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CONSERVATION POTENTIAL OF COMPACT FLUORESCENT LAMPS IN INDIA AND BRAZIL

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Conservation Potential of Compact Fluorescent Lamps in India and Brazil

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ABSTRACT

We evaluate the conservation potential of compact fluorescent lamps (CFLs) for managing the rapidly increasing electrical energy and peak demand in India and Brazil. Using very conservative assumptions, we find that the cost of conserved energy using 16 W CFLs is 4 and 6 times less than the long range marginal cost of electricity for the two countries. The cost of avoided peak installed capacity is 6 and 10 times less than the cost of new installed capacity for India and Brazil. The analysis is undertaken from the three separate perspectives of the national economies, the consumers, and the utilities. We find that because residential electricity is subsidized, the consumers have little or no incentive to purchase and install the CFLs, unless they too are subsidized. However, the benefits of CFL installation to the utility are so large that subsidizing them is a paying proposition for the utility in almost all cases. As an illustration of a gradual introduction strategy for CFLs, we calculate a scenario where national savings of the order of US \$ 1.2 million per day for India and US \$ 2.8 million per day for Brazil are reached in 10 years by a small and gradual transfer of subsidy from residential electricity to CFLs. We then explore the barriers to immediate large scale introduction of these lamps in the two countries. Specific technical and marketing problems are identified and discussed, which would require solution before such an introduction can be attempted. Lastly, we discuss the range of policy instruments, in addition to a subsidy scheme, that can be used for promoting the diffusion of these lamps in the domestic and commercial sector.

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1 Introduction

India and Brazil present interesting illustrations of LDCs straining to meet the ever increasing demand for electricity for increasing the GDP, the industrial output and living standards, but constrained by scarce capital and increasing environmental concerns from accessing available abundant potential power resources. Both countries have about 50 GW of installed generation capacity, and both hope to double it by the end of the century. Both foresee problems of raising enough capital to fund this increase, but developmental trends appear to require an installed capacity of more than 100 GW in the early years of the next century.[1] Furthermore, as observed by Williams (1988), capital costs for electricity production have been rising worldwide and are expected to continue to rise further.

Since the living standards of most of the population in the two countries are low, it is desirable that any reduction in energy consumption is accomplished without further decreasing the energy services available to them. Therefore new technologies can play a very important role in these countries towards decreasing household energy consumption through greater end use efficiency. Similar conclusions may also be reached for most other LDCs.

This paper describes the potential impact of compact fluorescent lamps on the power economies of the two countries, and points to the opportunities and barriers in reaping benefit of this new technical development.

1.1 Compact Fluorescent Lamps

All fluorescent lamps operate by discharging an electric arc through a mercury plasma enclosed in a glass envelope. The (mostly ultraviolet, or UV) photons emitted by the de-excitation of mercury atoms are converted to visible light by a phosphor coating on the inside of the glass envelope. The lumen depreciation (this refers to the decreasing ability of the phosphor to convert UV to visible light) of the halophosphate phosphor is a function of the electrical power loading and hence, for a particular wattage lamp, the diameter of the glass envelop had to be at least of a certain size. The color rendering ability of the lamps (measured with an index called CRI for color rendering index) was also poor, the light was of bluish tint having little visible emissions in the red. Therefore it was considered harsh and unsuitable for domestic use. If better color was desired, there would be a loss in efficiency. Research in the current decade has however led to the development of new rare earth phosphors, which can provide a light of quality very close to that from an incandescent lamp, without loss in efficiency in converting the UV to visible light. The new phosphors also can withstand higher power loading, enabling the tube diameter to be reduced to a little more than a centimeter and still have good lumen depreciation characteristics. This has led to the development of compact fluorescent lamps (Fig. 1). The lamps come with either the standard core-coil ballast or a modern electronic ballast integrated in the base.[2] (The electronic ballast provides additional advantages of a 10% higher efficacy , instant startup, and light output without flicker).

The compact fluorescent lamps fit into the same lamp-sockets as the incandescents, and use only 20% of the power to give the same light output. The PL version of the lamp has two separate parts; a compact glass element that burns for more than 10,000 hours, and the base (containing the starter, choke, and the sockets to fit into the lamp-point and for accepting the glass element) which lasts for more than 20,000 burning hours. (The SL version, which has the base fused to the glass element, may be less cost-effective owing to the non-separable base)[3] gives as much light as a 75 watt incandescent (owing to fluctuations in the supply voltages, the incandescents in the two countries are built more robustly, and rated at 12, not the usual 15 lumens/W; thus the lamps each supply about 900 lumens).

Present retail price of these lamps in the US ranges from $10 to $14. The US annual sales of CFLs in 1988 were about 10 million units (without any subsidy), and have been doubling annually for the past few years. For large volume purchases (order of 100,000 units), the 10,000 hour glass element of a PL-13 costs US$ 3.50; the 20,000 hour base costs another US$ 3.50 to Original Equipment Manufacturers (O.E.M. prices quoted in March 1989).[4]

1.2 Power Systems

There are some significant differences in the structure of the power systems in India and Brazil. Brazil's power system is mostly (90% of installed capacity in 1986) based on hydroelectric generation, and most of the future expansion will exploit the still abundant hydroelectric potential of the country.[5] There are inevitable environmental costs from flooding large areas of the rich Amazon basin for the power projects. India has increasingly relied on (mostly coal-fired) thermal power stations in its expansion of generation capacity. Its thermal power stations now contribute about 67% to the installed generation capacity.[6] The trend appears likely to continue owing to shorter lead time for thermal power stations, and less legal and political problems than those arising from submerging densely populated fertile land or fragile ecosystems in reservoirs of hydroelectric stations.

The power system of India is already unable to meet the peak demand over most of the country. In Brazil, the problem is at this time confined to some parts of the country during dry periods. India therefore resorts to scheduled power cuts, brown-outs, forced shutdown of industrial units during peak load time, and requiring industrial units to have their weekly holidays by rotation on different days of the week. These measures are still not enough. Electricity consumers suffer unscheduled power cuts when the system is unable to meet the demand. This leads to inconvenience and economic loss. Many industrial units in India have chosen to make investments in their own dedicated generation stations because the power system is not sufficiently reliable. These stations are run with expensive (and state subsidized) diesel, and represent capital investment that is kept idle most of the time, as an insurance for reliability of power available for production. When these small power stations are in use, they commonly have lower conversion efficiencies than the standard large power stations.

In Brazil, the power shortages are marginal, limited to some parts of the country during the dry periods. However, current trends in demand growth would lead to power shortages beginning within the next few years owing to the difficulty of raising large investments for power sector expansion.[7]

The major philosophy that has moulded the power system managers and decision makers in Brazil and India has been dedication to increasing the system capacity and utilization to meet the continuously increasing demand. This has made possible the remarkably rapid expansion of the power system in India (from 15 GW in 1970 to the present 54 GW) and Brazil (11 GW in 1970 to about 48 GW at present). But at this stage of the development of demand, sufficient inefficiencies in end use have accumulated in each country that conservation represents a substantial resource for increasing power availability. Geller et al. (1988)[8] discuss in detail potential savings in electricity demand in six main end uses in Brazil (industrial sector motors, domestic sector refrigerators and lighting, commercial sector motors and lighting, and street lighting). Potential annual savings of 83 TWh appear possible by the year 2000 with more efficient technology. This figure equals 20% of the country's projected electricity demand for that year.[9]

A broadening of the focus of the electricity planning in the two countries seems warranted; giving attention not merely to increasing the supply, but to increasing the energy services. This broader focus would include both supply and conservation options, with a view to meet the increasing demand for energy services by increases in supply and generation, and by improving the end use efficiencies, in a coordinated way so as to minimize costs.

1.3 Residential Loads

Electric lighting (all sectors) is estimated to account for about 17.4 per cent of India's annual electricity consumption, which reached 135 TWh in 1984-85.[10] We estimate that about 10 per cent of the total consumption is used for incandescent lighting.[11] Even more important is the contribution of lighting to the Indian peak demand, which occurs around 8 pm; if the full peak demand were to be met (which is presently not the case), we estimate that electric lighting will constitute about 30 to 35 per cent of this 'unrestricted' peak demand. Incandescent lighting would account for over half of this.[12,13] Furthermore, incandescent lighting consumption and its contribution to the peak electricity demand can be expected to grow rapidly because only about 30 per cent of the 130 million Indian households are electrified at the present, and the average annual electricity consumption per electrified household is only about 500 kWh. The low electrification rate is partly owing to low (about 27%) urbanization. Figure 2 shows the income distribution of the electrified and total households in India in 1979. The figure is based on published data[14] after making corrections for the common under-reporting of incomes in Indian household surveys, to match the published data on national incomes.[15,16] We make the reasonable assumption that though the absolute numbers have since changed, the pattern of income distribution in Fig. 2 is about the same at the present. After making adjustments for inflation and increase in per capita GNP from 1979 to 1985, 66 per cent of the electrified households had 1985 incomes less than Rs. 1000 per month; 92 per cent had incomes less than Rs. 2500 per month. (approximate exchange rate in 1985: US \$ 1 = Rs. 12). As we show, this has significant implications for dissemination of compact fluorescent lamps.

In 1987, electricity consumption in Brazil's residential sector was 38 TWh, 10% of which was for incandescent lighting (Fig. 3).[17] Residential lighting accounts for about 28% of residential peak and an estimated 8% of system evening peak (Fig. 4).[18,19] About 80% of the Brazilian population is urbanized; and about 85% of the 32 million households are electrified.[20] The average annual residential electricity consumption is 1,500 kWh per electrified household.[21] The top 20% of the electrified households account for nearly 50% of the residential electricity consumption.[22] About 37% of households have incomes less than 2 Minimum Wage Units (MWU) per month (equivalent to US\$ 108 in 1986), and only 4% earn more than 20 MWU.[23]

Comparing the energy consumption for lighting in the electrified households in India and Brazil, one striking difference emerges. In India, as the household income increases, installed lighting wattage increases more slowly than the total installed wattage. This results from the presently small penetration of non-lighting appliances in the electrified households. The installed residential wattage in India, by appliance, is shown in Fig. 5. Although the disaggregation of residential electricity use by appliance is not yet available, the low penetration of the non-lighting appliances can be inferred from the figure. As the household income levels increase, one finds increasing penetration of fans, televisions, refrigerators, ovens, kitchen appliances, electric water heaters, and finally room air-conditioners. The use of the appliances also increases with increasing income. The net result is that the share of electricity used for lighting drops steadily as the income level increases. In a recent study, the fraction of domestic electricity used for lighting was correlated with size of the city, which served as a rough measure of the average level of household income. The city sizes ranged from small villages to large metropolitan areas. The fraction of domestic electricity used for lighting decreased as a logarithm of the city population, with lighting accounting for about 70% in small villages, and about 25% in large metropolitan areas.[24]

Brazil, on the other hand shows the opposite trend. The fraction of domestic electricity used for lighting increases with increasing household incomes (Fig. 6). Brazil has higher rates of urbanization and household electrification, and its per capita income is about 7 time that of India.[25] One consequence of these factors is that Brazil has a much higher saturation of domestic non-lighting appliances. There are, on average, 1.1 TV sets and 0.92 refrigerators per electrified household.[26] In spite of their low income levels (about 2 MWU), even the households in what are called in Brazil "favelas" (shanty towns), show a relatively high penetration of electrical appliances.[27] This appears to result from the steady decline in real costs of domestic electrical appliances in Brazil over the last several years, and the existence of a large market for second hand appliances created as a result from saturation of appliances in upper income households. With increasing income, the Brazilian households continue to install more lamps. The long term future trend of lighting electricity use in India may be similar, after the household have reached a high level of electrification and of saturation with domestic electric appliances.

For the Indian situation, the future holds the electrification of the remaining 70% of the households. These households are poorer than the ones already electrified, and thus will use lighting as the main end use of domestic electricity till their income rises enough to afford other appliances. The annual production of incandescent lamps in India is shown in Fig. 7. The production presently doubles about every 10 years. This corresponds closely to the expansion of the electric power system in the country. However, as the analysis below shows, increasing use of incandescents in residential applications is wasteful of India's national resources.

2 Analysis

We analyze the economic benefits of replacing incandescent lamps with PL-13 compact fluorescent lamps from the separate viewpoints of the national economies, the consumers, and the electric utilities. Furthermore, the analysis for the consumers and the utilities considers a range of representative electricity prices, because the residential tariff structure in both the countries is designed to charge higher prices for successively higher consumption blocks. Since household income is a strong determinant of household electricity use, [28] analysis for different prices shows effectively the attractiveness of the CFLs to different household income categories.

The consumers, particularly the low-income domestic ones, do not have easy access to capital. As a result, they have a high discount rate for future savings resulting from their investments in energy efficient appliances. Following the pattern [29] found in the developed countries for lower income consumers, we have used a conservative discount rate (in current currency) of 35% for future savings by residential consumers in India and Brazil. [30] Although this paper considers the economics of replacing incandescents only with PL-13's, the lower wattage PL lamps should also be made available to suit individual requirements (the PL-5, the PL-9 etc.). The attractive economics of these lower wattage PL lamps can be calculated by the same procedures as given here. It is expected that CFLs will not directly compete with existing (40 W or 36 W) fluorescent lamps, since these have much higher lumen output and different applications.

In 1986 there were about 290 million incandescent lamps in use in India (weighted average wattage 65.5) [31] ; their number increases annually by about 7 per cent. The pattern of incandescent lamp use in south Bombay during an average day in March (weighted by wattage of lamps) is shown in Fig. 8. Installed wattage of domestic electric lamps, disaggregated by household income, is shown in Fig. 9. Both figures are based on household survey data obtained from south Bombay in the course of work summarized in [10,11]. At the time of peak demand, about 37 percent of the installed wattage of incandescent lamps was found to be in use. An average incandescent lamp point ('lamp socket' in US parlance) is used for about 1000 hours a year. The life of a single lamp may be often shorter than the listed 750 hours because of frequent overvoltage operation.

About 280 million incandescent bulbs are in use in Brazil, 80% within the residential sector.[32] Fluorescent lamps are rarely found in low income households; their penetration starts at monthly consumption levels around 100 kWh, reaching a penetration of 50% in households with monthly consumption levels above 500 kWh. Tables 1 and 2 show the main lighting characteristics according to household monthly electricity consumption and income. The fraction of electricity used for lighting increases from 9% to 15% as we move towards higher income households. The same trend is observed if we rank consumers by their monthly electricity consumption rather than income.[33] The lower 65% of the households (monthly consumption levels from 31 to 200 kWh), account for nearly 50% of electricity use for lighting. These households contribute, on an average, 125 W of lighting demand (at the meter) at the system peak; this is 7 times less than the corresponding value for households with monthly consumption levels above 500 kWh.

2.1 Assumptions

We assume that the lamps, if imported in large quantities (of the order of several 100,000s) will be available to the importing country at the O.E.M. prices. We assume a generous margin of US $ 1 per lamp for freight, insurance and transport, US $ 0.50 per lamp for warehousing and distribution, and another US $ 0.50 for advertizing, program management and handling. (These costs are low compared to the retailing overheads in the US, but are probably reasonable for a utility managed program in an LDC). We split the additional costs evenly between the glass element and the base.[34]

We assume that customs duties on imports of PL-13 (or the capital equipment for making them) are waived.[35] In the national perspective for India, a premium of 25% is added to the lamp cost to reflect the loss of scarce foreign exchange on importing the lamps.[36] However, both India and Brazil have strong enough technical infrastructure[37] that lamps can be manufactured indigenously once the annual sale volume approaches 1 million lamps.[38] The cheaper labor will then reduce the lamp costs, and the absence of any loss of foreign exchange will make the analysis appear even more favorable than presently. The successful development of these large markets and indigenous production would have important multiplying effects in the respective regions, easing the diffusion of this energy efficient technology in neighboring countries. The manufacture of the base of the lamp is relatively labor-intensive and can be started locally (with appropriate quality controls) earlier.

The CFLs will replace only the heavily used incandescents. Thus they will have a peak-coincidence use rate higher than that of the average incandescent. In absence of data on the distribution of peak-coincidence use rates of incandescents, we make the reasonable assumption that the heavily used incandescents (which get replaced with CFLs) have peak-coincidence disuse rates that are only half that of the average incandescent lamp. (For example, the average Bombay incandescent has a peak-coincidence use rate of 37%.[39] So (100 - 37 =) 63% are peak-coincidently in disuse. We assume that the CFLs introduced in the Indian system will have a disuse coincidence with the system peak of only half of this, i.e., 31.5%. In other words (100- 31.5 =) 68.5% of the CFL wattage will be in use peak-coincidently.) For the somewhat better lamped Brazilian households, we assume a 30% coincidence of the average incandescent with the peak demand. So, a Brazilian CFLs will have a peak-coincidence of use, by the above assumption, of 65%.

The assumption of the fraction of CFL wattage in use coincidently with the peak requires some discussion. We believe, for four reasons, that the peak-coincidence rate of use of the average metropolitan incandescent is a poor substitute for the peak-coincidence rate of the heavily used (say the top 30%) incandescents installed, and leads to serious underestimation of the CFL potential. First, the Bombay households (from which the Indian data is taken) are better lamped than the average Indian household, and thus use a lower fraction of the installed lamp wattage peak-coincidently. Second, the measured peak-coincidence rate refers to the average incandescent lamp; and this includes the sparsely used lamps in bathrooms and stairways and so on. The CFLs will replace the most intensively used incandescents, so the coincidence rate will be higher. Thirdly, we have data from a US utility[40] that promoted CFLs in its residential market. This evening-peaking utility used a coincidence rate of 65% for the CFLs that it promoted, as a conservative estimate. Since US residences are much better lamped than an average Indian or Brazilian residence, one would expect the coincidence rates of heavily used lamps in these households to be higher. And lastly, if the CFLs are used only 1000 hours a year, or about 3 hours a day, it is hard to see how they would have a coincidence rate of less than about 75% if the utility load was peaking consistently in the evening. More careful and detailed measurements of the distribution of peak-coincidence rate of the most-used incandescent lamps in the residential consumers are clearly needed; and we believe that these are likely to yield much larger values for peak-coincidence usage for the heavily used fraction of the installed incandescents than the average peak-coincidence rate. As mentioned above, in the absence of this data, we assume here that the CFLs will have a coincidence rate of disuse that is half that of the average incandescents, (i.e. the peak-coincidence rates of use of 68.5% for India and 65% for Brazil).

2.2 Preliminary Calculations

We here introduce what may be familiar concepts to some of the readers. The cost of an electricity conservation measure, amortized over the amount of electricity saved, yields a measure of the cost of conserving a unit of electricity. The concept is defined more precisely in Appendix A. This Cost of Conserved Energy is denoted by CCE and has units of $/kWh. Similarly, the net present value of a conservation measure leading to an avoided installation of a kW of generation capacity (for a duration of the life of a power plant), leads to the concept of Cost of Avoided Peak Installed Capacity (CAPIC). Again, the concept is defined more fully in Appendix A. International currency conversion rates used in this paper are Rs. 15 equals NCz$ 1 equals US$ 1.

First some basic calculations and nomenclature:

Price of electricity for the consumer = P/kWh

Per cent of subsidy to compact fluorescent lamp = S

$$\begin{aligned}
&Cost\ of\ the\ 10{,}000\ hour\ glass\ element = Rs.\ 67.50\ installed\ in\ India\\
&Cost\ of\ the\ 20{,}000\ hour\ base = Rs.\ 67.50\ installed\ in\ India\\
&Cost\ of\ the\ 10{,}000\ hour\ lamp = NCz\$\ 10.0\ produced\ \text{and}\ installed\ in\ Brazil
\end{aligned} \tag{1}$$

The PL-13 lamp consumes 13 W in the glass element, and 3 W in the base, a total of 16 W. It provides illumination of 900 lumens. This equals the lumen output of a 75 W incandescent lamp (rated at 12 lumens/W). We assume that the 16 W compact fluorescent will replace the average incandescent of 65.5 W (the value of the resulting increased illumination is ignored in the following analysis).

The PL-13 lamp saves a demand of 49.5 watts at the socket. Taking into account the transmission and distribution (T&D) losses of 20% for India and 15% for Brazil, this equals 61.88 W and 58.24 W at the power stations, respectively. But only a fraction of the installed CFLs will be in use peak-coincidently, so an average CFL saves at that time 42.38 watts (India) and 37.86 watts (Brazil) at the power station. This can be translated into avoided installed capacity by dividing it with a factor that scales for reliability effects. For the Indian case, we use the plant availability factor 0.573 (used by Central Electricity Authority of the Government of India in its long term forecasts for India). The Brazilian power plants have a much higher average availability factor because 95% of the installed capacity is hydroelectric. We use the figure of 0.9, consistent with the country's average factor for hydro plants.[41] In the present analysis we consider only the plant availability at peak hours; other factors that may drive the expansion of installed capacity, such as constraints on energy production (owing to limited water holding capacity of reservoirs), are not taken into account here. An accurate accounting of these factors would require a quantitative disaggregation of the contribution of peak and energy shortages that drive the power system expansion.

$$\begin{aligned}
&Avoided\ peak\ installed\ capacity\ per\ PL\text{-}13_{IN} = 73.97\ W\\
&Avoided\ peak\ installed\ capacity\ per\ PL\text{-}13_{BR} = 42.06\ W
\end{aligned} \tag{2}$$

In the equations above and throughout the rest of the text, subscripts IN and BR refer to calculation results for India and Brazil respectively.

For 1,000 hours of annual use, each lamp saves 49.5 kWh at the meter, which equals 61.88 kWh and 58.24 kWh at the generation point for India and Brazil respectively.

$$\text{Annual electricity saved per lamp}_{IN} = 61.88\ kWh$$

$$\text{Annual electricity saved per lamp}_{BR} = 58.24\ kWh \qquad (3)$$

In the following analysis, we use the Long Range Marginal Cost (LRMC)[42] of electricity for comparison with the cost of conserved electricity. A brief discussion of the meaning and appropriateness of LRMC for such a comparison is in order. LRMC is based on a long range (typically 20 years or more) forecast of the demand curve, typically using a large simulation model for minimizing the cost of meeting the predicted growth in the demand. This cost, distributed over the additional electricity that must be generated, yields the LRMC of electricity. The units of LRMC are in currency/kWh, and it is insensitive to the time of demand, since this information is already built into the forecast of the demand curve. A more detailed output of the simulation, however, can give the long range marginal cost of electricity as a function of the coincidence of the demanded energy with the system peak.[43]

The Diversified Load Factor (DLF) is a measure of the peak-coincidence of energy demand (i.e. the fraction of annual energy use that is used on-peak); a small DLF means most of the annual energy use is on-peak. For energy demand that occurs within a time slot of 3 hours around the peak, the marginal cost is more than twice that of the LRMC. Since the CFLs will have a high coincidence rate, *and* a small DLF[44], the value of energy saved will be much more than that estimated using the LRMC. However, we use LRMC for the sake of a conservative calculation here, and also because the calculations are not for a specific utility. In the latter case, more detailed analysis of the lighting load would allow a more careful treatment of the energy savings calculations.

2.3 The National Perspective

In the national perspective, any subsidies on the electricity and the lamp do not appear in the analysis on a per unit basis; any transfer of value as subsidy remains an internal transaction within the national economy. The subsidies do affect the cost calculations of the market and thus influence the volume of sale. This has significance for the total magnitude of savings that the country will achieve.

The LRMC for a typical Indian utility is about Rs. 1.35/kWh and investments costs are about Rs. 13,000/kW for installed capacity in power plants that last 30 years. For Brazil the LRMC is approximately US$ 0.12/kWh[45] and investment costs are about US$ 2,500/kW for installed capacity in hydro power plants that we assume have a life of 50 years.

As mentioned earlier, we add 25% to the cost of the (initially) imported compact fluorescent lamps to reflect the premium on scarce foreign exchange for India. In Brazil the PL version of lamps is already in production. So we leave out any such premium on the lamp costs, and assume the lamp and ballast have a life of 10,000 hours. We also take credit, for both the country calculations, for the incandescents that are not produced by the respective economies as a result of using the long-lasting compact fluorescents.

The cost of conserved electricity (CCE) is given by first calculating the annualized cost of one PL-13 to the economy at a social discount rate of 12% (in current currency)[46] :

$$\begin{aligned} net\ cost &= (annualized\ cost\ of\ PL\text{-}13\ (including\ a\ 25\%\ premium\ \text{for}\ India\ )) \\ &\quad -(avoided\ annual\ cost\ of\ incandescents\ ) \\ &= Rs.\ 19.56\ /\ year \\ &= NCz\$\ 1.28\ /\ year \end{aligned} \tag{4}$$

The CCE is given by the ratios of Eq. (4) to the annual electricity saved by the lamp at the generation point, Eq. (3):

$$\begin{aligned} CCE_{IN} &= 0.32\ Rs.\ /kWh\ = 0.02\ US\$\ /kWh \\ CCE_{BR} &= 0.02\ NCz\$\ /kWh\ = 0.02\ US\$\ /kWh \end{aligned} \tag{5}$$

The cost of avoided peak installed capacity (CAPIC) is calculated taking credit equaling the Net Present Value (NPV) of avoided purchase (and production) of incandescent lamps (worth Rs. 6.67 each year in India and NCz$ 0.49 in Brazil, see section 2.4), over a period of 30 years for India, and 50 years for Brazil. The cost of the CFLs for India is multiplied by a factor of 1.25 to reflect the premium on scarce foreign exchange, as mentioned earlier. We indicate the time-horizon of the NPV calculation (in years) by appending the number of years to the algebraic symbol. The NPV of one PL-13 installation operated over the life of one power plant (at a social discount rate of 12% in current currency) is:

$$\begin{aligned} NPV\text{-}30_{IN} &= Rs.\ 151.86 = US\$\ 10.13 \\ NPV\text{-}50_{BR} &= NCz\$\ 10.11 = US\$\ 10.11 \end{aligned} \tag{6}$$

This saves 73.97 W of installed capacity in India, and 42.06 W in Brazil Eq. (2). The respective ratios of Eq. (6) to these numbers give the CAPIC. We also use the index 30 or 50 with CAPIC to denote the different time-horizons when considering a predominantly thermal system (India) or a hydro system (Brazil).

$$\begin{aligned} CAPIC\text{-}30_{IN} &= 2052.97\ Rs\ /kW\ = 136.86\ US\$\ /kW \\ CAPIC\text{-}50_{BR} &= 240.36 NCz\$\ /kW\ = 240.36\ US\$\ /kW \end{aligned} \tag{7}$$

Compare this with the costs of new installed capacity: Rs. 13,000/kW for India, and NCz$ 2,500/kW for Brazil. There are also additional benefits from avoided costs of environmental damage, which we have not quantified here.

2.4 The Consumer's Perspective

The consumer's cost and benefit depend on the price of electricity (which is almost always subsidized), and any subsidy that the electric utility system may offer towards the purchase of the compact fluorescent lamp. If the consumer purchases electricity at a price P/kWh, and the lamps are subsidized to the extent of S per cent, the net annual benefit of buying one compact fluorescent lamp, perceived by the consumer (after annualizing all costs at a discount rate of 35% in current currency) is:

$$\begin{aligned} Net\ Annual\ Benefit &= (value\ of\ annually\ saved\ electricity) \\ &+ (avoided\ annual\ cost\ of\ incandescents) \\ &- (PL\text{-}13\ annualized\ costs) \end{aligned} \tag{8}$$

The consumer saves each year 49.5 kWh, worth 49.5 X P.

$$value\ of\ annually\ saved\ electricity = 49.5\ X\ P \tag{9}$$

The consumer also avoids buying 1.33 incandescent lamps each year, so:

$$\begin{aligned} avoided\ annual\ costs\ of\ incandescents_{IN} &= Rs.\ 6.67 = US\$\ 0.45 \\ avoided\ annual\ costs\ of\ incandescents_{BR} &= NCz\$\ 0.49 = US\$\ 0.49 \end{aligned} \tag{10}$$

The Indian consumer spends Rs. 67.50 x (1 - S/100) for the glass element, and an equal amount for the base. At a discount rate (in current rupees) of 35% per annum, the Capital Recovery Rate (CRR) for the glass element (life 10 years) is 0.3683, and for the base (life 20 years) it is 0.3509 . For Brazil, we assume a life of 10 years for the lamp, a cost of NCz$ 10.00 x (1 - S/100), and a CRR of 0.3683 corresponding to a discount rate of 35%.

$$\begin{aligned} PL\text{-}13\ annualized\ cost_{IN} &= Rs.\ 48.55\ X\ (1-S/100) = US\$\ 3.24\ X\ (1-S/100) \\ PL\text{-}13\ annualized\ cost_{BR} &= NCz\$\ 3.68\ X\ (1-S/100) = US\$\ 3.68\ X\ (1-S/100) \end{aligned} \tag{11}$$

The annual benefit to the consumer, Eq. (8), is the difference between the annual savings to the consumer, Eqs. (9) and (10), and the annualized cost of the CFL lamp, Eq. (11).

Equation (8) is shown for various realistic values of P and S in Figs. 10 and 11. The range of electricity prices shown in the Figs. 10 and 11 spans the range of residential and commercial electricity tariffs in each country. Notice that the most of the consumers (who are poorer and hence get cheap subsidized electricity), have no reason to purchase compact fluorescent lamps unless the lamps are also subsidized to the extent of about 50%.

2.5 The Perspective of the Electric Supply System

We calculate the economics of CFLs from the utilities' perspective in two different ways. First we calculate the annual benefit to the utility of subsidizing the purchase of one PL-13 lamp. Then we also calculate the CCE and CAPIC of CFLs for the utility at different rates of subsidy.

The net annual benefit of one compact fluorescent to the utility is given by the equation:

$$\begin{aligned} \mathit{Net\ Annual\ Benefit} &= (\mathit{avoided\ generation\ expenditure}) \\ &\quad - (\mathit{annualized\ subsidy\ offered}\ \text{for}\ PL-13) \\ &\quad - (\mathit{loss\ of\ revenue\ from\ decreased\ sale}) \end{aligned} \tag{12}$$

where,

$$\mathit{avoided\ generation\ expenditure} = (\mathit{generation\ saved})\ X\ (\mathit{marginal\ generation\ costs})$$

$$\begin{aligned} \mathit{avoided\ generation\ expenditure}_{IN} &= Rs.\ 83.53 \\ \mathit{avoided\ generation\ expenditure}_{BR} &= NCz\$\ 6.99 \end{aligned} \tag{13}$$

$$\begin{aligned} \mathit{annualized\ subsidy\ offered}\ \text{for}\ PL-13_{IN} &= Rs.\ 20.98\ X\ (S/100) \\ \mathit{annualized\ subsidy\ offered}\ \text{for}\ PL-13_{BR} &= NCz\$\ 1.77\ X\ (S/100) \end{aligned} \tag{14}$$

and

$$\mathit{loss\ of\ revenue\ from\ decreased\ sale} = 49.5\ X\ P \tag{15}$$

Equation 12 is plotted in Figs. 12 and 13 for three realistic values of P and variable S. The annualized subsidy to PL-13 equals the fraction of annualized cost of a PL-13 (at 12% discount rate) that is subsidized. The benefits to the utility are large from the majority of the consumers (who buy electricity much cheaper than the LRMC). The benefits are relatively smaller from those few consumers who pay prices close to the marginal cost of production. Notice that for an annualized subsidy outlay of about Rs. 10 (50% subsidy rate), the typical Indian utility will earn a net annual profit of between Rs. 33 and 53 per PL-13, because most of the electricity for lighting is sold at prices between Rs. 0.40 and 0.80 /kWh. Benefits are more significant for Brazil. Nearly 50% of the country's lighting electricity is consumed by households paying the intermediate tariff of 0.042 US$/kWh and even after giving a 100% subsidy to CFLs for these consumers the utility would annually benefit US$ 3.14 net per lamp. The higher benefits in Brazil compared to India arise from the larger difference between marginal electricity prices and residential tariffs.

An alternate measure of the economic merit of subsidizing a conservation measure is the cost of conserved electricity (i.e. the cost to the utility of conserving a kWh). So long as this cost is less than the cost of generating a kWh, the utility system should invest to conserve rather than generate electricity for meeting new demand. The cost of conserved electricity (CCE) can be obtained from Eq. (3) and (14):

$$CCE_{IN} = 0.34\ X\ (S/100)\ Rs./KWh = 0.02\ X\ (S/100)\ US\$/kWh$$

$$CCE_{BR} = 0.03\ X\ (S/100)\ NCz\$/kWh = 0.03\ X\ (S/100)\ US\$/kWh \qquad (16)$$

The Long Range Marginal Costs for a typical Indian or Brazilian utility are about 8 times higher than what they would pay to conserve the electricity by subsidizing the PL-13 lamps by about 50%.

The calculation of CAPIC follows the procedure in Appendix A. In India the utility pays a subsidy of Rs. 67.50 x (S/100) for purchase of the glass element of the CFL at the start of the first, the eleventh and the twenty first year. At the end of the thirty year period, the salvage value of the third lamp is zero (laboratory tests indicate a life of 14,000 burning hours for the PL lamps, but here we use the official figure of 10,000 hours). The utility also pays a subsidy of Rs. 67.50 x (S/100) for the purchase of the base of the CFL at the start of the first and the twenty-first year. At the end of the thirtieth year, half of the life of the CFL base is still unused, so there is a salvage value recovered at the end of the thirty year period equal to half the cost of the base. There is no premium factor of 25% for the loss of foreign exchange in the calculations from the Indian utility perspective. In Brazil, the utility pays NCz$ 10.00 x (S/100) subsidy to lamp purchase every 10 years over the 50 year lifetime of the hydroelectric plant. At a discount rate of 12%, this equals in local currency:

$$NPV\text{-}30_{IN} = Rs.\ 170.73\ X\ (S/100) = US\$\ 11.38\ X\ (S/100)$$

$$NPV\text{-}50_{BR} = NCz\$\ 14.70\ X\ (S/100) = US\$\ 14.70\ X\ (S/100) \qquad (17)$$

For the utility, the CAPIC is given dividing the NPV, Eq. (17), with saved peak installed capacity Eq. (2):

$$CAPIC\text{-}30_{IN} = 2308.10\ X\ (S/100)\ Rs./kW = 153.87\ X\ (S/100)\ US\$/kW$$

$$CAPIC\text{-}50_{BR} = 349.46\ X\ (S/100)\ NCz\$/kW = 349.46\ X\ (S/100)\ US\$/kW \qquad (18)$$

If the compact fluorescent lamps are subsidized 50%, the present worth of thereby saving one kW of installed peak-time capacity for 30 years is only Rs. 1154.05/kW for the Indian utility. For the Brazilian utility (with a 50 year plant life), the present worth is only NCz$ 174.73/kW. Besides, there is much shorter lead time needed for bringing this 'conservation power plant' on line!

3 A Scenario for CFL Introduction - Utility Savings

In both the countries, it is recognized that the electricity for the residential and commercial sectors is priced far below the long range marginal cost (LRMC), and several utilities have been considering raising the prices to more realistically reflect the cost of producing additional electricity of meet the rapidly increasing demand. International financial institutions are also interested in such a price adjustment to better allocate energy using the market mechanisms.

We illustrate a realistic scenario for introduction of CFLs in the residential and commercial sector, by assuming a transfer of a small part of the subsidy from electricity to CFLs in a gradual manner. We assume that the electricity prices for the residential and commercial consumers are raised at a (compounded) rate of 0.5% per annum for a period of 10 years, over and above any price increases presently planned. All the revenue from this increase of 0.5% is used to subsidize the CFLs. This arrangement gradually transfers a small part of subsidy from electricity to the more efficient end-use appliance. Since the CFLs are so much more efficient than the existing incandescent lamps, and also have a longer life, the utility gains much more revenue than it would by just increasing the electricity price. The new electricity prices are closer to the marginal costs and thus favor more rational allocation of energy use. And lastly, at least for India, since the poorest households use much larger fraction of their consumption for lighting, the suggested transfer of subsidy from electricity to CFLs helps the poorest households the most; their monthly bills decrease by much larger fractions than the bills of the more affluent households which have several non-lighting appliances installed.

Figure 14 shows the annual savings for Indian and Brazilian utilities under this scenario. The horizontal axis is the time (years), and the left vertical axis shows the annual savings calculated by taking the difference between LRMC and eq (16) (scenario A), or the annual additional revenue earned (scenario B). We assume for both the scenarios that the commercial and domestic consumption grows at 6% per annum (compounded). For scenario A we further assume that the CFLs are subsidized by 50% and last 10 years at 1000 hours of annual use. We also assume that the necessary technical and promotional issues (see sections 4 and 5 below) are resolved, and that all CFLs offered at 50% subsidy get sold. It can be seen from the figure that under these assumptions, the annual utility savings from use of CFLs at the end of the 10 years will reach about 450 million US dollars for India, and about 930 million US dollars for Brazil (1989 US$). India would then have about 109 million CFLs installed (20% saturation) and Brazil 168 million CFLs installed (36% saturation) in the estimated available lamp sockets (or "lamp points") assuming that the number of lamp sockets grew at a rate of 5% per annum compounded over this period. Under scenario A, the annual sales of CFLs reach about 25 million units for India and 40 million units for Brazil at the end of the 10 year period.

At the end of the 10 year period, the utilities would have saved (under scenario A) about 8 GW in peak installed capacity for India, and 7 GW for Brazil (this is shown on the right vertical axis which applies only for scenario A). What is perhaps more important, the utilities would have successfully mobilized private consumer savings to do so (first via slightly higher tariffs, and then in the form of rate-payer investments in CFL lamps).

A more precise calculation projecting the penetration of CFLs in the consumer territory of a particular utility can be undertaken only with more specific information. This is not attempted here since the purpose is to illustrate how a small shift of the existing subsidy from electrical energy to a more efficient end-use appliance can have a significant financial impact, at the same time ensuring progressive distribution of benefits of the shift among the consumers.

4 Technical and Marketing Issues

Although the foregoing economic analysis shows that the large scale introduction of CFLs would be very attractive, some technical and marketing issues must be resolved for their successful diffusion. This probably requires conducting a large field trial or experiment. Some of the issues are briefly mentioned here to highlight the need to conduct such experiments before designing a national or state-wide promotional program.

4.1 Technical

The CFLs with core-coil ballasts have power factors close to 0.5. This is by itself not a problem, in the sense that a lamp that is 5.5 times more efficient and has a power factor of 0.5 still draws 2 times less current than the resistive load that it replaces. Thus the net loss in transmission and distribution decreases, though the loss expressed as a fraction of the delivered load increases. This latter factor is of interest to the utility, as its investment in the transmission and distribution system is finally amortized through the sale of electricity. To decrease the losses in transmission and distribution, equipment has to be installed for correction of the power factors at the distribution transformers, or at some suitable point. The equipment has to correct for the changes in the power factor of the load, as the CFLs get switched on and off at different times of the day. Such equipment is available commercially in the international market; its satisfactory performance under the specific operating environment (temperature, humidity and moisture, dust, power surges and spikes, etc) needs to be verified before a large scale decision is made for such installation.

Alternately, it is possible to require that each lamp has its own capacitor to correct for the power factor. This has the advantage of not having to require centralized installations in distribution transformers for power factor correction. However, discussions with several experienced utility engineers in Brazil and India indicate that such a installation at the point of end-use is expensive and difficult to verify. The Indian experience, with requiring power-factor correcting capacitors on agricultural electric pump sets, was that numerous instances were found where the "capacitor" was a fake device which had no function other than to fool the inspectors. The consensus seems to be that the correction is best undertaken within the transmission and distribution network, where there is reliability of technical performance and service, and also the economies of scale.

The CFL with electronic ballasts can be manufactured with different levels of safeguards. The cheapest versions pollute the power lines with third and fifth harmonic distortions, at levels unacceptable to the utility. The power factor of most electronic ballasts is close to 0.6; but with additional hardware (and cost) it can be raised to 0.9, an acceptable number to utilities. Note here that the power factor is a product of two numbers: the phase power factor and the shape power factor. While almost all electronic ballasts have good phase power factor, the shape power factor is a matter of engineering design. The net product may be quite low for the cheaper ballasts. Some of the cheap electronic ballasts tend to burn themselves out if operated with a burnt out glass element. The life of the cheap ballast thus may be limited; it would survive only so long as the first glass element (with a burning life of 10,000 hours) does not burn out.

4.2 Marketing

There are several issues related to consumer behavior that are specific to the local context. It seems obvious that almost no LDC domestic consumers will buy the lamps at the present unsubsidized price. But the subsidy must be offered in a manner that does not involve much paper work and filling of forms on the one hand, and that is reasonably resistant to misuse and leakage of funds on the other. For this reason, it is best to design the subsidy scheme in close consultation with the local administration and the distribution utility.[47]

The consumer participation and the utility benefits could also change with the method of delivering the subsidy. In the presently on going program in Northern California, the utility (Pacific Gas and Electric) has distributed rebate coupons to the consumers for purchasing compact fluorescent lamps. This may raise the possibility that the consumer participation would drop once the subsidy scheme is withdrawn. Alternately, the utility can offer to rent the lamps to the consumer (if necessary, in exchange for a coupon that the utility mails along with the monthly bill); the utility recovers the rent on the subsidized lamp by adding an amortized amount to the monthly bill. This scheme is presently offered by the utility in Taunton, MA (Taunton Municipal Lighting Plant). According to TMLP [48], the lease payments cover the full cost of the lamps, the marketing and program management costs, and costs of anticipated breakages (TMLP offers to replace broken lamps free of cost, on a limited basis). For a monthly lease payment of US$ 0.20 per lamp recovered from the consumers through their monthly bills, TMLP finds that the cost of conserved energy (CCE) is less than even its Short-Range Marginal Cost (SRMC). These and other alternate mechanisms of subsidy have to be tested for effectiveness and consumer acceptance in a field trial and then "debugged" for the large national initiative.

Analyses of conservation programs in developed and developing countries indicate that the size of the subsidy is not the only crucial variable that determines consumer participation. Factors such as guarantees of technical performance of the device, the complexity and cumbersomeness of the procedure to obtain the subsidy, the confidence of the consumers in the integrity of the agency promoting the new technology, the ease of obtaining repair, maintenance, and service, etc. greatly influence the success of the promotional program.[49,50] For the same magnitude of subsidy, the consumer response can vary (owing to the above non-economic factors) by more than a factor of 10. These issues can be analyzed only in a field experiment, by a study of response to various marketing strategies.

A common feature for both Brazil and India is the existence of two levels of utilities. The six large generation utilities of Brazil[51] sell power to numerous smaller distribution utilities, who operate the distribution network to the level of individual meters. In India, most utilities undertake generation, transmission, and distribution (e.g. the State Electricity Boards), and others have only distribution activities (e.g. Bombay Electric Supply and Transport). In cases where the functions of generation and distribution are separated, it is necessary to determine what incentive the (usually smaller) sale and service utility has in decreasing its net sales by promotion of CFLs. The matter has to be resolved on a case by case basis by discussion among all the parties, and based on the structure of the tariff paid by the distribution utility to the generation utility. However it seems clear that unless the local sale and service network extends its operational support, the promotion of CFLs in the residential market will be an uphill task. Also, the distribution utilities often have a positive image with the consumers, and this can play an important role in the diffusion process.

5 Policy Implications

Diffusion of CFLs at a national level is a priority that can not be addressed single handedly by either the utilities, the government executive bodies, the academic researchers, or the marketing agencies. The task requires the coordinated efforts of all of these. Some of the policy instruments for CFL promotion are briefly discussed below. More detailed analyses will need to be specific to the national and regional contexts, and the opportunities and constraints that they offer.

5.1 Organizational Support

The selection of the specific panel of brand names and lamp types (for promotion or subsidy) requires a national institutional mechanism for testing and certification of the CFLs. There are such institutions in both Brazil and India, but presently neither of them aggressively participates in certification of luminous efficacy, burning life, sensitivity to voltage changes and to power line pollution. The utilities need this information to decide which CFLs should qualify for the subsidy program. Even if a CFL is partially subsidized, once it fails prematurely, it would be much more difficult to persuade the consumer to put up money again for the next installation.

For the program to succeed, the consumers who put up the money also need reassurance that they are not paying for a untested and unreliable product. In this case, research in the developed countries indicates that guarantees of technical performance by the subsidizing agency can be very important. The matter becomes simpler if the utility leases the lamps (and recovers their cost over several months through electricity bills). The lease payments assume a certain use and life for the lamp. If the lamp life is any shorter owing to breakage or use variation, the lease payments need not change, the dysfunctional lamp could be replaced free of cost.

The TMLP, mentioned above, leases SL-18 lamps to the consumers for US$ 0.20 per lamp per month. Any time the lamp fails, or the consumer is not satisfied, the lamp can be returned to the utility for either a replacement, or ending the lease payments. The payments have been calculated so that the utility can keep the program going indefinitely, and make a small profit after taking into account the costs of promotion, marketing, quality control, and reduced electricity sales. TMLP has its winter peak demand in the evening hours.

5.2 Tax Structure

Taxes can be a financial incentive to promote the diffusion of the CFLs. There is a heavy customs duty on import of capital equipment for manufacturing in India, which was recently (1988) waived for equipment to manufacture high efficacy lamps. This enlightened approach can be carried further in terms of elimination of excise duty and sales tax on the CFLs; these burdens only slow down the sale to lamps and thus hurt the national economy.

The annual tax on buildings can be raised every few years by a certain quantum with the provision that the increase will be cancelled when the owner presents a one time proof of purchase of a specified number of lamps (such a proof of purchase can be simply a part of the lamp carton). This will serve to introduce the CFLs into the existing building stock, and also ensure that the owners of building that continue to use incandescent lamps and thus burden the peak demand, pay a premium for doing so.

5.3 Education

Consumer education campaigns, (using multi-media advertizements, mailings, school childrens programs etc.) are needed to remove misconceptions, prejudices and reluctance to use fluorescent lamps in place of incandescents. In India, there seems to be some preference, in higher income households, for using incandescent lamps, though most of the resistance may arise from the large size, poor color rendering ability and the high color temperature of the fluorescents currently available in India. In Brazil, there appears to be no such resistance. The main point in any case may be that the consumers should be made aware that the lamps are economically attractive to them, and acceptable in terms of quality of light, and reliability of operation. In Brazil, PROCEL has made an effort to promote electricity conservation in the media as a 'trendy' and 'in' thing to do. Although the results are still being evaluated, a similar approach could be employed in the case of CFLs.

Training programs for policy makers at the municipal, state and national levels of the government will be needed for imaginatively implementing various promotional measures, only some of which are outlined in this section.

Enthusiastic support from utilities (of both kinds, those confined to distribution and those undertaking power generation) will be required as they are the principal beneficiaries and also the main contact with the consumers. Furthermore, the utilities may have to operate the rebate schemes or arrange the leasing of CFLs to the consumers. This requires constant exposure to lessons learnt from other similar programs, analyses of success and failure stories, and exchange of operational experience. Training programs can be the vehicle for this important activity.

5.4 Regulations and Standards

By this we mean the mandatory meeting of some requirements for the certification or registration or permission from a government body. New buildings always require a certification from a building inspector; the installation of CFLs (e.g. a certain number per 1000 square feet of floor area), can be part of the building inspector's standard. Regulations in most LDCs mean more avenues for corruption; so this must be undertaken with some care.

The large number of housing units owned by the state and central governments for their employees are immediately available for equipping with CFLs. These can also serve as demonstration projects and as a preliminary test of the technical performance of the selected CFL. Public sector commercial buildings also offer a similar opportunity.

5.5 Institutional Mechanisms

In the recent years, there have emerged a number of institutional mechanisms in the developed countries for financing investments in energy conservation, where the investment is paid off, (often with handsome interest), with the savings resulting from the conserved energy. No such institutional mechanisms exist in the LDCs. On the other hand, there are numerous institutions for lending funds for creating new housing. The interest rated charged by these institutions can be tied to the installation and use of CFLs. The lower interest payments from house-owners using CFLs will be augmented by payments from the utility directly to the financial institution. Similar arrangements with national and international financial institutions and the utilities are possible for raising the funds to operate the CFL programs.

The broadening of focus of the power planners from supply orientation to least cost orientation can be boosted by setting up a senior level office within each utility for demand management. The office should have the responsibility for implementing energy conservation technologies, and studying and recommending various policy and tariff options for the utility customers to reduce peak demand.

Environmental activist groups, consumer groups and other non-governmental organizations (NGO's) are natural supporters of CFLs because of the substantially less environmental damage resulting from efficient use of energy, and the freeing up of capital for other social investments. These constituencies should be educated about of the environmental and social benefits of CFLs and other efficient energy end-use devices, and their support sought in the promotional efforts.

6 Conclusions

Compact Fluorescent Lamps (CFLs) offer an opportunity to conserve energy without decreasing energy services in India and Brazil. The initial high cost of the lamps will be a very significant barrier to initial purchase of CFLs by the residential consumers who contribute significantly to the system peaks in the two countries. Since residential electricity is subsidized, the CFLs will be attractive to consumers only if they too are subsidized. This could be accomplished by transferring a small amount of existing subsidy from residential electricity to CFLs. A 50% subsidy to CFLs from the utility will pay back about 5 times that amount to the utility in terms of net savings (on an annualized basis). The benefits to the national economies are significantly large, about US$ 1 million per day for India at 20% saturation, and about US$ 2 million per day for Brazil at 36% saturation, in 10 years. However, before planning to introduce the CFLs in the country on a large scale, field trials and experiments are warranted to resolve a few technical and marketing details of such a diffusion scheme.

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APPENDIX A

The cost of conserved electricity (CCE) is the annualized cost of implementing an efficiency measure, divided by the annual energy savings. It is defined by the following formula:

CCE = A / B   where

A = (investment) X (its capital recovery rate)
+ net increase in annual O/M (operation and maintenance) cost

B = annual energy saved, kWh

The capital recovery rates, r, annualize the investments. In terms of the discount rate (in current currency), d, and the lifetime, n, it is given by the expression:

$$r = d / (1-(1+d)^{-n})$$

The cost of avoided peak installed capacity (CAPIC). While the CCE is annualized over the life of the hardware (e.g. ten years for a room air conditioner), the CAPIC is present value over the life of an avoided conventional peak power plant, which we take to be 30 years (India) or 50 years (Brazil). The formula is:

CAPIC = C / D   where

C = NPV of (investment + increase in O/M costs) over 30 (or 50) years

D = installed capacity saved, kW

The above definitions follow the methodology defined by Krause et al. [52]

APPENDIX B

In this appendix, we illustrate in detail the calculations shown in the main text to enable the interested reader to follow them closely, and redo them for other values of variables. For the sake of clarity, we show the more complex set of calculations, those for India. The calculations for Brazil are simpler since the glass element and the base of the CFL are not assumed separable and have the same life. The calculations are shown in Rupees for brevity. Divide the rupees by the conversion rate (Rs. 15 = US $ 1 assumed in the text) to get the dollar values.

The CFL costs $7+2=9 after all costs (except customs duty, ignored here,) are taken into account. Split this evenly between the base and the glass element. So each costs $4.50

Cost of 10,000 hour glass element installed in India = (US$ 4.50) X 15 = Rs. 67.5

Cost of 20,000 hour base installed in India = (US$ 4.50) X 15 = Rs. 67.5
This is Eq. (1) of the main text.

Power saved by CFL at the power plant = (65.5-16)/(1.0-0.2) = 61.8750 watts

But only 68.5% CFLs are in use peak-coincidently, so peak power saved =61.8750 X 0.685 = 42.3844 watts

Divide this by the plant availability factor, 0.573, to obtain peak installed capacity released by CFL. So,
42.3844/0.573 = 73.9692 watts
This gives Eq (2) of the main text.

Energy saved at the power-plant annually with 1000 hours of CFL use is 1000hours X 61.8750watts / 1000 = 61.8750 kWh
This gives Eq.(3) of the main text.

Calculations for the National Perspective:

First calculate the capital recovery rates from Appendix A. Use discount rate of 12%, and lifetimes of 20 years and 10 years for the detachable glass lamp and the ballast respectively. This yields:
CRR for lamp = CRR1 = 0.176984
CRR for base = CRR2 = 0.133879
Annualized cost of CFL = CRR1 X 67.50 X 1.25 (premium)
+ CRR2 X 67.5 X 1.25 (premium)
= 14.93304 + 11.29602
Subtract from this avoided cost of incandescents, Rs. 5 per incandescent, 1.33333 incandescents per year.
So, subtract 6.66667
The answer is Rs. 19.56239
This gives Eq. (4) of the main text.

Eq. (5) of the main text is the ratio of eq.s (4) and (3).

Care is taken in the calculation of NPV. The purchase of the CFL is made at the beginning of the first year (say at 12:01 AM of Jan 1), and the cost the incandescent to be used in its place is immediately avoided. So the savings from the first avoided incandescent are also realized at the same time as the CFL is purchased. For calculational simplicity, we make the approximation that the savings from avoided purchase of incandescents for the full year are realized on the first day of that year (i.e., instead of calculating discounted savings from one incandescent avoided on Jan 1 and another avoided 750 burning hours, or 9 months, later, we assume that savings of 1.333 incandescents avoided during each year are realized on Jan 1 of each year).

Therefore in calculating NPV, the expenditures and savings during the n-th year are discounted over the duration of n-1 years. Thus in the calculations from the national perspective of NPV of CFL installation, on January 1 of the first year, expenditure of the CFL (including the 25% additional penalty factor for loss of foreign exchange) is Rs. 168.75, and savings from avoided incandescents are Rs. 6.67. These contribute to the NPV without being discounted, so a net contribution of Rs. 162.08. As another illustration, on January 1 of year 21, we replace the CFL lamp and the base, an expenditure of Rs. 168.75, and save Rs. 6.67 on the avoided incandescents during the year. Discounting the difference at 12% over 21 - 1 = 20 years gives (168.75-6.67)/((1+0.12)**20) = 16.80 as that year's contribution to the NPV. At the end of the 30th year, half of the life of the CFL base remains, for which we take credit at 12:01 AM of Jan 1 of the 31st year. This gets discounted over 31-1 = 30 years at 12 percent. Adding all these factors together, we obtain the NPV from the national perspective of 151.86. This gives eq. 6 of the main text.

The calculation of CAPIC, eq. 7 of the main text, is the ratio of eq. 6 to eq. 2.

The calculations in Sections 2.4, and 2.5 follow the same procedure as described above.

Table 1

Brazil: Incandescent lighting characteristics in households by monthly consumption level

	<30kWh	31-200kWh	201-500kWh	>500kWh
Installed lighting Wattage/HH,(a)	180	424	790	2149
Watts/lamp,(a)	48	59	69	66
avg use of lamp per day (minutes)	20	9	8	3
lighting on-peak demand per HH (W),(a)	50(c)	125	255	853
monthly lighting energy use/HH (kWh),(a)	7	14	37	98
lighting as % of total HH electricity use	56	12	13	14
share of category in electrified households(%),(b)	16	65	17	2
share of category in residential electricity(%),(b)	0.2	51.1	34.8	13.9
share of category in residential lighting(%),(c)	6	49	34	11

Sources: (a) Ref. [15], (b) Ref. [18], (c) author's estimates.

Table 2

Brazil: Incandescent lighting characteristics in households by income class (Minimum Wage Units)

	<2	2-5	5-10	10-20	>20
lighting (kWh/month)	10	14	22	28	54
total electricity use per HH (kWh/month)	90	118	177	222	359
share of lighting in HH electricity use(%)	9	12	12	13	15
distribution of country's HH (%)	37	33	17	9	4

Sources: Ref.[15] and [19].

Note: 1 M.W.U.= US$ 54 (1986).

8 Notes and References

1. Williams, R. H., "Are Runaway Energy Capital Costs a Constraint on Development?", paper presented at the International Seminar *The New Era in the World Economy,* Fernand Braudel Institute of World Economics, São Paulo, Brazil, September 1988. Proceedings to be published by the Institute.

2. Luminous efficacy (units lumen/W) is a measure of the efficiency with which a light source converts power into visible light. For more details see, for example, Holms, R., *Illumination Engineering for Energy-Efficient Luminous Environments,* Prentice Hall, N.J. (1980).

3. We use the terms PL and SL to denote the two types of CFLs: with and without replaceable glass elements. In this notation, the number following the symbol stands for the wattage used in the light-emitting glass element. Thus a PL-13 lamp uses 13 watts of power in the light-emitting element. (It also uses 3 watts of power in the ballast, so a total of 16 watts). Although a similar notation is used by one of the large manufacturers of CFLs, we do not imply that the applicability of the analysis in this paper is limited to the CFLs produced by any particular manufacturer.

4. Private communication to AG from North American Philips, and from Westerfield Corp. March 1989.

5. Ministèrio das Minas e Energia, Centrais Elètricas Brasileiras S.A. - Eletrobràs, *Plano Nacional de Energia Elètrica 1987/2010 - Relatòrio Geral,* Rio de Janeiro, 1987.

6. Department of Power, Ministry of Energy, Government of India, *Annual Report 1987-1988,* New Delhi, 1988.

7. The private sector in Brazil owned (in 1986) 40% of the total installed thermal power capacity in the country, whereas it owned only 1.7% of installed hydroelectric capacity. Op. cit. ref [3].

8. Geller, H.S., J. Goldemberg, J.R. Moreira, R. Hukai, C. Scarpinella, and M. Ysohizawa, "Electricity Conservation in Brazil: Potential and Progress", ENERGY, vol. 13, no. 6, pp. 469-483, 1988.

9. op. cit. Ref. [3].

10. Remarks by Mr. K. L. Puri (Adviser, Energy Conservation, to the Cabinet Secretariat) at the Seminar on Efficient Electric Lighting, Ashoka Hotel, New Delhi, August 1988.

11. The electricity consumed in incandescent lighting can be estimated in

three different ways; all come close to the 10 per cent used in the main text.

(a) There are between 300 and 400 million incandescent lamps in the country. Let us assume there are only 300 million. These operate on the average for 1000 hours each year, and have a weighted average wattage of 65.5 W. This gives an annual consumption for incandescent lighting of 19.65 TWh, which equals 14.6% of the national consumption. Actual consumption is a little smaller owing to the pervasive brown-outs and blackouts during the evening hours.

(b) The commercial and domestic sectors account for 19.4% of the national consumption. Of this, between 50 and 70% is for lighting. About 60% of that lighting is for incandescent lighting. So between 5.8 and 8.1% is for incandescent lighting. To this, we must add the incandescent lighting from industry, public lighting, etc. This estimate of incandescent lighting is artificially depressed because it is based on consumption in the presence of blackouts and brown-outs, which commonly occur in India at the peak load time (6 PM - 10 PM), precisely when the lighting would have consumed more energy if it were available.

(c) As quoted in note [8], 17.4% of all consumption goes into lighting. If we assume that 60% of this is for incandescents, we obtain 10.44%.

12. Gadgil, A., Ramesh, S., Natarajan, B., and Natarajan, T.V., *Two Strategies for Load Levelling for India,* Phase I Final Report, submitted to Advisory Board on Energy by Tata Energy Research Institute, January 1987. Published by the ABE, March 1988.

13. Gadgil, A., and B. Natarajan, "Impact of Socio-Economic and Architectural Factors on Peak Electricity Demand: A Case Study of South Bombay", ENERGY, Vol. 14, No. 4, pp 229-236, 1989.

14. NCAER Staff, *Household Fuel Consumption Survey with Special Reference to Kerosene,* National Council for Applied Economic Research, New Delhi 1987.

15. CSO Staff, *National Account Statistics 1970-71 to 1979-80,* Central Statistical Organization, Government of India, New Delhi, 1980.

16. NCAER Staff, *Household Income and its Disposition,* National Council for Applied Economic Research, New Delhi, 1980.

17. An estimate of only 140 kWh/yr for lighting per electrified household contrasts with other values given in the literature (for example, Geller et al Ref [7], estimate it to be 340 kWh/yr). Our lower estimate is consistent with local surveys reported here (Tables 1 and 2) and with information

from incandescent lamp sales for the residential market in Brazil. In 1987, about 80 million lamps were sold to the residential market (ABILUX). Assuming a 1000 hour annual average lamp use, a generous 1000 hour lamp life, and 60 W per lamp, this gives 4.8 TWh or 12.5% of residential consumption.

18. Conselho Estadual de Energia - CESP/CPFL/Eletropaulo/Comgas, *Consumos residenciais de energia e refrigeração - Rio Claro,* São Paulo, 1986.

19. Atmann, J.L., G. De M. Jannuzzi, *A influência do consumidor residencial no consumo global de energia: o Horàrio de Verão,* Proceedings, I Congresso Brasileiro de Planejamento Energètico (forthcoming), Universidade Estadual de Campinas, São Paulo, Brasil, 1989.

20. FIBGE, *Pesquisa Nacional de Amostragem Domiciliar-1986,* Rio de Janeiro, 1987.

21. This figure is lower than what is obtained from Eletrobràs (the National Electricity Utility), and is based on the number of electrified households given by the National Statistical Bureau (IBGE). The discrepancy is probably due to the existence of multiple connections to single meter, still common in several urban and rural areas and not accounted for in the official Utility's statistics.

22. Special tabulations obtained by GDMJ from PLANTE, Eletrobràs, December 1988.

23. FIBGE, *Pesquisa Nacional de Amostragem Domiciliar-1986,* Rio de Janeiro, 1987.

24. Data on file with Tata Energy Research Institute, collected in connection with its report authored by Natarajan and Puri, titled *Energy in the Context of Urbanization,* submitted to Ministry of Urban Development, Government of India, 1988. Analysis presented in Gadgil, Natarajan, et al, *Two Strategies for Load Levelling for India, Phase II,* Final Report, Submitted by TERI to Advisory Board on Energy, 1988.

25. In 1986 average income per capita in India was US$ 282 and US$ 2,028 Brazil (1980 US$). International Monetary Fund, *International Financial Statistics Yearbook - 1987,* Washington DC, USA (1988).

26. Jannuzzi, G. De M., Schipper, L., "Electricity Conservation in the Brazilian Household Sector: Potential, Limitations and Recent Achievements," LBL Report, (in preparation).

27. Jannuzzi, G. De M., "The Consumption of Energy in Low-Income Urban Households", Pacific and Asian Journal of Energy, Vol. 1 (2), July 1987,

New Delhi.

28. Jannuzzi, G. De M., "*Residential Energy Demand in Brazil and Income* Classes: Issues for the Energy Sector", ENERGY POLICY, Vol. 17(3), June 1989. See also ref. [11].

29. See, for example, Chernoff, H., "Individual Purchase Criteria for Energy Durables: the Misuse of Life Cycle Cost", Energy Journal, Vol 4, No. 4, pp 81-86, (1984).

30. In their unpublished analysis of choice of cooking energy system in urban Bangalore households as a function of household income, B. S. Reddy and Amulya Reddy find discount rates for future savings ranging from 35% to 65%, increasing with increasing poverty. Personal communication to AG from Amulya Reddy, May 1989. Similar values are found by J. Dunkerley and colleagues in their soon to be published analysis of household cooking fuels in Hyderabad, Bangalore and other Indian cities. Personal communication to AG from Joy Dunkerley.

31. Private communication to AG from ELCOMA, the Electric Lamp and Component Manufacturers Association of India, 1986.

32. Private communication from PROCEL (Brazilian Electricity Conservation Program) to GDMJ, December, 1988.

33. The lowest level considered in Table 1 (<30 kWh/m) shows a very high percentage for lighting due to the absence of major appliances in this category.

34. We use Rs. 15 = US$ 1.00 and NCz$ 1.00 = US$ 1.00 as the exchange rates prevailing at the time of writing (March 89).

35. The current customs duty rate for India for electrical appliances is 270%.

36. Note however that power generation projects in LDCs require foreign exchange too. According to the presentation made at the 11th Annual Conference of the International Association of Energy Economics, (June 26-28, 1989, at Caracas Venezuela), by Dr. John Besant-Jones of the World Bank, the foreign exchange components in India and Brazil are between 30% and 40% of the total project investment. Furthermore, we do not advocate importing CFLs for eternity. Local production facilities should be set up as soon as their output (typically 1 to 2 million CFLs annually per factory) can be absorbed either locally or with exports.

37. Brazil currently produces 160 thousands CFLs (9 W type) per year which are sold at a retail price of US$ 25/unit (including ballast, lamp and adapter). Lamp prices obtained from Mr. Marcos J. Marques, Director,

Eletrobràs, to GDMJ, February 1989.

38. This approximate figure of annual sale volume which would justify setting up an automated production line, was obtained by AG from discussions with experts of Philips, Eindhoven, Holland, 1988.

39. Op Cit [10]

40. Private Communication to AG from Mr. Joseph Desmond, of Taunton Municipal Light Plant, Taunton, MA 02780, March 1989.

41. Data on plants in the State of São Paulo (which corresponds to about one third of the country's installed capacity) indicates availability factors varying from 0.84 to 0.95 (Companhia Energètica de São Paulo, Bulletin of Statistics of Operation, 1989).

42. See, for example, Munasinghe, M., and Schramm, G., *Energy Economics, Demand Management and Conservation Policy,* Van Nostrand, New York, (1983).

43. For example, for the Brazilian utility Companhia Paulista de Força e Luz-CPFL, the long range marginal cost of delivering a kWh to a residential consumer increases from NCz$ 0.015 off peak, to NCz$ 0.150 for 6 hours surrounding the system peak, to NCz$ 0.257 for 3 hours surrounding the system peak (Private communication from R. Placido, Companhia Paulista de Força e Luz - CPFL, to GDMJ, February 1989).

44. The distinction is worth noting because a DLF does not measure what fraction of the time during the peak load the appliance is drawing power. A constant load (e.g. a fan kept switched on for 8760 hours in the year) will have a high peak-coincidence factor but a large DLF. On the other hand, a lamp that is used on-peak but only for 10 days in the year will have a small DLF, but a small coincidence factor. Survey data indicate Diversified Load Factors for electric lighting of 18% for smaller Brazilian cities and 21% for São Paulo. See, for example, Op. Cit ref. [15].

45. Private communication from R. Placido, Companhia Paulista de Força e Luz to GDMJ, February 1989. This value assumes 15% T&D losses.

46. This is consistent with the norm used by the Planning Commission of the Government of India. See "Guidelines for the Preparation of Feasibility Reports for Industrial Projects", Project Appraisal Division, Planning Commission, Yojana Bhavan, New Delhi.

47. We recognize that a flat subsidy on CFLs would benefit the richer consumers (who pay higher electricity tariffs) more than the poorer ones, at least in absolute terms. Also, if the number of subsidized CFLs made available

per household is either very small (e.g. one) or very large (e.g. a hundred), there is a possibility that the CFLs will be sold by the poor households to the richer ones in the first case, and from within the utility service territory to outside it in the second. The issue is complex because investment horizons and discount rates are different depending on income levels. At least some of the complexities can be sorted out only after the utility or the government takes a decision on who are the best candidates for the promotion of CFL installation.

48. Private communication with AG from Mr. J. Desmond, TMLP, MA 02780

49. Agnihotri, S.B., "Diffusion of Water Pumping Windmills in Orissa - An Analysis of Success", Journal of the Solar Energy Society of India, SESI-J, Vol. 1, No. 2, (1987).

50. Stern, P.C., Aronson, E., Darley, J.M., Hill, D.H., Hirst, E., Kempton, W., and Willbanks, T.J., "The Effectiveness of Incentives for Residential Energy Conservation", EVALUATION REVIEW, (April 1986).

51. Furnas, CESP, Itaipu Binacional, Eletronorte, CHESF, Eletrosul.

52. Krause, F., Brown, J., Connel, D., DuPont, P., Greely, K., Meal, M., Meier, A., Mills, E., and Nordman, B., *Analysis of Michigan's Demand-Side Electricity Resources in the Residential Sector,* LBL Reports 23025, -26, -27, (April, 1988).

9 Figure Captions

Figure 1: Three compact fluorescent lamps (CFLs) are shown on the left, with a standard incandescent bulb on the right for size comparison. Some CFLs, such as the one on the extreme left come with their glass elements (the twin tubes at the top) detachable from the screw base. Others versions (e.g. the second from the left) have the glass element fixed and housed inside prismatic plastic cover. The base contains the choke (which is sometimes electronic), and the starter, and fits into standard US household sockets. Similar CFLs for use in European (and Indian) household sockets are also in mass production. Figure is adapted from Goldemberg, J., Reddy, A., Johansson, T., and Williams, R., *Energy for a Sustainable World,* Wiley Eastern, New Delhi (1988).

Figure 2: The distribution of annual household incomes for all and electrified households in India (1978-79). The bulk of the unelectrified households are poor, and will use lighting as their only electricity end-use when they are electrified. The pattern of distribution has probably remained unchanged till 1989. (For comparison, US$ 1 = Rs. 15).

Figure 3: Residential electricity use in Brazil. Data are for 1987, from Ref. [19].

Figure 4: Electricity load curves for Sao Paulo Light and Power Co., (1989), showing the high coincidence between residential and total electricity loads. Data are from Ref. [16].

Figure 5: Installed residential wattage for India, 1986. Data are from a household national sample survey conducted by NCAER, quoted in Ref. [11]. Although data on disaggregation of residential electricity use are not available for India, the figure shows clear dominance of lights and fans in the residential end-uses of electricity.

Figure 6: Disaggregated residential electricity use by end-appliances for Brazil, by household income categories. Data from Ref. [15].

Figure 7: Annual production of incandescent lamps in India, 1970-86. Data are from Center for Monitoring Indian Economy, (1987).

Figure 8: Fraction of installed wattage of incandescent lamps in use, as a function of the time of the day, for Bombay, 1986. The data were collected using a large house to house survey. As described in the text, use of this data for estimating all India use pattern is conservative because an average Indian electrified household has fewer lamps than an average Bombay household, and so will use the installed lamp wattage more intensively. Data from Ref. [11].

Figure 9: Pattern of residential lighting in Bombay, as a function of household monthly income. Data are from Ref. [11]. With increasing household income, the lighting wattage and its fraction contributed by incandescent lamps grows rapidly. These data from Bombay are unable to resolve a similar rapid rise in incandescent lamp fractional contribution at the bottom of the income scale, owing to poor resolution of income data in the lowest bracket, and because the Bombay household have generally higher incomes than the average electrified Indian households (see Fig. 2).

Figure 10: Net annual benefits to the Indian consumer from using a PL-13 compact fluorescent lamp, as a function of electricity price and subsidy offered to the lamp. An internal discount rate of 35% has been assumed, reflecting commonly observed consumer behavior in investing in energy saving appliances.

Figure 11: Net annual benefit to the Brazilian consumer from using a PL-13 compact fluorescent lamp. Notice that the benefits are higher for consumers that have to pay more for their electricity. For consumers paying the lowest (subsidized) electricity prices, it is uneconomical to invest in compact fluorescent lamps, unless the lamps too are subsidized (possibly from slightly higher electricity prices).

Figure 12: Net annual benefits to a typical Indian utility from installation and use of one PL-13 lamp by a consumer. Since the electricity is priced below its marginal cost of production, the installation of a compact fluorescent lamp yields higher returns to the utility when the lamp is installed in the house of a lower-rate consumer. The returns are also higher when the utility pays less subsidy. The calculations have used an internal discount rate for the utility of 12% in current currency. Most of the Indian residential consumers are sold electricity at prices between the top line (US$ 0.027/kWh) and the middle line (US$ 0.053/kWh). The benefits to the utility are so large that the utility would make money even if it gives the lamps away free (subsidy of 100%)!

Figure 13: Net annual benefits to a typical Brazilian utility from installation and use of one PL-13 lamp by a consumer. The same behavior of the graphs as in Fig 12 is observed. In the Brazil case, most of the consumers are sold electricity at prices near the center line (US$ 0.042/kWh). Again the utility stands to make money under almost all conditions (except when both the electricity prices and the subsidy fraction are high). Internal discount rate of 12% in current currency is assumed for the utility.

Figures 14A, and 14B: The figures illustrate a scenario for introduction of CFLs in the two countries where the subsidy to CFLs is financed exclusively from a 0.5% annual incremental rise in electricity prices. The lower graphs (labeled scenario B) show the income resulting from such a small electricity price rise. The upper graphs (labeled scenario A) show the annual savings to the utilities arising from investing the income shown in the lower graph to subsidize CFLs. Peak generation capacity freed up due to the CFLs installed is shown on the right vertical axis. At the end of the 10 year period, India would have 20% and Brazil 36% saturation of the lamp sockets with CFLs, and the annual sale of CFLs would have reached 25 and 40 million units in the two countries.

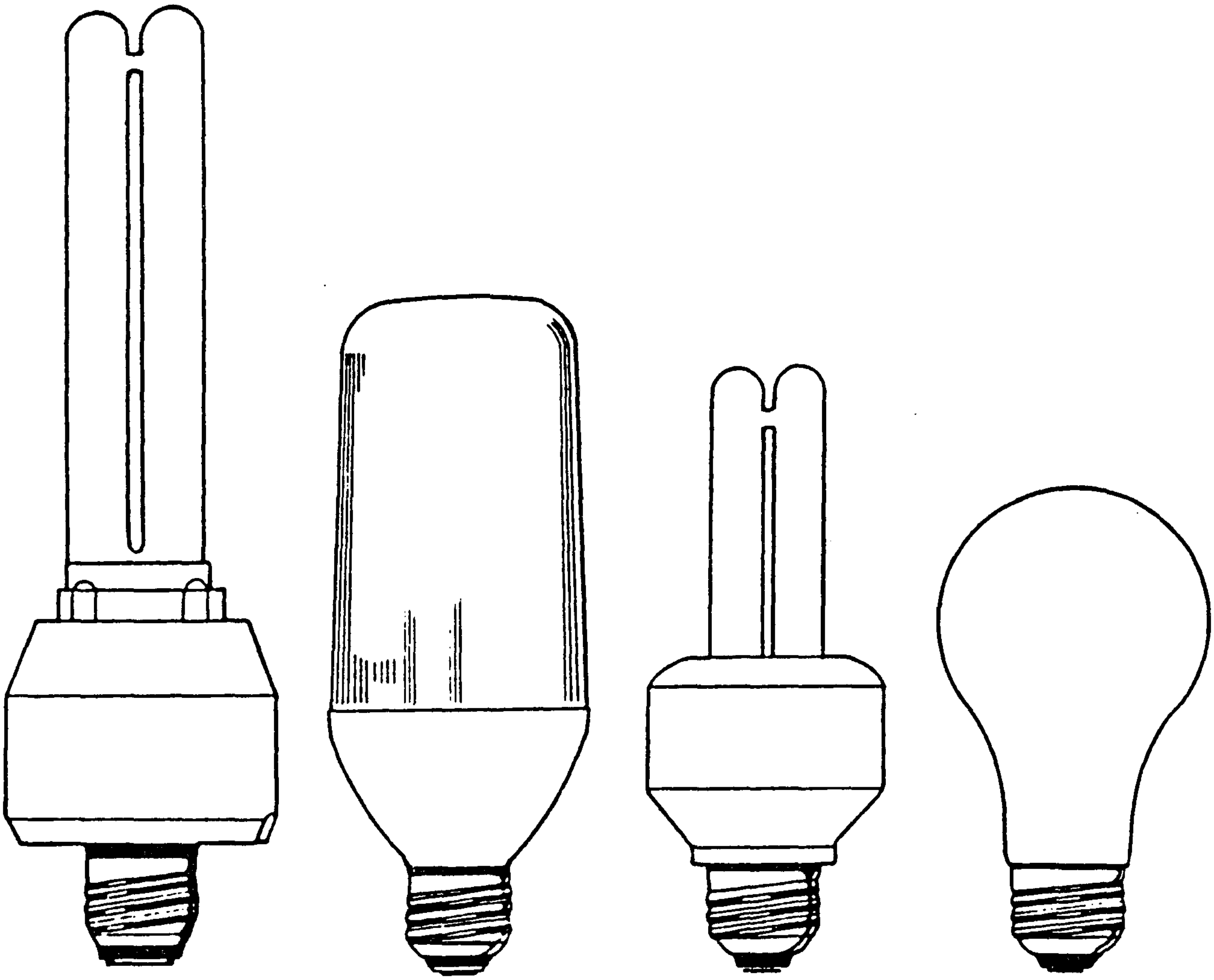


FIGURE 1

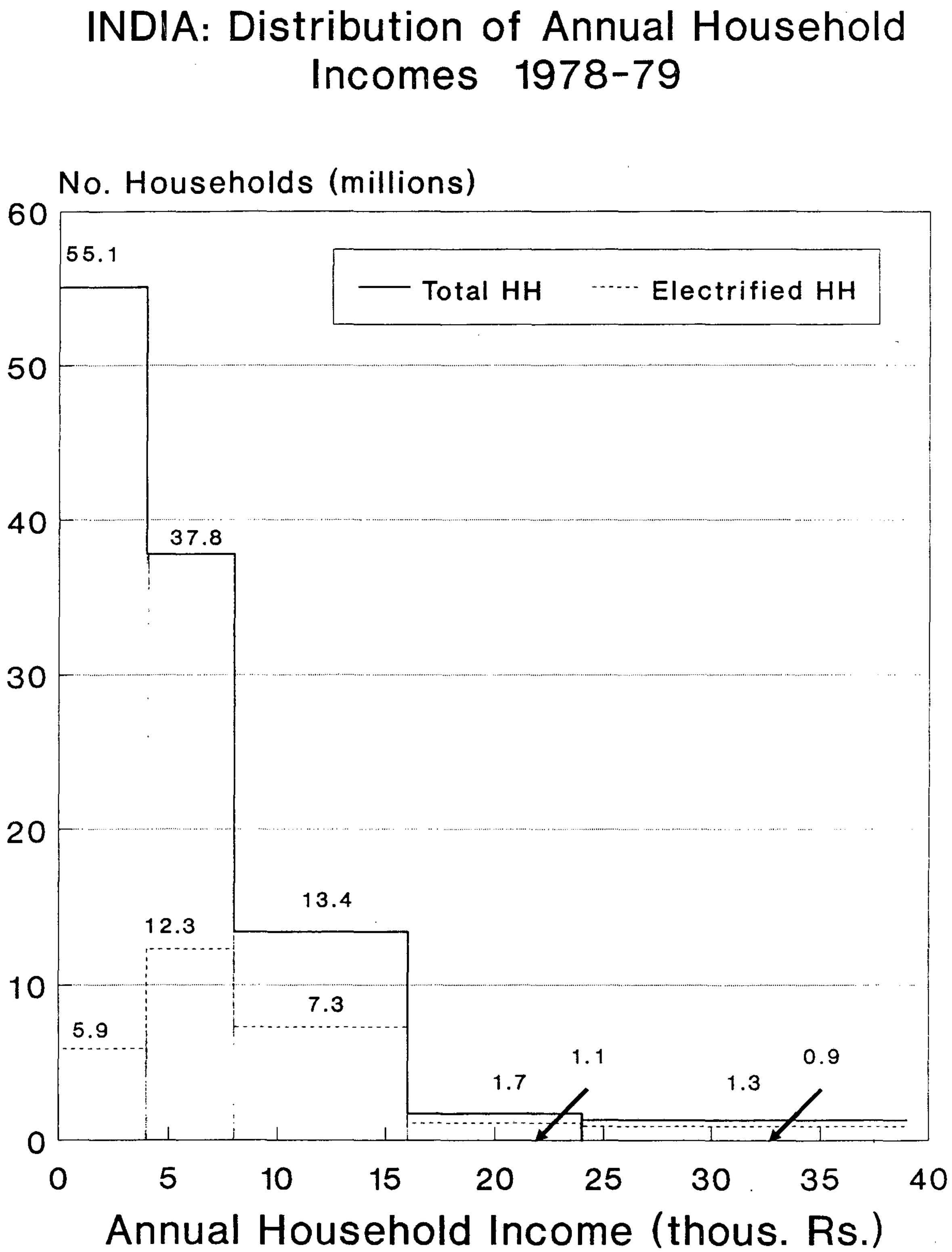
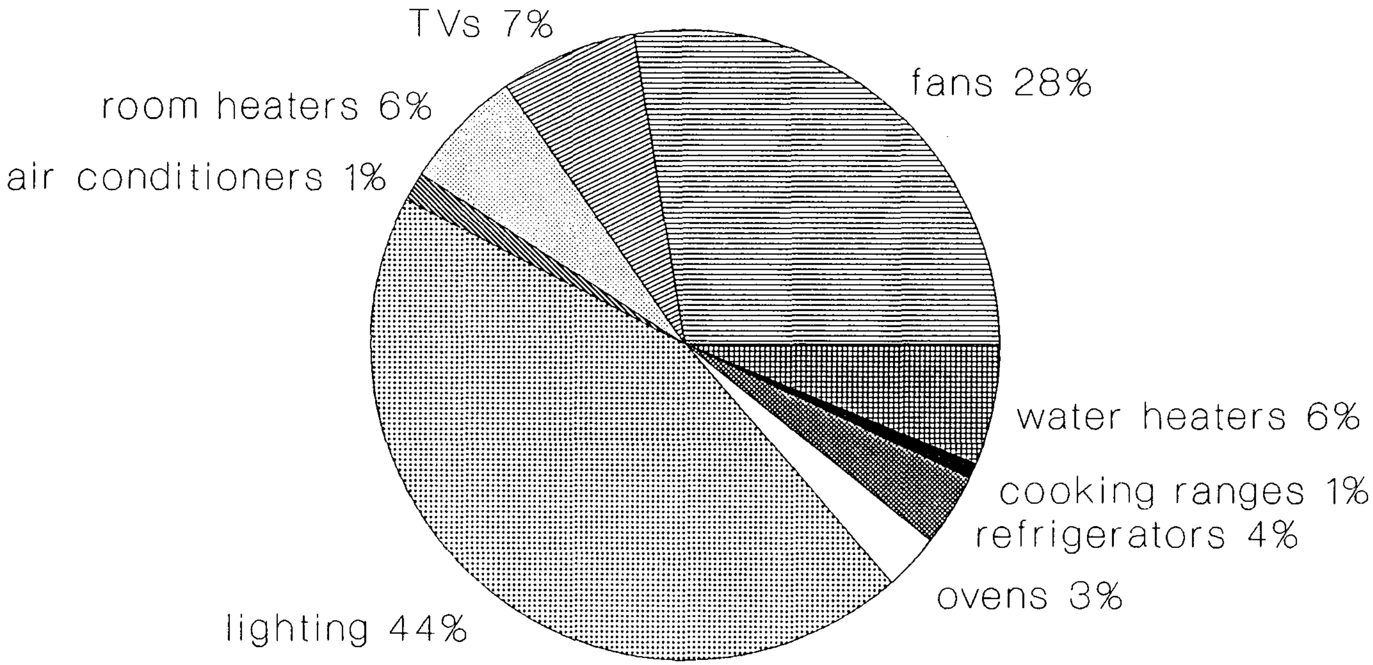

INDIA: Distribution of Annual Household Incomes 1978-79
No. Households (millions)
60
50
40
30
20
10
0
55.1
37.8
13.4
12.3
7.3
5.9
1.7
1.1
1.3
0.9
Total HH
Electrified HH
0
5
10
15
20
25
30
35
40
Annual Household Income (thous. Rs.)

FIGURE 2

India: Installed Residential Wattage

1986

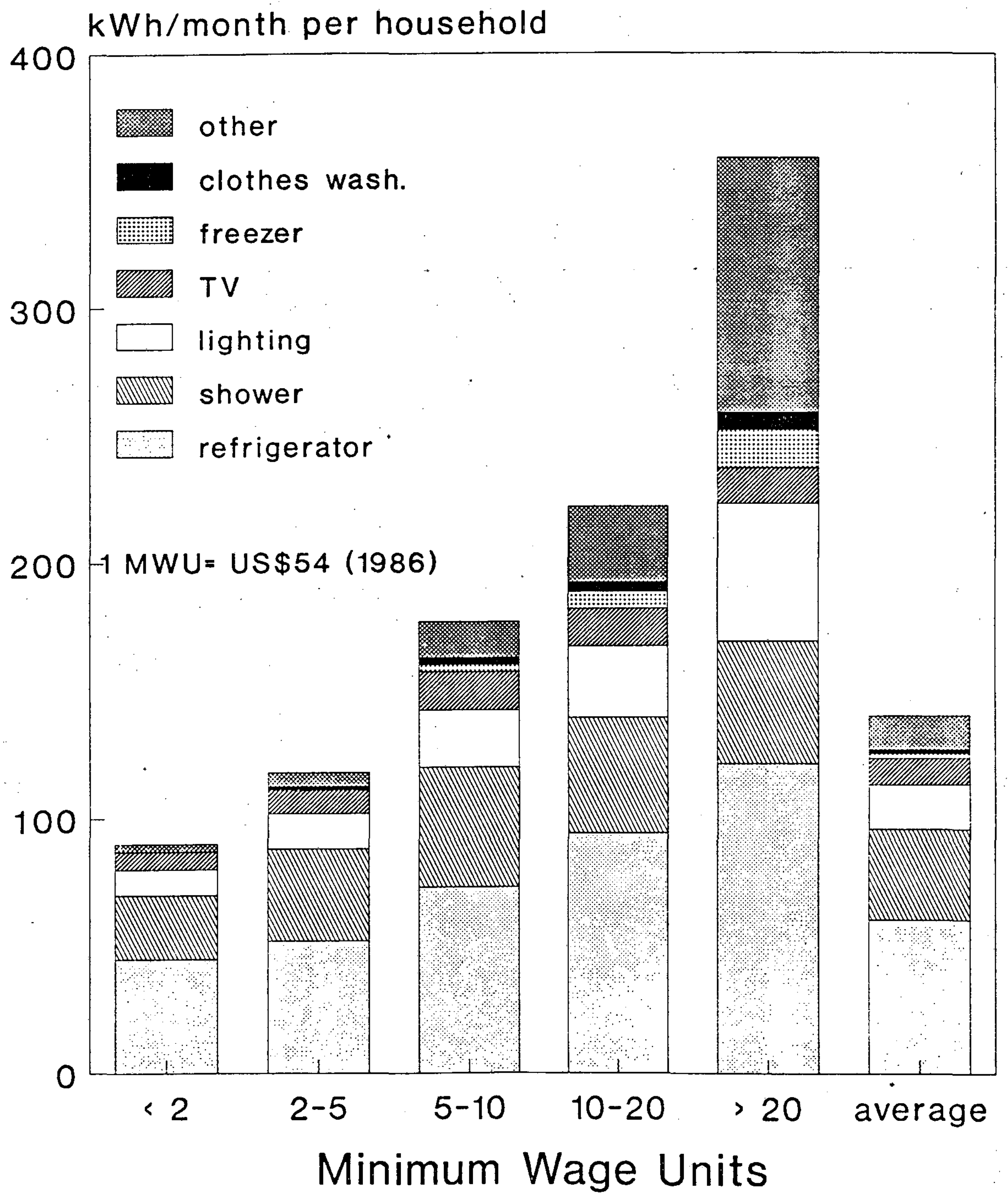


Total: 10.9 GW

Source: Gadgil & Natarajan (1987)

FIGURE 5

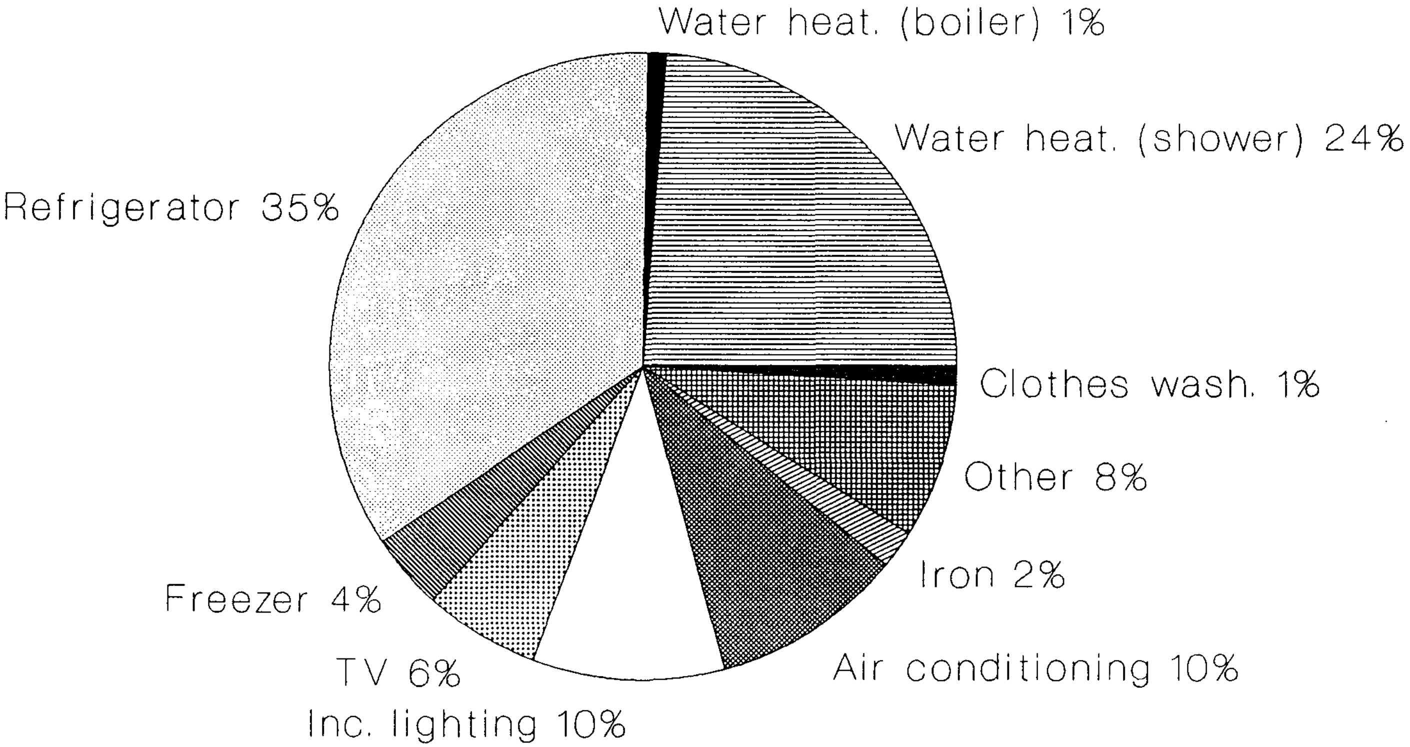
BRAZIL: Electricity Use - 1986



Source: Ref.[15] and authors' estimates.

FIGURE 6

BRAZIL: Residential Electricity Use
1987

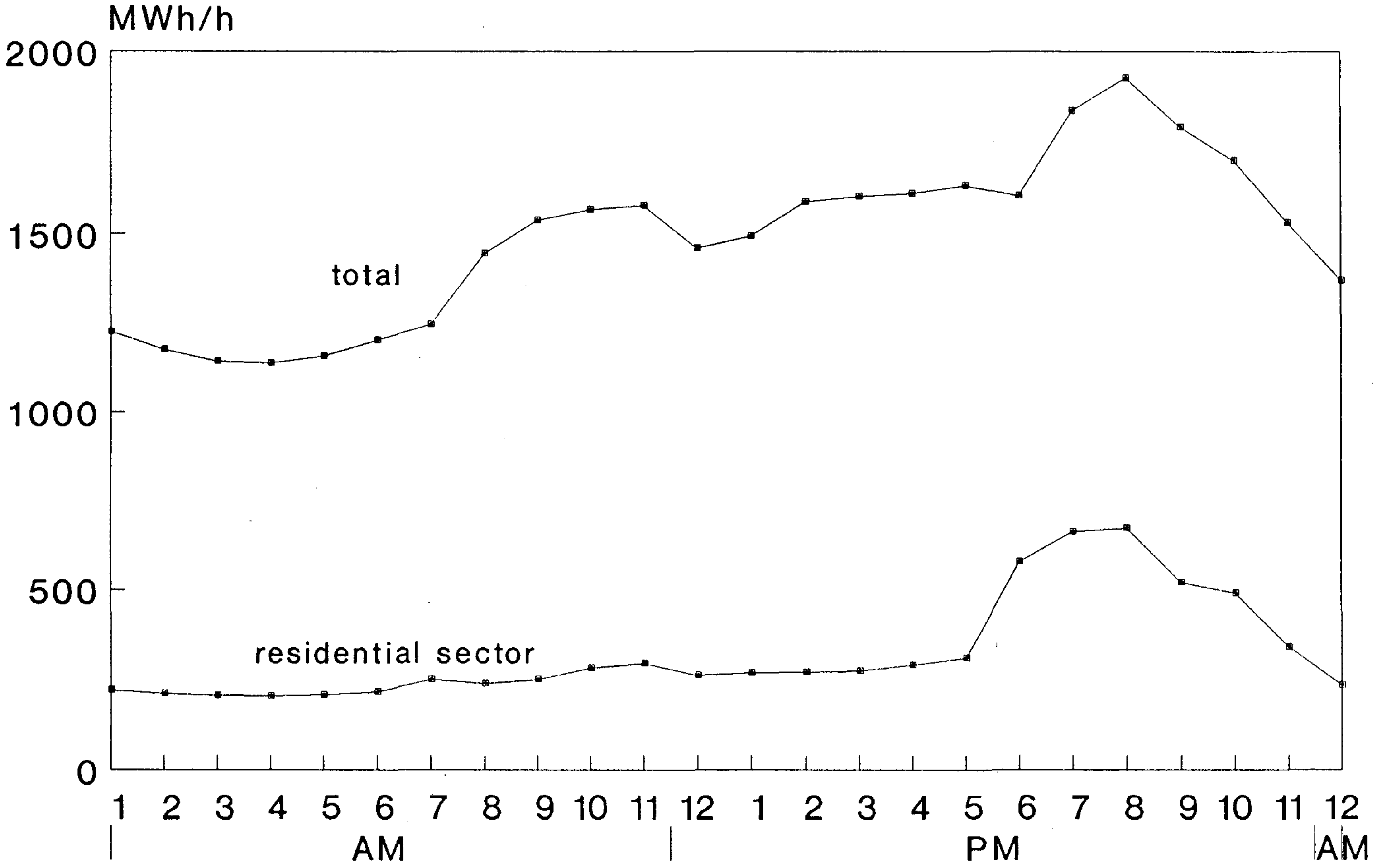


Total: 38 TWh

Source: Ref. [19].

FIGURE 3

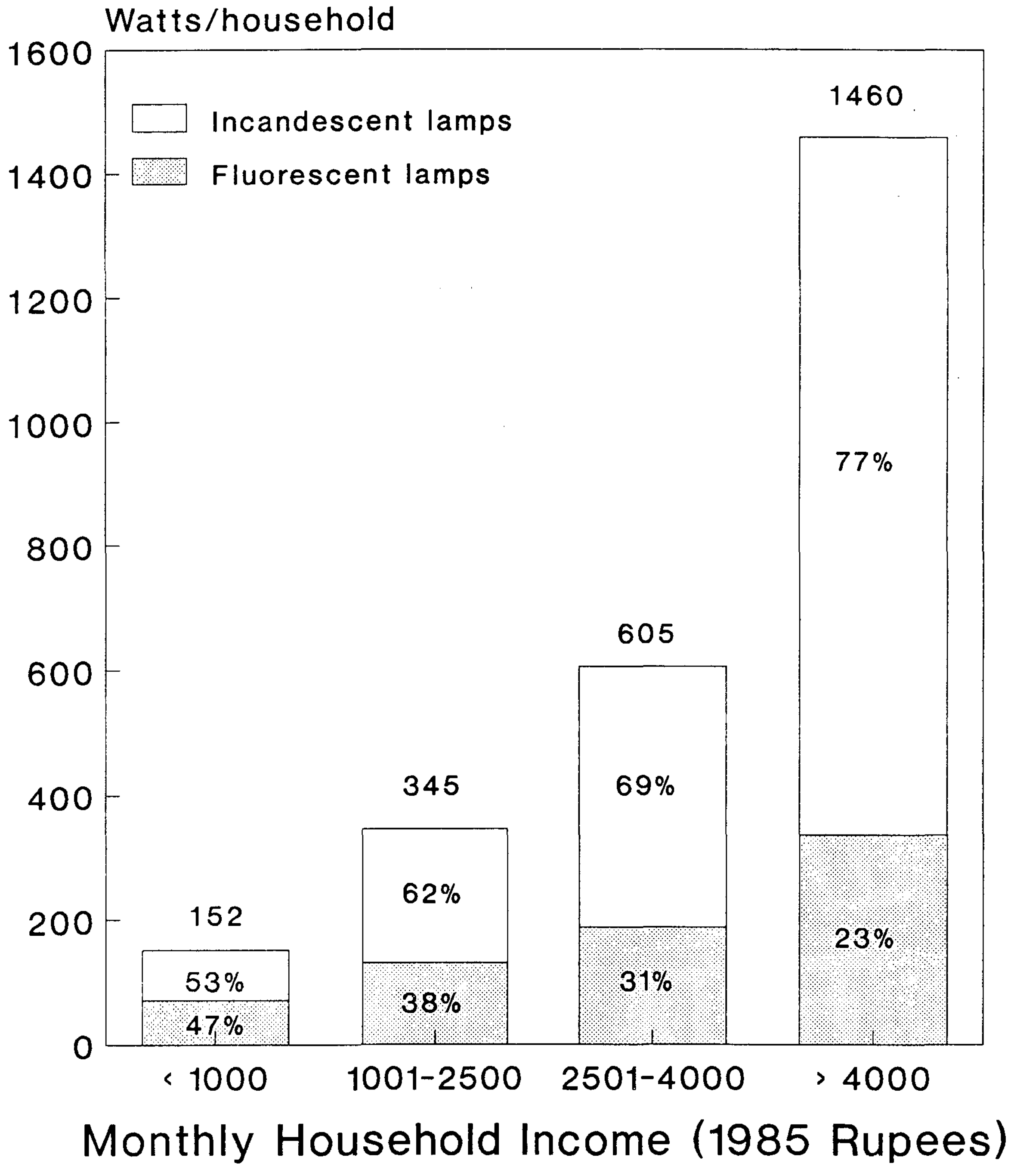
Brazil: Residential vs Total Load Curves



Source: Atmann & Jannuzzi (1989).
Note: Data refer to Tues-Fri avg for
Sao Paulo Light & Power Co. (CPFL).

FIGURE 4

India: Installed Domestic Lighting



Source: Gadgil & Natarajan (1987).
Note: Data refer to South Bombay (1985).

FIGURE 9

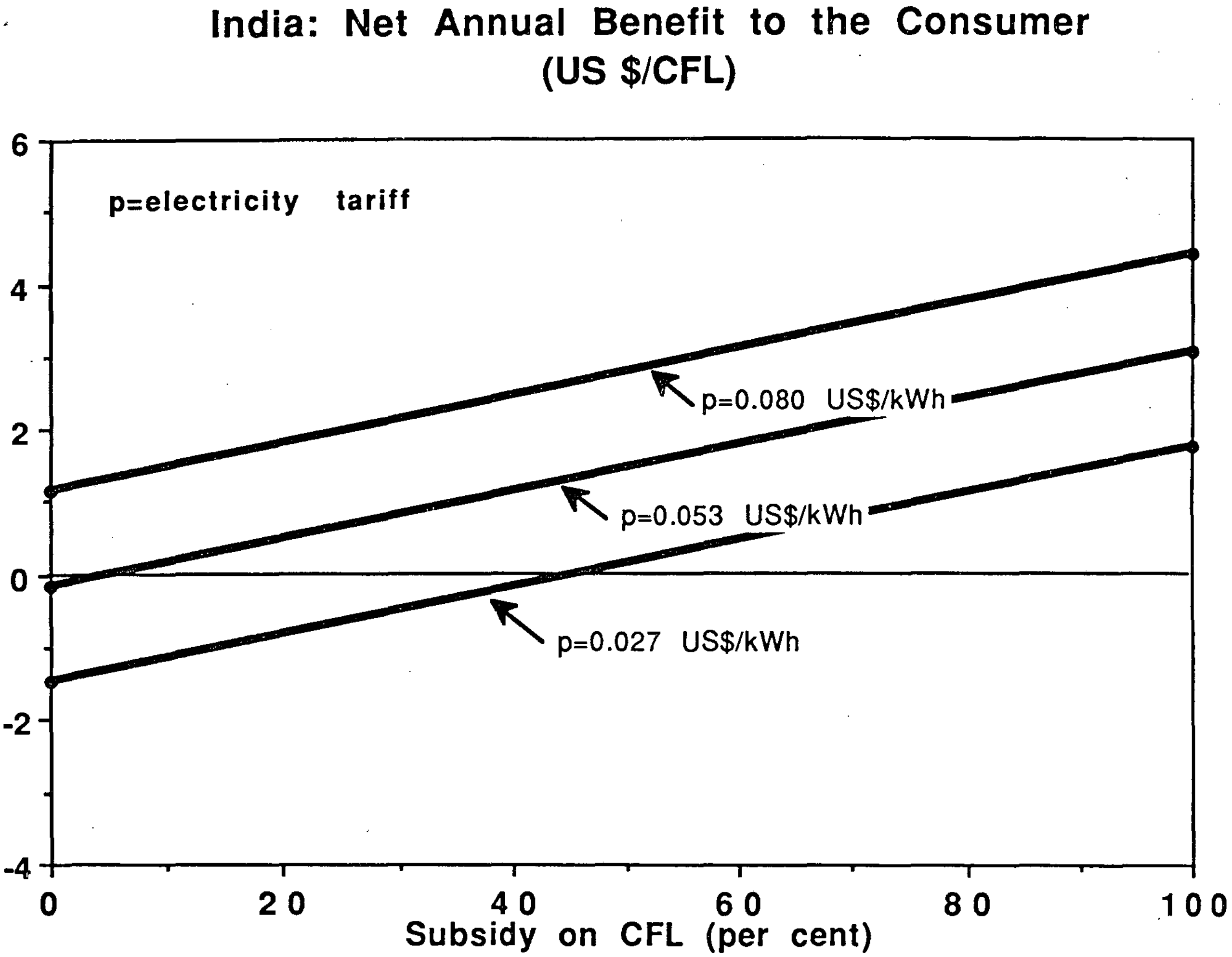
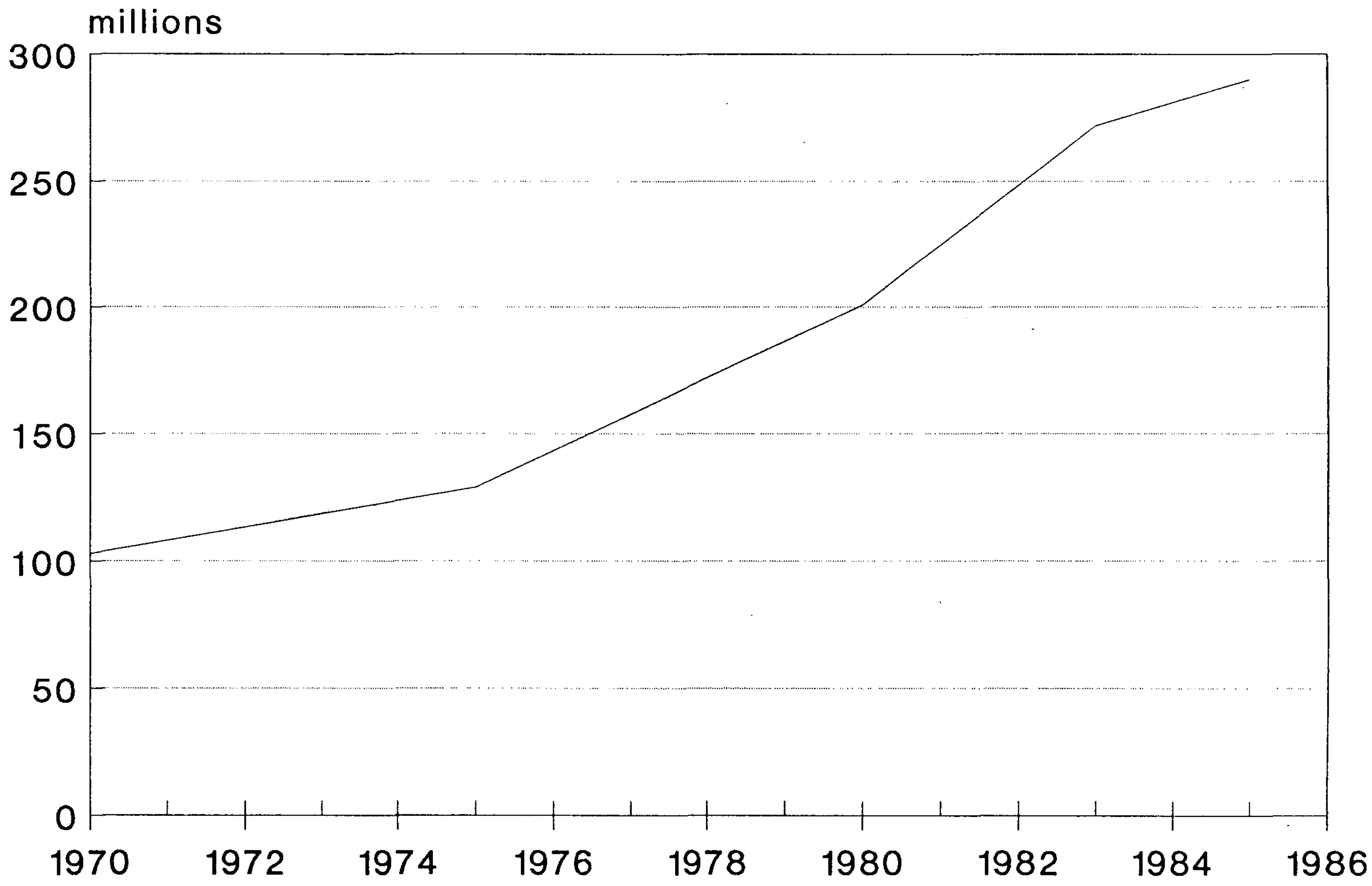

India: Net Annual Benefit to the Consumer
(US $/CFL)
p=electricity tariff
p=0.080 US$/kWh
p=0.053 US$/kWh
p=0.027 US$/kWh
6
4
2
0
-2
-4
0
20
40
60
80
100
Subsidy on CFL (per cent)

FIGURE 10

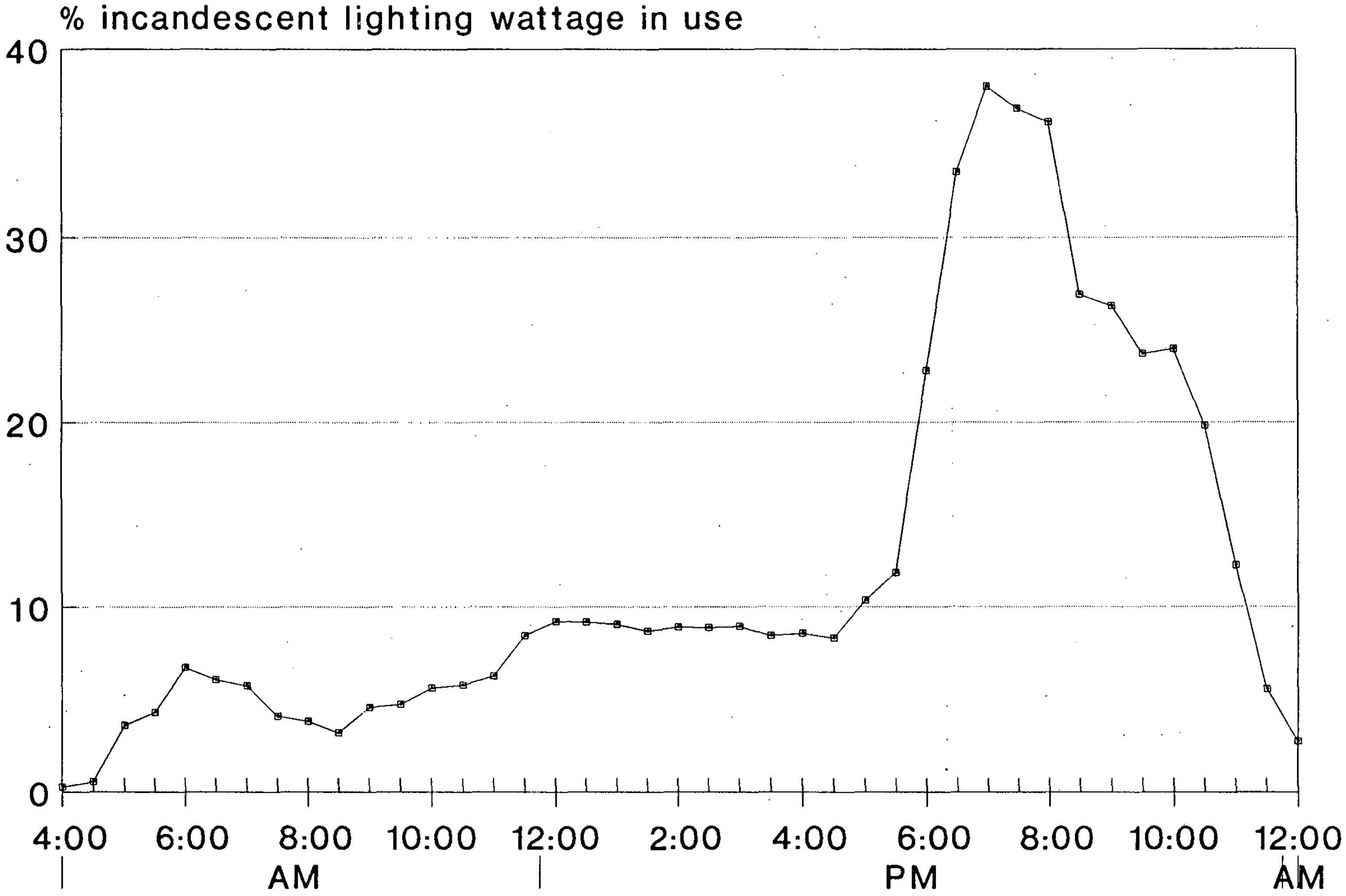
INDIA: Production of Incandescent Lamps



Source: Centre for Monotoring Indian
Economy (1987).

FIGURE 7

INDIA: Incandescent Lighting Duty Cycle



Source: TATA ENERGY RES. INST. (1988).

FIGURE 8

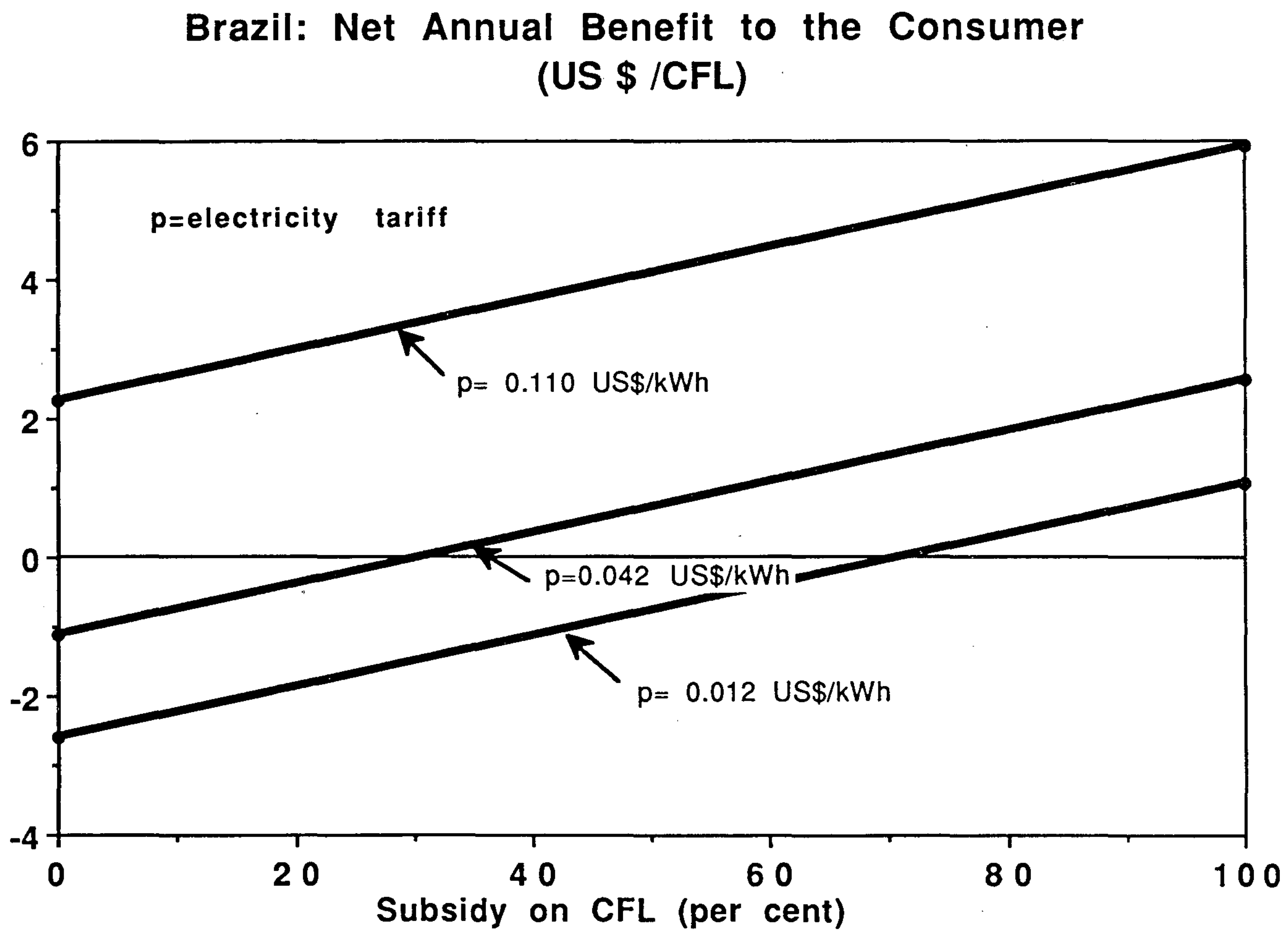

Brazil: Net Annual Benefit to the Consumer
(US $ /CFL)
p=electricity tariff
p= 0.110 US$/kWh
p=0.042 US$/kWh
p= 0.012 US$/kWh
6
4
2
0
-2
-4
0
20
40
60
80
100
Subsidy on CFL (per cent)

FIGURE 11

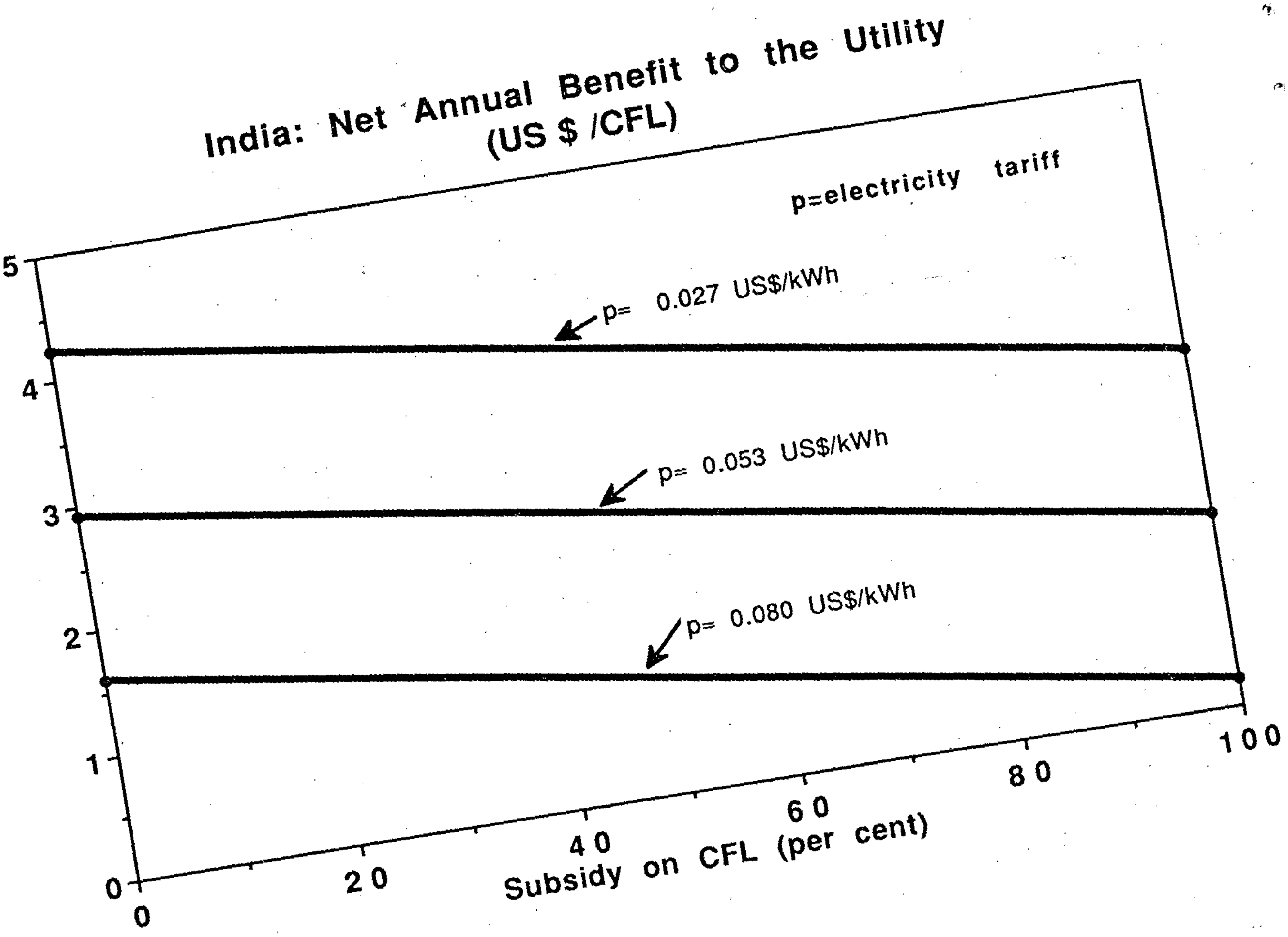

India: Net Annual Benefit to the Utility
(US $ /CFL)
p=electricity tariff
p= 0.027 US$/kWh
p= 0.053 US$/kWh
p= 0.080 US$/kWh
5
4
3
2
1
0
0
20
40
60
80
100
Subsidy on CFL (per cent)

FIGURE 12

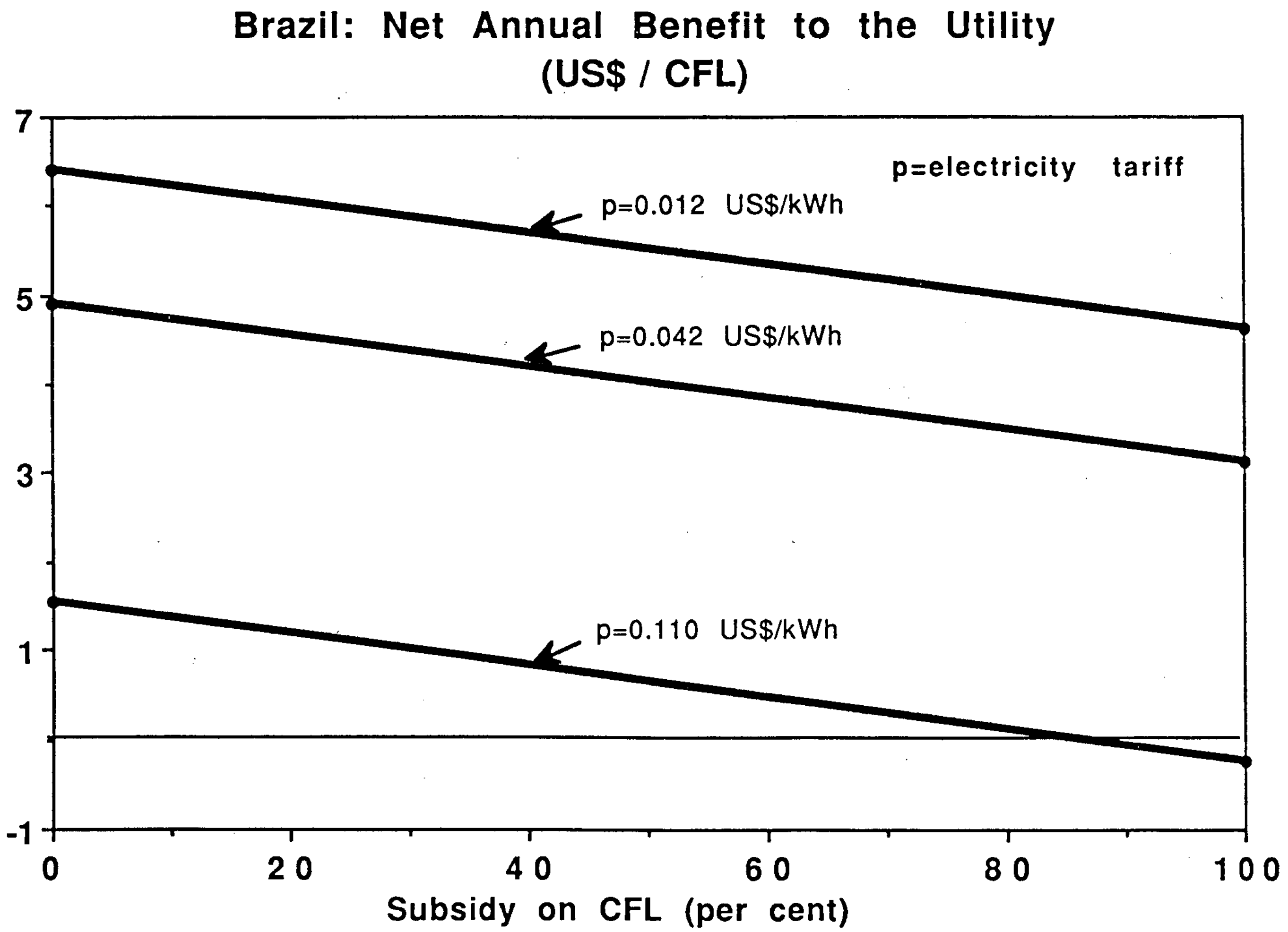

Brazil: Net Annual Benefit to the Utility
(US$ / CFL)
p=electricity tariff
p=0.012 US$/kWh
p=0.042 US$/kWh
p=0.110 US$/kWh
7
5
3
1
-1
0
20
40
60
80
100
Subsidy on CFL (per cent)

FIGURE 13

INDIA: Annual Savings to the Utilities

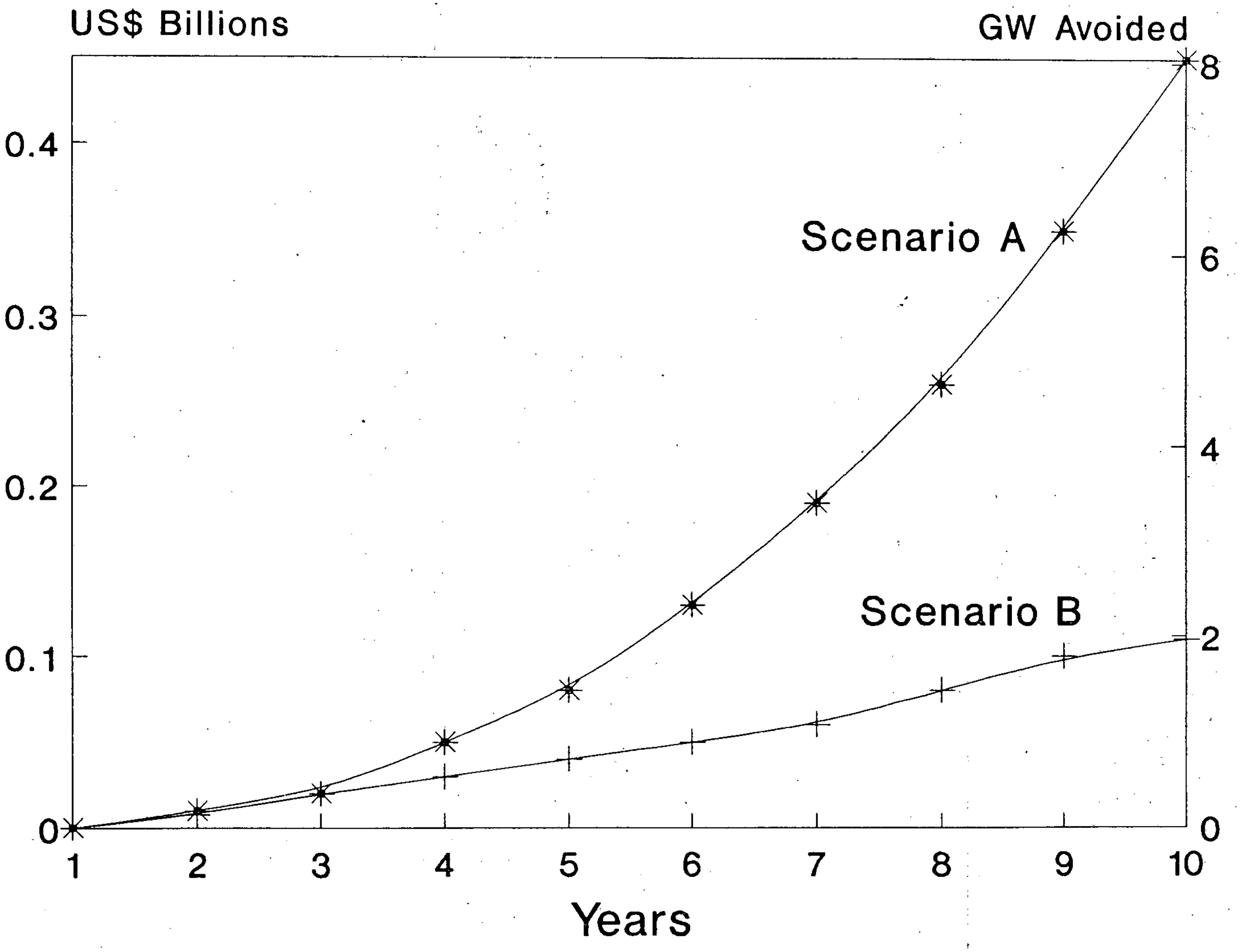


FIGURE 14A

BRAZIL: Annual Savings to the Utilities

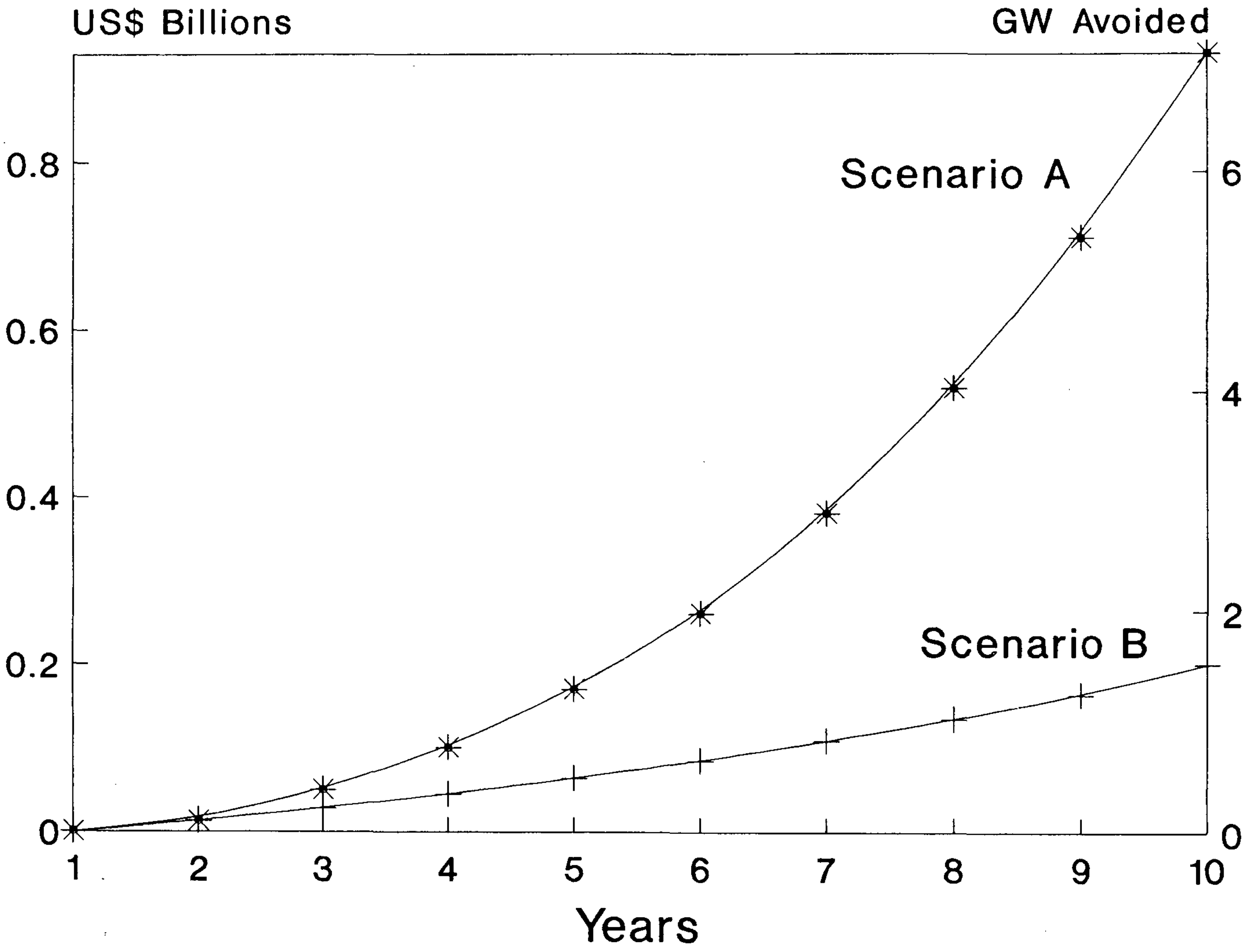


FIGURE 14B

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
INFORMATION RESOURCES DEPARTMENT
BERKELEY, CALIFORNIA 94720