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Greenhouse Gas Emission Mitigation: Sri Lanka Electricity Sector

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Abstract: The traditionally hydropower dominated electricity generation system in Sri Lanka has now turned into a thermal generation dominated system. As a result the expected fuel mix in the future large-scale thermal generation system would be dominated by petroleum products and coal. This will gradually increase greenhouse gas (GHG) and other environmental emissions in the power sector hence requiring special attention on possible mitigation measures.

This paper presents the results of an analysis of both supply-side and demand-side management (DSM) options available for mitigating emissions in the Sri Lanka electricity sector considering technical feasibility and their potential. The paper also examines the carbon abatement costs associated with such supply-side and DSM interventions using an Integrated Resource Planning (IRP) model developed by the Asian Institute of Technology. Further, it analyses a few case studies involving possible power generation projects under Clean Development Mechanism (CDM) where carbon abatement is financially rewarded. It has extended the analysis to investigate the impact of distributed power generation on emissions in the power sector.

It is concluded that while some DSM measures are economically attractive as mitigation measures, the supply-side options do not provide economically beneficial GHG mitigation possibilities in the Sri Lanka electricity generation sector. But the distributed power generation options such as mini-hydro, wind and dendro thermal systems are found to be providing attractive opportunities for carbon trading.

Key Words: Greenhouse gas emission, Clean Development Mechanism, Distributed Power Generation

1. Electricity Supply Industry

The Sri Lanka electricity supply industry has been dominated by hydropower generation for many years. By the year 2002 the total hydro capacity in the system amounted to 1172MW while the thermal generation capacity stood at 667MW excluding self generation. In addition there is a 3MW grid connected wind turbine plant installed in 1999. The hydro generation capacity includes not only the large hydropower plants but also the grid connected privately owned mini-hydro systems totalling to about 37MW of capacity [1].

The committed future generation capacity consists of 220MW of hydropower and 663MW of private sector owned thermal generation, which are all petroleum based [2].

Most of the generation capacity additions in the future will be oil fired and coal fired thermal generation in the form of steam turbine, gas turbine, combined cycle and diesel power plants. Though Sri Lanka is reported to have 2000MW of hydro potential most of the remaining large-hydro plants are economically too expensive to establish.

The latest drive towards introducing fuel-wood fired power plants (dendro) has led to starting construction of a few plants which will be ultimately connected to the national grid. While some of these plants will obtain their fuel-wood from dedicated energy plantations, others will depend on other forms of biomass such as coconut shells. Once more plants are added to the system they are likely to be in small capacities located all over the country reducing strain on the transmission system [3].

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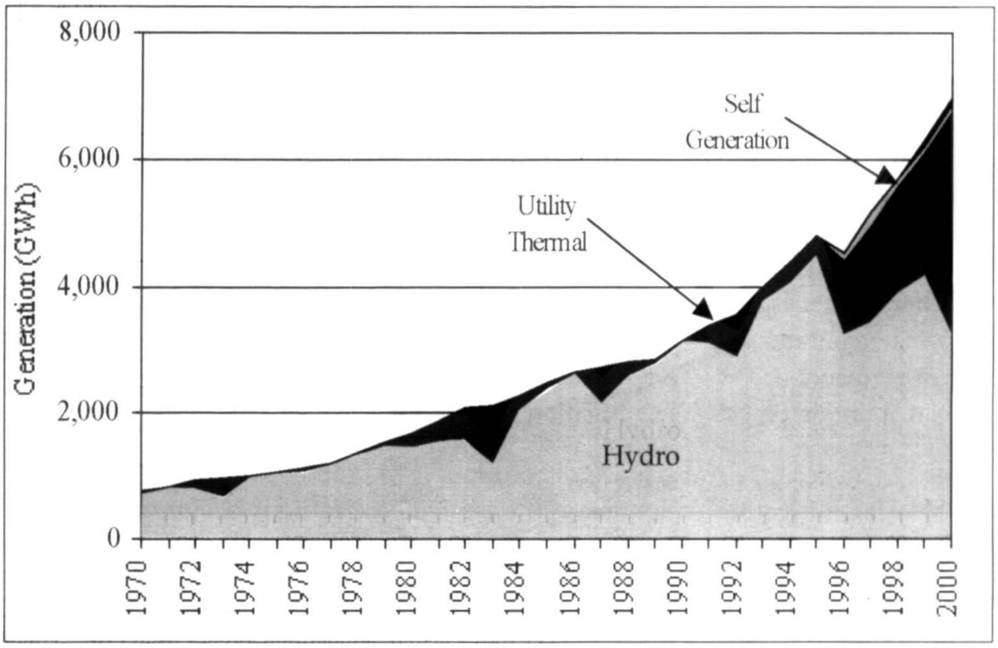

Source: Sri Lanka Energy Information System - 2002 [1]

Figure 1.1 - Historical Hydro and thermal Energy Share in Sri Lanka Power System

More wind turbine plants are also planned to be added to the Sri Lanka power system. A recent wind mapping exercise carried out with the support of USAID has suggested substantial wind power potential in the country and therefore increased contribution from wind power in the future is going to be a reality [5].

These small-scale generators based on renewable energy sources such as mini-hydro, wind and wood fired plants are connected or expected to be connected to the primary distribution system in various parts of the country and therefore can be considered as distributed power generation (DPG). These have the additional advantage of being closer to the loads thus avoiding transmission and part of the distribution losses.

2. Greenhouse Gas Emission Mitigation

Under the Kyoto Protocol of United Nations Framework Convention on Climate Change (UNFCCC) the developed countries (Annex 1 countries) are expected to reduce their greenhouse gas (GHG) emissions which are mainly CO2 emissions, to 5% below their 1990 emission levels by the year 2012. Though the Kyoto Protocol came into force in 2005 some Annex1 countries like the US and Australia have not ratified it. Therefore such countries are not bound by the protocol.

These emission reductions can be achieved in three different forms [4].

By reducing GHG emissions within their own territories through various programmes such as improved burning of fossil fuels, increased contribution from renewable energy at the expense of fossil fuels and improving other processes producing GHG emissions. These activities within their countries are sometimes too expensive to implement [4].

The second method of reducing GHG emissions in their national accounts is to buy those reductions from other countries in Annex 1 who may find it cheaper to reduce these emissions due to availability of cheaper technologies or other natural resources. This mechanism is termed as Joint Implementation, which is limited strictly between countries within Annex 1 [4].

These GHG emission reductions can also be achieved through activities implemented in countries that are not bound (non-annex countries) under the Kyoto Protocol to reduce their emissions. This group of non-annex countries mainly consists of developing countries where any emission reduction is likely to be relatively cheaper. What the Annex 1 countries are expected to do is to fund cleaner fuel sources and technologies in these non-annex countries and also pay them a mutually agreed price for carbon reductions as they are achieved. In return Annex 1 countries credit those carbon reductions (carbon credits) to their own national accounts. This arrangement of GHG emission reductions is called the Clean Development Mechanism (CDM) [4].

3. Objective and Limitations of the Study

The main objective of the study consists of three components:

- Examine the costs and benefits of supply-side and DSM options available for GHG emission mitigation
- Study possible projects under CDM available in the Sri Lanka power sector
- Investigate the impacts of distributed power generation on the overall GHG emissions

In order to address these three components both Traditional Resource Planning (TRP) and Integrated Resource Planning Techniques (IRP) are used [5].

The study only analyses cases that are applicable to the Sri Lanka electricity industry. Hence the technologies such as nuclear power as a GHG mitigation option are not considered. Further, the renewable energy based options are offered as candidate plants only in a realistically achievable time scale and are not offered as candidate plants in large blocks.

Similarly, only DSM measures which can be practically implemented and those that are presently being discussed at the local level are offered as options. Highly sophisticated end-use equipment such as infrared sensitive control devices and other technologies which may be commercially available but not appropriate in the local situation, are not considered.

Like in any other study of this nature, there is a degree of uncertainty in the input data. The supply side and demand side data are those used in the power industry and hence considered to be reasonably accurate. However, data at disaggregated level for demand categories and end-use devices are derived using best estimates based on surveys and studies conducted by various agencies.

4. Methodology

Integrated resource-planning (IRP) model and the related software developed by the Asian Institute of Technology (AIT), Bangkok for long-term electricity generation expansion planning is used in this study. This model determines the optimum generation expansion plan for a given planning period considering not only the different generation technologies but also the DSM options available for implementation in a given system [5].

During the study discussed in the paper, all technically feasible generation options for Sri Lanka are included in the objective function along with a list of selected DSM options. The optimisation is carried out to determine the generation expansion plan and its costs under different scenarios. These scenarios are then analysed to determine the impacts on the costs and all types of emissions including GHGs. It is important to note that this study was conducted during the period 2000-2003 based on the data available at that time.

5. Input Data

5.1 Electricity Demand

All data used in this study are based on actual 1998 data and others are derived or forecasted using nationally published data sources such as the Department of National Planning and Department of Census and Statistics. In order to analyse the effects of any variation in the demand forecast at least two additional demand forecasts are considered with a lower growth rate and higher growth rate compared to the base case [2].

Total or gross system losses calculated based on gross generation and 'as billed' sales figures, have, on average, increased by about 2-3% but remained within 15-19% in the past few years. However, Transmission Planning and Distribution Planning divisions of the CEB anticipate reductions in system losses due to planned improvements in the system. These anticipated loss reduction schemes are given in reference [2]. The study uses the modified demand forecast including these loss reduction targets and other interventions already planned, a scenario which is considered to be the business as usual case (BAU).

5.2 Existing and Committed Electricity Generation

The data on the fuel types used and their costs, data on existing and committed plants and data on existing and committed thermal plants are given in reference [2]. The energy output quantities of all hydro plants have been separated into season 1, "wet season" and season 2, "dry season". "Wet season" represents 3 months of the year when the hydro-reservoirs have a heavy inflow of water due to monsoon rains while the "dry season" consists of the remaining 9 months. Being a country in the tropical region, the Sri Lanka hydropower system is subject only to these two seasonal variations.

The emission factors associated with different gases for each type of thermal plant given in Table 5.5 are based on the guidelines of Intergovernmental Panel on Climate Change (IPCC) [6, 7].

5.3 Supply Side Options for Mitigation of GHG Emissions

Supply-side options considered are mainly categorised into three groups. They are the advanced cleaner technologies available on conventional fossil fuel systems, renewable energy based plants and efficiency improvement on existing generating plants.

Clean Coal Technologies

In this study Integrated Gasified Combined Cycle (IGCC) and Pressurised Fluidised Bed Combustion (PFBC) technologies associated with coal power plants are considered as candidates in which GHG emission mitigation can be achieved through efficient fuel burning processes. Since Sri Lanka is planning to add coal fired plants in the future these technologies provide an opportunity for GHG mitigation. The main characteristics of these clean coal technologies, which are used in the study, are given in Table 5.1 [10].

Renewable Energy Technologies

Hydropower

Sri Lanka still has a total of about 800 MW of additional hydropower potential, which can be developed in the future. Of this potential the candidate plants given in Table 5.2 [2] are considered to be the next most viable plants which cannot be justified at present solely on economic grounds. But when GHG emission mitigation is required under certain scenarios these plants may replace fossil fuel plants at a cost.

Table 5.1: Data on Candidate Clean Coal Plants

Plant Name Fuel Type	IGCC Coal	PFBC Coal
fuel consumption (kg/MWh)	0.32166	0.34091
calorific value (MJ/kg)	26.38	26.38
CO2 emission Factor (kg/MWh)	746.13	790.79
SO2 emission Factor (kg/MWh)	0.094	0.308
NOX emission Factor (kg/MWh)	0.308	0.431
capacity (MW)	300	300
min. operating Level (MW)	0	0
available year	3	3
Availability	0.9	0.9
capital cost '000 (US$)	396000	396000
non-depreciable capital '000 (US$)	0	0
heat rate (MJ/MWh)	8483	8994
operating cost '000 (US$/MWh)	0.002	0.002
annual maintenance (hours)	960	960
life time (years)	30	30
Fixed O&M '000 ($/MW per month)	1.667	1.667

Source: Final Report, Asian Regional Research Project on Energy Environment and Climate Change -Phase III [5]

Wind Power

Some studies have been undertaken on the assessment of wind energy potential in the country by the CEB. Data on the southeastern part of the country has been already collected and currently data collection in the northwestern part of the country is in progress. Also, there appears to be a considerable wind power potential in the central mountain region. The northern and northeastern regions too are expected to have a good wind regime though not quantified to date. Further, a study undertaken by the National Renewable Energy Laboratories (NREL) under the USAID SARI/ Energy programme has revealed that the total technical potential of wind power in the country at sites with excellent wind regimes can be as high as 24000MW [9].

Based on these already available data reasonable estimates have been made on the total wind power potential in the country. This is estimated to be around 1800 MW and its development is assumed to be in the form given in Table 5.3 [8].

Dendro Thermal

The other renewable option considered in the study is fuelwood fired power plants called dendro thermal power.

A total of 1700 MW of dendro thermal plants, which is expected to be developed in 10 MW units due to present technical constraints, is considered in the study. The cost and other characteristics are given Table 5.4 [3].

When certain study scenarios require GHG emission mitigation, dendro power plants can replace fossil fuel based systems even though they are expensive to establish and operate since the net lifecycle CO_2 emissions in dendro power is considered to be zero when the plants are fuelled with dedicated energy plantations.

Table 5.2: Data on Candidate Hydro Plants

Project Name	Ginganga	Broadlands	Uma Oya	Moragolla
Unit capacity (MW)	49	40	150	27
Available year	2	2	3	2
Maximum number of units	1	1	1	1
Availability	0.98	0.98	0.98	0.98
Capital cost '000 (US$)	139703.9	134112	431475	108491.4
Operating cost '000 (US$/MWh)	0	0	0	0
Life time	50	50	50	50
Fixed O&M '000 (US$/MW per month)	0.3286	0.3286	0.3286	0.3286
Available energy in season 1 (MWh)	68020	41370	185360	26500
Available energy in season 2 (MWh)	144050	103850	261340	84150

Source: Long Term Generation Expansion Plan [2]

Table 5.3: Data on Candidate Wind Plants

	Wind-30	Wind-3	Wind-60	Wind-75	Wind-150
Unit capacity (MW)	30	3	60	75	150
Available year	2	2	2	2	2
Maximum number of units	5	1	3	3	3
Availability	0.2	0.2	0.2	0.2	0.2
Capital cost '000 (US$)	33000	3300	66000	82500	165000
Operating cost '000 (US$/MWh)	0	0	0	0	0
Life time	30	30	30	30	30
Fixed O&M '000 ($/MW per month)	0.75	0.75	0.75	0.75	0.75
Available energy in season 1 (MWh)	18568	1857	37130	46426	92640
Available energy in season 2 (MWh)	36250	3626	72500	70618	181260

Source: Final Report, Asian Regional Research Project on Energy Environment and Climate Change -Phase III [5]

5.4 Demand Side Options

There are a large number of DSM measures which can be adopted in a given power system but what can be finally implemented depends heavily on the economics, awareness and acceptability of those measures by the consumers. There have been a few successful programmes involving popularisation of the use of compact fluorescent lamps (CFL) to replace incandescent lamps in the Sri Lanka domestic sector. Therefore there is a very good potential of using CFLs as a DSM measure. Though there have been no attempts in the past, the use of efficient refrigerators and air-conditioners in commercial and industrial installations seems to be the next DSM measure which is likely to be acceptable, if it is financially attractive to the consumers. Considering these the DSM options given in Table 5.5 are used in the study.

Table 5.4: Data on Candidate Dendro Thermal Plants

Fuel consumption '000 (kg/MWh)	1.2
Calorific value (MJ/kg)	15.91
CO_2 emission Factor (kg/MWh)	0
SO_2 emission Factor (kg/MWh)	0
NOX emission Factor (kg/MWh)	0
Capacity (MW)	10
Min. operating level (MW)	0
Available year	2
Availability	0.86
Capital cost '000 (US$)	12000
Non-depreciable capital '000 (US$)	0
Heat rate (MJ/MWh)	19093
Operating cost '000 (US$/MWh)	0.0025
Annual maintenance (hrs)	960
Life time (yrs)	25
Fixed O&M '000 (US$/MW per month)	1.8

Source: Feasibility of Dendro Power Based Electricity Generation in Sri Lanka [3]

Table 5.5: Data on Demand Side Management Options Considered

DSM option	DSM1	DSM2	DSM3	DSM4	DSM5
Cost per 1000 units (US$ '000)	4.32	4.81	5.91	244.58	1596.03
Available year	1	1	1	1	1
Life time (yrs)	7	7	7	10	10

DSM1 - Domestic 40 W Incandescent Bulbs are replaced by 11W CFL
DSM2 - Domestic 60/75 W Incandescent Bulbs are replaced by 15W CFL
DSM3 - 60-100 W Incandescent Bulbs in industrial and commercial institutions are replaced by 20W CFL
DSM4 - Commercial Refrigerators are replaced by Efficient Refrigerators
DSM5 - Air-Conditioners in industrial and commercial institutions are replaced by Efficient Air-Conditioners

Table 6.1a: Generation costs and emissions associated with different scenarios in sensitivity analysis

Case Study - Sensitivities ($ billion)	Generation Cost		CO_2(Gg '000)		SO_2(Gg)		NO_x(Gg)		LRAC (USCt/kW_h)	
	TRP	IRP	TRP	IRP	TRP	IRP	TRP	IRP	TRP	IRP
Base Case	1.57	1.25	102.64	80.32	327.63	279.74	189.05	157.4	2.47	. 2.23
10% CO2 Emission Reduction	1.63	1.32	90.23	69.35	317.86	261.03	180.42	145	2.53	2.34
20% CO2 Emission Reduction	1.71	1.39	80.63	60.63	298.2	215.66	167.88	121.33	2.66	2.48
30% CO2 Emission Reduction	1.80	1.47	71.57	55.7	278.27	229.95	155.32	125.72	2.82	2.61

Table 6.1b: Percentage change in costs and emissions under CO_2 emission mitigation scenarios

% Change against TRP Base Case	% Increase in Genera--tion Cost US$ Billion		% Reduction in Emissions						% Increase in LRAC (USCts/kWh)	
			CO_2(Gg '000)		SO_2(Gg)		NOX(Gg)			
	TRP	IRP	TRP	IRP	TRP	IRP	TRP	IRP	TRP	IRP
Base Case	0.00%	-20.38%	0.00%	21.75%	0.00%	14.62%	0.00%	16.74%	0.00%	-9.72%
10% CO_2 Emission Reduction	3.82%	-15.92%	12.09%	32.43%	2.98%	20.33%	4.56%	23.30%	2.43%	-5.26%
20% CO_2 Emission Reduction	8.92%	-11.46%	21.44%	40.93%	8.98%	34.18%	11.20%	35.82%	7.69%	0.40%
30% CO_2 Emission Reduction	14.65%	-6.37%	30.27%	45.73%	15.07%	29.81%	17.84%	33.50%	14.17%	5.67%

Table 6.2a: Performance of individual projects in terms of emission reductions

		Cost (US$ '000)	Increase in Cost (US$ '000)	CO_2 (Gg)	Reduction in CO_2 (Gg)	SO_2 (Mg)	Reduction in SO_2 (Mg)	NOx (Mg)	Reduction in Nox (Mg)	LRAC (USCts/k Wh)	Increase in LRAC (US Cts/k Wh)	AIC (US Cts/kWh)	Increase in AIC (US Cts/kWh)	AIC Without DSM Cost (USCts/k Wh)	Increase in AIC (US Cts/kWh)
Base Case	TRP	1573000	0	102640.3	0	327626.7	0	189052.9	0	2.47	0	3.85	0	3.85	0
	IRP	1252000	0	80321.8	0	279741.4	0	157401.2	0	2.23	0	3.74	0	3.59	0
Project 1	TRP	1636025	63025.1	100641.1	1999.2	278947.7	48679	164158.9	24894	2.56	0.09	4.17	0.32	4.17	0.32
	IRP	1294085	42084.5	78003.9	2317.9	241292.1	38449.3	137450	19951.2	2.31	0.08	3.99	0.25	3.84	0.25
Project 2	TRP	1612887	39887	101863.8	776.5	284806.6	42820.1	167526.4	21526.5	2.53	0.06	4.05	0.2	4.05	0.2
	IRP	1278501	26501.1	78944.4	1377.4	245798.9	33942.5	140040.3	17360.9	2.28	0.05	3.9	0.16	3.75	0.16
Project 3	TRP	1722559	149558.5	87292	15348.3	259222.5	68404.2	145009.8	44043.1	2.7	0.23	4.6	0.75	4.6	0.75
	IRP	1377986	125985.5	65141.9	15179.9	215850.5	63890.9	115782.3	41618.9	2.46	0.23	4.47	0.73	4.32	0.73
Project 4	TRP	1651838	78838.2	96712.9	5927.4	315590.5	12036.2	180897.1	8155.8	2.59	0.12	4.25	0.4	4.25	0.4
	IRP	1332541	80541.4	74689	5632.8	265690.5	14050.9	148540.2	8861	2.38	0.15	4.21	0.47	4.06	0.47
Project 5	TRP	1661494	88493.6	96405	6235.3	315766.8	11859.9	181069.8	7983.1	2.6	0.13	4.3	0.45	4.3	0.45
	IRP	1331947	79946.8	71097.6	9224.2	262598.7	17142.7	145438.4	11962.8	2.38	0.15	4.2	0.46	4.06	0.47

Table 6.2b: Marginal Abatement Cost in different CDM projects identified

		Reduction in CO_2 (Gg)	Increase in Cost (US$ '000)	Marginal Abatement Cost for CO_2 (US$/Gg)	Marginal Abatement Cost (US$/tonne of Carbon)
Project 1	TRP	1999.2	63025.1	82734	303
IGCC	IRP	2317.9	42084.5	61049	224
Project 2	TRP	776.5	39887	114967	422
PFBC	IRP	1377.4	26501.1	63124	231
Project 3	TRP	15348.3	149558.5	30495	112
LNG	IRP	15179.9	125985.5	29479	108
Project 4	TRP	5927.4	78838.2	36305	133
Wind	IRP	5632.8	80541.4	42018	154
Project 5	TRP	6235.3	88493.6	48028	176
Dendro	IRP	9224.2	79946.8	34553	127

Table 6.3a: CO_2 Emissions and Generation Costs

Scenario	Generation Cost Cost (US$ billion)	Increase (%)	CO_2(Gg)	Emission Reduction (%)
TRP Base- Without DPG	1.57	-	102640.3	-
TRP Base - With DPG	1.58	0.52%	99224.9	3.33%
IRP Base without DPG	1.19	-24.09%	76292.5	25.67%
IRP Base with DPG	1.21	-23.31%	72914.4	28.96%

5.5 Candidate CDM Projects

The CDM projects identified for the Sri Lanka power sector case study consists of two clean coal technologies, one cleaner fuel option and two renewable energy technologies.

CDM Project 1: 300MW capacity based on IGCC

A plant based on IGCC with a 300MW capacity is forced into the system so that it is commissioned in the year 2005 and 2008 respectively in TRP and IRP scenarios. These are the earliest times that a coal plant is added to the system.

CDM Project 2: 300MW capacity based on PFBC

A plant based on PFBC with a 300MW capacity is forced into the system so that it is commissioned in the year 2005 and 2008 respectively in TRP and IRP scenarios.

CDM Project 3: 500MW capacity based on LNG

A plant based on LNG with a 500MW capacity is forced into the system so that it is commissioned in the year 2007 and 2008 respectively in TRP and IRP scenarios allowing the LNG plants a reasonable lead time and enough time for the demand to increase to accommodate an additional generation capacity of 500MW.

CDM Project 4: 300MW of Wind Power

A wind capacity totalling 300MW is forced into the system in 2004 and 2005 so that a total of 300MW will be there by the time it comes to the first 300MW coal power plant in the base case.

CDM Project 5: 300MW of Dendro-thermal

Dendro-thermal plants of 300MW capacity in total is forced into the system by 2009 and 2008 in the TRP and IRP cases allowing sufficient time for the dendro power technology to mature in Sri Lanka.

5.6 Distributed Generation (DPG)

The DPG options considered in this study are limited to Mini Hydro, Dendro and Wind Power plants. Depending on the level of acceptability of the technologies and the detailed resource potential assessment, which is yet to be done, the following assumptions are made in this study.

- All mini hydro plants are added in blocks of 15MW and is limited to around 100 MW in total though some estimates run upto 150 to 175 MW of total potential.

- All dendro plants are added in blocks of 5MW and is limited to 80 MW though some estimates put the total potential at over 1700 MW.
- Wind plants are added to the system in blocks of 3MW and limited to 75MW though the total potential is estimated to be around 1800 MW.

6. Results

The study is carried out using the data given in section 5 with (IRP) and without DSM (TRP) measures in place, where appropriate.

6.1 Supply and Demand Side Options for GHG Mitigation

In this scenario all the supply-side options are considered in the TRP along with already planned transmission loss reduction targets. The only modification in the IRP study is that the DSM options are included in the objective function in addition to the supply-side options. The output emissions and costs for both TRP and IRP are given in Table 6.1.

6.2 Projects under CDM

During this component of the study the five CDM projects discussed in the previous section were examined both under TRP as well as IRP. The outcome is reported in Table 6.2.

6.3 Impact Of Distributed Power Generation

The distributed power generation options were included in the study by modifying the system demand considering the reduction in transmission and distribution losses. The outputs of the model under both TRP and IRP are given in Table 6.3a.

7. Analysis

7.1 Supply and Demand Side Options for GHG Mitigation

None of the clean coal technologies or renewable energy plants including large hydroelectric plants given in Section 5 is selected in the base case mainly due to the high costs associated with their installation and operation. This means that none of these cleaner technologies will be in use under normal circumstances where only the economic feasibility is considered.

It is important to note that the total installed capacity of new plants goes down by 825MW (300MW of coal and 525MW of gas turbines) when the DSM options are included under IRP. This has resulted in IRP model giving a reduction in overall costs as well as emissions. This means that the use of DSM measures not only is economically advantageous under normal circumstances but also reduces by GHGs by about 22% and other harmful emissions by about 15% creating a win-win situation in power system planning.

CO_2 Emission Control

The cost and other implications of CO_2 emission control are given in Table 6.1 for both TRP and IRP cases. All the comparisons are made against the BAU case, which is the TRP base case. It can be seen that switching over to the DSM options automatically reduces the CO_2 and other emissions. For instance, the cost of IRP base case is 20% less than that of BAU case at a CO_2 emission reduction of about 22%. Even a 46% reduction in CO_2 (against BAU) can be achieved in IRP at a 6% reduction in overall costs.

Under CO_2 emission control scenarios of the TRP based model where approximately 10%, 20% and 30% reductions in CO_2 are achieved, the average cost of these reductions amounts to US$ 46, US$ 57 and US$ 67 respectively for a tonne of carbon. In the IRP based model these values become little more expensive than those of TRP case since a certain level of CO_2 reduction has been already achieved with DSM measures in IRP. These values are US$ 55, US$ 66 and US$ 80 respectively per tonne of Carbon against IRP base case. The tighter the emission control regime the higher the cost of achieving it particularly due to the requirement to select more expensive renewable energy based technologies such as wind, hydro and dendro plants for the purpose of reducing CO_2 on a large scale. It is important to note that renewable energy based plants (wind and dendro) are selected only in scenarios where forced CO_2 emission reduction targets are imposed.

Unconstrained world trading of carbon is expected to fetch only US$ 24 a tonne of carbon [11]. Carbon abatement costs in Sri Lanka become less than this figure only in the case of IRP against the TRP base case where even a 46% overall CO_2 reduction can be achieved at a negative cost.

Correlations

The emissions of CO_2, NOx and SO_2 are highly correlated with each other (above 80% correlation) while generation cost is only weakly correlated to emissions (approximately a maximum of 30% correlation). In general, a greater percentage of CO_2 reduction can be achieved at a lesser percentage increase in generation costs. The long run average cost (LRAC) increases only by about 14% when making attempts to reduce CO_2 even by 30% under TRP. Even a 46% reduction in CO_2 (against BAU) can be achieved at only a mere 6% increase in LRAC under IRP.

7.2 Projects under CDM

Emissions and Costs

The CDM projects chosen above reduce emissions and CO_2 emissions in particular, while the overall costs increase from the base case scenario. These reductions in emissions and increase in total costs attributable to individual projects are shown in Table 6.2.

It can be seen from the table that the highest reduction in emission comes from Project 3 where the a 500MW LNG plant replaces a 300MW coal power plant. This is mainly because the emissions from LNG based plants are almost 50% less than that of equivalent coal based plants due to the different technologies they employ and the composition of the fuel.

The next most effective projects in terms of CO_2 emission reduction are wind power and dendro power plants where the reductions are approximately 1/3 to 2/3 of that of LNG option. This is because of the fact that 300MW of wind or dendro plants in units of small capacities cannot contribute the same amount of energy as that of a 300MW of LNG plant. As far as SOx and NOx emissions are concerned the second best projects are 300MW of IGCC or PFBC plants. Their CO_2 emission reductions are marginal. This is because, though these technologies may not improve the overall coal burning efficiency significantly, their process of combustion has a positive impact on other forms of gaseous and particulate emissions.

It can be seen that the highest increase in both the long run average cost (LRAC) and the average incremental cost (AIC) is recorded in the LNG based project. The second highest cost increases are in wind power and dendro power based projects. The lowest increase in costs are in the PFBC based project. These are mainly because the specific unit cost of these technologies follow the same pattern.

Marginal Abatement Costs

Both the quantities of CO_2 emission reductions as well as the cost of these reductions are important in implementing CDM projects. Table 6.2b shows the reduction of CO_2 emissions and the unit cost of these reductions in different projects considered in the study. It can be seen that the marginal carbon abatement cost varies from US$ 108 to US$ 422 per tonne of carbon. Considering these values and the quantities of CO_2 reductions while the LNG based project can be ranked first for a project under CDM, wind power and dendro power can be ranked second. In this exercise both clean coal technologies considered, IGCC and PFBC based options are ranked lowest.

Carbon Trading

Reference [11] gives the results of a study done by simulating different market conditions under different carbon trading scenarios, which could exist when the Kyoto Protocol comes into effect world over. It can be seen that the carbon prices can vary from US$ 24 per ton under unrestricted carbon trading scenario to US$ 186-534 per ton of abatement cost under no trading scenario. If purchasing of carbon is restricted, the prices fall even to as low as US$ 6 per ton [11].

When these carbon prices are compared with the cost of carbon abatement in the CDM projects examined in the above study it is apparent that none of those projects would be feasible under a free world carbon trading scenario. Even when the supply of carbon is limited to 50% or 25% of the total available for sale, Sri Lanka CDM projects are not viable. Only when the world carbon credit suppliers act as a cartel, the CDM project based on LNG become marginally viable.

7.3 Impact Of Distributed Power Generation

The DPG considered in the system consists of 5MW of dendro power, 45MW of mini-hydro and 3MW of wind power plants assumed to be distributed in various parts of the network but connected to the national grid supporting the centralised large generation system in supplying the system electricity demand. That is a total of 53MW of generation from DPG systems.

It was seen that the generation system consists of a total capacity of 2380MW without DPG. This comprises 1800MW of Coal Steam, 560MW of oil fired Gas Turbines and 20MW of Diesel based on residual oil. When DPGs are included in the system the centralised generation capacity reduces to a total of 2325MW with a plant combination of 1800MW of coal steam and 525MW of gas turbines. Effectively, the requirement of a 20MW residual oil based Diesel plant and a 35MW gas turbine has been removed due to these DPG systems. This is mainly due to the reduction in transmission and primary distribution losses envisaged under DPG. That means a reduction of fossil fuel based large generation capacity by 2.3% resulting from 53MW (2.2%) of small distributed renewable energy based plants. The total reduction in CO_2 emissions is about 3% at an average abatement cost of US$ 30 a tonne of Carbon. The increase in generation costs to achieve this reduction is a mere 0.52%. Though this cost of reduction is a little above the expected price of carbon under the worldwide carbon trading scenario predicted (US$ 24 per tonne of carbon) [11], it is still the lowest carbon reduction cost scenario Sri Lanka can expect under traditional planning [5,6].

When DPG is combined with the DSM schemes given in the previous section, a total reduction of 29% in CO_2 emissions can be experienced within the planning horizon while achieving a total cost reduction of 23%. The cost and CO_2 reductions for different scenarios are given in Table 6.3a.

8. Conclusions

This study was mainly focussed on examining the supply-side and demand-side options available for greenhouse gas (GHG) emission mitigation in the Sri Lanka power system. But the results obtained in the study are equally applicable to countries having similar resource utilisation in the power sector.

It is concluded that there are technically feasible and economically viable options for mitigating GHG emissions in the Sri Lanka power sector by as much as 46% from the business as usual scenario where traditional generation planning processes are used. These options include both DSM measures as well as renewable energy technologies such as wind, hydro and dendro power in addition to clean coal technologies. While some of the DSM measures are negative cost options, all the renewable energy and clean coal technologies impose a cost penalty in GHG mitigation. Further, it is also concluded that none of the available supply-side options can mitigate GHG emissions at the expected carbon prices under an unrestricted world carbon-trading scenario where the price of carbon is expected to be US$ 24 per ton.

It is important to note that these results should not be taken in isolation, especially because of the underlying assumptions of the availability of commercially proven clean technologies at economically competitive prices. Further, there are also very optimistic renewable based energy sources, which need evaluation of the true potential in the country, and the long-term viability of maintaining hitherto untested primary energy sources and systems associated with power generation in Sri Lanka. Further, some of these GHG emission reductions cannot be effected within the first few years as some clean coal technologies and renewable options have their own lead times.

It can be further concluded that the CDM projects considered in this study, which represent the most attractive possible options under a future CDM based carbon trading scenario, are not economically attractive for Sri Lanka since the carbon abatement costs are significantly high compared to the possible price of carbon under different world carbon trading environments.

Out of the selected CDM options the first option that Sri Lanka needs to choose, if at all it opts for CDM projects, is the use of LNG to replace coal power. This is particularly important considering that this is the option giving the highest carbon reduction within the planning horizon while having the lowest abatement cost.

The use of clean coal technologies such as IGCC and PFBC should be completely excluded because of their extremely high abatement costs. The second best option to be considered is wind power and dendro power on a large scale (300MW) but the abatement capacity is only one third to two thirds to that of the LNG option.

The other objective of this study was to examine the impact of distributed power generation (DPG) on the emissions in electricity generation sector, particularly the greenhouse gas (GHG) emissions.

From the analysis it can be concluded that the grid connected DPG reduce emissions with only a marginal increase in overall costs due to reduction in transmission and distribution network losses resulting from the distributed nature of generation. These reductions can be enhanced by opting for renewable energy based DPGs, as is the case presented in the paper, and coupling them with demand-side-management measures. Not only such DPGs bring environmental benefits but they are also economically attractive. Further, even if the off-grid renewable energy based DPGs manage to take over some of the remote grid connected loads or delay the grid connection of possible future loads on the grid, such scenarios will lead to overall reduction of emissions in the power sector.

Though this study was based on input data available up to 2002 since it was conducted during that period, the applicability of the methodology presented is valid even today.

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