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Governance of Environment and Sustainable Development in Bangladesh

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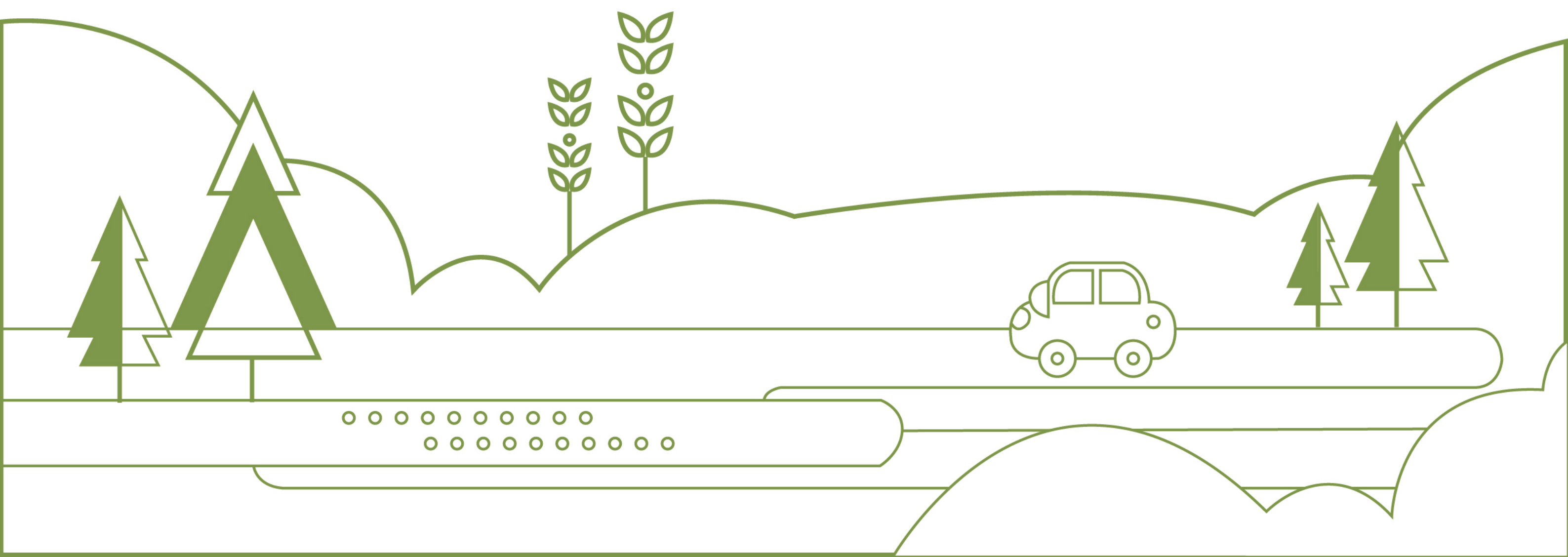

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About the Authors

Li Fengting, born in 1963, is a Professor and Ph.D. supervisor at the College of Environmental Science and Engineering, Tongji University. He is the director of UN Habitat-Tongji-Institute of Climate Change and Environment for Africa, the director of the Key Laboratory of Urban Mitigation and Adaptation to Climate Change in Shanghai (CMACC), China Meteorology Administration. He was elected as a Fellow of African Academy of Sciences in 2020 and a Fellow of the Chemical Industry and Engineering Society of China in 2023.

Prof. Li leads the team that focuses on the study of chemical molecular structure design to materials and is motivated by the goal of resolving engineering issues. They combine product design with the establishment of technical standards, and aim to promote the development and application of new materials in the environmental field, providing the market with effective green solutions. He broadened this field to hyperbranched polymer nano adsorbent functionalized materials, and has achieved outstanding outcomes in the deep treatment of drinking water, the separation and recovery of heavy metals and gases, industrial recycled water treatment, and the deep treatment and reuse of industrial wastewater and clean production of new energy battery materials. Since 2000, he has presided over more than 70 projects funded by the Ministry of Science and Technology, Shanghai Municipality, the United Nations Environment Programme (UNEP), and the United Nations Human Settlements Programme (UN-HABITAT). Prof. Li has also published more than 400 papers domestically and internationally, and has been granted more than 115 invention patents in China and the United States. His achievements have been adopted by more than 60 companies nationwide to produce water treatment chemicals and new energy materials. His research and application of full-chain resource utilization technology and equipment for aluminum dross won the first prize of science and technology of China Circular Economy Association and the gold award of international invention exhibition in Geneva. He has been awarded the United Nations Special Contribution Award for South-South Cooperation once, the first prize for technological invention in Shanghai twice, and the second prize for national teaching achievements twice.

Ying Wang is a Professor and Doctoral Supervisor at the College of Environmental Science and Engineering, Tongji University, where she also serves as the Associate Dean. She concurrently holds the position of Associate Dean at the UNEP-Tongji Institute of Environment for Sustainable Development. Her research focuses on fundamental studies and technological applications in sustainable electrochemical resource recovery aimed at achieving the goals of carbon peaking and carbon neutrality. Her expertise includes interfacial electrochemistry and nanocatalysis, electroanalytical detection of pollutants, design and fabrication of advanced environmental functional materials, development of innovative electrochemical water treatment technologies, and research on environmental pollution remediation.

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Contents

Abstract

Environmental protection has constantly been a critical issue of global concern, particularly in developing countries where rapid economic growth and urbanization have exacerbated environmental challenges. As a developing in Asia country, Bangladesh faces severe environmental issues, with pressing needs in air pollution control, solid waste management and water pollution mitigation. These problems will significantly hinder the country's sustainable development without timely and effective intervention.

Bangladesh faces multifaceted challenges in air pollution, including industrial emissions, pollution from motorized vehicles and an outdated energy infrastructure. For years, excessive concentrations of fine particulate matter ($PM_{2.5}$ and PM_{10}) have plagued major cities such as Dhaka, consistently exceeding international standards and posing severe public health risks. Studies indicate that emissions from vehicles and brick kilns are primary pollution sources, with $PM_{2.5}$ proven to contribute to respiratory and cardiovascular diseases. While research has advanced the analysis of pollution sources, tangible mitigation remains limited and transboundary pollution is increasingly recognized as a critical factor. The country further faces complex water contamination issues, including the contamination in groundwater with natural arsenic at chronically excessive levels severely endangering drinking water safety and public health, industrial wastewater discharge (particularly from textiles and tanneries) and agricultural runoff (especially from fertilizers and pesticides), leading to heavy metal pollution and eutrophication in water bodies. Although the government has implemented water quality management and pollution control policies, weak enforcement has limited their effectiveness. The country’s waste collection and disposal systems also remain underdeveloped, with most urban waste being dumped directly without sorting. Plastic pollution poses an especially severe challenge, as the accumulation of single-use plastic bags and bottles exerts tremendous pressure on the environment. Furthermore, inadequate management of hazardous waste including industrial, medical and chemical waste, further threatens ecosystems

and human health. Despite relevant legal frameworks, insufficient enforcement continues to hinder progress in addressing these solid waste management challenges.

While agriculture and manufacturing drive Bangladesh's economic growth, they exert significant pressure on the environment, particularly from the textile and garment industries. These sectors contribute substantially to greenhouse gas emissions, air and water pollution and soil contamination. Despite existing water pollution laws and regulations, weak enforcement of Bangladesh's pollution prevention initiatives has undermined efforts towards environmental protection, resulting in limited effectiveness of mitigation measures.

This study comprehensively assesses Bangladesh's environmental protection and sustainable development status by examining multiple sustainability-related factors through literature review and field investigations. Focusing on three critical areas—water pollution, air pollution and solid waste management, the research aims to systematically analyze prevailing environmental challenges and propose implementable recommendations for sustainable development.

Bangladesh faces escalating water scarcity and pollution, primarily from industrial effluents, agricultural runoff (pesticides/fertilizers), and urban sewage/seepage. To address this, we recommend: strengthening policy frameworks for water pollution control; optimizing industrial infrastructures to reduce pollution sources; implementing digital water quality monitoring systems; investing in wastewater treatment infrastructure and environmental restoration; enhancing public participation and environmental awareness. Notably, Bangladesh could adapt successful Chinese models like Shanghai's Suzhou Creek rehabilitation project, which has demonstrated effective water quality management and ecosystem recovery through integrated governance and technological solutions.

Bangladesh's severe air pollution stems from multiple sources including brick kilns, transportation, waste incineration and usage of fuel for energy generation at household level, resulting in hazardous concentrations of airborne pollutants that threaten public health. To address this crisis, the government must intensify air pollution prevention and control measures, including reducing emissions from diesel vehicles and non-road machinery while promoting the adoption of electric vehicle. A comprehensive approach should integrate advanced pollution control technologies and transition toward cleaner energy sources to decrease dependence on fossil fuel. International cooperation and technology transfer will be critical to support these efforts. Long-term solutions require enhanced public participation in environmental governance and sustained awareness campaigns to cultivate ecological consciousness among citizens.

Bangladesh's rapid urbanization has led to the current exponential generation of municipal solid waste, hazardous materials, and plastic pollution; a situation which is exacerbated by inadequate

recycling infrastructure and insufficient waste treatment facilities. The nation must prioritize establishing a robust waste management system that emphasizes industrial restructuring, source reduction, and widespread implementation of waste sorting and resource recovery programs. Policy enforcement mechanisms should be strengthened to encourage green lifestyles and multi-stakeholder engagement in waste management initiatives. Valuable lessons can be drawn from Shanghai's "Zero-Waste City", which demonstrates effective management of domestic, construction and industrial waste through circular economy approaches and resource optimization strategies.

In conclusion, Bangladesh urgently needs to strengthen policy formulation and implementation, enhance legal oversight, promote innovation and adoption of green technologies, and foster public participation and environmental awareness. The effective execution of these measures will be instrumental in addressing the country's water and air pollution as well as solid waste management challenges. This comprehensive approach will advance environmental sustainability, improve citizens' quality of life, and ultimately achieve the dual objectives of environmental protection and sustainable development.

Introduction

Bangladesh has long grappled with severe particulate matter ($PM_{2.5}$ and PM_{10}) pollution due to industrial emissions, pollution from motorized vehicles, and an outdated energy infrastructure. This persistent air quality crisis directly threatens the health and livelihoods of millions. As South Asia's most densely populated nation, Bangladesh is undergoing unprecedented urbanization and industrialization, with its capital Dhaka and other major cities experiencing alarmingly high concentrations of particulate in the air that chronically exceed international safety standards (Begum et al., 2005). Academic investigation of Bangladesh's air pollution began in the 1990s, with early studies highlighting how urban expansion degraded air quality through increased suspended particulates (Polissar et al., 1998). Subsequent research identified key pollution sources, particularly emissions from motorized vehicles, industrial discharges, and household combustion, confirming brick kilns and transportation as dominant contributors (Hoque and Clarke, 2013). Health impact studies later established $PM_{2.5}$ as a critical factor in respiratory and cardiovascular diseases (Begum et al., 2013). Over the past decade, satellite remote sensing and ground monitoring have enabled precise pollution assessments. Current findings reveal peak $PM_{2.5}$ and ozone levels during winter/dry seasons, primarily from traffic and industry (Rana and Khan, 2020). Transboundary pollution—particularly industrial and agricultural contaminants from India—has emerged as a compounding factor (Chowdhury et al., 2020), necessitating regional cooperation for improved monitoring and governance (Ahmed and Hossain, 2008). Bangladesh's multifaceted air pollution crisis continues to exert profound public health and socioeconomic impacts. While academic research has advanced pollution source apportionment, health risk quantification, and mitigation strategies, implementation remains inadequate. Future efforts must prioritize three dimensions: Cross-border pollution control mechanisms, large-scale adoption of clean energy alternatives, and strengthened policy enforcement frameworks. Through such integrated approaches, Bangladesh can achieve sustained air quality improvements and mitigate pollution's health burdens.

Water pollution issues have garnered increasing global attention in recent years, with developing countries being the most severely affected. Bangladesh, is located in South Asia; its water pollution problems are particularly complex and severe. The sources of water pollution are extensive, including naturally occurring arsenic in groundwater, untreated wastewater discharges from industries such as textiles and tanning facilities, and chemical pollution resulting from agricultural runoff (He et al., 2005; Sträter et al., 2010). The presence of these pollutants not only threaten the safety of the country's drinking water but also affects farmland irrigation and the integrity of aquatic ecosystems. Notably, the long-term exceedance of arsenic levels in groundwater poses significant health risks, even triggering rare chronic disease crises. This makes water pollution a central issue in Bangladesh's socioeconomic and environmental challenges. Scholars worldwide have explored the causes and impacts of Bangladesh's water pollution problems in recent years from various perspectives, aiming to propose effective solutions. These efforts seek to provide practical recommendations and solutions for the management and pollution control of water resource in Bangladesh. In the early 1990s, studies indicated that Bangladesh was among the countries most affected by arsenic contamination, with levels of arsenic in groundwater far exceeding World Health Organization (WHO) standards. This issue has spurred extensive research on arsenic exposure and health risks, particularly focusing on arsenic-induced skin diseases, cancers, and other illnesses (Flanagan et al., 2012). With Bangladesh's rapid economic growth, large volumes of untreated wastewater have been directly discharged into rivers, contaminating both surface and groundwater resources (Saha and Rahman, 2020). In recent years, researchers have identified the textile and leather industries as the primary sources of heavy metal pollution in Bangladesh's water bodies (Hasan, 2014). Bangladesh's water pollution problem is complex and multifaceted. Although researchers have made progress in identifying pollution sources, assessing health impacts and proposing policy interventions; existing governance measures remain insufficient to address the underlying issues. Meanwhile, the Bangladeshi government has recognized the public health hazards of water pollution and has introduced a series of water quality management and pollution control policies (Islam et al., 2018). However, despite gradual improvements in the policy framework, enforcement has often been inadequate, thereby significantly diminishing the actual effectiveness of water pollution governance. It is evident that while Bangladesh has enacted high-level policies, they have not been effectively implemented, and environmental pollution issues continue to pervade various sectors of the country (Miah et al., 2023).

Globally, approximately 2.01 billion tons of municipal solid waste are generated annually (Kaza et al., 2018), with about 33% not being managed ecologically sustainably (Jerin et al., 2022). Bangladesh has over 522 urban centers that produce thousands of tons of municipal solid waste daily, primarily from households, commercial activities and industrial production (Uddin et al., 2011; Yasin et al., 2013). Nonetheless, the predominant disposal method for municipal solid waste remains uncontrolled dumping in open landfills. This practice poses severe threats not only to the local ecological environment but also to residents' health (Roy et al., 2022). Scholars have conducted extensive research in response to the challenges of solid waste management in Bangladesh. For example, Roy et al. (2022) summarized the current technological status of municipal solid waste management in Bangladesh and explored the potential for waste-to-energy conversion. They proposed that thermal treatment-based waste-to-energy projects could serve as viable alternatives to traditional power generation technologies, contributing to effectively reducing solid waste volumes while concurrently supporting energy supply. Meem et al. (2021) focused on electronic waste management, analyzing its potential impacts on the environment and human health, and emphasized the importance of establishing effective recycling systems. Regarding the composition of solid waste, Alam and Qiao (2020) conducted a detailed analysis of the quantities and components of municipal solid waste in Bangladesh, providing a crucial data foundation for policy formulation. Ananno et al. (2021) addressed sustainable food waste management models, proposing innovative solutions to improve the efficiency and sustainability of waste treatment. Shams et al. (2017) analyzed Bangladesh's waste management policies from the perspective of greenhouse gas reduction, highlighting that policy refinement and enforcement are key to advancing sustainable development.

Although industrial development is a critical component of national economic growth, it concomitantly produces environmental pollution, particularly in Bangladesh. The ready-made garment (RMG) industry is Bangladesh's largest source of export revenue, accounting for 81.82% of the country's total export earnings in 2021-2022 (BBS, 2023). However, the RMG industry and its associated textile sector contribute significantly to environmental pollution, playing a major role in greenhouse gas emissions, air pollution, water pollution, and soil contamination caused by clothing waste in landfills (John and Mishra, 2023). Therefore, while Bangladesh relies heavily on this industry for economic growth, it must consider its environmental impacts and pay greater attention to the sustainability of economic development. Many scholars have investigated the environmental impacts of various industries in Bangladesh. Hoque and Clarke (2013) identified Bangladesh's five most polluting industries. These industries were analyzed for their pollution status and policy implementation. The researchers found that pollution prevention initiatives in Bangladesh are underutilized compared to those in developed countries. Gulfam-E-Jannat et al. (2023) critically analyzed pollution and treatment of effluents from textiles, tanneries, and landfill leachate, revealing that although the Bangladeshi government has established laws and regulations for water pollution, these are poorly enforced. Miah et al. (2023) found that 41.7% of the printing industry in Bangladesh still disposes of textile sludge in open environments.

Meanwhile, Bangladesh's rapid urbanization has led to growing energy demands. The country's current energy mix remains heavily reliant on fossil fuels, the extensive use of which causes severe environmental pollution. In Bangladesh, natural gas has consistently dominated both the final energy consumption infrastructure and the power generation mix. A study by British Petroleum predicts that, given current natural gas production and demand, Bangladesh's natural gas reserves will be depleted within the next 20 years (Mirzoev et al., 2021). Consequently, Bangladesh's current energy planning identifies coal-fired power generation as one of the future key energy supplies. According to Bangladesh's Power System Master Plan (PSMP)-2010, coal is projected to account for over 30% of power generation by 2030 (Roy, 2011; Ruhullah, 2011). Although Bangladesh views coal as a means to augment its power generation capacity due to energy cost considerations, the atmospheric pollutants emanating from coal combustion will have a profoundly deleterious impact on the surrounding environment and pose a significant threat to human health (Franco and Diaz, 2009). Therefore, the development of renewable energy is imperative for Bangladesh's future energy infrastructure. Numerous scholars have investigated Bangladesh's energy transition. Gulagi et al. (2020) analyzed Bangladesh's future energy transition and concluded that focusing on local renewable resources could reduce climate change vulnerability, with renewable sources projected to contribute 94% of power generation by 2050. Katekar et al. (2020) observed that Bangladesh has paid limited attention to renewable energy utilization, despite possessing enormous renewable energy potential that could not only address energy shortages but also substantially reduce fossil fuel import expenditures. Murshed et al. (2021) analyzed the environmental impacts of Bangladesh's energy consumption and other macroeconomic variables from 1975 to 2016, finding that a clean energy transition could effectively mitigate the country's worsening environmental challenges.

Existing research has provided important insights into air pollution, water pollution and solid waste management in Bangladesh, but numerous limitations in existing research persist. Current studies primarily focus on specific environmental issues, such as water pollution or solid waste pollution, lacking a systematic and multi-dimensional comprehensive analysis. With the objective of offering a more thorough examination of Bangladesh's environmentally sustainable development, this study systematically reviews the country's current environmental development status based on literature research and field investigations, covering water resource management, air pollution, solid waste treatment, industrial development and energy structure. It specifically analyzes key issues including the primary sources of water pollution, air pollution, and solid waste; relevant policies and laws implemented in Bangladesh and their shortcomings; the current status and deficiencies in industrial and energy infrastructure. Furthermore, this study incorporates advanced governance experiences from Shanghai, China, in related fields to provide reference for Bangladesh's green development, with the aim of offering valuable insights for policy formulation and environmental governance practices.

1 Brief Introduction to The People's Republic of Bangladesh

Brief Introduction to The People's Republic of Bangladesh

The People's Republic of Bangladesh, situated in the northeastern South Asian subcontinent, encompasses 147,570 km^2 with a population of approximately 170 million. The demographic composition of the country is predominantly of the Bengali ethnic group, and Islam is the state religion. The nation achieved independence in 1972, marking the culmination of its transition from colonial rule. Situated on the alluvial delta of the Ganges and Brahmaputra rivers, Bangladesh is primarily a flatland with a subtropical monsoon climate. Politically, it follows a parliamentary system, while agriculture and garment manufacturing serve as the pillars of its economy, which has shown significant vitality in recent years. The nation maintains an independent, non-aligned foreign policy. Its cultural tapestry integrates diverse elements, featuring multiple UNESCO-listed cultural heritage items, alongside distinctive culinary traditions and indigenous attire.

2 Water Pollution in Bangladesh: Growing Water Scarcity and Multi-Source Discharge Challenges

Water Pollution in Bangladesh: Growing Water Scarcity and Multi-Source Discharge Challenges

2.1 Water Resources Overview

Bangladesh features an extensive river network with 57 transboundary rivers, of which 54 originate from India and 3 from Myanmar. The country has three major rivers: the Ganges, Jamuna, and Meghna. The Ganges originates from the southern foothills of the Himalayas and, after merging with the Jamuna River in Bangladesh, is called the Padma River. The Ganges in Bangladesh encompasses a basin area of 46,000 km^2 and a width of approximately 3 km. The term "Jamuna River" is the appellation to denote the Brahmaputra River (known as the Yarlung Tsangpo in China) within Bangladesh. It has a basin area of 39,000 km^2 and stretches 240 km in Bangladesh. The Meghna River is formed by the confluence of two rivers originating from the eastern hills of India within Bangladesh. It has a basin area of 80,000 km^2 and a length of 902 km.

Bangladesh possesses abundant surface and groundwater resources. However, with rapid population growth and increasing population density, the country's per capita renewable inland freshwater resources have been declining annually. As shown in Figure 1, per capita renewable inland freshwater resources decreased from 1,514.13 m^3 in 1972 to 627.16 m^3 per capita.

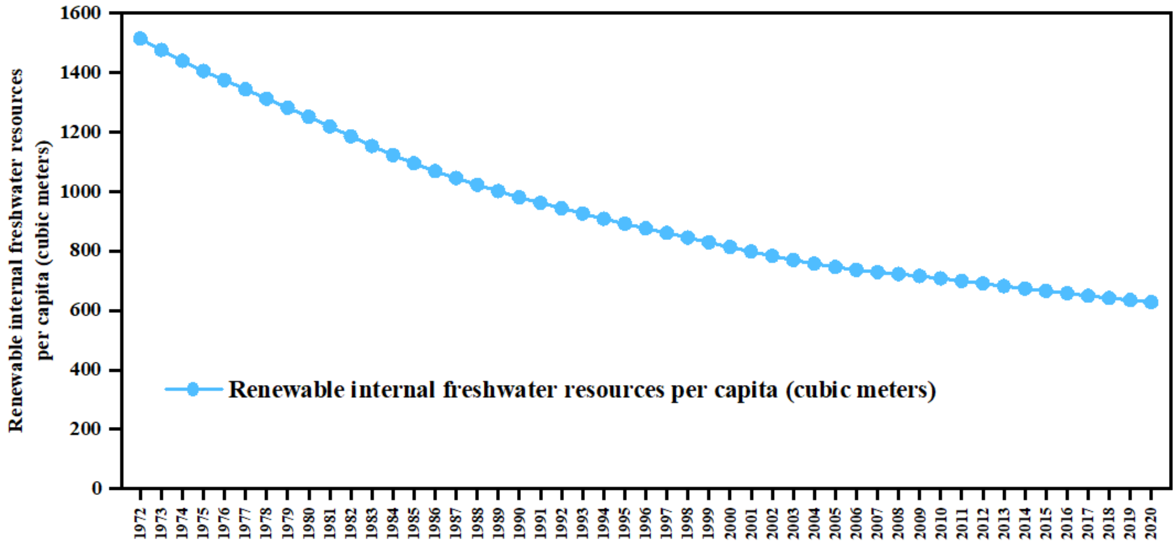

Figure 1. Changes in Bangladesh's Per Capita Renewable Inland Freshwater Resources (1972-2020)

Data source: Collected from the World Bank Open Data, Reference website: https://data.worldbank.org/indicator/ER.H2O.INTR.PC?view=chart

2.2Precipitation Characteristics

Bangladesh has a tropical monsoon climate characterized by high temperatures and substantial annual precipitation. Due to its proximity to the Bay of Bengal, the country is significantly influenced by the southwest monsoon, resulting in exceptionally heavy rainfall during the wet season. Notably, the northeastern Karo-Kasi-Jaintia hill region, known as the "Pole of Rainfall", receives up to 20,447 mm of annual precipitation, exceeding that of 90% of countries worldwide. Table 1 presents the monthly average precipitation and temperature in Bangladesh from 1991 to 2020. The data show a marked increase in rainfall after May, with July recording the highest monthly average precipitation at 492.7 mm. In contrast, December has the lowest monthly average precipitation, at just 5.6 mm. Temperatures in Bangladesh fluctuate between 18.7°C and 28.7°C.

Table 1. Monthly Average Temperature and Precipitation in Bangladesh (1991-2020)

	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Precipitation/mm	10.1	19.9	43.2	120.7	235.8	377.0	492.7	392.3	298.8	186.9	30.0	5.6
Monthly Temperature/℃	18.7	21.4	25.7	28.1	28.6	28.7	28.5	28.6	28.5	27.4	23.9	20.0

Data source: Collected by the auther

2.3 Major Sources of Water Pollution

Water pollution in Bangladesh has become increasingly severe, emerging as a critical environmental challenge that significantly impacts both socioeconomic development and public health. The root causes of water contamination primarily stem from rapid expansion of industrial activities, intensive agricultural practices, uncontrolled urban growth and inadequate environmental governance practices. As these factors continue to accumulate, the water pollution situation in Bangladesh has progressively deteriorated. Water sources are increasingly falling short of the standards required to meet daily living and production demands, resulting in widespread social and ecological consequences.

2.3.1 Industrial Water Pollution

Industrial wastewater discharge constitutes one of the primary sources of water pollution in Bangladesh, particularly in areas with concentrated textile and tannery industries, such as the capital region of Dhaka. These sectors not only serve as vital economic pillars for the country but are also major water resources consumers. The textile industry exhibits particularly huge water consumption, requiring 250-300 liters of water to produce each kilogram of textile products. The tannery industry demonstrates even greater water intensity. Collectively, these two industries impose substantial water demands while generating wastewater with high concentrations of diverse pollutants. Bangladesh hosts approximately 220 tanneries, 2,500 other manufacturing facilities, and 90 large-scale water-intensive enterprises. The vast majority of wastewater from these operations is discharged directly into nearby rivers without adequate treatment, thereby severely contaminating water bodies (Gulfam-E-Jannat et al., 2023).

The manufacturing of textile and tanneries necessitates extensive utilization of chemicals, including dyes, acid-base solutions and various inorganic compounds. In a typical Bangladeshi tannery, the processing of each ton of wet salted hides consumes approximately 40 m^3 of water and utilizes 450 kg of diverse chemicals. The resultant wastewater contains toxic substances such as heavy metals and dyes. Without effective treatment facilities, this contaminated water is discharged directly into rivers, causing severe deterioration of water quality. The wastewater from the textile industry in Bangladesh have a median BOD (biochemical oxygen demand), COD (chemical oxygen demand) and TSS (total suspended solids) levels far exceeding the government's permissible discharge limits (50 mg·L−1 for BOD, 200 mg·L−1 for COD, and 150 mg·L−1 for TSS), reaching 287, 747 and 270 mg·L−1 respectively (Gulfam-E-Jannat et al., 2023).

The Buriganga River has been identified as one of the most severely affected water bodies. Due to extreme pollution, it has been labelled a "dead river" due to its ecosystem's near collapse and biodiversity significant reduction. As tanneries and other industries lack efficient wastewater treatment facilities, toxic substances, including heavy metals such as chromium, nickel and arsenic from untreated wastewater, have infiltrated groundwater sources, posing serious threats to drinking water safety for nearby residents.

In addition, domestic sewage and resource-intensive industries such as fertilizer plants have caused severe river pollution. Dust and wastewater discharged during brick production, have not been properly treated. The indiscriminate industrial wastewater discharge has further deteriorated Bangladesh's water quality conditions.

2.3.2 Agricultural Water Pollution

Agriculture remains a pillar industry in Bangladesh, yet the extensive use of chemical fertilizers and pesticides in farming processes has caused significant water pollution issues. Historically, Bangladeshi farmers relied primarily on river water for irrigation. However, with accelerating industrialization and worsening water pollution, river water quality has progressively deteriorated, with severe sedimentation rendering many waterways unsuitable for irrigation. This has forced farmers to depend increasingly on groundwater, leading to over-extraction, which causes declining water tables and rising concentrations of toxic substances in underground water sources.

Additionally, there are many problems in the management of agricultural water use. Bangladeshi farmers apply large quantities of inorganic fertilizers, pesticides and insecticides annually to boost crop yields and disease resistance. While effective for agricultural productivity, these chemicals are not fully absorbed during application and ultimately flow into surrounding water bodies with irrigation runoff. The nitrogen and phosphorus in fertilizers react with organic matter in water, causing eutrophication. These nutrient overload causes excessive algal blooms (water blooms), severe reduction in water transparency and significant water quality degradation.

In rural areas, the absence of proper waste management systems has led farmers to indiscriminately dump household waste, animal manure, and agricultural waste into rivers or lakes. These pollutants remain in rivers and lakes, further exacerbating water pollution. Concurrently, the presence of harmful substances, including pesticide components in irrigation water results in their percolation into water bodies, making the water highly toxic and causing the degradation of local aquatic ecosystems. In some areas, fish populations have gradually disappeared, and water quality issues have triggered outbreaks of waterborne diseases in rural areas, seriously endangering residents' health.

2.3.3 Urban Water Pollution

With the continuous acceleration of urbanization in Bangladesh, especially in the large city of Dhaka, where the population is dense and a large amount of domestic sewage is generated, the problem of urban water pollution has become increasingly serious. The progression of urbanization, together with rapid population growth have been accompanied by concomitant increase in domestic sewage discharge. However, the construction of sewage treatment facilities in Bangladesh's large cities lags behind, and about 80% of domestic sewage in Dhaka is directly discharged into surrounding rivers without treatment, causing severe water pollution. The lack of effective sewage treatment facilities has led to the entry of a large number of chemical pollutants, including garbage, detergents, grease, pharmaceuticals and personal care products, into rivers through domestic sewage, further exacerbating the degree of water pollution.

In addition to domestic sewage, leachate from urban landfills and illegally dumped solid waste are also important sources of water pollution. With the acceleration of urbanization, solid waste such as garbage and food residues from markets and commercial areas in cities is randomly discharged into rivers, increasing the pollution burden on water bodies. The sewage pipe network in cities is incomplete, and domestic and industrial wastewater in many areas is directly discharged through illegal channels, leading to a significant decline in river water quality. At the same time, Bangladesh's medical waste treatment system also has serious loopholes. There are about 600 hospitals in Bangladesh and a large amount of toxic medical wastewater and liquid waste generated by these hospitals is directly discharged into rivers without treatment, posing a serious threat to water quality and the surrounding ecology. In addition, water transportation in Bangladesh's large cities also exacerbates the problem of water pollution. Hundreds of boats travel back and forth in the rivers around Dhaka every day. Waste, oil, chemicals, etc. from the boats are directly discharged into the water bodies, not only causing water pollution but also posing a fatal threat to aquatic biodiversity. With frequent traffic in the rivers, boat accidents occur from time to time, and leaking toxic liquids and pollutants further aggravate the water pollution situation.

It is worth noting that surface water and groundwater in Bangladesh currently face contamination from high concentrations of iron and arsenic. In addition, over-extraction of groundwater has led to declining water tables, thereby enabling the enrichment of toxic metals, most notably iron and arsenic, in groundwater. Arsenic poses significant health risks with long-term exposure (Smith et al., 2000). Islam et al. (2014) and Ali et al. (2016) reported arsenic concentrations of 5.67 mg/L and 11.6 mg/L in Bangladesh's Buriganga River and Karnaphuli River, respectively. Simultaneously, the highest arsenic concentration in sediments from Bangladesh's Korotoa River reached 52 mg/kg. Arsenic levels are notably high in the Bengal Delta, where approximately 35 million people have consumed arsenic-contaminated water over the past 20-30 years (Bilal et al., 2023). Bangladesh ranks among the countries with the most severe air pollution. Atmospheric deposition of toxic metals onto farmland and surface water has been identified as a significant contributor to contamination, with urban rivers absorbing additional metals annually through atmospheric deposition. Consequently, increasing amounts of water and sediments containing elevated concentrations of toxic substances are accumulating in the lower basins of Bangladesh's southern coastal regions. The combined effect of these pollutants with native contaminants in rivers has resulted in severe river water pollution that currently represents a critical environmental challenge.

2.4 Water Pollution Prevention and Legal Framework

Bangladesh initially established the legislative framework for environmental protection based on the Environment Conservation Act (1995), subsequently regulating the authority and responsibilities of urban water supply, drainage, and sewerage management agencies (WASA) through the Water Supply and Sewerage Authority Act (1996), and further clarifying pollutant discharge standards, environmental impact assessments, and environmental litigation provisions in the Environment Conservation Rules (1997) and the Environment Court Act (2000). The National Water Policy (1999) systematically introduced the principles of Integrated Water Resources Management (IWRM), taking into account drinking water, agricultural, industrial, and ecological water use in a coordinated manner. Subsequently, the National Water Management Plan (2004) refined the National Water Policy in areas such as agricultural irrigation, flood management, and water pollution prevention. The Bangladesh Water Act (2013) established a unified national framework for water resources management and strengthened the government's regulatory and allocation authority over surface water and groundwater. During this process, laws such as the Public Health Engineering Act and the Local Government Act were also implemented in coordination, focusing on drinking water safety, public health infrastructure and local-level water pollution control and water supply and drainage management.

Although specific achievements have been made in urban water pollution control and industrial wastewater treatment, the overall effectiveness of water pollution prevention remains to be strengthened due to insufficient human resources, funding, and technical support for relevant departments, low law enforcement coverage in remote areas, lagging municipal sewage pipe networks and rural water treatment facilities, as well as weak public awareness of monitoring and litigating illegal pollutant discharges.

2.5 China's Advanced Water Treatment Experience - Comprehensive Environmental Improvement of Shanghai's Suzhou Creek/Soochow Creek

2.5.1 Suzhou Creek Water Pollution

Since the 1980s, the water pollution in Suzhou Creek, known as Shanghai's "mother river", had become increasingly severe. Measurements showed that six pollution indicators in the urban section—dissolved oxygen (DO), BOD, COD, non-ionic ammonia, and total phosphorus—all fell below China's Class V surface water standards (the lowest standard). Due to severe dissolved oxygen deficiency, even reaching anaerobic conditions; a perennial black and odorous sewage belt stretching 23 km from the estuary to Huacao had formed. During dry seasons, the black and odorous sewage could extend upstream to near Huangdu, with the black and odorous period lasting over 300 days per year.

On the other hand, the urban section of the river had accumulated approximately 2 to 4 million tons of sediment at its bottom. The secondary pollution caused by this sediment further exacerbated water quality deterioration. Organic matter in the sediment underwent two decomposition processes under bacterial action: aerobic and anaerobic. The former consumes dissolved oxygen in the water, while the latter produces harmful substances such as organic acids, carbon dioxide, methane, ammonia, and sulfides. When sediment overflows from the lower to the upper layers of the water body, degradation occurs, further depleting dissolved oxygen and intensifying the black and odorous conditions. Effectively addressing Suzhou Creek's water pollution had become one of Shanghai's most pressing environmental sustainability challenges.

2.5.2 Comprehensive Water Quality Management of Shanghai's Suzhou Creek Section

The pollution control measures for Shanghai's Suzhou Creek adopted a comprehensive and phased governance strategy, aiming to achieve gradual water quality improvement and ecological restoration through a multi-pronged approach. The remediation work was divided into short-term, medium-term and long-term objectives, reflecting the principles of pollution control as the core, step-by-step implementation and focused priorities.

In the early remediation stage, the focus was on addressing the black and odorous water bodies in Suzhou Creek. To achieve this, the first step was to implement tributary interception projects. The six major tributaries of Suzhou Creek were the main sources of pollutants, and investigations showed that these tributaries discharged large amounts of sewage. Therefore, it was necessary to quickly construct interception pipelines and sewage facilities, especially in areas without urban drainage systems, such as around Hongqiao Airport and certain livestock farming zones, to establish effective interception systems and reduce pollutant discharge. Additionally, clean water diversion measures were employed by utilizing existing ship locks and tidal water diversion systems to increase flow velocity and enhance water exchange, enabling pollutants to flush out rapidly and preventing the worsening of black and odorous conditions. By increasing hydrodynamic forces, sewage accumulation in the river channel was swiftly cleared, restoring water mobility and improving quality. Suzhou Creek's experience was establishing separate systems for industrial wastewater and stormwater, building a comprehensive sewage pipeline network and treatment system, dredging the river channels, and diverting water into urban rivers to ensure water flow. Dhaka's situation is similar to Shanghai's, with relatively low elevation, so appropriate water diversion into urban areas should be implemented.

In the medium-term remediation phase, the emphasis shifted to improving water quality, particularly addressing sediment pollution. The sediment had accumulated large amounts of pollutants, which were a major factor affecting water quality. A combination of water flushing and manual dredging was used to gradually remove contaminated sediment from the river channels. Specifically, clean water was first diverted to dilute pollutants, followed by dredging with excavators, especially at critical black and odorous nodes like Huacao and Huangdu, where sluice gates were constructed to accelerate pollutant flushing through water storage and diversion. Simultaneously, aeration and oxygenation technology were applied to inject oxygen into severely polluted tributaries and slow-flowing sections, increasing dissolved oxygen levels in the water, mitigating the adverse effects of sediment, and enhancing the water's self-purification capacity, thereby improving water quality.

In the long-term remediation objectives, the focus is on restoring the ecological functions of Suzhou Creek. This will be achieved through implementing riverside greening, constructing a "green corridor", restoring biological communities, and enhancing the ecological purification capacity of the water body. Particularly in the central urban section, although the embankments are already made of reinforced concrete structures, which are not conducive to water purification and ecological restoration, the ecological environment can still be improved by increasing greenery and plant coverage. Meanwhile, natural-type revetment technology in suburban and rural sections will be applied, using vegetation-covered revetments to promote groundwater infiltration and water self-purification. In these areas, priority will be given to the application of natural-type revetment technology, gradually forming a 20-meter-wide green belt along the banks through increasing the width of green belts, ultimately establishing a green ecological corridor spanning the entire length of Suzhou Creek.

Overall, the pollution control of Suzhou Creek addresses multiple aspects, including pollution source control, enhanced water quality regulation, sediment treatment, increased dissolved oxygen in water bodies, and ecological environment improvement. These measures are implemented in phases, balancing pollution control with ecological restoration. The ultimate goal is to achieve clear water quality in Suzhou Creek, restore the river's ecological functions, and create a sustainable green ecological environment that provides citizens with a better living environment. At the same time, this will enhance the river's self-purification capacity, ensure long-term water quality improvement, and ultimately realize the governance vision of "flowing water does not stagnate, and fish thrive in the water".

3

Air Pollution: Multi-Source Emissions and Health Threats

Air Pollution: Multi-Source Emissions and Health Threats

The issue of air pollution, particularly the high concentrations of PM2.5, has become an urgent challenge for public health and environmental governance in Bangladesh. According to the 2023 Bangladesh Environmental Analysis by the World Bank, the annual average concentration of PM2.5 generally ranges between 60 and 100 μg/m3 nationwide, while in the capital Dhaka, this annual average concentration approaches 90 to 100 μg/m3, far exceeding the WHO' recommended air quality standard of 10 μg/m3. It has been demonstrated that, particularly during the dry season (November to March), PM2.5 levels can surge to two- or threefold the annual average, significantly exacerbating the threat posed by air pollution. PM2.5 refers to particulate matter with a diameter of 2.5 micrometers or less. Due to their small size, these particles can penetrate the respiratory tract, reach the lungs, and even enter the bloodstream. Long-term exposure to PM2.5 increases the risk of fatal diseases such as heart disease, lung cancer, and stroke, especially among the elderly, children, and immunocompromised individuals. Some studies even suggest that breathing Dhaka's air daily is equivalent to smoking 1.7 cigarettes per day in terms of harmful substance intake. As shown in Figure 2, the annual average PM2.5 exposure remained relatively stable at around 52 μg/m3 from 1990 to 2005. Since 2006, PM2.5 emissions have shown a downward trend but began rising again after 2011, with slight declines in recent years. In 2020, the average exposure was 42.38 μg/m3. During recorded years, 100% of the population was constantly exposed to PM2.5 levels above WHO guidelines.

According to the World Bank report, environmental pollution poses severe health risks in

Bangladesh, with air pollution and household pollution being key contributors to premature deaths and illnesses. Each year, over 160,000 people die from environment-related health issues, with total days lost to illness exceeding 2.5 billion. The aforementioned impacts are especially severe for low-income households, particularly those reliant on solid fuels and experiencing poor indoor air quality. Studies show that 55% of premature deaths in Bangladesh are directly linked to major environmental health risks, with air pollution playing a central role. Thus, air pollution has become one of the most pressing environmental health risks in Bangladesh, urgently requiring effective policy and technological interventions. The sources of air pollution in Bangladesh are complex, and many significant contributors remain under-recognized and poorly managed. Common sources include brick kilns, road traffic, and industrial emissions, which have long been the main contributors to air pollution. However, recent research highlights significant contributions from household activities, power generation, and waste burning—areas lacking sufficient attention and regulation.

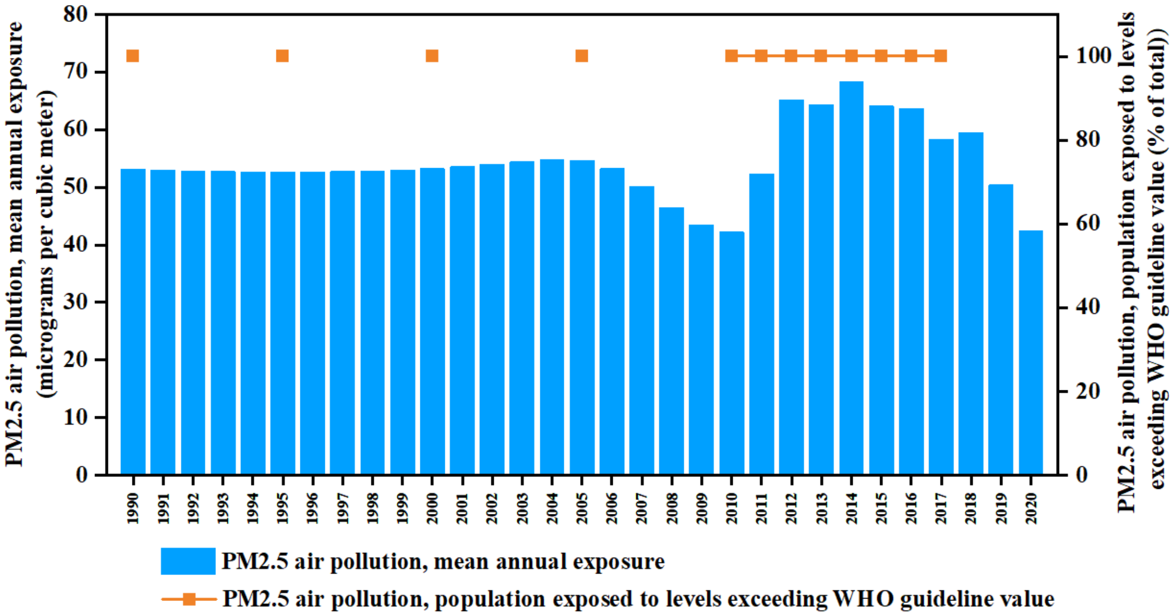

Figure 2 PM2.5 air pollution, average annual exposure, and population exposed to levels exceeding WHO guideline values in Bangladesh from 1990 to 2020

Data source: Collected from the World Bank Open Data, Reference website: https://data.worldbank.org/indicator/EN.ATM.PM25.MC.M3?end=2020&start=1990&view=chart; https://data.worldbank.org/indicator/EN.ATM.PM25.MC.ZS?end=2024&locations=BD&start=2000&view=chart

3.1 Major Sources of Air Pollution

3.1.1 Brick Kilns

Pollutants emitted from brick kilns include PM2.5, sulfur dioxide (SO2), nitrogen oxides (NOx), and other harmful gases. Traditional brick-making techniques commonly use low-grade coal or wood as fuel, releasing large amounts of pollutants during combustion. Kilns are often located in peri-urban or suburban areas where regulatory oversight is often deficient. According to research, emissions from brick kilns have a significant adverse impact on air quality, particularly in peri-urban areas where rural and urban zones converge. In some regions, brick kilns have even become one of the primary sources of PM2.5 pollution. Most brick kilns in Bangladesh rely on solid fuels such as wood, coal, and agricultural residues, which are typically high in sulfur content and particulate matter. During combustion, these fuels release large quantities of harmful gases and fine particulate pollutants. Furthermore, outdated brick-making technologies exacerbate the problem. A considerable number of kilns still operate using traditional open-burning techniques, such as single-chamber kilns, which are characterized by low energy efficiency and high pollution levels. Despite the availability of more advanced kiln technologies, their adoption remains limited due to cost constraints. Consequently, numerous small-scale kilns persist in using archaic and environmentally harmful production methods.

3.1.2 Brick Kilns Transportation Sector

Transportation emissions represent another significant contributing factor to elevated PM2.5 concentrations, particularly in urban areas like Dhaka. Traffic pollution comes mainly from exhaust emissions, traffic congestion and the use of substandard fuel. (1) Exhaust emissions: Outdated vehicles, that fail to meet modern emission standards, make a significant proportion of the vehicle fleet, particularly diesel and imported second-hand vehicles, emitting high levels of particulates, NOx, and CO. (2) Traffic congestion: Dense populations and heavy traffic lead to extended idling times, causing pollutants to accumulate in the air. Cycle rickshaws, a major cause of traffic congestion, remain an important livelihood for many locals and are difficult to replace in the short term. (3) Substandard fuel quality: In Bangladesh, fuels tend to be of lower quality and often contain elevated sulfur levels, leading to the release of substantial pollutants during vehicle operation, particularly from diesel engines.

3.1.3 Waste Incineration

The practice of open burning of waste in major cities such as Dhaka is a contributes significantly to air pollution. It is estimated that approximately 11% of PM2.5 emissions annually originate from the open burning of municipal solid waste. This practice not only leads to a sharp deterioration in air quality as well as increases the environmental costs associated with waste management. Due to the absence of an effective waste collection and recycling system, large volumes of solid waste continue to be discarded and burned, releasing substantial quantities of harmful pollutants. The adverse impact of plastic waste on ambient air quality is particularly severe, often resulting from deliberate or accidental open-air combustion. In Bangladesh, the burning of solid waste is a common method employed to reduce the volume of waste in landfills and urban spaces. However, due to limited public awareness and the lack of waste segregation, plastic materials are frequently incinerated along with other waste streams. Among these, the combustion of plastics made from polyvinyl chloride poses the greatest threat to air quality due to the release of highly toxic substances.

3.1.4 Household Fuel Utilization

About 74.2% of the population in Bangladesh continues to rely on solid fuels such as wood, straw, and dried dung for cooking, thereby causing prevailing severe indoor air pollution. Two-thirds of rural households still use traditional stoves, which emit high levels of pollutants and pose serious health hazards. Despite the efforts made to promote cleaner stoves, a confluence of economic, technical, and cultural barriers have impeded their widespread adoption and utilization.

3.2 Air Pollution Prevention and Relevant Legislation

Bangladesh began addressing high-emission brick kilns as early as 1989 with the enactment of the Brick Manufacturing and Kiln Control Act, targeting emission reduction from kiln combustion. This was followed by the Environmental Protection Act in 1995, establishing the national framework for environmental legislation, including air pollution control. The Environmental Protection Rules of 1997 clarified emission standards and regulatory measures. The Environmental Court Act of 2000 provided legal pathways for handling environmental disputes and strengthening enforcement. In 2013, the Brick Kiln Act was revised to better regulate high-emission kilns and promote cleaner, more efficient brick-making technologies. In recent years, the government has introduced vehicle emission standards and proposed the Clean Air Act to further improve comprehensive air pollution control in urban and industrial areas.

However, enforcement remains weak, high-emission kilns are still common, and emission reduction in sectors like cement and chemicals is insufficient. The Clean Air Act has yet to be fully legislated, and public and media participation in environmental oversight needs improvement. While the legal framework for water and air pollution control has been established, more efforts are needed in enforcement, infrastructure, and public engagement to achieve substantial environmental improvement.

3.3 Air Pollution Control in Shanghai

As one of the fastest-growing cities in China, Shanghai is a vital engine of national development. Its rapid economic expansion has generated significant economic value while concurrently contributing to the emission of substantial levels of pollution. This has resulted in significant strain on atmospheric quality and substantial challenges to environmental sustainability. In December 2013, Shanghai experienced a prolonged air pollution episode lasting nine consecutive days. The unprecedented duration and scale of the event highlighted the inadequacy of conventional response measures. It became evident to all relevant stakeholders that initiating the implementation of emergency warnings and mitigation measures and strategies only after the occurrence of pollution is ineffective. There is an urgent need for proactive strategies, starting with source-oriented pollution control. This event catalyzed a paradigm shift from end-of-pipe treatment to source prevention, emphasizing the importance of identifying and eliminating the root causes of pollution. In response, Shanghai adopted a multidimensional and integrated governance framework, achieving notable environmental improvements and offering valuable lessons for other cities.

Systematic Planning and Targeted Action: Shanghai Clean Air Action Plan (2013–2017): Launched in 2013, the plan covered six key sectors—energy, industry, transportation, construction, agriculture, and social life—with 187 specific measures aimed at resolving critical issues such as fossil fuel dependency, industrial structure, and transportation-related emissions. In 2018, a new phase of the Clean Air Initiative was launched, focusing on the growing problem of ozone pollution. The updated plan intensified controls on power plants, industrial volatile organic compounds (VOCs), and mobile sources, while promoting deeper, citywide remediation efforts.

Innovative Market Mechanisms and Regulatory Instruments: Shanghai introduced pilot programs for pollution discharge fees. In late 2015, the city began a VOC emission fee trial, implementing differentiated fee structures to incentivize emission reductions by enterprises, yielding positive results. Furthermore, Shanghai took the national lead in establishing a pollutant discharge permit system. By issuing permits that specify allowable emission volumes and pollutant types, the city created regulatory clarity while leveraging market mechanisms to encourage proactive pollution control by enterprises.

Cross-Regional Cooperation and Coordination: In 2013, the Yangtze River Delta Region—comprising Shanghai, Jiangsu, Zhejiang, and Anhui—established a collaborative air pollution prevention mechanism. This regional coordination encompasses restrictions on high-emission vehicles, unified emission standards, and joint control initiatives targeting diesel trucks. Additionally, a regional air quality forecasting and warning system was developed to enhance monitoring accuracy and emergency responsiveness.

Strengthened Supervision and Law Enforcement: Shanghai has implemented stringent enforcement and routine inspection program targeting a broad spectrum of pollution sources, including construction dust, industrial emissions, and mobile sources. Regulatory efforts have been particularly focused on construction sites and industrial facilities to ensure effective implementation of pollution control measures.

Data Monitoring and Scientific Support: Shanghai has built a comprehensive air quality monitoring network that includes online emissions monitoring systems, advanced supersites, and standard air quality monitoring stations. This infrastructure not only facilitates real-time supervision but also supports forecasting and early warning systems. Advanced technologies such as source apportionment and mobile monitoring (e.g., vehicular-based sensing) allow Shanghai to trace pollution sources with high precision and implement targeted mitigation strategies.

Government Initiatives and Public Participation: The municipal government has actively promoted the adoption of new energy vehicles (NEVs) and electric motorcycles to combat air pollution and reduce carbon emissions. Through subsidies, tax incentives, and investment in charging infrastructure, the government has encouraged the uptake of electric vehicles by consumers. Shanghai has expanded the deployment of electric buses and taxis in public transportation, accelerating transport electrification. The promotion of electric motorcycles has also helped ease traffic congestion and reduce urban pollution. Furthermore, the city has championed green mobility, encouraging citizens to use public transportation, shared bicycles, and electric vehicles as eco-friendly travel alternatives.

4

Solid Waste: Rapid Urbanization and Weak Recycling Systems

Solid Waste: Rapid Urbanization and Weak Recycling Systems

Bangladesh generates about 25,000 tons of solid waste per day, with cities such as Dhaka handling nearly 6,500 tons per day. Projections indicate that this figure will reach 8,500 tons by the year 2032. Alarmingly, 55% of solid waste in urban areas remains uncollected, contributing to pollution, public health risks and climate change.

4.1 Main Sources of Solid Waste

4.1.1 Municipal Solid Waste

Bangladesh has a population exceeding 160 million, of which approximately 29.4% residing in urban areas. In 2005, the municipal solid waste (MSW) generation rate was 13,332 tons per day, with an average of 0.41 kg per capita per day. Urban expansion and population growth have led to significant increase in waste generation. By 2014, the total urban population had reached 41.94 million, and waste generation had risen to 23,688 tons per day, averaging 0.56 kg per capita per day (Alam & Qiao, 2020). This figure is expected to continue rising with further urban population growth. The primary sources of urban solid waste in Bangladesh include households, industries, hospitals/clinics, fresh markets, shopping malls, restaurants/canteens, and slaughterhouses. Household waste constitutes for nearly 90% of total urban MSW, of which 80–92% comprises of organic waste such as food scraps, fruit peels, vegetable leaves, and post-meal waste. These organic wastes are the dominant component of urban solid waste, and they are typically challenging to manage due to their high propensity for decay and odor generation. Secondary sources include tourist sites, entertainment venues, and institutions, all of which also contribute indirectly to environmental degradation and public health risks.

4.1.2 Hazardous Waste

With the increasing use of chemicals and electronic products, the quantity and variety of hazardous waste in Bangladesh are rising rapidly. Many consumers purchase second-hand or refurbished electronic goods without considering their adverse effects on human health and the environment. Most of these items are ultimately discarded, exposing hazardous substances directly to the surrounding environment. Producers and importers of hazardous waste often lack awareness regarding the dangers posed by open dumping and uncontrolled exposure. Although a regulatory framework was introduced by the Bangladeshi government in 1996, it has failed to effect significant behavioral change. The illegal importation of second-hand goods and toxic chemicals remains prevalent, especially from developed countries. Examples include toxic e-waste and plastic waste from the United States; carcinogenic asbestos from Canada; substandard steel and tin sheets from the EU, Australia, and the United States; toxic waste oils from the UAE, Iran, and Kuwait; and metallic wastes containing cadmium, chromium, cobalt, antimony, hafnium, and thallium from Germany, Denmark, the Netherlands, the UK, Belgium, and Norway (ESDO, 2012).

4.1.3 Plastic Pollution

In 2010, Bangladesh was listed among the top 20 countries with the highest levels of mismanaged plastic waste (Jambeck et al., 2015). Although the overall quantity of plastic waste generated in Bangladesh is lower than that in developed nations, the mismanagement rate is alarmingly high. Much of the country's plastic waste ends up in open dumpsites without proper treatment or disposal. While each municipality is technically responsible for supervising waste collection and management, the majority of plastic waste is collected by the informal sector. Dhaka, the largest city with a population of 10 million, generates the bulk of the country's urban waste, followed by Chattogram (BBS, 2022). Plastic pollution in Bangladesh has long been neglected despite its steady increase alongside urbanization. Dhaka alone generates 6,646 tons of waste daily, of which 10% is plastic.

Only about half of the plastic waste is recycled. Approximately 48% is sent to landfills, while the rest is either dumped into rivers or discarded in drains and other areas under municipal jurisdiction (WB, 2021). Rivers, acting as conduits, transport mismanaged plastic waste from one region to another, playing a significant role in the spread of plastic pollution. The Ganges River is recognized as the second-largest source of oceanic plastic pollution globally (Chowdhury et al., 2020). Its tributaries feed into the Padma and Meghna Rivers, which eventually discharge into the Bay of Bengal. in particular, around 89% of plastic waste in Bangladesh's coastal regions remains improperly managed. The plastic industry has also significantly contributed to the increasing volume of unmanaged plastic waste. Approximately 5,000 plastic manufacturing enterprises operate in Bangladesh, employing around 1.2 million people (BIDA, 2021). These businesses produce vast amounts of plastic products to satisfy both domestic and international markets. Per capita plastic consumption rose from 3 kg in 2005 to 9 kg in 2020. In Dhaka alone, it increased from 9.2 kg to 22.25 kg annually over the same period (WB, 2021).

Another key driver of plastic waste generation is the lack of environmental awareness among Bangladeshi households. Plastics are rarely segregated at the source; instead, all household waste is collected together. While convenient, this practice contaminates recyclable plastics, making it difficult to separate later. Many informal recycling firms focus on collecting PET bottles due to their high market value and ease of cleaning. In contrast, materials like polyethylene packaging, low-density polyethylene (LDPE), and multilayered plastics are often neglected because they are harder to melt and separate and yield lower profits. Moreover, the recycling sector in Bangladesh lacks the necessary technologies to process complex items such as snack and food wrappers. Consequently, a large portion of polyethylene bags, wrappers, and packaging accumulate in landfills.

Waterborne plastic pollution is widespread in Bangladesh, particularly in coastal areas. Tourists frequently leave single-use plastic items on beaches, which are carried to the sea. Additionally, rainfall often washes landfill plastic waste into nearby canals and waterways, clogging drainage systems and intensifying urban flooding.

4.2 Legislation on Solid Waste Management

In accordance with the Environmental Conservation Act of 1995, Bangladesh imposed a ban on plastic shopping bags in 2002. However, the absence of viable alternatives and inadequate enforcement by regulatory authorities has rendered the ban largely ineffective. In 2020, the High Court of Bangladesh issued a directive mandating the strict nationwide enforcement of the plastic bag ban. This includes routine market inspections, closure of polyethylene bag manufacturing facilities, and the confiscation of related equipment. The Court further prohibited using, selling, and promoting plastic shopping bags and other single-use plastic products, such as straws, cotton swabs, cutlery, bottles, food containers, and plastic plates, in coastal hotels and restaurants. In 2010, the National 3R (Reduce, Reuse, Recycle) Strategy for Waste Management was revised, to regulate waste streams and reduce open dumping in fields, waterways, and floodplains by 2015.

However, due to weak enforcement mechanisms and insufficient institutional infrastructure, waste segregation at the household level remains almost nonexistent. This has made recycling highly challenging for waste collectors. Besides the plastic bag ban and the 3R strategy, the government of Bangladesh has undertaken several other initiatives to improve plastic and solid waste management. Nonetheless, existing regulations remain inadequate or unenforced. For example, while polyethylene bags are banned, there are no restrictions on the sources of plastic bags or the technologies used in their manufacture. Furthermore, despite growing recognition of the importance of a circular economy, the 3R strategy lacks a designated action plan to address challenges across all stages of the plastic value chain.

4.3 Shanghai's "Zero-Waste City" Initiative

As one of China's largest metropolises, Shanghai not only leads the nation in economic and cultural development but also faces increasingly severe challenges in solid waste management. Rapid urban population growth and evolving consumption patterns have led to a significant surge in waste generation, posing obstacles to the city's sustainable development. The major waste streams in Shanghai include household waste, construction waste, general industrial waste, hazardous medical waste, and agricultural waste. In 2024, Shanghai enacted the "Shanghai Zero-Waste City Construction Regulation", the first local legislation in China dedicated to building a "zero-waste city." This initiative signifies the city's strong commitment to waste reduction, classification, and resource recovery across various waste categories.

4.3.1 Domestic Waste

Shanghai's domestic waste is classified and managed according to the principle of "macro-segregation and micro-classification". The macro-segregation includes bulky waste (excluding household appliances such as refrigerators and televisions), aquatic waste, and construction waste (although not categorized as municipal waste, it is typically addressed within the same framework). The micro-classification consists of four primary categories: residual waste, household food waste, recyclables, and hazardous waste. Adhering to the principle of zero landfill for raw municipal waste, Shanghai has actively promoted the construction of waste incineration facilities, expanded the utilization pathways for household food waste, and explored source reduction strategies. The city is also working to establish an integrated collection and recycling network to address the current bottlenecks in resource recovery and the slow progress in waste reduction. All residual waste is incinerated, with improvements made to the incineration processes to accommodate the full implementation of waste classification. For household food waste, efforts include enhancing dehydration capacity at various stages, promoting co-treatment in agricultural organic fertilizer facilities, upgrading small-scale on-site treatment systems to meet regulatory standards, increasing centralized anaerobic digestion capacity, and researching the application of resource-based products and byproducts. In terms of policy, the city is advancing research on source reduction management mechanisms and progressively implementing reduction requirements. Sanitation infrastructure is planned based on the characteristics of different treatment approaches and administrative models, in alignment with the current spatial layout of waste management facilities.

4.3.2 Construction Waste

Construction waste in Shanghai is classified into five main categories based on its source and characteristics: construction spoil, slurry, general construction waste, demolition waste, and renovation waste. Construction spoil is disposed of at designated sites, which are strategically located in green areas, ecological buffer zones, and designated enclosed spaces. Slurry undergoes pretreatment before being sent to disposal facilities. Waste generated from renovation and demolition projects is sorted and then sent to disposal or recycling facilities, with disposal sites evenly distributed across the east, south, west, and north of the city to minimize transportation distance. Discarded concrete is directed to recycling facilities.

The primary methods for disposing of construction waste in Shanghai include land leveling in low-lying areas, backfilling for engineering projects, landscaping, temporary road surfacing, and the production of recycled aggregates and bricks. A significant portion of construction spoil is used directly for backfilling. Slurry is primarily utilized for land reclamation and agricultural restoration in low-lying areas. Discarded concrete is recycled into high-quality aggregates for use in engineering projects, with a near-100% recycling rate.

4.3.3 General Industrial Waste

Shanghai manages general industrial waste under the principle of “comprehensive coverage, tiered classification, and traceable destination”. Enterprises generating waste are required to report the entire waste generation, storage, collection, utilization, and disposal process, thereby achieving a closed-loop management system from source to terminal.

Regarding resource recovery, smelting slag is developed into mineral powder series, steel slag granules, hydraulic admixtures, and recycled concrete aggregates. Fly ash primarily produces wall materials, cement, concrete, pre-mixed mortar, and municipal engineering materials. Furnace slag is mainly used in wall materials, while desulfurization gypsum is utilized in manufacturing gypsum boards, decorative building materials, and insulation materials. Industrial boilers, self-owned incinerators, or licensed hazardous waste incineration enterprises are utilized for waste incineration. Industrial waste is landfilled through methods such as sea reclamation, lowland backfilling, or disposal in municipal landfill sites.

4.3.4 Hazardous and Medical Waste

Shanghai has established a closed-loop management system for hazardous waste by enhancing regulatory compliance across planning, registration, transfer documentation, and operational licensing. The management framework covers the generation, collection, storage, transfer, utilization, and disposal of hazardous waste, with a tiered strategy that prioritizes resource utilization, followed by incineration and, landfill as a contingency option.

Medical waste collection and disposal are fully covered by a "bus-style" logistics system operated by designated solid waste treatment companies. Waste is collected at the department level within medical institutions and temporarily stored in on-site designated areas until picked up by waste treatment personnel. This system follows a "four fixed" protocol—fixed personnel, vehicle, route, and time—managed through an integrated logistics information system. Shanghai's medical waste disposal capacity currently exceeds 400 tons per day.

4.3.5 Agricultural Waste

Resource utilization in the agricultural waste sector in Shanghai is relatively high, with "zero landfill" already achieved. Waste pesticide packaging and agricultural film are almost entirely recovered and disposed of, while animal manure and crop straw from grain and oil production are fully utilized as resources.

5 Environmental Pollution: An Inevitable Consequence of Urban Development

Environmental Pollution: An Inevitable Consequence of Urban Development

The current status of water, air, and solid waste pollution in Bangladesh is closely linked to the country's rapid urbanization and industrialization. Accelerated urban expansion, particularly in major cities such as Dhaka with extremely high population densities, has exacerbated problems related to household waste, wastewater, and air pollution. Emissions from motorized vehicles, construction dust, and open waste burning collectively contribute to deteriorating air quality. Simultaneously, inadequate infrastructure and lagging environmental management capabilities further compound the severity of pollution. The rapid growth of industrial activity, without robust environmental regulations and infrastructure, has led to inadequate control over pollutant discharges. For example, industrial wastewater treatment rates remain low, with large volumes of untreated effluent discharged into rivers and streams, damaging water resources and ecological systems. This section summarizes the interlinkage between urban development and environmental degradation in Bangladesh. The following sections will further analyze the country's industrial and energy structure.

5.1 Impact of Urbanization and Industrialization on Bangladesh's Environment

While industrialization has significantly contributed to urban economic growth, Bangladesh's industrial landscape remains dominated by highly polluting sectors. Labor-intensive and resource-intensive industries—such as textiles, footwear, pharmaceuticals, and food processing—form the core of the economy. These industries not only consume large quantities of freshwater but also involve extensive use of chemicals and generate substantial waste and pollutants emissions.

Additionally, the country lacks a substantial green economy, with limited development in high value-added or environmentally friendly industries. Bangladesh lags in high-tech manufacturing and renewable energy sectors compared to developed economies. Furthermore, resource utilization efficiency in Bangladesh remains low. Many traditional industries still follow outdated and inefficient production methods that result in excessive energy consumption and poor resource efficiency.

5.2 Energy Sector's Environmental Impact in Bangladesh

Bangladesh's energy mix is still heavily reliant on fossil fuels, particularly natural gas, with minimal contribution from renewable sources. This high-carbon energy structure is a major contributor to greenhouse gas emissions and air pollution. The country's reliance on coal-fired power generation and industrial boilers results in the release of significant amounts of SO2, NOx, and PM2.5, particularly in industrial and urban areas. Transitioning to cleaner energy, such as solar and wind, would significantly reduce emissions from the power sector, improve air quality, and lower carbon footprints. Moreover, renewable energy technologies require less cooling water compared to conventional thermal plants, reducing pressure on water resources. From an energy consumption perspective, the industrial (e.g., textiles, pharmaceuticals, food processing) and transport sectors (notably fossil fuel-powered vehicles) are the largest energy consumers. Using of outdated equipment and inefficient industrial processes further exacerbates energy waste and environmental degradation.

6 Industrial Structure: Lack of Diversification

Industrial Structure: Lack of Diversification

6.1 Heavy Reliance on the Textile Industry

Bangladesh's industrial structure remains relatively under-diversified, with its economy still overly reliant on traditional agriculture and the textile and garment industries. Although there has been some growth in the industrial and service sectors in recent years, the overall structure still lacks diversity, and the proportion of high-value-added industries remains low. Firstly, the country is heavily dependent on agriculture. While agriculture's share of GDP has gradually declined, it continues to play a vital role in employment and livelihood security in rural areas. Agricultural production mainly focused on rice, jute, and sugarcane crops. Although there is some degree of diversity, the sector lacks modernization and technology-driven transformation. The textile and garment industry holds a dominant position, accounting for over 80% of the country's total exports. Ready-made garments, including men's, women's, children's clothing, and home textiles, are particularly competitive in global markets, especially in Europe and North America. While this sector has contributed significantly to rapid economic growth, it mainly relies on low-cost labor and low value-added production, lacking high technological content and innovation. Other industrial sectors in Bangladesh remain relatively weak. Although some manufacturing sectors, such as food processing, do exist, they are generally small in scale, with limited technological capabilities and a lack of competitiveness. As a result, Bangladesh occupies a relatively marginal position in the global industrial value chain. Constrained by underdeveloped infrastructure, limited technological innovation, and capital shortages, the country struggles to make breakthroughs in high-value-added and technology-intensive industries.

Moreover, the lack of industrial diversification renders the Bangladeshi economy highly vulnerable to external market fluctuations and industry cycles. For example, volatility in global demand for textiles can directly affect the country's export revenues and employment levels. Despite its strong position in global textile markets, Bangladesh faces growing competition from other low-cost producers such as Vietnam, India, and Cambodia. The low value-added and labor-intensive characteristics of the industry also result in high resource consumption and serious environmental pollution, with slow progress in industrial upgrading and technological advancement.

6.2 Severe Environmental Pollution from the Textile Sector

The textile and leather industries are key pillars of the Bangladeshi economy but are also major contributors to environmental degradation, particularly in terms of water consumption and wastewater discharge. Most textile factories in the country lack adequate wastewater treatment facilities, leading to serious water pollution and placing immense pressure on local water resources and ecosystems.

Bangladesh currently has approximately 220 tanneries, 2,500 other manufacturing plants, and 90 large-scale enterprises with high water demands. The textile sector in particular consumes vast amounts of water. It is estimated that each factory uses between 250 to 300 liters of water to produce just one kilogram of textile products. This water-intensive production model results in significant water waste and pollution. The manufacturing process involves extensive use of dyes, inorganic chemicals, and other additives, which not only raise production costs but also generate large volumes of hazardous wastewater. In the leather industry, for instance, a typical tannery uses about 40 cubic meters of water and 450 kilograms of chemicals to process one ton of wet-salted hides. Most of the water used cannot be recycled, and approximately 90% becomes wastewater. This wastewater contains a high concentration of pollutants, including untreated dyes, heavy metals, and industrial chemicals, posing severe threats to aquatic environments. Alarmingly, the water demand of the textile and leather sectors is equivalent to the annual water usage of 60 million Bangladeshi people. As the country continues to industrialize and its population grows, the sustainable use of water resources is becoming increasingly critical.

In addition to water consumption, the textile industry also consumes a substantial amount of energy, particularly thermal energy and electricity for dyeing, drying, and steam treatment processes. These energy requirements lead to significant carbon emissions, exacerbating the issue of greenhouse gas emissions and contributing to climate change.

6.3 Shanghai's Pathway to Industrial Diversification

6.3.1 Promoting High-Tech Industries and Innovation-Driven Development

Shanghai has successfully attracted numerous high-tech enterprises and innovative talent by increasing investment in technological innovation, particularly in fields such as artificial intelligence, biomedicine, new energy, and semiconductors. The city has made significant efforts in establishing free trade zones, technology incubators, and support policies for innovative enterprises. Furthermore, Shanghai has established many national-level research institutions and innovation platforms, such as the Zhangjiang High-Tech Park, providing strong technological research and development support.

6.3.2 Developing Modern Service Industries with Cluster Development and Regional Coordination

As China's financial hub and a center for advanced manufacturing, Shanghai has promoted industrial diversification by deepening economic reforms and building a multi-tiered capital market system that includes stocks, bonds, and futures. The Shanghai Stock Exchange and the STAR Market offer robust financing channels for innovative enterprises, boosting the real economy. Shanghai also promotes collaboration between modern services and advanced manufacturing by leveraging its national finance, shipping, and trade centers. It has fostered clusters in finance, logistics, information technology, high-end equipment, new energy vehicles, biomedicine, and AI. For example, Pudong New Area has become a finance, technology, and manufacturing hub, producing strong complementary effects and innovation synergies.

6.3.3 Enhancing Infrastructure Construction and Modernization

Shanghai's infrastructure ranks among the most advanced globally, encompassing ports, airports, expressways, and modern utilities such as information communication technology and energy supply systems. The Port of Shanghai, one of the world's busiest, has led in container throughput for years. Recent upgrades include deep-water channels, automated terminals, and smart port technologies to improve operational efficiency and environmental sustainability. Shanghai's airports also rank among the top globally in-flight frequency and cargo handling capacity.

6.3.4 Sustainable Development and Green Economy

Shanghai integrates industrial growth with environmental protection and sustainable development. For instance, the city has proposed a "green development" model, developing new energy and energy-saving industries while promoting the green transformation of traditional sectors. Notable achievements include large-scale solar and wind power applications, initiatives such as building-integrated photovoltaics, and offshore wind projects. The city also invests in smart grids and distributed energy systems to enhance energy diversity and sustainability. In green transportation, Shanghai has promoted electric vehicles, buses, and taxis through supportive policies and infrastructure, including a widespread charging network. It also supports hydrogen fuel cell pilot projects and intelligent transportation systems to boost efficiency and reduce emissions.

6.3.5 Strengthening Talent Cultivation and Recruitment

Shanghai places great importance on education and talent development, particularly in higher education and vocational training. The city has partnered with top international universities to establish world-class academic and research institutions, attracting top-tier global talent. It also promotes vocational education reform to supply skilled technical workers and high-level professionals for industrial growth.

6.3.6 Optimizing Business Environment

As China's gateway to the world, Shanghai promotes trade liberalization and foreign investment by implementing free trade zones and bonded areas. The city has attracted major foreign companies, including Tesla and other new energy enterprises, which have generated employment, boosted the economy, and showcased its open business environment. Furthermore, Shanghai has become a critical node in global supply chains through active integration with the global economy.

7 Current Status and Structure of Energy Consumption

Current Status and Structure of Energy Consumption

7.1 Energy Consumption Patterns and Structure

Bangladesh's total final energy consumption generally shows an upward trend between 2000 and 2022, with particularly high growth after 2010. However, there is a brief decline in energy consumption in 2020 due to global events (e.g., the COVID-19 pandemic), followed by a resumption of growth.

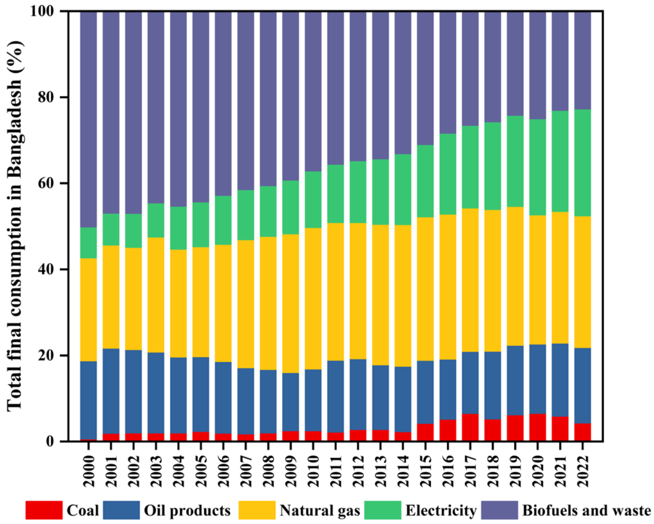

Figure 3 Share of final energy consumption in Bangladesh, 2000-2022

Data source: Collected from the International Energy Agency, Reference website: https://www.iea.org/countries/bangladesh/energy-mix

Among the changes in the consumption of various types of energy sources, (1) Natural gas has always been the major energy consumed in Bangladesh, with its consumption growing from 149,579

TJ in 2000 to 425,445 TJ in 2022, an increase of nearly 2.8 times. Its share was about 42.9 per cent in 2000 and remains around 40 per cent in 2022, indicating that the dominance of natural gas in the energy mix has not changed significantly; (2) Biomass and waste, on the other hand, have always been an important source of energy, and although consumption continued to grow between 2000 and 2014, it gradually declined after peaking in 2014 (349,459 TJ) to 315,807 TJ in 2022. Its share decreased from 44.8 per cent in 2000 to about 29.6 per cent in 2022, suggesting that Bangladesh is gradually reducing its dependence on traditional biomass energy sources; (3) Electricity consumption grows significantly, from 44,884 TJ in 2000 to 345,826 TJ in 2022, an increase of about 6.7 times. Its share increases from 12.9% (2000) to 32.4% (2022), reflecting the increasing electrification in Bangladesh; (4) While the consumption of petroleum products grows overall, from 113,660 TJ in 2000 to 243,907 TJ in 2022, an increase of about 2.1 times. Its share was 32.1 per cent in 2000 and was about 22.8 per cent in 2022, indicating that although the consumption of petroleum products has increased, its share in the energy mix has relatively decreased; (5) Coal consumption was low in 2000 (3,620 TJ) but reached 59,731 TJ in 2022, an increase of more than 16 times. However, its share in total energy consumption remains low, increasing from 1.1 per cent in 2000 to about 5.6 per cent in 2022, indicating that coal use has increased but is still not a major energy source.

7.2 Power Generation Structure

From 2000 to 2022, Bangladesh's total power generation has grown significantly, especially with the increasing contribution of natural gas and renewable energy sources (e.g., hydropower, wind, solar). While in 2000, Bangladesh's total power generation was largely dependent on natural gas (13,984 GWh) and hydropower (767 GWh), by 2022, the total power generation had risen significantly, and the mix of power supply had undergone a significant change.

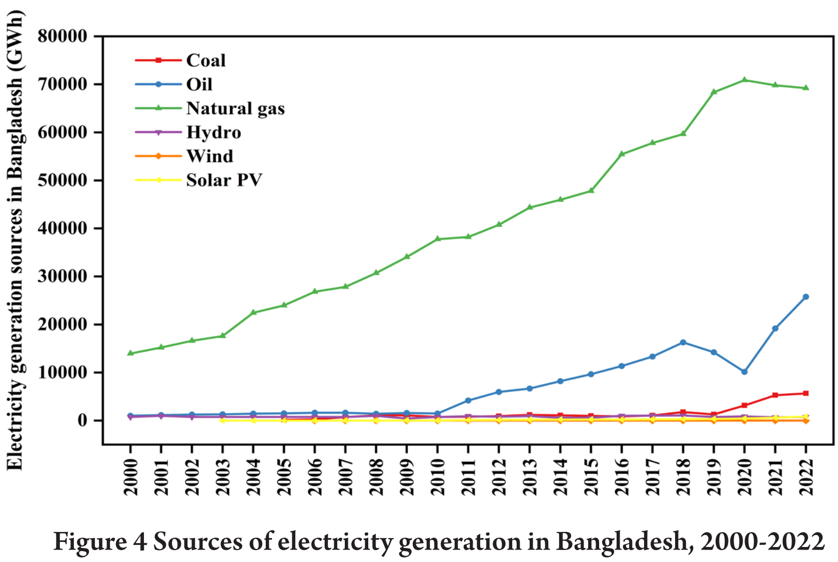

Figure 4 Sources of electricity generation in Bangladesh, 2000-2022

Data source: Collected from the International Energy Agency, Reference website: https://www.iea.org/countries/bangladesh/electricity

Among the fossil fuel-based power generation, natural gas has been the major source of electricity supply in Bangladesh, with the generation capacity growing from 13,984 GWh in 2000 to 69,214 GWh in 2022, an increase of nearly 4.95 times. Although declining, its share in total power generation is still the dominant energy source, indicating that Bangladesh's power mix is still highly dependent on natural gas. Prior to 2005, there was virtually no coal generation in Bangladesh's power mix. Since 2005, coal generation has gradually increased to reach 5,663 GWh by 2022, and its share has increased. This indicates that Bangladesh has increased coal generation in recent years, but its share is still much lower than that of natural gas. The overall growth in oil generation is faster, from 1,020 GWh in 2000 to 25,810 GWh in 2022, an increase of more than 25 times. The share of oil-based power generation rose from about 6.8 per cent in 2000 to 20.5 per cent in 2022.

Whereas, among the renewable energy generation, hydropower generation has not changed much and has stabilized in the range of 600-1,000 GWh, indicating that the development of hydropower resources in Bangladesh is limited and its share in the total generation is gradually declining. Wind power only started to appear in 2006, with a very small initial scale (1 GWh), and only reached 5 GWh by 2022, which is still negligible, indicating that the development of wind power in Bangladesh is still in its infancy, and has not yet resulted in large-scale commercial application. Solar power has been gradually developing since 2005, growing nearly 289 times from an initial 3 GWh to 865 GWh by 2022. Although the total amount is still relatively small, its faster growth rate suggests that there may be greater potential for development in the future.

Natural gas remains the dominant energy source, but its share has declined, suggesting that the energy mix is diversifying. However, the share of fossil fuels, such as coal and oil, in power generation has increased, albeit at a lower rate for coal, suggesting that Bangladesh is not relying on coal on a large scale as some other developing countries are, but is relying more on oil to supplement its power supply. The share of renewable energy in total electricity generation remains low despite significant growth, indicating that Bangladesh is still at an early stage of energy transition.

7.3 Shanghai's Energy Structure Optimization Strategy

7.3.1 Policy Framework and Market Mechanisms

In the top-level design, Shanghai has established the energy development direction of 'reducing coal, controlling oil, increasing gas and developing non-fossil energy' in the '14th Five-Year Plan', and has promoted the adjustment of energy structure through local legislation, carbon market construction and financial incentives. As the core operation centre of the national carbon trading market, Shanghai has included more than 2,000 key emitting enterprises in the carbon emission quota management system, with the carbon quota turnover accounting for more than 80% of the national total in 2023. In addition, Shanghai has launched the 'Carbon Universal' platform, which encourages residents to obtain carbon credits through low-carbon behaviors such as green travel and rubbish classification, so as to realize the market application of personal carbon emission reduction. In terms of policy protection, Shanghai has strengthened energy conservation management through policies such as the Shanghai Energy Conservation Regulations, which require 100% implementation of green building standards in new buildings and has implemented ladder tariffs for high energy-consuming enterprises to improve energy efficiency and promote industrial decarbonization. At the same time, the government has accelerated the promotion of clean energy technologies through special subsidies, providing a subsidy of RMB 0.25/kWh for distributed photovoltaic projects, and granting a subsidy of up to RMB 500,000/vehicle for the purchase of hydrogen fuel cell vehicles, which has strengthened the incentive for market players to invest in these technologies.

7.3.2 Diversified Deployment of Renewable Energy

In terms of renewable energy supply structure, Shanghai is actively developing offshore wind power, photovoltaic, biomass, and waste-to-energy to optimize the energy supply structure. The installed capacity of the Shanghai Donghai Bridge II wind power project reaches 300 MW, and the annual power generation can meet the demand of 500,000 households for electricity. At the same time, Shanghai is laying out a deep and distant sea floating wind power project, such as the Fengxian sea area planned wind power base, which is expected to break through the offshore resource limitations. Photovoltaic applications, Lingang new area to promote 'photovoltaic + carport', 'photovoltaic + agricultural greenhouses' and other integration projects, with a total installed capacity of more than 200 MW. The island of Chongming in Shanghai is building a 'zero-carbon community', and the coverage rate of rooftop photovoltaic has exceeded 60 percent, making it a demonstration area for distributed photovoltaic. In terms of biomass energy use, the Shanghai Laogang Eco-base has built the world's largest waste incineration power plant, with a daily average of 9,000 tons of waste, and an annual power generation capacity of more than 1 billion kilowatt-hours, which not only improves the level of waste resource utilization, but also ensures a stable supply of clean energy.

7.3.3 Deep Decarbonization in Industry and Transportation

Deep decarbonization in the industrial and transportation sectors is an important direction in Shanghai's energy transition. In the iron and steel industry, Baowu Iron & Steel Group, a leading company in the industry, has adopted hydrogen-rich carbon-cycle blast furnace technology to reduce coke consumption by 15%, and plans to achieve hydrogen substitution of traditional fossil fuels by 2035 to decarbonize the entire iron and steel production process. Regarding port construction, Shanghai Yangshan Port has accelerated the deployment of all-electric automatic guided vehicles (AGVs) and LNG-powered ships and is expected to reach 100% coverage of onshore power by 2025, reducing carbon emissions from docked ships by 90%. The construction of a new energy vehicle ecosystem is also in focus, with Tesla's Shanghai Super Factory reaching an annual capacity of 750,000 vehicles, driving the development of local battery companies, including Ningde Times. In addition, the city has accumulated more than 500,000 charging piles, providing a perfect infrastructure for promoting and applying new energy vehicles.

7.3.4 Smart Energy Systems and Technological Innovation

Regarding smart energy and technological innovation, Shanghai has optimized energy management through digital means and promoted the development of the hydrogen energy industry chain. The pilot construction of a virtual power plant in Huangpu District, Shanghai, aggregates energy storage facilities and air conditioning loads in commercial buildings to achieve a regulation capacity of 100 MW, equivalent to the load regulating level of a medium-sized thermal power plant, improving the flexibility of the power grid and the efficiency of energy use. In terms of the hydrogen industry, Shanghai Jiading District is building a 'hydrogen port', covering the complete industry chain from hydrogen production from green power electrolysis water, high-pressure storage and transportation to end-use applications (hydrogen buses, logistics vehicles). Meanwhile, the 'Digital Twin Grid' in Zhangjiang Science City in Pudong, Shanghai, uses real-time simulation and intelligent scheduling to predict and optimize power loads, reduce fault recovery time to milliseconds, and improve the reliability and resilience of grid operation.

8 Recommendations and Insights for Bangladesh's Environmental Management

Recommendations and Insights for Bangladesh's Environmental Management

Based on Shanghai's experience of governance in various environmental areas and the actual national context of Bangladesh, we propose environmental governance strategies for three timelines: short term (1-3 years), medium term (3-10 years) and long term (more than 10 years).

8.1 Water Pollution Control

In water pollution control, the short-term focus is on 'institutionalization + piloting', i.e., rapid curbing of pollution deterioration through regulatory amendments, pilot projects, and policy instruments (e.g., subsidies, fines). In the medium term, the focus is on 'scaling up + transformation', whereby successful experiences are scaled up across the country, supported by infrastructure development and industrial upgrading. The long-term focus will be on 'systems + intelligence' to modernize environmental governance through digital management.

8.1.1 Short-term (1-3 years)

Improve top-level design and policy framework. Launch the Five-Year National Integrated Water Pollution Control Programme, identify priority rivers for treatment and set phased water quality targets. Amend the existing Bangladesh Water Pollution Control Act to include mandatory standards for wastewater discharge in the chemical, textile, and pharmaceutical industries (e.g., COD $\leq$ 100mg/L, ammonia $\leq$ 15mg/L), and impose stepped fines on companies that exceed these standards (first warning, second fine, and third suspension of production). For local governments, consider setting up 'joint water pollution control offices' in major cities such as Dhaka, integrating resources from the environmental, water and agriculture sectors, and implementing a 'river chief system', whereby mayors or district chiefs are responsible for the management of key rivers, and make regular public announcements on the progress of management. The progress of treatment is made public regularly. In addition, a mapping of urban domestic sewage outfalls is carried out, for example, to set a target of completing the interception and rehabilitation of more than 50 per cent of outfalls by the end of the year.

Target key polluting industries for governance and source reduction. National textile printing and dyeing enterprises should implement 'One Factory, One Policy' Clean Production Transformation Plan, by requiring high water-consuming enterprises to upgrade reclaimed water systems (such as reverse osmosis technology). For local governments, consider pilot 'eco-agriculture subsidies' in major agricultural production areas. For example, provide a per-mu subsidy to farmers who use water-saving irrigation (e.g., drip irrigation) and organic fertilizers to reduce fertilizer run-off.

Strengthen basic monitoring and emergency response capacity building. A certain number of basic water-quality monitoring points are established in major rivers, and consideration can be given to issuing quarterly 'red and black lists of water quality in key rivers throughout the country', and initiating the accountability for those responsible for three consecutive 'black lists' of watersheds.

8.1.2 Medium-term (3-10 years)

Deepen treatment and facility construction. Promote the National Sewage Treatment Plant Plan, advance the construction of sewage treatment facilities nationwide, prioritize the construction of new sewage treatment plants in large cities and heavily polluted areas, and realize centralized treatment of urban domestic sewage. Existing sewage treatment facilities are upgraded to improve efficiency and pollutant removal rates. For local governments, consider incorporating the successful experience of Shanghai to accelerate the construction of municipal sewage treatment plants, optimize the layout of sewage treatment plants and reduce the problem of direct sewage discharge. In rural and remote areas, promote low-cost and easy-to-operate decentralized sewage treatment technologies (such as household sewage treatment units and small-scale water purification equipment) to reduce the pollution of surrounding water bodies caused by domestic sewage, and set a target year to cover a certain area of rural settlements to minimize water pollution in rural areas.

Accelerate the implementation of water pollution control and ecological restoration. For heavily polluted rivers and water bodies, ecological restoration measures such as the construction of artificial wetlands, the implementation of river dredging, and the installation of aquatic plant belts are undertaken to enhance the self-purification capacity of water bodies and implementing systematic ecological restoration projects for major polluted rivers in Bangladesh, including river training, wetland restoration, and ecological bank protection construction to improve water quality and enhance ecological diversity.

8.1.3 Long-term (10+ years)

Focus on strengthening systematic and intelligent management. In the future, consideration could be given to the establishment of a 'National Water Environment Intelligence Monitoring Platform for Bangladesh', which would integrate satellite remote sensing, drone inspections and IoT sensor data to enable 24-hour automated traceability of pollution sources (e.g., AI algorithms to identify illegal dischargers). Future legislation will require all industrial parks to achieve 'zero wastewater discharge'. For example, industries are required to build membrane bioreactors (MBR) and evaporation and crystallization facilities, and aim at the reuse rate of industrial wastewater to reach ≥95% by 2035. For local governments, wetland restoration are incorporated into urban master plans. For example, a 200-square-kilometre permanent wetland reserve is designated in eastern Dhaka, where commercial development is strictly prohibited and native aquatic plant cover is restored to a certain level.

8.2 Air Pollution Control

In the management of air pollutants in Bangladesh, short-term strategies focus on regulatory development, treatment of key sources, and initial electrification transition. Medium-term policies strengthen regulation, upgrade emission standards, and promote the integration of renewable energy sources. Long-term policies focus on full electrification, technological innovation, and international cooperation.

8.2.1 Short-term (1-3 years)

Strengthen air pollution prevention and control. Launch a Clean Air action Plan for Bangladesh, which sets targets and measures for governance in the light of the current state of local air pollution and clarifies the responsibilities of various departments. Local governments can learn from Shanghai's Special Emergency Response Plan for Heavy Air Pollution and formulate detailed emergency response and pollution prevention plans for pollution sources in different areas.

Target pollution from diesel vehicles and non-road machinery. Gradually push the implementation of emission standards, promote the formulation of emission standards for heavyduty diesel vehicles, and introduce transitional measures to phase out highly polluting diesel vehicles. At the same time, accelerate the promotion of electric vehicles and electric bicycles in urban areas to reduce carbon dioxide, nitrogen oxides and particulate emissions by fuel vehicles and thereby, improve air quality.

Focus on source management. For stationary emission sources (e.g., brick kilns), promote pollution control for key enterprises, strengthen environmental protection inspections for highly polluting enterprises, and formulate annual control plans to implement pollution control measures. For dust sources such as brick kilns, building construction, municipal roads, and stockyards, strengthen control, encourage the use of dust-free or low-dust materials, and enhance the covering and treatment of dusty spots.

8.2.2 Medium-term (3-10 years)

Improve the regulatory system for pollution sources. The central Government should establish a nationwide system to manage pollution source emissions, strengthen enterprise pollution emissions monitoring, ensure that data are open and transparent, and impose strict penalties and corrective measures on non-compliant enterprises. It should also promote a 'Classified Policy' governance model, especially for high-emission industries such as brick kilns, and formulate individual governance plans in accordance with the principle of 'One Factory, One Policy' to ensure the green transformation of the industry.

Gradually improve the bill on pollution prevention and control of motorized vehicles and non-road mobile machinery. Continuously research laws and regulations related to pollution prevention and control of motorized vehicles and non-road mobile machinery, and provide a policy basis for the formulation of stricter emission standards, vehicle oil upgrades and vehicle inspection standards. Investigate the establishment of a nationwide motorized vehicle emissions testing and regulatory system to ensure that vehicles meet environmental standards and that severe penalties are imposed on vehicles that exceed those standards.

8.2.3 Long-term (10+ years)

Long-term policies focus on sustainable development and long-term pollution control. It will continue to promote the adoption of electric vehicles and electric bicycles, as well as the gradual phasing out of fuel vehicles and the full electrification of Bangladesh's transport system. Strengthen technological innovation in air pollution control, encourage enterprises to invest in green production technologies, and promote upgrading of pollution control equipment. Further optimize the air quality management system and introduce artificial intelligence and big data technologies to achieve accurate pollution prediction and management. Combine international advanced experience, improve the legal system for air pollution control in Bangladesh and actively participate in international environmental cooperation to enhance pollution control capacity and technology.

8.3 Solid Waste Management

In solid waste management in Bangladesh, short-term strategies focus on regulatory development, infrastructure development, and plastics recycling, medium-term policies focus on resource utilization and waste segregation, and long-term policies emphasize the circular economy, technological innovation, and the establishment of a market for renewable resources.

8.3.1 Short-term (1-3 years)

Strengthen top-level design and solid waste management systems. The central government should regularly update the laws and regulations related to solid waste so that the policies are more in line with the actual development of Bangladesh, especially for densely populated areas and solid waste disposal challenges in urban areas, as well as to strengthen sharing of responsibilities among the government, enterprises and residents. Local governments can refer to Shanghai's experience and introduce policies similar to the Domestic Waste Management Regulations to promote separate management of domestic and construction waste, gradually expanding them to small and medium-sized cities, starting with large cities. Encourage enterprises to adopt low-cost and high-efficiency solid waste treatment technologies through financial subsidies and tax incentives, promote resource utilization of agricultural waste (e.g., straw, livestock and poultry manure) to facilitate the integration of the agricultural and environmental protection sectors.

Launch actions to manage the recycling of used plastics. Include a special policy on recycling waste plastics in the solid waste management system, develop a system for classifying and recycling plastics waste, and clarify the responsibilities of enterprises, consumers and the government. Legislation requires enterprises to reduce the use of single-use plastics and encourages research, development and promotion of alternative to plastic materials. Build plastic recycling plants in major cities and rural areas, and encourage citizens and enterprises to participate in plastic recycling through subsidies and incentive policies, to promote the development of a plastic recycling economy. Promote the development of the plastics recycling industry and encourage the use of recycled plastics in the manufacturing of construction materials and packaging products, so as to reduce the pressure of plastic waste on the environment.

8.3.2 Medium-term (3-10 years)

Gradually carry out source reduction targeting pollution sources. A green industrial policy is promoted, and tax incentives and subsidies are provided for textiles, food processing, and other industries that consume large amounts of resources and have outstanding pollution problems, to encourage enterprises to invest in cleaner production technologies, improve resource-use efficiency, and reduce the generation of waste. Promote green design and encourage enterprises to use biodegradable materials in the production process and reduce the use of disposable packaging to reduce environmental pollution while enhancing the international competitiveness of Bangladeshi products. In addition, subsidies are provided to small and medium-sized enterprises (SMEs) for cleaner production renovation, encouraging them to gradually promote green upgrading of their production facilities, and providing low-cost cleaner production technologies to areas that are relatively economically lagging behind to help them reduce pollutant emissions.

Improve end-of-pipe disposal and multi-source synergistic management. Priority should be given to building waste recycling facilities in major cities such as Dhaka, ensuring that waste segregation infrastructure is well developed, and attracting enterprises to invest in waste recycling plants and transport centres through the public-private partnership model. Local governments can also rationally set up recycling plants according to the economic conditions and population density of different regions to avoid waste of resources and improve recycling efficiency. Promote composting of wet waste and resource utilization of organic waste to reduce landfill, and gradually introduce waste incineration facilities to achieve energy-based waste treatment. Drawing on Shanghai's model of cross-industry synergistic utilization, promote resource utilization of solid waste in industrial parks and improve the recycling rate of industrial waste. Establishing a system for the recovery and resourcing of agricultural waste, and promoting the energy-based and fertilizer-based treatment of agricultural waste through financial subsidies and the construction of agricultural waste treatment facilities.

8.3.3 Long-term (10+ years)

Gradually upgrade the level of resource utilization. Adopt low-cost and high-efficiency biological treatment methods (e.g., black gadfly technology) to convert wet waste into organic fertilizer or biogas, reducing the environmental burden. Through policy support, promote the segregation, recycling and use of recycled materials for construction waste to reduce waste accumulation and environmental pollution. Develop resource utilization of plastic waste, promote segregation, recycling and reclamation of plastics waste in large cities and industrial areas, and promote enterprises to make new plastic products or other renewable materials from recycled plastics. To support companies and scientific research institutions in the research and development of efficient plastics recycling technologies through policy guidance. To promote the use of recycled plastics in the plastics products industry in order to reduce the use of virgin plastics and promote the development of the plastics recycling economy

Encourage the development of the renewable resources market. Establish laws and regulations related to the recycled resources market to ensure the healthy operation of the market for recycled building materials and recyclable items, and reduce the consumption of virgin resources. Through government support to establish a trading platform for recycled resources, promote the exchange and utilization of domestic and foreign recycled resources, and enhance the efficiency of resource utilization.

8.4 Proactive Industrial Restructuring

For Bangladesh's industrial restructuring, the short-term strategies focus needs to be on addressing fundamental issues, including optimization of traditional industries, infrastructure development, and initial environmental protection measures. In the medium-term strategies, there is an urgent need to focus on promoting industrial upgrading, developing new science and technology industries, optimizing regional industrial distribution, and accelerating the spread of green energy. In the long-term strategies, there is a need to focus on moving towards a high-value-added economy and achieving green and sustainable development.

8.4.1 Short-term (1-3 years)

Optimize traditional industries and improve competitiveness. Increase investment in labor-intensive industries, such as textiles and footwear, to improve production efficiency and enhance the added value of products through technological transformation. The central government should strengthen its efforts to attract foreign enterprises to set up factories in Bangladesh, promote investment in international brands, improve the industrial chain and boost export trade growth. Develop modern agriculture and food processing industries to increase the value-added of agricultural products, enhance food safety regulation and raise farmers' income.

Accelerate infrastructure construction. Focus on building transport facilities such as roads, railways, ports and airports to improve the domestic and international logistics environment and reduce the cost of industrial development. To create conditions for industrial agglomeration, local governments should plan industrial zones and support facilities in conjunction with urban expansion needs.

Promote environmentally friendly development. To improve urban environmental protection, consider developing environmental technology industries such as sewage treatment, rubbish classification, and recycling, and air pollution control. Gradually phase out highly polluting industries, such as outdated chemical industries, and encourage enterprises to transform to low-carbon and cleaner production.

8.4.2 Medium-term (3-10 years)

Expand new industries and promote technological upgrading. Develop the consumer electronics manufacturing industry, such as smartphones, home appliances and computer accessories, to promote the growth of the local technology industry. Promote clean energy sources such as solar photovoltaic and small-scale wind power generation in rural areas to gradually reduce reliance on traditional fossil energy sources while concurrently creating employment opportunities.

Promote industrial clustering and coordinated regional development. Local governments should use their own strengths to establish special industrial parks, such as textile industrial parks, chemical parks, and electronic industrial parks, to improve the efficiency of resource allocation. Relying on coastal resources, establish special economic zones in harbour areas to develop green manufacturing, shipping logistics, export processing, and other industries.

Deepen the green development strategy. Strengthen the development of energy-saving and environmental protection industries, such as waste-to-energy for power generation, sewage treatment plants, and resource recycling facilities, to increase the utilization rate of renewable resources. Encourage enterprises to adopt clean energy and formulate low-carbon emission policies to promote green economic growth.

8.4.3 Long-term (10+ years)

Move towards a high-value-added economic system. Gradually upgrade from labor-intensive to high-value-added industries, focusing on high-tech sectors such as artificial intelligence, biomedicine, and new materials. Establish Bangladesh's brands, improve the position of local enterprises in the global industrial chain, and reduce dependence on foreign-funded enterprises. Further deepen the development of the digital economy and promote the growth of financial technology, e-commerce, smart manufacturing, and other industries.

Improve the sustainable development model by gradually forming a comprehensive green energy system; to make clean energy, such as solar, wind and biomass, the main source of energy. Meanwhile, urban planning should be further strengthened, and smart cities should be built to promote sustainable urbanization. In addition, the harmonization of economic growth and ecological protection should be achieved through strict environmental regulation and technological innovation.

8.5 Gradual Energy Structure Optimization

In optimizing Bangladesh's energy mix, the focus in the short-term strategies should be on ensuring energy stability, promoting pilot photovoltaic power generation and developing initial policy support. In the medium-term strategies, it should increase the proportion of renewable energy, pilot the carbon market, and promote industrial energy efficiency and new energy transport. And in the long-term strategies, smart grids should be established, hydrogen technology should be encouraged, and a comprehensive digital and green energy transition should be achieved.

8.5.1 Short-term (1-3 years)

The Government should ensure stable supply of natural gas, promote photovoltaic demonstration projects, and formulate initial renewable energy policies. While ensuring the stability of natural gas power generation, the government should optimize energy management, improve the operational efficiency of the existing power system, and reduce the risk of energy shortages. In addition, it should accelerate the promotion of photovoltaic (PV) power generation, make full use of Bangladesh's advantageous sunshine potential, and promote distributed PV power generation projects in rural and remote areas to improve power accessibility and reduce dependence on fossil fuels. Furthermore, the government should gradually promote wind energy pilot projects; carry out small-scale offshore wind power demonstration projects in coastal areas, and explore the feasibility of wind energy through cooperation between the government and enterprises, to lay the foundation for the future development of the wind energy industry. Concurrently, the Government should introduce incentive policies for renewable energy and formulate incentives such as tax breaks and low-interest loans to encourage enterprises and individuals to invest in renewable energy projects and to increase the participation of all sectors of the society.

8.5.2 Medium-term (3-10 years)

Increase the proportion of renewable energy. The Government should expand investment in solar and wind energy to increase the share of clean energy in the energy mix and guide enterprises to effectively transition to renewable energy.

Promote industrial energy-saving transformation and new energy transport. The government should promote energy conservation and emission reduction in energy-intensive industries, promote energy-saving technologies such as high-efficiency boilers and waste heat recovery, and encourage enterprises to adopt renewable energy for power supply. In addition, electric cars and motorbikes can be promoted through measures such as subsidizing car purchases, building charging infrastructure and setting up low-emission zones, to reduce reliance on fossil fuels in the transport sector. Additionally, in major ports such as Chittagong, shore power technology and LNG-powered ships can be promoted to reduce carbon emissions from port operations and enhance the green development of the shipping industry.

8.5.3 Long-term (10+ years)

Build a smart grid to improve the flexibility and stability of the energy system. Consider introducing smart scheduling technology to establish a smart power scheduling system that uses artificial intelligence and big data to optimize power supply and improve power supply stability. It will also be combined with energy storage technologies (e.g., battery storage, grid-level energy storage systems) to balance power supply and demand and increase the utilization rate of renewable energy. Promote distributed energy management and establish 'micro-grid' systems in industrial parks, commercial centres and residential communities to allow local power generation and local consumption, reducing reliance on large power grids.

Implement digital energy management to improve energy efficiency. Bangladesh should build a National Energy Data Platform and establish an intelligent energy management system to monitor real-time energy consumption in power, industry, transport and other sectors and provide data support for government decision-making. Use big data analytics to optimize energy supply and demand matching and improve the overall efficiency of the energy system.

Promote international cooperation. Partnerships can be established with cities like Shanghai to introduce advanced smart grid, hydrogen energy, and digital energy management technologies. It can also join regional energy cooperation mechanisms and explore cross-border clean energy transmission with neighboring countries (e.g., India) to share clean energy resources.

9 Conclusion: Multidimensional Pathways Toward Sustainable Development

Conclusion: Multidimensional Pathways Toward Sustainable Development

Bangladesh is at a critical stage of rapid urbanization and economic transformation, which is accompanied by serious environmental challenges such as water and air pollution, and solid waste management. To achieve environmentally sustainable development, Bangladesh must adopt integrated policies and measures and find its development path within the global trend of environmental protection.

(1)Strengthening the policy framework and institutional safeguards. Bangladesh needs to improve its legal and regulatory system and promote comprehensive and systematic environmental governance through top-level design. Although Bangladesh already has relevant environmental laws and regulations, there are still large gaps in implementation and coverage. Therefore, it is necessary to increase the implementation of environmental policies at all levels of government and local administration. Taking into account the experience of Shanghai, Bangladesh could set milestones and provide local governments with more autonomy in implementation according to national conditions, while strengthening local governments' responsibilities in water quality, air and waste management and establishing a more flexible and efficient implementation mechanism.

(2)Green transformation of economic and industrial structure. The economic development of Bangladesh is still in the early stage of industrialization, especially with the dominance of labour-intensive industries such as textiles and food processing. However, while these industries provide many employment opportunities, they also stand out in terms of environmental pollution and resource wastage. To achieve environmentally sustainable development, Bangladesh needs to fundamentally promote a green transformation of its economic and industrial structure. Bangladesh should promote the development of green and low-carbon industries through government incentives, especially in the chemical and textile industries, where impacts in terms of water pollution are more serious, by strictly enforcing cleaner production standards and encouraging enterprises to invest in environmental protection facilities through financial subsidies. At the same time, it should also develop environmentally friendly agricultural technologies and promote water conservation, low-toxicity pesticides and eco-agriculture to reduce agricultural surface source pollution.

(3)Infrastructure development and technological innovation. Infrastructure development in Bangladesh is relatively lagging, especially in sewage treatment, waste segregation and recycling, pollution monitoring and so on. This is a serious problem facing Bangladesh currently, and it is necessary to accelerate the pace of construction of relevant infrastructure. In big cities, especially Dhaka and Chittagong, it is necessary to increase investment in sewage treatment plants and solid waste recycling facilities, while gradually upgrading the capacity of solid waste classification and resource recovery. In rural areas, Bangladesh can promote low-cost, easy-to-operate decentralized wastewater treatment technologies and solid waste recycling methods in accordance with its own economic level and geographic characteristics, which can solve the problem of domestic wastewater discharges and improve the efficiency of resource utilization at the same time. Bangladesh also needs to focus on independent innovation in environmental governance technologies and strengthen research and localization of environmental protection technologies to lay the technological foundation for long-term sustainable development.

(4)Green transport and energy reform. With the increase in demand for transport, the problem of traffic pollution in Bangladesh is becoming more and more serious. Conventional fuel vehicles, especially heavy diesel vehicles, are a significant source of air pollution. Therefore, there is an urgent need to promote green transformation in transport in Bangladesh. The popularity of electric vehicles and electric bicycles should be promoted and policies should be formulated to facilitate this transition, such as providing subsidies and establishing a green transport fund. To further reduce the burden of transport on the environment, Bangladesh should promote the development of efficient public transport systems and reduce the reliance on private cars. Traffic congestion and air pollution can be reduced by expanding and optimizing public transport networks, such as metro and buses, especially in densely populated urban areas. On the energy front, Bangladesh can gradually promote the development of natural gas and renewable energy sources. For example, solar energy, wind energy and other renewable energy sources have greater potential in Bangladesh, and technological research and development and policy support should be stepped up, especially in rural areas, where the application of renewable energy sources can be promoted through distributed energy sources, which will not only increase the self-sufficiency rate of energy, but also reduce dependence on traditional fossil energy sources.

(5)Public participation and environmental awareness. The awareness of environmental protection in Bangladesh is relatively weak, especially in villages and among low-income groups; the concept of environmental protection is not widespread enough. To mobilize the enthusiasm of the whole society for environmental protection, Bangladesh needs to intensify its efforts for environmental awareness and public participation. School education and community training can popularize environmental protection knowledge and enhance residents' sense of responsibility for environmental protection. The government can promote environmental awareness through media campaigns, social media platforms, and other channels, especially for rubbish classification and water conservation, to create a favourable atmosphere for all people to participate. At the same time, the government should encourage residents and enterprises to actively participate in environmental protection activities through reward mechanisms and green consumption incentives to enhance the popularity and effectiveness of environmental protection actions.

(6)International cooperation and technology introduction. The level of environmental protection technology in Bangladesh is relatively low, and capital is insufficient, so the construction of environmental protection facilities is under great pressure. Therefore, it is crucial to strengthen international co-operation and attract foreign capital and advanced technology. Through technical cooperation with international environmental organizations and developed countries, Bangladesh can introduce advanced pollution control technology, equipment, and management experience, especially in water pollution control, air pollution prevention, and solid waste treatment.

Overall, coherent and coordinated measures in policy formulation, industrial transformation, technological innovation, and infrastructure development are required for Bangladesh to achieve environmentally sustainable development. By strengthening environmental laws and regulations, promoting green transformation of industries, upgrading infrastructure capacity, promoting green transport and energy reform, enhancing public awareness for environmental protection and strengthening international cooperation, Bangladesh is expected to achieve significant results in environmental governance and sustainable development. At the same time, environmental governance should focus more on practicality and feasibility, formulate strategies that suit Bangladesh's situation, and promote environmental protection measures gradually and orderly. Through a systematic and integrated approach, Bangladesh can improve environmental quality, pave the way for green and sustainable economic growth in the future, and create a healthier and more livable environment for its people.

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The CCS was officially launched on March 24, 2024. Nestled within the dynamic campus of the University of Dhaka, CCS operates independently, focusing on comprehensive research initiatives spanning various dimensions of China's multifaceted landscape. The Academic Board, as the principal decision-making body, guides the Centre's strategic direction by overseeing annual plans, budget allocations, research endeavors, and program development.

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