that this percentage corresponds to the sales market share of efficient models, thus lowering the market-weighted base case UEC.

Table 17 gives the Base Case and Efficiency Case average UEC values by product in 2010.

Table 17. Average Unit Energy Consumption Values in 2010

Product	Base Case (kWh/year)	Efficiency Case (kWh/year)	Percentage Improvement
Refrigerator			
Direct-cool	381	208	45%
Frost-free	930	508	45%
Room air conditioner			
Window[10]	1191	1056	11%
Motors			
Agricultural – 5 HP	992[11]	875	12%
Industrial – 15 HP	4079	3264	20%
Industrial – 20 HP	5562	3387	39%

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[10] Consumption patterns and engineering parameters for window air conditioners assumed to hold for split systems for the purposes of this study.

[11] For comparison with other products, energy consumption and percentage improvement for motors is given in terms of losses, thus excluding the useful mechanical output energy produced by the motor.

Distribution transformer			
25 kVA	1036	441	57%
63 kVA	1834	797	57%
100 kVA	2619	1068	59%
160 kVA	3757	1653	56%
200 kVA	4989	1880	62%

Figure 6 shows the total electricity consumption by refrigerators over time in the Base Case and the High Efficiency Case. The sharp change in 2010 is a function of our method. In reality, there may be a ramp-up in the High Efficiency Case prior to 2010 as market forces and policies begin to have an impact. The significant opportunities for cost-effective efficiency improvement for this product are evident. The result of efficiency improvement is that growth of electricity consumption for this product is slowed to only a fraction of growth in the size of the stock.

Figure 6 – Total Electricity Consumption by Refrigerators in India

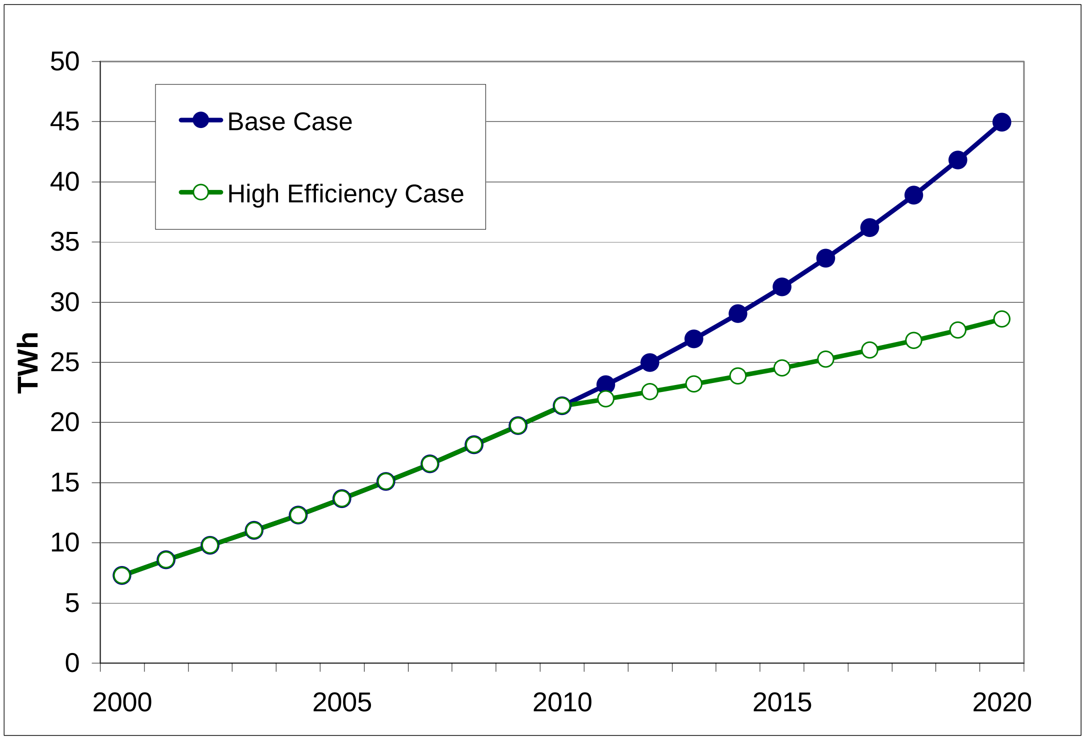


Figure 7 shows the total electricity consumption by room air conditioners over time in the Base Case and the High Efficiency Case. Because of constraints of cost-effectiveness, percentage efficiency improvement is much lower than in the refrigerator case.

Nevertheless, energy savings for air conditioners is significant, due to the extraordinary growth in the use of this product in India.

Figure 7 – Total Electricity Consumption by Air Conditioners in India

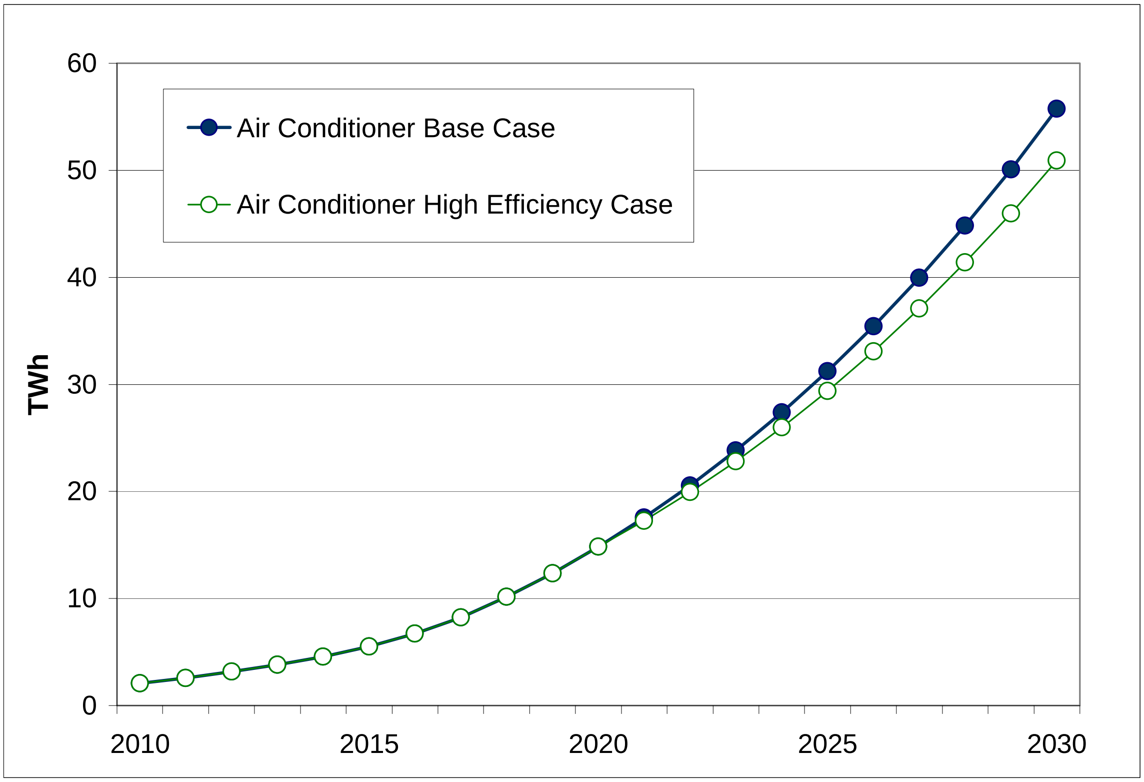


Figure 8 shows the total electricity consumption by motors over time in the Base Case and the High Efficiency Case. The percentage improvement in efficiency for motors is small compared to the other equipment types analyzed, since motors are already relatively efficient. In absolute terms, however, electricity savings from motors is comparable to the other products, since the baseline energy consumption is very high.

Figure 8 – Total Electricity Consumption by Motors

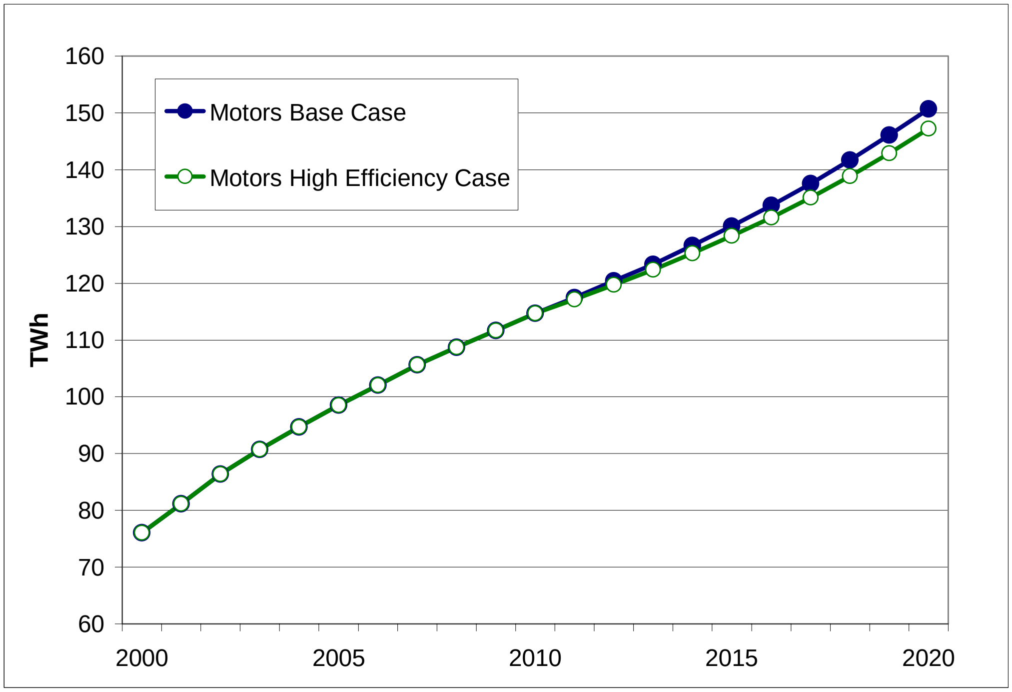
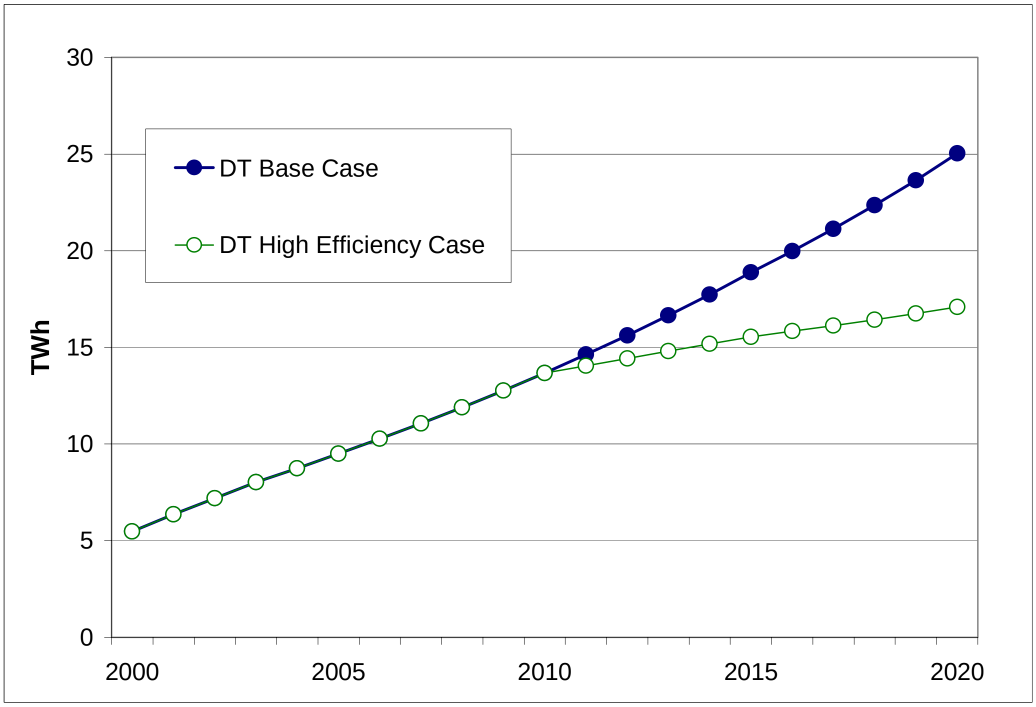


Figure 9 shows the total electricity consumption by distribution transformers over time in the Base Case and the High Efficiency Case. Total electricity consumption (losses) in transformers is equivalent to only a fraction of the other products studied. In this case, however, losses can be dramatically reduced through efficiency measures.

Figure 9 – Total Electricity Consumption by Distribution Transformers



Benefit to Consumers

The Net Present Value (NPV) to consumers represents the net financial savings to consumers yielded by use of the High Efficiency Case products, discounted to the present year (2005). Financial impacts are calculated at the national level using the aforementioned shipments and stock forecasts (see Appendix 2).

It is difficult to obtain a reliable forecast for marginal electricity prices in the Indian context. Production costs may increase or decrease according to world fuel prices and the availability of domestic coal and hydropower. An even more significant consideration is the increasing pressure to reduce subsidies, and general fiscal reform (privatization) of the power sector. According to recent estimates, average electricity tariffs in India cover only 69% of costs (Planning Commission 2002), which were estimated at 350 paise/kWh (equal to 7.7 US cents/kWh measured in 2004 dollars). The report estimates that residential tariffs cover only 56% of the cost of production.[12] The industrial and commercial sectors pay more than the cost of production (108% and 122% respectively). Agriculture is the most highly subsidized sector, with average tariffs covering only 12% of the cost of production.

We estimated marginal rates to consumers for each sector according to current tariff structures. This analysis shows that while residential tariffs are highly subsidized, the residential tariff is highly dependent on consumption so that households pay a much higher price for the last unit of electricity consumed than the average over the entire utility bill. Therefore, the energy saved by purchasing efficient equipment will yield greater cost savings than average tariffs would indicate. We find a marginal cost in the residential sector of 5.9 cents per kWh. Commercial consumers also pay a premium for consumption, with a marginal rate of 10.6 cents per kWh. The details of marginal rate calculation for these two sectors are given in Appendix 1.

For the industrial sector, although average costs are higher than those paid in the residential sector, there is little difference between average and marginal rates paid. The marginal rate is relatively constant over a wide range of consumption, and is found to be 7.6 cents per kWh, which is quite close to the cost of production. Finally, average agricultural rates are quite low and there is very little increase in charges as a function of total consumption. The marginal agricultural tariff is only 3.2 cents per kWh, and is quite insensitive to consumption..

We expect that between now and 2010, there will be continued efforts to bring residential and agricultural tariffs in line with the cost of electricity production. In particular, agricultural rates are a main focus of tariff reform in India, and have been raised significantly in several Indian states. The Common Minimum National Action Plan for Power issued in 1996 by the Chief Ministers of Indian States led by the Government of India decrees that “no sector…shall pay less than 50% of the average cost of supply” (IEA 2002). According to the most recent report on State Electricity Boards (Planning Commission 2002), the average cost of production was 7.7 cents per kWh. We therefore

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[12] Revenues received by utilities amount to less than this value, since there is a fair amount of electricity theft or non-collection of bills.

make the relatively conservative assumption that agricultural marginal tariffs will increase from the current value of 3.2 cents to 3.8 cents per kWh[13]. The residential sector will also be a likely target of tariff reform. Since the degree to which subsidies will be reduced is difficult to predict, however, we assume that current marginal rates will prevail throughout the forecast period.

The net savings in each year arises from the difference in incremental equipment and operating costs in the High Efficiency Case versus the Base Case. Net Present Value of the High Efficiency Case is then defined as the sum over the forecast period of the net national savings in each year, multiplied by the appropriate national discount rate. We use a national discount rate of 10%, the rate currently used by the World Bank for projects in India.

As an example of the time trend of impacts, consumer financial impacts for refrigerators in the High Efficiency Case are shown in Figure 10. From 2010 to 2020, incremental equipment costs and operating cost savings are steadily increasing as equipment is purchased and enters the stock under the high-efficiency policy regime. Operating cost savings grow more rapidly, since they are cumulative – refrigerators purchased in 2010 are still in the stock producing savings, while those purchased in 2011 also begin to provide savings. Savings peak in 2020 and thereafter decline, while incremental costs stop. This is because we do not count impacts for sales after 2020. After 2020, savings from the products shipped in the 11 years of the policy regime decline as these refrigerators are retired. The blue line shows the net savings in each year. The red line (NPV) represents these savings multiplied by the discount factor.

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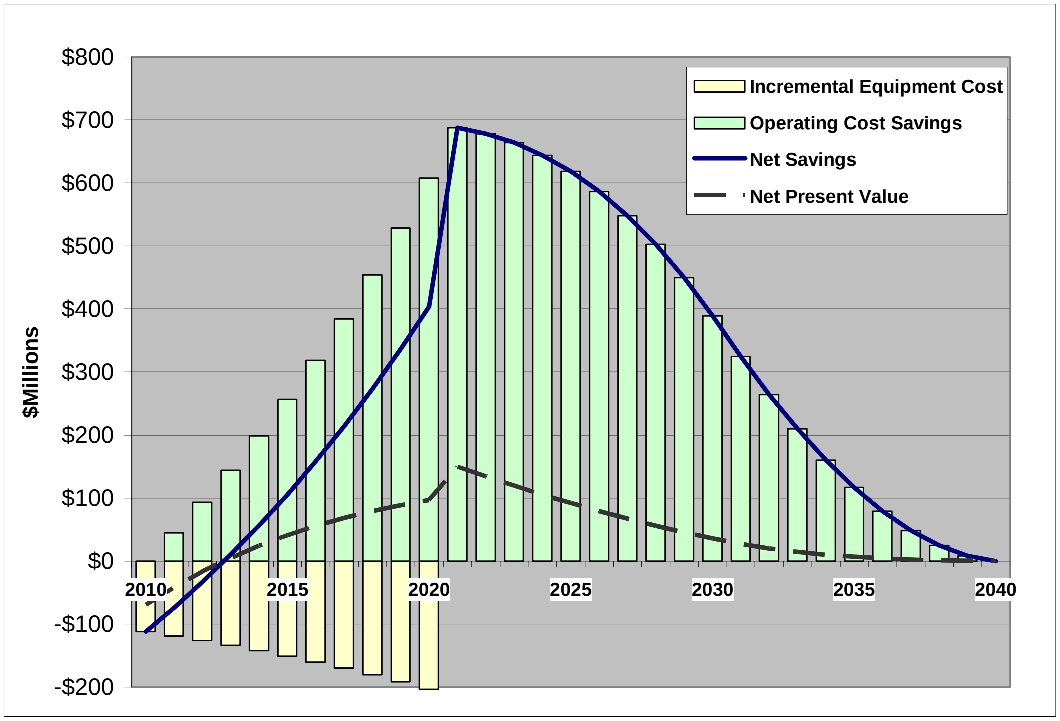
[13] Marginal tariffs in the agricultural sector are very close to average tariffs. We use the minimum average rate to assess cost efficiency.

Figure 10. Annual National Consumer Financial Impacts for Refrigerators in High Efficiency Case



For most products, we calculate NPV entirely on the basis of consumer impacts, thus assuming that the end user assumes the full incremental cost of high efficiency equipment with no rebates or other compensation, and financial benefits arise from reduced consumer electricity bills. In general, efficiency measures are highly cost effective to the consumer, thus NPV is positive. The exception is agricultural motors for which the cost of conserved energy is higher than the subsidized tariff of 3.8 cents/kWh, as discussed in the section on Life-Cycle Costs. In this case, we model the simple scenario that 50% of incremental costs of equipment to this sector will be subsidized by utility rebate programs or other government incentives. In this scenario, both costs and benefits are shared equally between the utility and the end user, making efficiency investment cost-effective for both parties.

The total estimated NPV benefit to Indian consumers of the High Efficiency Case is shown by product in Table 18. The total NPV across all of the considered products is $5.5 billion. In this calculation, the NPV for agricultural motors consumers is calculated according to the assumption that they would pay only half of the incremental equipment cost. Benefits gained by utilities are discussed in sections below.

Table 18. Estimated Present Value of Costs and Benefits to Indian Consumers of the High Efficiency Case ($ billion)

Product	Additional Product Costs	Electricity Cost Savings	NPV
Refrigerator	0.6	1.9	1.3
Room air conditioner	0.1	1.3	1.2
Motor	0.2	0.7	0.5
Distribution transformer	0.7	3.2	2.5
TOTAL	1.5	7.0	5.5

Primary Energy Savings and Avoided Emissions

Primary energy savings represent the energy use that would be avoided by the High Efficiency Case. In our main scenario, we assume that the current situation of electricity shortages is greatly relieved by 2010 (as envisioned by government plans). Thus, reduced electricity consumption from higher efficiency products does have an effect on electricity generation. To the extent that electricity shortages continue in the 2010-2020 period, the primary energy savings and avoided emissions would be lower than presented below, since much of the 'saved electricity' would be sold to a customer whose demand would otherwise be unmet.[14] This meeting of unmet demand has other benefits, however, as discussed below.

The calculation of primary energy savings considers the heat rate -- the power plant fuel input needed to produce one unit of electricity, and transmission and distribution losses as a fraction of generation. According to data collected by the Indian Ministry of Non-Conventional Energy (GoI 2003), the heat rate of currently operating plants is 9621 Btu/kWh, equal to an input-to-generation factor of 2.82. This factor is weighted over all electricity generation, including hydroelectric and nuclear (which have assumed factors of 0 and 3, respectively). We calculated the average heat rate for each year in the forecast according to current plants in operation, in combination with planned additions to 2020 (GoI 2003). The T&D loss rate is expected to drop from 32% today to 20% by 2020 (TERI 2001).

Table 19 shows the cumulative primary energy savings in the High Efficiency Case. Close to half of the savings come from more efficient refrigerators.

To calculate avoided CO_2 emissions, we note that the current rate of CO_2 emissions is 0.87 ton of CO_2 per generated MWh. This figure is expected to decrease to 0.79 $T(CO_2)/MWh$ by 2020 due to installation of more efficient thermal plants (GoI 2003). Cumulative avoided CO_2 emissions in the High Efficiency Case are summed over the lifetime of all products shipped between 2010 and 2020.

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[14] Shortages generally occur at times of the day when demand is above average. If 'saved electricity' is saved during times when demand is below average, there may not be any unmet demand, and thus no opportunity to sell the 'saved electricity'.

Table 19. Estimated Cumulative Primary Energy Savings and Avoided CO_2 Emissions in the High Efficiency Case for products shipped between 2010 and 2020

Product	MTOE	Million tons CO_2
Refrigerator	77	259
Room air conditioner	23	78
Motor	14	47
Distribution transformer	45	153
TOTAL	159	538

Benefit to Utilities

The impact of the High Efficiency Case on utilities depends on the extent to which the current situation of electricity shortages is relieved in the 2010-20 period. If shortages are greatly reduced, reduced electricity consumption from higher efficiency products would decrease generation requirements and may allow for a slower growth in new capacity and capital expenditures, thus reducing capital costs for utilities. We estimate a maximum savings of about 30 TWh from four products in 2020. An estimate of the impacts on generation from delivered energy savings is difficult without a detailed analysis of end use load shapes, but an order of magnitude estimate can be made by assuming constant loads for all products (simply dividing energy consumption by the number of hours in a year), yielding a power savings of about 3 GW. . At 1000 dollars cost per kW of generation capacity, 3 billion dollars worth of utility capital investments could be avoided.

On the other hand, the reduction in consumption reduces utility revenue. If electricity prices reflect the costs of supply, as for the commercial and industrial sector, the reduction in costs and the reduction in revenue may roughly cancel, and all savings benefits will accrue to the consumer.

If electricity prices are less than the costs of supply, as is currently the case for residential and agricultural consumers, the reduction in costs will be greater than the reduction in revenue. Utilities would see a net benefit in such a situation. For example, in the case of refrigerators, residential consumers would see a present (discounted) benefit of 1.9 billion dollars over the forecast period, based on a marginal electricity rate of 5.9 cents/kWh. Since the cost of production is 7.7 cents/kWh, utilities would enjoy net savings (costs reduced less revenue lost) of 440 million dollars. Agricultural tariffs are even more highly subsidized. In this case, efficiency improvement is only cost effective from the consumer’s point of view if incremental equipment costs are offset by incentive programs such as utility rebates. We assumed that utilities would bear half of the incremental equipment cost. If agricultural consumers pay only half the cost of production, then both costs and benefits of efficiency are shared equally between consumers and the utility. Based on this scenario, we calculated a Net Present Benefit of 65 million dollars to consumers. An equivalent amount would also be gained by utilities. Perhaps more importantly, the reduction in consumption of electricity in this highly subsidized sector contributes to the financial solvency of utilities.

If electricity shortages continue to be common in the post-2010 period, the impact of higher efficiency on utilities is more complicated to assess. During those times when there is a shortfall (typically during times of day when demand is high), the ‘saved electricity’ from higher efficiency could be sold to customers whose demand would otherwise be unmet. If subsidized electricity saved through higher efficiency can be sold to higher-tariff customers (such as industrial and commercial sectors), utilities would reap financial benefits.

Indirect Benefit to the Economy and Government

If shortages are much relieved, efficiency improvement in products used by residential and especially agricultural consumers can lower government subsidy payments to state electricity boards. In the case of refrigerators and residential air conditioners, lower consumption means that a greater percentage of the electricity produced is consumed by commercial and industrial customers, who pay more than the cost of production. For agricultural motors, lowered consumption means a reduction in operating costs spent to generate subsidized electricity. In this way, some portion of the current government subsidies for electricity could be transferred to a more cost-effective subsidy of high efficiency equipment.

If electricity shortages continue to be common, electricity consumption by customers whose demand would otherwise be unmet would allow for additional economic output or would provide services to households. Any contribution to the reduction in shortages from efficiency would have a direct impact on productivity, since industrial firms which experience scheduled interruptions have all other factors (capital, labor, materials) of production in place. Input increased in this way would directly impact employment. The additional economic output would also yield higher tax revenues to the government, which could be used to improve public services. One indication of the financial benefit due to savings in the industrial and commercial sectors is in terms of electricity consumption and sales tax on products produced. A recent study for the state of Maharashstra (Sathaye 2004) estimates the sales tax generated from each kWh consumed at 5.9 Rs., or 11 cents per kWh. This rate estimates the potential for increased sales tax for shortages avoided by implementation of efficiency measures.

In either case, reduced expenditure on electricity by consumers would allow for expenditure on other goods or services. Since electricity generation tends to be fairly capital-intensive, the transfer of expenditures from electricity to other goods or services could have a positive impact on employment.

Finally, reduced electricity generation due to improved efficiency would have local environmental benefits in terms of air quality.

8. Extension of Indian National Results to Other Countries

Introduction

As discussed above, India is an attractive target for efficiency programs because of its large size, strong economic growth, and the significant potential for efficiency improvement for key target equipment. In this section, we extend some of the results for India to other developing countries. The purpose of this extension is to identify other countries where significant energy, financial and environmental benefits may be achievable through cost-effective efficiency measures. Whereas the Indian results provide quantitative estimates of the impacts that could be achieved through efficiency programs, the results for other countries indicate areas where further investigation might be usefully made. Interested parties have a framework that can be used to acquire key data on equipment specifications and market features, as well as a methodology to produce detailed country-specific results such as that presented for India in the above sections. Thus, the current report can be seen as a first-order look at savings potential which could be easily improved using the current methodology as detailed country-specific data become available.

The countries chosen for analysis are shown in Table 20, along with India, which serves as a comparison.

Table 20 – Countries Chosen for Regional Extension

	GDP (2002)		Population (2005)	
	Billions $US	% of Region	Millions	% of Region
India	642	77%	1097	75%
Pakistan	95	11%	161	11%
Bangladesh	67	8%	153	10%
Other South Asia	29	4%	48	3%
Total South Asia	**833**	**100%**	**1459**	**100%**
Saudi Arabia	176	20%	26	7%
Iran	145	17%	71	19%
Israel	132	15%	7	2%
Egypt	103	12%	75	20%
Algeria	64	7%	33	9%
Other Mid-East North Africa	266	30%	169	44%
Total Middle East & North Africa	**878**	**100%**	**380**	**100%**
South Africa	226	48%	45	7%
Nigeria	41	9%	130	20%
Other Sub-Saharan Africa	208	44%	464	71%
Total Sub-Saharan Africa	**475**	**100%**	**650**	**100%**
Total Countries Considered (excluding India)	1690	77%	1797	72%
Total All Regions Excluding India	**2185**	**100%**	**2489**	**100%**

Source – World Bank

Two criteria were used in selecting the countries for extension of the analysis. First, we selected countries in the region of South Asia, the Middle East (including North Africa) and Sub-Saharan Africa, as these regions are the most likely to have a similar energy situation to that of India.

Secondly, we chose countries with the largest economies, in terms of GDP.
All countries were chosen which had a GDP of at least 60 Billion dollars (2004 dollars) in 2002, the last year for which data were available from the World Bank. In Sub-Saharan Africa, only one country - South Africa - fulfilled this criterion. We therefore included the second largest economy in the region – Nigeria, which had a GDP of 41 Billion dollars in 2002.

The table of selected countries shows several important features. First, India represents the large majority of the South Asian economy, with 77% of GDP. Pakistan and Bangladesh account for most of the remainder – only 4% of GDP is not accounted for by consideration of these three countries. Population and GDP is more distributed among the countries of the Middle East and North Africa. The five countries considered, Saudi Arabia, Iran, Israel, Egypt and Algeria account for 70% of GDP and 54% of the population of the region. The two countries chosen for Sub-Saharan Africa account for 56% of the region's GDP and 29% of its population.

Method

We made estimates of potential impacts of efficiency programs in the nine additional countries considered by assuming that detailed engineering parameters were similar in these countries to the Indian case. A more in-depth analysis would consider differences in common technologies and market preferences in each country. These data, however, are not readily available, and their collection is beyond the scope of this study. As a result, we do not report on individual customer benefits (Life Cycle Cost), as these are assumed to mirror the Indian results. Instead, we focus on the scaling of individual consumer impacts to the national scale, in order to give an idea of areas beyond India where more attention might be focused.

In estimating potential impacts for the regional extension we explicitly assumed that the following parameters were identical to the Indian case:

- Product class and capacity
- Baseline unit energy consumption
- Efficiency design options
- Incremental cost of efficiency improvement
- Baseline retail equipment price
- Equipment lifetime
- Discount rate of 10% used in calculating Net Present Value (NPV) of societal benefits.

For each end use considered, we made a rough market forecast in each country studied and applied the Indian product parameters in order to calculate national financial and environmental benefits. The analysis does not take into account current programs that may already be in place in different countries.

In estimating financial benefits to consumers, the variation in retail electricity prices is a critical parameter. This variation can arise from the local cost of production of electric power. A more important factor, however, may be government policy in setting tariffs, since electricity is highly subsidized in many developing countries. For this reason, we used tariffs appropriate to each particular country where tariffs were available. Where data were not available, Indian tariffs were used. Available tariff data are shown in Table 21.

Table 21 - Electricity Tariffs by Sector ($US cents / kWh)

	Residential	Commercial	Industrial	Agricultural
India	5.93	10.66	7.62	3.18
Pakistan	3.92	6.71	3.58	5.36
Bangladesh	5.18	8.70	6.61	3.18
Iran	1.58	5.71	3.07	0.24
Algeria	5.15	3.69	3.69	N/A
South Africa	3.98	N/A	N/A	N/A
Nigeria	3.10	6.58	6.58	N/A

Sources – Pakistan Water and Development Authority, Bangladesh Power Development Board, World Energy Council, Société algérienne de l'électricité et du gaz, South Africa ESKOM, Power Holding Company of Nigeria

The table shows that in, general, prevailing tariffs in these countries are quite low, even compared to the Indian case. This indicates a high degree of subsidy, which may result in low return rates to consumers from efficiency, but correspondingly higher benefit to governments which are currently incurring a substantial financial loss in providing wasted energy. Unlike the case of India, we do not assume that tariffs will increase in order to cover the cost of production for these countries. While we believe that pressures to reform tariffs in these countries will be similar to the Indian case, specific evidence to this effect is lacking. In the case of distribution transformers, we assume that the cost incurred to utilities through transformer losses are equivalent to those in India.

In calculating environmental benefits (avoided CO2 emissions), differences in the generation mix, transmission and distribution losses and carbon emission factors (g(CO_2)/kWh) for each country are taken into account (International Energy Agency)

Refrigerators

Household refrigerator sales are generally growing throughout the regions studied. Refrigerator ownership is strongly dependent on economic growth, as it is usually the first major appliance purchased by households upon reaching a significant level of income. Refrigerator ownership growth may also depend on domestic market development within the country, as middle income households in a country with a well-developed domestic production of refrigerators may find them more widely available, less-expensive, and more desirable. Finally, for poorer countries, low electrification rates may impede appliance ownership (see McNeil 2005)

We forecast refrigerator sales by extrapolation of sales data compiled by a market research firm (Gobi International 2002). The market data report provided household refrigerator sales for 1999-2001, along with a market forecast for the years 2002-2006. In addition to this report, supplemental data were used to estimate refrigerator sales in Egypt and Pakistan (Economist Intelligence Unit 2005), (The News International Pakistan 2005). Forecasting sales in this way, according to current growth rates, does not take into account the details of dynamics of new ownership and replacements. It does, however, give an idea of the size of the refrigerator market in each country, and one reasonable scenario for future growth.

Figure 11 – Refrigerator Shipments Forecast 2005-2020

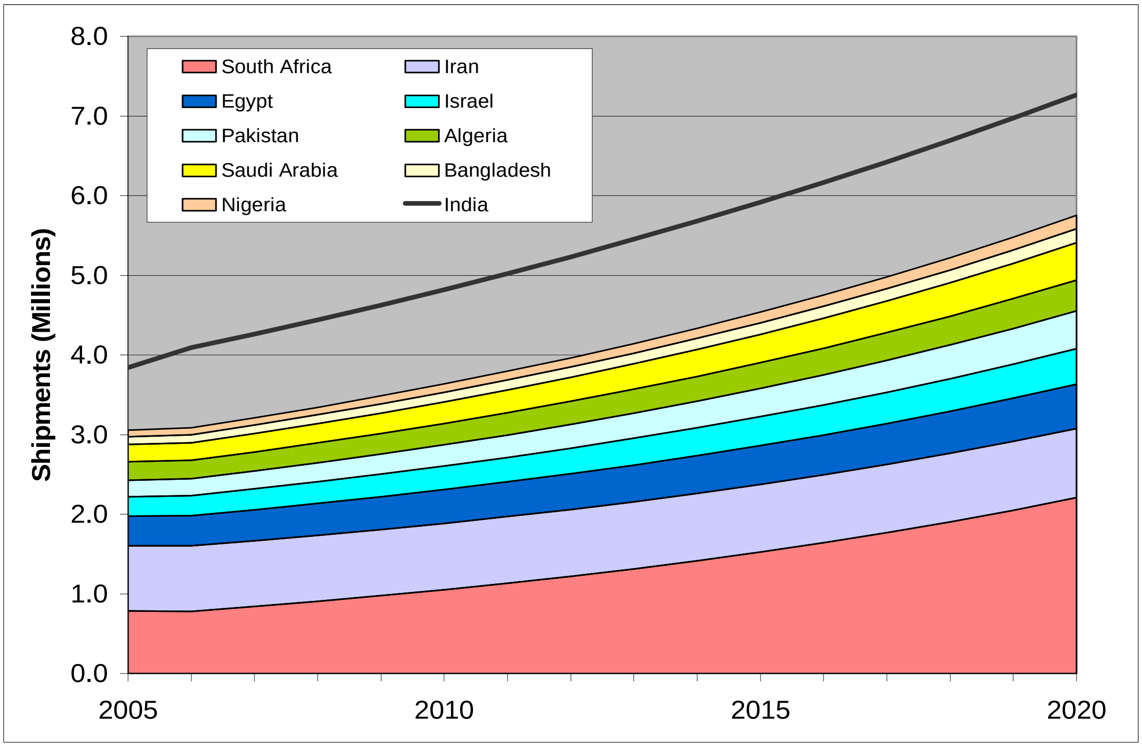


Figure 11 shows the forecast of refrigerator sales in each country. A striking feature is that the sum of sales over all countries studied is still smaller than the Indian market. This is perhaps not surprising, since the Indian economy is comparable in size to all other countries combined. Further, the Indian refrigerator market is highly mature, with extensive domestic production going back decades. Nevertheless, the market is significant in many areas, especially South Africa and Iran, which each will experience sales on the order of a million per year.

In calculating financial and environmental impacts, we made the assumption that the following parameters were identical to the Indian case:

- Unit energy consumption of single- and two-door refrigerator models
- Retail price of refrigerators

The relative market share of single vs. two-door models in 2005 is taken to be the same as in the Indian case (83% of the market is single-door). In the Indian forecast, however, the double-door market is known to be growing. For the other countries, market segmentation data were not available, so we assumed constant fractions throughout the forecast.

As in the Indian case, impacts are calculated for equipment shipped between 2010 and 2020.

Table 22 – Impacts of Improving Efficiency for Refrigerators shipped between 2010 and 2020

Country	Shipments 2010-2020	Site Energy Savings	Emissions	NPV
	Millions	TWh	MT(CO_2)	$Billions
India	77	272	178	2.73
Pakistan	4.0	12	5.6	0.06
Bangladesh	1.6	4.7	3.1	0.04
Saudi Arabia	4.0	12	7.6	0.10
Iran	9.4	28	17	0.01
Israel	4.0	12	11	0.11
Egypt	5.4	16	7.2	0.14
Algeria	3.6	11	8.0	0.08
South Africa	17	51	46	0.25
Nigeria	1.5	4.4	1.8	0.01
Total (non-India)	51	150	106	0.81

As shown in Table 22, shipments for all countries considered total about 51 million over the forecast, period, or about 2/3 of shipments forecast for India. Site energy savings, emissions, and net present value of financial benefits scale roughly. Of the countries considered, South Africa has by far the largest refrigerator market, and would therefore be an attractive candidate for efficiency programs. Iran also has a large market. Sales of refrigerators in Nigeria and Bangladesh are expected to remain quite low, presumably due to low incomes and lack of electrification, especially in rural areas. Total Net Present Value of financial impacts in the countries considered is about $750 million. In Iran, NPV is quite small, indicating low benefits to consumers there. This is due to the very low prevailing electricity price to residential consumers in that country. It should be noted, however that the Net Present Value calculation does not take into account government benefits in avoiding delivery of highly subsidized electricity.

Air Conditioners

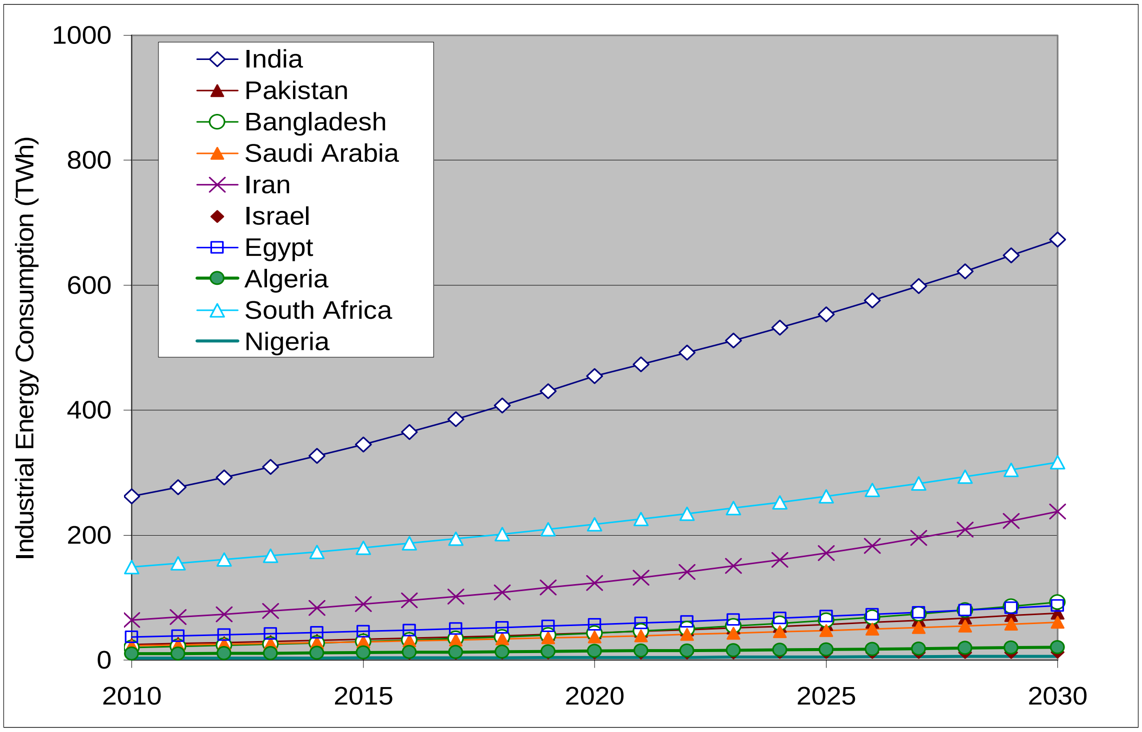
Air conditioners were not considered for analysis due to poor market data availability for this product. Some data are available in terms of imports and exports of air conditioners.

This is unreliable for larger economies, however, as they are likely to have significant domestic production (including assembly) of air conditioners. Market data for air conditioners is likely to be available for many developing countries; however this data must be collected on a country-by-country basis in collaboration with local industry or trade experts. This type of data collection, while important, is out of the scope of the current study. In addition to market effects, use patterns of air conditioners vary widely due to climatic effects.

Industrial Motors

Motors are by far the largest consumer of electricity in the industrial sector, typically accounting for two-thirds of the electricity in this sector, and up to half of total national electricity consumption in many countries, (Nadel 1992). For this reason, recent trends and projections of industrial electricity consumption are a logical indicator for estimates of industrial motor electricity consumption and growth. We made the general assumption that growth rates apply equivalently to motor shipments and stock consumption. Industrial electricity consumption data is available through the year 2002 from the International Energy Agency (IEA 2003). Consumption is forecast with a constant growth rate, according to recent growth (1997-2002). Industrial electricity consumption for all countries is shown in Figure 12.

Figure 12 – Industrial Electricity Consumption 2010-2030



As in the case of refrigerators, South Africa and Iran are the clear leaders in industrial electricity consumption; combined they account for almost as much as India. In particular, growth of industrial electricity in Iran was 7% between 1997 and 2002.

Assuming that this growth continues throughout the forecast, Iran's industrial consumption will approach the level of South Africa (and about a third as much as India) by the year 2030.

Since detailed engineering parameters were available for Indian industrial motors only for the 11 kW and 15 kW sizes, we only considered these two cases, which together represent about 10% of total motor sales. For other countries considered, only these two classes of motors are considered for efficiency improvement. The full potential of motors efficiency in these countries would likely be much larger. To summarize, the specific assumptions made for the case of industrial motors are:

- Operating hours and load factors equivalent to the Indian case.
- Fraction of industrial electricity from 11 kW and 15 kW motors is equivalent to Indian case.

Table 23 – Impacts of Improved Efficiency for 11 and 15 kW industrial motors shipped between 2010 and 2020

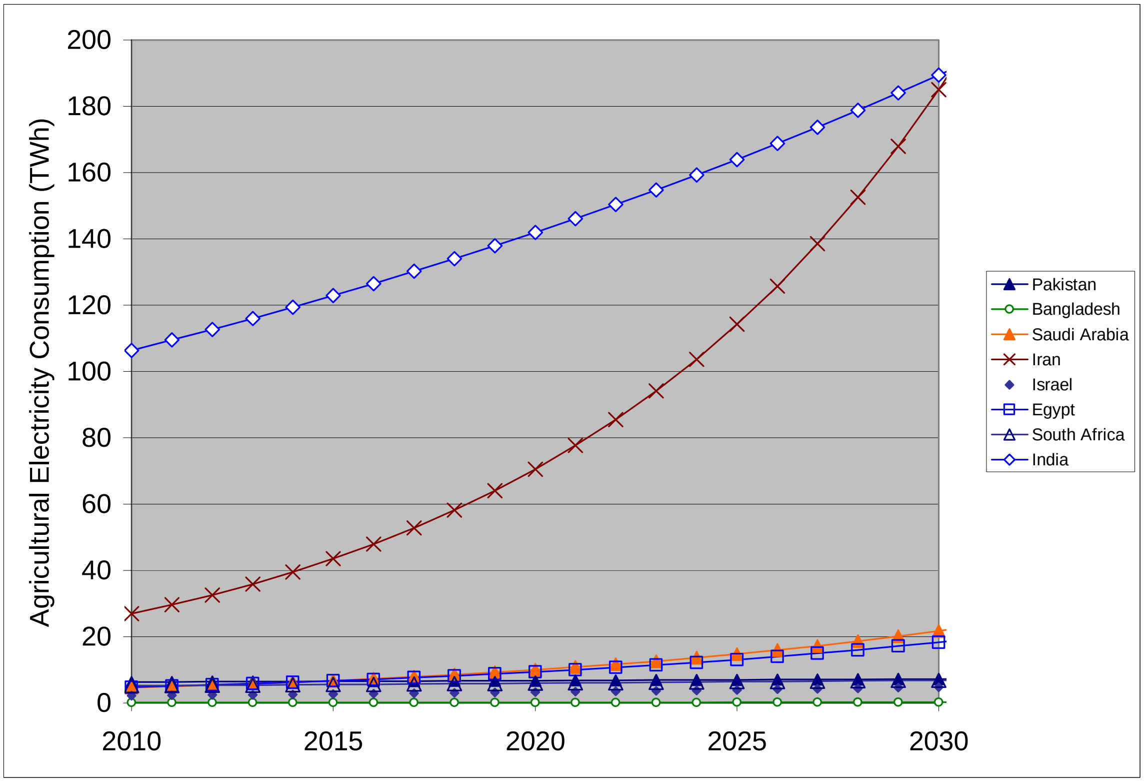
Country	Shipments 2010-2020	Site Energy Savings	Emissions	NPV
	Millions	TWh	MT(CO_2)	$Billions
India	1.5	33.1	31.6	0.43
Pakistan	0.15	3.2	1.50	0.02
Bangladesh	0.13	2.9	1.89	0.02
Saudi Arabia	0.13	2.8	1.80	0.03
Iran	0.40	8.6	5.17	0.01
Israel	0.05	1.0	0.92	0.01
Egypt	0.20	4.4	1.97	0.04
Algeria	0.05	1.1	0.85	0.01
South Africa	0.79	17.1	15.40	0.10
Nigeria	0.01	0.3	0.13	0.001
Total (non-India)	1.9	41.4	30	0.24

Estimates of motor efficiency impacts follow closely the patterns of refrigerator patterns. These results indicate that, in general, countries that could benefit significantly from refrigerator efficiency programs would also do well to include programs targeting industrial motors.

Agricultural Motors

As stated above, the situation for industrial motor savings parallels that of potential savings for refrigerators. The situation is somewhat different for motors used in agricultural pump sets. Even more than in the industrial sector consumption, agricultural electricity consumption in developing countries is dominated by the contribution of motors. Therefore, we use projected growth in agricultural electricity as a proxy for motor sales. Figure 13 shows agricultural electricity consumption, as forecast from current levels and growth rates from IEA.

Figure 13 – Agricultural Electricity Consumption 2010-2030



Source: International Energy Agency 2003. Data were not available for Algeria or Nigeria.

As in the case of industrial consumption, the growth rate of agricultural consumption in Iran is dramatic. Growth rates for Iran calculated from the 1997-2002 period are 13%. We used a more conservative estimate of 10%, which is the growth rate for the Middle East region as a whole. Iranian pump set sales are expected to approach Indian levels by 2030.

Agricultural electricity consumption depends not only on the size of the economy, but on the relative importance of the sector and, perhaps more importantly, the degree to which agricultural pumping is widely used and electrified. India is a large country with the majority of the population engaged in agriculture. Furthermore, it has been a specific goal of the Indian government to encourage (and subsidize) agricultural electrification. The IEA data would suggest that this is not the case in South Africa. Furthermore, although the agricultural sector is very important in Bangladesh, electricity consumption is extremely low, indicating little electrified farming.

Table 24 – Impacts of Improved Efficiency for Agricultural Motors shipped between 2010 and 2020

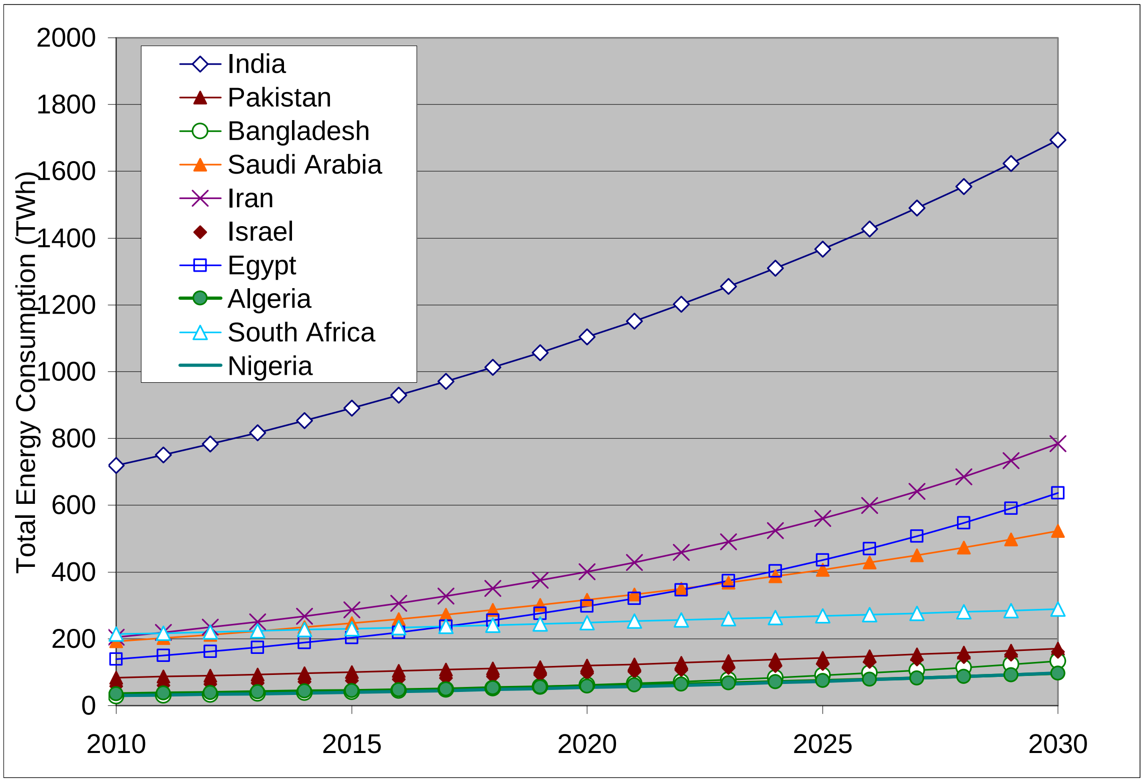
Country	Shipments 2010-2020	Site Energy Savings	Emissions	NPV
	Millions	TWh	MT(CO_2)	$Billions
India	15.4	16.5	15.7	0.14
Pakistan	0.88	1.5	0.71	0.00
Bangladesh	0.02	0.0	0.02	0.00
Saudi Arabia	0.93	1.6	1.0	0.01
Iran	6.0	10	6.2	-0.03
Israel	0.36	0.6	0.54	0.00
Egypt	0.91	1.5	0.69	0.01
Algeria	N/A	N/A	N/A	N/A
South Africa	0.75	1.3	1.15	0.01
Nigeria	N/A	N/A	N/A	N/A
Total (non-India)	9.9	17	10	-0.001

The energy savings estimates indicate that, after India, Iran may be a very attractive candidate for programs targeting efficiency of agricultural pump set motors. Net Present Value of efficiency in this country is negative, however, indicating that, since agricultural electricity tariffs are highly subsidized, government sponsored financial incentives may be an attractive option to encourage efficiency in this sector. Pakistan, Saudi Arabia and Egypt and South Africa may also benefit significantly.

Distribution Transformers

The forecast of potential savings using high-efficiency distribution transformers follows the method of motors. We forecast shipments of distribution transformers by scaling with the Indian case, and using growth in electricity consumption. Since electricity consumption for all sectors (with the exception of self-producers) passes through utility-owned distribution transformers, total national electricity consumption is expected to determine installations of distribution transformers. Total electricity consumption is shown in Figure 14.

Figure 14 – Total Electricity Consumption 2010-2030



Not surprisingly, electricity consumption scales closely with GDP. Therefore, the greatest savings are likely to be achieved through efficiency in the largest economies, as long as efficiency of currently installed equipment is relatively low, and the benefit per unit substituted is high, as in India.

Assumptions made for distribution transformers are:

- Market shares of transformers by rated capacity (in kVA) are the same as for India.
- Average loading (load relative to rated capacity) and system load factor (ratio of peak to average load) is the same as for India.
- Load growth rate over the life of the transformer is the same as India.

The energy savings potential from substitution of distribution transformers compares favorably to savings estimates for the other products analyzed. Iran, Saudi Arabia, South Africa and Egypt could all be candidates for programs focusing on this product.

Table 25 – Impacts of Improved Efficiency for Distribution Transformers shipped between 2010 and 2020

Country	Shipments 2010-2020	Site Energy Savings	Emissions	NPV
	GVA	TWh	MT(CO_2)	$Billions
India	361	160.7	153.3	2.51
Pakistan	40.4	13.2	6.2	0.18
Bangladesh	17.4	5.6	3.7	0.07
Saudi Arabia	100.5	32.7	21.0	0.43
Iran	118.4	38.4	23.0	0.50
Israel	30.4	9.9	8.7	0.13
Egypt	84.6	27.4	12.3	0.36
Algeria	18.5	6.0	4.5	0.08
South Africa	92.2	30.1	27.1	0.41
Nigeria	16.4	5.3	2.2	0.07
Total (non-India)	519	169	109	2.2

Conclusions

This analysis shows that, although no single country studied would receive as much energy savings and NPV benefit as India, there is significant potential for savings. In particular, South Africa and Iran are predicted to consume large amounts of electricity with equipment for which efficiency improvement has been demonstrated to be highly cost-effective.

Each of the end uses studied shows significant potential, except where usage is particularly low (due, for example to very low industrial capacity or low electrification rates in the agricultural sector).

In summary, we believe that the extension of the Indian results to other developing countries in adjacent regions points to countries where governments may consider implementation of efficiency programs. Further, we conclude that, given improved market and engineering data availability for these countries, the methodology we have demonstrated could be readily applied to produce impacts estimates for these countries at the level of detail that this report provides in the Indian case.

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Appendix A

Calculating Marginal Electricity Rates

An understanding of marginal electricity rates is crucial in assessing potential financial impacts from efficiency programs. The estimation of marginal tariffs for residential, commercial, industrial and agricultural customers allows for the calculation of the operating cost savings yielded by more efficient equipment.

The marginal price of electricity is the price per kWh of the last unit of electricity used by the consumer, as opposed to the average price, which is the total electricity bill (including fixed charges) divided by the total electricity used. The distinction is important, because a reduction in consumption due to a particular piece of efficient equipment will generally not affect fixed charges, but will reduce the usage in the highest category.

This study made an estimate of consumer marginal electricity prices by analyzing the tariff structures provided by a sample of State Electricity Boards (SEBs), in combination with estimates of household or business consumption. The marginal rate is taken to be the price of electricity for the block in which the average household or business consumption falls. These rates and the block definitions differ significantly from one state to the next. Therefore, the marginal rate had to be identified on a state-by-state basis. National average results were then obtained by weighting according to state electricity consumption.

India's power sector continues to be dominated by Central and State government-owned organizations. In most of the cases, the SEB is the generator, transmitter and distributor of power. Most of the tariffs have been collected from State Electricity Board websites.

Table A-1 presents the states for which some tariffs were available and also their population characteristics. Of the 28 Indian states and 7 union territories, tariff data were available for 15 states, which represent 83% of the total population (see table at end of this appendix). The calculation of national marginal electricity rates for the residential, commercial, industrial and agricultural sectors is summarized in Table A-1. The national sectoral rates are the average over all states for which tariffs were available, weighted by sectoral electricity sales in each state (electricity sales data from Planning Commission 2002).

Table A-1 – Sectoral Marginal Prices by State

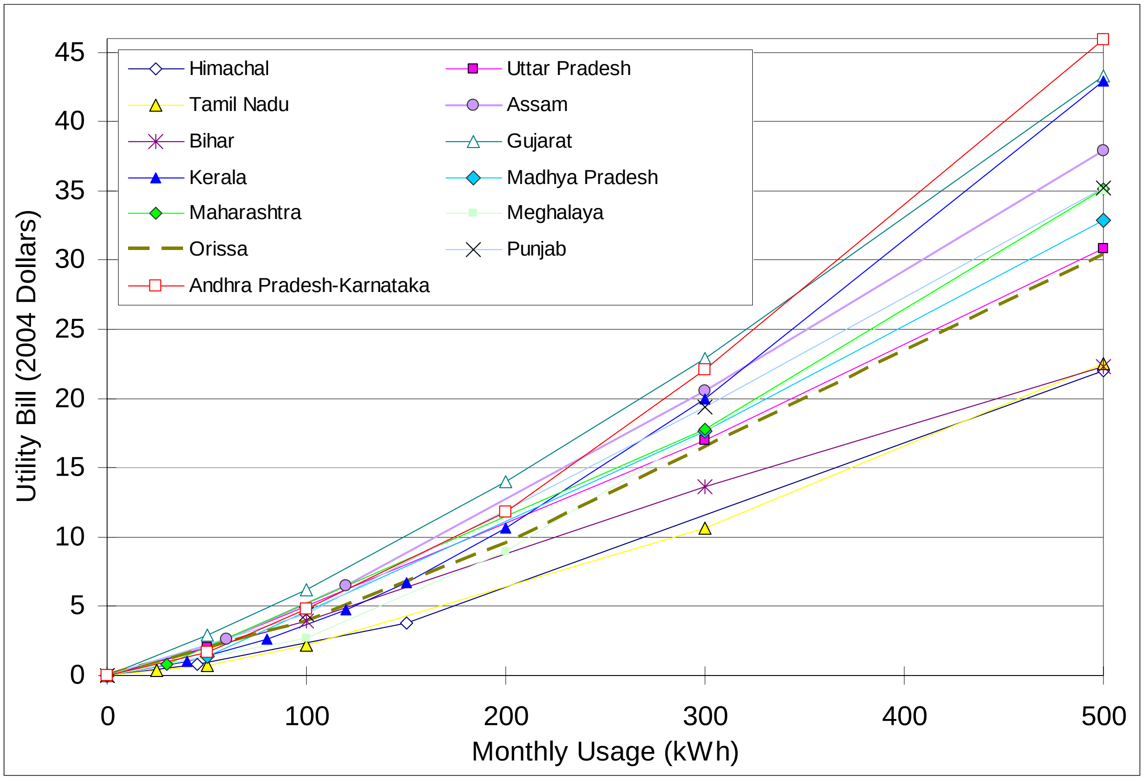
State	Electricity Sales				Marginal Electricity			
	Res.	Com.	Ind.	Ag.	Res.	Com.	Ind.	Ag.
	GWh / year				$ 2004 / kWh			
Andhra Pradesh	6955	1291	6786	11222	0.069	0.136	0.081	0.004
Assam	648	170	287	49	0.065	0.104	N/A	0.073
Bihar	1068	428	3759	1549	0.049	N/A	0.089	N/A
Gujarat	3122	889	9200	14507	0.078	0.102	0.081	0.015
Haryana	2359	446	2104	5171	N/A	N/A	0.092	N/A
Himachal	657	160	1225	18	0.028	N/A	0.049	0.011
Karnataka	4120	1184	3842	6457	0.066	0.136	0.070	N/A
Kerala	4946	895	3767	410	0.052	0.179	0.070	0.014
Madhya Pradesh	3785	885	6611	10200	0.065	0.092	0.114	0.052
Maharashtra	7521	1575	16894	10937	0.063	0.089	0.054	0.024
Meghalaya	137	47	118	0	0.041	0.090	0.079	0.022
Orissa	2166	429	2583	196	0.056	N/A	0.069	0.024
Punjab	4074	902	8295	8200	0.075	0.090	N/A	N/A
Tamil	6402	1935	12064	9066	0.028	0.087	0.072	0.074
Uttar Pradesh	7341	1911	5040	4965	0.060	0.087	0.100	0.043
West Bengal	2700	1179	2827	1360	0.054	N/A	0.072	N/A
Total/	**58001**	**14326**	**85402**	**84307**	**0.059**	**0.107**	**0.076**	**0.032**

Residential Tariffs

All residential tariffs surveyed are progressive, that is, the more the household consumes the more the kWh (unit) costs, as shown in Figure A-1. The bill is the sum of the fixed charges each month and the energy charges on the basis of a maximum load of 1 kW. Fixed charges for residential customers are negligible compared to the total bill except for low consumers of electricity.

In calculating marginal electricity prices for each state, we assume an average monthly household consumption of 112 kWh. This number is the average consumption in a sample of 369 “all-electric” homes (AEH) in Karnataka State representing the 963,000 total AEH households served by the Karnataka Electricity Board (Narasimha 2001). These households are most appropriate to characterize electrical consumption for households owning a refrigerator. All-electrical homes are a group of households connected to 3.5 kVA load and owning appliances, as opposed to the majority of connections which carry a 1.15 kVA load. The saturation rate for refrigerators in these households was found to be 58%. By comparison, only two percent of the non-AEH households was found to own a refrigerator.

Figure A-1 – Monthly Residential Electricity Bill vs. Consumption

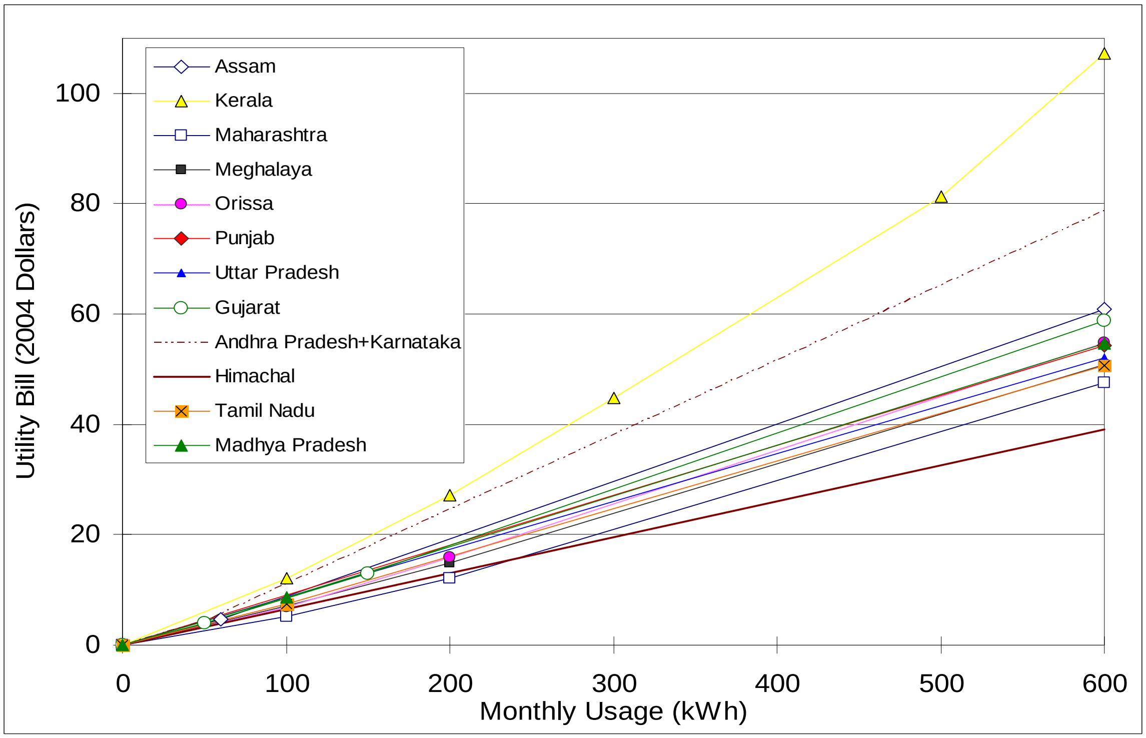


Marginal electricity price for a 112 kWh monthly consumption was determined for each state, and the national average of 5.9 USD cents per kWh was calculated by taking an average of all states for which tariff data were available, weighted by each state's residential electricity sales. The assumption of 112 kWh monthly consumption introduces some uncertainty in our estimation of average marginal rates, due to variability in consumption among households. Due to the tariff structure, however, this variability is reasonably small. In order to evaluate the uncertainty introduced by the average household consumption, we recalculated the average marginal tariff using household consumption over the range of 50 kWh to 250 kWh per month. The marginal tariff calculated varies by less than one USD cent over this entire range, giving confidence that the rate calculated using 112 kWh per month is close to the actual marginal rate.

Commercial Tariffs

Commercial tariffs were available for only 11 of 28 states and union territories. These States represent 67 % of the total population, but cover 77% of commercial electricity sales (SEB sales only) in India. The structure of the tariffs is represented in Figure A-2.

Figure A-2 – Monthly Commercial Electricity Bill vs. Consumption



Commercial rates are generally much higher than residential rates, and have less dependency on monthly consumption. As for residential rates, determination of the cost of the last kWh consumed requires an estimate of the average consumption of commercial buildings affected by efficiency programs, such as might be impacted by a minimum efficiency standard for air conditioners. A rough estimate based on Kerala electricity board data and the annual report of the Indian Energy Commission gave 800 kWh/month and per connection, which is quite high for a small business. Prices were therefore determined for a more likely monthly consumption of 500 kWh.[15] Applying this average consumption in the way that was done for residential prices -- the average was weighted with the commercial consumption -- yields an average price for the country of 10.7 USD cents per kWh.

The appropriate average consumption used is speculative, but marginal commercial electricity rates are highly insensitive to the precise value of consumption, except for very low consumption levels. In only two of the states surveyed (Kerala and Orissa) was there any dependence of marginal rates of consumption above 300 kWh per month. Therefore, we are confident that the marginal rate calculated using 500 kWh is close to the actual marginal rate paid for the average Indian commercial consumer.

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[15] Refinement of the estimate of monthly consumption for businesses likely to be affected by efficiency standards is an important area for further research..

Industrial Tariffs

Industrial tariffs were collected for 13 states. The structure of industrial tariffs differs significantly from those of the other sectors. Tariffs are dependent on whether the customer uses a low tension (HT) or low tension (LT) connection, and according to load (kW). Within these categories, however, marginal tariffs are relatively insensitive to consumption. In order to assess marginal industrial tariffs, some assumption about monthly consumption was necessary. Consumption was estimated assuming that the bulk of electricity consumption used by the customer was due to electric motors. Therefore, we estimated total consumption in terms of the total horsepower of installed motors. For each range of horsepower, we calculated monthly consumption assuming that motors are running 12 hours per day (1 and a half shifts), for 20 days per month. The average load per motor was assumed to be 0.8.

Table A-2 shows the marginal electricity rate for a wide range of motor horsepower. Rates for low tension were used unless there was no LT rate available for the given load. A load category of 40 HP was used for the analysis of high-efficiency motor impacts. This corresponds to the situation where several motors of 10 HP are installed. Rates are generally flat over several categories of load. Therefore, while there is a great deal of uncertainty in the average load of industrial enterprises that would participate in an efficiency program, this uncertainty has little impact on marginal rates.

Table A-2 – Marginal Industrial Tariffs by Load and State

	8 HP	20 HP	40 HP	70 HP	110 HP	150 HP
Haryana	9.22	9.22	9.22	9.22	8.87	8.87
Himachal Pradesh	4.34	4.34	4.88	4.88	4.88	5.86
Uttar Pradesh	9.54	9.54	9.98	9.98	7.81	7.81
Gujarat	7.59	8.13	8.13	8.13	8.13	8.13
Madhya Pradesh	6.51	8.68	11.39	11.39	8.65	8.65
Maharashtra	5.42	5.42	5.42	5.42	5.42	7.27
Andhra Pradesh	8.13	8.13	8.13	8.13	8.13	7.59
Karnataka	6.51	6.51	7.05	7.05	7.05	8.13
Kerala	7.05	7.05	7.05	7.05	7.05	6.51
Tamil Nadu	5.42	7.16	7.16	7.16	7.16	7.59
Bihar	8.46	8.46	8.89	8.89	3.86	3.86
Orissa	6.94	6.94	6.94	6.94	6.94	6.94
West Bengal	7.33	8.05	7.16	7.16	7.16	5.86
Meghalaya	7.92	7.92	7.92	7.92	7.92	4.55
Weighted Average	**6.78**	**7.33**	**7.62**	**7.62**	**6.98**	**7.40**

The national average marginal price for industrial customers is calculated by taking the average marginal price at the 40 HP level for each state, weighted by the total industrial electricity consumption (from SEBs) of each state. The resulting national marginal price for industrial customers is 7.6 USD cents per kWh.

Agricultural Tariffs

Of all sectors studied, tariffs in the agricultural sector are the lowest, and vary the least according to monthly consumption. Agricultural tariffs were available for 11 states. Marginal agricultural tariffs for these states are shown for a range of consumption level in Table A-3. The national marginal rate is an average over all states, weighted by each state's agricultural electricity sales (from SEBs). For the purposes of calculating efficiency benefits, we assumed marginal rates for the 60 to 100 kWh consumption range, which average 3.2 USD cents per kWh.

Table A-3 – Marginal Agricultural Tariffs by Monthly Consumption and State

	15-30 kWh	30-60 kWh	60-100 kWh	100-200 kWh	> 200 kWh
Andhra Pradesh	0.004	0.004	0.004	0.004	0.011
Assam	0.036	0.057	0.073	0.073	0.073
Gujarat	0.015	0.015	0.015	0.015	0.015
Himachal Pradesh	0.011	0.011	0.011	0.011	0.011
Kerala	0.014	0.014	0.014	0.014	0.014
Madhya Pradesh	0.052	0.052	0.052	0.052	0.052
Maharashtra	0.024	0.024	0.024	0.024	0.024
Meghalaya	0.022	0.022	0.022	0.022	0.022
Orissa	0.024	0.024	0.024	0.024	0.024
Tamil Nadu	0.074	0.074	0.074	0.087	0.087
Uttar Pradesh	0.043	0.043	0.043	0.043	0.043
Weighted Average	**0.032**	**0.032**	**0.032**	**0.034**	**0.035**

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Electricity prices:

Andhra Pradesh	http://www.ercap.org/HIGHLIGHTS_TARIFF FOR THE YEAR 2005.doc
Assam	http://www.aerc.nic.in/
Bihar	
Gujarat	http://www.gseb.com/
Himachal Pradesh	http://www.hpseb.com
Karnataka	http://www.kerc.org
Kerala	http://www.kseboa.org/
Madhya Pradesh	http://www.mp.nic.in/energy/mpseb/mainpage.html
Maharashtra	http://www.msebindia.com
Meghalaya	http://meseb.nic.in/
Orissa	http://www.orierc.org/
Punjab	http://www.psebindia.org/
TamilNadu	http://www.tn.gov.in/
Uttar Pradesh	http://www.uperc.org/Tariff_UPPCL_FY04.zip
West Bengal	http://www.wbseb.gov.in/tariff_domesticpurpose.htm

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Appendix B

Calculating National Impacts

The total stock and vintage of appliances in any given year is needed in order to calculate national energy consumption and savings. The stock is calculated using a straightforward accounting method that takes each year's sales as input. For each year, some fraction of the cohort installed in previous years remains, according to a survival function. From the survival function *Surv(age)* and shipments forecast *Shipments(year)*, the remaining stock in each year is given by:

$$Stock(year) = \sum_{age=1}^{4L/3} Shipments(year - age) \times Surv(age)$$

Total energy consumption by consumers in the Base Case and in the High Efficiency Case is calculated by multiplying the remaining stock from each cohort by the unit energy consumption. For each product, the site energy consumption of the stock in each year is therefore given by

$$SiteEnergy(year) = \sum_{age=1}^{4L/3} \sum_{class=DC,FF} Shipments_{Class}(year - age) \times Surv(age) \times UEC_{Class}(year - age)$$

where the sum is over both product classes. Site energy savings is given by the same formula, where the energy consumption term is replaced by ΔUEC, and

$$\Delta UEC = UEC^{PolicyCase} - UEC^{BaseCase}$$

The Net Present Value (NPV) to consumers represents the net financial savings to consumers yielded by use of the High Efficiency Case products, discounted to the present year (2005). Financial impacts are calculated at the national level using the aforementioned shipments and stock forecasts. Incremental equipment costs for each year are given by

$$\Delta EC(year)_{NATION} = \Delta EC(year) * Shipments(year)$$

Likewise, national operating costs are given according to the stock by

$$\Delta OC_{NATION}(year) = \Delta OC(year)*Stock(year)$$

where the unit operating cost savings varies from year to year due to changes in the marginal electricity price,

$$\Delta OC(year)=\Delta UEC \text{ x } MargElecPrice(year)$$

The net savings in each year arises from the difference in incremental equipment and operating costs in the High Efficiency Case versus the Base Case, $\Delta EC_{NATIONAL}$ and $\Delta OC_{NATIONAL}$. Net Present Value of the High Efficiency Case is then defined as the sum over the forecast period of the net national savings in each year, multiplied by the appropriate national discount rate

$$NPV = \sum_{year=y_0} \frac{\Delta OC_{NATIONAL}(year) - \Delta EC_{NATIONAL}(year)}{(1+DR_N)^{(year-y_0)}}$$

The calculation of primary energy savings considers the heat rate, the power plant fuel input needed to produce one unit of electricity, and transmission and distribution losses as a fraction of generation. The primary energy savings in each year is given by

$$PrimarySavings(year) = SiteSavings(year) \text{ x } HeatRate(year)/(1+TDRate(year))$$

Appendix C

Primary Energy and Emissions for Indian Power Sector

Heat Rate and Emission Factor

Heat rates and CO_2 emissions factors for installed generation in India (as of 2002) are taken from a governmental (GoI 2003). For each region, power plants are classified under their generation mode (coal, gas, lignite, diesel, hydro, nuclear). For each plant, data are given for installed capacity, fuel type, gross generation gross, net heat rate and CO_2 emissions.

In case of gas power plants the heat rate is taken from generation norms (CEA 2003-2003). In the report, the emission factors (EF) were calculated was follows:

$$EF\ (kg_{CO2}/MWh) = HeatRate\ (kcal/MWh) * EF_{fuel}\ (kg_{CO2}/kg_{fuel}) /\ Calorific\ value\ (kcal/kg_{fuel})$$

Calculations were made by region and state and then by generation type. The sample of plants represents over 85 coal plants and 33 gas plants all over the country. A heat rate factor of 3 was assumed for nuclear generation. CO_2 Emission factors for nuclear and hydroelectric generation were assumed to be zero. All the averages are weighted with the electricity generation. Table 1 summarizes the results by region. Emission factors are given in kg(CO_2)/MWh.

The weighted average heat rate of currently operating plants in India is 9621 Btu/kWh, equal to a heat rate factor of 2.82. The weighted average CO_2 emissions rate is 846 kg per MWh.

Table C-1 – 2002 Fuel Mix and Emission Factor by Region

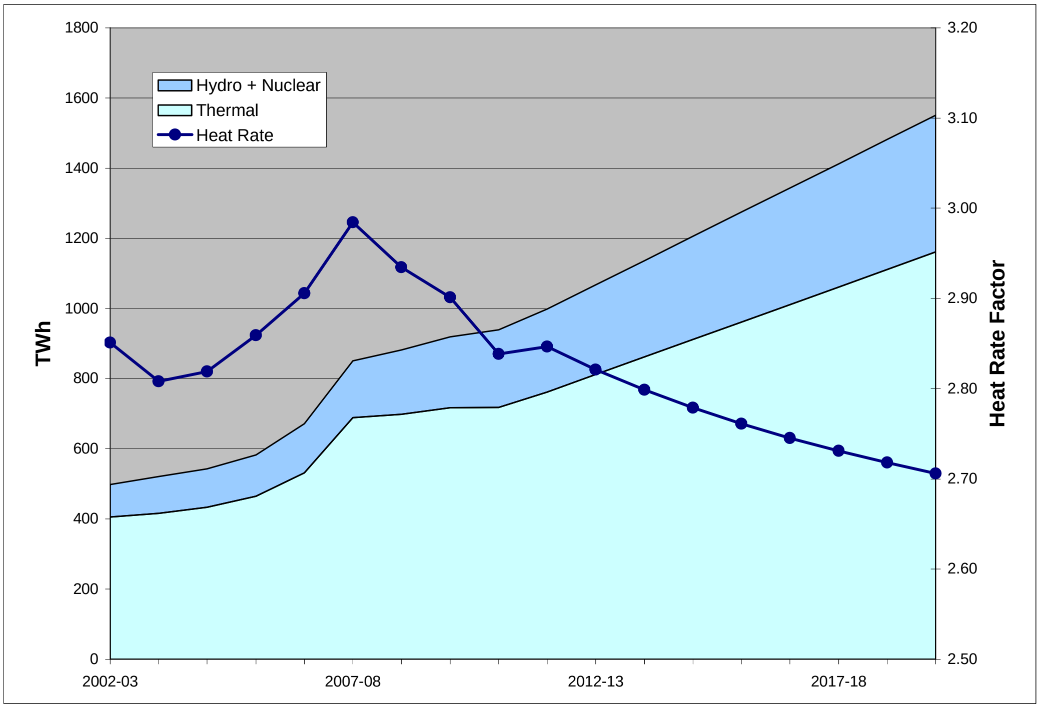
	Thermal CO_2 Emission Factor (kg/MWh)	Thermal Heat Rate	Thermal Percent of Elec Gen	Nuclear Percent of Elec Gen	Hydro Percent of Elec Gen	Elec Gen (TWh)	CO_2 Emission factor (kg/MWh)	Overall Heat Rate
Northern Region	1071	3.45	76	5	19	138	705	2.7
Western Region	1022	3.04	91	4	5	152	933	3.1
Southern Region	1027	3.13	74	4	22	121	760	2.4
Eastern Region	1379	3.43	86	0	14	57	1192	3.0
NE Region	627	2.79	65	0	35	5	210	1.0
India	1231	3.20	83	4	14	474	846	2.8

An estimate of heat rates and CO2 emissions factors during the period after 2010 relies on plans for the expansion of each type of generation in order to meet the expected rise of electricity production in the coming years. According to Planning Commission (2004), electricity generation will reach 1551 TWh by 2020. This level will be achieved by increase in capacity of existing plants and the construction of new plants in 2002-2012, as projected for the periods corresponding to the 10th and 11th 5-year plans.

Emissions are projected for each of these years in (GoI 2003). Heat rates of added capacity were estimated according to the fuel mix and plant type projected for construction or increase in capacity. From 2002-2012, 42% of new generation is expected to come from coal, 10% from lignite and 34% from hydroelectric, with the balance coming from oil, natural gas and nuclear plants.

During the period 2002-2007, most of the additions to capacity will be from thermal plants, with significant additions in hydroelectric, nuclear, and other renewable sources. Therefore, the average heat rate of the system will increase somewhat before peaking in fiscal year 2007-2008, and beginning a steady decline. Figure C-1 shows the composition of generation between 2002 and 2020, along with the trajectory of the heat rate factor. Similarly, the emissions factor of 846 kg(CO_2)/MWh is expected to decrease to 729 kg(CO_2)/MWh by 2020 due to installation of more efficient thermal plants.

Figure C-1 Generation Fuel Mix and Heat Rate Factor 2002-2020



Transmission and Distribution Losses

A revised estimation from the Planning Commission for the year 2001-2002 (Planning Commission 2002) gives transmission and distribution losses state by state for state electricity boards (SEBs) and electricity departments (EDs). Sales of power are used to weight the average. These data are presented in Table C-2.

Table C-2 – Transmission and Distribution Losses for SEBs and EDs – 2002

	T&D loss %	Sale of power (MkWh)
	2000-01	2000-01
	(R.E.)	(RE)
SEBs		
Andhra Pradesh	32.9	28418
Assam	38.6	1916
Bihar	25	7897
Delhi	47	9154
Gujarat	20	31435
Haryana	35	10958
Himachal Pradesh	18.3	3268
Jammu&Kashmir	56.4	2812
Karnataka (KPTCL)	36.5	17276
Kerala	17.2	10700
Madhya Pradesh	31	25571
Maharashtra	30	41598
Meghalaya	20.3	606
Orissa (GRIDCO)	49.9	10822
Punjab	17.5	22385
Rajasthan(Transco.)	29	17686
Tamil Nadu	16.5	33290
UP(Power corp.)	39.8	25310
West Bengal SEB	30	10000
EDs		
Arunachal Pradesh	34.3	102
Goa	32.9	1204
Manipur	49.9	182
Mizoram	42	138
Nagaland	40.8	165
Pondicherry	14.9	1413
Sikkim	20.1	108
Tripura	38.9	419
Total	**29.0**	**314833**

The weighted average T&D loss rate for India is 29.0%, which is very high compared to loss rates of 6-7% in the US and Europe, for example. The Government of India is taking steps to address the high rate of losses throughout the power system, and local utilities are making efforts to reduce these. One forecast (Planning Commission 2004) predicts that the situation will improve significantly by 2020, reaching 20% by that time. Our forecast assumes that the loss rate will decrease linearly over time until it reaches 20%, at which point it will stabilize.

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Appendix D: The role of copper in energy efficiency

Introduction

Copper is the first metal to have been used by the human race. Copper's unique properties make it an important contributor to enhancing the energy efficiency of appliances, motors, and hundreds of other commercial, industrial and residential devices.

How copper's fundamental characteristics make it a contributor to greater efficiency

- *Heat transfer vs. other materials:* Copper has an exceptionally high coefficient of heat transfer. For a given shape of material with a given temperature difference across it, copper will transfer over twice as much heat as aluminum, seven times as much heat as cast iron, eight to nine times as much as steel and over 20 times as much as stainless steel. In fact the only metal with a higher ability to transfer heat is silver, which is about 5% better, but costs around 60 times as much (2004 prices).

- *Electrical resistance vs. other materials:* Copper has an exceptionally high electrical conductivity which is a property closely-related to thermal conductivity. Copper conducts electricity at a rate around 60% better than that of aluminum, 5 times the rate of iron, 10 times that of steel and 18 times that of titanium. As with thermal conductivity, the only metal which can beat it is silver, by about 5%. Copper is therefore the preferred choice where high electrical conductivity is needed, and especially where this must be combined with compactness and affordability.

- *Substituting copper for other materials yields lower losses in some applications:* In many applications, space can be extremely limited. Here copper can be a very useful metal due to its highly efficient thermal and electrical conductivity. Although some other metals may deliver better performance per unit of weight, copper has tremendous advantages when space is limited. This can include applications in electric motors, electronic circuits and vehicle power transmission components.

- *Using more copper (without reducing use of other materials) yields lower losses in other applications:* Increasing the amount of copper in some applications can improve efficiency, even if the amount of other materials is not changed. A good example of this is in high efficiency motors (HEMs). A low-efficiency motor will use the minimum amount of copper to keep costs down. The motor will still function well, but will lose some energy as the copper conductors are not at the optimum size to minimize resistive current losses. Increasing the thickness of the conductors will cost effectively save energy for the motor user. HEMs cost more to purchase up front than old designs, but motor buyers can recoup the incremental cost many times over through reduced electricity bills.