ADB Economics
Working Paper Series

Economics of Energy Conservation: A Case Study

Herath Gunatilake and Dhammika Padmakanthi

No. 131 | October 2008

Asian Development Bank

ADB

ADB Economics Working Paper Series No. 131

Economics of Energy Conservation: A Case Study

Herath Gunatilake and Dhammika Padmakanthi

October 2008

Herath Gunatilake is Senior Economist in the Economic Analysis and Operations Support Division, Economics and Research Department, Asian Development Bank; Dhammika Padmakanthi is a Ph.D. student in the Faculty of Economics, Saga University, Japan. The authors acknowledge constructive comments received from Priyantha Wijayathunga of South Asia Department and Pradeep Perera of Southeast Asia Department, Asian Development Bank. They also acknowledge the valuable guidance received from Juzhong Zhuang of the Economics and Research Department in the completion of this paper.

Asian Development Bank

Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org/economics

October 2008
ISSN 1655-5252
Publication Stock No.: _______

The ADB Economics Working Paper Series is a forum for stimulating discussion and eliciting feedback on ongoing and recently completed research and policy studies undertaken by the Asian Development Bank (ADB) staff, consultants, or resource persons. The series deals with key economic and development problems, particularly those facing the Asia and Pacific region; as well as conceptual, analytical, or methodological issues relating to project/program economic analysis, and statistical data and measurement. The series aims to enhance the knowledge on Asia's development and policy challenges; strengthen analytical rigor and quality of ADB's country partnership strategies, and its subregional and country operations; and improve the quality and availability of statistical data and development indicators for monitoring development effectiveness.

The ADB Economics Working Paper Series is a quick-disseminating, informal publication whose titles could subsequently be revised for publication as articles in professional journals or chapters in books. The series is maintained by the Economics and Research Department.

Contents

Abstract

Global energy security relies heavily on exhaustible fossil fuels, whose use contributes significantly to global environmental problems. The recent unprecedented rise in oil prices and the threat of global warming highlight the urgent need for solutions to the energy and environment problem. Shifting to clean renewable energy sources—the long-term solution—has been slow despite efforts of the global community since the 1970s. Demand side management (DSM) is part of the solution to the energy crisis. Among DSM measures, energy conservation has greater potential in developing countries. This paper examines the financial and economic feasibility of adoption of an energy-conserving technology in the household sector in Sri Lanka. Results show that the adoption of this energy-conserving technology is financially profitable and economically viable. Systematic incorporation of environmental benefits further strengthens the case for energy conservation. The paper also discusses policy measures to solve low voluntary adoption, affordability issues, and information failures related to energy conservation.

I. Introduction

Energy security has been an important part of the global development agenda for more than four decades. Fueled by recent dramatic price hikes, the emerging energy crisis is reshaping the contemporary world. Global energy security relies heavily on fossil fuels—oil, natural gas, and coal—which comprise about 80% of global demand for primary energy (EIA 2007, IEA 2007). Being an exhaustible resource, fossil fuel prices are expected to increase eventually, as originally shown in the seminal article by Hotelling[1] (1931). After the oil price shocks of the 1970s (1973–1974 and 1978–1979) and a 6-year decline in the 1980s, oil prices continued to trend upward until the early 2000s. Oil price fluctuations in the 1980s were mainly attributed to the discovery of new sources and technological advances, which made some sources such as deep sea oil extraction economically feasible. Since 2006, oil prices have continued to trend upward and remained between US$60–100 per barrel, rising in the first half of 2008 to unprecedented levels.[2] Besides the pure stock effect, recent oil price hikes were driven in part by growing demands mainly from the developing economies. A weakening United States (US) dollar and a number of recent political economy factors[3] also contributed to the higher oil prices. While some of the short-term reasons behind the higher oil prices such as political tensions, speculation, and supply rigidities may disappear in the future, oil prices may continue to rise or at best would not fall below pre-2000 levels.

Extensive worldwide uses of fossil fuels—which are nonrenewable by nature—have not only threatened energy security, but also cause serious environmental concerns.[4] Climate change is foremost among the environmental concerns related to fossil fuel use. Cleaner renewable sources of energy are the ultimate solution to the emerging energy crisis. The

---

[1] Hotelling (1931) showed that the use cost or depletion premium, a part of the price of exhaustible resource, will increase at the rate of interest.

[2] At the time this paper was finalized, oil prices had hit a record high of US$146/barrel and then declined to about US$70/barrel. The most recent decline is attributed largely to the expected slowing down of the global economy due to financial market crises.

[3] These factors include fears over short supply; growing concerns over Iran's nuclear program; the likelihood of another war in the Middle East; supply disruptions in Iraq; hints of war on the border between Ecuador and Venezuela; and political tensions between Venezuela and multinational oil companies in the US.

[4] Burning fossil fuels produce around 21.3 billion tons of carbon dioxide (CO_2) per year, but it is estimated that natural processes can only absorb about half of that amount. CO_2 is one of the greenhouse gases that contribute to global warming, which climate scientists agree will cause major adverse effects such as reduced biodiversity and rising sea levels.

global community has been in continuous search since the 1970s for opportunities to shift to alternative renewable energy sources such as solar, wind, hydropower, biomass, and biofuel. Despite many desirable features, renewable sources of energy also have their own limitations. Pollution and other environmental problems associated with some sources, taking up large amounts of land (particularly biomass and biofuel), and inability to supply energy in large amounts due to unreliable input (e.g., solar and wind energy) are frequently quoted problems (de Vries et al. 2007, Green et al. 2007, Owen 2006). More recently, the large-scale production of biofuels (e.g., ethanol) has been blamed in part for the spike in the prices of food grains (ADB 2008). Some studies claim further that renewable energy sources cannot compete with fossil-based technologies due to a variety of reasons (Bye et al. 2008, Peters and Thielman 2008, de Vries 2007, Owen 2006). Given the slow shift away from fossil fuels, managing demand has become an important policy toward ensuring both energy security and environmental sustainability.

Energy demand could be managed by top-down and bottom-up approaches. Top-down approaches involve imposing energy taxes, charging higher energy prices, and imposing regulatory measures such as mandatory fuel efficiency standards (Berkhout et al. 2004). Bottom-up approaches represent energy conservation measures by end users (Wirl 2008). Demand side management (DSM) emerged in the US in response to the oil price shocks of the 1970s, whereby electric utilities implemented conservation and load management measures aimed at changing both the level and timing of electricity demand among customers. With the emergence of environmental consciousness, DSM experienced an impetus also as a tool in environmental policy in the 1990s (Masui et al. 2006, Feijoó et al. 2002). Since then, utility-sponsored DSM programs were broadened to include financial incentives such as low-interest loans, rebates, subsidies to adopt energy conserving technologies, and in some instances, free installation of energy-efficient technologies; performance contracting; direct load management; and real-time pricing (Loughran and Kulick 2004).

DSM measures are not without shortcomings. Potential negative impacts of DSM include reduced economic efficiency caused by taxes needed to finance conservation programs, and leakages such as free riding and conservation rebound effects[5] (Bränlund et al. 2007, Loughran and Kulick 2004, Sutherland 2000, Haugland 1996). Claims of profitability of DSM measures have also waned, to some extent, following the deregulation of electricity markets the world over (Wirl 2000). Besides cost, other factors that deter utilities from using energy-efficient technology include information and agency problems (Loughran and Kulick 2004). Despite these potential shortcomings, on balance, DSM has the potential to play an important role in facing the global energy and environmental crises.

---

[5] Conservation rebound effect refers to the induced consumption of energy due to lower prices or augmented incomes associated with energy conserving technologies.

Energy-conserving technologies, a subset of DSM measures, have been promoted as a win-win option based on engineering studies that showed energy consumption can be profitably reduced by 20% or more (Ficket, Gellings, and Lovins 1990).[6] The crux of the matter is that energy conservation technologies provide options to maintain social welfare with less energy and less environmental damages. Many studies support these claims, although with much lower estimates of energy savings than originally envisaged. UNESCAP (2008) has estimated the energy efficiency potential for selected countries and regions (Table 1). The table suggests that developing countries could make substantial energy savings, mostly from improvements in energy-intensive industries. Similar savings can also be realized in developed and developing economies in the household and commercial sectors, both in building design and in the use of electric lighting and appliances. The developing economies' transport sector shows the greatest potentials—especially in countries that use two- and three-wheelers, such as India, Indonesia, Philippines, Thailand, and Viet Nam.

Table 1: Energy Saving Potential in Selected Economies, 2010

	People's Republic of China[a]	Japan[b]	Russian Federation[c]	India[d]	Southeast Asia[e]
Industry	8–40%	2–18%	3,370–4,980 PJ[f]	8–40%	2,017 PJ
Household/Residential	10–40%	20–75%	1,905–2,198 PJ; 20–40%	10–70%	20–60%
Commercial and Public Sector		240–280 PJ			
Agriculture	10–50%		791–879 PJ		
Transportation	5–15%		967–1,172 PJ	5–25%	2,275 PJ

[a] Assumes 1995 as the base year.
[b] Assumes different prices for each sector, and 1990–1995 the base year for most sectors.
[c] Assumes 1990–1995 price levels of Western Europe and 1995–1997 as the base year.
[d] Assumes today's prices and 1992–1997 as the base year.
[e] Assumes 1998 prices and 1992–1998 as the base year.
[f] Petajoule (PJ) is a unit of power equal to 1015 joules, and corresponds to 31.6 million cubic square meters of natural gas, 23 million kilograms of oil, or 278 million kilowatt-hours of electricity.

Source: UNESCAP (2008).

From the same report (UNESCAP 2008), the International Energy Agency estimates that if countries focused on boosting energy efficiency, they would not only reduce global energy demand by 10% by 2030 but also could save US$560 billion between 2010 and 2030. There would also be lower investment requirements since every US$1 invested on demand-side management of electricity is estimated to save more than US$2 of investment in the power sector—or almost US$3 in developing countries where efficiency is currently much lower. However, country- and sector-specific studies on economics of energy conservation are required to formulate necessary policy responses for creating an enabling environment for energy conservation. This paper presents a convincing case for adopting energy-saving technology in the household sector in Sri Lanka.

---

[6] Lovins' famous and widely reproduced curve states that up to 70% can be saved with up to 3 cents cost increase per kWh (20% at "negative" costs or negawatts) (Wirl 2000).

II. Background: Energy Sector in Sri Lanka

Energy supply in Sri Lanka is mainly based on three primary sources, namely, hydroelectricity (12%), biomass (50%), and petroleum products (38%). Sri Lankan commercial energy consumption consists of oil (75%) and hydroelectricity (24%). In addition, Sri Lanka consumes large amounts of noncommercial fuel, specifically biomass, nearly all of which is wood. Domestic energy resources include biomass and hydropower, and the country has no known oil, gas, or coal resources.[7] The average expenditure on petroleum imports was about 9% of the total expenditure during the 1990s. This expenditure, on average, was about 11% of the export earnings during the same period. In 2002 the total expenditure on oil imports was 17% of export earnings, and went up to 31% in 2006. These figures show the degree of dependency of the Sri Lankan economy on external energy sources and vulnerability of the economy to energy price shocks. The recent increases in oil prices and continuous devaluation of the local currency have aggravated this situation further. This energy outlook clearly shows the desirability of using DSM measures in Sri Lanka.

This paper focuses on energy conservation in the electricity sector in Sri Lanka. The country's demand for electricity has been growing at an average rate of about 7% per annum over the past 20 years, and a 10% annual growth in demand is forecast for up to 2020 (Central Bank of Sri Lanka 2000). Meeting this growing demand requires substantial expansion of generation capacity. The potential for electricity generation through hydropower is limited as the natural potential for large and medium reservoirs is already tapped. Currently about 60% of electricity is generated using fossil fuel sources. Moreover, new power plants to be added to the system in the foreseeable future will be mostly thermal. Therefore, surging fossil fuel prices will make electricity expensive for consumers. On the other hand a substantial increase in gaseous emissions due to the use of fossil fuels in the power sector seems inevitable. There is already significant opposition to thermal power generation expansion by civil society. In fact, the construction of two coal power plants has been delayed due to opposition by environmental lobbyists. Given this gloomy economic and environmental scenario of expanded energy generation to meet growing demand, any effort to conserve energy at the outset is an attractive proposition.

Power consumption in Sri Lanka is characterized by relatively high demand in the domestic sector. The majority of Sri Lankans use electricity for domestic lighting purposes, which is estimated to be about 70% of the total household electricity demand. The use of less efficient lamps such as incandescent lamps is still prominent in Sri Lanka compared to industrialized countries. One of the energy-efficient lamps available in the market—compact fluorescent lamps (CFL)—consume one-fifth of the electricity that incandescent lamps use for the same lumen output. Early estimates showed that

---

[7] There are recent claims of availability of off-shore oil and gas resources. However, so far no conclusive evidence is available to support this claim.

of the total households in the country with access to electricity, only less than 20% of households use energy-efficient lamps (Jayalath et al. 1995). The World Bank provided assistance through its Energy Services Delivery Project to strengthen DSM during 1997–2002 in Sri Lanka. A DSM Unit was set up in the Ceylon Electricity Board (CEB) and a program of activities including load research and implementation of measures for energy efficiency in lighting was initiated.

These initiatives, along with the lessons learned in a previous pilot study (1994/1995) involving 600 households and a demonstration phase with 100,000 CFLs, resulted in the implementation of a countrywide program during 1998–1999 involving 500,000 CFLs. This scheme allowed domestic electricity consumers to purchase a maximum of four CFLs each, from a list of quality assured CFL brands, to replace their incandescent lamps. The cost of purchase could be repaid in 12 equal monthly installments without interest, along with their electricity bill. This program led to an estimated 34 megawatts (MW) reduction in the system peak and a saving of 37 gigawatt-hours (GWh) of electrical energy per year. After the implementation of the above scheme that lapsed in 2002, CFLs became widely available in the market, and most of the branded CFLs now carry a 2-year warranty. Despite the success of the pilot project of CFLs, recent estimates by CEB show that only about 32%[8] of households use CFLs. Therefore, there is significant potential to further conserve energy by using CFLs. This study examines the financial and economic feasibility of use of CFLs in the household sector.

III. Methods, Data, and Assumptions

This paper uses cost–benefit analysis (CBA) to examine the economic feasibility of replacing incandescent lamps with CFLs. The analysis is undertaken both from an individual's point of view (financial CBA) and society's point of view (economic CBA). The financial CBA was carried out at the household level to examine whether households have adequate financial incentives to voluntarily adopt energy-saving technology. Actual prices faced by households are used despite the fact that these prices may not necessarily reflect true marginal willingness-to-pay, or opportunity costs because of presence of distortions in the economy. Financial analysis does not account for environmental externalities as well. Therefore, financial analysis should be supplemented by an economic analysis to better understand the economic prospects of use of energy-saving technology. The economic CBA was carried out at the macro level, focusing on the costs and benefits of use of energy-saving technology from the society's point of view.

---

[8] Note that the number of households with access to electricity also increased substantially during the period 1995–2005.

The first step in the analysis is to conceptualize the benefits of energy savings from CFLs. It is reasonable to assume that energy conservation can avoid additional generation in an energy-deficient economy that faces growing demand. Avoided cost of generation is the main benefit of energy conservation. In addition, the avoided generation will also avoid release of additional pollutants to the atmosphere. Therefore avoided cost of pollution is the other benefit of energy conservation. However, to meaningfully use avoided costs as benefits, one needs to have a good understanding on what source of energy will be avoided, since avoided cost depends on the source of energy. If an economy does not face growing demand, resource cost savings of the most expensive current source of energy will constitute the benefits. However, this simplistic approach cannot be applied to Sri Lanka. In an expanding energy sector, avoided generation depends on avoided capacity additions. Therefore, some knowledge on the most likely energy expansion plan is critical to the accuracy of benefit estimation.

This section briefly describes the data and assumptions used in applying the above described conceptual framework to undertake CBA. To construct the scenario for replacing inefficient incandescent bulbs with CFLs, we consider the average number of bulbs used by a Sri Lankan household to be five bulbs. The usual life of a CFL is 10,000–15,000 hours[9] while that of an incandescent lamp is 1,000 hours (Lucas et al. 1995). We also assume that a 75 watt (W) incandescent lamp and a 15W CFL provide the same amount of lighting. Based on available information, the average lighting duration is 270 minutes (4 hours and 30 minutes) per day for an average household. Therefore a CFL would last about 7 years,[10] whereas an incandescent bulb with the same usage and 1,000 hours of life span would last only about 6 months. Therefore, a household that uses incandescent bulbs needs to replace the bulb every 6 months, while CFL users need to replace them only after 7 years. Thus, despite the higher initial costs, CFLs last longer.

Out of the total electricity consumption in the household sector, about 70% is used for lighting and the rest is shared by refrigerators, televisions, radios, fans, irons, water heaters, rice cookers, and other equipment. Electricity used for domestic lighting is 1442.28 GWh per year (CEB 2000). Monthly total electricity consumption of CFL users was estimated assuming CFL capacity of 15W, average lighting of 4.5 hours, and five bulbs per household. With these assumptions, the monthly electricity consumption was estimated to be 10.125 kilowatt-hours (kWh) per household. With 75W and similar assumptions, the incandescent bulbs consume 50.625 kWh of electricity per month. Total households that access electricity are estimated to be 2,521,077. If all households with access to electricity in the country use CFLs, the household sector can save 1846.8 GWh per year based on the above estimates.

The adoption of CFLs reduces the electricity bill by a considerable amount for a household. According to economic theory this would lead to an increase in household

---

[9] The analysis uses 12,500 hours as the life of a CFL.

[10] With 12,500 hours of life and current usage, a CFL can last about 7.6 years. To be conservative we used 7 years.

real income, even though their nominal income remains unchanged. An increase of real income has some effects on demand for electricity. Higher income may lead to increased electricity consumption; for example, the household may use fans for more hours. This study assumed away this conservation rebound effect on demand for electricity that arises with the use of energy-saving technology.

Tariff structure for electricity in year 2008 was used for all the calculations (see Appendix Table 1.1). In the case of electricity prices in Sri Lanka, CEB follows an increasing block rate system. In addition to electricity consumed units, each household has to pay a fixed charge, which also varies with the level of consumption. In this analysis, monthly electricity bill was calculated according to the existing increasing block rate system. Based on the above estimates of monthly electricity consumption and increasing block rate system, average monthly electricity bill for a household, which uses incandescent bulbs, is US$2.43 based on the tariff structure in 2008 (at the exchange rate of US$1 = Rs. 108). Average monthly electricity bill for a household, which uses CFLs, is US$0.84 based on the tariff structure in 2008. Based on market information, the analysis used the price of CFL and incandescent lamp to be US$3.70 and US$0.31, respectively.

IV. Results

This section first presents the results of the financial analysis. Results of the conventional CBA and the extended CBA follow. Except for the abovementioned general assumptions, the analyses were based on certain other specific assumptions, which are mentioned under each analysis.

A. Financial Analysis

The financial CBA was carried out to determine whether the project (replacing five incandescent bulbs with CFLs) is profitable to the household that had invested money to purchase CFLs. A 7-year cash flow was constructed for the analysis. It was assumed that the household replaces the five incandescent bulbs with CFLs at the beginning of the 7-year period. The benefits were of two types: cost saving in electricity (the difference in the electricity bill between incandescent bulbs and CFLs) and avoided costs of replacing the incandescent bulbs every 6 months. In this analysis the financial discount rate of 12.5% was used as the base case scenario. Sensitivity analysis was done using different discount rates (10%, 15%, 20%); increasing costs (by 5%, 10%); as well as decreasing benefit (by 5% and 10%). Monthly cash flow was computed over a 7-year period and discounting was performed using a monthly discount rate.[11] Results are presented in

---

[11] A simple approach was used to undertake discounting on a monthly basis. For example, if a cost or benefit occurs in the first month, and the discount rate is 12%, discounting was done at 1%. The costs and benefits that occur in the 12th month were discounted at 12%.

Table 2. The positive net present values (NPVs) and cost–benefit ratio greater than 1 show that adoption of the energy-saving technology is profitable to the households. The results show that there are adequate financial incentives for the households to adopt the energy-conserving technology. The results however raise the question as to why the adoption of energy conservation technology is low in Sri Lanka.

Table 2: Results of the Financial Analysis—Household Level

Case	NPV (US$)	Benefit–Cost Ratio
Base Case	***89.10***	***20.78***
10% Discount Rate	96.08	27.16
15% Discount Rate	82.89	16.81
20% Discount Rate	72.34	12.14
5% Cost Increase	88.88	19.79
10% Cost Increase	88.65	18.89
5% Benefit Decrease	84.42	19.73
10% Benefit Decrease	81.25	18.70

NPV = net present value.

B. Economic Analysis

The economic CBA was carried out for a 49-year period using the recommended social discount rate (6%) for Sri Lanka. It was assumed that households will replace CFLs with a new set of CFLs every 7th year. Sensitivity analysis was carried out using 7%, 9%, 12% discount rates. Further, it was assumed that project cost was increasing by 5% and 10%, and project benefit was decreasing by 5% and 10%. The market price of electricity was converted to its economic price using a conversion factor for electricity of 1.572[12] (Curry and Lucking 1992). Using an average conversion factor of 0.785 (Curry and Lucking 1992) the market prices of CFLs and incandescent bulbs were converted to their economic values. In a conventional CBA, benefits are of two types: resource cost savings due to avoided generation, and household savings due to lower electricity bills. The net benefits were calculated as follows:

net benefits = avoided generation costs + savings in electricity bill
– incremental CFL cost

As mentioned earlier, the avoided costs of generation depends on the source of energy. In Sri Lanka, despite the availability of least-cost expansion plans, its implementation has been irregular. Due to various political reasons and pressures from environmental lobbies, the low-cost energy options were either not implemented or delayed. This practice does not allow estimation of future avoided generation costs with reasonable certainty. Therefore different options for energy generation were incorporated in the sensitivity

---

[12] This conversion factor was calculated by taking into account the true opportunity cost of electricity generation in Sri Lanka. It clearly shows the prevalence of subsidies in the sector. Recent tariff increases on one hand reduce the economic price. On the other hand, the recent cost escalation of fossil fuels increases the economic price. In the absence of more recent information we use the available conversion factor for this analysis.

analysis.[13] The economic CBA was carried out for electricity generation under four expansion scenarios (i.e., hydropower, coal, diesel, and gas). Table 3 shows the details of the power project in the least-cost expansion plan. Note that the specific generation costs of coal, diesel, and gas plants were calculated assuming base load operation and assuming that all energy can be dispatched. To calculate the average generation cost, specific cost and electricity production by different power plants were considered. Table 3 indicates capacity and energy produced by different power plants.

Table 3: Estimated Cost of Electricity Generation in Candidate Plants

Project /Plant	Capacity (MW)	Cost (US cents/kWh)	Production (GWh/Year)
Hydro			
Ginganga	49	6.86	209
Broadlands	40	9.05	145
Uma oya	150	10.04	456
Moragolla	27	10.27	145
Thermal			
Coal – Trincomale (80% PF)	300	3.99	2276
Coal – West coast (80% PF)	300	4.13	2276
Combined cycle (60% PF)	300	5.70	-
Diesel – fuel oil (80% PF)	10	6.35	68
Diesel – residual oil (80 PF)	10	5.82	68
Steam – fuel oil (80% PF)	150	6.19	1138
Steam – fuel oil (80% PF)	300	5.45	2346
Gas turbine (30% PF)	35	9.91	259
Gas turbine (30% PF)	105	8.47	777

PF = annual plant factor, MW = megawatt, GWh = gigawatt-hour, kWh = kilowatt-hour.
Source: CEB (2001).

For each option, cost of generation was estimated as a weighted average of the costs of different plants. Forecast annual production of different plants was used as weights in this estimation. (See Appendix 2 for the sample calculation on the average cost in the hydropower sector.) In this analysis it was assumed that these specific costs are constant over the planning period. Table 4 shows the average cost of generation of electricity with the four sources considered in the CBA.

Table 4: Average Generation Cost
(US$/kilowatt-hour)

Source	Cost
Hydropower	0.076
Diesel	0.05
Gas	0.073
Coal	0.016

Table 5 shows the results of CBA under different scenarios of future avoided electricity generation. Note that avoided generation in reality would be a combination of the different sources. Given the uncertainties involved we did not try to use the most potential

---

[13] Had there been some certainty about the time-bound implementation of a definite least-cost energy expansion plan, the analysis could have been done with a higher level of precision and sophistication.

combination. Rather we used all possible scenarios to understand the economics of adoption of the energy-conserving technology. Results in Table 5 clearly show that under all possible scenarios of future electricity generation expansion, the use of energy-conserving bulbs improves social welfare significantly. Note that the analysis was carried out using a social discount rate of 6% as the base case scenario. In the sensitivity analysis, different discount rates were used. The results show that the potential net benefits of adoption of energy-conserving technology are robust against the discount rate changes.

Table 5: Results of the Economic Analysis: Avoided Cost of Generation Using Alternative Sources of Energy (US$ million)

Case	Hydro NPV	Coal NPV	Gas NPV	Diesel NPV
Base Case	4004.77	2203.81	3673.72	3083.47
7% Discount Rate	3506.58	1928.14	3216.43	2699.11
9% Discount Rate	2783.21	1527.94	2552.47	2141.06
12% Discount Rate	2104.01	1152.25	1929.06	1617.13
5% Cost Increase	4003.99	2203.03	3672.95	3082.69
10% Cost Increase	4003.21	2202.26	3672.16	3081.92
5% Benefit Decrease	3803.75	1992.31	3489.25	2928.54
10% Benefit Decrease	3602.74	1981.88	3304.79	2773.57

NPV = net present value.

The results clearly show that the economic benefits of the project significantly exceed the opportunity costs. The NPVs are substantially high: US$4004.77 million, US$2203.81 million, US$3673.72 million, and US$3083.47 million for electricity generation using hydro, coal, gas, and diesel, respectively. These NPVs for a small economy with only about 80% of the households having access to electricity clearly show that energy conservation is highly beneficial. Sensitivity analyses clearly indicate that this benefit is robust against changes in costs and benefits. Even if benefits decrease by 10% and costs increase by 10% together with a higher social discount rate of 12%, the net economic benefit is positive and significant for all the four scenarios of electricity generation. Thus the results unequivocally show that the adoption of energy-conserving technology is economically feasible and the potential contribution of energy conservation to social welfare improvement is substantial.

C. Extended Cost–Benefit Analysis

The above analysis considered only the conventional avoided costs of electricity generation such as capital costs, fuel costs, operation and maintenance, etc. In addition to these avoided costs, energy conservation also avoids environmental damages. This section presents the results of an extended CBA in which the environmental costs of additional generation are incorporated. The equation below explains how the net benefits were estimated.

net benefits = avoided generation costs + savings in electricity bill
+ avoided environmental damage cost – incremental CFL cost

In this section we incorporate the avoided environmental damage costs to the CBA using secondary data. The type of environmental damages varies with the source of energy. For example, the main environmental damages of hydropower arise from inundation of the land, including biodiversity loss, opportunity cost of lost production, and resettlement costs. The major hydropower potential in Sri Lanka is already exploited and future expansion depends on the generation of thermal power. Together with this shift, the major environmental issues will also shift toward those associated with thermal plants, which will be of quite a different nature. Thus, the environmental impacts of electricity generation in the future are linked to particulate matter emissions; gaseous emissions—carbon dioxide, sulphur dioxide, nitrous oxides, etc.—and warm water discharges into water bodies.

We use Ranasinghe's (1994) estimates of environmental damage costs in this study. As there are no known studies that estimate damage costs related to pollution associated with thermal power generation in Sri Lanka, Ranasinghe used studies done elsewhere. Based on guidelines developed by Meier and Munasinghe (1994),[14] Ranasinghe calculated environmental damage costs with reference to a case study of Kukule Ganga hydropower project located in the central region of Sri Lanka. The first step in approximating the environmental cost of air pollution is to define appropriate emission coefficients for the main thermal power pollutants of carbon dioxide, sulphur dioxide, nitrous oxides, and particulate matters. After an extensive review of the literature, Meier and Munasinghe suggested emission coefficients applicable to the main air pollutants in Sri Lanka. These emission coefficients are given in Appendix 1 (Appendix Table 1.3).

Most of the damage cost estimates in Meier and Munasinghe are attributable to mortality and morbidity effects and the degradation of visibility. Therefore, the loss of earnings (human capital) approach can be adopted to quantify the possible future health impacts of pollutants such as sulphur dioxide, nitrous oxides, and particulates in Sri Lanka. Respiratory diseases, such as bronchitis, are a significant health issue in Sri Lanka, as they account for 8% of hospital deaths and 9% of all hospitalization cases (Ranasinghe 1994). The link between the cause and effect is generally given by the dose response

---

[14] The Pace University study by Ottinger et al. (1990) was used as a guide to Meier and Munasinghe's (1994) study.

function, which is interpreted as the probability that an individual will contract bronchitis in any one year if exposed to a unit per volume of particulates for the entire year (Meier and Munasighe 1994).

Meier and Munasighe performed a reverse calculation to find out what would be the cost of illness per case, to overcome the lack of epidemiological data to develop a dose response function. There is considerable debate regarding the appropriateness of valuing human life.[15] The damage costs of the original study are based on a valuation of US$4 million per death and US$400,000 per nonfatal but disabling illness. Meier and Munasinghe valued nonfatal but disabling illness of a Sri Lankan at US$50,000 using the findings of a survey and considering the ratio of US per capita gross national product to that of Sri Lanka. They recommended 10% of the original damage costs for pollutants such as sulphur dioxide, nitrous oxides, and particulates for Sri Lanka (see Appendix Table 1.3).

Ranasinghe (1994) calculated environmental damage costs by using a more realistic estimate of the value of a nonfatal but disabling illness of a Sir Lankan by considering the average salary of a Sri Lankan. He asserts that the use of 5% of the original damage cost estimates for pollutants such as sulphur dioxide, nitrous oxides, and particulates is more reasonable for Sri Lanka. Based on this, the value of a nonfatal but disabling illness of a Sri Lankan is approximately valued at US$20,000. However this is still a lower bound of the damage costs, because Ranasinghe (1994) considered morbidity effects only. Incorporation of mortality effects will increase damage costs.

The “shadow project approach” was used for the valuation of the damage cost of carbon dioxide pollution. The original estimate of US$15/ton of carbon dioxide is based on the cost of reforestation of an area with the equivalent sequestration of carbon dioxide. The same value is suggested by Meier and Munasinghe for Sri Lanka. Ranasinghe (1994) suggests that a lower value of US$10/ton of carbon dioxide is more applicable, in line with the suggested carbon sequestration rate of 1.81–2.26 tons/acre/year by US-EPA (1992). This value is still likely to be conservative for two reasons: the cost of forestry programs in Sri Lanka is likely to be lower and the growth rates in the tropical forests are likely to be faster than in the temperate forests of the US. With these assumptions Ranasinghe estimated the environmental cost of air pollution caused by thermal plants in Sri Lanka, as shown in Table 6. This study used these estimates to undertake an extended CBA.

---

[15] See Gunatilake 2003 for a succinct discussion on issues related to human capital approach.

Table 6: Damage Cost of Air Pollution due to Thermal Power Generation (US$/kilowatt-hour)

Source	Environmental Damage Cost				
	Sulfur Dioxide	Nitrous Oxides	Particulate	Carbon Dioxide	Total
Diesel	0.333	0.060	0.001	0.640	1.035
Diesel + Nitrous Oxides	0.333	0.006	0.001	0.640	0.980
Coal (Mawella)	0.152	0.037	0.054	0.853	1.096
Coal + FGD (Mawella)	0.032	0.039	0.056	0.896	1.023
Coal (Trincomalee)	0.150	0.036	0.053	0.839	1.078
Coal + FGD (Trincomalee)	0.032	0.038	0.055	0.881	1.007
Gas Turbine	0.065	0.024	0.002	0.843	0.934

FGD = flue gas desulphurisation.
Source: Ranasinghe (1993).

Similar to the previous CBA, this extended analysis was carried out for a 49-year period using a 6% social discount rate for the base case. Sensitivity analysis was also carried out by using different discount rates and changing benefits and costs of the project. Avoided generation costs were considered for different sources of electricity generation as in the previous section. Table 7 presents the results of the extended CBA.

Table 7: Results of the Extended CBA—Electricity Generation Using Alternative Sources of Energy (US$ million)

Case	Coal NPV	Gas NPV	Diesel NPV
Base Case	2388.60	3945.81	3214.89
7% Discount Rate	2090.88	3454.90	2815.37
9% Discount Rate	1658.62	2742.12	2235.27
12% Discount Rate	1252.77	2072.85	1690.53
5% Cost Increase	2387.76	3945.04	3214.05
10% Cost Increase	2386.91	3944.26	3213.29
5% Benefit Decrease	2268.32	3747.75	3053.30
10% Benefit Decrease	2148.05	3549.68	2891.71

NPV = net present value.

The results of the extended CBA reaffirm the previous findings that adoption of energy-conserving technology improves social welfare significantly. The results are robust against changes in the discount rate and costs and benefits. Table 8 shows the difference in NPV between conventional CBA and extended CBA. Generally the NPV is higher in the case of extended CBA of energy conservation projects. In the case of coal power generation this difference is the highest. Naturally, the source that is dirtiest in energy generation should provide highest net benefits when avoided. Usually, incorporation of environmental benefits provides opportunities for more informed decision making. When conventional benefits are not adequate to outweigh the costs, environmental benefits play an important role. In this case, conventional benefits are adequate to justify energy conservation.

Nevertheless, incorporation of environmental benefits provides a stronger case for energy conservation. Note that we were unable to include hydropower generation in the extended CBA. However, hydropower generation is not free of environmental damages as mentioned earlier. We also did not incorporate the environmental damage cost due to release of warm water into streams. Had all these environmental benefits been incorporated into the analyses, benefits of energy conservation would increase further.

Table 8: Comparisons of Conventional and Extended Cost–Benefit Analysis Results

Source	NPV (US$ million)		Difference
	Conventional CBA	Extended CBA	
Coal	2203.81	2388.60	8.38
Gas	3673.72	3945.81	7.40
Diesel	3083.47	3214.89	4.26

CBA = cost–benefit analysis, NPV = net present value.

As discussed earlier, despite strong financial and economic incentives, voluntary adoption of CFLs is not high in Sri Lanka. Adoption of the new technology is higher among urban households compared to that of rural households. One may wonder why only about 32% of households have adopted this energy-saving technology, despite being profitable and economically viable. While financial profitability is one of the most influential factors that determine the adoption of an energy-conserving technology, there are various other factors that affect adoption decisions. These factors include misplaced incentives, lack of initial capital to purchase CFLs, flaws in market structure, distortions created by regulatory measures, lack of information or misinformation, limited availability of energy-efficient products, and manufacturing competition.

Misplaced incentives are transactions or exchanges where the economic benefits of energy conservation do not accrue to the person who is trying to conserve. The term has been used to describe the relationship between landlords and tenants with respect to acquisition of energy-efficient equipment for rental property. When the tenant is responsible for the energy/utility bills, it is in the landlord's interest to provide least-first-cost equipment rather than more efficient equipment for a given level of desired service. There is little or no incentive for the landlord to increase his or her own expense to acquire energy-efficient products or equipment under this circumstance. On the other hand, tenants who have a low planning horizon in terms of occupying a house may not have incentives to invest in energy-conserving technologies, especially when the returns are accruing over a long period of time. In Sri Lanka only a small proportion of households rent houses, therefore, the misplaced incentives is not a serious problem.

The financing barrier, sometimes called the liquidity constraint, refers to significant restrictions on capital availability for potential borrowers. Economic theory tells us that for a risk-adjusted price, the market should provide capital for all investment needs. In practice, it can be observed that some potential borrowers, for example, low-income individuals and small business owners, are frequently unable to borrow at any price as a result of their economic status or “credit worthiness”. This lack of access to capital inhibits investments in energy efficiency by these classes of consumers. Given that the adoption of CFLs is higher among urban high-income households (Padmakanthi 2003) higher initial capital is an important problem in adopting energy-conserving technology.

The market structure barrier refers to product supply decisions made by equipment manufacturers. This barrier suggests that certain powerful firms may be able to inhibit the introduction by competitors of energy-efficient, cost-effective products.

The regulation barrier refers to mispricing energy by regulatory bodies. Historically the price of electricity as set by regulators was frequently below the marginal cost to produce the electricity. Lower prices reduce the incentives to invest in energy conservation as such prices effectively reduce the benefits of energy conservation. Sri Lanka has been a good example for subsidized electricity up until recent times. Even today the lowest blocks in the pricing system of electricity are heavily subsidized, comprising disincentives to the adoption of energy-conserving technology.

Information problems constitute an important barrier to energy conservation. Energy planners are often unaware of the large potential for energy saving in developing countries. Referring to the relatively low level of commercial energy use in many developing countries, analysts believe that the only possibility for development lies in the direction of energy supply expansion. For instance, Munasinghe and Schramm (1983) noted that the increases in initial investment are traded off against future savings. Energy-efficient lighting is a new concept to low-income households. Generally households understand the term to mean “turning lights off more often” or using lower wattage. These information barriers seem to play a role in the low use of energy-efficient lamps in Sri Lanka.

V. Conclusion and Policy Implications

This study assesses the financial and economic feasibility of adoption of energy-conserving technology in the household sector. The financial CBA shows that the replacement of inefficient bulbs is financially profitable and that households have the financial incentive to adopt energy-conserving technology. Economic analysis revealed that this replacement is economically feasible under the four plausible scenarios of electricity generation. Sensitivity analysis clearly shows that the benefits are stable against different sources of energy generation in the future. The extended CBA indicates that the replacement of inefficient lighting technologies is environment-friendly and welfare-improving. Welfare gains from use of energy-saving lights are significantly high under all four scenarios of energy generation.

Despite the strong financial and economic incentives and the success of the pilot projects, the use of energy-saving bulbs is limited in Sri Lanka. Of the set of barriers to adopting this technology, two play a prominent role. The first is the high initial cost of CFLs; the second is poor awareness on the profitability of energy-saving technology. The previous program on easy payment system was successful but had limited coverage. In order to ameliorate information failures, a public awareness program can be initiated. Public expenditure on building awareness on energy-conserving technology can be easily justified based on the net benefits shown in this study. Given very attractive net benefits, even a subsidy program to provide the initial set of bulbs could be justified. However, subsidies should not be encouraged because they may have other negative impacts. Rather, more innovative public–private partnerships can be initiated to provide the initial set of bulbs at subsidized rates. The private sector, while providing the bulbs at subsidized rates, may be able to recover the cost of subsidies through clean development mechanism benefits.

In a recent development, on the advice of the Sustainable Energy Authority of Sri Lanka, the government has already banned importation and local manufacture of incandescent lamps over 75W effective July 2008. It intends to impose a total ban on incandescent lamps of all capacities from 2010. Given the limited success of voluntary adoption, proven energy savings, and significant economic gains from replacing inefficient bulbs, this ban is a justifiable policy option. However, an easy payment mechanism as well as a reinvigorated awareness building program should accompany this ban. Otherwise public support for this measure may not be forthcoming, especially during this high inflationary period in Sri Lanka.

Appendix 1: Tariff Structure and Environmental Damage Costs

Appendix Table 1.1: Tariff Structure: Domestic Consumers

Number of Units per Month	Unit Charge (Rs/kWh)	Fixed Charge (Rs/month)
<30	3.00	60
>30–60	4.00	90
>60–90	5.50	90
>90–120	10.00	90
>120–180	11.00	90
>180–240	15.00	90
>240–360	18.00	90
>360–600	21.00	90
>600	25.00	3,000

Source: Ceylon Electricity Board website (available: ceb.lk/).

Appendix Table 1.2: Emission Coefficients

Resource	Heat Rate (kcal/kWh)	Sulfur Dioxide (g/kWh)	Nitrous Oxides (g/kWh)	Particulates (g/kcal)	CO_2 (g/kWh)
Diesel	2134	0.0149	3.141	0.042	300
Diesel+ Nitrous Oxides	2134	0.0149	0.314	0.042	300
Coal (Mawella)	2269	0.0068	1.802	1.802	376
Coal +FGD (Mawella)	2382	0.0014	1.802	1.802	376
Coal (Trincomalee)	2232	0.0067	1.802	1.802	376
Coal + FGD (Trincomalee)	2344	0.0014	1.802	1.802	376
Gas Turbine	2908	0.0029	0.897	0.065	290

FGD = flue gas desulphurisation, kcal = kilocalorie, kWh = kilowatt-hour, g = grams.
Source: Meier and Munasinghe (1994).

Appendix Table 1.3: Damage Cost of Pollution due to Thermal Power Generation (US$/kilowatt-hour)

Resource	Sulfur Dioxide	Nitrous Oxides	Particulate	Carbon Dioxide	Total
Diesel	0.666	0.121	0.002	0.960	1.750
Diesel + Nitrous Oxides	0.666	0.012	0.002	0.960	1.641
Coal (Mawella)	0.304	0.074	0.107	1.280	1.765
Coal + FGD (Mawella)	0.064	0.077	0.112	1.343	1.597
Coal (Trincomalee)	0.299	0.073	0.105	1.259	1.736
Coal + FGD (Trincomalee)	0.063	0.076	0.111	1.322	1.572
Gas Turbine	0.130	0.047	0.005	1.265	1.447

FGD = flue gas desulphurisation.
Source: Meier and Munasinghe (1994).

Appendix 2: Sample Calculation of Average Generation Cost of Hydropower

$$Average\ generation\ \cos t = \frac{\sum\left[Energy\left(GWh\right)*Specific\ \cos ts\right]}{\sum\left[Energy\left(GWh\right)per-year\right]}$$

$$Average\ generation\ \cos t\ of\ hydropower = \frac{\left(\begin{array}{l}\left[Gingaga\begin{pmatrix}209\\GWh\end{pmatrix}*\begin{pmatrix}USCts\,6.86\\perkWh\end{pmatrix}\right]+\\\left[Broadlands\begin{pmatrix}145\\GWh\end{pmatrix}*\begin{pmatrix}USCts\,9.05\\perkWh\end{pmatrix}\right]+\\\left[Umaoya\begin{pmatrix}456\\GWh\end{pmatrix}*\begin{pmatrix}USCts\,10.04\\perkWh\end{pmatrix}\right]+\\\left[Moragolla\begin{pmatrix}145\\GWh\end{pmatrix}*\begin{pmatrix}USCts\,10.27\\perkWh\end{pmatrix}\right]\end{array}\right)}{\begin{array}{l}(209GWh)+(145GWh)+(456GWh)+\\(145GWh)\end{array}}$$

$$= 0.076\ US\$.kWh$$

References

ADB. 2008. Special Report: Food Prices and Inflation in Developing Asia: Is Poverty Reduction Coming to an End? Economics and Research Department, Asian Development Bank, Manila. Available: adb.org/Documents/reports/food-prices-inflation/food-prices-inflation.pdf

Berkhout, P. H. G., A. Ferrer-i-Carbonell, and J. C. Muskens. 2004. “The Ex-post Impact of an Energy Tax on Household Energy Demand.” *Energy Economics* 26(3):297–317.

Bränlund, R., T. Ghalwash, and J. Nordström. 2007. “Increased Energy Efficiency and the Rebound Effect: Effects on Consumption and Emissions.” *Energy Economics* 29:1–17.

Bye, T., A. Bruvoll, and F. R. Aune. 2008. “Inflow Shortages in Deregulated Power Markets—Reasons for Concern?” *Energy Economics* 30(4):1693–711.

Central Bank of Sri Lanka. 2000. *Annual Report: Central Bank of Sri Lanka*. Colombo.

CEB. 2000. *Sales and Generation Data Book*. Ceylon Electricity Board, Colombo.

———. 2001. *Report on Long Term Generation Expansion Plan 2002–2016*. Generation Planning Branch, Ceylon Electricity Board, Colombo.

Curry, S., and R. Lucking. 1992. *Shadow Price for Sri Lanka*. National Planning Department, Colombo.

de Vries, B. J. M., D. P. Van Vuuren, and M. M. Hoogwijk. 2007. “Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach.” *Energy Policy* 35:2590–610.

EIA. 2007. *International Energy Outlook* 2007. Energy Information Administration, Office of Integrated Analysis and Forecasting, United States Department of Energy, Washington, DC.

Feijoó, M. L., J. F. Franco, and J. M. Hernandez. 2002. “Global Warming and the Energy Efficiency of Spanish Industry.” *Energy Economics* 24:405–23.

Ficket, A. P., C. W. Gellings, and A. B. Lovins. 1990. “Efficient Use of Electricity.” *Scientific American* September 1990:65–74.

Green, C., S. Baksi, and M. Dilmaghani. 2007. “Challenges to a Climate Stabilizing Energy Future.” *Energy Policy* 35:616–26.

Gunatilake, H. 2003. *Environmental Valuation: Theory and Application*. Postgraduate Institute of Agriculture, University of Peradineya, Peradineya, Sri Lanka.

Haugland, T. 1996. “Social Benefits of Financial Investment Support in Energy Conservation Policy.” *The Energy Journal* 17(2):79–102.

Hotelling, H. 1931. “The Economics of Exhaustible Resources.” *The Journal of Political Economy* 39(2):137–75.

IEA. 2007. *World Energy Outlook 2007: China and India Insights*. International Energy Agency, Organisation for Economic Co-operation and Development, Paris.

Jayalath, M. S., M. N. S. Perera, and H. R. P. Wanniarachchi. 1995. *Demand–Side Management in Integrated Resource Planning of the Sri Lanka Power Sector*. United Nations Development Programme/Economic and Social Commission for Asia and the Pacific/Programme for Asian Cooperation on Energy and the Environment, Bangkok.

Loughran, D., and J. Kulick. 2004. “Demand-Side Management and Energy Efficiency in the United States.” *The Energy Journal* 25(1):19–43.

Lucas, J. R., W. J. L. S. Fernando, and V. B. Wjekoon. 1995. “Cost Benefit Analysis for Introduction of Compact Fluorescent Lamps: A Case Study for Sri Lanka”. Paper submitted to the Ministry of Irrigation, Power and Energy, Colombo.

Masui, T., T. Hanaoka, S. Hikita, and M. Kainuma. 2006. “Assessment of CO_2 Reductions and Economic Impacts Considering Energy-Saving Investments. 2006.” *The Energy Journal Special Issue (Endogenous Technological Change and the Economics of Atmospheric Stabilization)*:175–90.

Meier, P., and M. Munasinghe. 1994. *Incorporating Environmental Concerns into Power Sector Decision making: A Case Study of Sri Lanka.* World Bank Environment Paper No. 6, Environmental Policy & Research Division, World Bank, Washington, DC.

Munasinghe, M., and G. Schramm. 1983. *Energy Economics, Demand Management and Conservation Policy.* Van Nostrand Reinhold Company Inc., New York.

Ottinger R. L., D. R Wooley, N.A Robinson, D. R. Hodas, and S. E. Babb. 1990. *Environmental Costs of Electricity.* Pace University Center for Environmental Legal Studies. New York: Oceana Publications Inc.

Owen, A. 2006. "Renewable Energy: Externality Costs as Market Barriers." *Energy Policy* 34:632–42.

Padmakanthi, D. 2003. *Economics of Energy Conservation: The Case of Adoption of Compact Fluorescent Lamps in Household Sector in Sri Lanka*. Unpublished M.Sc. Thesis, Postgraduate Institute of Agriculture, Sri Lanka.

Peters, J., and S. Thielmann. 2008. "Promoting Biofuels: Implications for Developing Countries." *Energy Policy* 4:1538–44.

Ranasinghe, M. 1994. "Kukule Ganga Hydropower Project: A Case Study." Paper presented at the First Workshop on Environmental Economics and Policy Analysis, Harvard Institute for International Development, Harvard University.

Sutherland, R. J. 2000. "No Cost Efforts to Reduce Carbon Emissions in the U.S.: An Economic Perspective." *The Energy Journal* 21(30):89–112.

UNESCAP. 2008. *Energy Security and Sustainable Development in Asia and the Pacific*. United Nations Economic and Social Commission for Asia and the Pacific, Bangkok.

Wirl, F. 2000. "Lessons from Utility Conservation Programs." *The Energy Journal* 21(1):87–107.

———. 2008. Energy Conservation, Expectations and Uncertainty." *Energy Economics* 30(4):1957–72.

About the Paper

Herath Gunatilake and Dhammika Padmakanthi write that demand-side management is part of the solution to unsustainable reliance on fossil fuel energy. Using cost–benefit analyis, this paper shows that the use of energy-saving lamps in Sri Lanka has a potential to improve social welfare significantly. Incorporation of environmental benefits in the cost–benefit analysis further strengthens the case for energy conservation.

About the Asian Development Bank

Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org/economics
ISSN: 1655-5252
Publication Stock No.:

Printed in the Philippines