

Assessment of Technology-Economic Potentials of Energy Efficient Options for Mitigating Green House Gases

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1.0 Introduction

Sri Lanka through an Island cannot be in isolation with regard to the emission of GHGs to the environment. We have been and will be dependent, very significantly, on imported fossil fuels in whatever form for the sustenance of the economy thus increasing the share of GHG emission in the foreseeable future. It is therefore imperative that Sri Lanka closely evaluate and monitor the constraints associated with the utilization of fossil fuels. Even if our contribution to the emission of effluents by burning fuels. Even if our contribution to the emission of effluents by burning fossil fuels is insignificant, we have to be mindful of immediate local impacts apart from the global impacts of fossil fuels usage. The harmful effects of burning fossil fuel should be mitigated by adapting technological interactions as far as economically possible along with the rapid economic growth with the envisaged.

The per capita energy consumption in Sri Lanka, inclusive of all forms of energy, currently stands at 0.36 TOE per annum (TOE= 41.84 GJ). This below the world standards but is comparable with any other developing countries in the region. The growth oriented development path, together with increasing population and living standards needs increasing inputs of energy. This can only be supported in a resources oriented country like ours if energy supply can be optimize as all respects and demands rationalized. As such the challenge today is in sustain economic growth, managing within limits the harnessing of natural resources, hopefully resulting in the prevention of natural environment which sustain the life on earth.

The environmental consequences of large dams and reservoirs constructed for our hydropower cannot also be disregarded. Furthermore these large reservoirs are also concentrated in the centrally hilly region and the effects on the surrounding areas is also of great concern. The inundation of large areas of productive and most fertile land for hydropower generation alone, can longer be pursued.

In the above context Sri Lanka is concerned about the reservation of the environment for the future generation, while the energy needs of the present population for its very sustenance cannot be denied. With this in view the energy development path in Sri Lanka peruses a policy of meeting the energy demand at least cost to be economy, while preserving the environment.

This paper attempts the Techno-Economic potentials of Energy Efficient options, for mitigating the GHGs. The GHG emissions arise from a variety of human activities,

such as agriculture, Industrial processes, energy supply technologies, transport etc. The scope of this paper is limited to the GHG emissions from the electricity supply sector. An attempt is made in this paper to identify the energy efficiency opportunities in several key demand sectors such as industry, residential and commercial. In Sri Lanka most of the agricultural activities are carried out in a traditional manner. The limited mechanization of agricultural activity does not use electricity at all, except in some agro industries which are treated under the industrial sector.

In a population of 17.8 million people a substantial percentage of 80 % people live in the rural areas. Even though there is urban migration, this percentage has remained more or less static over the last 20 years or so. Only 40 % of the population have access to electricity and there is a uniform tariff applicable through out the country even though it is very much costly to supply electricity to sparsely populated rural areas. There have been some limited surveys conducted from time to time to assess the consumption patterns of rural and urban communities. The study is based on data from such surveys in the household sector and with well-judged estimates in certain areas where such data is not available.

The economy has had a moderate growth in the past five years and is expected to grow on the average of about 7% in the next five years. The rapid industrialization envisaged is to be the leading factor in the economy. This is quite evident from Table 1.0.

This industry-led economy is expected to continue well into foreseeable future

It is therefore clearly seen that sustaining economic growth as seen above, in the short and medium term, the energy demand will undoubtedly increase. It has been established that electricity/GDP elasticity is of the order of 1.5 which indicate that to sustain an average 7% growth in the economy the electricity demand growth would be in the region of 9-10%. The GDP – electricity index, which has declined over the years, is shown in fig.1.0. This can be contributed to many reasons such as structural changes in the economy whereby more energy intensive industries have been way to less energy intensive industry, and even some energy efficiency improvements carried out due to high cost of electricity in the country. These trends even though are apparent no major policy initiatives are implemented to sustain such trends nor are there any clear indication that it would persist. Thus it is important to assess the techno economic potentials of measures that would clearly propel the industrial growth following a least energy intensive path.

Table 1.0 Growth rate of GDP by Major Sectors at Constant prices

| Year | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | Average |
|---|-------|-------|-------|-------|-------|-------|---------|
| 1. Plantation Agriculture | 1.8 | 2.3 | 2.2 | 2.3 | 2.3 | 2.3 | 2.3 |
| 2. Other Agriculture | 1.5 | 3.7 | 3.8 | 4.5 | 4.5 | 4.5 | 4.2 |
| 3. Mining, Manuf. & Constr | 6.6 | 8.4 | 9.7 | 10.2 | 10.6 | 11.1 | 10.0 |
| 4, Services | 5.5 | 6.2 | 6.4 | 6.8 | 7.5 | 7.5 | 6.9 |
| 5. GDP | 5.5 | 6.0 | 6.5 | 7.0 | 7.5 | 7.7 | 6.9 |
| 6, GDP of (1994) Constant Market prices Rs. Billion | 576.2 | 610.8 | 650.5 | 696.0 | 748.2 | 805.8 | - |
| 7, GDP Deflator | 10.0 | 8.0 | 7.0 | 6.0 | 5.0 | 5.0 | 6.0 |

Source: *Public Investment 1995 – 1996, Dept. Of National Planning, Sri Lanka*

With the available data from industrial energy audit it has been possible to broadly categorize the industrial electricity consumption into motive power and lighting requirements. Apart from these uses, other uses were found to be insignificant, such as electric heating, ventilation, air conditioning, refrigeration, etc.. There are very few electric arc furnaces with a total demand not exceeding 5 MVA.

The service sector of the economy where the commercial sector is expected to play a predominant role consumes a large quantity of electricity, and is becoming a major consumer. The share of electricity consumption in the commercial sector has increased from 16% in 1980 to 24% in 1991 and is expected to reach 26% in 1995. Thus it is seen that increasing dependence on electricity by the commercial sector is inevitable. In the commercial sector the electricity consumption is mainly in lighting, air-conditioning and ventilation and other building services. Data available in the commercial sector is derived from energy audits of commercial buildings.

2.0 ELECTRICITY CONSUMPTION BY SECTOR AND END USE

2.1 Trends in Electricity Consumption

Electricity consumption in the country has been growing at rates above 10 % per annum in the 1980's as a result of the rapid economic growth experienced in those years. Also, contribution of electricity in the total energy demands has increased from 5% in 1972 to 11% in 1990 whereas the percentage of households that have access to electricity has increased from 10 % in 1997 to 30 % in 1990. This has increased to 44.5 % in 1994 according to CEB sources. Table 2.1 shows the generation, peak demand and sectoral consumption of electricity over the past ten years.

2.2 Forecasted Sectoral Electricity Consumption

Until recently, CEB has not paid special attention to sector-wise electricity demand forecasts, other than for those done for short periods of three years (market forecasts). However, recent developments in electricity sector has rendered it necessary to look into finer details of the composition of the future electricity demand.

With that in view, preliminary forecasts are now been done for different sectors separately, so it has been recognized that putting them together no longer make any sense, due to drastic changes observed in the growth rates of consumer accounts and consumption patterns. Table 2.2 shows a recent sectoral demand forecast prepared in a study project (yet to be published)

In forecasting demand in different sectors it has been estimated that the growth in industrial and commercial sectors will be higher than household sector, which will become almost saturated towards 2020's. In the next 25 years, the demand in industrial sector has increased by about 8 times while that of household sector has increased only by 4 times.

2.3 End- Use Electricity Consumption in Base Year

Finding reliable data at the end-use level is a major problem faced by researchers analysing electricity demand. As in the case of many other countries in the region, at present Sri Lanka does not have officially published statistics on end use appliances in the electricity sector. The data presented in Table 2.3 is a result of a recent study on electricity demand. Though not all, the most commonly used appliances in Sri Lankan households are considered.

According to table 2.3 most of the electricity consumed in household sector goes to lighting purposes, which accounts for nearly 30 % of the total household demand. Electricity is very rarely used in cooking as evident from the very low figure of 2.18 GWh. With the introduction of daytime television broadcasts and private TV as well as Radio transmitting stations, the consumption by TV and Radio has increased significantly.

2.4 Project End-Use Patterns

With the basic assumption that the present trend will continue in future, an exponential growth is assumed in projecting the number of electrified household demand in the future. To make results more accurate the household sector is sub- divided in to rural and urban sectors before the projections are done. It is assumed that 100% of the urban households and 80 % percent of the rural households will be electrified in the year 2020. Table 2.4 shows the details of electrification ratios.

Tables 2.5 and 2.6 shows projected electricity consumption and appliance stock by different end-use categories in the household sector. The demand for air-conditioning is quite low, and the refrigeration demand is given. Heating refers to household water heating and electric motors refer to fans. Demand for cooking using electricity is assumed to be due to rice cookers.

From the above figures it is evident that the household demand is basically due to lighting demand. Hence the

greatest potential in reducing the demand in the household sector, for example by DSM options also lies in that.

Industrial and commercial sector data are not available in desegregated levels. However it can be generally assumed that 90 % of industrial lighting load is by fluorescent lamps and the rest is by incandescent lamps. In commercial sector the total demand can be equally deviled between lighting and motor demand.

Table 2.1 Sectoral Electricity Consumption Pattern, 1982-1991

| Year | Generation (GWh) | Peak Demand (MW) | Sectoral Demand (GWh) | | | Total Demand (GWh) | Growth Rate(%) |
|------|------------------|------------------|-----------------------|------------|------------|--------------------|----------------|
| | | | Household | Industrial | Commercial | | |
| 1982 | 2066 | 431 | 613 | 787 | 285 | 1685 | - |
| 1983 | 2114 | 437 | 644 | 752 | 393 | 1789 | 6.17 |
| 1984 | 2261 | 487 | 747 | 857 | 271 | 1875 | 4.81 |
| 1985 | 2465 | 515 | 803 | 871 | 386 | 2060 | 9.87 |
| 1986 | 2652 | 540 | 827 | 926 | 480 | 2233 | 8.40 |
| 1987 | 2707 | 570 | 885 | 867 | 516 | 2268 | 1.57 |
| 1988 | 2800 | 594 | 913 | 906 | 553 | 2372 | 4.59 |
| 1989 | 2858 | 618 | 949 | 921 | 570 | 2440 | 2.87 |
| 1990 | 3149 | 640 | 1000 | 989 | 612 | 2601 | 6.60 |
| 1991 | 3376 | 685 | 1012 | 1048 | 681 | 2741 | 5.38 |

Table 2.2 Sectoral Electricity Demand forecast –in GWh

| Year | Sector | | | Total |
|------|-------------|------------|------------|----------|
| | Residential | Industrial | Commercial | |
| 1995 | 1304.88 | 1562.88 | 983.46 | 3851.22 |
| 2000 | 1848.00 | 2517.17 | 1698.67 | 6063.84 |
| 2010 | 3224.38 | 6133.33 | 4347.79 | 13705.50 |
| 2020 | 4913.13 | 12420.54 | 10264.75 | 27598.42 |

Source: EASAS Report {7}

Table 2.3 Techno-Economic Characteristics of Typical Existing End-use appliances-1995

| | Appliance | Rated Wattage (Avg.) | Appliance Cost (US\$) | Total Stock ('000's) | Electricity Consumption per year (GWh) | Avg.annual Operation hrs. (million hrs) |
|---|--------------|----------------------|-----------------------|----------------------|--|---|
| 1 | Lamps | 60 | 0.50-0.54 | 4963.81 | 410.36 | 8504.0 |
| 2 | Refrigerator | 100 | 200-598 | 155.16 | 90.61 | 906.1 |
| 3 | Fan | 75 | 39-95 | 311.93 | 68.31 | 910.8 |
| 4 | Water Heater | 235 | 2-5 | 173.10 | 15.79 | 15.8 |
| 5 | Rice Cooker | 750 | 60 | 13.30 | 2.18 | 2.9 |
| 6 | Iron | 750 | 30--50 | 635.16 | 46.89 | 62.5 |
| 7 | TV and Radio | 60/10 | 120--540 | 1566.08 | 76.01 | 3201.8 |
| 8 | Others | - | - | - | 586.53 | - |

Source: Households Energy Survey in Sri Lanka, carried out by University of Moratuwa in 1992

Note : The rated voltage of all the above appliances is 230 V (rms.) Ac at 50 Hz and 1 US\$ = 50 SL Rs. (Approx.)

Table 2.4 Percentage Households Electrified – Rural and Urban (1995-2020)

| | 1995 | 2000 | 2010 | 2020 |
|-------------------------|-------|-------|-------|-------|
| No. Of Households (mil) | 3.662 | 3.930 | 4.504 | 5.000 |
| Rural (%) | 82.3 | 82.2 | 82.1 | 82 |
| Urban (%) | 17.7 | 17.8 | 17.9 | 18.0 |
| Electrified Rural (%) | 34.0 | 43.0 | 62.0 | 80.0 |
| Electrified Urban (%) | 60.0 | 70.0 | 90.0 | 100.0 |

Source: EASA's Report

Table 2.5 Projected Electricity Consumption by End-Use in GWh (1995-2020) Household Sector

| Year | Lighting | Cooking | Refrigeration | Heating (Water) | Electric Motors (Fans) | Other Appliances |
|------|----------|---------|---------------|-----------------|------------------------|------------------|
| 1995 | 410.36 | 2.18 | 90.61 | 15.79 | 68.31 | 709.43 |
| 2000 | 541.89 | 3.03 | 162.10 | 22.34 | 115.26 | 1003.38 |
| 2010 | 849.14 | 5.22 | 522.03 | 39.73 | 261.86 | 1546.40 |
| 2020 | 1139.24 | 7.39 | 1160.41 | 61.59 | 526.70 | 2017.80 |

Source: Households Energy Survey in Sri Lanka, Carried out by University of Moratuwa in 1992

Table 2.6 Projected Appliance Stock by End-Use in Thousands (1992-2015) Household Sector

| Year | Lighting | Cooking | Refrigeration | Heating (Water) | Electric Motors (Fans) |
|------|----------|---------|---------------|-----------------|------------------------|
| 1995 | 4963.81 | 13.30 | 155.16 | 173.10 | 311.93 |
| 2000 | 6615.68 | 18.45 | 277.57 | 244.84 | 526.31 |
| 2010 | 10505.85 | 31.80 | 893.88 | 435.36 | 1195.70 |
| 2020 | 14340.00 | 45.00 | 1987.00 | 675.00 | 2405.00 |

Table 2.7 Projected Electricity Consumption by End-Use in GWh (1995- 2020) Industrial and Commercial Sectors

| Year | Industrial | | Commercial |
|------|------------|-----------------|------------|
| | Lighting | Electric Motors | |
| 1995 | 234.70 | 1328.20 | 983.40 |
| 2000 | 378.04 | 2139.00 | 1698.66 |
| 2010 | 921.25 | 5212.08 | 4184.74 |
| 2020 | 1865.63 | 10554.95 | 10264.70 |

Table 2.8 Projected Appliance Stock by End-Use in Thousands (1995- 2015) Industrial and Commercial Sectors.

| Year | Industrial | | | Commercial | |
|------|-------------------|--------------------|--------------------------|-------------------|--------------------|
| | Fluorescent (40W) | Incandescent (60W) | Electric Motors (7.5 kW) | Fluorescent (40W) | Incandescent (60W) |
| 1995 | 1446.78 | 107.17 | 60.65 | 2694.247 | 673.56 |
| 2000 | 2330.38 | 172.62 | 97.67 | 4653.86 | 1163.41 |
| 2005 | 3637.87 | 269.47 | 152.36 | 7304.57 | 1826.14 |
| 2010 | 5678.94 | 420.66 | 237.99 | 11465.04 | 2866.26 |
| 2015 | 8081.49 | 598.63 | 338.50 | 17956.21 | 4489.05 |

3.0 GHG Mitigation Potential of Efficient Electricity Utilization Technology Options

This chapter covers the opportunities to improve the electrical end-use efficiency in the residential, commercial and industrial sector lighting. The appliance ownership of rural households were obtained from the socio-economic survey conducted by the Ceylon Electricity Board (CEB) in 1987 and extended to 1997 with reasonable assumptions. The appliance ownership of urban households were estimates based on the rural survey and the surveys carried out recently

(yet unpublished). Due to the nonavailability of complete data on the industrial and commercial sector energy equipment, the analysis is base on the information gathered from energy audits carried out by various institutions.

The total energy saving potential, installed capacity saving potential and associated GHG mitigation potential were calculated for replacement of incandescent lamps by CFL in residential, commercial and industrial sector and replacement of fluorescent lamps by slim fluorescent lamps in commercial and

industrial sectors and replacement of magnetic ballast by electronic ballast in industrial and commercial sectors. The analysis was carried out for planning period of 18 years from 1997 to 2014.

3.1 Industrial Sector

The electricity consumption in the industries is mainly for motive power from motors and lighting by fluorescent and incandescent lamps. Motors are estimated to consume over 70 % of the total electricity for purchased by industry. Other types of energy activities are very small compared to the above.

At present above 90 % of the lighting devices in the industrial sector is by standard 40 W fluorescent lamps {8}. Efficiency improvement of fluorescent lamps is considered by replacement of magnetic ballast by electronic ballast and fluorescent lamps by slim fluorescent lamps. The potential savings of energy and associated GHG mitigation by switching over from 60W incandescent lamps to compact fluorescent lamp (CFL) of 11W was considered in the analysis. Average lighting hours is assumed to 10hours/day with the peak coincidence factor of 5%. We consider that the imported price of CFL (11W), electronic ballast (4W),

and slim fluorescent lamps (60W), magnetic ballast (12W) and fluorescent lamps (40W) are US\$ 0.5, 2.1 and 3.1 respectively {Marker source}. Subsidy offered by utility for buying CFL is considered as US\$ 2.4.

In the analysis, the replacement of the incandescent lamp is done with the equivalent CFL and the lifetime of Incandescent lamp is taken as 1000 hrs. while the CFL is taken as 8000 hrs. Lifetime of normal fluorescent lamp, slim fluorescent lamp, electronic ballast and magnetic ballast is taken as 6000 hrs.

The analysis for the industrial motors was carried out by considering the 30 % higher prices of 3% higher efficient motors. Also it is considered 4000 hrs of operation per year. The average motor capacity is assumed 7.5 kW. Peak coincidence factor (PCF) is assumed as 5%.

Table 3.1 presents the potential energy and capacity savings and avoided CO₂ emissions. Table gives the economic analysis of those measures in the industrial sector

Table 3.1 Potential Energy Savings, Capacity Savings and GHG Mitigation in Industrial Sector

| Year | Avoided Installed Capacity (kW) | | | | Annual Energy Savings (GWh) | | | | Avoided CO ₂ Emission (MT) | | | |
|------|---------------------------------|---------------|--------|--------|-----------------------------|---------------|-------|--------|---------------------------------------|---------------|----------|----------|
| | Electronic Ballast | Slim FL Lamps | CFL | Motors | Electronic Ballast | Slim FL Lamps | CFL | Motors | Electronic Ballast | Slim FL Lamps | CFL | Motors |
| 1997 | 1014.1 | 507.1 | 460.1 | 1459.5 | 60.3 | 30.2 | 27.4 | 77.8 | 12927.8 | 6463.9 | 5865.4 | 16671.9 |
| 2000 | 1349.9 | 674.9 | 612.5 | 1751.8 | 80.3 | 40.1 | 36.4 | 103.7 | 27902.4 | 13801.2 | 12523.3 | 35656.9 |
| 2005 | 2107.3 | 1053.6 | 956.1 | 2908.0 | 125.3 | 62.7 | 56.9 | 161.8 | 84421.7 | 42210.9 | 38302.4 | 108976.6 |
| 2010 | 3289.6 | 1644.8 | 1492.5 | 3978.2 | 195.7 | 97.8 | 88.8 | 252.7 | 200469.1 | 100234.5 | 90953.5 | 258939.9 |
| 2014 | 4362.3 | 2181.2 | 1979.2 | 5139.5 | 259.5 | 129.7 | 117.7 | 335.0 | 326986.0 | 163493.0 | 148354.7 | 422182.3 |

The total technical potential of CO₂ due to replacement of magnetic ballast by 7 electronic ballast during the planning period is 2,191,733 MT. According to the results of the economic analysis the CAPIC to the national economy is higher than capital cost of capacity addition (1300 \$/kW) and also CCE is higher than LRMC (5.8 US\$Ct/kWh). Therefore this option is not attractive to the national economy. The negative values of NAB to the consumers and utility of replacing magnetic ballast by electronic ballast show the unattractiveness of this option to the consumers and the utility. Therefore the economic potential of CO₂ mitigation of electronic ballast is zero. The reason for this ineffectiveness in economic term of the option is due to high capital cost of electronic ballast compared to the magnetic ballast and low PCF (5%) give the higher CAPIC value.

The total technical potential of CO₂ mitigation by switching over from normal fluorescent lamps is 1,095,867 MT. As in the case of electronic ballast the electronic ballast the economic analysis shows that

even this option is not cost effective from the national economy perspective and the consumers perspective.

The total technical potential of CO₂ mitigation of CFLs is 994,397 MT. Even though the CAPIC to the national economy is higher than the capital cost of new capacity addition due low PCF, this option seems to be attractive as CCE is lower than LRMC and NAB to the consumers is positive. Therefore full technical potential of CO₂ mitigation is economical.

The total technical potential of CO₂ mitigation due to the replacement of standard motors by efficient motors during the planning period is 2,829,582 MT. According to the results of the economic analysis the CAPIC to the national economic is higher than capital cost of capacity addition (1300 \$/kW) and also CCE is higher than LRMC (5.8US\$Ct/kWh). Therefore this option is not attractive to the national economy. The negative values of NAB to the consumers and utility of replacing standard motors by efficient motors show the unattractiveness of this option to the consumers and the utility. Therefore the economic potential of CO₂ mitigation of efficient motors is zero. The reason for

this ineffectiveness in economic term of the option is also due to high capital cost of efficient motors and low PCF (5%) give the higher CAPIC value. The NAB to the utility is negative for all three options as industrial sector tariff gives high return to utility.

3.2 Commercial Sector

Commercial sector comprises of hotels, restaurant, shops, offices and eating-houses. The electrical energy demand is mainly for lighting and fans. A small percentage of electrical energy is consumed by the air-condition and refrigeration system.

The results of the energy audits carried out on the hotels and other commercial buildings show that on the average the electrical energy consumption share for lighting and motors are equal. From the energy consumed in lighting, the share of fluorescent and incandescent is 80 % and 20 % respectively. The average power of the fluorescent lamp and the incandescent is 40W each. As in Industrial sector only efficiency improvements in incandescent lamps were considered. Average lighting hours is assumed to 10 hrs/day with peak coincidence factor (PCF) of 3% of

fluorescent lamps and PCF of 80 % of incandescent lamps as most of the incandescent lamps in commercial sector are in hotels high.

Table 3.3 gives the potential energy savings, capacity savings and avoided CO₂ emission in commercial sector.

The total technical potential of CO₂ mitigation of electronic ballast, slim fluorescent lamps and CFL in commercial sector over the planning period are 4,530,022 MT and 4, 671,584 MT respectively. Table 3.4 gives the economic analysis of the measures discussed in the commercial sector. As in the industrial sector electronic ballasts and the slim fluorescent are not economically attractive. CAPIC from national economy's and utility's perspective is lower than capital cost of capacity addition as peak savings of CFL is high as with high PCF of incandescent lamps in commercial sector (80%) . In commercial sector too the full technical potential of CO₂ mitigation of CFL is economical.

Table 3.2 Results of Industrial sector Economic Analysis.

| | | Motors | Electronic ballast | Slim FL lamps | CFL |
|---------------------------------|-----------------|----------|--------------------|---------------|---------|
| Perspective of National economy | CAPIC (\$/kW) | 45294.92 | 253669.14 | 75630.98 | 6671.02 |
| | CCE (USCts/kWh) | 10.24 | 71.00 | 12.70 | 1.42 |
| Perspective of Consumer | NAB (\$) | -12.73 | -18.16 | -0.56 | 13.28 |
| Perspective of the Utility | CAPIC (\$/kW) | - | - | - | 1334.20 |
| | CCE (USCts/kWh) | - | - | - | 0.36 |
| | NAB (\$) | -27.36 | -0.89 | -0.44 | -6.07 |

Table 3.3 Potential Energy Savings, Capacity Savings and GHG Mitigation in Commercial Sector

| Year | Avoided Installed Capacity (kW) | | | Annual Energy Savings (GWh) | | | Avoided CO ₂ Emission (MT) | | |
|------|---------------------------------|---------------|----------|-----------------------------|---------------|-------|---------------------------------------|---------------|----------|
| | Electronic Ballast | Slim FL Lamps | CFL | Electronic Ballast | Slim FL Lamps | CFL | Electronic Ballast | Slim FL Lamps | CFL |
| 1997 | 1165.2 | 582.6 | 39189.8 | 115.5 | 57.8 | 119.1 | 24757.1 | 12378.6 | 25530.8 |
| 2000 | 1617.5 | 808.7 | 48969.2 | 160.4 | 80.2 | 165.4 | 55123.0 | 27561.5 | 56845.6 |
| 2005 | 2538.8 | 1269.4 | 81793.6 | 251.7 | 125.8 | 259.6 | 169512.5 | 84756.2 | 174809.7 |
| 2010 | 3984.7 | 1992.4 | 112434.0 | 395.0 | 197.5 | 407.4 | 404721.1 | 202360.6 | 417368.6 |
| 2014 | 5705.2 | 2852.6 | 156893.4 | 565.6 | 282.8 | 583.3 | 712737.4 | 356368.7 | 735010.3 |

Table 3.4 Results of Commercial Sector Economic Analysis

| | | Electronic ballast | Slim FL lamps | CFL |
|---------------------------------|-----------------|--------------------|---------------|--------|
| Perspective of National economy | CAPIC (\$/kW) | 42278.1 | 75630.98 | 619.08 |
| | CCE (USCts/kWh) | 71.02 | 12.70 | 2.10 |
| Perspective of Consumer | NAB (\$) | -17.32 | -0.15 | 11.51 |
| Perspective of the Utility | CAPIC (\$/kW) | - | - | 123.80 |
| | CCE (USCts/kWh) | - | - | 0.52 |
| | NAB (\$) | -1.00 | -0.86 | -7.69 |

3.3 Residential Sector

Residential sector is divided into two subsectors namely rural and urban. The electrical energy usage in the residential sector is mainly for lighting, cooking, water heating and other appliances. Lighting from 6 p.m. to 9 p.m. occurs during the peak time of the daily electricity demand and (The low system load factor of 0.55 is mainly due to this. The reason data on the percentage households electrified shows that about 34% and 60% of the rural and urban households are electrified.

At present the usage of CFL in the residential sector is small compared to incandescent lamps. The average power of the incandescent lamp is 40W and the average number of lamps per household is 4.5 with 4 hours of operation per day. PCF is assumed as 100%. Average operating duration is taken as 4 hours per day (at peak time).

In this analysis the potential saving by switching over incandescent to CFL lamps was studied. The table 3.5 shows the results of the analysis.

The total CO₂ mitigation potential of CFL in residential sector is 6, 521, 896 MT and which is higher than other two sectors as total incandescent stock in residential sector is higher than the other two sectors. Economic potential CO₂ mitigation is also 6, 521, 896 MT as, the replacement of incandescent by CFL is economically attractive from all three perspectives. As peak savings of CFL is very high the CAPIC is very low compared to the capital cost of new capacity addition.

Table 3.5 Potential Energy Savings, Capacity savings and GHG Mitigation in Residential Sector

| Year | Avoided Installed Capacity (kW) | Annual Energy Savings (GWh) | Avoided CO ₂ Emission (MT) |
|------|---------------------------------|-----------------------------|---------------------------------------|
| 1997 | 305.1 | 296.8 | 63604.3 |
| 2000 | 326.3 | 352.6 | 121213.0 |
| 2005 | 437.6 | 444.3 | 299271.3 |
| 2010 | 482.9 | 560.0 | 573675.9 |
| 2014 | 533.1 | 634.2 | 799128.0 |

Table 3.6 Results of Residential Sector Economic Analysis

| Plant | Fuel Type | Size (MW) | Heat rates (kcal/kWh) | | Carbon Content (%) | Capital Cost (\$/kW) |
|-----------------|-----------------|-----------|-----------------------|----------|--------------------|----------------------|
| | | | Min Load | Avg Incr | | |
| Diesel | Residual Oil | 10 | 1932 | 1932 | 92 | 1188.2 |
| Coal 1 (Site 1) | Bituminous Coal | 150 | 3386 | 2285 | 74 | 1070.1 |
| Coal 2 (Site 2) | Bituminous Coal | 300 | 3546 | 2232 | 74 | 916.3 |
| Coal 3 (Site 2) | Bituminous Coal | 300 | 3546 | 2232 | 74 | 916.3 |
| Gas Turbine | Heavy Diesel | 22 | 2908 | 2908 | 92 | 537.2 |
| Combined Cycle | Heavy Diesel | 68 | 2025 | 2025 | 92 | 820.5 |

Source: Long term Generation Expansion Planning Studies 1995-2009

Table 4.1 Characteristics of Planned Thermal Plants

| | | CFL |
|---------------------------------|-----------------|--------|
| Perspective of National economy | CAPIC (\$/kW) | 370.84 |
| | CCE (USCts/kWh) | 4.48 |
| Perspective of Consumer | NAB (\$) | 0.66 |
| Perspective of the Utility | CAPIC (\$/kW) | 74.17 |
| | CCE (USCts/kWh) | 0.52 |
| | NAB (\$) | 0.27 |

4. Techno-Economic Potentials of Efficient Electricity Generation Technologies

Since hydropower plants do not contribute directly to CO₂ emissions, the present study is focused only on the CO₂ emissions of planned thermal plants. The characteristics of the planned thermal plants are presented in Table 4.1.

As the data for efficient generation technology options are available only for coal fired plants. Cost and technical data of efficient coal plants used for the study is presented in Table 4.2. Replacement of Coal 1 plant of 150 MW by Pressurized Fluidized Bed Combustion (PFBC) Technology of similar capacity (165 MW). Replacement of Coal 2 and 3 of 300 MW each by Integrated Gassification Combined Cycle (IGCC) technology is

considered in the study with IGCC of 265 MW. Table 4.3 presents the yearly avoided CO₂ emissions from 1997-2014.

According to the results shown in table 4.3, Total technical potential of mitigating CO₂ during the planning period of 18 years from 1997 to 2014 due to replacement of Coal 1 by PFBC is 1359.2 thousand tons of carbon. But this option is not economically attractive as NAB is negative hence the economical potential is zero. The technical potential of mitigating CO₂ due to replacement of Coal 2 and Coal 3 by IGCC are 5508.2 and 9740.9 thousand tones of carbon respectively. As both these options give positive NAB, these two options therefore are economical. Therefore this full technical potentials of CO₂ mitigation due to replacement of Coal 2 and 3 by IGCC are economically favorable.

Table 4.2 Cost and Technical data of Efficient Coal Plants

| Plant | Capacity (MW) | Heat rates (kcal/kWh) | | Capital Cost (\$/kW) |
|-------|---------------|-----------------------|----------|----------------------|
| | | Min Load | Avg Incr | |
| PFBC | 165 | 2176 | 2176 | 1585 |
| IGCC | 265 | 1872 | 1498 | 1125 |

Table 4.3 Avoided CO₂ Emissions- in thousand tons of Carbon

| Year | Coal 1, By PFBC | Coal 2 by IGCC | Coal 3 by IGCC |
|--------------------------------|-----------------|----------------|----------------|
| 1997 | - | - | - |
| 2000 | - | - | - |
| 2005 | 105.8 | 513.2 | - |
| 2010 | 97.6 | 505.8 | 1027.2 |
| 2014 | 87.9 | 467.2 | 2301.9 |
| Total | 1359.2 | 5508.2 | 9740.9 |
| Net Annual Benefit (NAB) in \$ | -2825405.7 | 17856998.1 | 53083445.6 |

5 Conclusion

Sri Lanka will continue to grow at around 7% of economic growth per annum for the next five years. The predominant growth factor being the manufacturing and construction sector growing at around 10%. Closely followed by services sector at 7%. This growth will demand an electricity demand growth of the order of 9-10% per annum.

The supply of electricity will within the next few years shift from a major hydro system to a predominantly thermal based system. By the year 2015, the almost 100% hydro electric generation of today will drop to a mere 18%. All thermal additions will be fossil fuel fired, emanating large quantities of GHGs.

Keeping in view the relatively large share of GHG emission of power sector in future, improvements in energy efficiency in electricity production and use appear to be an important logical option to mitigate GHG emissions from the electricity sector.

The analysis shows that there is a large technical potential of mitigating CO₂ by end use efficiency improvements. The economic potential of CO₂ mitigation using efficient electricity utilization technology is very low in case of electronic ballast and slim fluorescent lamps. CFLs offer a cost-effective opportunity to conserve energy and mitigation of CO₂ emissions. The total techno-economic potential of CO₂ mitigation by switching over from incandescent to CFL

from 1997- 2014 in industrial, commercial and residential sector are 994,397 MT, 4,671,584 MT and 6,521,896 respectively.

In supply side there is a large techno economic potential to mitigate CO₂ emissions by switching over from conventional coal plants to IGCC. It should be noted that there are only a limited number of commercially operated IGCC plants in the world. Only a limited no of Supply and Demand-side energy improvements were considered in the study due to lack of data. These options show that there is a significant potential to reduce CO₂ emissions from the electricity sector in Sri Lanka by efficiency improvements. If a wider set of supply and demand side energy efficiency improvements were considered the CO₂ mitigation potential could be even higher.

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