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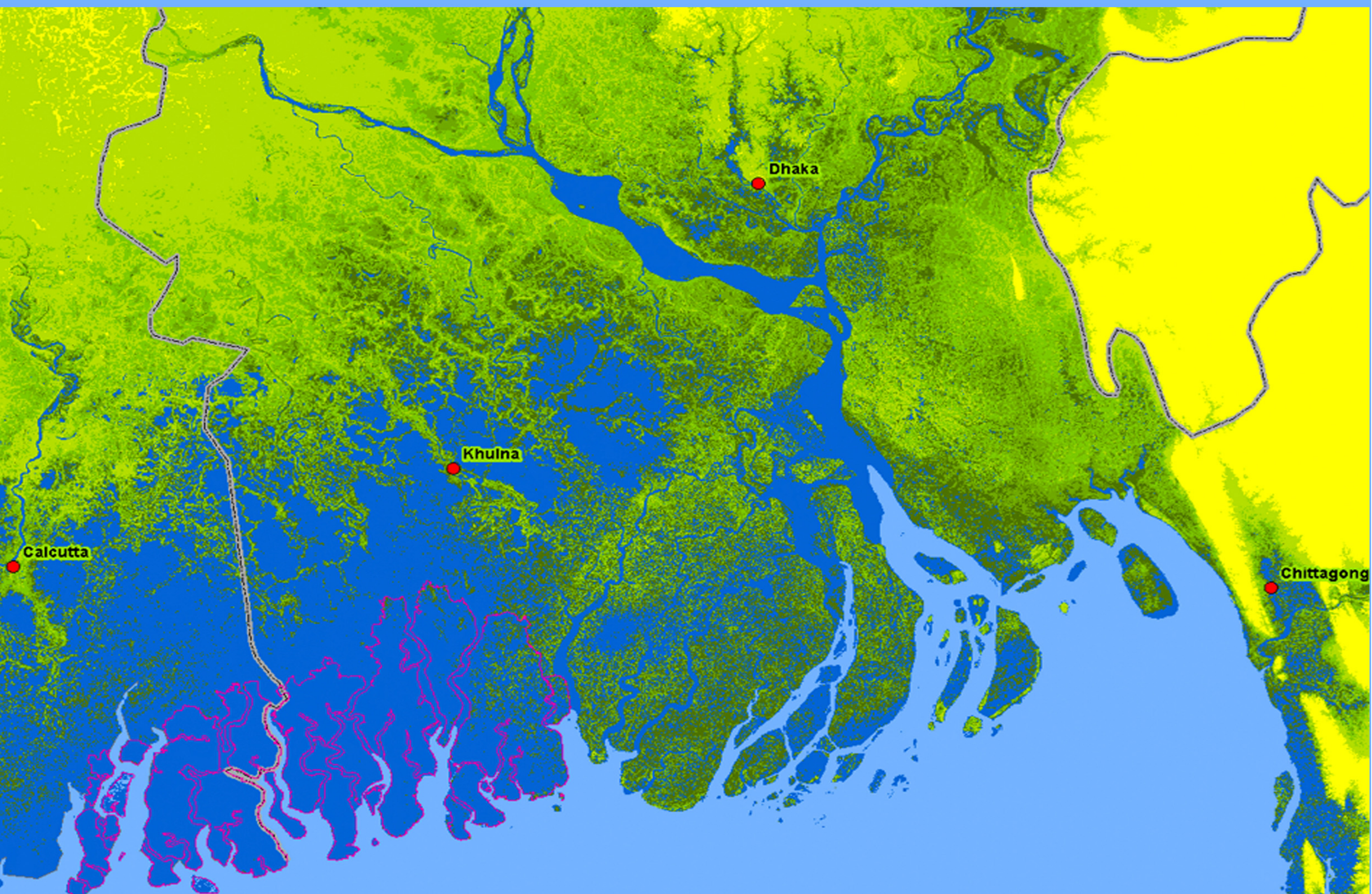

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Bangladesh Energy/Climate Nexus Part I Quest for Energy Fix and a Trailblazing Rural/Household Energy Sector

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Abstract

Bangladesh, at cross-hairs of the world's twin mega challenges, growing energy demand and fossil fuel-driven climate change, faces a conundrum as she seeks access to modern energy systems to augment her extraordinary economic growth of the past decade. Advances in the rural/household sector, encompassing the majority of the population and typically reliant on traditional fuels, are based on a unique combination of off-grid solar home systems for lighting and improved cook stoves for cleaner cooking, and heating, with significant domestic technology, innovation, and entrepreneurial contents. For the urban/industrial/commercial sector, currently based primarily on the country's dwindling gas reserve, energy planners have adopted the classical centralized generation and distribution system common in the West, with two seemingly contradictory approaches, reliance on imported coal and liquefied natural gas proffered for a rapid economic expansion, and utility-scale, 'clean' electricity generation with a smattering of nuclear plants and solar farms in order to meet the country's commitment to the Paris climate treaty. Both approaches rely on external technology, expertise, and concepts.

The paper gives a historic perspective on the country's often painful and environmentally damaging efforts to augment her meagre access to modern energy resources mainly for the urban/industrial/commercial energy sector, provides an overview of energy growth plans for this sector, and describes the remarkable progress in the hitherto neglected rural/household sector. The paper then notes, how the lessons from the historical perspective and the experience in the rural/household energy sector taken together, can inform development of a unique homegrown approach for the urban/industrial/commercial energy sector to fit the country's economic aspirations, terrain and, societal needs, instead of the current approach being pursued.

1 Introduction

Humanity faces two extraordinary challenges, the ability to provide sufficient energy resources for worldwide economic growth and mitigate the adverse impact of global climate change that is primarily blamed on use of fossil fuels as energy sources. These fuels have been instrumental in the rise of the 'developed' world and are now driving the growth in rapidly emerging economies. Bangladesh is at the nexus of this conundrum. The country needs massive amounts of energy to lift her millions out of poverty but does not have an unencumbered access to modern energy systems. On the other hand, despite her low carbon footprint, the country is facing the brunt of global climate change with more devastating floods and a potentially rising sea-level that could submerge a significant part of the country's coastal regions, possibly creating millions of climate refugees. This poses two major questions: 1) What are Bangladesh's energy options for the future and 2) how can the country cope with the impact of climate change? In this paper we primarily examine the first question and comment briefly on the second.

Despite the challenges noted, Bangladesh has made significant strides in achieving her Millennium Development Goals that ran through 2015. For the last two decades, the gross domestic product (GDP) has grown between 5% and 7% per year and a greater growth rate is envisioned. However, often the actual growth rate did fall behind somewhat compared to that projected by the Country's Five-year Plans due to a variety of reasons. Among others, lack of availability of sufficient and reliable power appears to be one.

There has been much discussion on Bangladesh's energy needs ever since the country won her war of independence in 1971. One study by the Energy Panel of Bangladesh Environmental Network (BEN) had assessed the country's energy landscape and made a broad set of recommendations encompassing suitable energy source options, organizational needs, funding, and domestic expertise growth (BEN 2007)[1]. Some of the recommendations of the BEN study are summarized in **Appendix A**. One major common perspective between the BEN study and other studies such as the by Japan International Cooperation Agency (JICA) developed Power Supply Master Plans (PSMP 2016) is the need for a comprehensive, integrated energy policy in Bangladesh; current efforts appear fragmented.

In order to better understand the energy path for Bangladesh, it should be recognized that the country has two major energy sectors, rural/household and urban/industrial/commercial, with an evolving mix (Badruzzaman 2015). In the rural/household sector, the country was heavily reliant on biomass-based cook stoves for cooking and boiling water, while for lighting, kerosene lamps and oil-based lanterns have been the mainstay. Electricity, needed for its rudimentary industrial/commercial sector and small urban population, was generated using a few thermal power stations.

However, since the 1960's, much has happened in Bangladesh's energy production. These include construction of the country's only hydroelectric power station in 1962, introduction of improved cook stoves designed in the laboratories of Bangladesh Council of Scientific and Industrial Research (BCSIR) in the 1980's, a major expansion in gas production through the late 1990's, an ongoing installation of solar home systems and solar irrigation systems in rural areas mostly by non-governmental organizations (NGO's) starting in 2000–2010 time frame (IDCOL 2018), and the current government's Power Supply Master Plans (PSMP) to generate large amounts of electricity (PSMP 2010–2011; 2016).

The PSMP's propose construction of several coal-fired plants, at least two nuclear plants, importation of liquefied natural gas (LNG) for gas-fired plants, and at a least a couple of solar parks or farms. In addition, nearly 300 MWe off-grid solar electricity capacity has been added (SREDA 2019). After an inexplicable slowdown of several years, the current government is considering renewal of gas exploration (GSMP 2018). Rural electrification has been a major endeavor of successive governments (Chowdhury 2009) and the government recently announced achievement of a 90% electrification country-wide (Prothom Alo 2018).

Thus, much progress has been made, and on paper, the country has a number promising options for energy generation for the next several years. However, some of the choices being exercised have raised concerns. In the current and companion papers, we examine the various choices being considered or developed and their potential impact. As with many developing countries, energy resource access and utilization have been challenging for Bangladesh, compounded by the complexities of evolving energy source choices over time, attendant economics, and associated policy decisions. The policy decisions have often been at the behest of external 'experts' who are not always conversant with the country's economic, technological, and societal perspectives. Foreign interests, from time to time, have compounded the energy and resource challenges in the developing world (War on Want 2016), and as we will see, Bangladesh has not been an exception to this.

Furthermore, climate change concerns have raised serious doubts about the wisdom of continued growth in use of green-house gas (GHG)-generating fossil fuels, which however, currently appear to offer the least expensive and quickest way to meet power needs for economic growth in the developing world, especially in Bangladesh. This presents the country with a dilemma. GHG-free energy sources, such as solar and wind, are either at their infancy or those such as conventional nuclear are extremely expensive, or potentially very risky. Here too external entities and interests appear to be present both in the pro- and anti-fossil fuel conversation and the associated 'clean' energy projects currently being developed.

Thus, before we discuss Bangladesh energy state and options, it would be worthwhile to briefly note the country's major and evolving energy sectors and review, from a historical perspective, how we arrived at the current state of energy to put context to the discussion that follows. Each major energy option brought online to date has caused a challenge and often an immitigable price to pay. It will be important to be cognizant of these perspectives as we examine the future.

2 Bangladesh Dual Energy Sectors

As mentioned above, Bangladesh continues to have two broadly distinct energy sectors with an evolving mix. The rural/household sector still encompasses the majority of the people and has been reliant on disease-causing biomass stoves for cooking and heating, and risky kerosene lamps for lighting. The urban/ industrial/commercial sector is mainly reliant on electrical power. Absence of reliable electricity had adversely impacted economic growth and led to frequent load-shedding. Efforts at improving both sectors have been underway, but with distinctly different characteristics. We provide a brief historical perspective on these developments, from the early days to about 2000, when novel energy options became more prevalent.

3 Bangladesh's Energy Journey: A survey

3.1 History of Rural/household Energy Sector

This sector had not received significant attention from policy planners till recently. In 2004, rural energy sources for cooking and heating were firewood (44%), crop residues (25%), dung (17%), and tree leaves (15%); electricity constituted only one percent of the total energy use (Asaduzzaman, Barnes and Khandker 2009). Efforts began after independence under a variety of entities to alleviate the burden of cooking with biomass by replacing traditional biomass stoves for cooking. Improved cook stoves (ICS) with much better combustion efficiency offered the promise of increasing the fuel utilization to approximately 30–50% from 10% in traditional stoves in developing countries for cooking and heating. This would reduce indoor air pollution, fuel requirement, and deforestation. In 2016, worldwide 3.8 million people, mostly women and children, died from indoor air pollution; nearly 50,000 were in Bangladesh (WHO 2016).

ICS programs got underway in Bangladesh in the early 1980's with a BCSIR program to design and disseminate improved stoves, mainly in rural areas. It was a government-subsidized program with multiple governmental entities involved. By 2000, over 300,000 ICS had been disseminated in Bangladesh. However, the program faced serious challenges, one of them being acceptance by the users. The BCSIR-inspired programs were discontinued but had clearly demonstrated the benefits while also identifying a number of challenges, such a need for routine monitoring and evaluation, funding, lack of coordination among various entities, etc. This has been reviewed in a recent paper (Badruzzaman 2015).

A number of biogas and bio-digester plants were introduced in the mid-2000's under microloan financing. New ICS and biogas programs under different models have been launched recently and will be discussed later in the paper.

Rural electrification was an obvious component of the country's post-independence development effort—The First Five Year Plan, 1973 (GoB, Planning Commission 1973). The Plan put forth rural electrification as a cleaner and more reliable source of power than diesel used in irrigation pumps and tube-wells. However, there was no mention of electricity for lighting in rural households. The Plan was skeptical about the economic viability of rural electrification and stated, "Although rural electrification will stimulate the economy through increased production in agriculture and industry, it may not in the short run bring adequate financial return on the investment, even if the tariffs are comparable to those prevailing in the urban high density loading areas. The programme will be economically viable only with the spread of electricity in the rural areas which can be accelerated by the formation of cooperatives of the users of electricity" (The First Five Year Plan, 1973, page 328).

The government introduced a grid-supported rural electrification program in the late 1970's through cooperatives. Starting in the early 2000's, off-grid roof-top solar home systems (SHS) were introduced through NGO's in rural areas (IDCOL, 2018). Over 4 million SHS set up till now, have begun to alleviate the lighting/cooling needs in these areas and positively impact people's lives. Despite its successes, the NGO-based program faces challenges, including encroachment by the government program. Both will be discussed in more detail later in the paper.

3.2 History of the Urban/Industrial/ Commercial Energy Sector

The history we relate next would primarily encompass electricity generation, the lynchpin of this sector.

Hydropower: The 230 MWe Karnafuli hydroelectric power station, reliant on the Kaptai dam constructed in Rangamati district in south-eastern Bangladesh, was first commissioned in 1962 and additional generators were installed through 1988. The earthen dam contemplated since 1906 was built between 1957 and 1962. It was constructed using American financial and engineering support. While the dam and the hydroelectric power station ushered a new source of electricity, it was accomplished at a huge cost because the dam's reservoir was created by inundating homes and cropland of thousands of tribal inhabitants most of whom were never appropriately informed of the likely impact of the project or compensated (Chakma, Chakma, Dewan and Ullah 1995). The ancient city of Rangamati was submerged; the ecological damage was incalculable. Over 100,000 people became either internal refugees or migrated to neighboring Indian states where they were not welcome.

It should be noted that displacement and non-compensation of people due to water projects such as dams is not unique to Bangladesh. International entities such as the World Bank are major funders of such projects and often they have either been unable or unwilling to implement resettlement of affected people (Bosshard 2015).

The displacement due to the Kaptai dam sowed the seeds of the armed conflict that has continued to simmer despite a peace treaty signed with the government in 1997 (Parveen and Faisal 2002). Raising the capacity of the plant is always a consideration and has been proposed recently (BPDB 2003, Kibria 2004). However, this would raise the reservoir water level further inundating land the people use for cultivation. Ironically, at the end of all this, the dam is unlikely to produce more than a very small fraction of the country's electricity and that too at an extraordinary cost.

Natural gas: Sources of significant amounts of natural gas had been identified in the 1950's or earlier. Natural gas was being supplied to homes in major cities for cooking since the 1960's. In 1974, the government of the newly-independent country invited foreign petroleum companies to explore and expand the indigenous gas reserve. However, it was not till the mid-1990's that major petroleum companies showed an interest in exploration. Meanwhile, BAPEX, the exploration arm of the national petroleum organization, PetroBangla, made significant discoveries and added capacity. Natural gas became the major energy resource for electricity supplied to cities and industries. For example, in 2004 44% of the natural gas was used in electricity generation. However, BAPEX was hampered by a lack of more modern technology and funds.

The 1997 Second Block Bidding drew many foreign petroleum companies, large and small. For reasons unknown, some small companies, often without technical or financial strengths, were generally preferred. Most foreign companies demanded the right to export the gas they extract, mainly to neighboring India. Their argument was that export was necessary in view of their expressed need to recoup the substantial investment they would have to make.

Many inside the country and in the Diaspora, including this author, argued that merely exporting gas without accounting for the country's own needs for the gas would be counterproductive and may cause domestic shortage of gas (Badruzzaman 2000). The government of the day, in its wisdom, did not allow export and the foreign companies which set up shop in the country supplied the gas to the domestic market and were profitable under the payment schedules agreed to, contrary to the fear they had expressed. By 2015, Chevron, the largest of the foreign companies in the country, was supplying over 50% of the country's natural gas. The recent shortage of gas has proved the wisdom in the cautions against export and of the then government's decision. However, from the early 2000's, domestic gas exploration has been sluggish for reasons hard to comprehend and it is only now that renewed exploration is being discussed. The same debate whether to export or not has resurfaced (Byron and Rahman 2019). We will examine this issue in the companion paper on fossil fuel sources.

Meanwhile, the 1997 blowout of an Occidental Oil Company's gas well in Magurchara near Srimangal and the 2005 Tengratila blowout of workover wells of Niko Resources in Chattak, Sylhet caused irrecoverable loss to the country's only source of marketed energy.[2] The incidents destroyed much more, ranging from vegetation, ecological habitats, and in the case of Magurchara a tea estate. The loss from the Magurchara incident alone was estimated to be in hundreds of millions of dollars (Dhaka Tribune 2019). Both incidents happened under the watch of small or marginally qualified foreign companies with limited technological capabilities. No direct compensation for the loss of resources has yet been received although some help to communities has been provided by the companies involved. These blowouts demonstrate the need for care in transparently choosing qualified partners, use of modern drilling practices for gas exploration, and strict compliance practices (Khan and Nasir 2014). These are often lacking in Bangladesh.

Domestic Coal: Bangladesh has about 1400 million short tons of mineable domestic coal reserves, much of it high quality, bituminous coal (GoB, Energy and Mineral Resources Division 2005, Draft Bangladesh Coal Policy). There is a producing underground coal mine at Barapukuria, Dinajpur in northern part of the country and an associated 200 MWe power plant. The mine is operated by Barapukuria Coal Mining Company, a subsidiary of PetroBangla a state-owned company (also known as Bangladesh Oil, Gas and Mineral Corporation). It was developed by a Chinese company, China National Machinery Import and Export Corporation (CMC). After the expiry of the initial development agreement in 2011, they entered into a development agreement with a consortium of Chinese companies comprising of CMC and Xuzhou Coal Mining Group. The estimated nearly one million metric tons extracted is slated for the power plant.

The performance of Barapukuria mine has not been stellar due to poor planning, operation, and possibly inappropriate technology (Wikipedia 2020). There have been fatalities or near fatalities from the operation of the mine, including the death of a British mining expert and a worker, injuries, a roof cave-in, and shutdown of a section of the mine. The 2500-acre underground mine includes 650 acres of agricultural land. According to a 2011 International Accounting Project report, nearly half of the agricultural land has been lost due to subsidence, several villages lost access to ground water, and water extracted for the mine resulted in a rapid drop of the local water level (Hoshour 2011).

Bangladesh also has shallow coal reserves in Phulbari. Open-pit mining was proposed to extract coal from these reserves. The process would damage water tables, destroy valuable cropland and displace over 100,000 people. Asia Energy Corporation, a wholly-owned subsidiary of London-based GCM Resources pushed for open-pit mining at Phulbari leading to opposition by domestic activists, experts from Bangladesh diaspora, and local community.

The (BEN 2007) study noted previously in the paper included technical arguments against such mining practices with examples of harm from Vietnam, India and Pennsylvania, USA.

On August 26, 2006, police firing on a large protest against open-pit mining in Phulbari, led to deaths of three teenagers and injuries to 100 others, provoking a country-wide agitation. In order to diffuse the situation, the government made a number of commitments including ban of open-pit mining in the district. Many overseas activist organizations pressured organizations invested in the project to drop out and several did.

However, Asia Energy never gave up its goal, maintained a local presence and its lobbying of government entities, and kept seeking investor funding. Activist efforts joined by international partners continued as did a low-level conflict with law enforcers. In February 2014, the Bangladesh Prime Minister announced that the issue of coal extraction was to be left to "future technology as food security and protecting the land of the farmers is the first priority" (EJ 2017). The announcement brought a sense of relief after a six-year struggle but it apparently did not fully dissuade GCM, the parent company of Asia Energy, from selling shares in London Stock Exchange citing the project. This resulted in recent protests in London (LMN 2019).

The above conflicts appeared to temper the push for open-pit mining, and point to government's abandonment of this approach to extract shallow deposits of domestic coal and consideration of use of imported coal, instead. However, despite the government's commitment against open-pit mining, the 2016 Power Supply Master Plan prepared by the JICA contains the following recommendations on open-pit mining: (PSMP 2016, Page 1–36): "a) Carrying out pilot operation of open cut mining technology in the Barapukuria coal mine and b) Approval of small scale open cut mining at Phulbari after the pilot operation at Barapukuria coal mine."

4 Current State of Bangladesh Energy-Generation Options

4.1 Urban/Industrial/Commercial Sector: An Overview

The government undertook an ambitious plan to increase electricity production through the 2010 Power Sector Master Plan (PSMP 2010–2011). It was updated in 2016 (PSMP 2016). The 2010 Master Plan has set the target of generating 24,000 MWe in 2021, 40,000 MW in 2031 and 60,000 MW in 2041 (Ahmad 2017). Domestic natural gas has been the major fuel for generating electricity in Bangladesh but its reserves has been decreasing and domestic gas exploration has been slow since the early 2000's. Thus, the PSMP anticipates the use of imported fossil fuels (coal and LNG) as the two major sources for expanding electricity production in Bangladesh. The 2010 version of the PSMP envisioned an evolution of installed capacity from 7300 MW in 2010 with 9% oil, 5% coal, 82% natural gas to 37,750 MW in 2030 with10% oil, 50% coal, 25% natural gas, 15% "other" including renewable and nuclear. The Payra power plant in Patuakhali, country's first large-scale coal plant began test production in mid-January (Byron 2020), ahead of the controversial Rampal plant under construction in very close proximity to the Sundarbans. The Rampal plant poses a significant risk for the World Heritage Site (Ahmed 2013, Harvey 2016). In general, the use of fossil fuels, especially coal, would increase the country's carbon footprint considerably. Implications of this outcome are discussed in a companion paper.

The government also plans addition of electricity capacity using nuclear plants and utility-scale solar farms. Two nuclear plants are planned. The first is being built at Rooppur in Ishwardi, Pabna. It has also generated much controversy (Rahman 2015). The government had approved the installation of a 200 Mwe, 1000 acre solar farm in Teknaf for grid-connected electricity (Mahapatra 2015, Rab 2017). Recently, arguments have been made for a larger share of grid-based solar power, possibly using some cropland (Kammen 2019). The nuclear plants and utility-scale solar farms would help to meet the country's commitments to mitigate climate change by using CO_2-free electricity generation, under the 2015 Paris Climate Treaty. However, both pose significant challenges. The issues are discussed in a companion paper.

4.2 Rural/Household Sector

4.2.1 Clean Cooking Program

According to the 2017 REN21 data, over 142 million (89%) people in Bangladesh rely on firewood, dung cakes, charcoal or crop residue to meet their household cooking needs (REN21 2017). Studies have shown that the associated percentage of wood-fuel harvest appears unsustainable (Bailis, et al. 2015). Kerosene lamps have been the major source of lighting. We first discuss the activities underway in cooking and heating in this energy sector. As noted previously, improved cook stoves designed by the BCSIR were first distributed in Bangladesh in the 1980's but did not see a significant acceptance (Badruzzaman 2015). The referenced paper also noted that the ICS program was reinitiated by several NGO's with government's encouragement and support from international development agencies (Barua 2007, GTZ 2010). The paper also noted the so-called market-based ICS program promoted by the USAID that included import of Indian ICS, which often were not at par with BCSIR-designed stoves.

In conjunction with ICS, biogas plants have been implemented in some areas for cooking. By 2015 over 45,000 biogas plants had been installed in the country (REN21 2017). The slurry from bio-digesters acts an organic fertilizer. It is important to note that these programs are in congruence with the Sustainable Development Goals (SDG's) identified by UN member States in 2015 (UN 2015, UNDP 2015). In fact, the programs encompass seven of the seventeen SDG's: SDG-3 (Health and well-being,) SDG-5 (Empowering women and girls, SDG-7 (Access to reliable, efficient modern energy,) SDG-13 (Combat climate change) and SDG-15 (Sustainably manage forests and halt land degradation) (Rosenthal, et al. 2018).

In addition to the local players, the UN Foundation entered the ICS space in Bangladesh through its multi-country Clean Cooking Alliance. The other countries are China, Ghana, India, Kenya, Nigeria, and Uganda. The foundation's objective is to strengthen the market for clean cookstoves and fuels (UN Foundation: 2010). Since user non-acceptance of ICS in the early days appeared to be based less on technical flaws and more on perception and unfamiliarity with a technology that was so intimately related to a family's life (namely, meal preparation), the Alliance launched a behavior modification campaign to increase awareness and promote the use of ICS. The Alliance awarded grants to companies working in the sector to allow investment in production, distribution, human resources, and marketing, to receive capacity-building support and training on marketing and financial management. They worked with the Ministry of Power to create a Household Energy Platform. The Alliance is utilizing the government's 10% reduction of import duty on ICS to make imported cooking technologies more affordable to consumers. Over 700,000 ICS have been installed in Bangladesh by 2015 (REN21 2017).

However, the import of ICS would drive out local ICS entrepreneurs. ICS technology is not a high-level technology and local scientists and engineers at BCSIR had designed good quality stoves. It is not clear why locally made ICS are not used or why resources are not being used to develop higher quality ICS technology in the country, if current local ICS did not suffice. Similarly, it should be possible to manufacture, install and repair biogas plants using in-country resources and expertise.

Recently, the State-owned development financial institution, Infrastructure Development Company Limited (IDCOL) that has been instrumental in the success of the off-grid solar-based rural electrification program (discussed later) has begun dissemination of ICS and biogas plants in rural areas. It is not clear if IDCOL will build its own full-fledged ICS program, including manufacturing, or will be simply a vehicle for distributing imported cook stoves (IDCOL 2018).

4.2.2 Rural Electrification

In development paradigms, rural electrification has been widely identified as a key driver for alleviating poverty and boosting economic growth, especially in countries where large fractions of the population are in rural areas. It has been very successful in Bangladesh (Sharif 2013). As we will see in the following discussion, rural electrification has been a two-step process first as a government-run and funded effort using conventional fossil-fuel based systems with significant challenges, and then as a donor-funded off-grid solar home system managed and funded by a semi-autonomous company in areas where grid connections were not available. Recently, the two appear to be competing and overlapping in the service they provide. We first discuss the direct government effort.

Rural Cooperatives: Rural electrification in Bangladesh began in 1977 under the Rural Electrification Board (REB) Ordinance, 1977. Its mandate was electrification of rural areas by building electric lines and substations. Its counterpart Bangladesh Power Development Board (BPDB) manages electric distribution in urban areas.

In view of the previously noted perspective of the country's planners on rural electrification, the effort in Bangladesh was modeled broadly after the US Rural Electricity Cooperatives created during the New Deal to bring electricity and telephones to rural America, in view of lack of incentive for nearest utilities. In that model, customers were the members of the cooperative. The financial model was based on earning of dividends or reinvestment of profits. The 2013 Rural Electrification Board Act, replaced the 1977 Ordinance and the Board was renamed Bangladesh Rural Electrical Board (BREB).

As of 2018, BREB or its predecessor, Rural Electric Board (REB), have developed over 78 operating rural electric cooperatives called Palli Bidyuit Samity (PBS), which have extended over 17 million new connections and constructed more than 330 thousand kilometers of electric lines (BREB 2018). BREB purchase power from national power development board, mainly. Tariff rates are below cost for domestic and agriculture consumers and above cost for industrial and commercial consumers. BREB set up a streamlined collection system to ensure financial stability. The program has been hailed as a major success and was showcased at an Africa Electricity Initiative Workshop (Chowdhury 2009).

Despite success in terms of system design and revenue collection, BREB-based rural electrification in Bangladesh had faced some systemic challenges. It is instructive to review these. One challenge was the low level of actual connections, despite building of electrical lines, for example, 53% official vs. 28% actual in 2009 (Palit and Chaurey 2011). However, this was similar to the situation in many other developing countries, except China. Figure 1 illustrates this for Bangladesh and India.

Although the trend of official vs. actual, is similar in both countries the reasons for the difference were different. According to the authors of the cited reference, these were as follows.

India: The low-level of rural electrification was attributed to:

1. Definition utilized for 'electrification.' Historically, level of electrification was measured as % of villages connected with the national grid extension to any point of the village vs. actual households getting connected. This was however, similar in several other South Asian countries.
2. Multiple national programs.
3. State government utilities were less interested in pushing national government targets; national government programs were often underfunded.
4. The government changed the definition of 'electrification' to the more realistic to actual connection. This led to many villages being de-electrified. The government created electricity supply (input) franchises and declared the political goal of "power for all." Unfortunately, only 20% connections were achieved vs. 61% target by 2012. The targets appeared highly unfeasible and overly optimistic.

Bangladesh: The reasons for significantly lower actuation connections relative to claims of electrification were:

1. A poor rural population could not afford the upfront cost of connection,
2. Impedance due to focus on enforced performance targets (revenue/km of line), collection efficiency (strong-arm tactics),
3. Inadequate electricity generation for the grid supply distribution set up, and
4. Inadequate financial resource

Despite the above challenges, the BREB claims to be on track for 100% electrical coverage by 2020 (Bangladesh Post 2019).

Off-grid Solar-based Rural Electrification: Until recently, the grid-based rural electrification discussed above did not reach most rural people, especially the poor. As we noted previously, inadequate generation of grid power was also a major problem. So starting in the late 1990's, NGO's began to deploy off-grid solar home systems (SHS). The nighttime electricity is supplied by batteries that store the solar electricity generated during the day. The funding and project implementation have been primarily through the state-owned development financial institution, Infrastructure Development Company Limited (IDCOL)(http://idcol.org/home/solar).

IDCOL initially received funding from the World Bank and Global Environmental Facility (GEF). Later, many other international agencies[3] came forward to provide financial support for expanding the SHS program. Donors provide grants and soft-term loans and IDCOL then invests these funds in Partner Organizations (PO's) and NGO's. PO's/NGO's with project plans apply for support to IDCOL which evaluates the project against both technical and financial viability metrics. As of January 2019, IDCOL has invested about USD 696 million (BDT 52,240 million). Of this amount, USD 600 million was in the form of loans and USD 96 million was in the form of grants. IDCOL provides technical and operations support through its technical and operations committees. Despite being a state-owned entity, IDCOL considers itself 'a for-profit social enterprise (IDCOL 2018).

The IDCOL SHS program began in January 2003 and as of January 2013, about 4.13 million SHSs have been installed; initial plans were to install 6 million SHS by 2016 (Haque 2013). It should be noted that SHS are limited in terms of the number of electrical outlets and gadgets they can support. At the upper end of the system deployed by IDCOL, at 85Wp,[4] it can support nine lamps, one black-and-white television, and a mobile phone charger. Despite the slower installation rate and the limited scope of SHS, the program has installed 185 MWp of power bringing electricity to remote areas not covered by the grid-based rural electrification program run by the BREB. IDCOL claims to have brought solar electricity to over 18 million or 12% of the country's population.

In terms of lighting, IDCOL estimates that its SHS program has reduced 1.14 million tons of kerosene use worth USD 411 million (at 30 cents per liter). They anticipate that the 4.13 million SHS already installed would avoid consumption of another 3.6 million tons of kerosene worth USD 1.3 billion over the next 15 years (IDCOL 2018).

Solar home systems have provided significant social benefits in rural Bangladesh. They have allowed longer study time for children in the evening and permitted women more freedom to pursue business opportunities such as weaving, making clothes for sale, or utilizing more time in leisure activities such watching TV or visiting friends after a long day, thereby measurably improving the economic well-being and quality of life for women and families. As discussed later rural electrification either through the grid system or the SHS has provided significantly greater benefits to the more vulnerable segments of a household, women and girls.

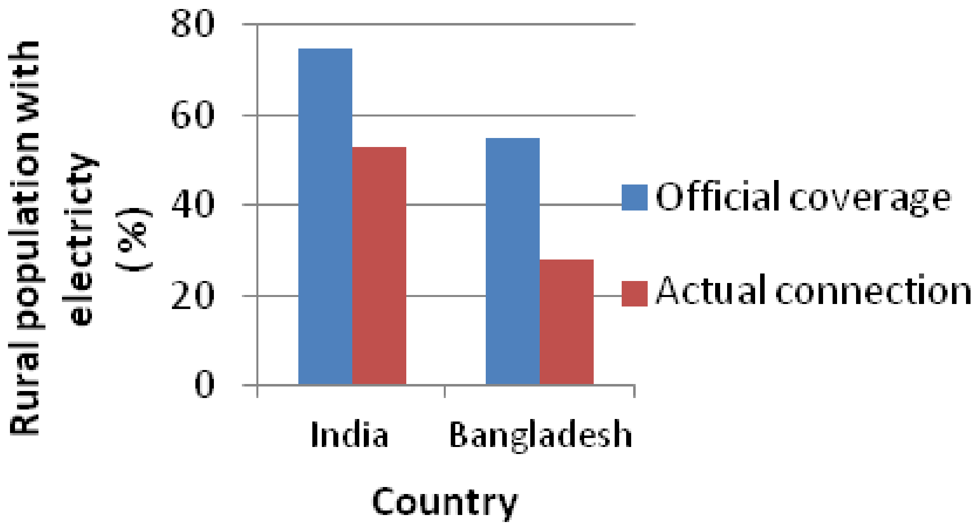

Figure 1: Rural Electrification. Official vs. Actual Electrification in two South Asian Countries (Palit and Chaurey, 2011

BREB Vs. IDCOL programs- competing versions of rural electrification? A recent news story titled, 'Solar energy dims as grid power expands,' (The Daily Star 2016) has brought to fore an inherent but undiscussed tension between separately pursued grid-based vs. SHS rural electrification. The story states, "Solar home system providers find their market squeezed due to the rapid expansion of electricity connections in off-grid areas, particularly by Bangladesh Rural Electrification Board (BREB)." IDCOL would be particularly affected since it is a profit-based enterprise. Figure 2 illustrates the situation. The figure depicts a continuing growth of REB connections while IDCOL SHS installation peaked around 2013 and then declined steadily. In 2018 only 4,160 SHS were installed vs. 853,026 at its peak in 2013.

This challenge has been compounded by the BREB renewing its own effort in the SHS space; BREB had installed the first SHS's in the country in 1993. By June 2019, BREB has installed 53,762 SHS and solar roof-top systems through its cooperatives, under a "No Profit, No Loss" model for a total capacity of 6.762 MWp (BREB 2019). BREB has also introduced a net-metering system to optimize between its grid-based and its SHS/roof-top systems, and sell the excess SHS electricity to the grid. As of June 2019, BREB had generated 751, 613 kWh of electricity from SHS and exported 184,951 kWh (24.6%) of it to the grid.

While the total number and capacity of SHS by BREB is still small compared to those of IDCOL-installed SHS, BREB's "No profit, No Loss" model and ability to export its excess solar production to the grid using net-metering has put a significant pressure on IDCOL's standalone SHS systems, set up with a for-profit model.

IDCOL recognized this in its 2018 report by stating, "….. the market of the SHS is currently nonexistent due to government's free distribution of SHSs under its safety net program (KABIKHA/TR program)." This has forced IDCOL to reduce its SHS effort and diversify into other sectors, both in non-energy and energy sectors. In the latter, IDCOL are now focusing on SHS-based mini grids, biogas plants and ICS.

The implication of the competing SHS implementation by two entities, BREB and IDCOL, both related to the state, is troubling. Grid electricity is more seamless to access with no on-site generation and storage system to worry about, and thus users would generally prefer it. In addition, if they install the BREB SHS, they would possibly sell excess solar electricity back to the grid. IDCOL SHS users with a standalone solar system would not be able to do so and may be left with stranded excess electricity. If grid electricity reaches their area, users may opt to switch but will be stuck with paying for the off-grid system they may not use. For the country as a whole this would imply waste of hundreds of millions of dollars of investment.

The predicament faced by off-grid or mini-grid systems should the main grid arrive is not unique to Bangladesh or to solar-based systems. A recent World Bank report examined this in three Asian countries, Cambodia, Indonesia and Sri Lanka (Tenenbaum, Greacen and Vaghela 2018). In Cambodia, the mini grids used diesel plants. In Sri Lanka and Indonesia these were based on

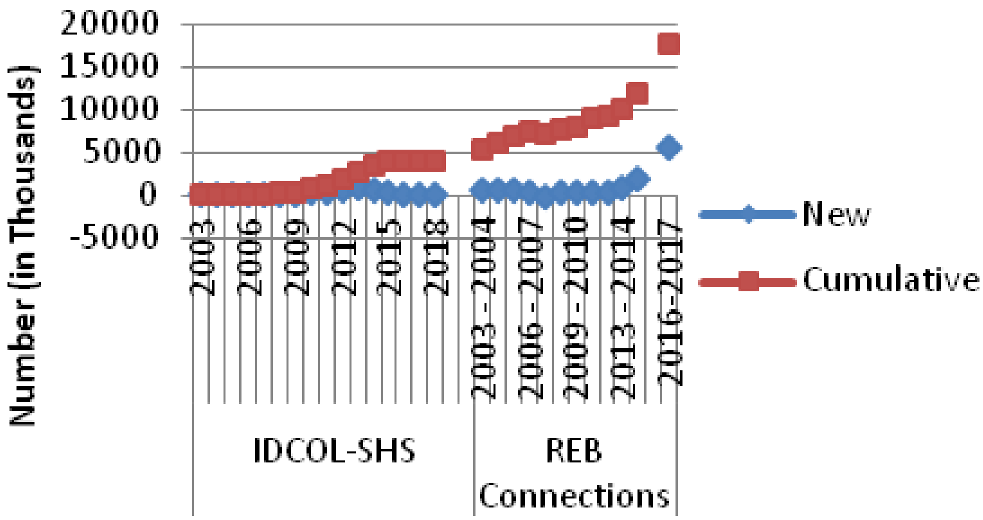

Figure 2: IDCOL SHS installations vs. Rural Electrical Board Connections in Bangladesh

micro-hydro. Using the three case studies, the report concluded that the prevailing view that mini grid (or off-grid) and main grid systems are separate and mutually exclusive paths to rural electrification is overly simplistic, and together the two seemingly competing systems "can lead to more reliable and less expensive electricity for consumers." Each country utilized unique approaches, from the regulatory 'stick' to financial incentives to leverage the benefits of the two systems. Since solar power is often intermittent and Bangladesh national grid has not always been reliable, an interconnected system is likely to offer greater system reliability, and with net-metering introduced by BREB, the cost to consumers could be much smaller. BREB and IDCOL should explore the lessons in the World Bank report in conjunction with the two unique advantages their own systems offer.

5 Generic Challenges of Rural Electrification

While the above data provide a window into the challenges to rural electrification in Bangladesh, this was not unique to the country. In fact, several researchers have observed that impact of grid-based rural electrification has been mixed when viewed across several countries, despite it being a key component of the development paradigm. For example, rural electrification may have had a modest impact on labor participation and no effect on asset ownership, etc., in India (Burlig and Peronas 2016). In Kenya, it "may reduce social welfare as the costs of grid expansion significantly outweigh its benefits" (Lee, Miguel and Wolfam 2016). A systematic study by the World Bank unearthed similar insights into the actual impact of rural electrification in Bangladesh and explained some of the observations above (Samad and Zhang 2017). The authors surveyed over 7000 households for 2005 and 2010 and correlated the results to a number of parameters. They found the following:

1. The length of daily power outages had a strong negative impact on almost all developmental outcomes. An hour of power outage increase per day was associated with about 5.9% increase in kerosene use and 0.3% reduction in annual income.

2. There was no difference between no electrification and grid outage of 21 hours or more.

3. Benefits of electrification increased with years of exposure to grid electricity.

4. Labor market benefits appeared to take the longest time to materialize.

5. Rural electrification led to longer study and evening work hours with girls and women benefiting from it disproportionately. It is not clear why the authors imply this to be a detriment.

The benefits of grid-based rural electrification were predicated on a steady power supply, and grid failure can be a major problem, as Samad and Zhang (2017) illustrate. Off-grid SHS with battery support would address this. Affordability of connecting to the grid has been another challenge. Off-grid SHS would face similar challenges. Micro-finance was introduced to address the financing challenge. As the example cited next illustrates, SHS can be expensive and often requires funding support.

6 Rural/household Sector: Room for Integrated Small Energy Systems?

In the above discussion of the rural energy sector, we noted two tracks in off-grid energy generation and utilization, one for clean cooking and the other for electricity generation, often with separate funding mechanisms. Also, since most are donor-funded or government subsidized, off-the-shelf costs of the systems are difficult to discern. Thus, in order to examine the potential for an integrated small energy system consisting of both cooking/heating and lighting components, and their system costs, the author helped organize and then mentor a pilot project in Bangladesh during 2010–2012 (ALO 2011). The system consisted of ICS, biogas plants, SHS, and solar school systems. The project was funded primarily under the Corporate Social Responsibility (CSR) program of a major international oil company operating in the country and in partnership with two California-based Bangladeshi diaspora non-profits. The project was implemented with the help of a local NGO familiar with the community.[5] Details of the project are described elsewhere. Here we note its key elements and major lessons learned.

Alternative Livelihood Options (ALO) Project: The objective of this pilot project was to explore improving the quality of life through Small Distributed Clean Energy Systems in remote, rural, and poor communities. The targeted population was the poorest in the community, namely, day-laborers, share-croppers, small entrepreneurs with no access to electricity or other modern energy sources, and often no political connections to get access even if gridlines existed nearby. The project included 1000 families in two villages. The average household income of a family of five was Taka (Tk.) 4,000 (USD 50) per month; Taka is the name of the Bangladesh currency. The energy systems distributed were 500 ICS in each village, two biogas plants, one in each village, 150 SHS in 150 households, and solar schools systems in six primary schools with 2000 students. Since SHS and solar school systems would include batteries, the collection and safe disposal of these were built into the program.

The financial model was initial reliance on funding by the sponsors (the oil company and the two diaspora non-profits) and growth from the savings achieved by the project. The ICS cost Tk. 800 (USD 10) per unit and the biogas plant cost Tk. 48,000 (USD 600)/unit. An SHS, running three lights and one fan, cost Tk. 27,500 (USD 344)/unit. The solar school system cost Tk. 126,000 (USD 1,575) /unit. It ran eight lights, one cell charger and 6 fans. A family with the average household income (of Tk. 4000/month or USD 50/month) can afford an ICS. However, the ICS efficiency was no more than 25% relative to the 30–50% indicated previously based on laboratory testing.

The fuel cost saving obtained from the ICS component of the project was substantial but considerably lower in the field than that would be if fuel-use efficiencies claimed by designers from laboratory data were met.

The biogas plant and the SHS were out of the reach of a family's financial means. The pilot CSR project paid for the costs in this instance. Of course, savings from not needing kerosene lessened the burden, but were not sufficient to meet the SHS cost. In general, a funding mechanism, in the form of subsidies, micro-loans, grants, or something similar would be needed to implement these systems. Savings in wood fuel cost from the ICS accommodated some of the SHS cost, for example, demonstrating the advantage of an integrated system.

The project sought to measure a number of quality of life indicator. A key indicator of interest was reduction in air pollution. However, the planned direct monitoring of air pollution exposure in the field by having women wear small personal monitors on their outfit did not materialize due to a number of reasons, including the cost of the these monitors. The potential pollution reduction was indirectly ascertained by monitoring respiratory health outcome of the users of ICS; 90% fewer clinic visits for respiratory illnesses were noted. The risk of kerosene-based fires and associated injuries and deaths were eliminated. Longer evening study hours by the students and a higher attendance rates by them were reported. Women were able visit friends or engage in other recreational activities at night.

Several productive economic activities were generated from the project. A number of the users set up ICS-repair businesses. The project, from its savings, was able provide some micro-loans for new business start-ups, mostly run by women, for vegetable production, duck farming, tailoring, etc. Thus, the systems led to benefits similar to those noted from IDCOL and BREB solar systems. However, the pilot project also illustrated long-term financial viability challenges such (CSR-funded) projects would face in general that need careful evaluation that is beyond the scope of the current paper.

While the above gains achieved in the early years of the CSR pilot project were significant, as time went on system breakdowns began to impact performance of solar panels and ICS. Only one of the two biogas plants remained functional for the duration of the project. Also, uncertainty in the fuel supply due to the sale of the cows the biogas plant relied on was another challenge. In the early years of the project, the SHS, though somewhat expensive, were welcomed by the villagers; they had no access to grid electricity. However, as grid-based electricity became more available in the project area a few years later, the villagers did not want the SHS systems, especially, if these could not be readily repaired or replaced.

Thus, a part of the investment appeared largely wasted as would be the case for IDCOL SHS systems should the BREB system usurp their use. One exception in the CSR pilot project was the continued use of the SHS by some users who were prone to power outages which were frequent for many grid connected users. This illustrates the benefits of a coupled system.

However, the CSR project was more than on electricity. It demonstrated that integrated small energy systems can bring clean energy for cooking *and* lighting to thousands of rural households in Bangladesh, often very poor, and outside the radar of the country's development activities.

Common Lessons from IDCOL SHS and Rural Small Energy Systems Projects: We have noted the benefits (and challenges) of the IDCOL projects and the CSR pilot project individually. Here we note the benefits common to both. Stand-alone, individual SHS allow electrification in remote areas outside the grid. However, when such systems are introduced, provisions should be made for potential future connections to the grid using net-metering, if and when grid electricity reaches the community. Having the SHS would increase the community's access to clean electricity. Also, a coupled (grid-and roof-top solar) system could improve grid reliability. Finally, the community is likely to develop an appreciation of solar electricity as the country transitions out of fossil fuel-based electricity. Perhaps, going forward IDCOL can partner with the BREB to implement net-metering in the area covered by its SHS.

Another key lesson from both programs is the challenges of keeping the systems in good repair. It is more difficult with distributed systems without a clear supply chain and availability of qualified repair establishments, and ultimately a dedicated monitoring and evaluation program.

Finally, both initiatives demonstrate the value of distributed energy generation and supply systems in rural communities, especially in this riverine country, without the need to set up expensive transmission lines or fuel transport systems; local resources would provide a significant part of their energy solution. Of course, the attendant challenges, some of which are noted in the paper, would have to be accounted for starting in the planning phase.

7 Climate Mitigation and Adaptation in Rural Bangladesh

While the paper does not focus on adaptation to climate change, we note a couple of innovative, locally conceived climate mitigation and adaptation approaches that have been developed in the flood-prone country. One such concept in northern Bangladesh is a mitigation-cum-adaptation approach with floating schools in barges/boats with solar panels on rooftop providing electricity for lighting, fans and computers in the classroom inside the barge. It was pioneered by a Bangladeshi architect, Mohammed Rezwan, in 2002, though his NGO, Shidulai Swanirvar Sangstha, with funding from outside development organizations (Shidulai Swanirvar Sangstha 2002). The boat is also used to gather children for the class from homes that have been cut-off by flood waters. The NGO now has 23 such solar boat schools. The project won the 2007 Ashden Award.[6] The boats are also used to provide adult education and training in sustainable agriculture that the next example illustrates.

The author, accompanied by his spouse, visited the Shidulai project on the Gumani river in early 2019. The Figures 3 and 4 depict one such solar boat school and the activities inside the boat. The photos were taken by the author with the permission of Shidulai personnel that conducted the visit. The photos is included in the paper with thanks to Shidulai

The children were from economically disadvantaged rural families and normally they would often spend their day swimming in the river. Here they were attending school.

The students' joy of learning was evident as they excitedly told the visitors what they were learning on the computer powered by the solar panel on top of the boat. They intimated that they learned better when the computer was used for live demonstration instead of just using books. One child beamed as he showed the US-based visitors that he could write his name in both Bangla and English.

The boat schools were used for adult education on various topics, in late afternoons. An example is depicted in Figure 5.

The concept of floating gardens depicted in Figure 5 evolved from the recent work with farmers by Practical Action, an NGO. The technology uses locally available materials to grow vegetables even during the floods (https://www.youtube.com/watch?v=_JatsIs73RA) These gardens are made up of layers of water hyacinth, bamboo, cow dung and compost, placed on rafts. The crops are then grown on the top layer of soil. The garden floats to the top of the water during the rainy season and returns to

Figure 3: A Shidulai floating solar boat school (Shidulai Swanirvar Sangstha 2002)

ground level when the floods subside.

8 Lessons for the Future?

Distributed energy systems, both in electricity generation and transmission appear to fit Bangladesh's rural/household sector. This raises an obvious question. Would it fit the urban/industrial/commercial sector as well? A complete answer to this question is beyond the scope of the present paper and will be discussed in a future paper. Obviously, there will have to be a sizeable centralized segment in Bangladesh's energy system but clearly the country's entire energy system does not have to be centralized, as is currently planned. Local solar minigrids can often be appropriate in urban areas as well and can be valuable in the age of climate change. Let's illustrate it with a recent event in California, USA.

Potential advantages of localized grids were recognized during the recent power outages suffered by the centralized grid due to wild-fires in California. These fires, often caused naturally, are also started by electrical sparks at the electrical line connections. Fires in 2017 disrupted the lives of millions and caused burning down of entire towns with tens of deaths. In 2019, California's largest utility, Pacific Gas and Electric, used planned power shutdowns during the fire season to prevent such fires, leaving millions of homes, often entire communities, many businesses, schools, and universities without power for days. Many of these entities were well beyond fire zones but the centralized nature of the electric grid necessitated the shutdown of large parts of the grid (Glanz and Plumer 2019). The experience has led to rethinking of the nature of electrical transmission in the State away from centralized grid to micro- and mini-grids utilizing solar (Our Daily Planet 2019).[7]

Recognition of the above example in Bangladesh could help save billions of dollars that would be needed to build centralized systems. Building and maintaining transmission lines, especially over long distances, in a country cross-crossed by rivers, streams, ponds, and other water bodies, and prone to cyclones, tornadoes and floods, would be extraordinarily challenging and expensive. This can be prevented or minimized as the distributed solar system built by IDCOL indicates.

Figure 4: Inside a Shidulai boat school classroom. Note the fans, lights and the laptop computer the teacher is using for the instruction. (Shidulai Swanirvar Sangstha 2002)

9 Summary

Bangladesh, a developing country with two distinct but related energy sectors and limited access to modern energy systems, has made a complicated journey in the quest for energy access. An overview of this journey indicates that energy solutions encouraged by external experts with limited understanding of the country's energy sectors, their evolving mix of energy use, societal aspirations, and history have often resulted in difficult and untenable situations. The long-term damage inflicted by the Kaptai Dam hydroelectric project that did not appropriately plan for and address its aftermath and the gas blowouts at the hands of unprepared foreign partners should inform the pursuit of three key grid-scale electricity projects underway or under planning. These are the Rampal coal plant that could irreparably damage the Sundarbans, the Rooppur nuclear plant under construction that could be catastrophic in a very high population density country, or large utility-scale solar farms some have been suggested on croplands, potentially endangering the country's food security. The history of Bangladesh's energy journey reviewed in the paper points to the need for caution as the country pursues these (coal, nuclear and solar farm) options. Companion papers will examine these in more detail.

The rural/household sector assessed in this paper has shown a remarkable forward march from about 1% electrification in 2004 to over 90% claimed fifteen years later. This has been possible due to the introduction of off-grid solar systems by various entities supported by IDCOL a government-supported financing organization and government's own grid-based rural electrification program through rural cooperatives. However, there appear to be a turf-war brewing between IDCOL and BREB as the latter moves into the off-grid solar electricity space. The paper suggests an approach to avoid that and draw on the strengths of both.

An integrated, clean small energy systems pilot project noted in the paper illustrated the advantages of a system that supplies both clean cooking/heating and clean electricity solutions, especially to the very poor in rural communities. In addition to health and social benefits, it can often give rise to entrepreneurship growth. As was illustrated in the CSR project, ICS manufacture, installation, and repair can become a business, as would supplying the fuel for the ICS and biogas plants. Programs that involve imported ICS will adversely affect the local

Figure 5: A copy of a slide on the floating garden technique being taught to a group of women farmers (not shown) in the Shidulai solar floating school in the afternoon. (Shidulai Swanirvar Sangstha 2002)

ICS business, however. Of course, since ICS rely on fuel wood, a sustainable management of vegetation is a must to prevent deforestation. While solar plant systems are manufactured in Bangladesh, in-country manufacture of the actual panels should be considered, instead of their import. In general, self-sufficiency and local entrepreneurs in small energy systems components will drive local economic activity and should be actively promoted instead of importing the various components.

Integrated small energy systems could also benefit the urban poor, especially those in the slums, often living under grid lines but with no electricity connection, and inhaling the dangerous smoke that their traditional cook stoves belch out.

Rural electrification programs offer valuable lessons. IDCOL's roof-top distributed solar home systems allowed for a more rapid penetration of electricity in rural homes; the government's grid-based rural electrification was slower. The recent attempts by the government to enter the SHS market combining it with its grid-based system to sell excess solar electricity back to the grid while raising the prospect of two competing entities also demonstrates the potential for a partnership between the two to increase grid reliability and resilience. This benefit clearly can inform decisions that are being considered for electricity generation and distribution in the urban/industrial/commercial energy sector.

Finally, the paper shows that despite their limitations, rural energy programs discussed in the paper illustrate the strengths of locally grown solutions developed by people (either in government or NGO's) familiar with the country's terrain, history, and societal needs. The IDCOL program and the solar boat school program by Shidulai noted in the paper are clear examples of this. Such examples should clearly inform the country's decision makers to incorporate Bangladeshi talent, resident and non-resident, and not just external entities and experts, as has often been the case especially in the urban/industrial/commercial sector (to be discussed in companion papers) while they plan the country's energy future.

Abbreviations

BAPA: Bangaldesh Poribesh Andolon

BAPEX: Bangladesh Petroleum Exploration and Production Company

BCSIR: Bangladesh Council of Scientific and Industrial Research

BEN: Bangaldesh Environmental Network

BPDB: Bangaldesh Power Development Board

BREB: Bangladesh Rural Electrification Board

CSR: Corporate Social Responsibility

GDP: Gross Domestic Product

GEF: Global Environmental Facility

GHG: Green-house Gas

GSMP: Gas Sector Master Plan

GTZ: German Technical Cooperation Program of the German government

ICS: Improved Cook-stove

IDCOL: Infrastructre Development Company Limited

JICA: Japan International Cooperation Agency

MWe: Megawatt-electric

NGO: Non-Governmental Organization

PO: Partner organiztion

PBS: Palli Biddut Samity (Village electricty cooperative)

PSMP: Power System Master Plan

SHS: Solar home system

USAID: US Agency for International Development

Appendix A: A Summary of BEN Energy Panel Recommendations

The BEN Energy Panel made number of detailed recommendations. The key ones are briefly listed next.

- Developmentof a comprehensive strategy with multiple components: These would include a clear identification of options for energy sources, short and long term, a choice of utilization options for preferred energy sources, based on sound economic analysis and optimized to the country's best interests, assessment of environmental, land-use, social and resource impacts of each source option, and incorporation of safeguards against adverse impacts. The report cautioned that no energy source, not even so-called clean energy sources, is totally harmless.

  The other elements of the proposed strategy were steps to increase the local technical expertise base in the energy sector, strengthening or development of relevant institutions, the associated legal, regulatory and enforcement frameworks to support the strategy, and approaches to manage the upsides and downsides of the strategy.
- Judicious consideration of multiple energy source options: This would include increased exploration of the domestic natural gas resource, postponement of domestic coal exploitation, especially by open-pit mining, until the economic environmental and economic challenges are better understood, avoidance of the conventional nuclear power option and exploration of safer, novel nuclear technologies that were being developed at the time the report was being prepared, and a greater consideration of renewable options.
- Greater attention to the rural/household energy sector.
- Setting up of a non-partisan Center of Energy Excellence consisting of appropriate expertise to provide a central and permanent location for unbiased discussion, dialog and input to decision makers on energy technology, economics and policy issues, to allow the development of a comprehensive energy strategy the panel recommended as noted above. Such a center was particularly needed in view of the fragmented discussion that was underway in the country's energy options, often modulated by external interests.

Endnotes

1. The BEN study report was also conveyed to the then Energy Secretary in September, 2007.
2. Marketed energy is from fossil fuels, hydro, nuclear and modern renewable sources such as solar and wind.
3. These included GIZ, KfW, ADB, IDB, GPOBA, JICA, USAID and DFID.
4. Wp stands for watt-peak. Solar modules are rated in Wp. This value specifies the output power achieved by a solar module under full solar radiation. The actual electricity generation would generally be lower.
5. The oil company was Chevron, the two diaspora organizations were SpaandanB (https://www.facebook.com/ spaandanbbangladesh) and Agami (www.agami.org) both based in the San Francisco Bay Area of California, and the NGO was Bangladesh-based Center for Natural Resource Studies (CNRS) (cnrs.org.bd). The author was a research scientist at Chevron when the pilot project was developed and implemented.
6. Ashden is a London-based charity that promotes sustainable energy and regional development. It offers annual awards to highlight accomplishments in these goals: https://en.wikipedia.org/wiki/Ashden
7. Many California homes even in urban areas and connected to the grid, also have roof-top solar and

are a part of the net-metering system that sells the excess solar generation back to the grid. Forming local grids with these may be an option.

8. Dr. Ahmad is the Secretary, Power Division, Ministry of Power, Energy and Mineral Resources, Government of Bangladesh.

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References

Ahmad, K. (2017), Energy and Economic Growth Nexus: Challenges for Emerging Economies, *in* '2017 BAPA-BEN Conference on Sustainable Development Goals', Presentation at Dhaka, Bangladesh, January 13–14.

Ahmed, M. (2013), 'Rampal Power Plant: A ticking bomb for the Sundarbans', bdnews24,com, Opinion Page, October 1, https://opinion.bdnews24.com/2013/10/01/rampal-power-plant-a-ticking-bomb-for-the-sundarbans/.

ALO (2011), 'Chevron Launches Alternative Livelihood Options (ALO) to Improve Living Standards of Community', https://www.chevron bangladesh.com/documents/news/SangjogApril2011.pdf.

Asaduzzaman, M., Barnes, D. F. and Khandker, S. R. (2009), *Restoring Balance: Bangladesh's Rural Energy Realities*, Energy Sector Management Assistance Program (ESMAP), The World Bank.

Badruzzaman, A. (2000), 'Comprehensive Bangladesh gas strategy needed ahead of export decision', *Oil & Gas Journal* **98**(34).

Badruzzaman, A. (2015), Energy Challenges and Opportunities: World and Bangladesh—A Comparison of Perspectives, *in* 'Conference on Bangladesh in the 21st Century', Adapted from 2008 BDI Conference, Harvard University, Cambridge, MA. https://drive.google.com/file/d/1c06ivg-zD4JzPqQJXq24nuuiBN2cicq4/view.

Bailis, et al. (2015), *The carbon footprint of traditional woodfuels, nature climate change*, Nature Climate Change, Macmillan Publishers Limited. DOI: 10.1038/NCLIMATE2491.

Bangladesh Post (2019), 'REB to ensure house to house electricity', November 27, https://bangladeshpost.net/posts/reb-to-ensure-house-to-house-electricity-18563, accesses January 8, 2020.

Barua, D. C. (2007), *An Introduction to Grameen Shakti*, Grameen Bank Bhaban, Dhaka, Bangladesh.

BEN (2007), 'Energy Strategy for Bangladesh: A Brief Survey with Recommendations', http://ben-global.net/publications/.

Bosshard, P. (2015), 'Dammed, Displaced and Forgotten', Huffington Post, First published on March 27, 2015, Updated December 06, 2017, https://www.huffpost.com/entry/dammed-displaced-and-forg_b_6956512.

BPDB (2003), Consulting Services for Social Impact Assessment (SIA) Study for Kaptai Hydroelectric Extension Project (6th and 7th), Unpublished power plant report, Bangladesh Power Development Board Completion (Final) Report.

BREB (2016), 'Bangladesh Rural Electrification Board', http://reb.brebms.com/documents/generation/generation_breb_17_05_2016.pdf, accesses January 8, 2020.

BREB (2018), 'Bangladesh Rural Electrification Board', http://reb.brebms.com/index.php/2-reb, Retrieved Jan 5, 2020.

BREB (2019), 'BREB's Renewable Program', BREB_renewable_15102019.pdf.

Burlig, F. and Peronas, L. (2016), *Out of the Darkness and Into the Light? Development Effects of Rural Electrification*, Working paper 268, Energy Institute at Haas, University of California, Berkeley.

Byron, R. K. (2020), 'Payra coal power plant takes off', The Daily Star, Dhaka, Bangladesh, January 14, https://www.thedailystar.net/frontpage/news/payra-coal-power-plant-takes-1853791, Retrieved January 24, 2020.

Byron, R. K. and Rahman, M. F. (2019), 'IOCs can now export gas', The Daily Star, Dhaka, Bangladesh, September, 03, https://www.thedailystar.net/frontpage/international-oil-companies-can-now-export-gas-from-bangladesh-1794613, Retrieved 12/29/2019.

Chakma, H., Chakma, T., Dewan, P. and Ullah, M. (1995), *Bara Parang: The tale of the Development Refugees of the Chittagong Hill Tracts*, Centre for Sustainable Development (CFSD), Dhaka, Bangladesh.

Chowdhury, N. H. (2009), Rural Electrification Bangladesh Experience, *in* 'Proc. of African Electrification Initiative Practitioner Workshop', The International Bank for Reconstruction and Development, THE WORLD BANK GROUP, Maputo, Mozambique.

Dhaka Tribune (2019), 'Compensation Still Lacking 22 Years on from Magurchara Tragedy', June 14, https://www.dhakatribune.com/bangladesh/nation/2019/06/14/compensation-still-lacking-22-years-on-from-magurchara-tragedy.

EJ (2017), 'Phulbari coal mine project, Bangladesh, Environmental Justice', January 25, https://ejatlas.org/conflict/protest-against-open-pit-coal -mine-project-in-phulbari-region.

Glanz, J. and Plumer, B. (2019), 'In a High-Tech State, Blackouts are a Low-Tech Way to Prevent Fires', The New York Times, Published October 12, Updated October 26. https://www.nytimes.com/2019/10/12/business/power-blackouts-california-microgrids.html.

GoB, Energy and Mineral Resources Division (2005), *Draft Bangladesh Coal Policy*, Energy and Mineral Resources Division, Ministry of Power, Energy and Mineral Resources, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.

GoB, Planning Commission (1973), *The First Five Year Plan, 1973–78*, Planning Commission, Government of People's Republic of Bangladesh.

GSMP (2018), Gas Sector Master Plan Bangladesh 2017, Final report, Petrobangla, PowerCell, BANGLADESH. https://mpemr.gov.bd/assets/media/pdffiles/Bangladesh_GSMP_Final_Report.pdf.

GTZ (2010), 'Sustainable energy for development', http://www.gtz.de/en/weltweit/asien-pazifik/ banglade-sch/19993.htm.

Haque, N. (2013), *Rural Energy Access: A Nexus approach to Sustainable Development and Poverty Eradication*, IDCOL Solar Home System Program, 4–6 December, Addis Ababa, Ethiopia.

Harvey, C. (2016), 'A new power plant could devastate the world's largest mangrove forest', Washington Post Energy and Environment, July 18, https://www.washingtonpost.com/news/energy-environment/wp/2016/07/18/a-new-power-plant-could-devastate-the-worlds-largest-mangrove-forest/?utm_term=.c7d1fe8f4033.

Hoshour, K. (2011), *Massive protest against Phulbari & Barapukuria coal mines in Bangladesh*, International Accountability Project, March 4.

IDCOL (2018), IDCOL Annual Report 2018, 2018 http://www.idcol.org/home/an report, Infrastructure Development Company Limited, UTC Buillding, Kawran Bazar, Dhaka, Bangladesh.

Kammen, D. (2019), Clean Energy in Bangladesh-Innovation for a Clean Energy Economy in Bangladesh, *in* 'Bangladesh Research Notes', based on a presentation in November 2018, University of California, Berkeley.

Khan, M. I. A. and Nasir, F. b. (2014), 'A Review over Major Gas Blowouts In Bangladesh, Their Effects and the Measures to Prevent Them in Future', *International Journal of Scientific and Technology Research* **3**(9).

Kibria, Z. (2004), The Dam at Kaptaimukh inBangladesh: Proposed Extension Plan and Issues of (non-) compliance, *in* 'Addressing Existing Dams', Presented to the Dams and Development Project (DDP) workshop on June 14–16, United Nations Environment Programme (UNEP), Nairobi, Kenya.

Lee, K., Miguel, E. and Wolfam, C. (2016), 'Appliance Ownership and Aspirations among Electric Grid and Home Solar Households in Rural Kenya', *American Economic Review* **106**(5), 89–94.

LMN (2019), 'Press Release: protesters oppose GCM Resources in London and Bangladesh', December 16, https://londonminingnetwork.org/2019/12/press-release-protesters-oppose-gcm-resources-in-london-and-bangladesh/, Retrieved January 18, 2020.

Mahapatra, S. (2015), 'Bangladesh Approves 200 MW-Solar Power Project By SunEdison', November 26, http://cleantechnica.com/2015/11/26/bangladesh-approves-200-mw-solar-power-project-sunedison/.

Our Daily Planet (2019), 'Microgrids the Solution to CA's Wildfires?', October 15, https://www.ourdailyplanet.com/story/microgrids-the-solution-to-cas-wildfires/.

Palit, D. and Chaurey, A. (2011), 'Off-grid rural electrification experiences from South Asia-Status and best practices, OASYS South Asia Research Project', *Energy for Sustainable Development* **15**(3), 266–276.

Parveen, S. and Faisal, I. M. (2002), 'People versus Power: The Geopolitics of Kaptai Dam in Bangladesh', *International Journal of Water Resources* **18**(1).

Prothom Alo (2018), '90% village under power supply: Minister', Prothom Alo English Desk, Dhaka, Bangladesh, June 22, https://en.prothomalo.com/bangladesh/news/178236/90%25-village-under-power-supply-Minister.

PSMP (2010–2011), Power System Master Plan Final Report 2010–2011, Technical report, Power Division, Ministry of Power, Energy and Mineral Resources, Government of the People's Republic of Bangladesh.

PSMP (2016), Power System Master Plan Final Report 2016, Technical report, Power Division, Ministry of Power, Energy and Mineral Resources, Government of the People's Republic of Bangladesh.

Rab, M. A. (2017), Solar as Viable Primary Energy Hype or Panacea?, *in* '2017 BAPA-BEN Conference on Sustainable Development Goals', presentation at Dhaka, Bangladesh, January 13–14.

Rahman, A. (2015), 'Ruppur Nuclear Power Plant: Bangladesh's potential Blackhole', The Daily Star, Dhaka, Bangladesh, December 30, https://www.thedailystar.net/op-ed/politics/ruppur-nuclear-power-plant-bangladeshs-potential-blackhole-194017.

REN21 (2017), *Renewables 2017 Global Status Report*, REN21 Secretariat, Paris, ISBN 978-3-9818107-6-9.

Rosenthal, et al. (2018), 'Clean cooking and the SDGs: Integrated analytical approaches to guide energy interventions for health and environment goals', *Energy for Sustainable Development, Elsevier* **42**, 152–159.

Samad, H. and Zhang, F. (2017), *Heterogeneous Effects of Rural Electrification: Evidence from Bangladesh*, Policy Research Working Paper No. 8102, Open Knowledge Repository, World Bank Group, Washington, DC. https://openknowledge. worldbank.org/handle/10986/27302.

Sharif, I. (2013), 'Rural Electrification: the success story of Bangladesh', United Nations Practitioners Network, October 2, https://cleanenergysolutions.org/sites/default/files/documents/Islam-Sharif-SKJ-Bangladesh-UN.pdf, Rccessed December 31, 2019.

Shidulai Swanirvar Sangstha (2002), 'Shidulai Swanirvar Sangstha: Operating School Boats Since 2002', https://www.shidhulai.org/, Retrieved October 24, 2020.

SREDA (2019), 'Sustainable and Renewable Energy Development Authority (SREDA) of Bangladesh.Renewable energy present status', http://www.sreda.gov.bd/index.php/site/re, Rccessed December 31, 2019.

Tenenbaum, B., Greacen, C. and Vaghela, D. (2018), Mini Grids and Arrival of Main Grid: Lessons from Cambodia, Sri Lanka, and Indonesia, Technical report 013/18, Energy Sector Management Assistance Program (ESMAP), World Bank, Washington DC.

The Daily Star (2016), 'Solar energy dims as grid power expands', The Daily Star, Dhaka, Bangladesh, August 25, https://www.thedailystar.net/business/solar-energy-dims-grid-power-expands-1274971, Retrived January 4. 2020.

UN (2015), 'Sustainable Development Goals (SDG)', On 25 September 2015, at the United Nations Headquarters in New York, 193 world leaders committed to the 17 Sustainable Development Goals (or Global Goals). These are a series of ambitious objectives and targets to end extreme poverty and hunger, fight inequality and injustice, and tackle climate change, by 2030, https://www.un.org/sustainabledevelopment/sustainable-development-goals/, Retrived October 24, 2020.

UN Foundation: (2010), 'Clean Cooking Alliance', The Clean Cooking Alliance works with a global network of partners to build an inclusive industry that makes clean cooking accessible to the three billion people who live each day without it, Established in 2010, https://www.cleancookingalliance.org/country-profiles/focus-countries/6-bangladesh.html, Retrieved, January 18, 2020.

UNDP (2015), 'Sustainable Development Goals, United Nations Development Programme', https://www.undp.org/content/undp/en/home/sustainable-development-goals.html.

War on Want (2016), 'The New Colonialism, Britain's scramble for Africa's energy and mineral resource', https://waronwant.org/sites/default/files/TheNewColonialism.pdf.

WHO (2016), 'Mortality from household air pollution. Global Health Observatory (GHO) data', https://www.who.int/gho/phe/indoor_air_pollution/burden/en/.

Wikipedia (2020), 'Barapukuria coal mine', https://www.sourcewatch.org/index.php/Barapukuriacoal-mine.