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Energy in developing economies: A 2050 approach

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Enabling a transition to low carbon economies in developing countries

Case Study: Bangladesh

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Abstract

There is little doubt that energy demand is expected to grow rapidly in most developing countries over the next decades. For Bangladesh, economic growth has been accelerating and it is expected that the population will grow from an estimated 150 million people in 2008 to 200 million by 2050, with almost half of the population living in urban areas.

An examination of options for meeting the expected energy demand for 2050 on the assumption that economic growth will continue is necessary in order to plan infrastructure investments that will still be functioning in 2050.

A simple scenario was constructed to predict the energy use in 2050. We estimate that by 2050, an electricity generating capacity of ca. 200 GWp will be needed. The scale of this challenge should not be underestimated. Even with the discovery of large coal deposits and the dwindling gas reserves in Bangladesh, fossil fuels will not be able to provide the bulk of the electricity demand unless there are substantial imports. Renewable energy, particularly solar and biomass, will need to expanded to generate electricity at scale to meet increasing demand. Therefore, massive expansion of renewable energy is not only desirable but necessary in the medium to long term.

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Introduction

The two main features of Bangladesh's demographic and economic context that are highlighted in the Bangladesh's Climate Change Strategy and Action Plan of 2009 [1] are that (a) economic growth has been accelerating over the last 5 years, with the opportunity that it could become a middle-income country by 2020, and that (b) Bangladesh's population growth rate per annum has fallen to 1.4% in 2006. However, it is still expected that the population will grow from an estimated 150 million people in 2008 to 200 million by 2050, with almost half of the population living in urban areas: Dhaka alone is predicted to become a 'mega city' of 40 million people. Moreover, though the percentage of people living in poverty has declined from 59% to 40%, there are still over 50 million people living below the poverty line [1]. Despite the challenge of climate change that could negatively affect the continuation of economic growth, the Government of Bangladesh has committed, in its Poverty Reduction Strategy Paper, to halving the number of people in poverty by 2015 through pro-poor development.

Bangladesh currently has a total energy use per capita of between 1700-2600 kWh per year of which roughly 8% was electricity (25.6 TWh in 2007 [2]). This compares to developed countries such as the UK which have energy use per capita around 45,000 kWh / year of which roughly 15% was electricity (370 TWh in 2009). Although UK energy use per capita is expected to decrease by 2050, electricity demand is expected to double by 2050 to 30% of energy use (750 TWh), mostly because of improvements in efficiency, and the electrification of transport and heating. This analysis has been carried out in order to calculate how the UK will meet its requirement to reduce GHG emissions by 80% by 2050 [3]. Whilst this constraint is not appropriate for Bangladesh an examination of options for meeting the expected energy demand for 2050 on the assumption that economic growth will continue is necessary in order to plan infrastructure investments that will still be functioning in 2050.

Economic growth has always been closely coupled with energy consumption, and it is therefore a sensible approximation to assume that energy use/capita will increase with GDP/capita. In recent years Bangladesh has been able to sustain economic growth of roughly 6% and GDP is currently approximately $600/capita [2]. As part of a UK-Bangladesh pilot project on collaboration on research on climate change, we have constructed a simple scenario to predict the energy use in Bangladesh in 2050 [4].

Climate change and Bangladesh

The impacts of runaway climate change are likely to be felt particularly severely in Bangladesh, and consequently adaption is a priority. Even if international negotiations are successful and manmade climate change is controlled and the average global temperature rise is kept below 2°C then Bangladesh is still likely to see more frequent and severe floods, tropical cyclones, storm surges and droughts. If the average global temperature rise is not kept below 2°C then Bangladesh could lose a significant percentage of its land area to sea level rise.

Over the last 35 years Bangladesh has invested over $10 billion in preventing and minimizing the consequences of natural disasters [1]. Such as flood management schemes, coastal polders, cyclone and flood shelters, the raising of roads and highways, state-of-the-art warning systems and disaster preparedness. As stated in the Strategy the challenge that Bangladesh now faces is to scale up these adaption efforts to create a suitable environment for the economic and social development of the country. However, Bangladesh should also plan for the contingency that average global

Photo 1: Example of flooding in Bangladesh

temperature rise is not kept below 2°C.

Bangladesh faces an additional challenge that it must make large investments in energy infrastructure, to support economic growth independent of climate change, but, if possible, this investment could also contribute to global efforts to reduce GHG emissions, ideally following the principles of contraction and convergence. In addition, any new infrastructure in Bangladesh must be designed to be resilient to the consequences of sea level rise, increased frequency of flooding and droughts and extreme weather events.

Electricity generation and supply in Bangladesh

Over 80 million people in Bangladesh do not have access to electricity, relying on biomass stoves for cooking and kerosene lamps for lighting [5]. The remaining 60 million or so have access to intermittent electricity supplies, with load shedding (of between 500 and 1000 MW in the late afternoon and evening) a persistent problem [5, 6]. In rural areas, 75% of people in 2005 were not connected to the grid in contrast to 50% of those living in Dhaka, showing a rural-urban divide in electricity provision [7].

Installed capacity at the beginning of 2009 was 5,430 MW, but of the 99 power plants then available less than half of this capacity was from power plants dating from 10 years or less, with much of the rest coming from power plants that were between 11 and 30 years old, and the remainder from power plants over 30 years old. Thus the generation capacity for the summer of 2009 was calculated at 4,500 MW, with peak demand of 6000 MW [5]. Maintenance costs (both financially and in terms of time) have been an ongoing issue. 'According to the World Bank… there are 1,000 MW-capable over-priced and under-performing public sector power plants. Another 2,500 MW-capable plants have remained incomplete due to procurement problems' [8].

500 MWs from three new publicly-owned power stations and 700 additional MWs from a number of small private ('rental') stations are due to be online by mid-2010 [5]. A further 2,000 MW is expected to come on-stream between 2011 and 2014 from publicly-owned power stations fuelled by gas. Dependable capacity is therefore expected to have risen by almost a third to 6,900 MW by 2013. But maximum demand is expected to have risen to 8,400 MW in the same period, meaning that the supply-demand gap is still likely to be around 1,500 MW [5]. Between 2014 and 2016, a further 3,850 MW may come online from a number of proposed power stations, some gas, some coal, and one nuclear. In February 2010, the Bangladesh government signed a deal for a joint venture with India for developing a 1,320 MW coal-powered station, as well as to lay down an electricity transmission line to allow Bangladesh to import electricity from India. Russia has also agreed to cooperate with Bangladesh in developing nuclear power.

Eighty-five per cent of electricity is generated from Bangladeshi gas fields, accounting for 50% of gas usage (gas is also used by industry and to produce fertilizer [urea] in what are said to be relatively inefficient processes). There have been increasing shortages of natural gas since 2005 'adding to the sector's woes' [9]. Indeed the Power Division has proposed that 'no gas supply should be given to gas-fired power plants after 2012, in order to conserve diminishing gas reserve for domestic use only' [10]. Whilst there appear to be differences of opinion in relation to the urgency of the gas supply issue, there is a general concern that dependence on locally-supplied gas is unlikely to be a long-term option, though exploration for new gas reserves in the Bay of Bengal continues.

2.9 billion tons of coal reserves have been discovered in Bangladesh in 5 different fields, most of which is only likely to be accessible as open-cast mining, thus with potentially large social, environmental

Photo 2: Large disparities in quality of life exist, not just between cities and rural areas but within urban areas

and agricultural implications [11]. One coal mine has been developed with a million ton capacity over 30 years: it is presently supplying two 125 MW power plants and could supply a further one [5].

Privately-owned diesel generators, dependent on fuel imports, provide additional capacity for those who can afford them. Almost all businesses own such 'captive' generators; it is estimated that in total 12% of sales go towards the additional costs of running them, at a cost of 2% of GDP [9].

The power tariff does not reflect the costs of generation and transmission, requiring the public sector to subsidize the power sector with direct budget transfers and through squeezing of assets, often in an ad hoc and unpredictable manner [9]. Moreover, according to the World Bank, evidence 'from a Poverty and Social Impact Analysis carried out by the IMF shows that these energy subsidies (i) mostly accrue to those who consume more electricity, (ii) crowd out other development expenditures in the budget, and (iii) add to inflationary pressures arising from higher bank financing of the public sector deficit.' [9]

Many papers have been written on the challenges of rolling out electricity supply to the rural poor and the importance of renewable energy [10, 12-23]. However, little attention has been paid to the challenge of how to provide a sustainable electricity supply to large urban conurbations, such as Dhaka, which currently consume much of the current electricity supply, and sustain most of the non-agricultural economy. The problem of how to provide electricity for urban areas is perhaps more acute, as the energy demands are larger and currently heavily dependent upon unsustainable fossil fuels, either imports or rapidly depleting reserves of natural gas. The effect on the health and growth of the urban economy of regular rolling blackouts is already large [5] and this perhaps explains the shift in focus of energy policy over recent years from rolling out electricity supply to the rural poor to meeting demand in urban areas in order to sustain economic growth.

This focus has therefore been on how to meet the immediate and most pressing challenge of meeting existing and projected demand in urban areas and therefore building new electricity generating capacity rather than extending the grid in order to respond to the 'energy crisis'. In this paper we describe how renewable energy generation is an equally valid response to the 'energy crisis' in developed urban areas as it is to the large scale rollout of electricity to the rural poor.

In summary, energy demand in Bangladesh currently exceeds supply and inadequate electricity generation capacity in particular is broadly recognized as an impediment to growth.

Current energy policy

Bangladesh Government has historically been focused on conventional energy [7], with many policy analysts seeing coal, and to a lesser extent nuclear, as the solution to the energy crisis. In the Renewable Energy Policy [24], the ambition for power generation from renewables is 10% by 2020. Moreover, future images of the energy system seem to be based on a largely centralized national grid approach, with appropriate 'state of the art' identified as being large-scale, expensive and relatively untested (e.g. carbon capture and storage). There appears to be little current focus on establishing community-level distributed energy systems, though Rahmatullah et al. [25] have argued that the Rural Electrification Board (REB) should be promoting such an approach. The interim solution for remote non-grid areas is seen as household-level systems, with projects largely following the same model, be it biogas or solar PV, with little experimentation with different versions of the technology or other approaches [7].

Bangladesh currently has a total energy use per capita of between 1700-2600 kWh / year of which roughly 8% was electricity (25.6 TWh in 2007 [2]). Economic growth has always been closely coupled with energy consumption, and it is therefore a sensible approximation to assume that energy use/capita will increase with GDP/capita. In recent years Bangladesh has been able to sustain economic growth of roughly 6% and GDP is currently approximately $600/capita [2]. A simple scenario is constructed to predict energy use in 2050 using the following assumptions, as shown in Table 1.

- GDP/capita and energy/capita increase by 6% per year
- Electricity generation increase by 10% per year
- Population increases to 200 million in 2050, therefore grows by 0.56% per year

Year	kWh / person	Population / millions	Total energy / TWh	Electricity Demand / TWh (GW)	Percent electricity	$ / capita
Yearly growth	6%	0.56%	[6.6%]	10%	n/a	6%
2010	2,150	160	344	28 (3.2 GW)	8.1%	$600
2020	3,850	169	651	73 (8.3 GW)	11.1%	$1,075
2030	6,895	179	1,234	188 (21.5 GW)	15.3%	$1,924
2040	12,349	189	2,336	489 (56 GW)	20.9%	$3,446
2050	22,114	200	4,424	1,267 (145 GW)	28.6%	$6,171

Table 1: Projections for future energy demand, economic and population growth

The scale of this challenge should not be underestimated, combined with the additional challenges of providing the infrastructure to support a population approaching 200 million to a standard of living commensurate with becoming a developed country.

To put this into context, UK electricity demand is currently around 370 TWh (42 GW), and work completed by the UK Government [3] has shown that it could double by 2050 to 750 TWh (85 GW). If Bangladesh were to achieve energy consumption which was approximately 50% of that in the UK by 2050, with a population approximately 3 times larger, and with similar consumption patterns, i.e. transport and heat demand are both mostly electrified, then it would require approximately 1,267 TWh (145 GW) of electricity generation.

Therefore, these assumptions and this scenario is broadly commensurate with a contraction and convergence by 2050 of developed and developing countries. However, the goal should clearly not be to compare Bangladesh to the UK or to achieve energy consumption per capita targets, but to deliver the services necessary to deliver a good quality of life. For example the high population density of Bangladesh may reduce transport demand per capita compared to other countries.

However, it is clear the scale of the infrastructure that needs to be delivered by 2020 and beyond to 2050 requires significant expansion of all sectors of the economy including electricity generating capacity, and there will be many constraints on this. An indication of the requirements of a future energy system in 2050 is shown in Table 2.

Metric	2010	2050
Capacity	5.5 GWp	~200 GWp
Demand	40 TWh (4.6 GW)	1,267 TWh (145 GW)
Supply	28 TWh (3.2 GW)	1,267 TWh (145 GW)
Grid	Centralised	Interconnected smart grids
Price	Government subsidised	Liberalised markets
Fuel	Gas Centralised generation	Coal, Nuclear or Solar Significant distributed generation
Transport	Limited access Expensive Reliant on gas or oil imports	Subways and public transport in urban areas National and regional high speed railways Electric vehicles for private users

Population	160 million	200 million
Electricity access	60 million	200 million
Water access	Limited provision	99+% provision
Sewerage access	Limited provision	99+% provision

Table 2: Key differences between the energy and infrastructure requirements between 2010 and 2050

How can this be delivered?

Installing an electricity generating capacity of ca. 200 GWp from the current position represents a big challenge. Clearly it will require a large investment. However, given the particularity of Bangladesh, it is pertinent to ask how this can be delivered. Below we sketch out how this might be done.

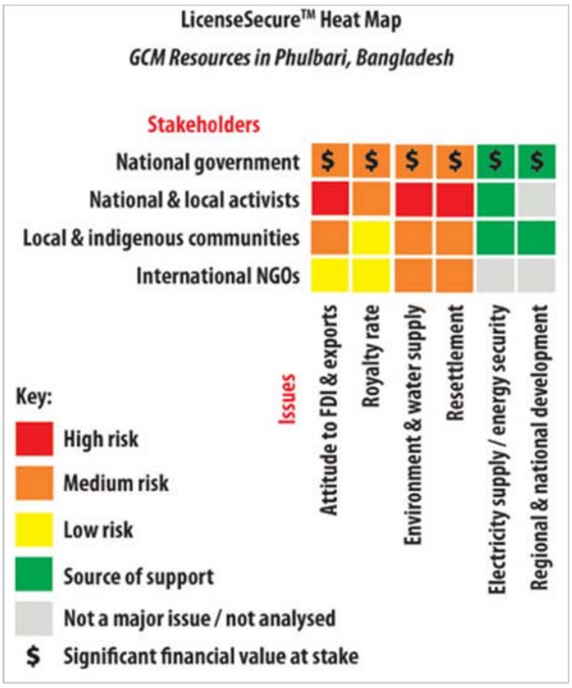
Coal

Bangladesh is likely to develop its coal resources to meet most of its commercial energy needs in the near future in the light of the dwindling supply of indigenous natural gas. Large discoveries of coal have been made in Bangladesh in recent years, with over 2 billion tonnes of proven reserves. However there are significant environmental, political and social challenges associated with coal mining at this scale in a densely populated country; an illustration of the risks associated with mining in the Phulbari region is shown in the Figure 1.

Notwithstanding these challenges, the proven reserves currently equal roughly 450 GW/years of electricity generation. Considering the average life of a power plant is 40-50 years then domestic coal production could support approximately 10 GW of power stations for 40-50 years.

Demand for electricity in Bangladesh is projected to reach 10 GW in 2015 and 14 GW in 2020, with current demand around 5 GW this means that current coal reserves could be used to support the building of new coal power stations out to 2020, but beyond 2020 domestic coal could no longer support further power stations, and further expansion would require substantial imports.

Finally, carbon capture and storage CCS technology is unlikely to be available until 2020 at the earliest, by which time new coal fired power stations may not be justifiable based upon domestic production. Unless coal fired power stations built during 2010-2020 are designed to be CCS ready then CCS is unlikely to have much relevance for Bangladesh. CCS will also reduce the total amount of electricity capable of being generated using domestic reserves (by about 10-20%) because of the high energy requirements for the CCS process itself.



http://www.miningenvironmental.com/special-features/bangladesh-coal-controversy-power-to-the-people

Figure 1: The risks associated with coal mining in the Phulbari region

Nuclear

Nuclear power, at first glance, appears to be an attractive solution for Bangladesh because it does not require major land use or infrastructure changes. However, there are a number of barriers to deployment that should not be ignored. Firstly, the current generation of nuclear reactors would make Bangladesh dependent upon uranium imports.

Secondly, it is unlikely that sustainable waste solutions could be found within Bangladesh. Future versions of nuclear technology such as fast breeder or travelling wave reactors could mitigate these risks by reducing uranium requirements and minimising waste production. However, the risks of accidental releases (even small ones) to the environment could be particularly devastating in a densely populated river delta region heavily reliant upon agriculture. Finally, nuclear reactors typically have to be sited on major rivers or on the coast in order to provide adequate cooling water, therefore potential disturbance due to floods and cyclones may also pose an additional risk.

Solar energy

Solar energy presents a huge, almost limitless resource of effectively free renewable energy. It is also the largest renewable resource that Bangladesh has access to with no major risks or uncertainties in technology readiness. Rooftops present an opportunity to avoid land use changes in rural areas and represent a wasted resource in urban areas. Daily average solar radiation varies between 3 and 6.5 kWh m^{-2} day^{-1} [13], with maximum radiation in March and April and the minimum in December and January.

There are three main technologies that can take advantage of solar energy to provide either electricity and/or heat. Photovoltaic panels (Solar PV) are a scalable technology which converts solar energy directly to electrical energy. The panels can be installed on rooftops powering individual households or in large ground based installations providing utility scale power. Solar thermal panels are also a scalable technology with converts solar energy into low grade hot water, normally deployed on rooftops it is suitable for providing domestic or commercial heating and hot water. They tend to be cheaper than solar PV, although installation and maintenance costs are similar. Finally, concentrating solar power (CSP) concentrates sunlight using mirrors, known as heliostats, to either directly heat water or a liquid which can be stored and used to heat water to generate steam and drive a turbine. The technology is therefore well understood but it has taken many years to develop it such that it can be deployed at scale and at a reasonable cost.

Solar PV

Solar PV installation rates in Bangladesh are increasing rapidly. By July 2009, 25 MW of solar PV had been installed in the forms of Solar Home Systems, Centralized (AC) Systems, Centralized (AC) market electrification and roof top PV mini-grid system to pump water, for railway signaling, to power refrigerators, etc. Much of this is being driven by investment through donor agencies or international aid agencies.

The current aim is that by 2012 one million households will be powered form solar PV panel, producing 50 MW of power [26]. However, the World Bank notes that the market for SHS may become saturated before the 1 million target is reached due to their relative upfront expense, and the risk that consumer confidence in the technology may fall as current SHS equipment wears out, and requires greater maintenance [9].

Typically systems are sold in the range of 20-150 Wp and are coupled with an energy storage system consisting of batteries. Prices range from 15k to 79k Taka respectively. Main players are the Infrastructure Development Company Ltd which had installed more than 400,000 systems by October 2009, Grameen Shakti which had installed more than 283,000 systems by October 2009 and Bangladesh Rural Advancement Committee. Grameen Shakti aims to install more than 1 million systems by 2015, and a further 1 million biogas plants, and 10 million improved cooking stoves.

There have been only limited attempts to use solar PV to generate power beyond the scale of the household or individual building. However, Rahmatullah et al. suggest that the first solar electrification project REB undertook in 1993 was the installation of 30 kWp solar PV on an island of 29 sq. km in Karimpur and Nazarpur unions of Narsingdi Sadar Thana [25]. It served ‘806 different… consumers including health centres, market places and sports clubs’. However, they were later connected to the national grid, and ‘the PV installations were disconnected and handed over to the Pally Bidyut Samiti at Norshingdi for installation in some other remote villages’. According to the Poverty Reduction Strategy Paper, REB has also undertaken ‘another renewable energy project for providing 6000 homes with power from a solar photo voltaic system for the isolated and remote areas of the coastal belt.

Solar energy is also the only viable long term solution where domestic industry can capture a significant percentage of the value chain, and therefore contribute to fundamental economic growth. For example nuclear will be an entirely bought in technology, whereas the solar panels only consist of 40-50% of the value of a solar power module, the remaining 50-60% is power electronics, installation and maintenance which is all suitable for domestic industry and expertise. Early investment is likely to be necessary to secure significant domestic participation in the value chain.

Calculating the potential for solar PV is relatively straightforward but often too simplistic. The important factors are the efficiency of the solar panels and the load factor which is a function of multiple considerations.

Manufacturers typically provide the peak power of their solar panels which is calculated under Standard Testing Conditions (STC) which is equivalent to 1000 W m^{-2} at 25^{o}C and is primarily a function of the efficiency of the solar cells. 10% efficiency will deliver a peak power of 100 W_p under STC. However, solar panels are normally sold in units of power, rather than area, and the costs are normally considered as a function of power $/$W_p$ rather than area $/m^2. Therefore for the customer efficiency should only be important if the available surface area is important. For calculations of solar resource arbitrary efficiencies of 10% are normally assumed [12], which will equal 100 W_p m^{-2}.

However, when considering the potential solar resource, a far more important consideration to take into account is the load factor. Khan and Khan [27] list the following correction factors for STC which must be taken into account when estimating the load factor. A correction for the average shining factor as a function of the time of day, i.e. the average angle of the solar panels relative to the sun, with a correction for diffuse light of 0.686, must be included. In addition, corrections for the real average solar insolation, which in Dhaka is around 900 W m^{-2} of 0.9, temperature of 0.94, and the accumulation of dust on the panels of 0.95.

Khan and Khan [27] therefore estimate that the average solar incident radiation during sunshine hours is actually only 550 W m^{-2} rather than 1000 W m^{-2}. In contrast [12] calculated that the average solar incident radiation during sunshine hours is 740 W m^{-2}. Effective sunlight hours are about 10 hours in summer and 7 in winter, giving an average of 8.5 hours. However, climatic conditions, such as cloud and rainfall during the summer and rainy seasons, and fog in winter, reduce this to an average of just 6 hours [27] or 6.5 hours according to [12].

Therefore, using the average of the two methods, 645 W m^{-2} for 6.25 hours a day, the average solar energy that shines on a solar panel during a day will be roughly 4 kWh m^{-2} day^{-1}, which with an efficiency of 10% will generate 400 Wh m^{-2} day^{-1}. Compared to the rated power of the solar panels, which if they are 10% will be 100 W m^{-2} and therefore should be capable of producing 2.4 kWh m^{-2} day^{-1} the average load factor in Bangladesh would be 16.7%. The efficiency will have no effect on the load factor, as the rated power and energy generated are both a function of the efficiency and it therefore cancels out.

For the purposes of calculating the energy that can be generated from solar panels in Bangladesh the most important consideration is the installed capacity and load factor. The efficiency determines the surface area that is required to achieve a given installed capacity. Therefore, only if the cost of available surface area is high in comparison to solar panel costs or the potential solar resource is low will maximising W_p/m^2 and efficiency be important. However, considering that the costs of the solar modules are relatively high and the potential solar resource just from existing rooftops is extremely large, then maximising $/$W_p$ is far more important in the near term.

In principle it is possible to generate all of Bangladesh's electricity from solar-PV as can be demonstrated with some simple calculations. If only 5% of Bangladesh's surface area (7,375 km^2) was covered in solar-PV with an average efficiency of 10%, this would be equivalent to 738 GW_p of installed capacity. With a load factor of 16.7% this would generate 1,080 TWh of electricity (123 GW_{av}), roughly 85% of predicted 2050 electricity demand in Table 1. This is clearly highly ambitious, but technically feasible. A study in Dhaka showed that the city has roughly 10.554 km^2 of 'bright' roof-tops within the Dhaka City Corporation (DCC) ward area (134.282 km^2), roughly 7.9% of the city area [6]. Problems would be encountered around the time of day and year that the electricity would be generated, with obvious supply problems at night time and during monsoon months. Therefore the amount of energy storage capacity required to smooth supply in order to meet demand would be almost totally impractical.

Therefore a sensible approach has to be taken when considering what the ambitious but reasonably accessible potential for solar-PV might be. A starting point is to limit installations to buildings, which is a reasonable assumption considering this minimises potential competition for land use. Mondal et al. [12] noted that total household roof area is about 4,670 km^2 which is about 3.2% of total land area which could therefore be used to generate roughly 690 TWh of electricity (79 GW_{av} : 472 GW_p). Mondal et al. [13] and Uddin et al. [22] referenced an Asian Development Bank report from 2003 which estimated that over 50 GW_{av} could be generated from solar PV, which is similar to that calculated here. Therefore, it is perhaps more useful to consider the likelihood and cost of various deployment scenarios. The global supply chain in Solar-PV is far larger than in Bangladesh, with installation rates in 2008 of 5.6 GW and an annual growth rate approaching 40%, as shown in table 3.

Year	Installed capacity (GWp)	Annual growth rate	Installation rate (GWp)
2004	3.8	38%	1.1
2005	5.2	34%	1.3
2006	6.8	31%	1.6
2007	9.2	35%	2.4
2008	14.7	61%	5.6

Table 3: The status of solar-PV in the World [28]

Countries such as the USA, Germany, Japan and Spain have demonstrated that high (greater than 1GW per year) annual installation rates are possible, and there is no reason, other than access to finance, that installation rates in Bangladesh could not multiply dramatically for a number of years without imposing a noticeable burden upon the supply chain. Spain did this in 2007, starting from a low base and increasing its capacity by 480% in one year [29].

In Bangladesh, the current aim is that by 2012 one million households will be powered from solar PV panel, producing 50 MW of power [26]. Typically systems are sold in the range of 20-150 Wp and are coupled with an energy storage system consisting of batteries. Prices range from 15k to 79k Taka respectively. Main players are the Infrastructure Development Company Ltd which had installed more than 400,000 systems by October 2009, Grameen Shakti which had installed more than 283,000 systems by October 2009 and Bangladesh Rural Advancement Committee.

It is difficult to estimate the total installed capacity of solar PV in Bangladesh at present. However, assuming an average system size of 85 W_p and roughly ¾ million installations to date, installed capacity in 2009 would be roughly 64 MW_p generating roughly 93 GWh (11 MW_{av}) equivalent to roughly 0.33% of electricity demand. To achieve the aim of generating 50 MW_{av} power by 2012 would require an additional 200 MW_p of installed capacity, which at a cost of roughly \$4 per W_p would require over \$800 million of investment.

However, continuing this rate of investment which would be roughly \$250 million a year, and assuming a cost reduction each year, would deliver 868 MW_p and generate 1.27 TWh a year (145 MW_{av}) by 2020, equivalent to almost 2% of electricity demand shown in table 1. If solar PV was to deliver almost 5% of electricity demand by 2020 then investment would have to approach \$500 million a year in 2010 (roughly 0.5% of GDP) and increase with growth in GDP reaching almost \$900 million a year in 2020.

Installation rates with this level of investment could reach over 320 MW_p per year by 2020. By 2050 installed capacity would reach 65 GW_p producing 95 TWh of electricity, roughly 7.5% of demand, as shown in table 4. This assumes that the cost of manufacturing and installing solar PV systems continues to decrease by about 20% for every doubling of installed capacity, which is true for the last twenty years, and that the industry continues to grow at an average rate of at least 30% per annum [17]. The area required by 2050 would be 650 km^2 which would be less than 15% of current available building surface area.

By 2030 the installation rate would have reached almost 1 GW_p a year, which is highly plausible considering the European Photovoltaic Industry Association [28] predict that the solar-PV supply chain is expected to deliver and sustain production to support a market between 80 GW and 160 GW a year worldwide by 2030. Bangladesh would therefore represent approximately 1% of the global market under this scenario.

Although a simplistic model, it does demonstrate the scale and rough costs of what could be deployed in the short and long term. Leveraging international investment to deliver an order of magnitude increase in installation rates to deliver multiple GW of installed solar PV capacity by 2020 is also entirely achievable.

Year	Electricity demand / TWh	Yearly Investment / $million	Cost / $/W$_p$	Installation Rate / GW$_p$	Installed Capacity / GW$_p$	Area / km^2	Electricity produced / TWh	% electricity
Yearly growth	10%	6%	-4%	10%	n/a	n/a	n/a	n/a
2010	28	$500	4.23	0.12	0.18	1.8	0.27	1.0%
2020	73	$895	2.81	0.32	2.3	23	3.4	4.6%
2030	188	$1,604	1.87	0.86	8.0	80	12	6.2%
2040	489	$2,872	1.24	2.31	23	234	34	7.0%
2050	1,267	$5,143	0.83	6.22	65	650	95	7.5%

Table 4: Projections for the potential of solar-PV assuming 0.5% of GDP is invested annually and growth continues at 6%

Concentrated Solar Power

Using the same assumptions as above of an average solar incident radiation during sunshine of 645 W m^{-2} and 6.25 hours of sunshine a day, a CSP plant with conversion efficiency of 50% and a land area efficiency of 50% it would require an area of 24 km^2 to generate 8.76 TWh (1 GW$_{av}$) of electricity in a year. The exact installed capacity would be a function of the size of the heliostats and the collectors, the energy storage capacity and the size of the turbines and generators, but would certainly be larger than 1 GW$_p$.

If CSP was used to generate all the electricity that Bangladesh is projected to require by 2050 as shown in table 1, then an area of over 3,460 km^2 would be required to generate 1,267 TWh of electricity. This would be 2.35% of the total surface area of Bangladesh.

The global supply chain for CSP is only just developing. At the end of 2008 there was only 0.5 GW$_p$ of CSP globally, compared to almost 15 GW$_p$ of solar-PV. However, the rate of new installations is currently doubling every year, and by 2015 the installed capacity of CSP is expected to be greater than 12 GW$_p$ with projects already in the pipeline, with over half that capacity in the USA and a third in Spain [30]. The supply chain in 2015 could be as large as 4-5 GW a year, and growing at an impressive rate. According to the German Aerospace Center [31] CSP could become competitive with world market prices of most fossil fuel generation by 2015, with costs approaching $0.06 kWh^{-1} by 2020 through efficiency improvements and mass production of equipment. Although it remains to be seen if this is optimistic or not, if this was delivered it would drive demand significantly.

Even under conservative assumptions, it is not unrealistic to predict that by 2020 there will be a significant number of standard designs of CSP technology commercially available at a reasonable cost, with a maturing supply chain capable of installing 20 GW a year or more. Therefore, it can reasonably be assumed that the growth in electricity demand in Bangladesh beyond 2020 predicted in table 1, of 0.8 GW$_{av}$ a year in 2020 growing to 2 GW$_{av}$ a year in 2030, could reasonably be delivered with CSP. It is also likely that there would be opportunities for Bangladesh to explore early deployment and begin to benefit from development of the technology.

For all solar technologies large scale deployment would require significant land use changes, except in the case of building mounted solar-PV which could take advantage of existing rooftops. Although suitable for distributed generation and individual ownership financing for solar PV may be more accessible at community levels helping overcome high initial costs. Solar panels would still be distributed across individual's rooftops or on community buildings and small micro-grids could serve communities. Hybrid combinations with other technologies could also overcome intermittency and have also been demonstrated to be cheaper [21]. CSP is only likely to be viable at a utility level but presents a viable long term solution to provide large scale electricity generation. Solar energy is therefore a viable renewable option on the scale necessary with no major risks or uncertainties in technology readiness. The only barrier is finance, and current costs make this expensive, but solar PV module costs are projected to reduce by around 4% annually and energy from conventional sources is expected to rise. In addition, solar energy is likely to be a cheaper option for off-grid locations (~60% of the population) well before grid connected locations considering the capital costs of building a grid infrastructure. It may also be the only option in the near and even medium term for some regions.

Biomass and anaerobic digestion

Anaerobic digestion (AD) on a (high tech) community scale has the potential to contribute a significant additional amount of energy in the short term (within 10 years) and sustainably in the long term. This could be in the form of transport fuel, generating electricity or replacing natural gas. This may be expensive, but there are potentially large co-benefits if it is implemented alongside the roll-out of modern sewerage, water and waste infrastructure.

The potential of biogas as a renewable energy source for Bangladesh is relatively well-documented. In 1997, GTZ's Bangladesh Country study of biogas stated: 'The cattle dung available from 22 million cows and buffaloes [2 million of the 8.5 million households who own 'bovines' have 3 to 4 cows, and a further million have more than 5 cows [32]] is nearly 0.22 million tons / day. Similarly Islam et al. [18] in 2008 estimated that animal dung available from 24.48 million cattle and buffalo is nearly 0.186 million tons / day. One ton of dung can produce 37 m^3 of biogas [13]. Available cattle dung can therefore produce between 2.5 to 3.0 x 10^9 m^3 of gas per year which is the energy equivalent of between 2.5 to 3 million tons of coal. In addition Islam et al. [18] mention that a substantial amount of biogas can be produced from human and other animal excreta (particularly poultry), garbage and water hyacinth.'

The 2006 SNV report [32] outlines a number of other reasons why biogas is an attractive option for Bangladesh: the availability of high quality construction materials (cement, bricks, iron rods, sand, and 'khoa' instead of gravel), water, and the types of temperatures ideal for biogas production. The social benefits are that (a) the biogas produced is quicker (saving an hour of time per day), easier and less-smoky as a cooking fuel than biomass, (b) it provides a way to manage sanitation effectively, (c) it saves biomass and reduces GHG emissions, (d) the slurry produced is of higher quality than farmyard manure, and (e) the cost of plant construction can be recovered in 5 years on a potential 20 year lifespan for the technology. However, the project document also notes the technical challenges of high water tables and monsoon flooding, together with the fact that numbers of cattle per household are declining.

In addition the burning of biomass in traditional stoves contributes to poor air quality and causes health problems, the efficiency of conversion of traditional stoves is also very low, therefore the true energy requirement is likely to be far lower than the energy content of the fuel. By redesigning solid fuel burners, or diverting biomass to electricity or biogas production it may be possible to improve the efficiency of the system and improve air quality and health considerably. A considerable amount of additional biomass is also produced in the form of waste food, agricultural residues, sewage and manure and commercial and industrial waste.

According to BCAS [33], the Chinese fixed dome biogas plant has proven to be the 'most suitable for Bangladesh', and a local variant is the 'only design that is being applied in the country' now.

In terms of experiences of the socio-cultural acceptability of different fuels for the bio digester, there are no issues with the use of cow dung whatever religious affiliation in Bangladesh as this is traditionally often used as a fuel, though it is also important for

Photo 3: A rural village in Bangladesh

fertilizer and in construction; whilst poultry litter is perceived as smelling more unpleasant, there also appears to be no concerns with its use; indeed its use in bio digestion is seen as a way to tackle the issue of odor. There have been concerns over the use of night soil, but there are several hundred biogas digesters that use human excreta as one of the source materials and in consultation with religious leaders who have assured households that use of the resulting gas for cooking is clean in religious terms, users have come to accept it [33].

Of the 25,000 biogas digesters constructed by 2005, two thousands of these used poultry litter. The BCAS study of the use of biogas from poultry farms in Bangladesh found that (a) the poultry farms tended to be quite small (employing one or two people, usually men), (b) the production of biogas did not cause much additional work (just mixing the litter with water), and (c) the output was usually as gas that was mostly used as cooking fuel. One hundred birds provided enough litter to fuel the cooking of one meal for a 4-person rural household per day. There are over 100,000 poultry farms in Bangladesh, as shown in table 5, of over 100 birds each that produce about 5900 tons of litter daily.

Poultry Farm Size (No of birds)	No. of farms (approximate)
100 – 249	15,000
250 – 499	35,000
500 – 999	45,000
1,000 – 4,999	12,000
5,000 – 9,999	8,000
10,000 – 50,000	1,200
> 50,000	50
Total	116,250

Table 5: Poultry farm potential in Bangladesh [33].

The study found a few private and public sector organizations attempting to produce power from biogas, using retrofitted LPG or natural gas generators as no appropriate generators were being produced in Bangladesh at that time. Most have had limited success, although one poultry farm, Bogra Poultry Complex, had been generating sufficient electricity for its own needs for 5 years, and therefore had disconnected from REB-supplied grid. The farmers were also pleased with the quality of the slurry produced which could be used when sun-dried as fertilizer or as fish feed in fish farms.

The economics of constructing and running a biogas plant in 2005 were found to be positive where both the biogas and fertilizer produced are used, particularly the larger the farm. The economics for producing electricity were negative until a farm-size of 500 birds, when it needed to be produced alongside fertilizer or gas. Producing gas remained more profitable than electricity, however large the farm. An evaluation of a Bangladesh Council of Scientific Industrial Research project found that where there was grid electricity available, there was more interest in having gas produced from a biogas digester than electricity. However increasing stress on the national grid may be making electricity generation more attractive, particularly as poultry farms require both heat and light.

Photo 4: Even in cities considerable biomass is still available

Biogas is a mixture of methane and carbon dioxide with small amounts of moisture and hydrogen sulfide. Few of the biogas plants were fitted with scrubbing technology, although the Institute for Fuel Research and Development has apparently developed such technology [33]. Other problems that were detected in the study were that (a) the appropriate charging rate and slurry: water ratio are not being maintained, (b) initial financing was often not available, (c) there was sometimes a lack of training, and (d) the slurry was often not used, and there was need to focus on marketing of this product to add value. Other recommendations included the use of clay, jute and dung in the construction of the biogas plant to reduce the costs. 'A package of solar and biogas with credit support for poultry and dairy farms may change the life style of rural people.' [33]

'Bangladesh Council of Scientific Industrial Research and Local Government Engineering Department have so far trained more than 1,800 engineers, supervisors and masons on the construction, operation and maintenance of fixed-dome biogas plants. This is an important aspect for undertaking a dissemination project as there is sufficient number of expertise available all over the country' [33].

With a population of 160 million increasing to 200 million the amount of biomass energy available in sewage will be considerable. However in order to take advantage of this adequate sewage systems must be in place, but this is necessary for many other reasons, not least sanitation, health, and improving water quality. Therefore, over the next forty years it will be necessary to invest in sewage infrastructure anyway. Investing in anaerobic digestion to dispose of sewage sludge, generating energy and other valuable by-products is likely to be the lowest cost option. It should therefore be seen as an opportunity to reduce costs by generating revenue to subsidise necessary investments rather than an additional cost. To calculate the potential for biogas production from sewage sludge in Bangladesh a quick comparison with the UK is conducted. The UK generated 0.56 TWh of electricity from anaerobic digestion of approximately two thirds of sewage sludge in 2008. With a population of 160 million compared to 60 million, if the average Bangladeshi produced the same amount of sewage sludge per person it should be possible to generate over 7.5 TWh of biogas.

Assuming an average value of roughly 6.5 kWh m^{-3} for the energy content of biogas the potential for biogas in Bangladesh is considerable. Cattle dung available from 22 million cows and buffaloes would generate almost 20 TWh a year. Chicken litter available from the 100,000 poultry farms would generated over 0.5 TWh a year. Similarly a comparison with the UK's food waste of about 20 million tonnes per year for 60 million people, assuming a similar amount of waste for 160 million people (assuming a third less waste because of lower incomes) and based upon the energy content of the biogas produced from anaerobic digestion of food waste of 3.0 GJ/tonne about 17 TWh of biogas could be produced.

A reasonable estimate therefore suggests that at least 45 TWh of biogas could be produced, although further more detailed analysis is necessary. Electricity production from biogas is generally between 20-30% efficient. However, although it would be possible to use this biogas to generated over 11 TWh (1.3 GW) of electricity it may be better used directly as a cooking or transport fuel where there are fewer substitutes.

Emerging but relatively mature fuel cell technology is being developed that can operate on biogas from anaerobic digesters to generate electricity on a small scale more efficiently than combustion engines. Operating as part of a network of distributed generators (a virtual gas fired power station) using biogas or initially a mixture of biogas and natural gas these could present an early opportunity to generate significant quantities of electricity in both urban and rural environments. They would also increase resilience in the system due to the distributed nature of the generation and could be a key transition technology and increase the efficiency of electricity production from limited biomass resources. Systems are modular in nature, and therefore scalable, with currently available systems ranging from 1kW to 2.8 MW.

Energy from waste

Modern waste contains many combustible materials, most of which are biomass derived, but also petrochemical derived such as plastics. Modern waste hierarchies suggest that Reducing, Reusing, and Recycling waste should all occur (in that order) before energy recovery, but it is still likely that modern Energy from Waste (EfW) plants could generate useful quantities of electricity and reduce pressure on other waste disposal mechanisms such as landfill.

Biomass with a high water and low cellulose content is most suitable for anaerobic digestion, but contaminated biomass or residual biomass with low water content and high cellulose content (i.e. wood) and residual plastics should be processed in EfW plants rather than landfill. Modern gasification, pyrolysis or plasma arc vitrification technologies are suitable for processing large volumes of mixed and contaminated waste. They are ideal for large cities and some industrial processes. Well planned sorting, recycling and waste reduction strategies can minimise the need for mixed waste processing facilities.

Hydroelectric and tidal streams

Further expansion of hydropower is expected to be limited, but the estimated exploitable capacity is estimated to be 745 MW, of which around 200 MW can be produced by small and mini-sized hydropower plants [13]. There is an unknown potential for tidal stream, lagoons and or river flow. Opportunities may exist to combine these with flood defences and water management. The technology is relatively mature; however, the impacts on natural water flows and risks are unknown.

Wind energy

Wind speeds across much of the country are likely to be too low for economic deployment of wind turbines. However, in rural hilly and coastal areas wind speeds may be high enough (>5m/s) and present opportunities. In urban areas wind speeds are likely to be too low (<5m/s) due to disruption of wind patterns by the urban environment.

The economics of micro-wind are likely to be only favourable with larger (>6kW) pole mounted installations which will tend to be more appropriate for communities rather than individual households. The technology at this scale is proven and mature. To estimate the potential, one 20kW wind turbine per village (estimated 68,000) and a load factor of 25% would generate 3.0 TWh (340 MW_{av}) of electricity. Although Larger utility scale (MW) wind turbines are also proven and mature, but again will only be suitable in limited hilly and coastal areas with suitable average wind speeds. The potential for large scale wind was estimated in 2003 to be 2 GW [13], and therefore could present an opportunity, although potential cyclone damage may pose an unacceptable risk unless cyclone proof designs can be developed and proven.

Energy efficiency

In all countries the most significant opportunity for lowering emission lies in improving energy efficiency. However, considering that access to energy in Bangladesh is probably one of the key restraints on economic growth, the rebound effect, where energy saved through energy efficiency is used elsewhere is likely to be close to 100%. Therefore, energy efficiency is unlikely to lower energy demand in Bangladesh, but instead contribute to economic growth. In conclusion, energy efficiency measures should be pursued just as aggressively in Bangladesh as in developed countries, but for different reasons. To put another way, energy that is locked into inefficient systems and processes can be thought of as limiting the growth of Bangladesh.

Due to the relatively low and subsidised energy price and inefficient government institutions, the commercial use of energy remains inefficient and wasteful. To change this, proper incentive structures will have to be designed and regulation has to be far more effective. This is a technological as well as a regulatory challenge. However, the potential cost and energy savings are huge. Access to finance is still an issue as financial institutions are not familiar with green technologies and opportunities around carbon credits.

Summary

The analysis carried out in this paper suggests that renewable sources, particularly solar and biomass, will need to be utilised extensively to meet the expected increases in demand for energy. Although there is a core of expertise and interest in renewable energy in a variety of academic, government and NGO departments within Bangladesh, the mixed experiences and low-tech approach taken to date, particularly with biogas, may represent an obstacle in promoting these technologies as technologies of the future rather than the past. There is also a risk that advocating a more distributed approach (particularly if powered by solar and biogas arrangements) may be perceived as appropriate for marginal rural areas, but not for the developed economy Bangladesh is seeking to become. Moreover, such an approach may be resisted by those who benefit currently – or hope to in the future – from a more centralized, large infrastructure approach. However, it is important to stress:

1. That solar and biogas are continually evolving, but proven, technologies – often very 'state of the art' -- which can be used on different scales and with different sophistication: developing further technological expertise together with practical experience in this evolving arena is likely to be beneficial not only in terms of Bangladesh's energy balance sheet, but in terms of potential contribution to economic growth if it aims to become a leader in the field;
2. These ideas build on over twenty years of experience within Bangladesh not only in relation to biogas and solar PV deployment, but in relation to the development of energy cooperatives and in the use of micro-finance and revolving funds as a development tool;
3. What is new in the analysis presented below, however, is the idea of integrating all these aspects so as to create an energy-water-waste system that draws on the latest developments in solar PV and biogas to serve a whole community, be it urban or rural, in a way that is likely to contribute to national energy security;
4. How cutting edge such an approach is likely to be, in terms of not only the potential to leapfrog in terms of technology, but in terms of institutions and infrastructures, that will avoid the legacies that are increasingly plaguing the 'developed' world and avoiding the possibility of large-scale, big-investment stranded assets in the longer-term.

There is a real need for a comprehensive renewable energy opportunity assessment to be undertaken. In urban areas the density of the solar radiation is high enough to meet a considerable level of demand and land use has already been given over to human activities and rooftops present ideal opportunities to minimise land use change. The same is true of biomass, as the high population densities gives rise to large sewage and waste food volumes, and food processing facilities and farms will present additional opportunities.

Key barriers to deployment of large scale renewables, even in cities are the lack of grid connections, both in terms of enabling supply and also in terms of demand (many potential customers are not connected) and reaching the majority of the population. Distributed generation may enable this high capital cost investment to be avoided (similar to leap-frogging from fixed line telephony to mobile phones seen in many developing countries) and could be used to stimulate the development of community scale micro grids. This is also likely to be at a scale that enables participation of local industries in the development, deployment and maintenance, at an appropriate skill level for the local workforce and the right size for local companies or cooperatives to finance, promoting regional development rather than having to import high tech equipment.

This will be equally true in the suburbs and high population density cities as in rural villages, the only difference will be the relevant technologies, feedstock's and infrastructure requirements. Table 6 summarises the opportunities identified at present.

Energy Sources	Viability	Available practical resource / year
Solar PV	Very attractive short & long term option, Bangladesh has excellent solar radiation. Viable technology and already being installed, albeit at modest rates. Barrier is finance.	Estimated at least ~860TWh (100GW)
Concentrating Solar Power	Very attractive long term option, costs are expected to approach those of nuclear within 5-10 years.	Effectively unlimited, and only limited by competition for land use
Wind (small, onshore)	Viable, technically feasible now, viable with wind speeds above 5 m/s, average is 4.5 m/s so enough sites should exist.	Estimated ~0.87 TWh (102 MW_{av})
Wind (large, onshore)	Unknown, technically and economically feasible but large capital costs and requires grid connections.	Estimated ~17 TWh (2 GW) [13]
Wind (large, offshore)	Unknown, technically and economically feasible but large capital costs and requires grid connections.	Unknown theoretical potential
Hydro (small)	Viable, technically and economically feasible.	Estimate ~1.75 TWh (0.2 GW) [13]
Hydro (large)	Viable, technically and economically feasible but large capital costs and requires grid connections, also potentially large environmental impacts.	Estimate ~4.8 TWh (0.55 GW) [13]
Marine (small, tidal)	Viable, technically and economically feasible now, coastal regions and islands.	Unknown theoretical potential
Marine (large, tidal)	Not yet viable, expensive technology	Unknown theoretical potential
Marine (wave)	Not yet viable, expensive technology	Minimum 1TWh (100MW) Unknown theoretical potential
Biomass	Viable, currently being used extensively but mostly in non-optimised systems.	Presently 80-90 TWh of biomass burning, efficiency could probably be doubled. Waste biomass resource indicate at least 45 TWh of biogas could be generated.
Geothermal	Unknown	Unknown theoretical potential
Imports	Significant resources elsewhere in the region make electricity imports accessible	Effectively unlimited regional solar resources and considerable hydroelectric resources
Coal	Viable technology. Highest CO_2 emissions. Considerable barriers and environmental and political challenges associated with domestic coal mining. Imports possible.	Domestic production only 80 TWh (10 GW) For 40-50 years *With CCS & domestic production only* *68 TWh (8.5 GW)* *For 40-50 years*
Nuclear	Viable technology but with significant barriers and risks. New technologies may mitigate some risks.	Limited by access to Uranium and/or new technologies

Table 6: Bangladesh's energy opportunity map

In the near term (10 years) it should be possible to generate approximately 23 TWh (equivalent to 2.67GW) of electricity from solar-PV if $1m^2$ per person is installed across the country. It is likely that it will be possible to double the efficiency of existing uses of primary biomass (80-90TWh) being burnt for heating and cooking, therefore delivering double the service from the same amount of biomass or reducing pressure on natural services and deforestation. Alternatively biomass could then be diverted to fuel production for transport or electricity production and produce 13.5 TWh (1.5GW) of electricity.

Also in the near term waste biomass should be able to generate around 45 TWh of biogas, which could be used directly as a transport fuel or to displace natural gas, or used to generate approximately 11 TWh (1.3GW) of electricity. Micro-wind turbines could be expected to generate around 2.3 TWh (0.26GW) of electricity per year, perhaps much more. Hydroelectric schemes could be expanded and generate around 2.2 TWh (0.26GW). Other small-scale scale tidal schemes could contribute significant amounts. It is likely that large offshore wind could contribute significant amounts of power, although further analysis is needed.

In total approximately 6GW of renewable electricity capacity has been found which could be exploitable within 10 years, much of this is distributed and will require a major re-think in the provision of electricity. Further expansion in renewable energy production beyond 2020 would require increases in solar-PV and CSP deployment, large scale deployment of wind and/or developments in less mature technologies.

Regional Energy Planning

The analysis presented here suggests that Bangladesh will find it very challenging to generate all the electricity that it needs within its borders. A regional approach to energy and other resources will probably be mutually beneficial to both Bangladesh and its neighbours. In particular the greater availability of marginal or desert land in some neighbours could be used to generate large amounts of solar power, and the significant hydroelectric potential of the Himalayan region could be used to smooth demand and store energy regionally.

There are plans to develop concentrated solar power (CSP) plants in desert regions of the world combined with a network of high voltage DC transmission lines. The highest profile of these are the Desertec projects, and the two largest examples are being developed by Consortia of companies in Europe, Africa, and the Middle East and in the USA. Prototype plants are already being built, and the world's first CSP plant over 100 MW is expected to be operational in Egypt by the end of 2010. Fledgling plans for an Indian Desertec also exist. For example, the Thar desert with an area of 0.28 million km^2 in Western Indian would be capable of powering the entire subcontinent on its own. An area between 4-8 km^2 is required to generate roughly 8 TWh (1 GW) depending upon technology and solar radiation.

Domestic conventional hydroelectricity is not a viable option in Bangladesh because of its flat topography. However, some small scale micro-hydro or tidal range hydro may be feasible these are unlikely to contribute significantly to domestic electricity generation in the long term. However, Bangladesh's neighbours have significant untapped potential for hydroelectric electricity generation. Nepal alone is estimated to have the potential for 83 GW of generating capacity, of which 42 GW is considered to be technically feasible [34], Myanmar is estimated to have the potential for over 108 GW of generating capacity [35], and India is estimated to have almost 150 GW of technically feasible capacity and an additional 100 GW of pumped storage capacity [36]. Similar estimates in Bhutan and regions of China near Bangladesh are likely. In Nepal private sector developers are keen to take advantage of this potential and some projects are being developed to enable electricity to be exported to India, despite domestic demand for electricity in Nepal currently being greater than supply. India is also keen to take advantage of its domestic opportunities.

One of the key benefits of hydroelectric electricity generation is its disposable nature, which means it can easily be turned on or off and used to follow peaks or high demand, or even used in reverse to store energy from other electricity generation during periods of low demand. A regional strategy that uses the large hydroelectric electricity generation potential of the Himalayan region to smooth supply from other more intermittent renewables in the region would probably deliver greater benefits than strategies optimised on a country by country basis.

Technically it is likely that developing a regional energy strategy may be more cost effective than developing a self-sufficient system in Bangladesh. Political barriers may be greater. A regional approach would require effort to integrate electricity grids, and could also benefit from regional strategies and plans to manage resources such as water, biomass and food production alongside electricity.

Mini-grids, Micro-grids and Leapfrogs: A service driven approach

Crucial community services are often interrelated; therefore synergies and economies of scale are likely to be gained by linking them together. These synergies are more likely to be possible on a community or large scale where fluctuations in load are more predictable. In addition hybrid combinations of energy technologies offer synergies, such as using anaerobic digesters to produce gas which can be stored and then used to generate electricity during cloudy periods or at night time, combined with solar-PV to provide cheap unlimited energy to augment limited biomass resources.

In addition waste disposal schemes could be funded by a price for waste set by using biomass as a feedstock for anaerobic digesters. Water for irrigation or domestic or industrial use requires energy for pumping but with adequate storage would not be needed on-demand. This could then be used as a disposable load for the grid during periods of high demand, which is likely to be at a far lower cost than investing in electrical storage (i.e. batteries). Completing the circle, by integrating the energy, waste and water sectors, additional incentives are established to prevent unauthorised disposal of hazardous waste which could contaminate ground water, and by relying on biomass as a feedstock, incentives are provided to invest in adequate irrigation and to return biomass residues as fertilisers to the soil to maintain security of supply of biomass.

Photo 5: “Gonogobeshona” – ACTIONAID supported research by communities

Cooperative models are identified as a key enabler at the community scale, and by being operated by the community the incentive will also be there to invest profits in future capacity in order to protect security of supply of services to the community. This will be true in both urban and rural environments. Crucially those in the urban middle class probably represent the best opportunity in the near term as they will be able and willing to pay for services but are not wealthy enough to have paid for individual solutions. As communities develop services it will be possible to aggregate services and benefit from economies of scale, but the transition may be via community scale service providers.

Urban areas represent very concentrated energy and service demands, and therefore it is not technically possible to provide the energy or service demands of a modern city within the boundaries of the city itself. Modern cities therefore rely on large supply chains and power stations to provide energy which is harvested over an area much larger than the city itself. As such electricity generation is likely to be situated outside the boundaries of the city but would be part a large scale energy infrastructure which is connected to the city via a ‘national’ grid.

A large barrier at this scale is the lack of grid connections, both in terms of connecting large electricity supplies and also in terms of demand and reaching the majority of the population, as many potential customers are still not connected. They do not use enough electricity to be attractive customers because they do not have access to electricity. A potential transition to overcome this ‘chicken and egg’ situation is to stimulate the development of community scale micro grids and distributed generation. This could enable the high capital cost investment to be avoided or subsidised (similar to the leap-frogging from fixed line telephony to mobile phones seen in many developing countries). However, rates of return in investment will probably be higher in the wealthier suburbs and high population density cities compared to rural villages hence Government support will probably still be needed. At some point the connecting up of micro-grids to the national grid may be economically attractive to benefit from economies of scale and enable customers to use more electricity, but as mentioned above the transition via community scale service providers, micro generation, and micro grids may present the quickest and cheapest way to build a national grid.

There is a large opportunity that with proper planning Bangladesh could leapfrog conventional energy systems and technologies and move towards a decarbonised smart grid. Indeed this is the aim of most developed countries who are faced with the prospect of an ageing energy system in need of replacement. To do this at scale, for industry and urban areas, and not just rural areas present a huge challenge. However considering the necessity to invest in infrastructure in order to support a growing economy the question is not whether to invest, but whether to invest in new technology or old.

Most renewable technologies compared to fossil fuel based technologies represent a shift from low initial investment and high running costs to high initial investment and low running costs[1]. This is currently a barrier because investors most often heavily discount future value and expect short payback periods and therefore consider most renewable technologies as 'more expensive' even though many already payback the investment over their lifetime. In addition they also significantly de-risk the customer from rising fossil fuel prices and uncertainties in supply. This risk is often 'unknown' as is the future price of oil and with this uncertainty the risk is either ignored or undervalued by typical investors. Therefore, the challenge of persuading investors that they are better off investing a large sum of money now with a potentially long payback time (but not always) can be substantial. Focussing incentives on overcoming these barriers will be crucial in stimulating investment in a low carbon economy.

Transition pathways

None of this is very helpful unless it is possible to identify transition pathways that bridge the gap between the current systems and the idealised future systems. Policy makers must meet the needs of the population both now and in the future, and it is no good investing in the future if it doesn't also improve people's quality of life and delivers economic growth in the short term. Therefore, some technologies and investments will be part of the transition and some will be part of the end game. For example, coal fired power stations with the capability of being retro-fitted for CCS, although not part of the end game may well be necessary to sustain economic growth over the short to medium term until newer technologies such as CSP are capable of being deployed at scale. However, in order to minimise wasted investment and stranded assets and maximise the opportunities from leapfrogging it is necessary to develop strategic plans that encompass decades and not just the single term of a government. The lessons from the UK 2050 pathways project have shown that it is not necessary, indeed it is not possible, to correctly predict the future, but it is important to identify what is possible and what is likely, and then plan accordingly. Cross-party political consensus is then necessary on what to achieve and by when. The timescales and level of investment required over the next 40 years mean that this task is both urgent and necessary for all developing and developed countries.

Conclusions

There is a real need for a comprehensive renewable energy opportunity assessment for Bangladesh to be undertaken. The most promising technologies in terms of available practical resource and nationwide geographic availability are solar and biomass, in particular solar-PV and anaerobic digestion. These present the largest available practical resource and are currently available. Key barriers to deployment of large scale renewables, even in cities, are the lack

[1] Managing the feedstock stream for AD can be labour intensive, providing jobs and also generates additional products with subsequent revenue streams. If waste stream management is combined with recycling there may be other major co-benefits.

of grid connections, both in terms of enabling supply and also in terms of demand (many potential customers are not connected) and reaching the majority of the population. Distributed generation may enable this high capital cost investment to be avoided (similar to leap-frogging from fixed line telephony to mobile phones seen in many developing countries) and could be used to stimulate the development of community scale micro grids.

It is likely that Bangladesh will find it challenging to generate all the energy that it needs within its borders. A regional approach to energy and other resources will probably be mutually beneficial to both Bangladesh and its neighbours. In particular the greater availability of marginal or desert land in some neighbours could be used to generate large amounts of solar power, and the significant hydroelectric potential of the Himalayan region could be used to smooth demand and store energy regionally.

Energy policy and visions in Bangladesh still seem to be largely focused on 'conventional' energy based on a conventional state-private sector-run centralised energy system; therefore most efforts to solve the current energy crisis and meet large predicted future energy needs are focused on developing coal, nuclear and regional electricity imports. Renewable energy largely seems to be perceived as an interim solution for poorer households which are based in areas without access to the grid, rather than as a potential long-term development strategy for a future 'state of the art' energy system that provides energy security and flexibility of response. With the appropriate policy, technical, institutional and financial incentives and support, Bangladesh could harness the innate solar and biogas potential it offers with proven -- but continually evolving -- technologies at rates that are much more ambitious than is currently being realised.

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