![ADB]

Energy Policy Options for Sustainable Development in Bangladesh

Herath Gunatilake and David Roland-Holst

Asian Development Bank

Energy Policy Options for Sustainable Development in Bangladesh

Herath Gunatilake and David Roland-Holst

No. 359   November 2013

Herath Gunatilake is Lead Energy Economist at the South Asia Department, Asian Development Bank. David Roland-Holst is Professor of Economics at the University of California Berkeley.

Asian Development Bank

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

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

CONTENTS

ABSTRACT

Bangladesh today faces a different future than it did decades ago when relatively abundant natural gas seemed to be the key to prosperity. To support more evidence-based dialogue on energy development, allocation, and pricing reform, this study uses a computable general equilibrium model to evaluate major energy policy issues facing Bangladesh. A relatively small negative growth impact of increased energy prices can be easily counteracted by an economy-wide increase in energy efficiency or subsidized gas for fertilizer production. A gas price increase does not lead to significant inflationary pressures in the country's economy. Diversification of the power sector fuel mix by introducing coal provides good macroeconomic indicators but results in higher carbon emissions. Investing the gas revenue in physical and social infrastructure provides the best macroeconomic indicators. This best policy option, however, further increases carbon emissions. Impacts of these different policies in terms of increased household income are more or less equally distributed among different household groups. Most of the attractive policy options have the drawback of higher carbon emissions, and supplementary policies and suitable technology adoption should play a balancing role.

I. INTRODUCTION

Bangladesh is standing at historical crossroads with respect to energy policy. Past decades of relatively abundant natural gas supported a set of policies that are unlikely to be sustainable in future decades. As of 5 April 2012, the country faced shortages of 400 million cubic feet of gas and 1,400 megawatts of electricity per day, according to official estimates. The country still faces widespread poverty and the potential of conflict to arise as a result of energy and water shortages (Karim 2012). Energy shortages not only affect individual citizens, but also discourage business leaders who fear that these problems could undermine the industrial and agricultural sectors as well. A better understanding of the topic is significant not only for resolving the energy sector crises, but also long term sustainable development of the country. This paper is intended to provide evidence-based policy dialogue on the country's energy policy options for sustainable development.

Available evidence suggests that natural gas is very inefficiently allocated across the country (Gunatilake, Haque, and Weerahewa [Forthcoming]). Moreover, this misallocation is reinforced by official pricing policies that encourage inappropriate technology choice and wasteful resource use in the power generation, fertilizer manufacturing, transportation, household cooking, and other industries. The same policies also act against energy efficiency, development of gas reserves, financial sustainability of power utilities, and the increase of much needed access to electricity. With closer attention to both domestic and international economic realities, these policies could be reformed to enhance economic growth, livelihood improvement, and energy security objectives for Bangladesh.

It is increasingly understood that in today's world, economic linkages are so complex that relying on the intuition of policy makers alone is grossly insufficient to make effective policies and be able to achieve reasonable results. Indeed, much evidence now suggests that indirect effects of many policies outweigh direct effects and, if not adequately understood, can substantially offset or even reverse them (Dixit 1986 and Bartel and Thomas1985). This paper assesses the macroeconomic impacts of the number of energy policy options using a dynamic computable general equilibrium model. The policies examined in this paper include: (i) increasing the gas prices; (ii) energy efficiency improvement; (iii) retaining subsidized gas for fertilizer making; (iv) diversification of power sector fuel mix; (v) exporting 10% gas at international market price; and (vi) improved gas revenue management—investment of augmented gas revenues on physical and social infrastructure. The rationale for these policies is described in Sections II and III. Section IV presents the details of the computable general equilibrium (CGE) model and policy scenarios. Section V presents the results, and Section VI presents the conclusions.

II. GAS SECTOR OVERVIEW

Domestically produced natural gas provides the majority of Bangladesh's commercial energy. The country has limited alternatives and will continue to rely primarily on this energy source to fuel its development. Bangladesh imports most of its oil requirement and remains heavily dependent on biomass for energy production, particularly in rural areas. The country suffers from endemic energy poverty, and 96 million people remain without access to electricity (IEA 2011). The country's electrification rate of 45%–50% is far below that of its neighbor India at 70-75%, and Sri Lanka at 95%. Lack of access to electricity remains one of the main development challenges, and an essential criterion for success in Bangladesh's development.

Per capita electric power consumption (Table 1) in Bangladesh is low even relative to income per capita (BP 2009 and WB 2009), suggests the country's economy grows despite serious constraints on energy infrastructure. Sustaining the growth may not be possible without removing the energy infrastructure constraints. Almost three-quarters of Bangladesh's population live in rural areas, and about half are employed in agriculture (World Bank 2010), and Bangladesh's electrical sector is more appropriate to an agrarian society. If the economy proceeds with energy-intensive industrialization and urbanization like developed countries, electrification and energy production will have to expand substantially.

Table 1: National Power Consumption Comparison

Country	2009 Electric Power Consumption (kWh per Capita)
Bangladesh	252
China, People's Republic of	2,631
India	597
Pakistan	449

kWh = kilowatt-hour.
Source: IEA: 2012.

Bangladesh's gas industry is primarily managed by state-owned enterprises (SOEs), grouped under the Bangladesh Oil, Gas, and Mineral Corporation (Petrobangla), which are involved in all stages of onshore exploration, production, and transmission. These companies have survived with government guarantees, and have not generated resource rent from this valuable and dwindling resource. The energy industry has argued that tariff and price controls have prevented them from raising end-user prices while input prices have gone up. At the same time, however, widely publicized scandals have led to allegations of widespread mismanagement. As with many state-owned enterprises, Bangladesh's gas companies may face conflict of interest due to political interference, soft budget constraints, and the lack of accountability to investors and capital market discipline.

Bangladesh faces another challenge as its proven reserves of natural gas are highly uncertain (Figure 1). In 2001, a joint research project with the United States Geological Survey estimated the country's total potential at 30 trillion cubic feet (TCF), but it remains unclear how much of this will ever be recovered. As Table 2 makes clear, after discounting for recoverability and past production, available reserves may be as low as 13.53 TCF.

Figure 1: Proven Gas Reserves
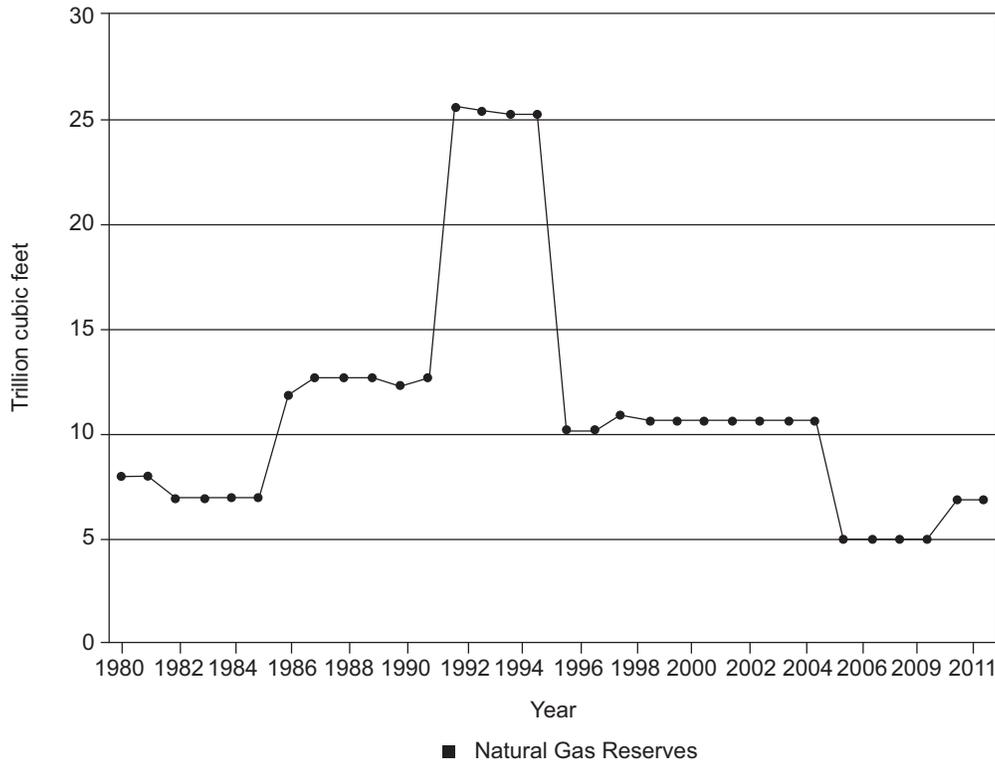
Source: US Energy Information Administration (2011)

Table 2: Estimates of Proven Gas Reserves, 2009

Gas (Proven+Probable)	28.62 TCF
Recoverable	20.63 TCF
Cumulative Gas Production as June 2007	7.10 TCF
Remaining Reserves	13.53 TCF

Note: TCF = trillion dry cubic feet.
Source: Petrobangla 2008

As of 2011, British Petroleum (BP) estimated available reserves at 12.8 TCF, with a reserve to annual production ratio of 18.3, meaning, at existing capacity and domestic demand, reserves would be exhausted in less than 20 years (BP 2011). In the same year, however, the domestic production consortium signed an agreement with a foreign company, while Bangladesh Petroleum Exploration and Production Company Limited announced the discovery of new reserves estimated to be at least 1 TCF and perhaps as much as 2.4 TCF. With reserves fluctuating annually by up to 15%, the supply side of the country's gas market remains plagued by uncertainty and risk.

Projected figures from Petrobangla and the US Energy Information Administration figure of proven gas reserves on Figure 1 reinforce the impression that Bangladesh could soon face a domestic supply problem. Financial constraints appear to limit the prospect for heavy investments required for nuclear energy. Bangladesh has not taken serious steps to use its coal

resources. As demand continues to grow, this may become the leading concern of energy policy, and will spill over into other areas as subsidizing energy imports impose increasing strain on government finances.

In 2001, Unocal proposed to build a pipeline from Bangladesh to India in order to export Bangladeshi gas to the Hazira–Bijapur–Jagdishpur pipeline, the backbone of India's gas infrastructure. Indian demand for gas would have built foreign exchange reserves, and the World Bank projected that Bangladesh would profit more from exporting gas than gas-intensive, value-added products like electricity or fertilizer, which were then Bangladesh's major gas-based product. The suggestion was met with enormous political resistance from opposition parties motivated both by uncertainty about the extent of domestic gas reserves and by nationalist demands to fulfill demand at home before exporting. Bangladesh ultimately declined to export, a policy that continues to this day.

The recent discovery of large offshore reserves by French oil giant Total in 2009, who later renounced their exploration rights, citing "commercial non-viability" after a $30 million survey, may have helped improve prospects for the country's reserves. Bangladesh's national companies have restricted their operations to onshore gas fields, and the country appears to be completely dependent on international oil companies for the technology and investments to pursue offshore exploration. With the resolution of a maritime dispute with Myanmar in March 2012, outside energy firms have taken an interest in buying exploration rights of the blocks on sale. As of April 2012, ConocoPhillips owns exploration rights to two deep-water blocks, and Santos is the only operator of an offshore gas field in the Sangu block of the Bay of Bengal. Due to the long-standing maritime dispute between Bangladesh, India and Myanmar, investors have repeatedly shied away from offshore exploration and development, and little geological data is available on the deep sea of Bangladesh, so the extent of the reserves in the Bay of Bengal remains unknown. So far, only two commercially viable gas finds have been discovered in offshore Bangladesh, one in 1996 and the other in 2012. The projected gas demand and supply is shown in Figure 2.

Figure 2: Projected Supply and Demand
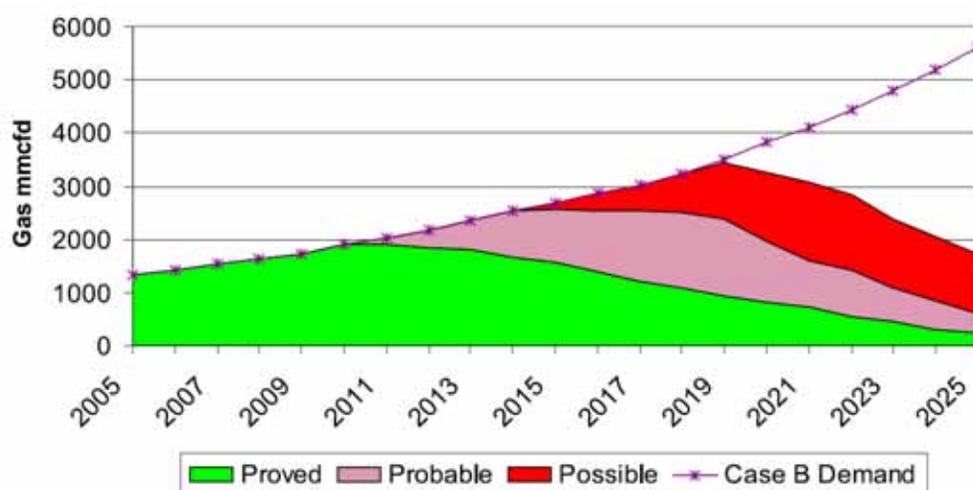
mmcfd = million cubic feet per day.
Source: Sarwar (2008)

Bangladesh does not currently import natural gas. The debate about exports hinges on the extent to which new discoveries in the Bay of Bengal can increase Bangladesh's proven reserves, creating excess capacity above expected domestic demand growth. The prospect of exhausting reserves has been the strongest argument leveled against a gas export policy, one that has resonated across Bangladeshi society. Current energy shortages have reinforced a political environment hostile to exporting in the short term.

Figure 3 shows the gas allocation among the sectors and how these allocations changed over time. It is evident that the power sector utilizes most of the gas in Bangladesh and gas allocation for fertilizer production declined over time. Another important sector picked up gas use in recent times is the transpiration sector (use of compressed natural gas [CNG]). Gunatilake, Haque and Weerahewa (Forthcoming) estimate economic value of gas in different sectors of Bangladesh and claim that there is large inefficiency in current allocation.

Figure 3: Changes in Sectoral Use of Gas in % (2001 and 2011)
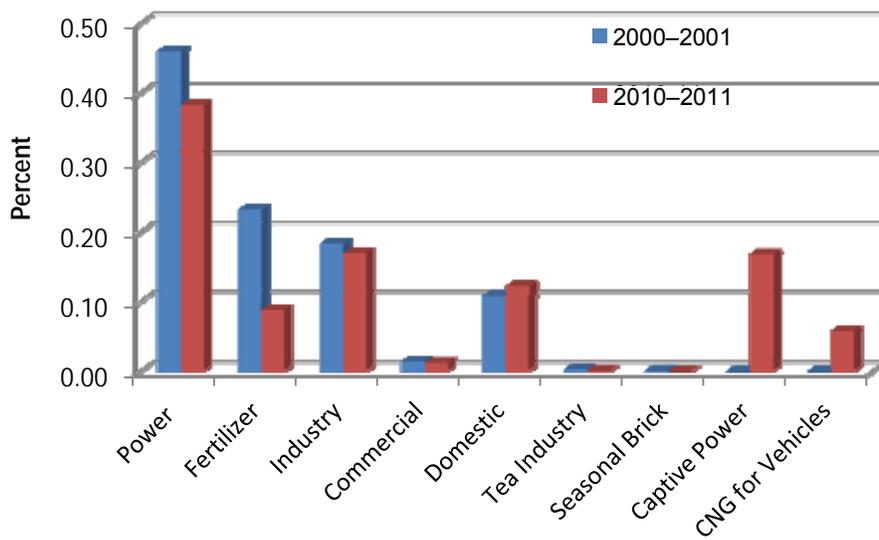
CNG = compressed natural gas.
Source: Authors' estimates

Economic development in Bangladesh has been shaped by energy policy in a number of ways. The urban centers of Dhaka and Chittagong have clearly benefited from growing industrial sectors due to the placement of gas infrastructure, and urban residents in general benefit from much higher electrification rates than their rural counterparts, a common feature in developing countries. Eastern Bangladesh, where all of the onshore gas fields are found, has benefited from this energy source. Natural gas has not been distributed widely in Western Bangladesh, where the transaction costs of building gas-transporting infrastructure have constrained energy supplies.

As a matter of government policy as important as reserves is the issue of gas tariffs, which in Bangladesh is highly controlled. The degree of price stratification is apparent in the next figure, which compares average domestic and world prices with prices administered to different demand categories (Figure 4). A few salient features of these trends have important policy implications. First, world wholesale gas prices, even accounting for the steep fall over the last few years, have remained above domestic retail prices for at least a decade. This divergence promotes overuse of gas domestically and increases the opportunity cost of forgone gas revenues in terms of investments in the economy. Second, the degree of price discrimination between domestic activities is dramatic, with strong bias in favor of power and fertilizer sectors, and against households and businesses and industry (Table 3). The prevailing retail prices are very low compared to gas prices in the region.

A differentiated energy tariff regime has encouraged different sectors. The fertilizer sector enjoys the lowest tariff for gas. Power and agriculture have both been favored by gas policy because they are assumed to benefit the largest proportion of people, and shortfalls or tariff increases in either could be costly from a political perspective. The argument has been raised that this is inefficient, as electricity access in Bangladesh is so low that it is doubtful power subsidies really benefit the poor. With an electrification rate of 45%–50%, it is possible that lower tariffs disproportionately benefit urban dwellers with an already higher standard of living than the majority of Bangladeshis. We shall return to this issue in Section V.

Figure 4: Annual Dry Gas Prices (Taka/m^3)
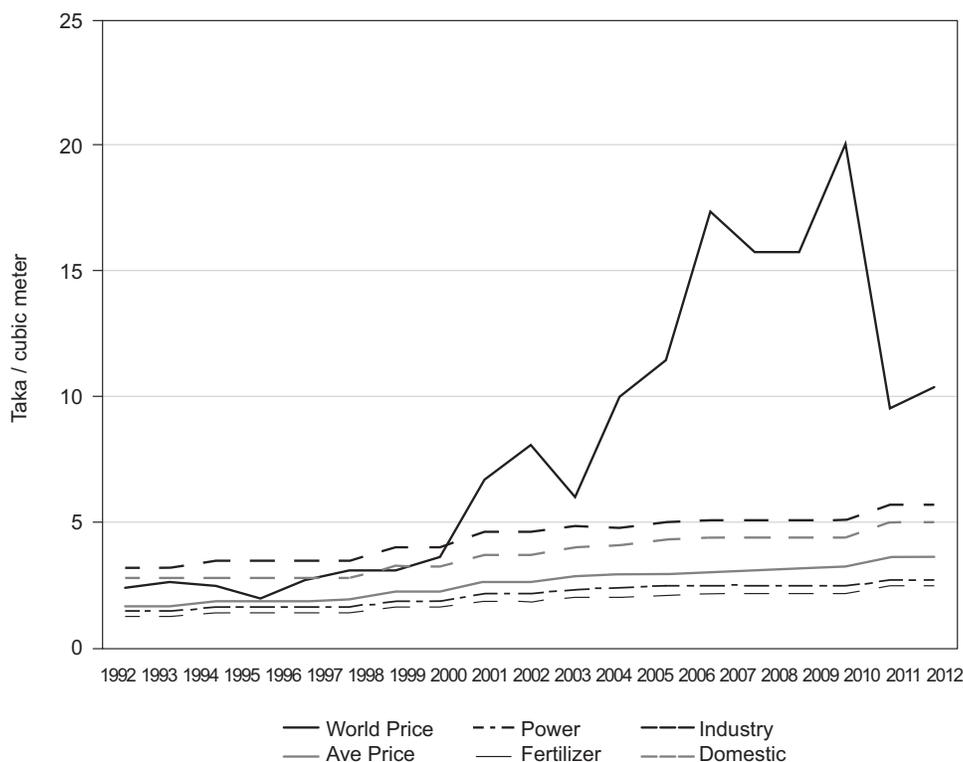
m^3 = cubic meter.
Sources: Authors' estimates from IEA, World Bank, and Petrobangla sources

Table 3: Gas Prices in Selected Neighboring Countries ($/m^3)

Country	Bangladesh	Pakistan	India	Malaysia	Thailand	Indonesia	Singapore
Effective Date of Tariff	19 Sept 2011	7 Aug 2011	1 Dec 2011	1 Jun 2011	1 Jun 2011	1 Jun 2011	1 Jun 2011
Consumer Category							
Power	1.05	5.14	5.06	4.36	5.81	6.70	13.79
IPP	1.05	4.34					
Fertilizer							
Feed Stock	0.96	1.17	5.06				
Power	1.56	4.99					
Industry	2.19	4.99	18.19	5.12	6.20	5.97	35.21
Captive Power	1.56	4.99					
CNG	8.60	6.57	16.17				
Large Commercial	3.54	6.05	18.19	5.12			
Small Commercial	3.54	6.05	23.51	5.12			
Domestic	1.93	1.24	12.27				

CNG = compressed natural gas, IPP = independent power producers, m^3 = cubic meter.
Source: Authors' estimates

Gas is by far the leading fuel for electric power generation and, due to the limited hydropower generation capacity, natural gas is the most cost-competitive option. The Bangladesh Chamber of Commerce has released a paper calling for increased use of coal, which might become competitive if gas subsidies were to be removed, but the government has hesitated to move towards this option due to opposition from citizens' groups. The current method of importing petroleum fuels to make up the gas shortage seems an extremely expensive solution for the government, and one that is almost certainly unsustainable. Nuclear power requires investment of time and capital that the government does not have, and renewable energy options available for Bangladesh are far too expensive (solar), or short in supply (wind). Traditional biomass still plays an important role as an alternative fuel. Table 4 shows alternative energy sources and their costs. It clearly shows that Bangladesh will face drastic energy price increases if the current pricing policy is not revised to gradually increase gas and power prices comparable with international market prices.

Table 4: Cost of Alternative Fuels for Various Categories of Consumers

Consumer Category	Cost of gas, Tk/mcf	Product	HSFO	Gasoline	Diesel	Kerosene	LPG[2]	Fuel wood
		Equivalent Amount	26.28 liter	30.12 liter	26.77 liter	27.14 liter	20.5 kg	110 kg
		Unit Price	60	89	61	61	56	8
Power	79.85			1,577	–	1,633	–	–
Industrial	165.94			1,577	–	1,633	–	1,148	–
Commercial	268.16			–	–	–	1,656	1,148	880
Captive Power	118.36			–	–	1,633	–	1,148	–
CNG	849.50[1]			–	2,681	1,633	–	1,148	–
Domestic	146.11			–	–	–	1,656	1,148	880

– = not applicable, CNG = compressed natural gas, HOBC = high octane blending component (premium gasoline), HSD = high speed diesel, HSFO = high sulfur fuel oil, kg = kilogram, LPG = liquefied petroleum gas, mcf = thousand cubic feet, MS = motor spirit (regular gasoline), SKO = superior kerosene oil.

Notes:
[1]   Includes refueling stations' margin of Tk7/cm.
[2]   Though the government–fixed price for 12.5-kg LPG cylinders is Tk700, due to high demand, the market selling price is over Tk1,500.
Source: Authors' estimates

Natural gas has become an integral part of the Bangladeshi economy. Bangladesh has developed gas-intensive industries such as fertilizer, and has highly subsidized gas, leading to relatively inefficient industrial and power plants. The need for captive power was recognized as early as 1996 in order to address the problem of emerging power shortages. The median firm owns a power generator, relying on it to produce 28% of its energy (Islam 2008), a pattern of proliferation of small generators that fail to achieve economic scale and inflate energy demand. The government has dealt with energy shortages in a number of ways. Gas rationing is now common for fertilizer production, businesses, and households, and several industrial plants have been taken off of the gas grid until capacity has risen to meet demand.

Table 5 illustrates a different point of view on the topic. According to the source, both fertilizer and electricity production are being overrepresented, and from a revenue perspective—industry, commercial, and domestic uses of gas have been unreasonably constrained by the current policy mix. A report by the Bangladesh Chamber of Commerce agrees with the assessment that prices should be liberalized and that priority should be shifted away from power, where opportunities exist for coal or for electricity imports from Bhutan, India, or Nepal exist (Islam 2008).

Table 5: Natural Gas Use and Revenue by Sectors (%)

Sector	Gas Use (%)	Revenue (%)
Power	40.07	30.64
Fertilizer	13.46	8.80
Industry	15.77	24.07
Commercial	1.13	2.71
Tea Estate	0.14	0.21
Domestic	11.81	15.82
CNG	3.90	2.81
Captive Power	13.72	14.94

CNG = compressed natural gas.
Source: Authors' estimates

It is evident that the very low gas tariffs, inadequate gas revenues, and the lack of proper gas revenue management system, are not conducive to economic growth and equitable distribution of the benefits of natural gas. It is estimated that current gas revenue of $300 million per year can be increased to $2.9 billion per year if gas is priced at the average gas price in India and Pakistan (Gunatilake and Raihan [Forthcoming])). The general observation is that tariff rates are significantly below the economic value of gas in all sectors, and that government pricing policy has focused mainly on electricity production, while discouraging other sectors. Consensus is being built across all studies examined on the need for alignment with market prices, as well as on the need for a reevaluation of government priorities in gas allocation. Overall, the low tariff rates have created gas shortages due to excess demand and underinvestment, that the benefits of these low rates are unequally distributed.

III. POWER SECTOR OVERVIEW

Inefficient pricing and allocation of natural gas are closely linked with the performance of the power sector. Access to power in Bangladesh is limited to about 45%–50% of the population and those who have access faces severe power shortages. Load shedding in Dhaka in 2011 and during the summer of 2012 was about 5 hours per day. Power shortages have constrained the potential economic growth in Bangladesh and cost of which have been estimated to be about 0.5% of GDP. According to "Vision 2021"—the government's policy statement—the government's vision for the power sector is to ensure universal access to grid electricity by the year 2020, with an interim target to reach an access level of 68% by year 2015. According to government estimates, about 20,000 megawatts (MW) of new generation capacity need to be added to the system by 2020, together with matching transmission and distribution improvements to reach the universal access.

Key characteristics of the power sector of Bangladesh include: (i) supply–demand imbalance; (ii) over-reliance on a single source of energy—natural gas; (iii) limited access to electricity and low consumption; and (iv) poor grid reliability and medium to high system losses. The available power generation capacity in Bangladesh by June 2011 was 4,890 MW, whereas the estimated unconstrained demand was 6,765 MW, leaving about 30% of the peak demand unmet. Load shedding is required in certain areas owing to capacity constraints in generation. Transmission and distribution constraints exacerbate the situation. Natural gas accounted for about 81% of generation in 2011. The balance was generated by diesel (8%), fuel oil (6%), coal (2%), and hydropower (3%).

The major challenges in the power sector of Bangladesh are: (i) providing universal access to power; (ii) providing good quality and reliable power supply; (iii) ensuring gas availability for generation; (iv) long-term energy security and fuel diversity; (v) cost recovery and financial sustainability of power sector agencies; and (vi) mainstreaming renewable energy. Providing access to the grid for the remaining 50% of the population is one of the main challenges faced by the sector. This requires construction of new power plants, streamlining maintenance and improving the efficiency of existing power plants. Heavy dependence on natural gas has provided much needed electricity at lower cost, allowing Bangladesh to report lower production costs of electricity compared with other countries. The declining reserves of gas, however, has curtailed the operation of some power plants and delayed construction of others. Tariff revisions have so far been unable to bring the electricity prices to cost-recovery level.

The Bangladesh Power Development Board (BPDB) is the largest single institution in the energy sector, with 53% of power generating capacity, which includes power generation by BPDB and its subsidiary companies. BPDB's average bulk electricity supply cost and its average bulk selling rate to distribution entities are presented in Table 6. Independent power producer (IPP) tariffs paid by BPDB average 3.52 Taka (Tk) per kilowatt-hour (kWh), (for FY2011, 18% increase over FY2010). Small IPPs and rental power plant paid by BPDB average Tk7.30 per kWh, (for FY2011, 353% increase over FY 2010). BPDB's own units charge an average Tk2.6 per kWh. BPDB's average (pooled) bulk electricity supply cost is Tk4.20 per kWh (against Tk2.68 per kWh in 2010, corresponding to a 57% increase).

Table 6: Current Cost of Electricity Generation (FY2011)

Generating Plant/Fuel	Installed Capacity (MW)	Generation (GWh)	Plant Factor (%)	Generation Cost Tk million	Generation Cost Tk/kWh
IPP	1,231	8,564.02	79.53	30,142.30	3.52
Furnace Oil Based	105	748.58	81.39	8,877.75	11.86
Gas Based	1,126	7,815.44	77.66	21,264.55	2.72
Small IPP and Rental	1,709	6,247.63	42.69	45,635.60	7.30
Furnace Oil Based	410	740.97	23.18	6,684.81	9.02
Diesel Based	535	1,899.17	43.17	28,499.54	15.01
Gas Based	764	3,607.48	61.73	10,451.25	2.90
Public	864	8,788.08	80.92	15,846.28	1.80
Gas Based	864	8,788.08	80.92	15,846.28	1.80
BPDB	2,688	9,212.69	33.50	23,988.33	2.60
Hydro	230	875.60	43.46	894.43	1.02
Coal	220	779.60	46.98	4,318.06	5.54
Furnace Oil Based	170	290.54	19.51	4,517.49	15.55
Diesel Based	161	274.96	13.89	6,294.73	22.89
Gas Based Plants	2,297	8,062.13	43.16	16,799.17	2.08

BPDB = Bangladesh Power Development Board, GWh = gigawatt-hour, IPP = independent power producers, kWh = kilowatt-hour, MW = megawatt, Tk = taka.
Source: BPDB (2012)

BPDB bulk power sales create losses of Tk1.70 per kWh aggregating to losses of about Tk36,190 million (about $450 million) in 2011. In FY2010, the losses were Tk0.29 per kWh. The increase in bulk energy sales (GWh) in FY2011 was 7.5% over the previous year. A key requirement of a healthy financial position of utilities is cost reflective pricing. As shown in Table 7, this basic cost recovery has not been achieved in the power sector even with heavily subsidized gas was used for the bulk of power generation. This poor financial performance does not allow utilities to generate adequate revenue to invest in the sector for improving much needed access to electricity.

Table 7: Estimated BPDB Losses Due to Inadequate Tariff Structure (FY2011)

Bulk Consumer	% of Sales	Sales Unit million kWh	Average Selling Price Tk/kWh	Average Supply Cost Tk/kWh	Losses Per Unit Tk/kWh	Total Losses Tk million
DPDC	20.83	5,964.05				
DESCO	10.91	3,122.74				
WZPDCL	6.44	1,842.52	2.50[1]	4.20	(1.70)	36,190
REB	36.19	10,359.41				
Sub total	74.37	21,288.72				
BPDB own distribution	25.63					
Total	**100.00**					

BPDB = Bangladesh Power Development Board, DESCO = Dhaka Electricity Supply Company, DPDC = Dhaka Power Distribution Company, kWh = kilowatt-hour, REB = Rural Electricity Board, Tk = taka, WZPDCL= Western Zone Power Distribution Company.
Source: BPDB (2012)

1 Bulk Energy Sales in 2011 was 28,627 GWh (Page 6) and the corresponding revenue Tk71,528.45 million (Page 85); BPDB Annual Report, 2012.

Electricity, priced at less than production cost, leads to excess demand and shortages, and exacerbates the gas shortages. Subsidized gas is provided to generate electricity with the assumption that the poor benefit from the indigenous resource. However, since rural electrification rates are far below urban rates, the majority of the rural poor are not benefited from tariffs in electricity or gas, other than indirectly through consumption of products such as fertilizer. An increase in price which would strengthen the gas and power sectors' balance sheets, allowing for greater reinvestment, which in turn could alleviate energy poverty by increasing the access to electricity for the rural populations.

IV. POLICY SCENARIOS

To assess the long term impacts of policy reforms of Bangladesh's energy sector generally, its natural gas sector in particular, we use a dynamic economic forecasting model. This inter-temporal decision tool is designed to trace detailed interactions among demand, supply, and resource use within economies and in their trade with the global economy. In today's world, economic linkages are so complex that it is unlikely that policy makers relying on intuition alone will achieve any reasonable results. Indeed, much evidence now suggests that indirect effects of many policies outweigh direct effects and, if not adequately understood, can substantially offset or even reverse them. Because of their ability to capture exactly such linkages, computable general equilibrium (CGE) models have become preferred tools for tracing supply and demand linkages across extended chains of price-directed exchanges. Because of their detailed behavioral specification, these models are particularly good at elucidating adjustments in income distribution and structure of the economy.

The model we use here was calibrated to a new social accounting matrix (SAM), estimated for Bangladesh as of the year 2010. The general structure of the Bangladesh CGE and SAM are summarized in Appendix 1, but suffice for the present to describe the combination of these as a dynamic economic forecasting model that permits assessment of alternative policy scenarios for the country. In the present study, we used it to evaluate several leading issues related to the country's natural gas policy, although these comprise only a few of the issues that can be addressed with this framework. The following table presents seven scenarios considered in the context of natural gas and power sector issues discussed in the preceding sections.

Table 8: Policy Scenarios

	Scenario	Description
1	Baseline	Business-as-usual reference trends. No policy changes.
2	MKT	Equalize natural gas prices across all uses, using a reference market price from India and Pakistan (Tk 5/m^3)
3	MKTEE	Scenario 2, combined with 1% annual increases in average energy use efficiency.
4	Fert	Scenario 3, but fertilizer is exempt from price reform.
5	Coal50	Imported coal is used to meet 50% of domestic electric power production.
6	GasExp	Natural gas marketing at world prices is permitted up to 10% of domestic use.
7	GasCoal	Scenario 6 combined with domestic coal for 50% of domestic electric power.
8	InfDev	Infrastructure investment increased with half of new natural gas marketing revenues.

m^3 = cubic meter, Tk = taka.
Source: Compiled by authors

First, we evaluate a baseline or business-as-usual scenario across the forecast period (2010–2030). This assumes no change in current policies and stable trends in global prices, and we use it as a dynamic reference case for the policy alternatives considered. In the second scenario (MKT), we assume the government removes administered price interventions in domestic natural gas markets, eliminating the price dispersion seen in Figure 4 and increasing the price to Tk5/m^3. Because Bangladesh both subsidizes and taxes gas, depending on the use, removing price distortions will increase prices for some economic actors and lower them for others. The net result for the economy as a whole is an empirical question (indeed an interesting one in itself), that is of great relevance to the country's overall economic performance.

Generally speaking, the patterns of price adjustment that emerge from the MKT scenario suggest that energy costs will rise for the economy as a whole, conferring small welfare costs under existing patterns of technology use. If however, the economy were to react to higher energy prices by increasing efficiency, these costs could be averted. Historically, energy subsidies in most countries have been associated with low efficiency levels, while higher energy prices appear to induce conservation behavior and technology adoption that can substantially improve energy efficiency, saving money while stimulating innovation and growth. To assess the potential of such responses to offset the welfare costs by removing Bangladeshi energy subsidies, as well as contribute to sustainable growth objectives, we examine a third scenario (MKTEE) that implements the same gas pricing policy in MKT but assumes that the economy responds with very modest, but sustained 1% annual improvement in overall energy use efficiency. In many industrial economies, these efficiency improvements have exceeded the assumed rate for decades, and given the relatively low initial energy efficiency levels in Bangladesh today, we believe this is a modest expectation for induced conservation and new technology adoption.

A fourth scenario is intended to represent another important dimension of the country's natural gas policy dialogue, price policies for the fertilizer industry. As mentioned in previous sections, because natural gas is a primary input to another primary input (fertilizer), believed to contribute to food security and benefit the poor, this may deserve some special consideration. However, as evident from the gas sector review, gas supply to fertilizer production is declining and whenever gas shortages are experienced, fertilizer sector gas supply is the first to stop. The fourth (Fert) scenario is the same as MKTEE, except that fertilizer gas subsidies are retained at baseline levels.

Scenario five (Coal50) represents another leading natural gas policy issue, the argument that less expensive coal should be used as a substitute for natural gas to generate the country's electric power. Although this would increase Bangladesh's import bill, it would also hold the potential reduced cost across the economy, improving export competitiveness, and raising real incomes. For this scenario, we assume that electric power investments shift at comparable fixed cost from gas to coal over the 20-year period under consideration, achieving 50% replacement of gas-fired capacity by 2030.

The sixth scenario (GasExp) represents the obverse of the coal import story. Even though global natural gas prices have fallen substantially in recent years, they remain well above domestic prices and significantly so, on a trended basis. For this reason, subsidized gas use in Bangladesh has a high opportunity cost, in terms of foreign exchange and government revenues that might be earned by collecting resource rents at optimal level. For the sake of illustration, we assume Bangladesh export at 10% of annual total supply of gas. This scenario is

intended to support dialogue on this important choice facing the country—selling the gas at international market price—with better evidence.

The seventh scenario combines all the components of a new energy agenda for the country, uniform domestic market prices for gas (except to the fertilizer sector), modest energy efficiency, 10% natural gas pricing at the international market price, and partial coal substitution for gas in electric power generation, but this time with domestic coal. Because this substitution would require a very substantial increase in domestic coal production, we estimate it can only be competitive to about a 25% fuel share, with the rest imported.

The eighth scenario assumes that 50% of augmented natural gas revenues are invested on physical and social infrastructure. Motivation for this comes from Hartwick's rule, which says that sustaining an economy dependant on an exhaustible resource requires investing the resource rent on reproducible capital (Hartwick 1977). Even if the gas prices are increased without proper revenue management regime, this may not necessarily have the expected positive impacts. This last scenario examines the economy-wide impacts of gas price increase and investing the revenue on physical and social infrastructure such as power plants, roads, water supply and sanitation, schools, and hospitals.

V. AGGREGATE RESULTS

Applying the Bangladesh dynamic forecasting model to the eight scenarios described above, we obtained the results summarized in Table 9:

Table 9: Macroeconomic Results
(% change from Baseline in 2030)

	MKT	MKTEE	Fert	Coal50	GasExp	GasCoal	InfDev
Real GDP	−0.5	1.5	4.0	4.5	7.7	24.6	81.9
HH Real Income	−0.5	1.1	3.7	3.7	6.5	20.2	63.0
Real Consumption	−0.5	1.1	3.8	3.8	6.8	21.6	71.9
Exports	−1.4	1.0	3.3	4.7	10.6	27.9	80.5
Imports	0.5	0.6	2.2	1.9	9.4	22.1	59.3
CPI	−0.3	−0.1	−1.0	−1.3	2.1	0.1	−6.7
Real Wage	−0.3	0.5	1.5	1.1	5.6	10.2	21.7
Rental	−3.5	−1.3	−1.3	−2.7	0.6	0.5	2.9
Revenue	12.5	13.2	6.5	14.1	17.2	24.2	62.9
CO_2 Emissions	−3.1	−5.8	−3.5	19.5	23.1	34.1	121.3

CO_2 = carbon dioxide, CPI = consumer price index, GDP = gross domestic product, HH = household.
Note: Revenue measures the change in government revenue collection, assuming a constant real government budget balance across scenarios.
Source: Authors' estimates

A number of salient findings emerge from these results, those that would likely be robust against reasonable uncertainty regarding external events and the degree of behavioral response. First, removing Bangladesh's long established price supports for domestic natural gas, while politically difficult, would not significantly undermine the country's long-term economic growth. Even without the kind of private efficiency responses and complementary policies considered here, the economy's overall GDP would only be 0.5% smaller, 2 decades from now. Of course there can be many dramatic structural adjustments beneath the smooth veneer of

macroeconomic advocates, but clearly energy price subsidies are not essential to the country's overall progress. Indeed, the baseline scenario assumes stable resource costs, while we know that the country's gas reserves are threatened by continued subsidies and trend usage patterns. These two facts, combined with fiscal sustainability questions, suggest that the baseline scenario itself may be too optimistic. The revenue impact of this scenario suggests that the government could reduce tax collections over 12% by 2030 if gas prices were increased to average gas price in India and Pakistan. In the long run, CPI also registers a minor decline mainly due to economic contraction.

The second scenario reminds us that raising average resource costs has an adverse aggregate welfare effect on the economy as a whole, but what level of conservation and new energy efficiency (EE) would be needed to offset this? The answer might be surprising to subsidy advocates, but in fact only very modest EE improvement, 1% per year for electricity use, would convert unsustainable price supports and resource depletion into a more sustainable, growth-oriented story. Again, these kinds of improvements are well within reach by even the most advanced economies (e.g., California averaged 1.4% EE improvement during 1972–2006). For a developing country like Bangladesh, where inefficiency is a widespread and chronic legacy of underinvestment and adverse incentives, the potential for improvement is far greater. So too would be the attendant growth benefits.

Exempting the fertilizer sector would more than offset the aggregate welfare costs of natural gas price reform. The reason for this is simple, fertilizer is not merely an input to agriculture but something that increases its productivity. Making this productive input less expensive reduces cost of living, especially for lower-income groups for whom food is a dominant budgetary category (note the relatively large CPI decline). In addition to notable real income increase, subsidized gas for fertilizer production provides higher level of growth, perhaps due to the significant contribution of agriculture sector to the economy. It is important that this indirect (gas input) subsidy not promote unsustainable patterns of fertilizer application.

Even though it may take time to introduce fuel sources other than gas for power production, diversifying the fuel mix in power sector is a critical need for long term energy security in Bangladesh. Many have observed that coal would be a more cost effective fuel for Bangladesh's electric power sector. Our results (Coal50) strongly support this reasoning, suggesting that gas can generate better economic values in household cooking, transport, and industry sectors. Gunatilake, Haque, and Weerahewa (Forthcoming) also confirms the higher value addition of gas in household cooking, transport, and fertilizer sectors. Using coal for electricity generation would make gas available for more productive sectors. Indeed, making coal a primary electric power fuel would reduce domestic energy costs and allow the economy to experience higher real consumption, savings, and investment among households and enterprises. Switching to more cost-effective electric power while reforming gas prices to respond to market forces would take real Bangladeshi GDP 5% higher by 2030. The growth increment would be about 25% under combined impacts of gas price increase, energy efficiency improvement, fertilizer subsidy, together with diversification of the fuel mix in power sector.

Fuel source diversification with coal is not without additional cost. The carbon emissions increase by about 20% from the baseline. It may also be observed that, despite its negative environmental reputation, electric power would be a good place to introduce coal, as its emissions would be more concentrated and thereby easier to monitor and manage. In distributed use, e.g., transport, household heating, and cooking, gas would be more appropriate for converse reasons. The coal scenario results highlight one of the major development challenges facing developing countries: using cost effective fuel to enhance development result

in more carbon emissions. This problem can be ameliorated to some extent by using clean coal technologies such as super critical and ultra-critical coal technologies. Carbon capture and storage is another feasible technology but its cost may offset the advantages of cheap fuel.

The sixth scenario asks the energy trade question from the opposite perspective, what is the growth opportunity cost of restricting export sales for Bangladesh natural gas. Our results are unambiguous on this point; even modest sales concessions (10% of domestic supply) would significantly increase the country's aggregate income, employment, and trade. By realizing market prices for at least a fraction of the nation's mineral resources, Bangladesh increases national wealth while promoting more sustainable domestic resource use. While gas exports improve most of the macroeconomic indicators, it also increases carbon emissions. This is mainly due to use of other carbon-intensive fuels in place of gas. Even though we consider gas export for the purpose of illustration, this policy option is not politically feasible given energy security concerns. However, similar impact can be expected selling gas at international market prices locally. In this case, incremental increase in carbon emissions (from scenario 5) may not happen.

The seventh scenario deploys all the gas policy reform measures considered, and the long-term benefits for real growth and incomes, when combined with domestic coal sourcing, are more than additive. This finding makes it clear that energy policy reform, to be most effective, should be a multifaceted exercise. This will more effectively distribute adjustment burdens and animate new economic potential, allowing the country to rise to a higher long-term trajectory of growth and development.

Finally, scenario 8 shows the benefits of following Hartwick's rule, investing the gas revenue on reproducible capital. The public investment scenario reminds us of the productivity and growth dividends from infrastructure investment. Reducing trade and transport margins (CPI drops nearly 7%, and real incomes rise accordingly) improve private profitability across the economy, resulting in substantially higher GDP. This strategy also appears to be very beneficial to the public sectors whose fiscal revenues increase over 60% by 2030. Infrastructure expansion and additional growth also release more carbon emission to the atmosphere, demonstrating the typical development dilemma facing developing nations in their efforts to meet energy requirements.

Environmental impacts of the policies considered would vary, with atmospheric emissions depending on fuel switching, efficiency measures, and aggregate growth. In this case, both gas market reforms and energy efficiency reduce CO_2 and other greenhouse gas (GHG) emissions, while coal substitution increases emission intensity and growth does too. These tradeoffs represent a dilemma for all developing countries, but there are now a wide range of technology choices to address this. The growth and revenue dividends in some of these scenarios suggest that there could be substantial opportunities for complementary mitigation and clean-up policies.

VI. HOUSEHOLD RESULTS

Even though Bangladesh's population is predominately rural and predominately low income, there are important sources of economic diversity in the country. Measured in Table 10 by a basic aggregate welfare measure, real consumption, we can see how the eight scenarios will affect different households according to where they are in income distribution, in supply chains,

labor markets, and where they live. Note that these results are cumulative, measuring the change in total household real consumption over the whole period considered (2012–2030).

Results are difficult to generalize, but a quick glance at the results in Table 13 shows the most of the policy scenarios affect different groups similarly. An important message from the first two scenarios is that energy efficiency can produce savings that offset higher energy price costs for every household category. This does not mean that households can accomplish this alone, because part of the benefit is lower energy price trends from aggregate conservation. It does mean, however, that conservation and energy efficiency promotion should be an integral part of any policies intended to achieve effective gas price reform.

Meanwhile, a food-oriented policy (Fert) falls somewhat uniformly in comparison to energy diversification and export policies. Of course rural dwellers are poorer, but monetized food costs are a larger proportion of rural household budgets, and reducing cost of production in agriculture generally benefits rural and urban populations similarly. Thus, all households benefit from the indirect food subsidy coming from cheap gas for fertilizer production.

Table 10: Household Real Consumption
(cumulative % change, 2012–2030)

	MKT	MKTEE	Fert	Coal50	GasExp	GasCoal	InfDev
Baripur Rural	−0.5	0.7	2.2	2.2	4.1	12.0	37.1
Baripur Urban	−0.6	0.5	1.9	1.8	4.0	11.6	36.3
Chittagong Rural	−0.5	0.7	2.3	2.3	4.2	12.6	38.7
Chittagong Urban	−0.6	0.5	1.7	1.6	3.8	11.5	36.5
Chittagong SMA	−0.5	0.6	2.0	2.0	4.1	12.2	38.0
Dhaka Rural	−0.5	0.7	2.2	2.3	4.3	12.1	36.9
Dhaka SMA	−0.5	0.5	1.9	1.9	3.8	11.6	37.4
Dhaka Urban	−0.6	0.5	1.8	1.7	3.8	11.4	36.0
Khulna SMA	−0.5	0.6	2.1	2.1	4.2	12.4	38.6
Khulna Urban	−0.6	0.5	1.8	1.7	3.9	11.6	36.4
Kulna Rural	−0.5	0.7	2.4	2.5	4.5	12.7	38.4
Rajshahi Rural	−0.5	0.8	2.5	2.5	4.9	14.3	42.8
Rajshahi SMA	−0.7	0.6	1.9	1.8	4.1	11.8	36.6
Rajshahi Urban	−0.6	0.5	1.9	1.9	4.5	13.4	41.0
Sylhet Rural	−0.6	0.7	2.1	2.2	4.2	12.1	37.5
Sylhet Urban	−0.6	0.3	1.4	1.2	3.4	10.3	33.2
Weighted Average	−0.5	0.7	2.2	2.2	4.3	12.6	38.8
Min	−0.70	0.30	1.40	1.20	3.40	10.30	33.20
Max	−0.50	0.80	2.50	2.50	4.90	14.30	42.80
std	0.070189	0.123669	0.274398	0.34364	0.341924	0.880884	2.107148

SMA = standard metropolitan area.
Source: Estimates by authors

Energy fuel diversification (Coal50) affects households quite diversely because of large differences in baseline household electricity use. As was mentioned in the introductory sections of this paper, electrification remains a work in progress across the country, and until it is complete the benefits of more affordable electricity policies will affect quite unequally across Bangladesh. For the gas export policy, we are seeing essentially a macroeconomic impact on average domestic energy prices and aggregate foreign savings. Both of these are positive, but distribution of impacts is fairly neutral on households. Combining the two energy trade policies

provide higher benefits for all households, which are less than additive but about average in terms of distributional incidence.

The most significant benefits accrue when the growth dividends of energy policy reform—augmented gas revenues—are reinvested in infrastructure (InfDev scenario). Here we see that infrastructure can improve market access, the main gateway out of poverty for both rural and urban poor, and increase the profitability of investment for higher income groups. Given the heterogeneous infrastructure constraints facing different groups, the income impact is diverse. However, all the differences discussed here are minor and most of the people benefit from energy pricing reform and other policies.

VII. CONCLUSIONS

Bangladesh today faces a different future than it did decades ago when relatively abundant natural gas seemed to be the key to prosperity. Known reserves are not expected to last more than 2 decades on current use trends, energy price policies appear to seriously undermine energy security and economic efficiency, and the fiscal costs of those policies pose serious questions. To support more evidence-based dialogue on energy development, allocation, and pricing reform, this study uses a detailed economic forecasting model to evaluate leading energy issues facing Bangladesh. This study uses this model to evaluate a variety of policy options that are under active discussion and consideration by public and private stakeholders. In particular, we consider reforms that would make gas prices more market determined and uniform across private uses, as well as energy efficiency potential, the special nature of the fertilizer sector to receive subsidized gas, coal substitution for electric power generation, and the prospect of exporting part of the country's natural gas reserves at more competitive international prices, and investing augment gas revenues for infrastructure development.

The relatively small negative growth impact of increased energy price can be easily counteracted by economy-wide increase in energy efficiency. Quite contrary to the general expectation, the gas price increase without supplementary policies of energy efficiency or fertilizer subsidy does not increase inflation. This is due to the contractionary effect of gas price increase. Subsidized gas for fertilizer production more than compensates the negative economic impact of high gas price through its productivity impact in agriculture. Diversification of power sector fuel mix by introducing coal provides good macroeconomic indicators, but result to higher carbon emissions. Investing the gas revenue in infrastructure provides the best macroeconomic indicators. This best policy option, however, further increases carbon emissions. The impacts of these different policies in terms of increased household income are more or less equally distributed among different groups.

Polices considered in this study are quite diverse, but all have important implications for the country's energy sector, particularly in terms of economy-wide efficiency, equity, and sustainability. Our results suggest that, although its energy future is more challenging than in the early days of gas abundance, Bangladesh has many options for energy policy reform for a sustainable future. To realize the vast human and economic potential of this country, more balanced consideration of political and economic criteria will be essential. Because most of the attractive policy options have the drawback of higher carbon emissions, supplementary policies and suitable technology adoption should play a balancing role.

ANNEX 1: SUMMARY OF THE BANGLADESH CGE MODEL

The Bangladesh computable general equilibrium (CGE) model is in reality a constellation of research tools designed to elucidate economy–environment linkages in Bangladesh. This section provides a brief summary of the formal structure of the Bangladesh model. For the purposes of this report, the 2010 Bangladesh social accounting matrix (SAM) was aggregated along certain dimensions. The detailed equations of the model are completely documented elsewhere (Guntilake, Raihan, and Roland-Holst 2012), and for the present we only discuss its salient structural components.

A.   Structure of the CGE Model

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economywide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the general algebraic modeling system (GAMS) programming language, and calibrated to the new Bangladesh SAM estimated for the year 2010.[1] The result is a single-economy model calibrated over the 20-year time path from 2010 to 2030.[2]

---

[1]   See e.g., Meeraus et al (1992) for GAMS.

[2]   The present specification is one of the most advanced examples of this empirical method, already applied to over 50 individual countries and/or regions.

B.   Production

All sectors are assumed to operate under constant returns-to-scale and cost optimization. Production technology is modeled by a nesting of constant elasticity of substitution (CES) function.

In each period, the supply of primary factors—capital, land, and labor—is usually predetermined.[3] The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.[4] Once the optimal combination of inputs is determined, sector output prices are calculated assuming competitive supply conditions in all markets.

Consumption and Closure Rule. All income generated by economic activity is assumed to be distributed to consumers. Each representative consumer allocates optimally his/her disposable income among the different commodities and saving. The consumption/saving decision is completely static: saving is treated as a "good" and its amount is determined simultaneously with the demand for the other commodities, the price of saving being set arbitrarily equal to the average price of consumer goods.

The government collects income taxes, indirect taxes on intermediate inputs, outputs, and consumer expenditures. The default closure of the model assumes that the government deficit/saving is exogenously specified.[5] The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

C.   Trade

Goods are assumed to be differentiated by region of origin. In other words, goods classified in the same sector are different according to whether they are produced domestically or imported. This assumption is frequently known as the Armington assumption. The degree of substitutability, as well as the import penetration shares are allowed to vary across commodities. The model assumes a single Armington agent. This strong assumption implies that the propensity to import and the degree of substitutability between domestic and imported goods is uniform across economic agents. This assumption reduces tremendously the dimensionality of the model. In many cases this assumption is imposed by the data. A symmetric assumption is made on the export side where domestic producers are assumed to differentiate the domestic market and the export market. This is modeled using a constant elasticity of transformation (CET) function.

---

[3]   Capital supply is to some extent influenced by the current period's level of investment.
[4]   For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium prices to be determined by the model.
[5]   In the reference simulation, the real government fiscal balance converges (linearly) towards 0 by the final period of the simulation.

D.   Dynamic Features and Calibration

The current version of the model has a simple recursive dynamic structure as agents are assumed to be myopic to base their decisions on static expectations about prices and quantities. Dynamics in the model originate in three sources: (i) accumulation of productive capital and labor growth; (ii) shifts in production technology; and (iii) the putty/semi-putty specification of technology.

E.   Capital Accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sector level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total savings generated by the economy, consistent with the closure rule of the model.

F.   The Putty/Semi-putty Specification

The substitution possibilities among production factors are assumed to be higher with the new than the old capital vintages—technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (e.g., the imposition of an emissions fee), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

G.   Dynamic Calibration

The model is calibrated on exogenous growth rates of population, labor force, and gross domestic product. In the so-called Baseline scenario, the dynamics are calibrated in each region by imposing the assumption of a balanced growth path. This implies that the ratio between labor and capital (in efficiency units) is held constant over time.[6] When alternative scenarios around the baseline are simulated, the technical efficiency parameter is held constant, and the growth of capital is endogenously determined by the saving/investment relation.

H.   Emissions

The Bangladesh dynamic CGE model captures emissions from production activities in agriculture, industry, and services, as well as in final demand and use of final goods (e.g., appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. We model both CO_2 and the other primary greenhouse gases, which are converted to CO_2 equivalent. Following standards set in the research literature, emissions in production are modeled as factor inputs. The base version of the model does not have a full representation of

---

[6] This involves computing in each period a measure of Harrod-neutral technical progress in the capital–labor bundle as a residual. This is a standard calibration procedure in dynamic CGE modeling.

emission reduction or abatement. Emissions abatement occurs by substituting additional labor or capital for emissions when an emissions tax is applied. This is an accepted modeling practice, although in specific instances it may either understate or overstate actual emissions reduction potential (Babiker, Gilbert, and Reilly (2001). In this framework, emission levels have an underlying monotone relationship with production levels, but can be reduced by increasing use of other productive factors such as capital and labor. The latter represent investments in lower intensity technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource-use levels.

Table A1.2: Emission Categories

Air Pollutants		
1.	Suspended particulates	PART
2.	Sulfur dioxide (SO_2)	SO_2
3.	Nitrogen dioxide (NO_2)	NO_2
4.	Volatile organic compounds	VOC
5.	Carbon monoxide (CO)	CO
6.	Toxic air index	TOXAIR
7.	Biological air index	BIOAIR
8.	Carbon Dioxide (CO_2)	
Water Pollutants		
8.	Biochemical oxygen demand	BOD
9.	Total suspended solids	TSS
10.	Toxic water index	TOXWAT
11.	Biological water index	BIOWAT
Land Pollutants		
12.	Toxic land index	TOXSOL
13.	Biological land index	BIOSOL

Source: Compiled by authors

The model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table A1.2. Our focus in the current study is the emission of CO_2 and other greenhouse gases, but the other effluents are relevant to a variety of environmental policy issues.

An essential characteristic of the Bangladesh dynamic model's approach to emissions modeling is endogeneity, i.e., emission rates vary with behavioral decisions about fuel mix and efficiency (technology adoption and use). This feature is essential to capture structural adjustments arising from market-based climate policies such as Pigouvian taxes or cap and trade, as well as the effects of technological change.

ANNEX 2: SUMMARY OF THE BANGLADESH SOCIAL ACCOUNTING MATRIX

Table A2.1: Institutions in the 2010 Bangladesh Social Accounting Matrix

Institution	Definition	
aCereal	Activity	Wheat, Rice, Millet, and other Grains
aCrops	Activity	Other Crops
aLvstk	Activity	Livestock
aOthAg	Activity	Other Agricultural Goods and Services
aCoal	Activity	Coal Extraction and Trade
aOil	Activity	Petroleum Extraction and Trade
aGas	Activity	Natural Gas Extraction and Trade
aMinrl	Activity	Mineral Mining
aMeatD	Activity	Meat and Dairy
aFoodPr	Activity	Other Food Processing
aTxtApp	Activity	Textile and Apparel
aManuf	Activity	Other Manufacturing
aChem	Activity	Chemicals
aMetal	Activity	Metal Products
aElect	Activity	Electricity
aGasDist	Activity	Natural Gas Distribution
aWater	Activity	Water
aConst	Activity	Construction
aTrade	Activity	Wholesale and Retail Trade
aTransp	Activity	Transportation Services
aComm	Activity	Communications
aBusServ	Activity	Private Services
aPubServ	Activity	Public Administration
kCereal	Commodity	Wheat, Rice, Millet, and other Grains
kCrops	Commodity	Other Crops
kLvstk	Commodity	Livestock
kOthAg	Commodity	Other Agricultural Goods and Services
kCoal	Commodity	Coal Extraction and Trade
kOil	Commodity	Petroleum Extraction and Trade
kGas	Commodity	Natural Gas Extraction and Trade
kMinrl	Commodity	Mineral Mining
kMeatD	Commodity	Meat and Dairy
kFoodPr	Commodity	Other Food Processing
kTxtApp	Commodity	Textile and Apparel
kManuf	Commodity	Other Manufacturing
kChem	Commodity	Chemicals
kMetal	Commodity	Metal Products
kElect	Commodity	Electricity
kGasDist	Commodity	Natural Gas Distribution
kWater	Commodity	Water
kConst	Commodity	Construction
kTrade	Commodity	Wholesale and Retail Trade
kTransp	Commodity	Transportation Services
kComm	Commodity	Communications
kBusServ	Commodity	Private Services
kPubServ	Commodity	Public Administration
Land	Factor	Land
UnSkil	Factor	Unskilled Labor
Skill	Factor	Skilled Labor
Captl	Factor	Capital
natrs	Factor	Natural Resources
indtx	Fiscal	Indirect Taxes
fctts	Fiscal	Factor Taxes
dirtx	Fiscal	Income Taxes
imptx	Fiscal	Import Tariffs
exptx	Fiscal	Export Taxes

Institution	Definition	
ent	Institution	Enterprises
BariRur	Household	Barishal Rural
BariUrb	Household	Barishal Urban
ChitRur	Household	Chittagong Rural
ChitUrb	Household	Chittagong Urban
ChitSMA	Household	Chittagong SMA
DhakaRur	Household	Dhaka Rural
DhakaUrb	Household	Dhaka Urban
DhakaSMA	Household	Dhaka SMA
KulnaRur	Household	Kulna Rural
KhulnaUrb	Household	Khulna Urban
KhulnaSMA	Household	Khulna SMA
RajRur	Household	Rajshahi Rural
RajUrb	Household	Rajshahi Urban
RajSMA	Household	Rajshahi SMA
SylhetRur	Household	Sylhet Rural
SylhetUrb	Household	Sylhet Urban
inv	Institution	Capital Account
gov	Institution	Government
row	Institution	Rest of World

SMA = standard metropolitan area.
Source: Compiled by authors

REFERENCES

Ahmed, A. and I. Mahbub Uddin. 2008. *Global Forest Coalition, Underlying Causes of Deforestation and Forest Degradation in Bangladesh.* Last modified August 2008 (accessed 12 April 2012).

Asian Development Bank. 2010. *Natural Gas Pricing in Bangladesh: A Preliminary Assessment.* Last modified 25 November 2010 (accessed 12 April 2012).

Babiker, M., E. M. Gilbert, and J. Reilly. 2001. Distortionary Taxation in General Equilibrium Climate Modeling, Paper prepared for the Fourth Annual Conference on Global Economic Analysis, Purdue University W. Lafayette, IN. 27–29 June.

Bartel, A. P., and L. G. Thomas. 1985. Direct and Indirect Effects of Regulation. *Journal of Law and Economics* 28(1): 42–58.

Bergman, David. 2011. *Asia Calling, Bangladesh Opens its Gas Fields to US Company.* Last modified 31 December 2011 (accessed 12 April 2012).

BPDB 2012, Annual Report, Bangladesh Power Development Board, www.bpdb.gov.bd/.../annual_report/ANNUAL_REPORT__2011-2012.PDF

British Petroleum. 2008. Statistical Review of Global Energy, www.bp.com/.../globalbp/ globalbp.../statistical_energy_review_2008/.../statistical_review_of_world_energy_full_re view_2008.pdf, Accesed 12 April 2012

———. 2009. *Statistical Review of Global Energy.* www.bp.com/.../bp.../2009.../ statistical_review_of_world_energy_full_report_2009.pdf

———. 2010. *Statistical Review of Global Energy.* http://www.bp.com/assets/bp_internet/ globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review _2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full _report_2011.pdf

———.2011. *Statistical Review of Global Energy.* www.bp.com/content/.../bp/.../ statistical_review_of_world_energy_2013.pdf

Chowdhury, Syed Tashfin. 2011. Bangladesh Gas Find Boosts Supply Hopes. 4 October. *Asia Times.*

CIA World Factbook, Bangladesh. 2009. Last modified 2009 (accessed 12 April 2012).

Dixit, Avinash. 1986. Comparative Statics for Oligopoly. *International Economic Review* 27(1): 18–32.

Gunatilake, H., E. Haque, and J. Weerahewa. Forthcoming Economic Values and Allocation of Natural Gas Among Different Sectors in Bangladesh: Is the Current Allocation Efficient? Forthcoming as a South Asia Department (SARD) working paper, Asian Development Bank, Manila.

Guntilake, H., S. Raihan, and D. Roland-Holst. 2012. A Dynamic CGE Model for Bangladesh: Technical Documentation, Working Paper, Department of Agricultural and Resource Economics, University of California, Berkeley.

Gunatilake, H., and S. Raihan. Forthcoming. Opportunity Cost of Natural Gas Subsidy in Bangladesh. South Asia Working Paper Series. Manila: Asian Development Bank.

Hartwick, J. M. (1977), "Intergenerational Equity and the Investing of Rents from Exhaustible Resources." *American Economic Review* 66:972–974.

IEA. 2011. *Energy For All: Financing Access for the Poor*. International Energy Agency, Paris.

———. 2012. World Energy Outlook. International Energy Agency, Paris.

Imam, Badrul. 2002. *Banglapedia, Gas, Natural.* Accessed 12 April 2012. http://www.banglapedia.org/httpdocs/HT/G_0045.HTM

Islam, Ifty. 2008a. Asian Tigers Capital Partners, Can Bangladesh be the Next Asian Tiger? Powerpoint Presentation in Dhaka. Accessed 12 April 2012.

———. 2008b. The Federation of Bangladesh Chambers of Commerce and Industry, Maximizing Growth for Bangladesh: A Private Sector Vision. Accessed 12 April 2012.

Jaccard, Mark, Mujibur Khan, and John Richards. 2000. Natural Gas Options for Bangladesh. *IUBAT-CPR Commentary 1*. Accessed 12 April 2012.

Karim, Naium-Ul. 2012. Bangladeshis Boil Over Power, Water, Gas Shortage Amid Rising Temperature. 3 June, *Xinhua News Agency.* Accessed 12 April 2012 article.wn.com/.../WNATE019D9702EA452B2C9F45C4BA5115142/

Petrobangla, 2008. *Annual Report 2008.* Accessed 12 April 2012.

———. 2010. *Annual Report 2010.* Accessed 12 April 2012.

Pokharel, Bipin. 2010. *Power Shortage, Its Impacts and the Hydropower Sustainability Assessment Protocol: In the Context of South Asia.* McGill University, Accessed 12 April 2012.

Rashid, M. M. 2007. The Exploration of Natural Gas and its Export Potential in Bangladesh. *Science Technology Society 12.* (245). Accessed 12 April 2012.

Rahman, Azizur. 2012. Offshore Gas-blocks to be Re-demarcated. 24, March, 2013 *The Financial Express*, 24 March. Accessed 12 April 2012 www.thefinancialexpress-bd.com/more.php?news_id...2012-03

Quadir, Serajul. 2009. Total Abandons Bangladesh Oil Exploration Rights. 17, March 2009. *Reuters.* Accessed 12 April 2012 fr.reuters.com/article/idUKDHA50144820090317.

Sarwar, M. 2008. Petrobangla, Gas Infrastructure in Bangladesh. Powerpoint presentation in Delhi. Accessed 12 April 2012.

Transparency International. 2011. Corruption Perceptions Index 2011. Accessed 12 April 2012. http://cpi.transparency.org/cpi2011/results/

U.S. Energy Information Administration. 2011. *Annual Energy Review*. Accessed 12 April 2012.

World Bank. 2008. *Bangladesh Economic Update*. web.worldbank.org/.../ 0,,contentMDK:22345866~pagePK:2865106~piPK:2865128~theSitePK:223547,00.html

———. 2009. *Bangladesh Economic Update*. Accessed 12 April 2012. Web.worldbank.org/.../ 0,,contentMDK:22345866~pagePK:2865106~piPK:2865128~theSitePK:223547,00.html

———. 2010. Bangladesh Economic Update. Accesed 12 April 2012 web.worldbank.org/.../ 0,,contentMDK:22576618~menuPK:2246552~pagePK:2865106~piPK:2865128~theSite PK:223547,00.html

Energy Policy Options for Sustainable Development in Bangladesh
This paper uses a computable general equilibrium model to evaluate macroeconomic impacts of available energy policy options for Bangladesh. Relatively small negative growth impacts of increased gas prices can be readily counteracted by energy efficiency improvements or provision of subsidized gas for fertilizer production. Diversification of fuel mix for power generation is welfare improving, and investing augmented gas revenue for infrastructure development provides the best macroeconomic indicators. Most of the attractive energy policy options have the drawback of higher carbon emissions, and supplementary policies should play a balancing role.

About the Asian Development Bank
ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to two-thirds of the world's poor: 1.7 billion people who live on less than $2 a day, with 828 million struggling on less than $1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.