SMART ENERGY OPTIONS FOR BANGLADESH

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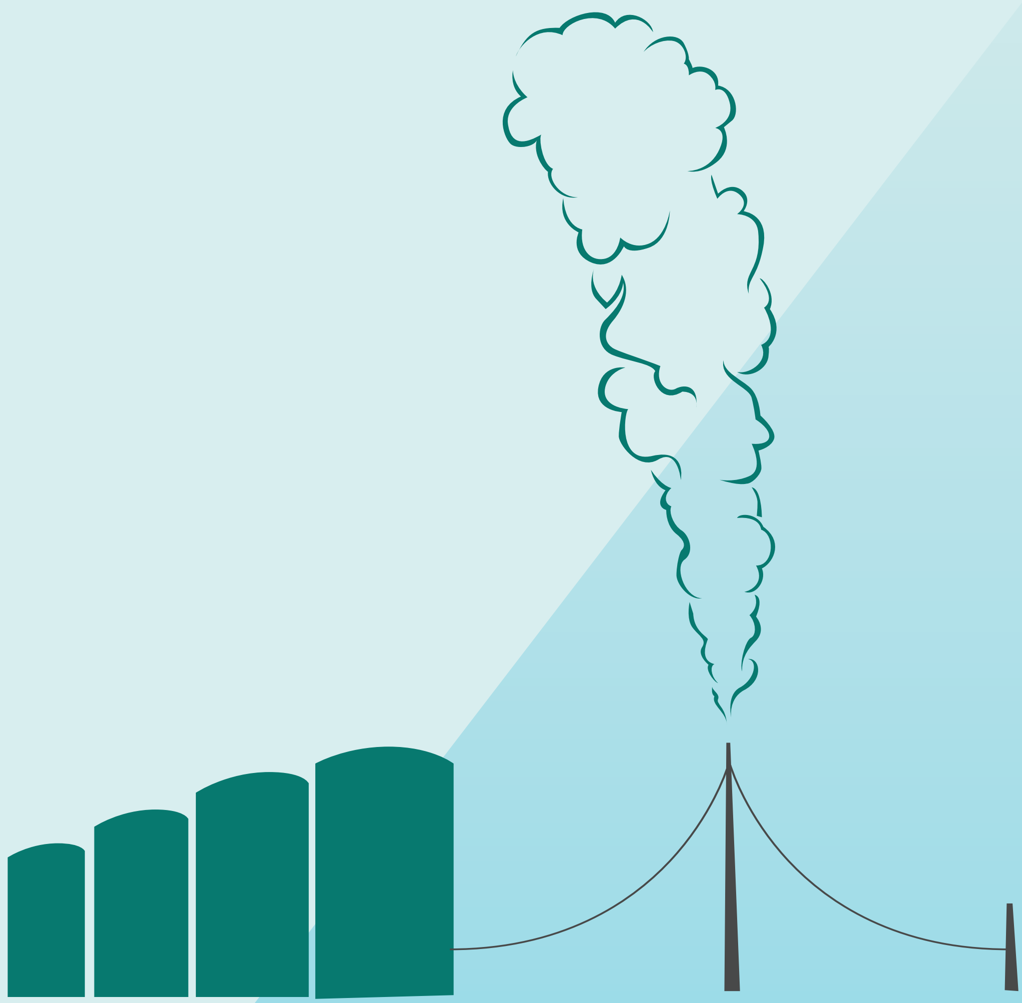

Benefits and Costs of Addressing Bangladesh's Energy Challenges

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Smart Energy Options for Bangladesh

Bangladesh Priorities

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ABBREVIATIONS

ADB – Asian Development Bank

ASEAN – Association of Southeast Asian Nations

CDM – Clean Development Mechanism

FAO – Food and Agriculture Organization

GHG – greenhouse gas

GMS – Greater Mekong Sub-region

ICT – information and communication technology

MDGs – Millennium Development Goals

PRC – People's Republic of China

SMEs – small and medium-sized enterprises

INTRODUCTION AND BACKGROUND..1
ENERGY DIVERSIFICATION OPTIONS FOR BANGLADESH 2
SCOPE FOR PRICE AND OTHER ENERGY POLICY REFORM 9
COST-BENEFIT INDICATORS AND DETAILED IMPACT ASSESSMENT 12
AGGREGATE RESULTS 12
SCENARIO BENEFIT COST ASSESSMENT 15
TABLE 7: NET BENEFITS OF ALTERNATIVE BANGLADESH ENERGY SCENARIOS.. 17
HOUSEHOLD RESULTS.. 18
CONCLUSIONS 20
REFERENCES..27
APPENDIX A: SUMMARY OF THE BANGLADESH CGE MODEL 29
STRUCTURE OF THE CGE MODEL 29
PRODUCTION.. 30
CONSUMPTION AND CLOSURE RULE... 30
C. TRADE 31
D. DYNAMIC FEATURES AND CALIBRATION 31
E. CAPITAL ACCUMULATION.. 31
F. THE PUTTY/SEMI-PUTTY SPECIFICATION 32
G. DYNAMIC CALIBRATION 32
H. EMISSIONS 32
APPENDIX B: SUMMARY OF THE BANGLADESH SOCIAL ACCOUNTING MATRIX 33
ADDENDUM...37
BACKGROUND 37
PRIMARY ENERGY SUPPLY 37
ELECTRICITY SUPPLY 39
ENERGY SCENARIOS 2016-2030 41
BENEFITS AND COSTS..42
LITERATURE 43

Introduction and Background

Bangladesh today faces a different future than it imagined decades ago, when relatively abundant natural gas seemed to be the key to prosperity. Energy policies that undervalue this resource have depleted it dramatically, undermining investment present and future energy services and depriving this populous low-income country of essential long-term public goods and services. To support more evidence-based dialog on national energy development, allocation, and pricing, this study uses a computable general equilibrium model to evaluate economic impacts of major energy policy options open to Bangladesh.

We find that aligning gas prices with the international opportunity cost of this resource could make a fundamental contribution to long-term growth prospects. Relatively small negative growth impacts of rationalized energy prices can be easily counteracted by economy-wide improvements in energy efficiency or subsidized gas for fertilizer production. Gas price increases do not induce significant inflationary pressures in the country's economy. Diversification of power sector fuel mix could also improve macroeconomic prospects, but result in higher carbon emissions. Investing gas revenue in physical and social infrastructure provides the macroeconomic outcomes, but complementary policies will be needed to mitigate emissions impacts. The macroeconomic benefits of more market oriented energy pricing are also distributed relatively equally. Perhaps ironically, low income groups are insulated from gas prices by very low initial levels of energy access.

This paper assesses the macroeconomic impacts of the variety of Bangladesh energy policy options using a dynamic computable general equilibrium model. The policies examined include: (i) rationalizing gas prices; (ii) energy efficiency improvements; (iii) retaining subsidized gas for fertilizer production; (iv) diversification of the power sector fuel mix; (v) exporting 10% gas at international market prices; and (vi) improved gas revenue management, i.e. investment of augmented gas revenues in physical and social infrastructure. The rationale for these policy reforms is described in the next two sections. The fourth section presents policy scenarios. The final two sections present results and conclusions, respectively.

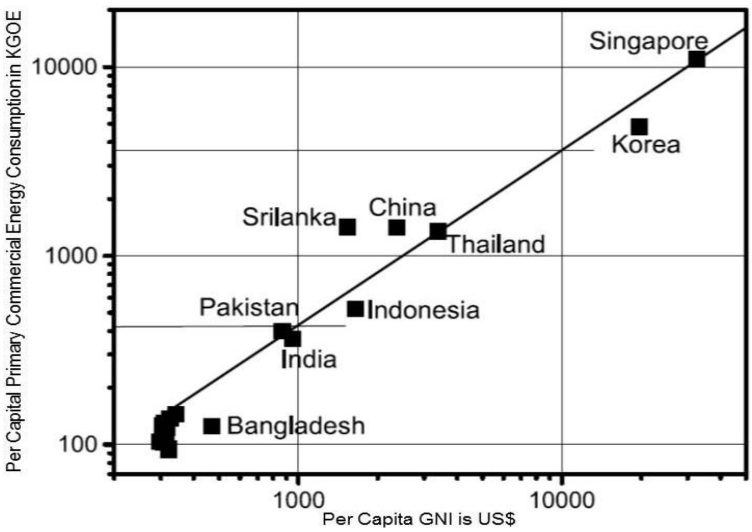
Energy Diversification Options for Bangladesh

Domestically produced natural gas provides 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 to meet most of its oil needs, and remains heavily dependent on biomass for domestic energy production, particularly in rural areas. Despite once abundant resource endowments, 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 neighbors India (75%), and Sri Lanka (95%). Lack of access to electricity remains one of the country's main development challenges.

Per capita electric power consumption (Table 1) in Bangladesh is among the world's lowest, even after taking account of relatively high poverty incidence (Fig. 1). Thus suggests that the country's economy grows despite serious energy constraints, yet current trends suggest that even this resilience is at risk. Almost three-quarters of Bangladesh's population live in rural areas, and about half are employed in agriculture (World Bank, 2010), and the national electric power sector is more appropriate to that of an agrarian society. If the economy aspires to more energy-intensive industrialization and urbanization like developed countries, electrification and energy production will have to expand substantially.

Fig. 1: Per Capita Commercial Energy Consumption versus

Per Capita Gross National Income (GNI) of some selected Asian countries.



KGOE = Kilogram of oil equivalent

Source: Per Capita Energy BP (2009) / Per Capita GNI (WB, 2009)

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 sufficient resource rents from gas to be self-financing. The energy industry argues that tariffs set by authorities have prevented them from raising end-user prices, while input prices and distribution costs have gone up. At the same time, however, widely publicized scandals have led to allegations of chronic mismanagement. As with many state-owned enterprises, Bangladesh's gas companies may face conflicts of interest and moral hazard due to political interference, soft budget constraints, and lack of accountability to investors and capital market discipline.

Bangladesh faces another important risk factor, as its proven reserves of natural gas are highly uncertain. 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 1 makes clear, after discounting for recoverability and past production, available reserves may be as low as 13.53 TCF.

Table 1: Estimates of proven gas reserves, 2009

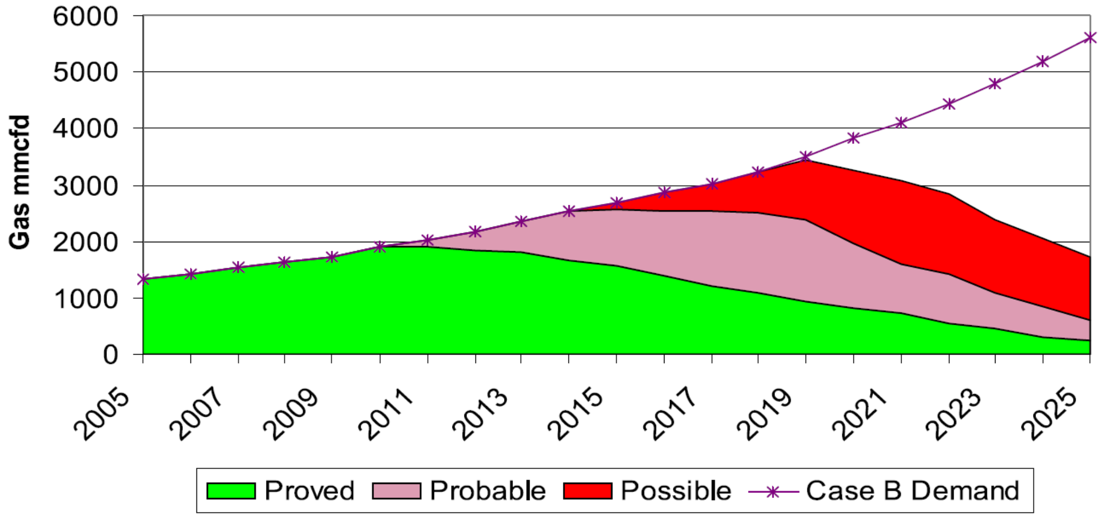
Gas (Proven+Probable)	28.62 TCF
Recoverable	20.63 TCF
Cumulative Gas Production as June 2007	7.10 TCF
Remaining Reserves	13.53 TCF

Note: TCF=trillion 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, existing production capacity and domestic demand, reserves would be exhausted in less than 20 years (BP, 2011). In 2011 Bangladesh Petroleum Exploration and Production Company announced the discovery of new reserves estimated to be at least 1 TCF and perhaps as much as 2.4 TCF. With reserve estimates fluctuating annually by up to 15%, the supply side of the country's gas market remains plagued by risk and concomitant underinvestment. Projected figures from Petrobangla and the US Energy Information Administration (Fig. 2), reinforce the impression that Bangladesh could exhaust its gas reserves in about 20 years. Financial constraints appear to limit the prospect for heavy investments required for nuclear energy, and Bangladesh has not taken serious steps to develop its coal resources. As demand continues to grow, this may become the leading concern of energy policy for the country, spilling over into other sectors as subsidizing energy imports imposing increasing strain on government finances.

Bangladesh's state gas companies have restricted their operations to onshore gas fields, while the country appears to be completely dependent on international oil companies for the technology and investments to pursue offshore gas. The discovery of large offshore reserves by French oil giant Total in 2009, temporarily improved the country's reserve prospects, but Total later renounced its exploration rights, citing "commercial non-viability" after a $30 million survey. With the resolution of a maritime dispute with Myanmar in March 2012, outside energy firms have taken an interest in buying exploration rights to the blocks offered for 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 long-standing maritime disputes 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. The projected gas demand and supply are shown in Fig. 2.

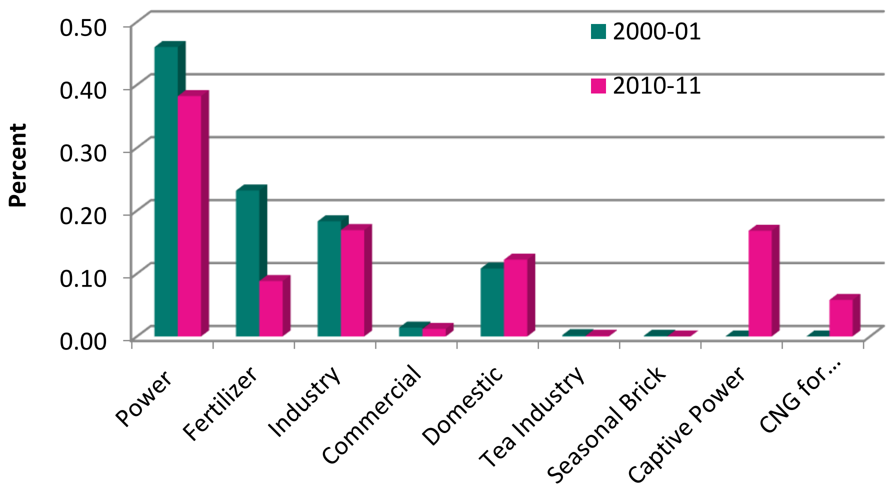
Fig. 2. Projected gas supply and demand



mmcfd = _million cubic feet per day
Source: Sarwar (2008).

Figure 3 shows the gas allocation across sectors and how these allocations have changed over time. It is evident that the power sector utilize most of the gas in Bangladesh and gas allocation for fertilizer production declined over time. Another important sector to adopt gas (CNG) in recent times is transportation. Gunatilake et al. (2013) estimate the economic value of gas in different sectors of Bangladesh and claim that there is substantial inefficiency in current allocation patterns. About 57% of gas is currently allocated to power sector but only 9-22% of the economic value is captured by the current gas price. Transport sector generates the highest economic value for gas but only 5.5% of the gas is currently allocated to transportation. Fertilizer and household cooking sectors also generate higher use values, but only 12% and 36% of the economic values, respectively, are captured by current pricing regime.

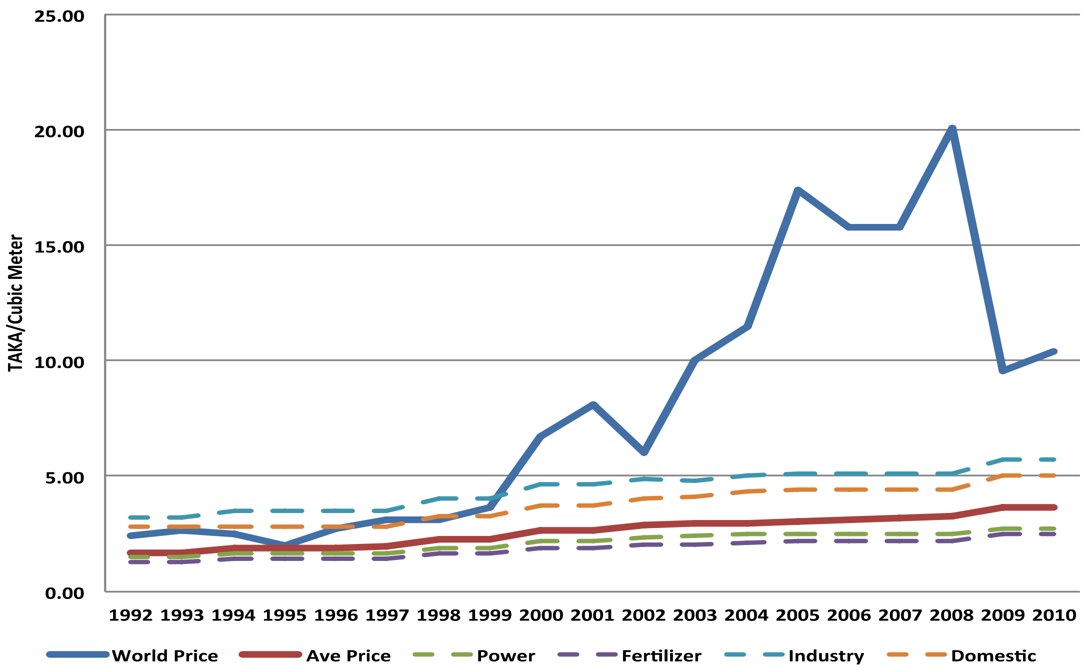
Fig. 3. Changes in sectoral use of gas in % (2001 and 2011).



CNG = compressed natural gas
Source: Authors' estimates

At least as important as reserves is the issue of gas tariffs, which in Bangladesh are controlled as a matter of government policy. The degree of price stratification is apparent in the next figure, which compares average domestic and world prices with prices administered for different demand categories (Fig. 4). A few salient features of these trends have important policy implications. Firstly, world wholesale gas prices, even accounting for the steep fall over the last few years, have remained well above domestic retail prices for at least a decade. This divergence promotes overuse of gas domestically and sharply increases the opportunity cost of forgone gas revenues in terms of public financial capacity and investments in the economy. Secondly, 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 2). In short, domestic gas prices are completely discordant with the opportunity cost of this resource to the government, promoting waste and seriously undermining capacity for investment in public goods and services for this low income economy.

Fig. 4: Dry gas prices (Taka/m3).



m^3 = cubic meter.

Source: Author estimates from IEA, World Bank, and Petrobangla sources.

Table 2: Gas prices in selected neighboring countries ($/m3)

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.

A differentiated energy pricing regime has seriously distorted sectoral energy costs and (thereby) use and investment decisions. 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. However, doubts have risen about whether power subsidies really benefit the poor, given electrification rates in poor household of only 45%–50%. Moreover, it is possible that lower tariffs disproportionately benefit urban dwellers with an already higher standard of living than the majority of Bangladeshis. Nevertheless, gas shortfalls for urban population (or tariff increases) could be politically costly. We shall return to this issue in Section 5 below.

Gas is by far the leading fuel for electric power generation and, due to the limited availability of other energy resources, the Bangladesh Chamber of Commerce has been calling for coal development, which might become competitive if gas subsidies were removed. The government has hesitated on this option due to coal mining opposition from citizens' groups. Having said this, the current method of importing petroleum fuels to make up the gas shortage remains an extremely expensive solution for the government, and one that is almost certainly unsustainable. Nuclear power requires investments of time and capital that the government does not have, and renewable energy options available for Bangladesh also appear far too expensive (solar), or short in supply (hydro and wind). Traditional biomass is 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 does not gradually raise gas and power prices to parity with international market prices.

Table 3: 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

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.

[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.

It is evident that the very low gas tariffs, combined inadequate gas revenue, are not conducive to economic growth and equitable distribution of benefits from this essential energy resource. It is estimated that current gas revenue of $300 million per year could be increased to $2.9 billion per annum if the gas were sold at average gas price in India and Pakistan (Gunatilake and Reihan, 2013). Current tariff rates are significantly below the economic value of gas in all sectors, and that government gas allocation policy has focused mainly on electricity production, while discouraging other uses. It is evident that low tariff rates have also contributed excess consumption and gas shortages and, because of de facto electric power rationing, the benefits of low gas costs are very unequally distributed.

The most salient characteristics of the Bangladesh power sector 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 significant 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 using by diesel (8%), fuel oil (6%), coal (2%), and hydropower (3%).

Inefficient natural gas pricing and allocation strongly influence the performance of power sector, including low rates of public access (50%–55%) and chronic intermittency. Load shedding in Dhaka in 2011-12 sustained averages of 5 hours per day. Power shortages have constrained aggregate economic growth in Bangladesh, with estimated costs of about 0.5% of Gross Domestic Product (GDP). According to "Vision 2021"—the government's policy statement—the government aspires to ensure universal access to grid electricity by 2020, with an interim target 68% public access by year 2015. By the governmen's own estimates, this would require 20 Gigawatts (GW) of additional generation capacity by 2020, together with complementary transmission and distribution infrastructure that can reach half the country's population, unserved, in both urban and rural areas. Constituting a 400% expansion of today's power sector in just six years. It is very difficult to see how these goals can be met in the current fiscal and investment climate.

The Bangladesh Power Development Board (BPDB) is the largest entity in the energy sector, representing 53% of generating capacity. BPDB's average bulk electricity supply cost and its average bulk selling rate to distribution entities are summarized in Table 4. BPDB pays independent power producers (IPP) an average of Taka (Tk) 3.52 per kilowatt-hour (kWh). BPDB's average (pooled) bulk electricity supply cost is Tk4.20 per kWh, while its average tariff is Tk 2.50 per kWh, creating losses of Tk1.70 per kWh, aggregating to a Tk36,190 million (about $450M) shortfall in 2011. For the corresponding period in FY2010, the losses were Tk0.29 per kWh, aggregating to a deficit of Tk5,742 million ($70M), when bulk energy sales were 7.5% lower than in 2012. A key requirement of a healthy financial position of utilities is cost-responsive pricing. As shown in Table 4, basic cost recovery has not been achieved in the Bangladesh power sector, even though heavily subsidized gas is used for the bulk of power generation. These chronic deficits prevent utilities from investing to expand much needed electric power access and improve reliability.

Table 4: 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	5964.05				
DESCO	10.91	3122.74				
WZPDCL	6.44	1842.52	2.50[1]	4.20	(1.70)	36,190
REB	36.19	10359.41				
Sub total	74.37	21288.72				
BPDB own distribution	25.63					
Total	**100%**					

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)

Scope for Price and other Energy Policy Reform

To assess the long term implications of Bangladesh's energy policies 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 between 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 intuition offers only scant guidance about how to achieve public objectives. 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 abilities 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 exchange. Because of their detailed behavioral specifications, these models are particularly good at elucidating adjustments in income distribution and economic structure.

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

The model we use here was calibrated to a new social accounting matrix (SAM), estimated for Bangladesh for year 2010. The general structure of the Bangladesh CGE and SAM are summarized in Appendix A, 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 energy policy, although these comprise only a few of the issues that can be addressed with this framework. Table 5 presents seven scenarios considered in the context of natural gas and power sector issues discussed in the preceding sections.

Table 5: 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 total gas supply.
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

Firstly, 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 Fig. 5 and achieving setting the economy wide average gas price for all uses at Tk 5/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 policies but assumes the economy responds with very modest, but sustained 1% annual improvement in overall energy use efficiency. In many industrial economies, these efficiency improvement 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 dialog, price policies for the fertilizer industry. Natural gas is a primary input to another primary input (fertilizer), believed to contribute to food security and benefit large masses of poor. Hence, fertilizer sector 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. Gas exports are not feasible give energy security concerns and declining gas reserves. Gas export also require investments on necessary infrastructure. This scenario is intended only to support dialog on this important choice facing the country—selling the gas at international 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 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, it 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.

Cost-Benefit Indicators and Detailed Impact Assessment

A number of salient findings emerge from these results, ones that would likely be robust against reasonable uncertainty regarding external events and the degree of behavioral response. First, removing Bangladesh's long established price subsidies for domestic natural gas, while politically difficult, would not significantly undermine the country's long-term economic growth.

Aggregate results

We apply the Bangladesh dynamic forecasting model at national and household levels. Applying the Bangladesh dynamic forecasting model to the eight scenarios described above, we obtained aggregate results summarized in Table 6. Even without the kind of private efficiency responses and complementary policies considered here, the economy's overall real GDP would rise very slightly (0.5%) because of efficiency gains, but generally higher energy prices would reduce personal consumption, wages, and export competitiveness over the next two decades. Of course there can be many dramatic structural adjustments beneath the smooth veneer of macroeconomic advocates, but clearly energy price subsidies are dramatically improving the country's growth prospects. Moreover, noting that energy price rationalization would increase government revenue by 12%, this could make a available a broad spectrum of public goods and services to promote growth from other directions. Moreover, 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% or increase expenditure on education health and basic services by the same if gas prices were increased to average gas price in India and Pakistan.

Table 6: 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%		4.7%	10.6%	27.9%	80.5%
			3.3%				
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%

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

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) technologies 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 energy 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 of 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.

Together with EE improvements, 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, which may result in environmental issues like water pollution.

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 et al. (2014) also confirms the higher value addition of gas in these sectors. Using coal for electricity generation would free the government from gas sector subsidies without facing energy cost escalation. 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 4.5% 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 costs. 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 highlights one of the major development challenges facing developing countries; use of low cost fuel to enhance development results in more carbon emissions. This problem can be ameliorated to some extent by using clean coal technologies such as super critical and ultra super 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 the 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, too.

The seventh scenario deploys in 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 livelihood and mutually beneficial engagement with the global economy.

Finally, scenario 8 shows the benefits of following Hartwick's rule, investing gas revenue in 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) improves 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. The opportunity cost of gas subsidy and benefits of investing gas revenue for infrastructure development is examined in details by Gunatilake and Reihan (2014).

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 emissions intensity and growth (ceteris paribus) 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.

Scenario Benefit Cost Assessment

While the above growth scenarios are encouraging in absolute terms, it is important to take account of two factors if we are to assess the true sustainability implications of energy options faced by Bangladesh. Firstly, while income and consumption growth statistics in Table 6 suggest that the the hypothetical policy reforms could yield real growth dividends, these must be evaluated against potential environmental costs of potential increases in climate change inducing greenhouse gases (GHGs). We know that emissions are linked to economic activity via three channels. The first is aggregate growth, where overall expansion of economic activity, uniformly across sectors of the economy, must increase emissions. The second source of emission changes, the sectoral composition of growth, allows for positive shifts in sector emission intensity (industrialization) or negative shifts, as we have seen in post-industrial OECD economies. Finally, technological change can increase or decrease emissions with growth, depending on whether or not new technologies are more or less pollution intensive per unit of output.

Our scenario results demonstrate the roles of all three components. When pure growth stimulus is at work (scenarios 2 and 8), aggregate effects will increase emissions. When technology effects dominate (EE scenarios), emissions per dollar of GDP and perhaps in total will fall. Finally, scenarios which shift electric power activity toward more emission-intensive fuels (coal) will increase emissions at a higher rate than the baseline. At the end of the day, these potentially adverse climate impacts will affect livelihoods according to two criteria, the interest rate that discounts future costs and benefits, and the social cost (SCC) of any increase in carbon emissions.

Table 7: Net Benefits of Alternative Bangladesh Energy Scenarios

		Change from Baseline (income in 2015 USD Billions)													
Baseline		**MKT**		**MKTEE**		**Fert**		**Coal50**		**GasExp**		**GasCoal**		**InfDev**	
Income	GHG	Income	GHG	Income	GHG	Income	GHG	Income	GHG	Income	GHG	Income	GHG	Income	GHG
214	59.1	0.2	0.0	0.2	-0.2	0.6	-0.1	0.6	0.3	1.0	0.2	2.9	1.2	8.5	3.4
225	61.2	0.4	0.1	0.4	-0.4	1.1	-0.3	1.2	0.5	2.1	0.4	5.9	2.4	16.9	6.8
237	63.3	0.6	0.1	0.6	-0.6	1.7	-0.4	1.7	0.8	3.1	0.6	8.8	3.7	25.4	10.2
248	65.4	0.8	0.1	0.8	-0.8	2.2	-0.5	2.3	1.0	4.1	0.9	11.8	4.9	33.8	13.6
260	67.5	1.0	0.1	1.1	-1.1	2.8	-0.6	2.9	1.3	5.2	1.1	14.7	6.1	42.3	17.0
274	70.1	1.2	0.1	1.4	-1.3	3.6	-0.8	3.8	1.5	6.7	1.4	19.6	7.9	58.6	23.0
288	72.8	1.4	0.2	1.7	-1.5	4.5	-0.9	4.6	1.6	8.2	1.7	24.6	9.8	75.0	29.0
303	75.5	1.6	0.2	2.0	-1.8	5.4	-1.0	5.5	1.8	9.7	2.1	29.5	11.7	91.3	35.0
317	78.2	1.8	0.2	2.3	-2.0	6.2	-1.2	6.3	2.0	11.2	2.4	34.4	13.5	107.7	40.9
332	80.9	2.0	0.2	2.7	-2.3	7.1	-1.3	7.2	2.1	12.7	2.7	39.4	15.4	124.1	46.9
350	84.3	2.2	0.2	3.1	-2.6	8.4	-1.5	8.4	2.6	14.7	3.2	47.0	18.1	151.9	56.7
368	87.6	2.3	0.2	3.5	-2.9	9.7	-1.6	9.6	3.2	16.8	3.7	54.5	20.8	179.7	66.5
386	91.0	2.5	0.2	4.0	-3.2	11.0	-1.7	10.9	3.7	18.9	4.2	62.1	23.5	207.6	76.3
405	94.4	2.7	0.2	4.4	-3.5	12.3	-1.9	12.1	4.2	21.0	4.7	69.7	26.2	235.4	86.1
423	97.8	2.8	0.2	4.9	-3.8	13.6	-2.0	13.3	4.7	23.1	5.2	77.3	28.9	263.2	95.9

SCC (USD/MT)	**Discount Rate**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**	**NPV**	**BCR**
$22.90	3%	$18	2.97	$25	NA	$66	NA	$65	2.87	$115	4.60	$362	2.58	$732	2.66
$5.18	5%	$15	13.51	$20	NA	$54	NA	$54	2.85	$95	4.61	$298	2.57	$595	2.66
$-	10%	$10	NA	$13	NA	$34	NA	$34	2.81	$60	4.63	$187	2.56	$369	2.64

Definitions:
Income is National Income (GDP net of public income). GHG is all greenhouse gases in MMTCO2 equilvalents. SCC is the Social Cost of Carbon (see Toll: 2015).
National real income is defined as real GDP adjusted for changes in household purchasing power (equivalent variation real income)
Greenhouse gas esmissions are expressed in CO2 equivalent millions of metric tons (correcting non-CO2 gases for radiative forcing potential).
NPV , measured in 2015 USD billions, is the discounted present value of annual Benefits (National Income) minus Costs (social cost of GHG emissions changes)

The results for net benefit-cost assessment of Bangladesh energy scenarios are given in Table 7. Despite the diversity of scenarios, these estimates reveal a number of salient characteristics of relevance to policy makers. Firstly, absolute (equivalent variation income) benefits are substantial regardless of the interest rate (within reasonable intervals). Second, GHG emissions can increases substantially in some of the pro-growth scenarios, both those allowing for more carbon intensive fuels and those that do not, yet present value of aggregate benefits net of the cost of these emissions (at several levels of GHG social cost) remain significantly positive. Finally, even when coal is imported to release gas for export to earn foreign exchange, the net social benefit to Bangladesh is positive. We do not advocate conventional fuel intensive growth strategies, but we do acknowledge the right to develop, and it is clear that foreign exchange and commensurate public funds have a very high growth opportunity cost in Bangladesh.

Household results

Even though Bangladesh's population is predominately rural and predominately low income, there are important sources of economic diversity in the country. Results presented in in Table 8 are by basic aggregate welfare metric, consumption adjusted for changes in purchasing power (at 2015 prices). In this section we examine 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 also 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 8 shows that 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 8: 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	–0.5	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	0.07	0.12	0.27	0.34	0.34	0.88	2.11

SMA = Standard metropolitan area
Source: Authors' estimates

Energy fuel diversification (Coal50) affects households quite similarly in spite of large differences in baseline household electricity use. For the gas export policy, we are seeing essentially a macroeconomic impact on average domestic energy prices and aggregate foreign savings. Both of these have 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 discussed above.

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 dialog on energy development, allocation, and pricing reform. Using a detailed economic forecasting model, we evaluate a variety of policy options that are under active discussion and consideration by public and private stakeholders in Bangladesh. 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 prices can be easily offset by relatively modest economy-wide increases in energy efficiency. Contrary to widely held local expectations, the gas price increase without supplementary policies of energy efficiency or fertilizer subsidy does not increase inflation significantly. This is due to the contractionary effect of higher gas prices. 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 the carbon emissions. 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 this developing 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 energy policy reform options to support a more prosperous and 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, complementary technology adoption policies should packaged with these reforms.

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Appendix A: 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 et al., 2012), and for the present we only discuss its salient structural components.

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.[2] The result is a single-economy model calibrated over the 20-year time path from 2010 to 2030.[3]

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.[4] 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.[5] 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.[6] The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

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2 See Brooke et al. (1992) for GAMS.

3 T he present specification is one of the most advanced examples of this empirical method, already applied to over 50 individual countries and/or regions.

4 Capital supply is to some extent influenced by the current period's level of investment.

5 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.

6 In the reference simulation, the real government fiscal balance converges (linearly) towards 0 by the final period of the simulation.

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.

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.[7] 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 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 et al., 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

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[7] 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.

technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource-use levels.

Table A.1 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 of relevance 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.

Appendix B: Summary of the Bangladesh social accounting matrix

Table B.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

Institution	Definition	
natrs	Factor	Natural Resources
indtx	Fiscal	Indirect Taxes
fctts	Fiscal	Factor Taxes
dirtx	Fiscal	Income Taxes
imptx	Fiscal	Import Tariffs
exptx	Fiscal	Export Taxes
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

SMU = Standard metropolitan area
Source: Compiled by authors

Smart Energy Options for Bangladesh Addendum

Bangladesh Priorities

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Background

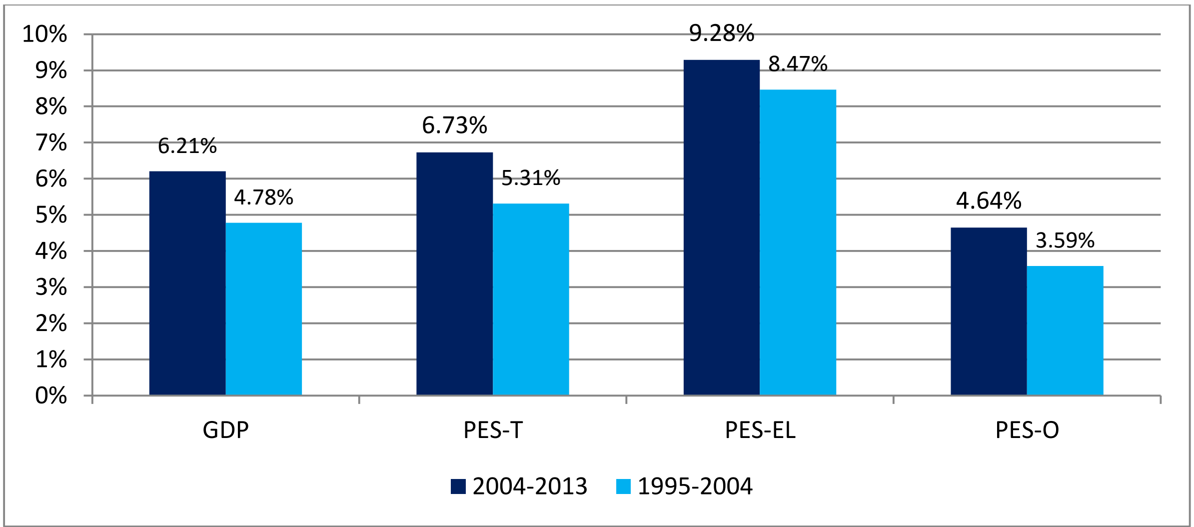
The paper "Smart energy options for Bangladesh" applies a CGE model to estimate the income effects of various energy sector options in Bangladesh. The premise of the paper is that the Bangladeshi economy is energy constrained, in particular by its heavy reliance on a limited supply of domestically produced natural gas, and that the economy could grow faster by rationalizing natural gas prices and expanding its access to both imported and domestically produced coal.

The paper goes on to estimate the benefits of several energy sector options in terms of increased GDP. This addendum provides background information on the energy sector over the last decade, and estimates of the cost of increased energy supply in each option. Benefits in terms of increased GDP and cost of energy supply are then compared and presented as benefit-cost ratios and present values (PV) over the 2016-2030 time horizon.

Primary energy supply

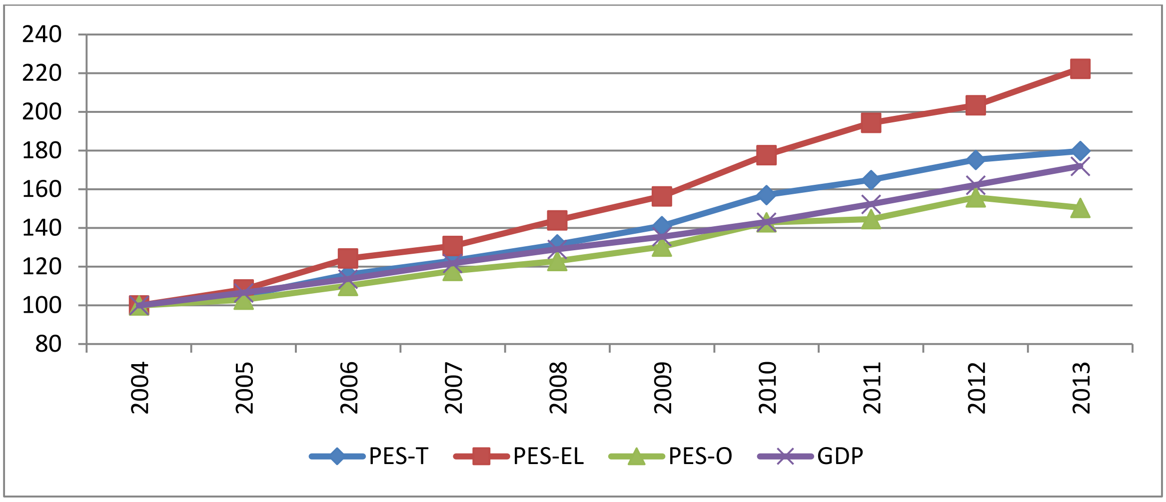
GDP of Bangladesh grew at a robust 6.2% per year from 2014 to 2013, up from 4.8% from 1995 to 2004. Modern primary energy supply for domestic consumption (excluding traditional biomass consumption) increased at a somewhat higher rate, driven by annual growth rate of 9% for electricity production.

Figure 1. Annual growth in GDP and primary energy supply for domestic consumption in Bangladesh, 1995-2013



Note: Primary energy supply does here not include biomass consumption. GDP=gross domestic product; PES-T= total primary energy supply; PES-EL= primary energy supply for electricity production; PES-O= other primary energy supply. Source: Produced from IEA Energy Balances and World Bank World Development Indicators.

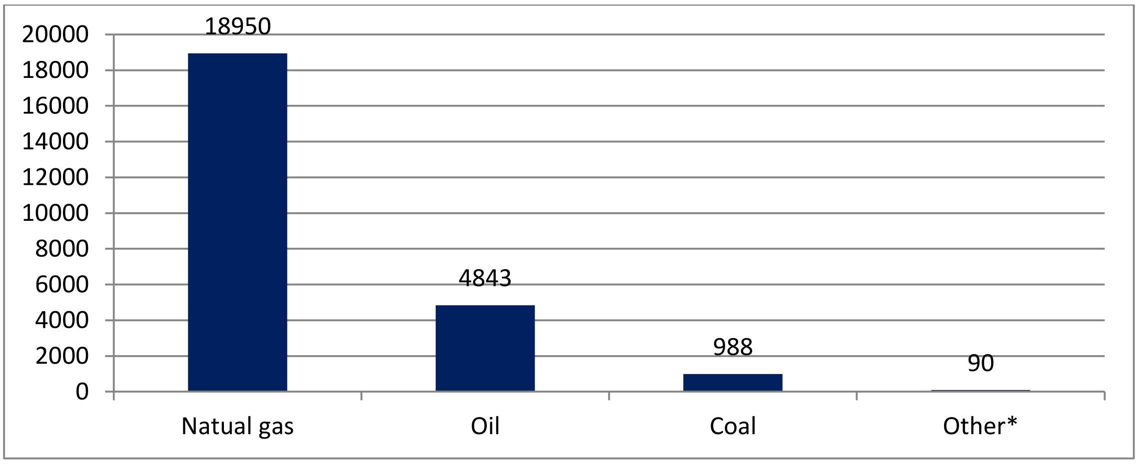
Figure 2. Growth in GDP and primary energy supply for domestic consumption in Bangladesh, 2004-2013 (Index=100 in 2004)



Note: Primary energy supply does here not include biomass consumption. GDP=gross domestic product; PES-T= total primary energy supply; PES-EL= primary energy supply for electricity production; PES-O= other primary energy supply. Source: Produced from IEA Energy Balances and World Bank World Development Indicators.

Modern primary energy supply for domestic consumption (excluding traditional biomass consumption) stood at 24.8 million toe in 2013. Over 76% was domestically produced natural gas while coal remained at less than 1 million toe. The share of natural gas in total modern primary energy supply increased from 71% in 2004 to 76% in 2013, while the share of oil declined from 26% to 19.5% and share of coal increased from 2.5% to 4%.

Figure 3. Bangladesh primary energy supply for domestic consumption (ktoe), 2013

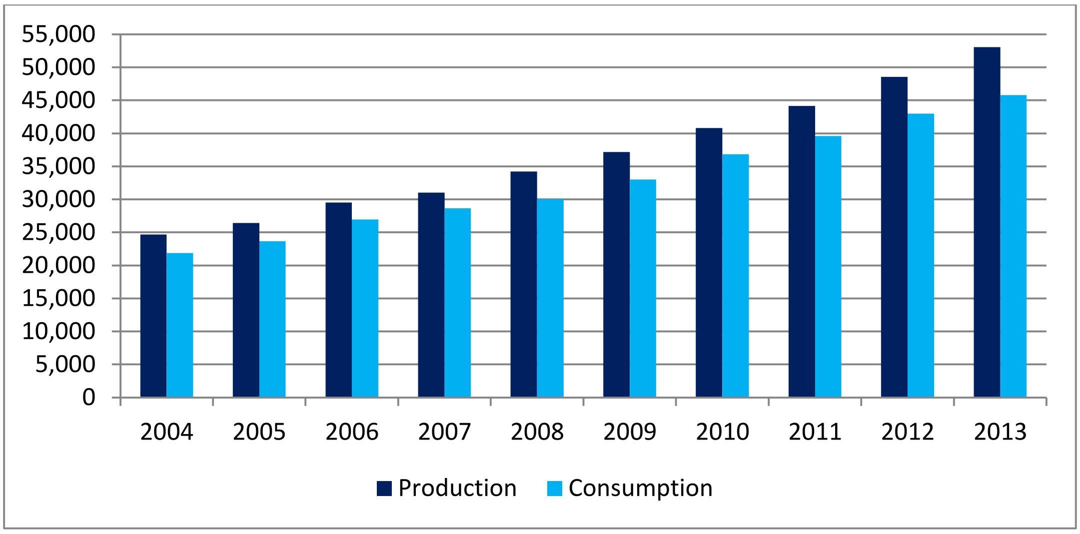


Note: Not including traditional biomass consumption. Source: Produced from IEA Energy Balances of Bangladesh 2013.

Electricity supply

Domestic electricity production in Bangladesh reached 53,000 GWh in 2013. Annual production growth was 8.9% per year during this period, and 9.6% per year from 1995 to 2004.

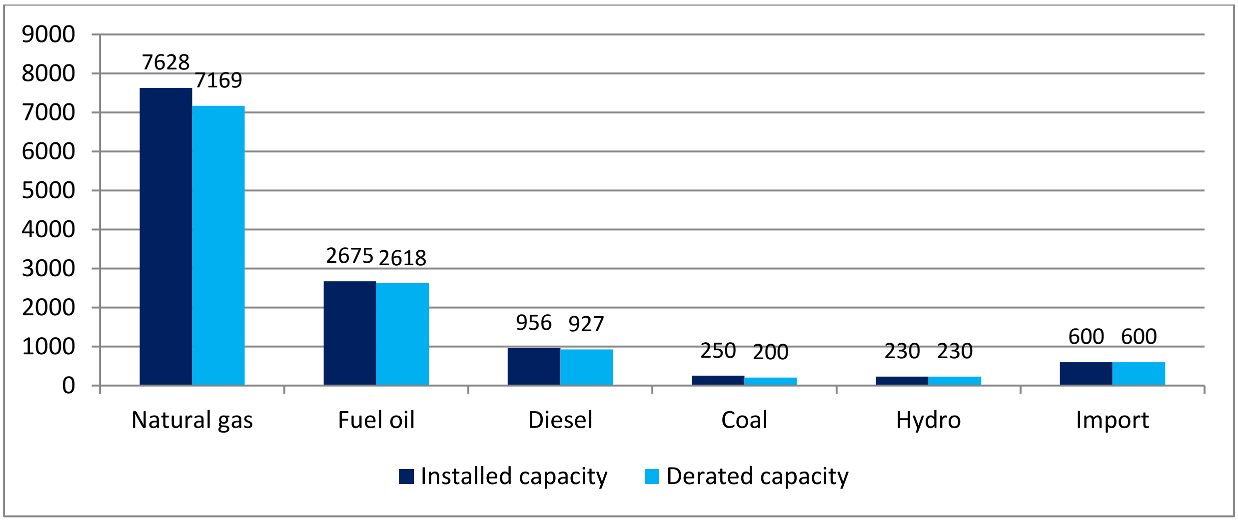
Figure 4. Annual electricity production and consumption (GWh), 2004-2013



Source: Produced from IEA Energy Balances of Bangladesh 2004-2013.

Installed/derated electric power generation capacity was 12,339/11,744 MW as of April 10, 2016. Installed capacity continues to be dominated by natural gas (62%), with fuel oil as a distant second (22%). Import from India has reached 600 MW while coal fired generation capacity is at 250/200 MW. However, in terms of fuel share in electricity production, natural gas has accounted for about 90% of total fuel use over the last decade.

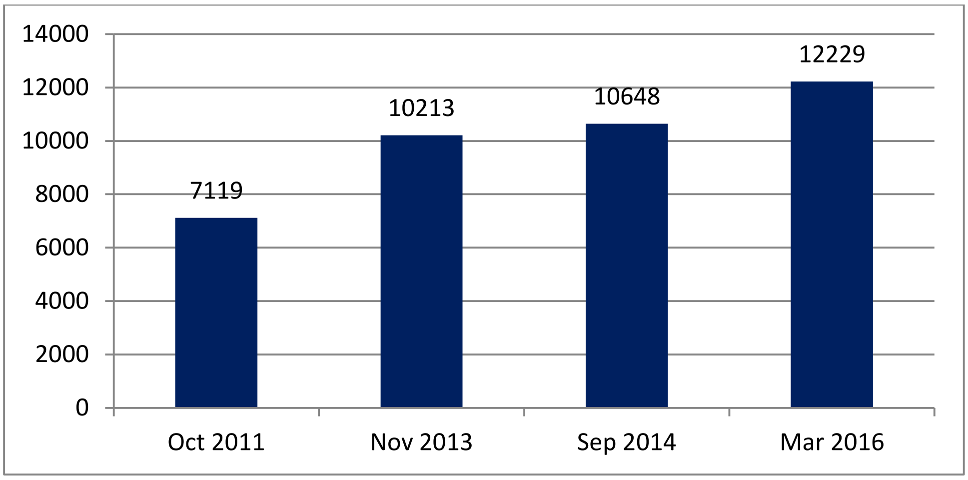
Figure 5. Electric power generation capacity by fuel/source (MW), April 10, 2016



Source: Produced from Bangladesh Power Development Board website.

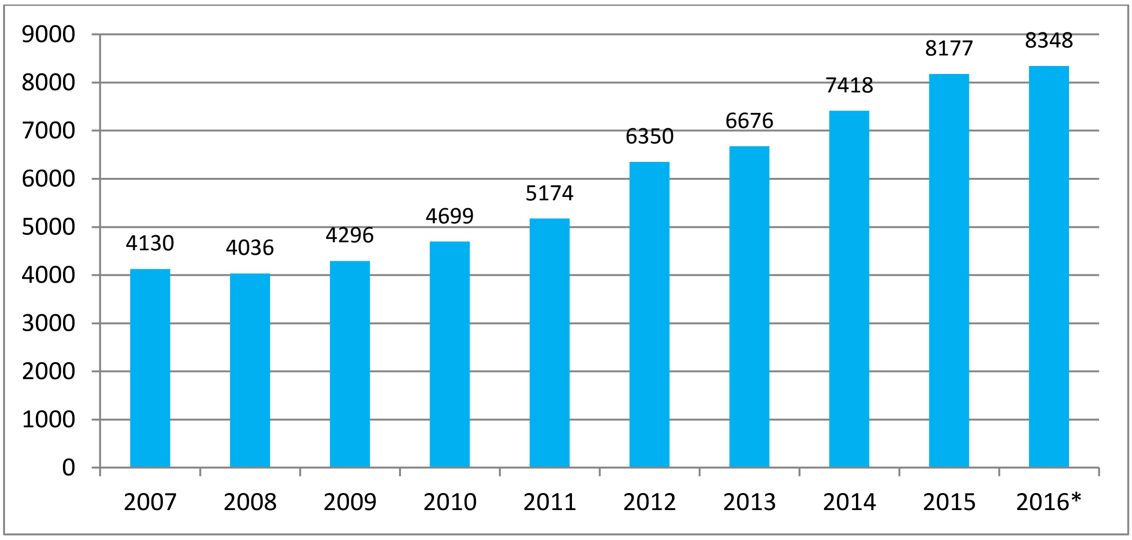
Installed electric generating capacity has increased by 72% from 2011 to 2016, or at an annual rate of 11%. Maximum generation increased by a similar magnitude over this period, and has been 65-73% of installed capacity during 2011-2016.

Figure 6. Installed electric power generation capacity (MW), 2011-2016



Source: Produced from Bangladesh Power Development Board website.

Figure 7. Maximum electric power generation (MW), 2007-2016



* As of April 9, 2016, while maximum generation generally occur in July-September. Source: Produced from Bangladesh Power Development Board website.

Energy scenarios 2016-2030

In the wake of heavy reliance on domestically produced natural gas, dwindling gas reserves, and electricity shortages, the Bangladesh Power System Master Plan 2010 (PSMP 2010) laid out an energy sector vision for 2030. This vision included active development of domestic primary energy resources, establishment of a power system portfolio based on fuel diversification, and building of an infrastructure necessary for a stable power supply.

The PSMP envisioned a fuel composition of 50% coal, 25% natural gas, and 25% other fuels/energies by 2030, with coal consumption consisting of both imported and domestically produced coal. This composition is in stark contrast to the composition in 2013 with natural gas constituting 76% of primary energy and 87% of electricity production.

While coal consumption was less than 1 million toe in 2013 and coal fired power plants in operation was only 250 MW in 2016, several coal fired plants are at various stages of construction and preparation.

However, increased domestic coal mining and production met resistance among the population. This was one of the factors that motivated the initiation of the Power System Master Plan 2015 (PSMP 2015) in late 2014 with scheduled completion in December 2015 (finished??). This plan will in particular look at scaled down scenario of domestic coal production along with import of LNG.

The "Smart energy options for Bangladesh" paper assesses some energy scenarios along the lines of the PSMP 2010 and other scenarios including rationalization of natural gas prices, continued support to the fertilizer industry, 10% export of natural gas production, and investment of incremental government revenues from natural gas price rationalization.

Three scenarios assessed in the paper are subjected to estimation of benefits and costs in this Addendum:

1) By 2030, use of imported coal to meet 50% of electricity demand; and

2) By 2030, use of a combination of half imported and half domestically produced coal to meet 50% of electricity demand.

3) Scenario 2 along with natural gas price rationalization receives a partial assessment, with presentation of income benefits and energy cost, but net benefits in terms of energy efficiency improvements from adapting to higher gas prices are not estimated due data constraints.

While the new PSMP 2015 considers a scaled down vision of domestic coal production, the "Smart energy options for Bangladesh" paper demonstrates that forsaking domestic coal production has very high foregone benefits, as seen below.

Benefits and costs

Benefits

Scenario 1: Relaxing the energy supply constraint by importing coal for 50% of electricity production by 2030 provides an incremental GDP growth rate of 0.2% per year, worth US$ 34-66 billion over the period 2016-2030, relative to the baseline growth path with energy constraints.

Scenario 2: Developing the domestic coal industry and by 2030 use a combination of half imported and half domestically produced coal to meet 50% of electricity demand provides an incremental GDP growth rate of 0.8% per year, worth US$ 127-250 billion relative to baseline.

Scenario 3: Developing the domestic coal industry and undertaking a rationalization of natural gas prices boosts GDP growth by 1.0% per year, worth US$ 161-315 billion relative to baseline.

Costs

The cost of the three energy scenarios is estimated as the cost of incremental energy required to provide the increase in GDP presented above. This is calculated as follows:

1) Growth in electricity and primary energy consumption relative to growth in GDP is assumed constant and the same as during 2004-2013.

2) Cost of electricity supply is Tk 6.91 from new power plants, according to the PSMP 2010. This is converted to US$ at the exchange rate of Tk 70 in 2010.

3) Cost of electricity supply from coal fired plants using domestically produced coal is estimated from data in the PSMP 2010 to be about 10% less expensive than from plants using imported coal.

4) Average cost of other primary energy (oil, gas, coal) is assumed to be US$ 50 per toe.

The cost of electricity supply from coal plants includes port handling of imported coal and transportation of imported and domestic coal to the power plants.

The incremental energy cost in the coal import scenario is estimated at US$ 1.4-2.7 billion. Incorporating the global cost of increase in greenhouse gas (GHG) emissions from increased energy consumption brings the cost to US$ 1.4-3.2 billion. The incremental cost of the two scenarios with domestic coal for electricity production is 3.6-4.8 times higher, as these scenarios provide higher economic growth and energy consumption.

Benefit-cost ratios

Benefits in terms of increased GDP are over 24 times the cost of increasing energy supply by importing coal (BCR of Coal 50 in table 1). Even when accounting for the global cost of increased GHG emissions, the benefits are 20-24 times the cost (table 2).

The benefit-cost ratios (BCRs) of the scenario with imported and domestic coal for electricity production are somewhat higher at over 25 (Coal I&D_1 in table 1). This is because of the cost of electricity production with domestic coal is somewhat lower than the cost with imported coal. However, when incorporating the cost of GHG emissions, the BCRs in scenario 1 & 2 are about the same due to the much larger increase in GHGs in scenario 2.

In the last scenario with natural gas price rationalization, the benefits are larger than in the second scenario without price rationalization, but the estimated BCRs are the same because the benefits of energy savings from efficiency improvements less the cost of efficiency improvements are not estimated due to data constraints. In reality the BCRs would be expected to be somewhat higher than in the second scenario. This is because as users of energy face higher gas prices they will undertake measures to save energy as long as the cost of these measures is less than the benefit of energy savings (positive net benefits).

Scenarios 2 & 3 demonstrate the value of domestic coal production as estimated by the CGE model in the "Smart energy options for Bangladesh" paper. Thus foregone benefits of not being able to implement domestic coal production at a scale envisioned by the PSMP 2010 are very large.

If indeed the benefits are of an order of magnitude estimated in the CGE model, they are likely to exceed the resources required to address all concerns raised by the populations opposing domestic coal mining.

Table 1. Present value of benefits and costs of energy sector options without GHG (2015 US$ billion), 2016-2030

Discount rate	Coal 50			Coal I&D_1			Coal I&D_2		
	Benefits	Costs	**BCR**	Benefits	Costs	**BCR**	Benefits	Costs	**BCR**
3%	66	2.7	**24.4**	250	9.8	**25.6**	315	12.3	**25.6**
5%	54	2.2	**24.4**	204	7.9	**25.6**	258	10.0	**25.7**
10%	34	1.4	**24.7**	127	4.9	**25.9**	161	6.2	**25.9**

Note: Coal 50 is import of coal for 50% of electricity production by 2030. Coal I&D_1 and _2 are imported and domestic coal for electricity production, without and with natural gas price rationalization.

Table 2. Present value of benefits and costs of energy sector options with GHG (2015 US$ billion), 2016-2030

Discount rate	**Coal 50**			**Coal I&D_1**			**Coal I&D_2**		
	Benefits	Costs	**BCR**	Benefits	Costs	**BCR**	Benefits	Costs	**BCR**
3%	66	3.2	**20.4**	250	13.2	**18.9**	315	15.5	**20.3**
5%	54	2.3	**23.4**	204	8.6	**23.7**	258	10.6	**24.2**
10%	34	1.4	**24.7**	127	4.9	**25.9**	161	6.2	**25.9**

Note: Coal 50 is import of coal for 50% of electricity production by 2030. Coal I&D_1 and _2 are imported and domestic coal for electricity production, without and with natural gas price rationalization.

Literature

PSMP 2010: The Study For Master Plan On Coal Power Development In The People's Republic Of Bangladesh, http://www.bpdb.gov.bd/download/PSMP/PSMP2010.pdf

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