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REVIEW

A review of policies and initiatives for climate change mitigation and environmental sustainability in Bangladesh

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Abstract

Mitigating climate change via initiatives such as reducing emissions of greenhouse gases (GHG) and renewable energy (RE) generation helps in reducing environmental pollution, increasing efficiency, and saving costs in the energy industry. Bangladesh recently formulated some policies and initiatives for reducing GHG emissions that have been increasing at an alarming rate lately, which are driven largely by economic growth, energy security, and local environmental concerns. However, little is known about the impacts of the existing policies and initiatives on curbing GHG emissions and promoting environmental sustainability, especially from the agriculture and energy sectors that contribute 44% and 39% to the country's net emissions, respectively. This study, therefore, reviews the extent of GHG emissions in the country and analyzes the country's key policies and initiatives for mitigating climate change and promoting environmental sustainability. The key finding is that despite the existence of a national energy policy and initiatives such as RE development, rational and efficient use of energy, Intended Nationally Determined Contributions, clean development mechanism, international and private sector collaboration, GHG emissions are projected to continue to grow at high rates due to population growth, industrialization, energy consumption growth that outpace government initiatives to reduce emission levels. The paper concludes that good governance, behavioral transformation, and public awareness about climate change are vital steps for reducing GHG emissions and promoting environmental sustainability.

Keywords Greenhouse gas emissions · Carbon trading · Renewable energy · Clean development mechanism · Solar home systems

1 Introduction

There is a growing interest in the role of rapidly growing developing countries in climate change mitigation. Rapid population growth and intense human activities have drastically altered the terrestrial carbon cycle and other natural processes and cycles. About 400

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petagrams of carbon have been released into the atmosphere within the last two centuries, significantly increasing the atmospheric level of carbon dioxide (CO_2) to the historic level of 400 parts per million (ppm) (Sabine et al. 2004; Hashimoto 2019). Combustion of fossil fuels such as oil, gas, and coal that provides nearly three-quarters of global energy is among the major sources of CO_2 emissions (Ahiduzzaman and Sadrul Islam 2011). Methane (CH_4) and nitrous oxide (N_2O) are other greenhouse gasses (GHG) that contribute considerably to global warming. If GHG emissions increase the average global temperature by 2 °C above the preindustrial levels, a catastrophic global warming might occur, with severe consequences including heat waves, melting glaciers and rising sea-level, shifting rainfall patterns, increasing hurricane and flood events, water stress and droughts, ecosystem changes, and health risks such as spread of diseases (Chandler et al. 2002; Otto et al. 2018; Kalra and Kumar 2019).

To avert the catastropic consequences of climate change, it is necessary to maintain the average global GHG concentrations below 400 ppm by protecting the sinks for GHG, cutting anthropogenic emissions, rational use of energy, renewable energy (RE) utilization, as well as carbon capture, trading and storage (Reay et al. 2008; Cooper and Sehlke 2012; Tollefson 2018; Hashimoto 2019). Indeed, the ongoing global debate on climate change is increasingly focusing on what role the rapidly growing developing countries that rely heavily on fossil fuels for energy generation can play in reducing their GHG emissions, which could exceed those from developed countries by 2050 (Abubakar and Dano 2019; Chandler et al. 2002; Rahman et al. 2018). While several developing countries are reluctant to curb their GHG emissions, a few have implemented some emissions mitigation initiatives. Despite their little or no contradiction with socioeconomic development, such initiatives often face some challenges such as public opposition, low technical capacity, and inadequate investments (Abubakar and Aina 2016; Hasan et al. 2019a; Malik et al. 2019).

Bangladesh, a South Asian nation of about 160 million people and per capita GDP of $4200 in 2017 (CIA 2019), has recently formulated some climate change mitigation policies and initiatives that were driven largely by economic, energy security and local environmental concerns (Xenarios and Polatidis 2015). The country is highly vulnerable to climate change impacts, including frequent floods, tropical storms, landslides, and coastal erosion with colossal loss of lives and property (Solomon 2007). The Germanwatch Global Climate Risk Index 2017 that estimates country-wise losses due to extreme weather events ranked Bangladesh as the sixth most climate-affected country in the world (Kreft et al. 2016). About 2.3 billion dollars' worth of damage was caused by Cyclone Sidr in 2007, including the destruction of homes, schools, farmlands, and livelihoods of at least two million families and basic infrastructure such as roads and embankments (Garatwa 2011). A one-meter sea-level rise can devastate around 22,000 km^2 of the country (~17% of land surface), affecting the health and safety of about 17 million people, biodiversity, and livelihood including agriculture, forestry, and fishery (Uzzaman 2014). For instance, rising temperatures and sea levels are a threat to crop yields such as wheat, potato, and lentils, which are heavily dependent on cool weather (Pender 2010). Moreover, heavier fog in the winter can cause blight in potatoes and reduce the production of onions and pepper. Research has shown that heat stress, shorter growing seasons, and higher evapotranspiration decrease wheat yields by 31–68% and rice yield by 17–18% (Karim et al. 1999). Erratic rainfall patterns, particularly in the northwest of the country, have already posed a challenge in selecting planting and harvesting time (Ahmed 2006).

Therefore, reducing GHG emissions can produce multiple benefits for the built and natural environments by cutting the release of air pollutants, and bringing significant environmental, health, and socioeconomic benefits. Mitigating GHG emissions from the industrial sector can reduce the costs of waste disposal, maintenance and operation and may increase its productivity and enhance public images and brand values (Solomon 2007). Strategies for mitigating GHG emissions from the transportation sector can increase accessibility to public transit and promote walking and cycling, which have significant health benefits. Mitigation strategies can also save fuel and parking costs for automobile users, and reduce traffic accidents, congestion, fuel use, and noise in the community (Maizlish et al. 2013; Shindell et al. 2011).

Given that mitigating GHG emissions helps restore and increase agricultural productivity (Remais et al. 2014), Bangladesh as an agro-based country would substantially benefit from emissions reduction. The introduction of a more efficient alternate irrigation system can reduce agriculture-related GHG emissions by around 46% without decreasing crop yields (Begum et al. 2017). Also, strategies such as bio-diversification, water harvesting, and soil management are effective in maintaining yields, increasing resilience, and reducing GHG emissions (Shams et al. 2017). Research has shown that waste to energy recovery, reuse and recycling, and waste minimization can annually reduce 1.29 $MtCO_2e$ of emissions and save USD 2.89 million (Mainali et al. 2017). Similarly, efficient management of poultry litter by installing anaerobic digesters can help produce bio-fertilizer and biogas for cooking purposes, reducing agriculture emissions by about 65% (Ahmed et al. 2017).

The GHG emissions in the country are increasing despite the enormous benefits that can be gained by mitigating them. From 1990 to 2014, the GHG emissions from the energy sector have increased by 378%, while the emissions from the agriculture and waste management sectors have increased by 27% and 50.8%, respectively (World Resource Institute 2019). As a consequence, the government recently formulated some policies and initiatives to meet the county's energy demand through sustainable energy sources, while fostering environmental sustainability. Besides reducing environmental pollution, mitigating GHG emissions has several economic co-benefits, such as cost savings and increasing the efficiency in energy production, lowering maintenance and operation costs, and creating jobs in the RE sector, significance of which is felt more in developing than in developed nations (Solomon 2007). In 2005, the country submitted the National Adaptation Program of Action (NAPA) to the United Nations Framework Convention on Climate Change (UNFCCC). In 2009, Bangladesh Climate Change Strategy and Action Plan (BCCSAP) was prepared to foster mitigation and adaptation activities to reduce GHG emissions from all possible sources of emissions without hampering national food security and development. However, little is known about the impacts of the existing policies and initiatives on curbing GHG emissions and promoting environmental sustainability, especially from the agriculture and energy sectors that contribute 44% and 39% to the country's net emissions, respectively. Thus, it is necessity to fill this knowledge gap by evaluating the impact of the existing policies and initiatives on mitigating GHG emissions and fostering environmental sustainability in the country.

Against the prevailing background, this paper analyzes the key climate change mitigation policies and initiatives in Bangladesh and their contribution to promoting environmental sustainability. Similar studies conducted in the country have researched GHG emission levels, sources and impacts (Miah and Alam 2002; Shahid 2011), trends in energy consumption (Ahiduzzaman and Islam 2009; Azad et al. 2006; Chary and Bohara 2010), and RE technologies and their utilization for electricity generation (Ahmed et al. 2014; Kabir and Uddin 2015; Mondal et al. 2010; Sarkar et al. 2003; Sufian and Bala 2006). The rest of the article is organized as follows. Section 2 reviews the related literature, while Sect. 3 examines the sources and levels of GHG emissions in the country. The double exponential smoothing function was employed to gain insight into the county's GHG emissions until

2030. This technique is more reliable than longer-term forecasting methods. Section 4 presents an analysis of the existing policies and initiatives for mitigating GHG emissions in the country. The analysis is expected to help the country's decision-makers to understand the impact of the policies and initiatives on curbing GHG emissions. Section 5 assesses the implications of the policies on environmental sustainability. Finally, Sect. 6 presents the concluding remarks.

2 Literature review

A review of the literature reveals that several policies for curbing GHG emissions and adapting to climate change have been implemented worldwide. Sarkodie and Strezov (2019) investigated climate change vulnerability and adaptation readiness of 192 countries and revealed that Scandinavian countries are less vulnerable to climate change, but they have high readiness to combat it. In contrast, African countries are highly sensitive to climate change but do not have adequate resilience and adaptive capacity (Abubakar and Aina 2019). Reducing climate stress also requires socioeconomic and governance interventions (Sarkodie and Strezov 2019). Owusu and Asumadu-Sarkodie (2016) explored the opportunities of RE deployment such as energy access, energy security, economic and social development, and environmental and health co-benefits. Challenges to RE deployment include access to adequate raw materials to sustain future RE deployment, lack of information, increasing demand for energy, and market failures. Incorporation of decarbonization policies into the major emitting sectors such as agriculture, energy, industry, transport, health, buildings, forest, and water resources are crucial for developed countries to combat climate change. Efforts are also required to strengthen institutions, improve research capacity and institutional training, and develop international collaboration and partnership (Hasan et al. 2019b).

However, it is evident from the literature that decoupling economic growth from mitigating GHG emissions is one of the major challenges for developing countries in curbing GHG emissions (Chandler et al. 2002). Mohiuddin et al. (2016) investigated the empirical relationship between CO_2 emissions, GDP, energy consumption, and electricity production from non-renewable sources in Pakistan. The results from a vector error correction model indicate that energy consumption and electricity production from non-renewable sources and GDP growth contribute to CO_2 emissions. Therefore, the authors proposed government intervention to promote the use of solar panels and afforestation programs. Given that developing countries are more likely to increase their GHG emissions while striving for economic development, Chandler et al. (2002) recommend considering country-specific circumstances such as the institutional structure, socioeconomic factors, and geography to develop policies and strategies for curbing GHG emissions.

The emissions reduction strategies of the GHG-intensive corporate firms are also crucial to combat climate change, as they are among the largest sources of anthropogenic GHG emissions (Cadez et al. 2019). To understand the major determinants of corporate emissions reduction strategies, Cadez et al. (2019) tested a conceptual model based on investigating 247 firms that are enlisted under the European Union's Emissions Trading Scheme (EU ETS). The findings revealed that the market pressures to reduce emissions help GHG-intensive firms adopt proactive environmental strategies. The study also shows that GHG emissions can be reduced more effectively when a firm incorporates environmental concerns at the top strategic level rather than at a low functional level. Also, firms with a higher perceived uncertainty regarding GHG-related regulations reduced their emissions more effectively than firms that are less concerned with environmental policy uncertainty. The investigation of corporate strategies to reduce emissions by Cadez and Czerny (2016) found that stringent carbon policies have effective emissions reduction potentials. However, the current techniques used to determine the environmental performance of a firm are not holistic (Cadez and Guilding 2017). In most cases, the environmental performance of a firm is determined in relative terms, such as waste reduction of a firm relative to its size, ratio of waste recycled to waste produced, or increased emissions versus the value of sold products. None of these techniques affirm the reduction of total pollution (Cadez and Guilding 2017). Therefore, Cadez and Guilding (2017) suggested measuring environmental performances based on an eco-efficiency component and an eco-effectiveness component, where the eco-efficiency measure will look for optimizing input–output relationships and the eco-effectiveness measure will focus on systemic changes adopted by a firm for reducing total pollution levels.

3 GHG emissions in Bangladesh

According to 2014 statistics, the major sources of GHG emissions in Bangladesh were agriculture, energy, waste management, industrial processes, and bunker fuels, and their shares in total GHG emissions were 44.1%, 38.5%, 11.1%, 5.5%, and 0.8%, respectively (World Resource Institute 2019). Carbon dioxide is the highest GHG produced, followed by CH_4 and N_2O. In 2017, the country ranked 48th in the world in terms of CO_2 emission from energy consumption, by consuming 80 million tons of CO_2 (CIA 2019). In 2014, the country's GHG emissions accounted for about 4.5% and 0.4% of the total CO_2 emissions in South Asia and the world, respectively (World Resource Institute 2019).

The major contributors to CO_2 emissions include changes in forest and other biomass stocks, energy generation industries, manufacturing industries, transportation, residences, and industrial processes, and their shares in total CO_2 emissions were 32.3%, 23.7%, 15.3%, 10.4%, 8.3%, and 5.3%, respectively (MEF 2009). This shows that close to two-thirds of the total CO_2 emissions came from the energy sector and about a third came from land-use changes and forestry. Waste management is next in terms of CO_2 emissions (MEF 2009). Apart from the energy sector, the total GHG emissions from agriculture, waste, industrial processes, and bunker fuels remained steady between 2000 and 2014. An evaluation using a double exponential smoothing function (Rahman et al. 2017), indicates that under both the business as usual (BAU) scenario and the government initiatives scenario (i.e., reducing GHG emissions by 5% from the BAU scenario by 2030), the energy sector will become the largest GHG emitter by 2023 followed by agriculture, waste, industrial processes, and bunker fuels (Fig. 1). Agriculture and energy sectors contribute almost two-thirds of the total GHG emissions in the nation, and these aspects are discussed in more detail in the following sub-sections.

3.1 Agriculture sector

The agriculture sector is the single largest source of CH_4 emissions in Bangladesh. In 2014, the sector was responsible for GHG emissions of about 74.6 million tons of CO_2 equivalent ($MtCO_2e$) and CH_4 emissions of 70.8 $MtCO_2e$ (World Resource Institute 2019). Rice cultivation and enteric fermentation are the two main contributors to

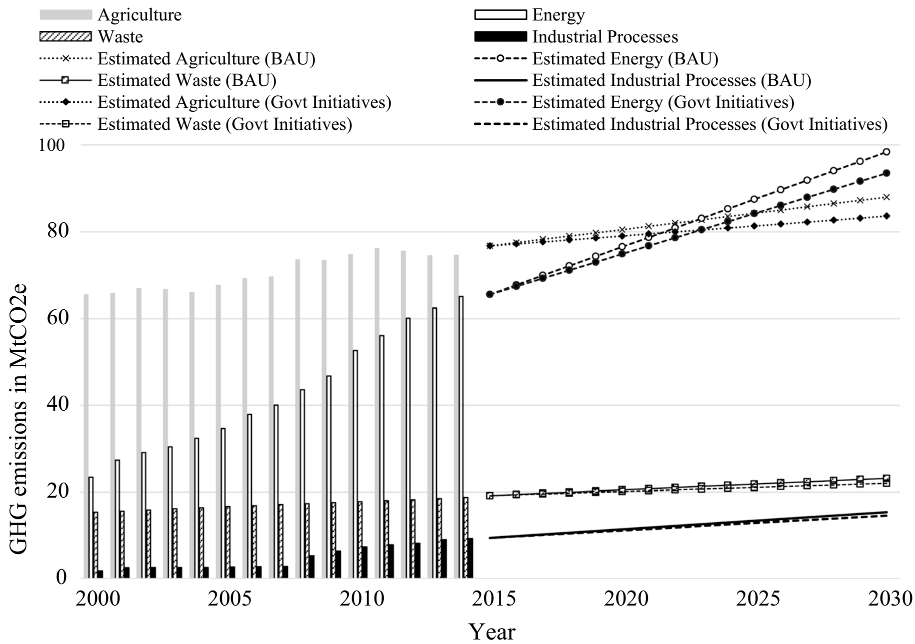


Fig. 1 Trends of GHG emissions in Bangladesh (World Resource Institute 2019)

CH_4 emissions (Murad and Ratnatunga 2013). From 1990 to 2014, the country's overall CH_4 emissions excluding land-use change and forestry rose by 37% (from 55.9 $MtCO_2e$ to 76.6 $MtCO_2e$) (World Resource Institute 2019). Similarly, the level of N_2O emissions, which is produced from poultry litter, climbed from 17.5 $MtCO_2e$ in 1990 to 25.6 $MtCO_2e$ in 2014 (World Resource Institute 2019). The use of nitrogen fertilizers also contributed to N_2O emissions in this sector. From 2002 to 2014, fertilizer consumption has increased by almost half, from 188.6 kg per hectare of arable land to 279.2 kg (World Bank 2018). The burning of agriculture by-products is another source of GHG emissions.

Although the share of the total GHG emissions from the agriculture sector currently surpasses that of the energy sector, emissions from the latter has increased significantly compared to the former (Fig. 1). From 2000 to 2014, the amount of GHG emitted from the agriculture sector increased by 27%, while emissions from the energy sector rose by 378% (Fig. 1). At the current rate, the energy sector will become the largest contributor to GHG emissions in the country by 2023 and emissions are expected to reach about 98.5 $MtCO_2e$ by 2030 (World Resource Institute 2019). Given that any possible disequilibrium between CO_2 emissions and agricultural production would likely take about 17 years to reach the convergence point in the long-run equilibrium (Murad and Ratnatunga 2013), the agriculture sector thus has the intrinsic advantage to increase its output without any substantial contribution to GHG emissions (Bala and Hossain 2010).

While GHG emissions from the agriculture sector have remained steady from 2010 to 2015 (Fig. 1), the total production from crops has almost doubled from 2010 to 2017, according to the Bangladesh Bureau of Statistics (BBS 2018) (Table 1). Rice production has increased by 20.5% within the same period, although its contribution to the total

Table 1 Total crops production in Bangladesh ('000 metric tons), 2010–2017 (BBS 2018)

Crop	2010		2017		Change 2010–2017
Rice	28,054	76.39%	33,804	47.74%	20.50%
Other cereals	2386	6.50%	4337	6.13%	81.77%
Fibers	1053	2.87%	8313	11.74%	689.46%
Fruits	360	0.98%	5018	7.09%	1293.89%
Vegetables	885	2.41%	4048	5.72%	357.40%
Spices and condiments	706	1.92%	2538	3.58%	259.49%
Oil seeds	903	2.46%	975	1.38%	7.97%
Pulses	576	1.57%	387	0.55%	−32.81%
Drugs and narcotics	312	0.85%	634	0.90%	103.21%
Potato	1151	3.13%	10,479	14.80%	810.43%
Fodder	41	0.11%	252	0.36%	514.63%
Sugar crops	297	0.81%	–	–	–
Flower	1	0.00%	23	0.03%	2200%
Total	36,725		70,808		92.81%

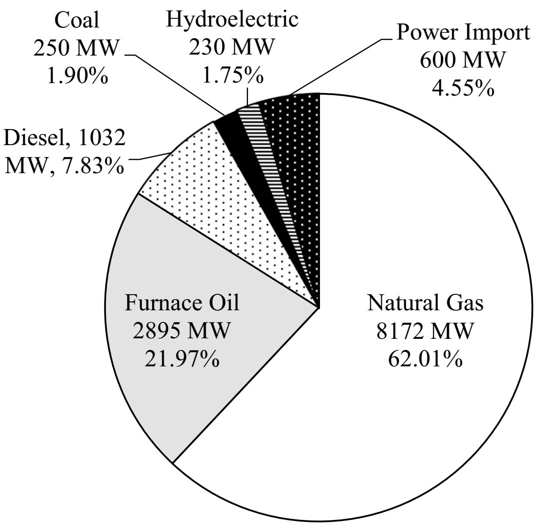


Fig. 2 Total installed electricity generation capacity by fuel types in 2017 (BPDB 2018)

crop production has declined from 76.4 to 47.7%. Except for the production of pulses, all crops have seen an increase in the production from 2010 to 2019, with fruits having experienced the highest increase in production (Table 1).

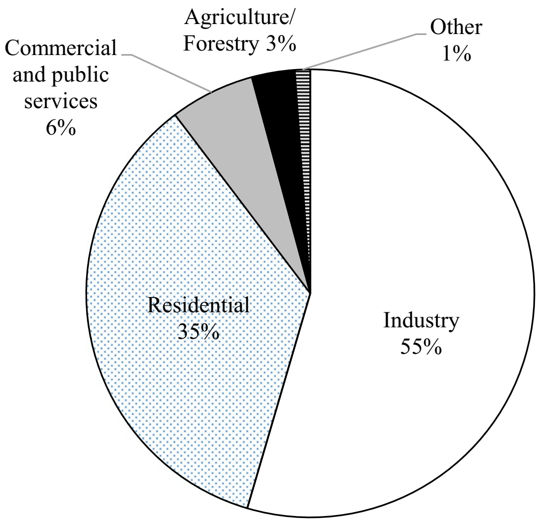
3.2 Energy sector

Between 2000 and 2014, global energy-related emissions soared to an annual average of 7.6% (World Resource Institute 2019). Within this sector, CO_2 emissions are about one and a half times that of CH_4 and N_2O combined (MEF 2012). Emissions from electricity generation are the major source of energy sector emissions, followed by other fuel combustions, manufacturing and construction, transportation, and fugitive emissions. In 2014, electricity generation contributed about half of the total emissions from energy sector, while emissions from manufacturing and construction, transportation, other fuel combustions, and fugitive emissions accounted for 15.6%, 13.6%, 20.3%, and 0.02% of the total energy sector emissions, respectively (World Resource Institute 2019). Between 1990 and 2014, emissions from electricity generation have increased more than seven times (4.5–32.9 $MtCO_2e$), while emissions from the transport sector have risen more than fivefold (1.7–8.8 $MtCO_2e$) and emissions from the manufacturing and construction sectors have increased fourfold (2.3–10.2 $MtCO_2e$) (World Resource Institute 2019).

As shown in Fig. 2, natural gas is the dominant (62%) energy source for electricity generation in Banglasdesh, followed by furnace oil, diesel, coal, and hydroelectricity (BPDB 2018). The country also imports 600 MW electricity from India through grid transmission. Out of the total installed generation capacity, the private sector produces 5973 MW or 44% (BPDB 2018). The data in Fig. 3 show that in February 2017, industries consumed more than half of the produced electricity, followed by residential areas, which together consumed 90% of the total (BPDB 2018). This implies that electricity generation from renewables for industrial and residential use can promote environmental sustainability by reducing the combustion of natural gas.

According to 2017 statistics, about 88% of the country's population has access to electricity (World Bank 2018). The per capita annual consumption of electricity in 2014 was 320.2 kilowatts hour (kWh) (World Bank 2018). However, there is a growing demand for electricity, which is projected to reach 560.6 kWh per capita in 2030 under the BAU scenario (Fig. 4). As the government aims to meet the growing electricity demand at an affordable price and ensure electricity for all by 2021 (MPEMR 2010), some initiatives have been taken including the construction of a nuclear electricity plant at Rooppur (World Nuclear Association 2019), coal-fired electricity plants at Rampal and Payra (Hasan et al. 2018), and solar home systems (SHSs) in rural areas (IDCOL 2018). Under the government initiatives scenario, the estimated per capita electricity generation by 2030 would be about 600 kWh which is about 7% above the actual per capita electricity demand. The government's reliance on various energy sources is due to a low reserves-to-production ratio

Fig. 3 Total electricity consumption by different sectors in 2017 (BPDB 2018)



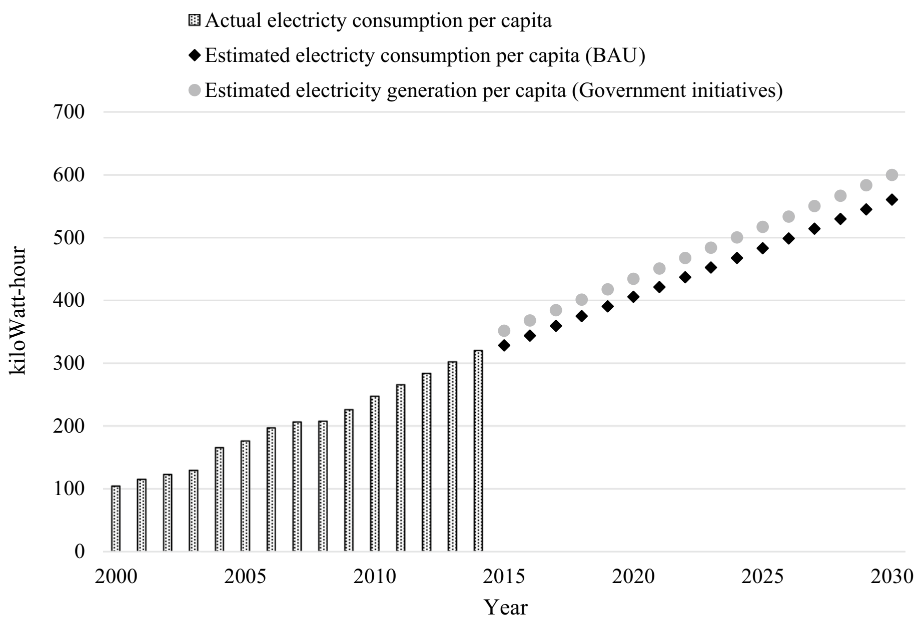


Fig. 4 Actual and estimated per capita annual electricity consumption in Bangladesh (World Bank 2018)

of natural gas in the country. In 2018, the country's estimated proven gas reserves were 0.2 trillion cubic meters which would only last for 5.9 years under the BAU consumption scenario (CIA 2019). As a consequence, about 20,000 MW of electricity would be generated by 2030 from 58 million tons of coal. About 33 million tons of coal are expected to be sourced from domestic mines, while the rest of the coal will be imported from Indonesia, Australia, and South Africa (Rahman 2013). Besides environmental pollution and GHG emissions associated with coal-firing, the existing coal reserve of around 5.2 million tons are far below the required 33 million tons. However, the policy of using coal-fired power plants will work against climate change mitigation and environmental sustainability.

The per capita electricity consumption in the country has increased over three times from 104.6 kWh to 320.2 kWh between 2000 and 2014 (World Bank 2018). If such a trend continues, the per capita electricity consumption can reach 560.6 kWh in 2030 (Fig. 4). While the electricity consumption increases on average by 5.43% annually, electricity generation increases by 5.37% (BPDB 2018). Due to this gap, the rate of load shedding is rising at a rate of 6.72% annually (World Bank 2018). In 2008, load shedding reached 32.57% of the maximum demand and posed a great threat to some industries. Also, due to the low electricity generation capacity, a total deficit of nearly 1900 MW was reported in 2009 with a projected peak demand of 6060 MW (BPDB 2018). In 2012, a shortage of natural gas and furnace oil resulted in a loss of 642 MW and 470 MW of power generation, respectively (Rahman 2013). The situation is worsened by the widening gap between electricity generation rates and installed capacity, caused by shortages of gas and rainfall in hydroelectricity plants, and lack of maintenance and rehabilitation of facilities.

According to the data from the US Energy Information Administration, the country's trend of CO_2 emissions is comparable to that of Myanmar and India (Table 2). From 2006 to 2016, the emissions in the three countries increased in the range of 170–180%.

Table 2 Trends of CO_2 emissions, energy intensity, and RE generation in Bangladesh, India, and Myanmar, 2006–2016. *Source*: EIA (2019)

Country	CO_2 emissions (million metric tons of CO_2)			Energy intensity (million British thermal Units/Person)			Renewables (million Kwh)		
	2006	2016	Increase (%)	2006	2016	Increase (%)	2006	2016	Increase (%)
Bangladesh	45.06	79.20	175.79	5.16	8.43	163.37	0.24	0.40	58.68
India	1257.91	2154.76	171.30	14.8	21.9	147.97	40.50	89.60	45.20
Myanmar	14.94	27.01	180.80	5.31	9.67	182.11	0.77	3.13	24.67

In 2016, Bangladesh ranked second to India in overall emissions, with 79 million metric tons (MMT) of CO_2, and second to Myanmar in the percentage increase and the overall energy intensity. Regarding RE generation, the country ranked the lowest among the three countries.

4 Policies and initiatives for mitigating GHG emissions in Bangladesh

The government has adopted some policies, plans, and programs under several government agencies: the Ministry of Power, Energy and Mineral Resources (MPEMR); Ministry of Environment and Forests (MEF); Sustainable Energy Development Authority (SEDA); Bangladesh Atomic Energy Commission (BAEC); and Bangladesh Centre for Scientific and Industrial Research (BCSIR). The policies and initiatives that are expected to play a significant role in reducing GHG emissions are outlined in governmental policy documents and reports such as Intended Nationally Determined Contributions (INDCs), the Power System Master Plan, BCCSAP, the 2008 RE Policy, the Energy Efficiency and Conservation Master Plan, the National Sustainable Development Plan, the Perspective Plan (Vision 2021), National Energy Plan, and Seventh Five-Year Plan. These policies and initiatives are expected to:

(i) develop RE sources;
(ii) ensure efficiency in both energy production and consumption;
(iii) lower emissions from agriculture;
(iv) sustainably manage exploration of gas and reservoirs;
(v) effectively manage urban waste;
(vi) develop coal mines and coal-fired power plants; and
(vii) carry out afforestation and reforestation programs (MEF 2009).

Despite the high emissions from the agriculture sector, policies targeting climate mitigation in the agriculture sector are limited (Begum et al. 2019). The policies are mainly on methane reduction, research, and the introduction of new technologies. This may be due to the lack of information to track the emissions and target emissions sources in policies (Begum et al. 2019). The details of those climate change policies and initiatives are described in the following sub-sections.

4.1 Intended Nationally Determined Contributions (INDCs)

Under the INDCs, a twofold strategy toward mitigating climate change has been adopted: (a) developing a resilient low-carbon economy and (b) focusing on building climate change resilience to save human lives and livelihood from the negative impacts of floods, erratic rainfall, drought, extreme temperature, sea-level rise, ocean acidification, and salinity intrusion. In its INDCs, the country pledged to make an unconditional 5% reduction in GHG emissions from the 2011 level by 2030, and conditional 15% reduction, depending on international support through investments, financing, capacity building, and technology transfer (MEF 2015).

Policy options proposed in the INDC include the following: (i) ensuring energy security by developing a low-carbon economy; (ii) exploring natural gas resources and bringing efficiency in the natural gas reservoir management; (iii) meeting future electricity demand through low-carbon coal; (iv) promoting RE production and uses; (v) introducing efficient farming systems and introducing new technologies in the agriculture sector to reduce methane emissions; (vi) managing domestic urban waste, thereby reducing associated GHG emissions; (vii) scaling up the reforestation and afforestation programs; (viii) promoting energy-saving electrical devices; (ix) managing water and energy demand in the built environment through appropriate policy measures; and (x) reducing emissions from transportation by increasing accessibility to public transportation. The specific policies on agricultural emissions include reducing draft cattle by 50%, increasing the share of organic fertilizers by 35%, and ensuring that 20% of rice cultivation adopts climate-friendly irrigation methods (MEF 2015).

4.2 National energy policy (NEP)

The NEP was formulated in 1996 to promote sustainable strategies for proper exploration, production, transmission, distribution, and rational use of energy (MPEMR 2004). The policy underscored not only the importance of energy to national socioeconomic development but also the need for efficient energy generation and distribution, energy access to all Bangladeshi citizens, as well as environmental sustainability. The guidelines developed to meet these goals include strategic planning and management, energy integration and rural development, small and captive power policy, private sector power generation, and RE (MPEMR 2004).

Using a 6% annual economic growth rate, an additional 6000 MW of electricity will be required by 2020 in the country, out of which the conventional sources, atomic energy, and renewables are expected to generate 3000 MW, 1000 MW, and 2000 MW, respectively (MPEMR 2008) (Fig. 5). To generate the 2000 MW from renewables, some salient steps have already been taken, which include creating legal support and a favorable environment for RE generation, developing local RE technologies, and providing funds to develop standardized RE configurations to meet common energy and power applications.

Tax breaks, incentives, and targets are also key policies for promoting RE development. In the 2009–2010 budget, all equipment and raw materials for RE production were exempted from the 15% value-added tax. Also, the government has earmarked around USD 19.1 million as an incentive to public and private sectors to deploy RE (Rahman and Khondaker 2012). However, despite various supports, the government

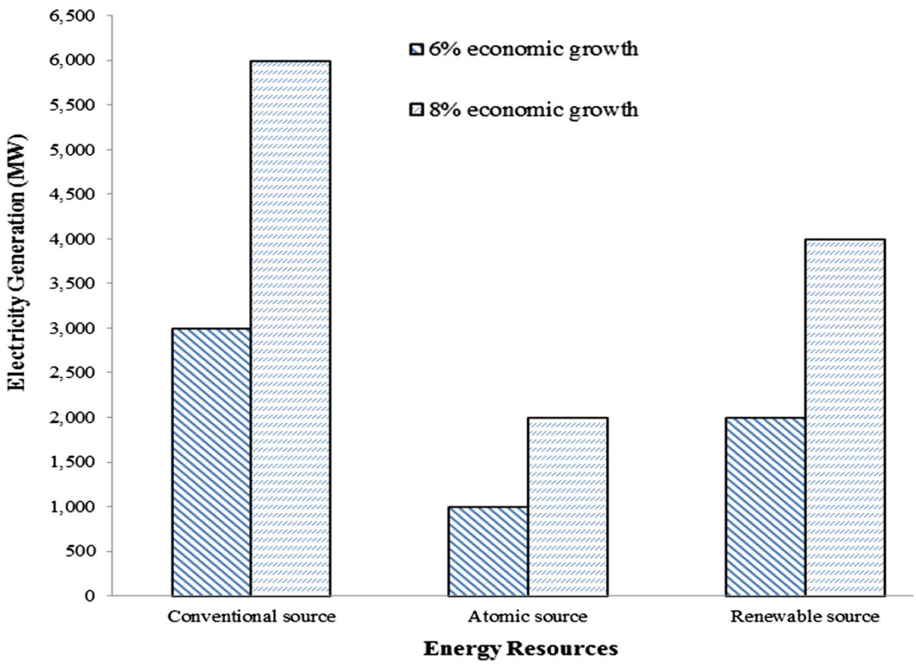


Fig. 5 Projected additional power generation by sources, 2020 (MPEMR 2008)

could not make adequate progress towards achieving its renewable and atomic energy targets for 2020. The country's first nuclear power plants at Rooppur are not expected to start generating electricity until 2023 (World Nuclear Association 2019). Similarly, the target of generating 2000 MW of electricity from renewables by 2020 seems to be very hard to achieve as the amount of electricity generated from renewables in 2019 was only 308.1 MW (SREDA 2019), and the deployment of solar and other renewables has been slow and inadequate.

4.3 Five-year development plan

Currently, the government is focusing more on low-carbon development and emissions mitigation initiatives in its seventh five-year development plan (2016–2020). Under the plan, government officials and stakeholders are receiving training on low-carbon development at national and local levels. To build energy-saving capacity, technological innovations are being harnessed and implemented along with training programs. Energy demand management through revising existing tax policies and tariff structures is ongoing, and new investment opportunities targeting different clean technology funds across the world are being pursued. While cost-effective methods of manufacturing ready-made garments and textile have been implemented, incentives have been proposed to curb GHG emissions from cement, steel, and dairy industries. Also, policy measures have been implemented to encourage the construction of low-energy and eco-friendly buildings. Similarly, the Bangladesh Climate Change Trust Fund (BCCTF) is actively involved in mangrove plantation in 195,000 hectares of coastal land, stress-tolerant seeds dissemination, and rainwater harvesting to avoid flooding in urban areas (MEF 2015). Coordination among various public and non-government agencies is being established through regular communications to disseminate mitigation education, and ideas. Similarly, investments in research and development are being sought through collaboration among development partners (Planning Commission 2015).

Regarding the agriculture sector, the government plans to increase the use of technology and mechanized farming, which may lead to a reduction in draft animals, thereby lowering methane emissions (Planning Commission 2015). Also, the development plan includes policies that will promote climate change research, climate-smart technologies, and RE in the agriculture sector. Furthermore, the plan proposed the adoption of geospatial technologies, remote sensing, and geographic information systems, to monitor land-use practices and changes for climate change mitigation (Planning Commission 2015).

4.4 RE development initiatives

Deploying RE resources such as solar, wind, biomass, and hydroelectricity to increase their current supply of 18% of the global energy generation is the primary means of reducing GHG emissions (Ahiduzzaman and Sadrul Islam 2011; Hossen et al. 2017). In Bangladesh, the increasing energy demand coupled with mounting pressure on the petroleum resources have necessitated exploring and developing RE resources and rational use of energy (RUE). In 2008, an RE Policy was promulgated to support both the public and private sectors to generate 10% of national electricity demand from renewable energy technologies (RETs) (MPEMR 2008). However, even in 2017, the country's capacity for generating electricity from renewables and hydroelectricity was only 4% of the total installed capacity for electricity generation, while the remaining 96% was generated from fossil fuels (CIA 2019). Table 3 shows the installed capacity of the RETs that are currently operating. The following subsections analyze the existing key RE initiatives in the country: solar, wind, biomass, and hydroelectricity.

4.4.1 Solar energy

Solar energy systems such as photovoltaic (PV) systems, solar lanterns (LED-based), SHSs, solar water pumping for irrigation, briquetting technology, and solar heaters, refrigerators, dryers, and cookers are actively contributing to meeting the energy demand of

Table 3 Summary of electricity generation from the proposed RETs (SREDA 2015a, b)

RETs	Total capacity (MW)	RETs	Total capacity (MW)
Solar LED-based lantern	55	Grid-connected PV system	600
Solar LED-based lantern + 10 W CFL	165	Solar PV system	40,000
SHS	360	Rice husk gasifier	100
Mini grids	30,000	Wind electricity	1000
Mini grids of moderate size	10,000	Micro hydro generator	1.2
Solar water pumping	1200	Biogas power plant	400

several communities worldwide. In Bangladesh, there is an ongoing program to generate 500 MW of electricity from solar energy for rural schools, health centers, remote railway stations, and religious establishments (Alauddin 2015). Installing solar panels in public offices for lighting and cooling purposes is also another initiative toward meeting the target. The private sector is also encouraged to develop commercial products based on RE such as solar mini-grids, solar irrigation systems, solar rooftop applications, and solar parks.

An SHS is a sustainable supplement to other solar grid systems because of its low running cost. Since 1996 when it was introduced to the country, the SHS has achieved substantial market penetration. In 2014, the number of installed SHSs in the country exceeded 3 million with an aggregate capacity of 135 MW, which rose to 4.13 million installations by 2018, increasing the installed capacity to 185 MW. Between 2007 and 2018, the number of installed SHSs has rapidly risen from 128,813 to 4,135,512 (IDCOL 2018). Under the BAU scenario, the total installation of SHSs is expected to reach around 9.6 million units by 2030. However, under the government initiatives scenario, the targeted number of SHSs by 2030 is 11.2 million (Fig. 6).

Also, the Infrastructure Development Company Limited (IDCOL) has established a program to generate 150 MW through solar PV systems and promote the use of solar water-heating systems, solar water pumping, and solar cookers in the handloom industry, health centers, hotels, farmlands, and homes. So far, 61,500 solar PV systems and 260 hot box cookers have generated about 3 MW of power in off-grid hill tracks, rural areas, and coastal regions (Chhetri et al. 2008). As an average of 4 to 6.5 kWh/m^2 solar radiation is received daily (Islam et al. 2010), the country has vast potential for utilizing solar energy, especially in rural areas where electricity demand is low. Given that around 61.26% of rural households (19.31 million people) and 13.74% of urban households (5.73 million people) do not have access to electricity currently, utilizing solar energy for power generation is a necessary solution. Estimates indicate that by covering only one percent of Bangladeshi landmass (1302 km^2) with 10% efficient solar panels, an extra 40,000 MW of electricity can be generated and added to the national grid (SREDA 2015a, b).

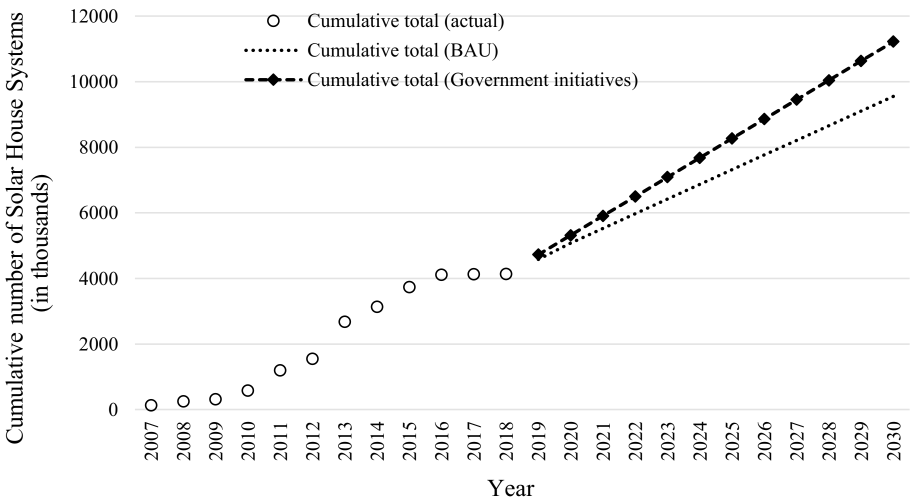


Fig. 6 Cumulative growth of installed SHSs in Bangladesh (IDCOL 2018)

Similarly, BCCTF has allocated around USD 400 million for 236 projects on rural electrification using solar energy since 2015 (MEF 2015). Although SHSs, and grid-connected PV systems can help significantly reduce GHG emissions, the required capital investment and technological complexity are undermining these initiatives (Ahsan et al. 2010). A survey has found that only 3% of the households can purchase SHSs, while about 57% of households can do so with credit, and the remaining 40% can only procure them through government subsidies, on a lease, or payments on an installment basis. Therefore, high initial investment and poor socioeconomic conditions of the people may profoundly affect the use of solar energy.

4.4.2 Wind energy

Currently, two pilot wind power plants with 1.9 MW total capacities are operating in Muhuri Dam in Feni (0.9 MW) and Kutubdia Island (1.0 MW). Unlike solar, wind energy is underutilized in the country. Mondal et al. (2010) analyzed the country's wind map and concluded that up to 100 h/year of power can be exploited from wind energy alone. A wind energy assessment has found that a typical wind turbine with a rated capacity of 1 kW can annually generate 2243 kWh, with estimated production costs of 12.3 ($ 0.175) Taka/kWh and total reduction in emissions of 1.8 $MtCO_2e$ per annum (Bhuiyan et al. 2011).

Similarly, Nandi and Ghosh (2010) conducted a techno-economic assessment of off-grid hybrid systems at Kutubdia Island and recommended that a wind-PV-diesel system is viable with 0% annual competence of shortage and 20% energy cost reduction, while a wind-diesel system is viable with 5% competence of shortage and 50% energy cost saving. These hybrid systems can prevent 44% GHG from entering the local atmosphere. Also, solar and wind energy systems (wind-PV-battery) can generate 89,151 kWh annually in southeastern Bangladesh, with 53% and 47% generated from wind and solar energy, respectively (Nandi and Ghosh 2010). This hybrid system is compatible with a 8–12 km grid extension and depends on the solar and wind speed variation. The system can effectively prevent 25 t CO_2/year from entering the local atmosphere. The policy of utilizing wind energy should be vigorously pursued as this could undoubtedly increase the share of renewables in the country's electricity generation from renewables.

4.4.3 Biomass

In Bangladesh, biomass-based fuel fulfills about 60% of the total household energy demands (Islam et al. 2008). Biomass technologies were introduced in the 1970s, especially in the rural areas where the number of installed biogas plants have reached 25,000 in 2008 and 70,000 in 2015 (280% increase), with an estimated potential of 4 million plants (Alauddin 2015). In 2003, the national biomass recovery and total biomass generation rates were 86.276 Mt and 148.983 Mt, respectively (Hossain and Badr 2007). The total national recoverable biomass is around 312.613 TWh per annum capable of generating 223.794 TWh of electricity (Hossain and Badr 2007) or 566 MW in another estimate (Mondal and Denich 2010). The country can generate around 6.62 million tons of biomass from rice husk alone, which can generate up to 1066 MW of electricity by 2030 (Ahiduzzaman and Sadrul Islam 2011). This forecast is based on an estimated annual production of 8–9 million metric tons (Mt) of rice husk from the average of 45 million Mt of paddy produced in the country and assuming a 20% husk yield (UNESCAP 2018). This quantum of electricity can substitute the electricity used in rice processing that is currently sourced from biomass and solar energy (Sufian and Bala 2006).

Biomass gasification which refers to the process of producing a combustible gas mixture by converting solid fuels, such as agricultural residues, wood waste, and husk is a viable alternative to conventional fuel and can help address the country's energy crisis. It can be used for thermal applications, running internal combustion engines, and in grid-supplied electric power. Due to recent technological advancements, the conversion of waste biomass into energy is a promising technology particularly for community-based small-scale independent power plants (Hasan et al. 2009). However, despite this enormous potential, only power plants generating only 250 kW based on biomass gasification using rice husks have been recently installed. Also, a 2006 study on energy recovery from municipal solid wastes in Dhaka revealed that the percentage share of electricity generation from solid wastes has been decreasing, which limits the potential of biomass as a clean alternative energy source (Ahmed et al. 2014). Therefore, the increasing use of forest biomass resources for cooking in rural Bangladesh is affecting carbon sequestration and contributing to increasing GHG emissions.

4.4.4 Hydroelectricity

Although hydroelectricity contributes the largest share of electricity generation around the world (1000 GW), a 230 MW power plant at Kaptai is the only hydroelectric plant in the country. However, the Bangladesh Power Development Board (BPDB) has identified two other suitable sites for hydropower plants; one at Sangu with an installed capacity of 140 MW and another at Matamuhuri with a capacity of 75 MW. As flat terrain is unsuitable for hydropower plants and Bangladesh's terrain is mostly flat, the scope for exploiting large hydropower sites is limited (Razan et al. 2012; Alauddin 2015). A study showed that small hydropower plants with an electricity generation capacity of 125 MW are economically viable (Mondal and Denich 2010). However, the electricity generation capacity of a few potential sites identified in Bangladesh ranges from 10 kW to 5 MW (Mondal and Denich 2010). This shows the economic unfeasibility of building small hydropower plants in Bangladesh. Given this limited potential for hydroelectricity generation in Bangladesh, initiatives should emphasize on the three previously discussed RE resources.

4.5 Rational and efficient use of energy

Rational and efficient use of energy resources is a key strategy for conserving natural resources and mitigating GHG emissions. In Bangladesh, natural gas constituted around 68% of the total energy consumption in 2018, while the shares of oil, coal, and hydroelectricity in the energy mix were 25%, 6%, and about 1%, respectively (BP 2019). As shown in Fig. 7, from 2004 to 2018, natural gas consumption increased from about 12 to 24 million tons of oil equivalent (MtOe), while oil consumption increased from 4 to 9 MtOe. From 2004 to 2018, the total national energy consumption increased from 16 to 35.7 MtOe. Under the BAU scenario, the annual total energy consumption can reach 51.4 MtOe in 2030 (Fig. 7). However, the government's Energy Efficiency and Conservation Master Plan aims to improve energy efficiency and thus reduce national energy consumption by 20% by 2030 (SREDA 2015a, b). Therefore, under the government initiatives scenario, the estimated total energy consumption in 2030 would likely be 41.1 MtOe.

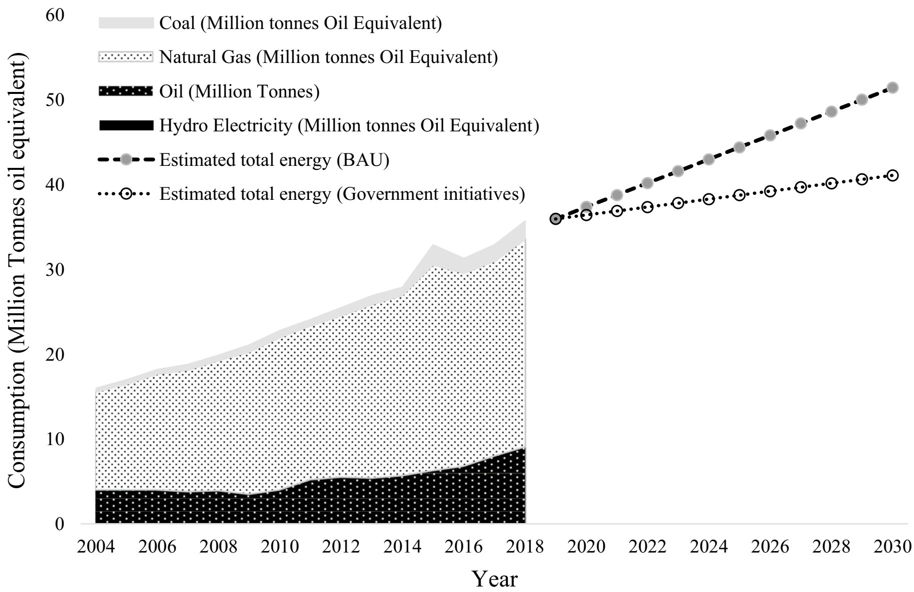


Fig. 7 Annual consumption of oil, gas, coal, and hydroelectricity in Bangladesh (BP 2019)

The government also mandated factories to efficiently use energy resources and establish an environmental management system (EMS). EMS is envisaged to result in 30% cost savings in manufacturing, 20% reduction in chemical waste consumption, and reduction of GHG emissions by 30% (Alshuwaikhat and Abubakar 2007). The efficient use of energy resources has been observed in some export-oriented manufacturing industries such as garments factories by adopting green and energy-saving technologies. Miah and Alam (2002) have revealed that the total annual forest area lost to wood combustion as a fuel in brick making was around 4.2 million m^3 consisting of 1.5 million m^3 round wood and 2.8 million m^3 branches. They also found that all brickfields produced 4.1 $MtCO_2$, 18 kilo-tons of CH_4, 155 kilo-tons of CO, and 123 tons of N_2O per annum. To address this issue, the brick making industry has introduced energy-efficient brick manufacturing technology which uses 50% less energy and emits less GHG, through its green brick project. Use of biomasses such as rice straw or cane leaves as fuels for producing fired bricks is found more efficient than the use of rice husk. As the rice straw and cane leaves have shorter GHG lifecycles than rice husk, promoting the use of such biomasses can significantly mitigate GHG emissions in the brick making industries (Talang et al. 2017).

Promoting the use of compressed natural gas (CNG) in vehicles is another government initiative taken in 2000 to reduce GHG emissions and improve air quality. First, petroleum-fueled three-wheeler rickshaw vehicles were banned from operation until the vehicles are retrofitted to run on CNG. Second, 9000 new automatic rickshaws that run on CNG were procured (Wadud and Khan 2011). Third, to encourage private vehicles to convert to using CNG, policy initiatives which include exempting sales taxes, import duties, and surcharges on CNG storage cylinders and conversion kits, as well as the removal of subsidy on gasoline, were introduced (Hossain 2004). From 2011 to 2016, the number of converted vehicles rose from 1379 to 248,006, representing an average of 41,105 vehicles converted annually (Rupantarita Prakritik Gas Company Limited 2018). A similar scheme recorded some success in Brazil where a tax rebate for buyers of cars with low-powered engines was responsible for about 2 million tons of carbon abatement in 2000 (Chandler et al. 2002). Besides curbing GHG emissions, this initiative can reduce the country's reliance on imported petroleum fuels for the transportation sector.

4.6 Clean development mechanism (CDM)

CDM was developed at the inception of the Kyoto protocol for trading GHG emissions of the developed countries with developing countries. In general, the CDM projects and programs benefit developing countries in adopting climate change mitigation initiatives which otherwise are not financially feasible for the business as usual case. In Bangladesh, initiatives related to CDM resulted in five projects and seven programs (Table 4) that will reduce GHG emission by 4.86 million $MtCO_2e$ annually (UNFCCC 2018). The sectoral areas of these projects and programs include the energy sector, manufacturing industries, and waste management.

The CDM helps foster environmental sustainability in developing countries, while providing developed countries some flexibility in meeting their emission reduction targets. In Bangladesh, the CDM projects help reduce GHG emissions and foster environmental sustainability, as well as contribute to capacity building and technological advancement (Baul et al. 2018). However, the CDM opportunities have not been substantially harnessed as only two out of 13 projects have been issued Certified Emissions Reductions (CERs) so far. The SHS project and the improved cooking stove project have issued 454,545 CERs and 808,434 CERs, respectively, between 2013 and 2018 (UNFCCC 2018). Although the gas leakage reduction project is the single largest CDM project in terms of emission reduction (90%), CERs have not been issued so far under this mega CDM project. Also, the landfill

Table 4 Registered programs and projects under CDM in Bangladesh (UNFCCC 2018)

Title of program/project	Registration date	Annual reductions of GHG emissions ($MtCO_2e$)
Programmatic CDM project using municipal organic waste in 64 districts	January 2015	6978
Promoting access to domestic biogas in rural areas	July 2014	662
Energy and water-saving promotion program for textile dyeing process in textile and garment industries	May 2014	908
Energy efficiency program in rural areas	June 2013	55,198
Installation of SHS	June 2012	45,713
Improved cooking stoves	July 2011	50,233
Efficient lighting initiative of Bangladesh	May 2011	17,540
Reducing gas leakages within the Titas gas distribution network	March 2015	4,378,506
Akij particle biomass thermal energy generation CDM project	December 2014	41,912
Improving kiln efficiency in brick making industries (Bundle-2)	July 2012	40,104
Improving kiln efficiency in brick making industries	August 2011	54,704
Composting of organic waste in Dhaka	May 2006	89,259
Landfill gas extraction and use at the Matuail landfill site, Dhaka	September 2005	80,000
Total		4,861,717

gas extraction project which aimed to earn money through selling CERs has not submitted any CER issuance request (UNFCCC 2018). The request for issuing CERs under all the CDM projects can help Bangladesh earn income and simultaneously reduce emissions.

4.7 Private sector and non-government organizations (NGOs) initiatives

The impacts of climate change on the economy and environment can be devastating unless they are effectively addressed by all stakeholders. Studies have revealed that global warming can reduce global income by 25% and cause a USD72 trillion loss in the World's GDP. The private sector will also incur losses as climate change threatens supply chain and businesses. Both large and small businesses are affected by extreme weather events such as drought, flooding, cyclone, and saline water intrusion. Over 1000 private companies formed the 'Carbon Pricing Leadership Coalitions' at the Conference of the Parties 21 in Paris to establish effective policies on the carbon price to encourage innovation, create jobs, maintain competitiveness, and reduce emissions (World Bank 2016).

In Bangladesh, small and medium-sized enterprises (SMEs) account for over 90% of the private sector which employ 70%–80% of the non-agriculture labor forces (International Monetary Fund 2013). Being one of the countries most vulnerable to climate change, the effect of climate change on these SMEs can be devastating. The disastrous floods of 2008 and the 2007 cyclone cost around USD 2 billion and USD 1.7 billion, respectively, with the private sector incurring a significant share of the losses (World Bank 2010). This provides economic justification for partnering in climate change mitigation activities. Fifty six social enterprises and NGOs are working as partner organizations under the Infrastructure Development Company Limited (IDCOL) and helping customers to install SHSs. About USD 696 million have been invested in this program, with 75,000 households participating and about 4.12 million SHSs have been installed as of May 2017, which is acclaimed as the world's largest off-grid RE program (IDCOL 2018). The Partnership for Clean Textile (PaCT) program is another private sector investment in climate change mitigation activities established in 2013 under a partnership between International Finance Corporation (IFC) and the BRAC Bank and the Industrial Development Leasing Company of Bangladesh Limited. Under this partnership, about USD 11 million was invested in various resource-efficient technologies to ensure efficiency in the operation of about 200 textile factories and 13 global brands. Between 2013 and 2016, this program reduced GHG emissions by about 0.46 million metric tons of CO_2 equivalent ($MtCO_2e$) and saved around USD 16.3 million by reducing water and energy consumption (IFC 2018).

To minimize crop losses caused by extreme climatic events such as flooding, cyclones, or drought, the Bangladesh Green-Delta Insurance have developed an index-based insurance program. This program supports around 75,000 farmers using a Pilot Program for Climate Resilience to increase their revenues through sustainable agro-business practices and climate-smart technologies. Also, the largest private seed companies such as Energypac, Agro-G Limited, and Supreme Seed are partnering with IFC and NGOs to promote the use and marketing of stress-tolerant rice seeds. About 600 dealers and 67,000 farmers received training and cultivated high-yield stress-tolerant varieties in their fields. Farmers earned 15% more revenue compared to their past earnings using these high-yield seeds (IFC 2018).

In 2010, the Bangladesh Venture Fund (BVF) was created with the help of IFC and the Small Enterprise Assistance Funds to finance energy efficiency and RE projects. The BVF invested about USD 1 million to foster energy efficiency and the use of energy-saving appliances (IFC 2018). Also, the Central Bank of Bangladesh supports commercial banks and other micro-financial institutions with an interest rate below 5% to promote investment in SHSs, solar irrigation pumps, wind energy, hydroelectricity, biogas, hybrid Hoffman kilns, effluent treatment plants, and product recycling (Rahimafrooz 2018). The BRAC bank limited has introduced "green banking" to finance RE and energy-efficient equipment for ready-made garments and other industries, and the Mutual Trust Bank Limited has offered the Green Energy Loan to finance some RE products such as solar irrigation pumps, recyclable cups, and cleaner brick kilns. Manufacturers such as Rahimafrooz (Bangladesh) limited launched the Rahimafrooz RE limited (RREL) to provide solar energy solutions to households, telecommunications, farmlands, and schools. Their activities include the SHSs for households, the solar-hybrid solution for telecommunication tower of base transceiver stations, and the solar-powered irrigation, and water-heating systems. Also, the RREL has initiated a CDM-based consultancy and carbon trading service called 'Bangladesh Carbon' to develop and commercialize various CDM projects, thereby earn foreign exchange (Rahimafrooz 2018). Initiatives by the private sector companies and NGOs are playing an important role in curbing GHG emissions through investments in and the promotion of RE technologies, especially the SHS, and should, therefore, be supported by the government.

4.8 International collaboration

Climate change mitigation initiatives in developing countries will not succeed without collaboration among countries, the private sector, and local and international organizations/agencies. In Bangladesh, the Ministry of Power, Energy and Mineral Resources (MPEMR) has entered into many research and institutional development partnerships on RE. For example, Chemonics is an international company that is collaborating with the Ministry to promote energy sector development for economic development, energy security, and climate change adaptation. Also, the World Bank coordinates with the Ministry, energy utility authorities, and energy end users to strengthen regulatory climate, increase energy efficiency, and promote clean energy development. Locally, the Sustainable Energy Development Agency (SEDA) encourages RE development through collaboration with academics, the private sector, NGOs, implementing agencies, Bangladesh Solar Energy Society, and financial institutions (MPEMR 2008). SEDA provides sustainable energy facilities and financing mechanisms through subsidies, grants, and carbon/CDM funds for private and public sector investments. SEDA also prepares action plans for sustainable energy management, coordinates different activities of the RE agencies and organizations, and provides funds for reducing GHG emission via programs such as mechanical irrigation appliances driven by biogas, solar or bio-diesel, and community practices for forest management and conservation.

German Technical Cooperation Agency (GTZ) also collaborates with the MPEMR to promote RE technologies and projects. The role of MPEMR was to revise the NEP and develop the framework of SEDA operations with support from GTZ and the United Nations Development Programme (UNDP) (Islam et al. 2010). The IDCOL is also running one of the world's most successful solar energy programs with co-financing from the Netherlands DGIS, and GTZ in Bangladesh to develop the market for SHSs. Moreover, GTZ has also started working with NGOs and private sector enterprises to promote biogas-based electricity generation by introducing biogas plants at dairy and poultry farms, slaughterhouses, dormitories, and municipalities. Implementation of the improved cooking system and reducing system losses are the other successful programs of GTZ in the energy sector.

Similarly, in September 2011 Bangladesh and India signed a memorandum of understanding to cooperate in institutional support, exchange of information, capacity building, technical support, and RE research and development. The country has also joined the South Asian Association for Regional Cooperation (SAARC) Energy Centre (SEC) in 2005 for establishing common energy policies to strengthen its regional energy issues (Chary and Bohara 2010). The main rationale behind the SEC is to catalyze and accelerate economic growth by enhancing regional capabilities. Based on the studies on similar economic climate in three major countries of SAARC (India, Pakistan, and Bangladesh), SEC has focused on setting up mutually beneficial energy policies. These policies are expected to enable each country to achieve its growth objectives. Similarly, a comprehensive assessment of potential loations for wind power generation in the country through a collaboration among GIZ (Gesellschaft für Internationale Zusammenarbeit), LGED, BCSIR, Bangladesh Center for Advanced Studies, and RE Resource Center of University of Dhaka is underway. Likewise, USAID is presently funding the power division of the government to prepare a wind map for the whole country (Alauddin 2015). More of these collaborations among international and local stakeholders, especially in research and development, enhancing technical capabilities, and financing mechanisms can help generate more RE, lower GHG emissions, and promote environmental sustainability.

5 The sustainability implications of policies for mitigating GHG emissions

Mitigating GHG emissions can provide Bangladesh significant environmental benefits. However, GHG emissions from agriculture and energy generation sectors are following a rapidly increasing trend. Government policies are crucial for mitigating GHG emissions and ensuring sustainability. As the energy sector is the fastest-growing emitting sector and emissions from electricity generation play an important in energy sector emissions, it is crucial to assess the sustainability of the government's power sector policies.

According to the government's Power System Master Plan 2016, Bangladesh aims to increase the share of coal, nuclear, and biofuel energy sources in the power generation mix (Power Division 2016). In 2017, the share of coal-fired electricity in the total electricity generation mix was 1.9% and the government intends to increase it to 20% by 2040 (Power Division 2016). Under the high coal scenario, the government has proposed a 55% share of coal-fired electricity in the electricity generation mix by 2040 (PSMP 2016). By 2023, there will be 13 coal-fired power plants in the country and the required coal will be imported from Australia, China, and Indonesia (IEA 2019). Electricity generation from coal is one of the dirtiest and unsustainable ways of power generation, and it negatively affects the environment. Coal-fired power plants contribute to global warming and cause air pollution, which is associated with the rising incidence of asthma, lung ailments, cancer, and other diseases. Therefore, increasing the share of coal-fired electricity in the power generation mix will increase the country's GHG emissions from the energy sector. There are two main reasons advanced in favor of coal-fired power plants in the Power System Master Plan 2016. Firstly, coal is considered to be the cheapest source of primary energy in the current energy market. Secondly, the country is rich in high-quality coal that is being mined from a several sites. This showcases that the government is more inclined toward short-term economic benefits than long-term environmental costs.

The government formulated the country's RE policy in 2008 given that RE is the most sustainable energy source for climate change mitigation. (MPEMR 2008). The policy aims to meet 5% of the total electricity demand by 2015 and 10% by 2020 from renewable sources (MPEMR 2008). However, in September 2019, electricity generated from solar and hydro sources was 38 MW and 230 MW, respectively, and the share of renewable sources in the electricity generation mix was 1.4% (BPDP 2019). This illustrates how far behind the government is from its renewable electricity targets. Although the adoption of SHSs has witnessed an increasing trend in recent years, it is not adequate to significantly reduce the amount of GHG emissions from the energy sector. Therefore, combating climate change by reducing GHG emissions is a great challenge for the country.

Besides the energy sector, agriculture and forestry sectors are two of the major sources of GHG emissions in Bangladesh. The proportion of forests compared to the country's total land area is very low. In 1990, the share of forest land was about 11.4% which decreased to 11.0% in 2015 (World Bank 2018). Although the government proposed to conduct coastal afforestation programs, as well as homestead and community forestry programs in their Climate Change Strategy and Action Plan 2009, there has been little progress to enhance this carbon sink. Similarly, the rapid growth of the population poses a challenge to the efforts of reducing emissions from the agriculture and forestry sector. Food production and housing development for the growing population decrease forest land, thereby increasing emissions and reducing carbon sinks. In addition, the large-scale use of forest biomass in rural areas decreases forest land and contributes to GHG emissions.

Another key challenge for reducing GHG emissions from its major sources is the high foreign direct investment (FDI) in energy-intensive industries such as leather, cement, steel, ship-breaking, and chemical industries. In 2018, FDI inflows in Bangladesh were USD 3.6 billion and the share of FDI inflows in the manufacturing and power sector was 73% (Bangladesh Bank 2019). Cheap labor and flexible environmental regulations are some of the key factors responsible for the increased investments in these carbon-intensive industries. Since FDI inflows contribute to the GDP growth, the government seems to be reluctant to impose strict foreign investment policies. After the energy sector, the manufacturing sector is typically the second-largest contributor to GHG emissions, and as the country industrializes, emissions in this sector will inevitably go up. The manufacturing sector is fairly effective in optimizing carbon efficiencies from fossil fuel use but reluctant to venture into low-carbon alternatives as this is an indication that the same may apply also to Bangladesh (Cadez and Czerny 2010). As a result, the country's economic growth policies largely lack environmental sustainability concerns.

Most of the policies and initiatives are expected to be implemented by 2020 or 2030, so it is difficult to access their achievement now especially in the context of limited data. However, the data on GHG emissions and RE generation can serve as proxies for assessing the policies. According to EIA (2019), from 2015 to 2016 the country's total CO_2 emissions have increased from 73 MMT to 79 MMT (6 MMT CO_2 increment), while those of its neighboring countries (India and Myanmar) have both increased by about 4 MMT of CO_2. Moreover, from 2015 to 2016, the country's RE generation has increased by only about 0.02 Million Kwh (EIA 2019).

6 Concluding remarks

The major sources of GHG in Bangladesh include changes in forest and other biomass stocks, energy and transformation industries, and agricultural activities. Although the per capita GHG emission is less than that of many developing countries, the country is exploring GHG mitigation initiatives and opportunities for long-term economic benefits, energy security, and local environmental concerns. These initiatives include developing RE, rational and efficient use of energy, CDM, and international collaboration, which have several co-benefits in terms of socioeconomic development and environmental sustainability. This study shows that the use of non-forest biomass for energy is meeting an appreciable portion of energy demand without increasing emissions of GHG and the collaboration by the government, NGOs, and international donor agencies have delivered electricity by solar panels to more than 1 million rural households within few years. The successful implementation of few projects under CDM is also contributing to GHG reduction. The use of RE resources including wind, solar, and non-forest biomass, apart from cutting down emissions, is contributing to meeting the increasing energy demand and providing energy security which is pivotal to the country's economic growth and development. The establishment of the Infrastructure Development Company Limited and Sustainable Energy Development Agency and the development of policies such as the RE Policy and cooperation with other countries are effective in ensuring sustainable energy development.

Despite various initiatives, there are limitations and challenges in reducing GHG emissions. One of the challenges toward reducing GHG emissions from various sectors is the growing population, which is likely to increase the demand for food and electricity and may reduce forest lands due to housing development and economic activities. Government policies are also contributing to the problem. For instance, the government proposed to increase the share of coal-fired electricity in the total power generation mix from 1.9% to 20% by 2041, which may limit the future emissions reduction possibilities of the country. Also, the government could not achieve its RE targets proposed in the Renewable Energy Policy 2008. The policy aimed to increase the share of RE sources in the power generation mix to 10% by 2020, whereas the share of renewables until September 2019 was only 1.4%. High FDI inflows in the carbon-intensive manufacturing industries also limit the emissions reduction possibilities of the country. Priority to low-cost energy sources (such as coal) and emphasis on accelerated economic growth over environmental sustainability seem to contribute to the problem. The pre-determined motive in favor of implementing coal-fired power projects (Hasan et al. 2018), corruption (Rahman 2018), and the urgency to address more serious issues such as unemployment (Feldman 2015) or Rohingya refugee crises (Martin et al. 2018) may be some of the underlying causes, which limit the country from effectively combating climate change. Moreover, efforts should be directed toward developing more policy targets in the agriculture sector, as the sector has one of the highest emissions.

Given the aforementioned challenges, it is crucial to ensure accountability and transparency at various levels of policy formulation and implementation. Curbing GHG emissions without compromising economic growth can be achieved by ensuring good governance, transformative sustainable changes in behavior, integrating the efforts of all the stakeholders including the government and private sectors, NGOs, CBOs, international organizations, donor agencies, and the general public. International cooperation and technology transfer from developed countries is crucial as it is proposed by Owusu and Asumadu-Sarkodie (2016). Stringent carbon policies by the government may push corporate organizations to adopt effective climate change strategies in their business plans (Cadez and Czerny 2016). Opportunities in the global carbon market also need to be sought. As carbon trading and CDMs do not contradict economic development objectives and environmental sustainability, the government should support various stakeholders to focus on expanding and increasing the capacity of existing CDMs and implementing new ones. Future research could investigate the obstacles to GHG mitigation efforts in Bangladesh in detail.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article is based on analyses of secondary data and does not contain any experiments conducted on human participants or animals.

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