Adaptation measures (AMs) and mitigation policies (MPs) to climate change and sustainable blue economy: a global perspective

Fahim Hossain

ABSTRACT

Erratic patterns in climate have been forcing people to develop new adaptation and mitigation tools. Although world leaders have agreed to control greenhouse gases' (GHGs) emission, the current rate of emission may not stop global climate change (GCC). Scientists have been working to scientifically explain the effects of GHG emission on GCC, however, all climate changing phenomena may not be fully understandable now and more research is necessary to comprehend those knowledge gaps. Climate change has been severely affecting the ecological and socio-economic development but these effects can be mitigated by supporting sustainable technological and economic development as AMs and MPs. MPs to climate change may trade off the negative impacts of GCC and exploring and employing lucrative opportunities in blue economy can help in developing those AMs and MPs. Moreover, it is not possible to rapidly divert all global manufacturing processes into benign technological and economic perfection. For this reason, Bangladesh and other coastal countries are very aware of the need to introduce cost-effective AMs and MPs and society and environment oriented blue economy. Some worthwhile adaptation and mitigation strategies are discussed to minimize the carbon footprint, as remedies to curtail GCC impacts. Scientific relations of GCC with GHG emission and opportunities of blue economy are also explored.

Key words | adaptations and mitigations, blue economy, carbon balance, climate change impact, water and industry

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HIGHLIGHTS

- AMs and MPs are imperative to control the current level of GHG emissions.
- Fossil fuel can potentially be replaced by hydrogen and nitrogen based fuels.
- Sustainable food production and water resources management are inevitable for prudent AMs.
- Ocean economy can bolster sustainable food production and economic growth.

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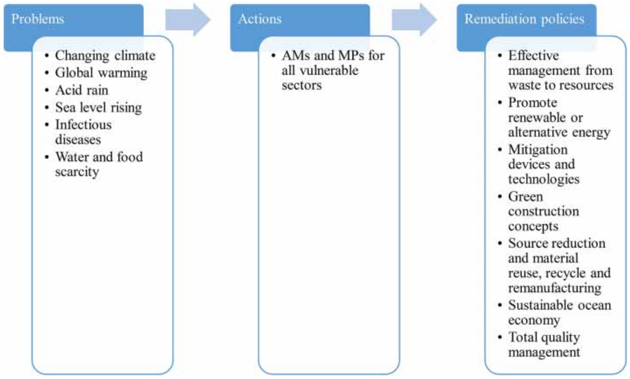
GRAPHICAL ABSTRACT



INTRODUCTION

Concern about global climate change (GCC) has been increasing with time as emission of greenhouse gases (GHGs) has escalated at an alarming rate due to uncontrolled anthropogenic activities. In May 2018, the National Oceanic and Atmospheric Administration (NOAA) in Colorado recorded 408.97 parts per million (ppm) of average atmospheric carbon dioxide (CO_2) concentration and this value is the highest in 800,000 years (NOAA 2018). This global carbon dioxide has been released into the atmosphere due to fossil fuel burning to support industrial activities and change in land use (LU) for agricultural activities, although natural sinks like oceans and forests accumulate approximately 56% of that CO_2 (Raupach *et al.* 2007). At this moment, the annual growth rate of atmospheric CO_2 has reached about 2.19 ppm/year (NOAA 2018) as it is not possible to curtail the industrial and agricultural activities that are supporting the growing population on earth.

However, the actual scenario is more menacing because of the involvement of other greenhouse gases such as water vapor, methane (CH_4), non-methane volatile organic carbons (NMVOCs), tropospheric ozone (O_3), nitrous oxide (NO_x), sulphur gases (SO_x), aerosols, fluorinated gases (i.e. chlorofluorocarbons, CFCs; hydrofluorocarbons, HFCs; perfluorocarbons, PFGs; sulfur hexafluoride, SF_6; nitrogen trifluoride, NF_3), carbon monoxide (CO), hydrogen chloride (HCl), etc. in the global warming process. The global atmospheric concentration of methane and nitrous oxide was 1786 parts per billion (ppb) and 327 ppb, respectively, measured in 2015, and both gases have been showing an increasing trend (USEPA 2016). These other greenhouse gases have more global warming potential (GWP) than CO_2. For example, CH_4, NO_x, and fluorinated gases absorb about 28–36 times, 265–298 times and thousands times more energy, respectively, than CO_2 (Foster *et al.* 2009).

Greenhouse gases are prominent contributors to global warming and GCC. Some of the indicators of the GCC include but are not limited to sea level rising (SLR) in the coastal areas, land loss due to water level rising, ocean acidity, ocean heating, sea surface temperature fluctuation, frequent coastal flooding and storms, i.e. cyclone, heavy precipitation, abnormal dry conditions, ice melting in Antarctica etc. The GHGs, GCC and above mentioned indicators have an effect on each other and it is worth mentioning that the interactions are a two-way process instead of one-way.

As a result, the GCC is affecting not only green economy that can be defined as 'all actions for minimizing or eliminating environmental damages or risks and ecological scarcities without sacrificing social and economic well-being by prudent utilization of available resources' (United Nations Environment Programme 2016), but also blue economy which can be defined as 'all economic activities derived from sustainably utilizing various resources from oceans, seas and coasts for economic development, social well-being, environmental and ecological safeguard' (World

Bank & United Nations Department of Economic & Social Affairs 2017; European Union 2018). Bangladesh is also a victim of the negative impacts of GCC. Bangladesh has to scrutinize the potential opportunities of blue economy in its 710 km coastlines and vast continental shelf of the Bay of Bengal (i.e. an area of about 24,800 square nautical miles) (Ahsan 2013) to array a *quid pro quo* relationship with climate change. Therefore, it is a wakeup call for the habitat of the world and Bangladesh to think about adaptation measures (AMs) and mitigation policies (MPs) to climate change and develop a sustainable blue economy. In this context, a large number of organizations are working together for feasible and sustainable solutions to dampen the negative impacts of climate change.

However, sustainable cost-effective AMs and MPs will take more time to thrive as bridging the knowledge gap is still in the fledging stage. For example, research on renewable energy has been flourishing very rapidly but effective and efficient developments and applications of solar energy, eco-friendly bio-fuels and environment friendly energy storage devices are very challenging in terms of resource utilization and recovery and pollution mitigation. Until 2017, renewable energy has been contributing only about 17.7% of the total energy demand for the whole world (World Bioenergy Association 2019). Few countries are, however, patronizing the infrastructure for a hydrogen and nitrogen based transportation system but bioenergy is still a dilemma as most of them are basically carbon-based fuels that are also grabbing food from millions of starving people. The agricultural sector is continuously struggling to cope with these and other influencing issues, but nevertheless land use and water, the most important driving fuel, are beyond the reach for many agriculturists although triple cropping and eco-friendly husbandry are in the front line as an adaptation and mitigation mechanism against changing climate. Water, a very precious commodity and right, is not easily available to about two billion people (UN 2018) because of excess water extraction, drought, changing precipitation patterns and changing climate. The health sector is pitifully devastated by emerging diseases, e.g. Ebola virus disease (EVD), Zika virus disease (ZVD) and Coronavirus disease (CVD) and it has been challenging to develop vaccines and reliable treatments with medicines because 30 °C is the tolerance temperature in medicine production but the warming environment further exacerbates the situation and imposes risks or uncertainty. Leaders in the political sector have been acrimoniously debating since 1979 over climate change issues where a holistic approach for adaptation and mitigation policy is still out of reach. So, immediate actions and policy implementations are necessary by supporting integrated climate risk management efforts. Devising cost effective on-site GHG source minimization processes is crucial for sustainable achievement in controlling heat-trapping elements and halogen compounds' emission in the atmosphere so that the anthropogenic contribution to global warming and ozone layer depletion can be reduced. Dependence on fossil and other carbon-based fuels must be curtailed and carbon free renewable energy sources should be the vanguard in the energy sector. The agriculture and water sectors must work collaboratively to attain maximum yield for both sectors where cost-effective secondary pollution-free water extraction, recharge, treatment and reclamation will assist thermo-tolerant plants and animal farming. Optimized outcomes from practicing AM and MP in all sectors may not be viable by adapting current research investigations and technological innovations but promoting a carbon neutral policy and other pollution abatement mechanisms, e.g. halogen reduction or degradation, should be the foremost priority to combat climate change as increased pollution may augment the climate related disaster and impacts. The objectives of this study are to discuss the possible sources of greenhouse gases, and their influence on GCC, AMs and MPs for reducing GCC stimuli. Additionally, supportable solutions will be suggested to explore the potential of blue economy so that a tradeoff situation can be developed between blue economy and changing climate.

METHODOLOGY

The depiction of the interaction science of GHGs, GCC indicators, possible impacts with attainable acclimatization and opportunities of blue economy was explained by evaluating different scientific rationales related to climate change. In this context, numerous published scientific resources were analyzed and a conceptual framework was developed for the study (Figure 1) of AMs and MPs for different sectors

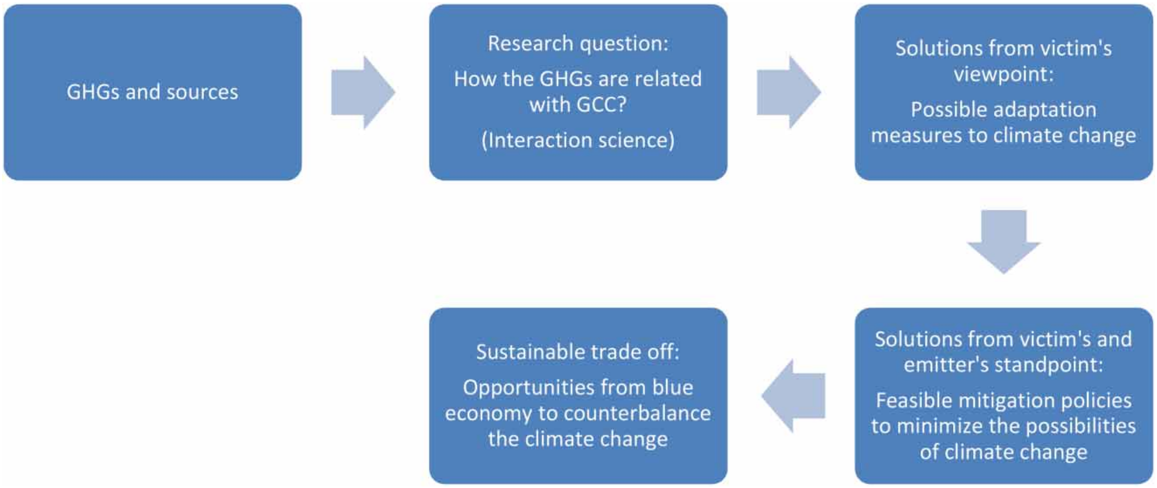


Figure 1 | Conceptual framework of the study.

that can be affected by GWP and climate change issues. The conceptual framework is basically supporting the three principle objectives emphasized in article 2 of the UN Framework Convention on Climate Change (UN 1992): (1) AMs and MPs may be adopted to safeguard the ecosystem and environment in such a way that atmospheric GHG emission could be controlled to minimize the dangerous anthropogenic intrusion into the climate system; (2) food production can not be sacrificed to meet the demand and (3) sustainable economic development. The first point was fulfilled by the adaptation and mitigation section and the other two points were achieved in the blue economy section of this study. A comprehensive but succinct diagram would be represented to show the interrelationship between emitted GHGs and their possible gaseous-aqueous phase cycle for heat trapping and releasing to influence the global warming process. The AMs were consequently discussed as victims of climate change would try to adapt more feasible and cost effective measures to protect their ecosystems and environment, while both emitters and victims would introduce state-of-the-art technologies to minimize GHG emission and possible adverse impacts of climate change and therefore, exploration of resources of blue economy could be focused as a sustainable food production process where economic growth and AMs with MPs are intertwined to achieve synergy. Besides, the blue economy has an enormous influence on the standard of living of coastal people who are the most victimized fraction of the impacts of climate change and inclusion of the blue economy can provide financial support for mitigating climate change.

DISCUSSION

GHG emission sources and possible impacts on GCC and blue economy

The sources of greenhouse gases are probably identified and the possibility of source reduction has been profoundly analyzed by the researchers so that global average temperature rise can be kept below 1.5 °C above pre-industrial levels. The US Department of Energy (USDoE) and US Environmental Protection Agency (USEPA) have estimated that 9,900 million metric tons of carbon dioxide equivalents ($MtCO_2e$) was emitted globally from fossil fuel in 2014 (IPCC 2014a; Boden *et al.* 2017). On the other hand, global non-CO_2 GHG emission was 12,000 $MtCO_2e$ in 2014, estimated by USEPA (2014). Therefore, possible GHGs and emission sources are carefully investigated and presented in Table 1 so that it is possible to estimate detailed carbon and non-carbon gas flux per annum. Again, all AMs and MPs will be considered as possible and probable sinks for GHGs because natural and anthropogenic sinks may synergistically work to abate the effect of GCC.

The indicators of GCC are related with GHGs emission by some scientific bases. The scientific interactions are

Table 1 | Infrared radiation absorption by gases and other elements and their potential emission sources

General group	Gases	Emission sources
GHGs	CO_2	Fossil fuels burning by transportation and industry (Le Quéré *et al.* 2009)
		Electricity production (Olivier *et al.* 1996)
		Burning of international bunker fuel (Raupach *et al.* 2007)
		Chemical reactions in industry (Olivier *et al.* 1996)
		Solid waste management (SWM) in landfills (Olivier *et al.* 1996)
		Wastewater treatment and sludge management process (Olivier *et al.* 1996)
		Livestock management (Olivier *et al.* 1996)
		Land use change (LUC) (Le Quéré *et al.* 2009)
		Oceans (Olivier *et al.* 1996)
	CH_4	Paddy cultivation (Lelieveld *et al.* 1998)
		Wetlands due to organic degradation (Lelieveld *et al.* 1998)
		From streams and river beds (Stanley *et al.* 2016)
		From digestive tracts of termites because of protozoa and bacteria (Lelieveld *et al.* 1998)
		Microbes in oceans (Lelieveld *et al.* 1998)
		Wild ruminants and domestic animals (Crutzen *et al.* 1986)
		SWM in landfills (Lelieveld *et al.* 1998)
		Industrial and domestic waste and sludge management by anaerobic process (Isaksen *et al.* 2014)
		Biomass burning (Lelieveld *et al.* 1998)
		Venting and flaring from oil and gas industry (Isaksen *et al.* 2014)
		Coal mining and other minings (Isaksen *et al.* 2014)
		Polar region (Shakhova *et al.* 2019)
	NO_x	Domestic wastewater treatment plants (Griffis *et al.* 2017)
		Fossil fuel burning and other combustions (Olivier *et al.* 1996)
		Synthetic fertilizer use in agriculture (Griffis *et al.* 2017)
		Animal manure applied to soils (Olivier *et al.* 2017)
		Direct emission from soil (Olivier *et al.* 2017)
		Forest fires (Griffis *et al.* 2017)
		Farming process and biomass burning (Olivier *et al.* 1996)
		Transportation and power generation (Olivier *et al.* 1996)
	O_3	Reaction with NOx and volatile organic carbons (VOC) (Olivier *et al.* 1996)
		During thunderstorms (Olivier *et al.* 1996)
	CFCs & HCFCs	Heating and cooling process (Olivier *et al.* 1996)
		Solvent use (Olivier *et al.* 1996)
	NMVOC	Biofuels and biomass burning (Olivier *et al.* 1996)
		Bulk chemical production (Olivier *et al.* 1996)
		Oil and gas industry (Grazón *et al.* 2015)
		Road transportation (Grazón *et al.* 2015)
		Painting (Grazón *et al.* 2015)
	SO_x	Volcanic eruption (Bates *et al.* 1992)
		Sludge management (Liu *et al.* 2012)
		LU & plants (Bates *et al.* 1992)
		Algae in oceans (Charlson *et al.* 1987)
		Chemicals and metals production (Olivier *et al.* 1996)
		Agricultural waste and fossil fuel burning (Olivier *et al.* 1996)
Other elements absorbing infrared radiation	Aerosols	Mineral and sea salt dust (Boucher 2015)
		Burning process (Boucher 2015)
	Water vapors	From different sources
	CO	Wild fire (Olivier *et al.* 1996)
		Biomass burning (Olivier *et al.* 1996)
		Road transportation and energy production (Olivier *et al.* 1996)
	HCl	Power and heat generation (McCulloch *et al.* 1999)
		Chlorinated content burning (McCulloch *et al.* 1999)
	Hydrogen (H_2)	Biomass burning (Derwent *et al.* 2006)
		Methane and organic compounds oxidation (Derwent *et al.* 2006)
		Road transportation (Derwent *et al.* 2006)

presented to understand the fundamental trends of climate change so that scientists can think about mitigation and adaptation tools for controlling GHG emission in a cost effective manner (Figure 2). These interactions may establish more concrete foundations for future research. However, some complex interplay may not be fully realized at this moment as more advanced and sophisticated research initiatives will be necessary to minimize the knowledge gap on those issues. For example, elevated CO_2 concentration and photosynthesis rate (Sellers *et al.* 1996; Harvey 2010) and increased CO_2 concentration and storms (Lambert 1995; Beersma *et al.* 1997) correlation are under debate and controversies on these relations should be dispelled by establishing an easy rapport within the scientific community.

AMs and MPs

It is vital to comprehend the interactions such as river-ocean, land-water, human-water, human-land, environment-health and health-climate for developing effective

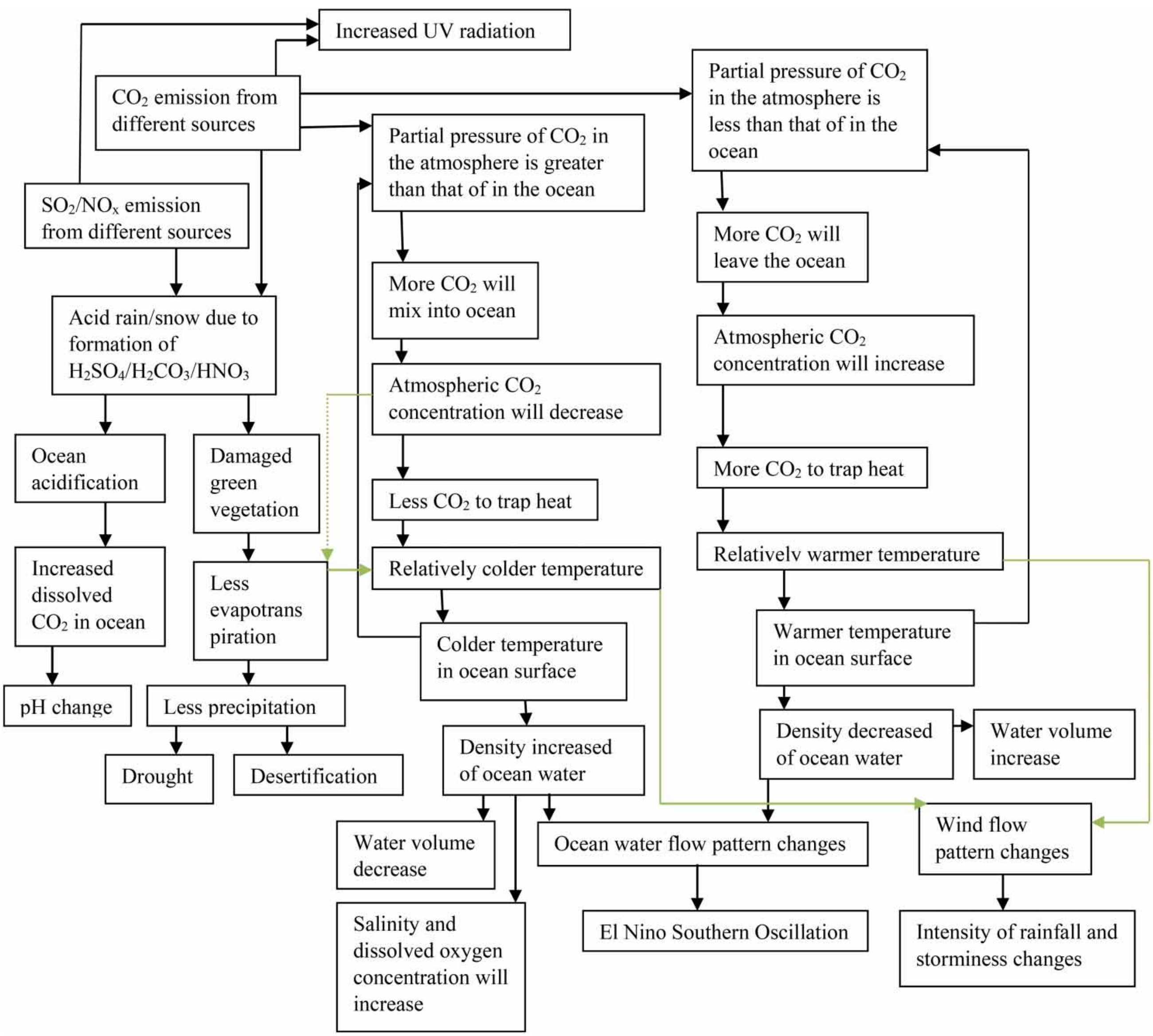


Figure 2 | Complex interaction science of GHGs, GCC and impact on blue economy.

measures and policies. Adaptations are selective measures to protect the social, economic and environmental interest of humans and all other creatures from actual or expected negative stimuli of climate change and explore the benefits as a precaution. Mitigations are anthropogenic initiatives employing different kinds of resources to minimize both positive and negative climate change stimuli so that AMs can be reduced (IPCC 2007b). AMs are considered as low-cost alternatives to safeguard the victims (or emitters) while MPs are regarded as high-cost options to serve both victims and emitters globally. AMs and MPs are not the duties for one single government but a holistic approach must be practiced by the stakeholders for controlling and monitoring the changing climate nonetheless. A number of AMs to climate change and possible MPs are suggested as follows:

- It is suggested to increase the height of the plinth level of structures in coastal areas as an adaptation measure for SLR. About 1.29 mm/year of regional average sea level change has been observed in stations near the northern part of the Indian Ocean as long-term records in any station near the Bay of Bengal are not available (Brammer 2014). An SLR record will help structural engineers to determine a feasible height of plinth level. Besides, riverine countries like Bangladesh should carefully increase the navigability of their rivers so that they act as a buffer zone for coastal flooding and SLR. However, salt water intrusion can undermine the process; plantation of halophytes (Radulovich *et al.* 2017) in the mixing zone of fresh water and salty water can effectively solve this problem. Coastal surface and groundwater monitoring and management with limited groundwater extraction may also constrain rapid seawater intrusion.
- Likewise, infrastructure codes in coastal areas should be developed to prevent salinity impact. Diagrid and other material conserving structures also mitigate GHG emission from material manufacturing processes.
- Concepts of green building development are generally applied to promote efficient water, light, e.g. light-emitting diode (LED) light, sound and energy use and management, sensor based energy and water controlling systems, renewable energy applications and carbon balancing, enhance refrigerant management, waste conversion into resources by purple bacteria (Lee *et al.* 2002; Tao *et al.* 2008; Hülsen *et al.* 2018; Vasiliadou *et al.* 2018) and blue-green algae (Benemann 1979; Abdel-Raouf *et al.* 2012), recycling low-emitting construction materials, site selection for conserving ecosystem and biodiversity, landscape management and carbon balanced or carbon free transportation system. Again, sustainable sources of construction materials, those materials' albedo, GHG footprint, and life cycle assessment (LCA) evaluation have an effect on reducing climate change impact. Nano-coated paints or paints laden with nanoparticles such as titanium dioxide (TiO_2) or zinc oxide (ZnO) can degrade GHGs in the presence of sunlight or UV light in the atmosphere (Burton 2012; Yunus *et al.* 2012). These concepts have the potential for increasing resiliency and adaptation capacity by reducing GHG emission in the product life cycle.

Energy intensive infrastructures, e.g. hospitals and shopping malls, must be equipped with sensor based water and energy conservation systems, insulated heating networks during winter, well ventilated wind and lighting systems, collection points for recyclable materials and energy extraction facilities so that GHG emissions and the carbon footprint can be reduced.

- Researchers should develop cost effective and practical desalination technologies (i.e. high-intensity solar light induced evaporation and subsequent condensation process) so that coastal countries adapt those technologies for meeting water demand. In this case, a country can not only minimize its groundwater extraction but also abate land subsidence possibilities and aquifer compaction potential, as well as deadly earthquakes. A situation similar to Venice, Italy, may exacerbate the impact of SLR in low-lying countries. Environmental engineers, according to spatial differences, are developing viable technologies by analyzing some reliable and imperative geological, geographical, hydrological, and atmospheric parameters.
- Water treatment and resource recovery processes (RRP) harness renewable energy based technologies such as solar disinfection, solar water pumping, solar- and wind-induced energy systems and photolysis or photo-induced treatment technology as well. Besides, sawdust,

tire crump, scrap cloth, foam scrap and other natural derivatives have likely application as microorganisms' growth media in biological water and wastewater treatment facilities (Hossain *et al.* 2010; Chang *et al.* 2010b) to reduce the carbon footprint in the treatment process. The practice of using natural low-cost organic and inorganic adsorbents and ion-exchanging agents, natural coagulants (i.e. moringa seeds, cassava powder, tannins, tamarind seeds, neem leaf powder and cactus) (Yin 2010; Saleem & Bachmann 2019) and flocculants, and natural and thermostable disinfectants can minimize the GHG footprint in water and wastewater treatment and abate the possibility of disease spread by pathogens.

Again, gravity wastewater collection system and management has momentous prospects for reducing GHG emission. Odor management and sewer corrosion minimization should be quickly and proficiently practiced (Anastasios & Tolkou 2015) as elevated temperature influences both odor and corrosion. Hydrogen sulfide (H_2S), a precursor of acid rain, controlled by hydrogen peroxide (H_2O_2) or iron and caustic products (Equations (1)–(7), Metcalf & Eddy 2013), elevated slope, ventilation enhancement in sewer systems, static in-line mixer to support air stripping, inverted syphon introduction, bio-filter and chemical- or bio-scrubber installation, and reactor coverage help in odor control. Rusting and corrosion may be prevented by epoxy paints, plastic lining, polymer coating, rubber coating, galvanization, electroplating, cathodic polymerization, and different alloys (i.e. titanium, zirconium, zinc, aluminum, silver, copper); as decay of equipment, collection systems and storage facilities may multiply GHG emission in the atmosphere and regulatory authorities will incur extra financial burden. Moreover, bio-solid management and resource recovery such as metals or nutrients by forming struvite (Equation (8), Doyel & Persons 2002), biofuels, biogas, biohydrogen, bio-diesel, bio-polymers (Puyol *et al.* 2017) will be an issue for treatment plant operators as both bio-solids and recovered nutrients can be applied as fertilizer and other beneficial purposes by dwindling the supply of energy and resources, and can minimize the GHG footprint. Treatment processes and operation designers and operators should be alert about solid retention time (SRT), dissolved oxygen (DO) concentration, volume of stabilization pond, aerobic or anaerobic reactor's dimensions, biochemical kinetics, simultaneously introducing mixotrophic (Wang *et al.* 2020) and syntrophic (Kouzuma *et al.* 2015) consortia (Figure 3), sludge production rate and disinfection process efficacy. Sludge produced from treatment processes can be further used as fertilizer, composting and backfill materials (Lu *et al.* 2012) after ensuring there is no presence of pathogens and harmful metals in the recovered sludge since contaminated sludge can leach pollutants in the groundwater.

Different H_2S removal pathways are discussed below.

By H_2O_2:

$$H_2S + H_2O_2 \rightarrow S^0 + 2H_2O, pH < 8.5 \quad (1)$$

By caustic products:

$$H_2S + 2NaOH \rightarrow Na_2S + 2H_2O \quad (2)$$

By sodium hypochlorite (NaOCl):

$$H_2S + 4NaOCl + 2NaOH \rightarrow Na_2SO_4 + 2H_2O + 4NaCl \quad (3)$$

$$H_2S + NaOCl \rightarrow S^0 + NaCl + H_2O \quad (4)$$

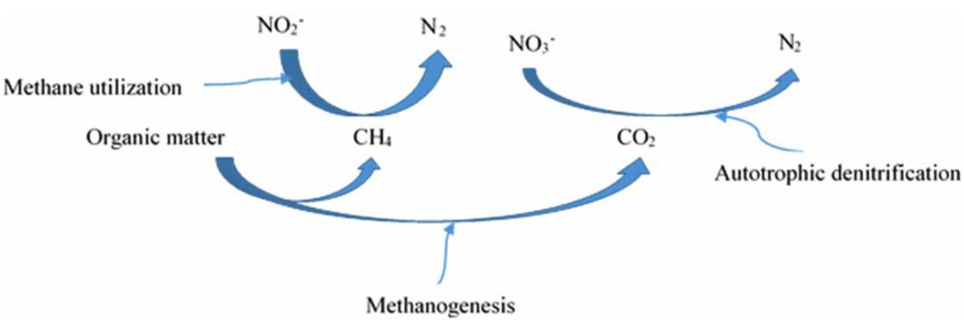


Figure 3 | Mixotrophic and syntrophic consortia for nitrate/nitrite and organic matter removal from wastewater in anaerobic/anoxic environment.

By potassium permanganate ($KMnO_4$):

$$3H_2S + 2KMnO_4 \rightarrow 3S + 2KOH + 2MnO_2 + H_2O, \ \ pH < 7.0 \quad (5)$$

$$3H_2S + 8KMnO_4 \rightarrow 3K_2SO_4 + 2KOH + 8MnO_4 + 2H_2O, \ \ pH > 7.0 \quad (6)$$

By Fe^0:

$$Fe^0 + H_2S \rightarrow FeS + H_2O \quad (7)$$

Resource recovery from nutrient:

$$Mg^{2+} + NH_4^+ + PO_4^{3-} + 6H_2O \rightarrow MgNH_4PO_4.6H_2O \quad (8)$$

Although mixotrophic consortiums, i.e. heterotrophic and autotrophic cultures, in the same reactor can develop an internal carbon cycle, reinforcing autotrophic denitrification in the presence of: elemental sulfur (S^0) and iron (Fe^0); hydrogen gas (H_2); other reduced inorganic sulfur compounds (RISCs), e.g. sulfide (S^{2-}) or H_2S or thiosulfate ($S_2O_3^{2-}$); iron (Fe^{2+}); manganese (Mn^{2+}); arsenite (As^{3+}) as electron donor (Equations (9)–(16), Di Capua *et al.* 2019) has noteworthy impacts on the abatement of CO_2 generation or can be employed as an inorganic carbon source during the treatment process. However, those electron donors should be optimally utilized as excess amounts may not only increase further treatment costs (Di Capua *et al.* 2019) but also trigger substrate inhibition when limited amounts of electron donor can promote a substrate limited process. Moreover, enzyme and co-enzyme/-factor limitations should be carefully monitored so that unintentional emission of NO_x can be avoided from resource recovery facilities. Enzyme responsive materials (ERMs) (Zelzer *et al.* 2013) can play an important role in enzymatic reaction pathways to accelerate the reaction rate and reach the desired end-products in the microbial remediation process. Besides syntrophic consortium can hopefully downgrade the GWP from the resource recovery facility.

Autotrophic denitrification with different electron donors and CO_2 as carbon source:

$$H_2 + 0.355NO_3^- + 0.049CO_2 + 0.355H^+ \rightarrow 0.010C_5H_7O_2N + 0.172N_2 + 1.143H_2O \quad (9)$$

$$Fe^0 + 0.4NO_3^- + 1.2H_2O \rightarrow Fe^{2+} + 0.2N_2 + 2.4OH^- \quad (10)$$

$$S^0 + 0.876NO_3^- + 0.343H_2O + 0.379HCO_3^- + 0.023CO_2 + 0.08NH_4^+ \rightarrow 0.08C_5H_7O_2N + 0.824H^+ + 0.44N_2 + SO_4^{2-} \quad (11)$$

$$Fe^{2+} + 0.2NO_3^- + 2.4H_2O \rightarrow Fe(OH)_3 + 0.1N_2 + 1.8H^+ \quad (12)$$

$$Mn^{2+} + 0.4NO_3^- + 0.8H_2O \rightarrow MnO_2 + 0.2N_2 + 1.6H^+ \quad (13)$$

$$HS^- + 1.23NO_3^- + 0.573H^+ + 0.438HCO^- + 0.027CO_2 + 0.093NH_4^+ \rightarrow 0.093C_5H_7O_2N + 0.866H_2O + 0.614N_2 + SO_4^{2-} \quad (14)$$

$$S_2O_3^{2-} + 1.24NO_3^- + 0.45HCO_3^- + 0.09NH_4^+ + 0.11H_2O \rightarrow 0.09C_5H_7O_2N + 0.4H^+ + 0.62N_2 + 2SO_4^{2-} \quad (15)$$

$$H_2AsO_3 + 0.4NO_3^- + 1.6H^+ \rightarrow HAsO_4^{2-} + 0.2N_2 + 0.2H_2O \quad (16)$$

Significant amounts, i.e. about 1.773 teragrams (Tg) of C/year or 6.5 Tg of CO_2/year and about 0.344 Tg of C/year or 1.26 Tg of CO_2/year (estimated by author), are possible to remove from the atmosphere when H_2 and S^0, respectively, are the electron donor in biological nitrate (NO_3^-) removal if the wastewater discharge is about 2.212 km^3/year and the average NO_3^- concentration is 30 mg/L (WWAP 2017). Other processes, e.g. Anaerobic/Anoxic Ammonium Oxidation (ANAMMOX), Completely Autotrophic Nitrogen removal Over Nitrite (CANON), Stable High rate Ammonia Removal Over Nitrite (SHARON) and Complete Ammonia Oxidizer (COMAMMOX), have validated their prodigious prospects for nitrogen removal as well as abatement or balancing of CO_2 emission from biological wastewater treatment. So the impact of judicious biological wastewater treatment on atmospheric C balancing can be imaginable from the above mentioned amounts.

As long-term extreme precipitation increases the hydraulic loading on a wastewater treatment facility, rainwater and fog harvesting in residential, offices, commercial and institutional buildings may minimize the hydraulic loading for a treatment facility as well as conserve water for non-potable use. Further, a government can curtail its non-potable water demand for a specific time by introducing an alternative like rainwater harvesting.

Climate change affects the water availability for daily consumption as frequent drought, extreme temperature conditions, wind flow, lack of rain, slow precipitation, flooding and water quality have an enormous impact on the water cycle. Moreover, sea surface temperature fluctuation and partial pressure of GHGs in the atmosphere influence the El-Nino/Southern Oscillation (ENSO) phenomena and develop a situation of water abundance in one part of the world and extreme drought in other parts. As water consumption is not a seasonal demand, integrated water resources management (IWRM) such as water allocation, rationing and augmentation on a local, regional and continental basis is the foremost priority for effective management of this precious resource without considering any transboundary barrier while protecting the interest of all countries along the transboundary water. Passive on-site wastewater treatment process (POWTP), point-of-use (POU) water treatment, low impact development (LID) such as natural or constructed wetlands and surface reservoirs, best management practice (BMP) such as permeable pavement or concrete with pollutant sorption capability and bio-swales (Chang *et al.* 2010a), green walls and roofs with urban forest beside water retaining pavement (Charlesworth 2010), green belt around cities and rain gardens (EC 2015), different reclamation and reuse techniques, managed aquifer recharge, water metering to reduce leakage and loss, and domestic and industrial water conservation therefore solve problems related to water availability, quality, quantity and usability.

Geoengineering or climate engineering (Figure 4), an anthropogenic intervention to climate change, can be designed to reduce the solar radiation on earth, although rigorous research is needed to comprehend the full potential of this engineering. Solar radiation management, i.e. marine cloud seeding or brightening by spraying water or seawater to form bigger clouds, can increase cloud reflectivity; space sunshade, a costly and time consuming approach by thin lightweight discs, can be placed into the space so that solar light will be reflected back; injecting sulfate (SO_4^{2-}) particles or aerosols in the stratosphere has an enormous impact on aerosol-cloud formation and eventually increases the reflectivity of

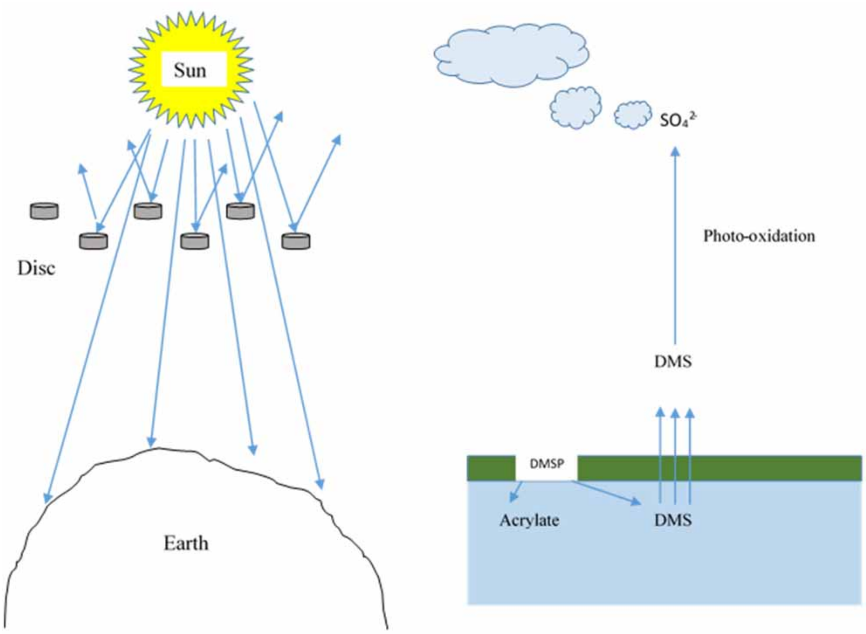


Figure 4 | Different climate engineering approaches.

solar radiation but the possibility of H_2SO_4 formation may not be ignored; white roofing techniques, plants with high reflectivity and preventing ice melting by putting light color blankets on top can contribute to reducing global warming (The Royal Society 2009). Similarly, marine algae degradation in water can release dimethyl sulfoniopropionate (DMSP), which in the presence of DMSP-lyase forms dimethyl sulfide (DMS), a volatile gas. Photo-oxidation of DMS forms SO_4^{2-} and facilitates in enhancing solar reflectivity and global cooling (Vallina & Simo 2007). However, DMS consumers, e.g. phytoplankton or methanogens or chemotrophs in the ocean, can fluctuate DMS flux in the atmosphere (Johnston *et al.* 2012). Solar reflectivity from the ground surface may not be effective in reducing warming as reflected heat will be adsorbed somewhere in the atmosphere.

Industries that are emitting greenhouse gases adapt controlling measures such as selective catalytic and non-catalytic reduction (SCR & SNR), carbon sorption, wet absorption, bio-filter, thermal and catalytic incineration, and limestone scrubbers to reduce source emissions. Simultaneously, increasing reforestation or afforestation by industries can trade off some GHG impacts. In coastal areas, forestation, reforestation and forest preservation are mechanisms to fight against storm surges, soil erosion at the benthic zone, flooding, etc. Tracking of top carbon emitters must be a priority for the government while providing incentives for reducing the carbon footprint in all industries.

Furthermore, food industries should carefully monitor their food processing to minimize food waste that must eventually be disposed of in landfill or composting processes. Aerobic or anaerobic biological degradation of food and other wastes emit CO_2 and CH_4 that should not be flamed in air. A process operator is supposed to collect CH_4 gas to sell in the market and correspondingly CO_2 can be sorbed on different adsorbents, e.g. zeolites and its composites, functionalized porous silica, activated carbon, metal-carbon composites or doped carbon, metal-organic frameworks (MOF), layered double hydroxides (LDH) composites and highly or moderately alkaline solutions (Wickramaratne & Jaroniec 2013; Tavan & Hosseini 2017; Chen *et al.* 2018; Megías-Sayago *et al.* 2019). However, CO_2 can be captured and supplied in electricity generation facilities to counterbalance some of the CO_2 produced during electricity generation. Likewise, electricity generation facilities ought to practice this CO_2 reclamation process for the CO_2 generated in their own facilities.

Every day an astronomical amount of solid waste (SW) is generated all over the world. This waste occupies sizeable land areas and emits noticeable amounts of GHGs when disposal is a prominent issue. SW incineration deteriorates the GHG emission as well. In that case, source reduction, recycle, reuse and remanufacturing (i.e. 4Rs) of waste products can be stylish eco-friendly alternatives for the SWM problem and attenuate GHG emission. For example, installing potable water fountains on streets and in communities will reduce the demand for bottled water as well as the volume of SW.

Biological reclamation of SW is another cost-effective, easy and beneficial management process. Aerobic or anaerobic composting and vermicomposting are rapid decomposition processes for biodegradable SWM and, moreover, compost has been used as soil conditioner, soil nutrient enhancer and carbon replenisher. However, biological transformation of SW has a dilemma: (1) GHG can be produced because of biochemical reactions and (2) produced GHGs can be utilized as an energy source and other industrial chemical productions. Researchers (Coteron & Hayhurst 1993; Tchobanoglous *et al.* 1993; Müller 2001) have perceived the following transformations (Equations (17)–(22)):

GHG generation:

$$\begin{aligned}&\text{Organic matter} + O_2 + \text{Nutrient} + \text{Aerobic bacteria}\\&\quad \rightarrow \text{New cells} + CO_2 + H_2O + NH_3 + SO_4^{2-} + \text{Heat}\\&\qquad + \text{Resistant organic matter}\end{aligned} \tag{17}$$

$$\begin{aligned}&\text{Organic matter} + H_2O + \text{Nutrient}\\&\quad + \text{Anaerobic bacteria}\\&\quad \rightarrow \text{New cells} + CO_2 + CH_4 + NH_3 + H_2S + \text{Heat}\\&\qquad + \text{Resistant organic matter}\end{aligned} \tag{18}$$

GHG mitigation:

$$CH_4 + H_2O \xrightarrow{\text{Ni catalyst at } 700\text{–}1100^{O}\text{C}} CO + 3H_2 \tag{19}$$

$$CO + 2H_2 \xrightarrow{\text{Cu–ZnO–Al}_2\text{O}_3\text{, }250^{\circ}\text{C, 50 atm}} CH_3OH \tag{20}$$

Resource recovery from waste:

$$(C_6H_{10}O_5)_n + H_2O \xrightarrow{\text{acid}} nC_6H_{12}O_6$$

$$C_6H_{12}O_6 \xrightarrow{\textit{Saccharomyces}\text{, Enzyme}} 2CO_2 + 2C_2H_5OH \quad (21)$$

$$2C_6H_{12}O_6 \xrightarrow{\textit{Clostridium}\text{, Enzyme}} 4H_2 + 5CO_2 + C_3H_6O + C_4H_{10}O \quad (22)$$

Carbon sequestration in ocean and terrestrial ecosystems is an alternative for reducing atmospheric CO_2 concentration. However, the movement of tectonic plates and earthquake prone areas should be carefully identified and avoided for carbon storing as CO_2 may return on the surface through ground and underwater fissures. Situations as in Lake Nyos and Lake Monoun aggravate the underground carbon storage condition rather than receive benefits.

Further, the ocean iron fertilization process (Aumont & Bopp 2006) has been studied for a long time to boost phytoplankton growth and ocean fisheries while intensifying the CO_2 sorption capacity by the ocean. However, diatoms' growth, a toxic algae forming domoic acid (Silver *et al.* 2010), may hamper this sequestration process if the desalination process is supported.

Natural gas reserves should be effectively maintained for controlling emission from gas mines.

In the agricultural sector, GCC mitigation is considered as a crucial task. Salt and water tolerant crops, drought tolerant crops, high-yielding crops, crops cultivated by low-flow or drip irrigation, energy crops (i.e. corn, soybeans, sugarcane, canola, palm, jatropha, cotton seed, sunflowers, rapeseed, wheat, switchgrass, sorghum, cassava) (Schmer *et al.* 2008; Valentine *et al.* 2012), aquaculture, hydroponics, floating gardens, environment friendly pest and disease controlling processes, seed banking, crop relocation, soil moisture and nutrient conservation techniques etc., should be introduced. However, biofuels derived from edible crops should be avoided as more edible crops will be cultivated by altering land-use patterns. Agricultural waste burying, rather than burning, appears an economical eco-friendly process of carbon sequestration and significantly reduces GHG emission. Besides, green litter burying or keeping them on the ground is a smart process to replenish soil nutrients and restrict synthesized fertilizer use, a potent N-based gas source. However, burning can also damage the diversity of helpful microbiota in the surrounding soil and regrowth of that microbiota may take some time to return to its original condition.

Likewise, highland agriculture, roof-top cultivation and floating gardens protect farmers' interests against frequent flooding and SLR. Aztec and Inca civilizations practiced highland or terrace farming and shallow river or lake bank farming, known as chinampas, to protect their food security during adverse climatic conditions. Application of biological pest control; trap cropping instead of chemical pesticides and balance among C_3 (i.e. rice, wheat), C_4 (i.e. sugarcane, maize) and crassulacean acid metabolism (CAM, i.e. pineapple) type photosynthesis supporting plants reduces the possibility of further environmental pollution. C_4-type plants, however, have preference because of their higher photosynthesis efficiency (Kajala *et al.* 2011; Wang *et al.* 2012).

As the global population is increasing and industrial activities are also accelerating at the same pace, LU has changed and its climate change impacts have been noticed. LUC includes deforestation, biomass burning during deforestation and filling up water bodies for residential, commercial and agricultural purposes. Average CO_2 emissions for LUC are about 0.5–2.7 giga-tonnes of carbon per year (Gt C/year) which is about 6–39% of the atmospheric CO_2 growth rate (IPCC 2007a). A multistory system for fish, cattle and poultry farming, crop rotation, high-yield crop cultivation, roof top gardening and forest agriculture can abate emission associated LUC.

Wetlands and paddy fields emit a significant quantity of CH_4 due to the plant's own CH_4 production process in the presence of pectin (Wassmann *et al.* 2000) or degradation of plant litter. Wetlands are used to treat wastewater by plain sedimentation, removing nutrient and heavy metals by biological and phytoremediation (i.e. sunflower, willow and many others) processes. Wetlands and paddy fields have been contributing about 110 (Strömberg 1998) and 40–140 teragrams of CH_4 per year (Tg CH_4/year) (Sass *et al.* 1999), respectively. CH_4 emission, as well as GWP of CH_4, can be reduced by lowering the water level in the paddy fields (Li *et al.* 2002), adding soil additives or organic matter, controlling plant litter (Epule *et al.* 2011) and introducing CH_4 utilizing microorganisms (basically bacteria and archaea), i.e. *Pseudomonas methanica* or *Methanomonas methanooxidans* (Equations (23) and (24), Malcom Pirnie 1999). CH_4 oxidation is generally completed in the presence of methane monooxygenase (MMO) enzymes and several other enzymes, i.e. methanol dehydrogenase (MDH), formaldehyde dehydrogenase (FDH) and formate dehydrogenase (FtDH) are liable for the conversion of methanol to CO_2 (Hütsch 2001). In this regard, further research is necessary for the application of this concept in a realistic and safe way.

Abatement of GWP from wetlands:

$$CH_4 + 0.5O_2 \rightarrow CH_3OH \rightarrow HCHO \rightarrow HCOOH \rightarrow CO_2 \quad (23)$$

$$CH_4 + 0.5O_2 \rightarrow CO + 2H_2 \quad (24)$$

Again, microbes influence on rice cultivation and their survival rate in reduced water depth must be evaluated to comprehend the full potential of this notion. By the mid-season, the water drainage system in rice cultivation, productivity of rice and conservation of water can be increased while slashing CH_4 emission from the fields by about 10–80% although NO_x emission may be increased. This drainage increases the soil oxygen content, improves root activity and progressively reduces anaerobic conditions (Epule *et al.* 2011). Again, grass-like nonedible plants are preferable to use in wetlands to support phytoremediation because of the bio-concentration and bioaccumulation of pollutants in roots, stems, leaves and fruits of vegetable and fruit plants.

While the world population has been increasing at an alarming rate and food should be grown in an intelligent way to support that burgeoning demand, hydroponics has been solving both hunger and GHG emission problems. By this process, farmers can increase the yield per unit area and more land area will be freed for other activities. Effective fertilizer utilization, water management and reduced GHG emission are possible, however sufficient food production is also ensured in a closed or open environment.

Improper livestock management has earth-shattering negative consequences on climate change. Ruminants have a tendency to produce CH_4 because of microorganisms breakdown of carbohydrates in their digestive system. CO_2 and N_2O are typically emitted by the production cycle and supply chain management of forage and manure management, respectively. CH_4, N_2O and CO_2 emission from the livestock sector are about 44, 29 and 27%, respectively, which is about 14.7% of all anthropogenic GHG emissions (Gerber *et al.* 2013). In this context, meat consumption should be reduced and changes in human dietary patterns must be made. Moreover, effective manure storage and utilization, optimized fertilizer management, dietary system and composition change, i.e. increased fat and protein content in animals' diets, thermo-tolerant breeds or livestock, e.g. sheep and goats, agro-forestry, double-cropping and crop rotation, feeding time and frequency change, reducing malnutrition and mortality, improving grazing land management by introducing legume inter-seeding and new plant species, improved breeding tactics, changing rumen mechanism, cross-breeding for more meat, milk and egg production, livestock diversification, stable diet for proper growth and healthy reproduction, minimization of farming knowledge gaps, high-yield forage planting and biogas production from manure should be practiced as adaptation and mitigation strategies for this sector (Rojas-Downing *et al.* 2017).

The Government of Bangladesh and other developing countries should allocate more funding to research on renewable or green energy, i.e. solar and wind energy, hydrogen cell, tidal energy, geothermal energy, bio energy, nuclear energy, hydro energy etc., to reduce the pressure on fossil fuel. Approximately 25 and 21% of total greenhouse gases were emitted from electrical/heat generation and the manufacturing industry, respectively, in 2010 (IPCC 2014b). So, carbon footprint reduction is suggested in energy generation and product manufacturing processes by supplementing with renewable energy.

Hydrogen, an indirect GHG, has prodigious potential as an alternative or zero emission fuel to support the transportation and industrial sector. It has been a great challenge to utilize hydrogen in energy generation, as well as efficient separation and extraction of hydrogen from hydrogen containing elements. Steam reforming, thermochemical water splitting, photolysis, electrolysis, partial oxidation (Kalamaras & Efstathiou 2013; Joy *et al.* 2018), and photocatalytic organic degradation are the major technologies for commercial hydrogen production. Therefore, a number of catalysts, i.e. titanium di-oxide (TiO_2) as rutile, anatase and brookite; metal and inorganic doped TiO_2; strontium

(Sr)-neodymium (Nd) based nanocomposite oxides, e.g. $SrNd_2O_6$, $Sr_2Nd_2O_7$, $Sr_5Nd_4O_{15}$; Bismuth (Bi)/lead (Pb)-tungsten (W) based oxides, e.g. $PbWO_4$, $Bi_2W_2O_9$; molybdenum (Mo) and vanadium (V) based oxides e.g. Bi_2GaVO_7, Bi_2YVO_8; indium (In), gallium (Ga), germanium (Ge), tin (Sn) & antimony (Sb) based oxides; cerium (Ce) based oxides, e.g. CeO_2; ZnS; cadmium (Cd)-selenium (Se) composite; Zn^{2+}, Mg^{2+} and beryllium (Be^{2+}) doped GaN with RuO_2; in the presence of UV light and other catalysts, i.e. $SrTiO_3$; platinum (Pt) loaded WO_3; $BaZrO_3$-$BaTaO_2N$ with Fe^{2+}/Fe^{3+}; metal sulfides; GaN:ZnO composites with co-catalyst; quantum dots (QDs); TiO_2 based composites in the presence of solar or visible light, can rapidly and effectively split water for H_2 production where crystallinity, composite dimensions, temperature, pressure, pH, band gap, solution type and light source can affect the H_2 production (Ismail & Bahnemann 2014). High photon flux density (PFD) in specific radiation reactors (Robinson 2013) can accelerate the water splitting rate or H_2 fuel production in the presence of catalysts. Moreover, energy production from hydrogen may solve potable or non-potable water scarcity problems. The following reactions (Equations (25) and (26), Joy *et al.* 2018) are generally observed in hydrogen separation and utilization in cyclic order:

$$2H_2O + hv \xrightarrow{Photocatalyst} 2H_2 + O_2 \tag{25}$$

$$2H_{2\,(g)} + O_{2\,(g)} \rightarrow 2H_2O(g) + \text{Energy} \tag{26}$$

where *hv* is any photon source. It is suggested to use pure oxygen in the energy generation process to increase efficiency; otherwise, application of atmospheric oxygen can produce trivial amounts of NO_x and water vapor, two GHGs. Metal oxides catalyzed water splitting can be explained by Equations (27)–(30) (Joy *et al.* 2018):

$$ZnO(s) + heat \rightarrow Zn(s) + 0.5O_2(g) \quad (\text{At } 1600^\circ C) \tag{27}$$

$$Zn(s) + H_2O(g) + heat \rightarrow ZnO(s) + H_2(g) \quad (\text{At } 700^\circ C) \tag{28}$$

$$MO + heat \rightarrow M + 0.5O_2 \tag{29}$$

$$M + H_2O + heat \rightarrow MO + H_2 \tag{30}$$

where *M* is a metal ion.

Moreover, mitigation of CH_4 and CO_2 is feasible by the Carnol process as shown by Equations (31) and (32) (Steinberg 1995) where production and utilization of H_2 fuel can further facilitate CH_3OH yield for industrial applications. The net benefit gained by this process is extraction of 3 moles of CH_4 from the atmosphere while the net CO_2 emission is zero:

$$3CH_4 \xrightarrow{800^\circ C,\ >1\ atm} 3C + 6H_2 \tag{31}$$

$$2CO_2 + 6H_2 \xrightarrow{260^\circ C,\ 50\ atm} 2CH_3OH + 2H_2O \tag{32}$$

Ammonia, basically a nitrogen based fuel, can be used in internal combustion, diesel and rocket engines to curtail GHG emission. Other nitrogen based fuels are ammonium nitrate (NH_4NO_3), ammonium dinitramide (ADN), aqueous ammonium carbonate ($(NH_4)_2CO_3$), aqueous ammonium acetate ($NH_4CH_3CO_2$), aqueous ammonium carbamate ($NH_4H_2NCO_2$), aqueous ammonium formate (NH_4HCO_2), aqueous urea, aqueous ammonium hydroxide urea (AHU), aqueous ammonium hydroxide ammonium nitrate (AAN) and aqueous urea ammonium nitrate (UAN) and their combustion reactions are shown below in Equations (33)–(36) (Dana *et al.* 2016). The produced nitrogen can be recycled for the production of ammonium again:

$$N_2 + 3H_2O \xrightarrow{450^\circ C,\ 7\ MPa} 2NH_3 + 1.5O_2 \tag{33}$$

$$NH_4OH + 0.22NH_2CONH_2 + 0.3H_2O + 1.09O_2 \rightarrow 0.72N_2 + 3.25H_2O + 0.22CO_2 \tag{34}$$

$$3NH_4NO_3 + 2NH_4OH + 3.9H_2O \rightarrow 4N_2 + 14.9H_2O \tag{35}$$

$$3NH_4NO_3 + NH_2CONH_2 + 5.56H_2O \rightarrow 4N_2 + 13.56H_2O + CO_2 \tag{36}$$

The health sector should be well prepared as the outbreak of water- and air-borne diseases may increase. Rainfall patterns, temperature fluctuations, heat waves, recurrent flooding and storms, uncertainty in climate and weather patterns etc. have intensified the negative impacts on the health sector. While rainfall abstraction develops mosquito breeding sites in warmer weather, heavy rainfall destroys those vector breeding sites or transfers the larva from one place to another. The warmer the temperature, the faster the mosquito and pathogens may finish their life cycle (Deichstetter 2017) and trigger dengue, malaria, chikungunya, yellow fever and Japanese encephalitis outbreaks. So warmer temperatures can not only increase mosquitoes but also increase pathogen concentration in aquatic and aerial environments. Increased atmospheric GHG concentration and ozone layer depletion increases skin cancer, asthma, throat irritation, and respiratory inflammation which may have severe life expectancy impacts.

A shortage of pure and sufficient water, lack of proper sanitation, inadequate execution of water, sanitation and hygiene (WASH) regulations, elevated air and water temperature, above average rainfall, rainfall abstraction due to insufficient and improper drainage systems and flooding have a tremendous impact on disease spreading (Jutla *et al.* 2013). So health officials must create awareness to reduce the impacts on human health. Reducing dependence on vehicles and increasing walking, running or cycling can bestow benefits on respiratory and cardiovascular health while significantly decreasing the GHG emissions by transportation, a major contributor to global warming. Thermo-tolerant medicine and vaccine formulations by pharmaceutical industries mollify the climate change impacts on the health sector. Novel nano-level (Hossain *et al.* 2014) and natural disinfectants must be prudently instituted to annihilate pathogens and superbugs, besides reducing disinfection by-product (DBP) formation and recovering probability of the pathogens.

Although an essential means to support the economic cycle of the world, the transportation sector is one of the foremost contributors to GHG emissions. As a result, scientists have been trying to develop unprecedented types of transport facilities such as hybrid, electric, hydrogen powered, liquid nitrogen powered, solar, and green vehicles with light carbon fiber bodies to downgrade momentum. Travelers also need to buy small cars, practice car pooling, use public transport, organize video conferences, reduce air travel and depend on renewable energy. On the other hand, transportation authorities should design roads and highways to eliminate or reduce traffic congestion by introducing separate bicycle and bus lanes, divide the office time into different time slots (i.e. public offices, educational institutions and banks, and private offices start at 6:00, 8:00 and 10:00AM, respectively) and construct durable and sustainable roads.

Although the manufacturing process of vehicles is not supported by zero carbon emissions, synthetic fuels or carbon neutral fuels or biofuels consumption can reduce GHG emission from these mobile sources. Waste fish fat consumption for generating electricity and running vehicles may be a potential alternative to fossil fuel although the combustion process should be evaluated in terms of CO_2 emission (Daw *et al.* 2009). Preference for fuels (in terms of CO_2 emission) to be used in the combustion process can be shown as:

$$\text{Diesel} < \text{Gasoline} < \text{Propane} < \text{Natural gas} < \text{Biofuel}$$

Moreover, CO_2 fuel production by CO_2 hydrogenation and methanol dehydration for the production of dimethyl ether (DME) (Zeman & Keith 2008) have been gaining attention (Equations (37) and (38)) as alternative fuels and a CO_2 mitigation policy. Both unburned fuels can recover about 10 moles of CO_2 from the atmosphere; both organics have various industrial applications except as fuel, however burning those fuels will impose a net-zero carbon footprint:

$$2CO_2(g) + 6H_2(g) \rightarrow C_2H_6O(g) + 3H_2O \quad (37)$$

$$8CO_2(g) + 25H_2(g) \rightarrow C_8H_{18}(l) + 16H_2O \quad (38)$$

Wild fires, a billion dollar weather disaster in the USA and the world, have been considered as an anthropogenic climate-change impact. Heat waves, drought, elevated temperature and regional weather patterns can increase wild fire frequency (Ross & Lott 2000). Though forests have been deemed as well-known CO_2 sinks, wild fires emit significant amounts of CO_2, CH_4, CO and NO_x into the atmosphere. Carbon emission by wild fires is estimated to be about 4.5–520 teragrams carbon (C) per year (Tg C/year) from a burning area of about 0.22×10^6–11.17×10^6 ha/year (Oris *et al.* 2014) while global forest carbon sink is about 4.05 ± 0.67 petagrams of C/year (Pg C/year) (Pan *et al.* 2011).

Carbon emissions will increase and the carbon deposition rate will decrease in forests if wild fire intensity has an increasing trend. Usually, prescribed fires have been suggested, but it is imprudent to manage a vast ecosystem in this way. Forests have their own way of recovery. Wild fires can be prevented by introducing moisture storing plants, planting fire-resistant or fire-retardant plants, planting plants with large leaf surface areas to support more photosynthesis, evolving small retention or detention ponds inside the forests and following precautionary measures to avoid fires.

Acid rain neutralization by soil and leaf de-escalates climate change shocks without diminishing soil nutrients and fertility. In general, soil mineral composition includes Fe^{++}, Fe^{+++}, Ca^{++}, PO_4^{3-} and many others as bioavailability of these ions has vital importance for plant growth and productivity. Solid crystalized forms of salt may not be bioavailable although acid neutralization by salt formation is a possibility. Acid-base-soil interaction with pH is a significant factor in this deactivation process. Noticeable acid formation, neutralization pathways and recovery mechanisms (Equations (39)–(54)) may be as follows (Wang *et al.* 2002; Dabirian *et al.* 2012; Uzun *et al.* 2016):

Acid formation from GHGs:

$$CO_2(g) + H_2O\ (aq) \leftrightarrow H_2CO_3(aq) \tag{39}$$

$$NO\ (g) + 0.5O_2(g) \rightarrow NO_2(g) \tag{40}$$

$$3NO_2(g) + H_2O \rightarrow 2HNO_3(aq) + NO(g) \tag{41}$$

$$2H_2S + SO_2 \xrightarrow{\text{Catalyst, }250^{o}\text{C}} 3S + 2H_2O \tag{42}$$

$$2S + 2H_2O + 3O_2 \rightarrow 2H_2SO_4 \tag{43}$$

$$SO_2(g) + O_2 \rightarrow SO_3(g) + H_2O \rightarrow H_2SO_4 \tag{44}$$

Acid neutralization pathways:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2 \tag{45}$$

$$CaCO_3 + HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O \tag{46}$$

$$Fe^{++} + H_2SO_4 \rightarrow FeSO_4 + 2H^+ \tag{47}$$

$$Fe^{+++} + H_2SO_4 \rightarrow Fe_2(SO_4)_3 + 2H^+ \tag{48}$$

$$2H^+ + 2e^-(\textit{i.e. from organic carbon}) \leftrightarrow H_2(g)/H_2(aq) \tag{49}$$

$$H_2SO_4(aq) + NH_4^+(aq) \rightarrow (NH_4)_2SO_4(aq) \tag{50}$$

GWP minimization:

$$Mg_2SiO_4 + 2CO_2 \rightarrow 2MgCO_3 + SiO_2 \tag{51}$$

$$Mg_2SiO_4 + CO_2 + 2H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + MgCO_3 \tag{52}$$

$$Pyroxene + CO_2 \rightarrow Dolomite + Quartz \tag{53}$$

$$CaMgSi_2O_6 + CO_2 + H_2O \rightarrow Ca_2Mg_5Si_8O_{22}(OH)_2 + CaCO_3 + SiO_2 \tag{54}$$

Likewise, *Malanthora* leaves have ion exchange capacity with acid rain (Equation (55)) and their ion exchange capacity was increased with increasing acid rain intensity (Johnson & Parnell 1986):

$$K^+X^-_{leaf} + H^+_{rain} \leftrightarrow K^+_{rain} + H^+X^-_{leaf} \tag{55}$$

Sea walls (de Ruig 1998) or tsunami barriers can be constructed around the most vulnerable coastal areas to prevent the effect of SLR or sudden tsunami waves. Movable seawalls are generally favorable for supporting watercraft transport. Vertical and curved seawalls are fabricated to protect public property near coastal areas. Increasing efficiency and effectiveness of delta works, other constructed devices like floating breakwaters, rip-rap structures, dams, slices and levees have a synergistic impact on preventing the coastlines from SLR. Delta works can preclude salt water intrusion and increase internal water management efficiency, albeit treated wastewater discharge into ocean, sediment transport system, saltwater-fresh water ecology and flood management can be hampered by delta works (d'Angremond 2003). During delta work planning, it is imperative to consider changing the ocean dynamic topography, sea water temperature, ecological river restoration, river reconnection (UN Water 2017), buffer strips (EC 2015), wind and wave forces, water density and flowing water mass near the planned area.

Governments should regulate the nutrient-laden water or wastewater discharge in oceans and different water bodies as uncontrolled nutrient discharge accelerates dead zone formation since dead zone formation damages a gigantic natural GHG sink. Farmers are encouraged to use optimum amounts of fertilizer or organic fertilizer without compromising food production.

Volcanic eruptions spew out not only lava and ash but also different types of GHGs. These erupted ashes can reflect the solar radiation to turn the earth into a cold place, increase soil water holding capacity and porosity, enhance soil nutrients and fertility, improve composting efficiency and augment crop yield, although ashes and gases have a tendency to reduce soil enzymatic activity and microbial respiration, accelerate GWP due to emission of GHGs and boost the possibility of acid rain (Basu *et al.* 2009; Symanowicz *et al.* 2018). Moreover, lava increases SLR risk.

Early flood, drought, landslide, cyclone, tornado, tsunami, avalanche, blizzard, earthquake, cold and heat waves, volcanic eruption and limnic eruption warning and disaster response management mitigates climate change disaster (UN Water 2017).

The cement industry has been emitting about 8% of global CO_2, when bio-cement and bio-clogging (Equations (56)–(60), Stabnikov *et al.* 2011; Achal *et al.* 2015) can be an alternative for supporting this burgeoning industry and reducing GHG emission. The game changing strategy is therefore to change the composition of cement clinker (Patel 2013) so that properties of cement can be optimally changed to enhance strength, reduce the GHG footprint and achieve cost effectiveness. Again, in this context, bio-silica, obtained from sawdust, paper mill sludge, rice straw, wheat straw, vetiver grass, corn cob, sugar cane, palm tree and bamboo leaf, is mixed with Portland cement to yield bio-cement (Equation (61), Hosseini *et al.* 2011). Energy efficient windows with low-emissivity glass (E-glass) or photovoltaic glass (PV glass) can be installed in construction projects to indemnify against damage from climate change and reduce cement demand. Again, steel or titanium structures may also diminish concrete demand but two industries, i.e. steel and concrete, will swap the GHG emission footprint and introduce carbon neutral technologies. Therefore, future research should be focused on the GHG footprint from different alternative industries related to the construction industry:

$$(NH_2)_2CO + 3H_2O \xrightarrow{urease+Bacillus\ sp.} 2NH_4^+ + HCO_3^- + OH^- \quad (56)$$

$$CaCl_2 + HCO_3^- + OH^- \xrightarrow{carbonic\ anhydrase+Bacillus\ sp.} CaCO_3 + H_2O + 2Cl^- \quad (57)$$

$$6CaSO_4 + 4H_2O + 6CO_2 \xrightarrow{enzyme+Desulfovibrio} 6CaCO_3 + 4H_2S + 2S + 11O_2 \quad (58)$$

$$CaC_6H_{10}O_6 + 6O_2 \xrightarrow{B.\ cohnii+enzyme} CaCO_3 + 5CO_2 + 5H_2O \quad (59)$$

$$5CO_2 + Ca(OH)_2 \rightarrow 5CaCO_3 + 5H_2O \quad (60)$$

$$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2H_2O \rightarrow CaH_2SiO_4.2H_2O \quad (61)$$

Although a significant number of practical AMs and MPs are discussed for different sectors to diminish antagonistic impacts of climate change and global warming, deceleration or hindrance may be expected due to the following reasons:

1. Resource availability is an important factor to devise innovative mitigation technologies and adaptation processes.
2. Government's low bargaining capability with major GHG emitters can hamper effective application of AMs and MPs.
3. Government's willingness to adapt, encourage, patronize and suggest effective AMs and MPs can influence the efficacy of policy development.
4. Financial status of a government is an important factor.
5. Alternative policy development may change attention towards adaptation and mitigation.
6. Public awareness of resource conservation or recovery and climate change may affect the trade-off for climate change.
7. Knowledge gaps and sluggish technological development may demoralize the adaptation and mitigation policy.
8. Bureaucratic affairs may be a great problem for the implementation of AMs and MPs.

Consequences if suggested AMs and MPs are not adopted

As signs of climate change have emerged, it is an imperative task to carefully adopt resilient and affordable measures and policies without hampering the sustainable growth of the world. Climate change consequences on future generations must be negated, otherwise catastrophic outcomes will be expected. Some outcomes of uncontrolled climate change are mentioned below:

(1) Increasing rate of atmospheric GHG will amplify the global mean temperature, and change in precipitation and storm patterns. If current rates of GHG emission persist, the IPCC has estimated that by 2100, atmospheric CO_2 concentration will be 1,300 ppm and the global mean surface temperature will increase by 4 °C (IPCC 2014b), which will drastically change all economic, social and environmental systems.

(2) Changing climate can negatively change photosynthesis and respiration processes, water availability, metabolism and decomposition mechanisms. Biodiversity distribution will be towards the poles and upward in elevation due to increasing temperature between the Tropic of Cancer and Tropic of Capricorn (Hughes 2000).

(3) About 470–760 million coastal people, estimated by National Aeronautics and Space Administration (NASA), will be inundated through SLR because of the increasing global mean surface temperature by 4 °C. By using the Gravity Recovery and Climate Experiment (GRACE) satellite (later by Jason-3 satellite), the global mean sea level (GMSL) rise is estimated to be about 0.66–0.74 mm/year due to Greenland ice melting and 0.19–0.25 mm/year due to Antarctica ice melting (Nerem *et al.* 2018). In this scenario, the coastal areas of Louisiana, Florida, Massachusetts, New York in the USA, some eastern parts of Mexico, South America, Vietnam, Cambodia, Maldives, Sri Lanka, Kiribati, Tuvalu, southern parts of Bangladesh, and the east coast of Africa, including Madagascar, may be profoundly affected by threats of SLR. Moreover, 17 million people in Bangladesh will be flooded by SLR of 1.5 m (FitzGerald *et al.* 2008). Sea water temperature, ocean acidification, massive biodiversity loss or change and food source change pose an enormous threat to terrestrial and aquatic lives due to elevated temperature and climate change.

(4) Emerging vector-borne pathogens and disease outbreak have been impairing healthcare quality. Medicine and vaccine shelf life will be reduced and the pharmaceutical industry will face frequent problems in product expiration. Discharge of antibiotics, pharmaceutically active chemicals (PhACs), recalcitrant organic elements, endocrine-disrupting chemicals (EDCs), pesticides, dioxins and mutagens in water bodies have deteriorated the situation, and the environmental pollution problem will reach calamitous levels. Water-borne, -washed, -based and -vector diseases have a wide range of possibilities to spread and trigger an epidemic and a pandemic.

(5) About 795 million people, estimated by UN World Food Programme (WFP), have no healthy food for an active life (FAO IFAD & WFP 2015). In this context, a grim scenario can be envisaged if climate change impacts are superimposed on the agricultural and food industries. Water scarcity (i.e. water shortage, water stress and water crisis), changing precipitation pattern, frequent drought and flood, duration of seasons and increasing population will significantly change the food production cycle.

(6) As water and food are not only precious commodities but also rights, world politics will be stressful. Countries will be more interested in consensus rather than war. The fate and transport of water and air pollutants are generally transboundary in nature and very difficult to detect due to the increasing population. Volatile political situations may persist in intestine issues and international affairs of a country.

(7) As climate change has been negatively impacting food production, the health sector, energy generation and environmental issues, economists will always find anomalies in accounting and opportunity cost analysis.

(8) Elevated temperature and climate change will also influence water and wastewater treatment processes from different perspectives: (i) Aeration cost can be increased in an appreciable manner as dissolved oxygen concentration is generally decreased in water with increasing

temperature; (ii) Wastewater collection systems can experience frequent breakdowns due to thermal expansion; (iii) Extreme rainfall increases the volume of storm water. On the other hand, water consumption may increase due to extreme temperature and generate more wastewater than usual. As a result, combined wastewater volume may increase the total treatment cost (Metcalf & Eddy 2013); (iv) SLR has an influence on the hydraulic profile of the wastewater treatment and discharge systems.

Table 2 | Opportunities of blue economy

Opportunities of blue economy
Marine fishing
Aquaculture
Marine biotechnology
Oil and gas exploration
Mining
Renewable energy
Tourism and trade
Transportation
Biodiversity

Opportunities from sustainable blue economy

Again, climate change influences the economic development of a country and industries should change their business culture, all through the manufacturing process, to adapt to climate change. Climate change is influencing not only the industrial economy but also the green and blue economies. As climate change is not a problem for a single country, multilateral efforts are necessary to support boundless trading for global economic growth without sacrificing a country's sovereignty. On this issue, the World Trade Organization (WTO) has daunting challenges to form a legislative committee with the help of other organizations like the United Nations (UN), the World Bank (WB), the Asian Development Bank (ADB), and the Intergovernmental Panel on Climate Change (IPCC) etc. to develop 'win-win' carbon trading policies between top carbon emitters and low carbon emitters. When countries are dealing with climate change and global warming, the blue or ocean economy has the potential to play a significant role in global economy. Besides, the World Bank has estimated that the blue economy can contribute 3–6 trillion USD in the global economy (Patil *et al.* 2018) with a nice interplay among protein and food security, job creation, economic growth and sustainable blue ecosystem, so the blue economy has a noticeable opportunity to support a country like Bangladesh's economy (Table 2).

Some prominent opportunities are:

- Marine fisheries and aquaculture (i.e. pond and integrated) processes contribute enormously to a country's gross domestic product (GDP) by emerging environmentally friendly marine ecosystems and minimizing carbon emission. These may significantly solve problems related to unemployment and deficiency of protein for underprivileged coastal people. Once SLR is inundating new areas, coastal people have more chance to trade off the loss due to GCC. About 145 million tons of fish were utilized globally as food and 56.6 million people were involved in capturing fish and aquaculture products (FAO 2016). It is easy to realize the potential of marine fisheries for supplying a protein source and supporting job creation and, furthermore, mariculture; oyster, lobster and ornamental fish farming; pearls, roes, caviar and fish oil extraction also meaningfully promote excellence in the economy. Year round fish farming is easier in warm water (Brown 2006) and sea water warming due to GCC intensifies the farming prospects. Increasing fishing effort and capacity and deep sea fishing with enhancement and diversification in fishing are considered as better adaptations for fish farming (Daw *et al.* 2009).
- Seaweed, aquatic plants and other aquatic bionetwork development reduce food scarcity and increase food security in coastal areas. Global seaweed demand is about 10–12 million tons/year (Nayer & Bott 2014) while Bangladesh is only producing about 5,000 tons/year (Sarkar *et al.* 2016). Seaweed is a rich source of iodine, iron, calcium, vitamin A, C, K and it has many culinary, medicinal and pharmaceutical applications (Nayer & Bott 2014). However, overexploitation must be carefully avoided so that the marine ecological cycle is sustainable.
- Marine tourism through wildlife observation, sea grass beds of marine flowers, artificial coral and oyster reef

improvement and protection has been encouraged by governments. However, alertness should be created to reduce coastal pollution, for example plastic and organic chemical pollution. Plastic, along with other recyclable materials, should be a catalyst to reduce GHG emission (Chang *et al.* 2012) rather than a source of global pollution.

- Oil and gas exploration develop a new sector for economic development. Still, experienced manpower, precise technological applications and affordable environmental regulations must be employed so that oil spills and gas leakage can be minimized to avoid any offshore ecological and environmental disasters. Appropriately produced water treatment is an essential task to get maximum return from this sector.
- Oceans, which cover two-thirds of the earth, have vast surface areas to extract different ores and minerals like iron, calcium, magnesium, sodium, uranium and many more. Abundance of mineral reserves in oceans is enormous compared to land reserves of minerals (Bardy 2010). It is possible to extract about 4.73×10^{19} kg salts from 1.38×10^{21} kg of seawater while total dissolved solids concentration is 35,000 g/m^3.
- The energy-water-environment nexus has long been pronounced but sustainable balanced interrelation and integration is very challenging to establish in the energy sector. Hydro energy, a long-term goal for the energy sector, has little carbon footprint. Moreover, it is also possible to derive renewable energies such as tidal, wind and ocean energy conversion processes, although catastrophic environmental impacts may jeopardize the benefits received from extracting energy from oceans.
- Oceans, a gigantic store of resources and energy, have realistic and achievable prospects for uninterrupted energy generation. Energy generation from oceans can be a fully zero carbon emission process and it is possible to obtain a potable water supply from the same system (Figures 5 and 6). Floating or permanent structures

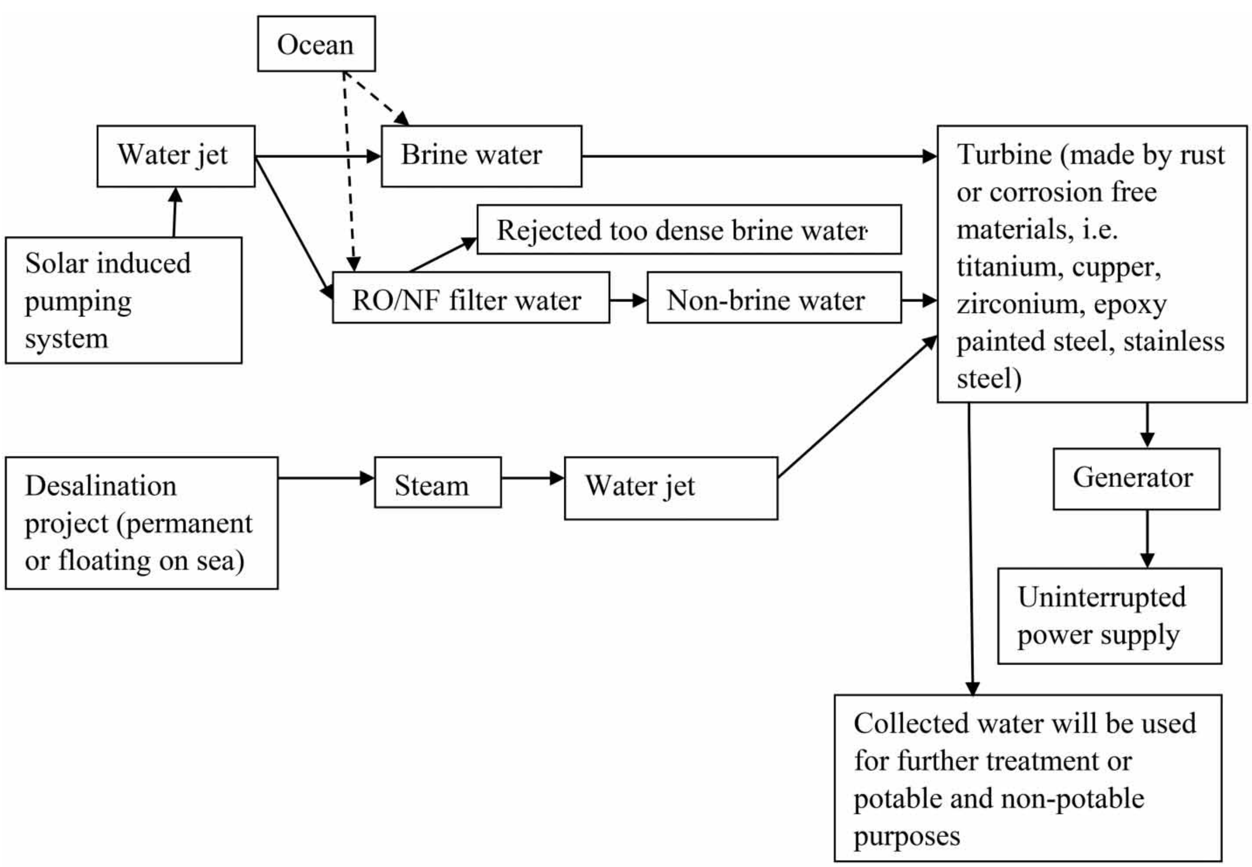


Figure 5 | Power generation from oceans.

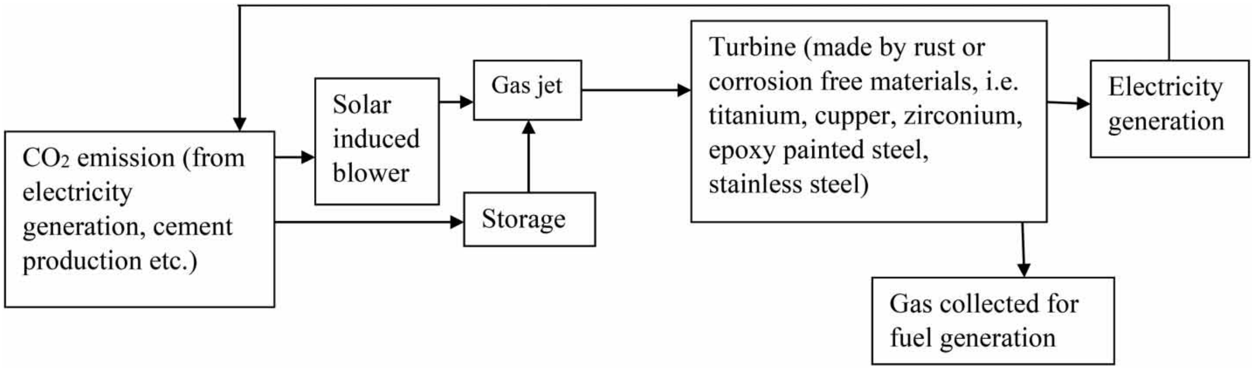


Figure 6 | Reclamation of emitted CO_2.

should support the full process. This type of floating commercial or residential structure will reduce the impact of SLR in coastal areas. However, implementation of the technology may be difficult as tsunamis and submarine earthquakes may trigger intense water waves to derail the whole process.

- Risk and uncertainty analysis can be carried out to understand the potential of blue economy and avoid perilous conditions by prudential judgment in business selection, investment, marketing and revenue generation. Any economic activity faces the risk of recession and depression and the blue economy is also a part of that normal business cycle, nevertheless, capital requirements in this economy are fairly small. Risk is one kind of opportunity for developing a specific business when a country has better bargaining capacity and know-how on managing a resource effectively and efficiently. Possible risks and uncertainty associated with the blue economy are shown in Table 3.

Future research potential

In the above discussion of this report, viable AMs and MPs from all industries were rigorously presented to curtail GHG emissions for balancing already imperiled environment,

Table 3 | Risk and uncertainty associated with blue economy

Political and legal risks	Social and cultural risks	Economics risks	Environmental risks	Technological risks
Conflict between countries	Social awareness	Recession	Underwater earthquake	Manpower
Government types	Social unrest	Depression	Tsunamis	Training and knowledge
Government and foreign rules and regulations	Language and cultural barriers	Marketing policy	Cyclones	Technological change
Contact violation		Government subsidy	Water and air pollution	Technology transfer
		Service	Climate change	Operation and maintenance
		Inflation	Oil spill	Research and development
		Tariffs	Gas leaks	Obsolete technology
		Import or export quota	Flooding	Ignorance
		Government restriction	Disposal	
		Dumping	Safety issues	

capricious economy and inharmonious society. While every corner of the world may be a victim of changing climate, researchers have been tirelessly working for ensuring fresh air, clean potable water, unceasing energy, green building and a staple fortified food supply for supporting the daily needs of the population without compromising on adaptation and mitigation to a changing climate. In this context, future research should target biological treatment and management of resources for effective pollution control, efficacious biogeochemical cycle management, cost effective renewable energy improvement for minimizing GHG in every industry, innovative thermo-tolerant drug and vaccine development to elevate life expectancy and better agricultural yield of crops and fruits for promoting a hunger-free world. Resources like energy, water and air are everywhere, but the main challenges are how to extract those from different sources, how to store them for future utilization and when and where to employ those purified resources in a cost effective manner without exacerbating the climate change and catalyzing a further larger problem.

CONCLUSIONS

Nature has its own way of recovering from the changing climate but anthropogenic invasion exacerbates the natural mending process. Climate change may have a profound impact on an already imperiled environment and humanity. So it is a critical task for humans to seek some measurable, practical and benign mechanisms so that a global average temperature rise below 1.5 °C can be achievable. Adaptable and realistic rules and regulations for the world to mitigate the threats of climate change are essential.

In this study, it is observed that some indicators of the GCC, e.g. SLR, ocean warming, frequent coastal flooding, are related with GHG emission for the following scientific reasoning, and far-reaching emission reduction measures are imperative. As a result, a number of measures and policies are suggested for all sectors to reduce the impacts of climate change but all these propositions need significant effort in terms of economic, social and environmental points of view. Besides, local, regional and national level issues will get priority to adopt any AM and MP as every country may not suffer in the same way. Many industries need to give extra attention to emission control issues. The production of GHG will cost a country's GDP and financial constraints may force a search for feasible alternatives to boost the GDP. There may be other alternatives to raise the GDP of a country but supporting the blue economy is a better solution for poverty-stricken coastal people. Moreover, climate change is not only a problem for one single country but also a threat to the global community. It may be possible to escape the disaster of climate change by the current inhabitors of the Earth but future generations may be the victims of the activities of the current generation. Again, atmospheric CO_2 concentration is considered as the thermostat of the world and careful balancing can ensure a world free from climate disasters.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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