ASIA LEAST-COST GREENHOUSE GAS ABATEMENT STRATEGY (ALGAS)

Cost of Emission Reductions / Sink Enhancement Initiatives (CERI) Curves

Task - C.3

Prepared by

Bangladesh Institute of Development Studies (BIDS)

In Collaboration with

Bangladesh Centre for Advanced Studies (BCAS)

Bangladesh University of Engineering and Technology (BUET)

and

Bangladesh Unnayan Parishad (BUP)

C.3 Cost of Emission Reduction Initiative Curves

Two different sets of costs of emission reduction initiative curves (CERI) of the Bangladesh energy sector model are developed - one for the energy consuming sectors as a whole and the other for the individual cross-cutting technologies. Also CERI curve for the comprehensive model where all mitigation/abatement options in all sectors are considered together.

The Bangladesh energy sector model is constituted of 5 end-use demand sectors - agriculture sector, commercial sector, industrial sector, residential sector (dis-aggregated into rural and urban) and transport sector. Before we move into the estimated CERI curves, a brief description of the baseline scenario and sectoral or technology-specific mitigation/abatement options are provided below.

Baseline Scenario

Baseline scenario for the Bangladesh energy sector model constitutes all existing technologies plus committed or planned technologies. Baseline technologies are differentiated from mitigation/abatement technologies in that the latter set of technologies are available in the horizon but not considered to be adopted in the economy in the near/foreseeable future either because of their costs or social acceptability barrier.

Agriculture Sector: In the agriculture sector, only commercial energy consumption is considered for the baseline model. Commercial energy in the agriculture sector is primarily demanded for irrigation and soil cultivation services. A total of 6 irrigation and 1 soil cultivation existing technology constitute the baseline set. They are,

- Low lift pump-diesel
- Low lift pump-electric
- Shallow tube well-diesel
- Shallow tube well-electric
- Deep tube well-diesel
- Deep tube well-electric
- Tiller-diesel

Commercial Sector: Energy in the commercial sector is primarily demanded for cooking, lighting, cooling, refrigeration services and for running office equipment, entertainment and other services. No major changes in the pattern of use of energy for commercial cooking services or introduction of new efficient cooking technologies are considered in the commercial sector. Baseline cooking technologies in the commercial sector are,

- biomass stoves,
- coal stoves,
- kerosene stoves-pressure system, and
- natural gas stoves

In the baseline, lighting demand is met by electricity with two devices,

- incandescent bulbs of 100 watts, and
- fluorescent tubes of 40 watts

Cooling demand is met by fans and air-conditioners. Baseline cooling technologies are,

- ceiling fans of 65 watts,
- window type air-conditioners (1.5 tons cooling capacity) of 2.25 KW, and
- central air-conditioners (34 tons cooling capacity) of 45 KW

Refrigeration demand is being fulfilled through 240 liter refrigerators of 120 watts. Considering the diverse nature of office/entertainment equipment in the commercial sector, no attempt is made to dis-aggregate them. The model is just meeting the energy demand for this kind of services.

Industrial Sector: Baseline demand for industrial energy services is met through existing technologies in the 6 industrial sub-sectors and through some cross-cutting technologies such as lighting, cooling, process heat and motive power generation in the remaining industrial sub-sectors. The 6 independent process technologies are,

- brick making,
- paddy parboiling & milling,
- sugar industries,
- cement factories,
- paper and pulp factories, and
- fertilizer factories.

Data availability was the main criterion for treating these industries separately.

Brick burning and paddy parboiling & milling processes are traditional technologies - grossly inefficient and heavily dependent on biomass fuels; sugar factories are of average efficiency given their small sizes and mode of operation - sugar recovery rate is around 8.0% - improvement potential is up to 11.0%; cement production is a wet process consuming huge energy in the dryers; paper production is batch process but considering the scale of production, energy efficient alternative process i.e., continuous may not be cost-effective in our case. Fertilizer factories in the country combine both energy inefficient and efficient technologies. Recently established factories are state-of-the-art technologies and there is hardly any scope of energy efficiency improvement.

For other industries not listed above, lighting and cooling technologies are similar to those of commercial lighting and cooling technologies defined above. Industrial process heat is generated through boilers of 4 types,

- biomass boilers,
- coal-fired boilers,
- fuel oil fired boilers, and

- natural gas fired boilers

Industrial motive power demand is met by motors of 5 types,

- less than 1 hp,
- 1-10 hp,
- 10-30 hp,
- 3-100 hp, and
- greater than 100 hp

Residential Sector: Energy consumption in rural and urban areas is treated separately in the model as the pattern and intensity of energy use indicate significant variation between rural and urban areas. The 1991 population census definition of rural area is followed here. By that definition, rural area includes Thana centers, hats and bazars or market-towns with electricity (BBS 1995:629).

Cooking, lighting, cooling and refrigeration are the primary energy services demand in rural areas. In the baseline, 7 types of cooking technologies are defined,

- biomass stoves-traditional,
- biomass stoves-improved (unnata chula),
- kerosene stoves-wick system,
- kerosene stoves-pressure system,
- coal-stoves
- LPG stoves, and
- natural gas stoves

Among these only the traditional biomass stove and LPG stove were in use in 1990. The improved biomass stove (unnata chula), certainly a mitigation technology, is appearing in the baseline as it is a deliberate policy of the govt. under implementation. This technology is assumed to be adopted by the rural population in the year 2000 or afterwards.

Rural lighting demand is met through kerosene lamps (both kupi and lantern) and incandescent bulbs of 60 watts although fluorescent tubes of 40 watts is also an option made available in the model for use in the baseline. Cooling services demand is served through ceiling fans of 65 watts only while refrigeration services demand is met through 240 liters refrigerators of 120 watts.

Urban energy services demand are similar to rural areas but the pattern and intensity of use are different. In addition to the 7 cooking devices defined for rural areas, one more technology - electric stove was also defined in the model. In 1990, urban cooking services was met through traditional biomass stoves, kerosene stoves (wick system), LPG stoves, natural gas stoves and electric stoves. Use of improved biomass cookstoves (unnata chula) started in 1995 in urban areas.

Urban lighting and refrigeration services demand are met through similar technologies as defined for the rural areas. Urban cooling is met through fans and air-conditioners of window type.

Transport Sector: Demand categories for transport services as well as modes or devices to meet such demand are widely varied compared to any of the other sectors considered in the Bangladesh MARKAL model. A total of 8 types of passenger transport services and 3 types of goods transport services are demanded in the transport sector. They are met through various modes of transport as shown below:

- intercity passenger,
    1. reconditioned bus-52 seater
    2. reconditioned bus 36/40 seater
    3. reconditioned AC bus

- local passenger
    1. reconditioned bus-52 seater
    2. reconditioned AC bus
    3. minibus
    4. double decker

- jeep/car/micro passenger
    1. reconditioned car
    2. reconditioned jeep
    3. reconditioned microbus
    4. CNG converted car-starting from 1995
    5. CNG converted jeep-starting from 1995

- 3-wheeler passenger
    1. baby taxi
    2. mishuk
    3. tempo

- 2-wheeler passenger
    1. motorcycle

- rail passenger
    1. existing rail transport

- water passenger
    1. diesel based water transport,
    2. fuel oil base water transport

- air-passenger
    1. international
    2. domestic

Compressed natural gas (CNG) fuelled vehicles, a mitigation option available in 1995 and thereafter, are defined as baseline technologies in the car/jeep/micro passenger transport demand category as it is a government policy now to promote CNG vehicles for reducing air pollution in the city areas and to reduce dependence on imported fuels. It is assumed that, starting from 1995, CNG vehicles will displace at least 10% of the car/jeep/micro passenger transport demand by 2020.

Road freight transport is met through existing trucks and rail wagons; water freight transport is met through two devices - diesel based and fuel oil based barge/cargo etc.

Conversion Technology: Baseline electric conversion technologies include all existing combined cycle, combustion turbine, steam turbine and hydro power plants plus all committed gas based, coal based and fuel oil based power plants. Committed power plants are assumed to be slightly better technologies (in terms of energy efficiency) of the same types of existing technologies.

Process Technology: Natural gas pipeline and compressed natural gas plants are the two main process technologies in the baseline model. Industrial self-power generation technologies (bagasse and natural gas based) are also treated as the baseline process technologies in the model.

Resource Supplies: A total of 5 biomass energy (bagasse, dung, firewood, husk and plant residue) sources (indigenous) are defined in the baseline model with their upper bounds explicitly defined. All types of liquid fuels are imported in the model with their actual imported amount explicitly defined for 1990 and for 1995 in some cases. For other periods, the model is allowed to import any amount of petroleum to meet the projected future demands of energy services. Coal is also imported in the model along with a coal mine defined to be available after 2000. An upper limit of 1 million tonnes of annual coal extraction possibility is explicitly incorporated in the model for all years after 2000. Once this limit is reached for this relatively cheaper indigenous coal, the model is bound to import the excess demand for coal energy services. Natural gas is supplied in the model through gas mining activity with its proven recoverable stock and 1990 level extraction explicitly defined.

Mitigation Scenarios

Two major approaches are followed to generate mitigation/abatement scenarios for the Bangladesh energy sector model. The first is the sectoral approach, in which all possible abatement options in a particular sector are considered without drawing any implication on the energy consumption or GHG emission that might have in other sectors as well. The second approach followed is the identification of cross-cutting mitigation/abatement options regardless of their possible adoption in different sectors at the same time. Considering all the sectors together and the technologies therein, we also attempted a comprehensive mitigation scenario. So the abatement scenarios in the Bangladesh energy sector modelling are:

a. Sectoral Scenarios

- Agriculture Sector
- Commercial Sector
- Industrial Sector
- Residential Sector
- Transport Sector

- Power Generation Sector

b. Technology Specific Scenarios

- Compact Fluorescent Lights (CFLs)
- Efficient Boilers
- Efficient Motors
- Efficient Air-conditioners
- Efficient Refrigerators
- 4-Stroke Vehicles
- Metered Natural Gas

c. Comprehensive Model
(all mitigation/abatement options in all sectors are considered together in this model)

Agriculture Sector: No mitigation possibility for the commercial energy using technologies in the agriculture sector is assumed.

Commercial Sector: Compact fluorescent lights (CFL) of 15 watts is the only mitigation lighting device in the commercial sector. For commercial cooling, three mitigation technologies are defined. They are,

- window type air-conditioners with deflective glass wall (expected to be 9% more energy efficient than the existing ACs),
- window type air-conditioners - efficient (25% more energy efficient than the existing ACs),
- central air-conditioners - efficient (25% more energy efficient than the existing central ACs)

For commercial refrigeration, one efficient refrigerator assumed to be 25% more energy efficient over the existing refrigerators is defined as the mitigation technology.

Industrial Sector: Lighting and cooling mitigation technologies for the industrial sector are similar to those of commercial sector listed above. Mitigation technologies for industrial process heat generation are,

- biomass boiler-improved (10% more energy efficient than the existing biomass boiler),
- coal boiler-improved (10% more energy efficient than the existing coal boiler),
- fuel oil boiler-improved (10% more energy efficient than the existing fuel oil boiler),
- gas boiler-improved (10% more energy efficient than the existing gas boiler), and
- gas boiler-efficent (20% more energy efficient than the existing gas boiler)

For industrial motive power generation, efficiency improvement possibility is considered for motors of less than 1 hp and 1-10 hp only (30% and 6% more efficient than the corresponding existing motors). Efficiency of motors of 10 hp or higher rating are already in the range of 85-95% and no further improvement in their efficiency is envisaged.

Among the 6 itemized industries, no mitigation option for fertilizer factories is considered. For others, one energy efficient option either in terms of modernization of the whole process or in terms of housekeeping/retrofitting options are considered. They are,

- brick burning-modern process (5 times more efficient than the existing one),
- paddy parboiling & milling-improved process (twice as efficient as the existing process),
- sugar mills-housekeeping,
- paper mills-housekeeping, and
- cement factories-retrofitting.

Residential Sector: Compact fluorescent lights, metered natural gas and efficient refrigeration are considered as mitigation options for rural areas. For urban areas, two more efficient technologies for ACs - air-conditioner with deflective glass wall and efficient air-conditioners are also considered as mitigation options. It is assumed that metered gas will be available in rural areas in 2010 or so and will meet at least 10% cooking services demand by 2020. For urban areas, metered gas will be available at least 5 years earlier and gradually cover 15% of urban cooking services demand by 2020.

Transport Sector: For all kinds of road transport (automobile) services, new/improved vehicles in place of reconditioned ones are considered to be the mitigation technologies. In most cases, 10-15% energy efficiency is assumed over the reconditioned existing transport devices. In the 3-wheeler passenger transport category, 4-stroke vehicles entering in 2005 or afterwards and gradually displacing 50% of 3-wheeler passenger transport demand by 2000 is assumed to be another mitigation option. No mitigation or energy efficiency improvement possibility is envisaged for other modes of transport.

Conversion Technology: Natural gas based new standard/efficient combined cycle (50% efficiency), combustion turbine (35% efficiency) and steam turbine (40% efficiency) power plants are assumed to be the mitigation option in power generation against 27%, 25% and 35% efficiencies of the respective technologies in the baseline model.

Other Scenarios: In addition to these sectoral mitigation scenarios, we also attempted cross-sectoral or technology specific mitigation/abatement scenarios considering the advantage of technology specific approach in project formulation and implementation. This is also important because more than one cross-cutting mitigation/abatement options may be pursued or implemented simultaneously rather than one by one basis. For example, one may be interested to know how much national CO_2 emission would be reduced and at what costs if efficient lighting device such as compact fluorescent lights are to meet 10-15% lighting services demand in the residential sector and 30-40% in the commercial and industrial sector simultaneously. We tried to answer this kind of questions with a scenario called *CFLs in All Sectors.* Similar other scenarios attempted are *Metered Gas* in rural and urban areas simultaneously, *4-Stroke Vehicles*, *Efficient Boilers*, *Efficient Motors*, *Efficient Air-conditioners* and *Efficient Refrigerators*. To see what would be the aggregate CO_2 emission reduction potential of all mitigation technologies in all sectors together and/or what technology or set of technologies dominates over others in reducing national CO_2 emissions over the modelling time horizon, we put all the mitigation/abatement technologies in all sectors together in a single scenario named as the *Comprehensive Model*.

CO_2 Emissions Trade-off Curves (CERI Curves)

Below we provide the CERI curves of the sectoral abatement options as well as for the cross-cutting technology-specific abatement options described above. The horizontal axis in the CERI curves thus represents the differential CO_2 emissions reduction due to the mitigation technologies in concern and the vertical axis represents the differential costs of the mitigation technologies over that of baseline technologies.

Figure 1 shows CERI curves for the baseline, sectoral and comprehensive models. The indexed points on the curves indicate 0%, 5%, 10%, 15%, and 20% reduction in cumulative CO_2 emissions. These upward sloping curves indicate that the more one wants to reduce CO2 emissions, the more one has to incur costs, cost escalation being the highest and exponentially rising for the largest reduction constraint. The negative differential costs for the industrial sector mitigation options and the comprehensive model indicate that these two are win-win mitigation options. In other words, they actually pay-off the economy rather than putting a heavy burden and simultaneously help reduce the aggregate CO_2 emissions.

Figure 1: Baseline and Sectoral CERI Curves

Figure 2: Baseline and Technology Specific CERI Curves

Figure 3 gives a summary picture of the mitigation/abatement technology specific CERI curves considered in this study. One gets an impression from this curves that not all options have a positive costs to the economy - some do provide negative costs or benefits to the economy. The prominent ones figure in this category are improvement in the industrial boiler efficiency, improvement in the power generation system, improvement in the industrial motors or the comprehensive model as a whole where all sectoral and technology specific mitigation options are considered together.

In Figure 4, a more closer look to the industry sector CERI curves is given since the industry sector came out as the major cost saving, energy saving and simultaneously, major CO_2 reducing option. Here we see, that improvement in the boiler efficiency is the most cost saving and at the same time CO_2 reducing option. It does not incur a positive unless a very strict constraint on the CO_2 emission is imposed. Improvement in the motor efficiency also promises some cost savings at the initial stage of CO_2 reduction regime but it does incur a positive cost once that option is exploited. Costs, however, soars very high for efficient motors as a mitigation option with stricter emission constraints.

Figure 4: Baseline and Industrial Sector CERI Curves

The next figure (Figure 5) shows the baseline and efficient lighting CERI curves. The only efficient lighting device considered in the model is the compact fluorescent lights which is about 4 times energy efficient and has about 10 times longer life than that of a 60 watt incandescent bulb. Given its very high initial investment cost (about 25 times), this energy efficient technology is not picked up by the model even at a very high CO_2 emission reduction constraint. But since, this option is considered to be a national priority mitigation option, we actually forced the model to use this technology to meet certain proportion of lighting demand in different sectors. The CERI curve below shows the CO_2 emission reduction and associated costs over baseline technologies if CFLs are to meet about 40% lighting demand in the commercial and industrial sectors by the year 2020 beginning from 2% in 2000; 10% lighting demand in the urban areas by 2020 and only 5% lighting demand in the rural areas by 2020. Such a target has proved to be very ambitious, as indicated by the model, if the nation does not require to reduce its CO_2 emission over the period 1990-2020. In such an unconstrained CO_2 emission regime, the model reduces only 3 million tonnes of CO_2 at a cost of 5 billion dollars (or equivalently, 1667 $/tonnes of CO_2 reduction). But at the 20% CO_2 reduction constraint, such cost reduces to only about 4 billion dollars for 348 million tonnes of CO_2 emission reduction (or equivalently, 11.5 $/tonnes of CO_2 emission reduction).

Figure 5: Baseline and Efficient Lighting CERI Curves

Figure 6 shows the CERI curves for supply side options for CO2 emission reduction, particularly, the efficient power generation options. These curves are of special interest considering the very inefficient and aged electricity generation technologies the country now using to meet the ever increasing electricity demand. In the efficient power generation technologies, we considered gas based efficient combined cycle, combustion turbine and steam turbine power plants. The model indicates that, use of efficient technology for electricity generation is actually a cost-saving option, at least up to a moderate level of CO_2 emission reduction constraint. Being a country in the non-Annex I group of countries who do not have any explicit CO_2 emission reduction obligation/commitment in the foreseeable future, Bangladesh should certainly take advantage of this win-win option.

Figure 6: Baseline and Efficient Power Supply CERI Curves

Least-Cost GHG Mitigation Options

Table below provides the economic results in terms of \$/tonne of CO_2 emission reduction in different mitigation scenarios for different constraints on the cumulative emission reduction. It is clear from the table that there is no unique estimate of \$/tonne CO_2 emission reduction. Rather it varies quite significantly at different levels of emission constraints. The no constraint case of each mitigation scenario produces the extreme results positive or negative. This is because in the no constraint case, the model is not forced to reduce any amount of CO_2 emission while utilizing some efficient but new technologies for which the investment in the initial periods is accounted for in the total system cost. These investment in the initial periods ensures the availability of the abatement technology for its whole lifetime and thus it is possible to reduce more and more quantum of CO_2 emission without any further investment in the subsequent periods. This is reflected in the rapidly reduced \$/tonne estimates with moderately stringent CO_2 emission constraint. With further stringent constraints, the model has to invest for yet costlier but more and more efficient technology and thus the \$/tonne estimates for most stringent emission reduction constraint are somewhat higher than for moderately stringent constraints.

Table 1: \$/tonne of CO_2 emission reduction in different mitigation scenarios

Scenarios	Cumulative (1990-2020) CO_2 emission reduction				
	No constraint	5%	10%	15%	20%
Commercial sector	642	27	29	34	88
Industrial sector	-31	-20	-13	-6	0
Residential sector	1205	26	29	35	90
Transport sector	-84	10	-21	28	60
Power generation	-107	-12	8	21	73
CFLs	523	29	31	35	91
Efficient boilers	-31	-15	-6	1	7
Efficient Motors	-148	-8	11	21	72
Efficient ACs	-107	11	21	28	83
Efficient refrigerators	-28	12	22	29	84
4-stroke vehicles	42	13	22	29	91
Metered gas	1207	24	29	34	97
Comprehensive model	-24	-16	-9	-2	4

With such an wide variation in the \$/tonne estimates of CO_2 emission reduction, it is very difficult to comment on which of the mitigation option/sector is the least-cost option/sector. One can still make an observation that, industrial sector is the least-cost (in fact, most benefit yielding) sector to choose among different sectors while power generation sector ranks the second. Among the mitigation/abatement technologies, boiler efficiency improvement is certainly the least-cost (or, most paying-off) option. Improvement in the efficiency of industrial motors ranks the second best abatement technology for CO_2 emission reduction.

On the other hand, commercial sector, residential sector and compact fluorescent lights are the costlier abatement/mitigation sectors/options incurring huge positive costs to the economy.