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Future Aspects and Environmental Benefits of Renewable Energy in Bangladesh

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ABSTRACT

Bangladesh really needs to sort out its future energy situation. Their own natural gas and oil are running out, but they need more and more electricity. Right now, only a tiny bit of their power (like, less than 5%) comes from things like solar or wind. So, this research looks at whether using more sun power, plant energy (biomass), and other clean sources makes sense money-wise and if it could work for making electricity. The whole world needs to cut down on greenhouse gases to fight climate change, and this study points out how using clean energy can help Bangladesh do its part in the power sector. Everyone expects a big jump in how much clean energy we use globally. However, countries like Bangladesh are stuck buying expensive oil and gas from other places, which hurts their wallets. Plus, the air is getting dirtier, which means they need clean, long-lasting energy answers fast. This paper says that renewable energy is a smart and reasonable way forward for Bangladesh and the rest of the world. It also mentions that Bangladesh's location is pretty good for using things like solar power everywhere. By comparing how we use dirty fuels and clean energy now, both around the world and just in Bangladesh, this paper wants to show the good things that could happen in the future and how much better it would be for the environment if Bangladesh switched to primarily using renewable energy.

INTRODUCTION

The progress of human society has always been greatly helped by energy. It allows for better economies and a better way of life for people everywhere. However, the way we usually make energy, mostly by burning fossil fuels in power plants, causes serious and lasting problems for the environment and for the world's long-term economy. When these limited resources are burned, greenhouse gases are released into the air. This makes human-caused climate change worse. Also, other harmful substances like nitrogen and sulfur oxides, carbon monoxide, and ground-level ozone are released, which are known to be dangerous to people's health.Furthermore, the amount of fossil fuels in the world is limited. Predictions suggest that they could run out within this century. Because of this, a complete shift to ways of making energy that are much better for the environment and will essentially never run out is clearly needed.

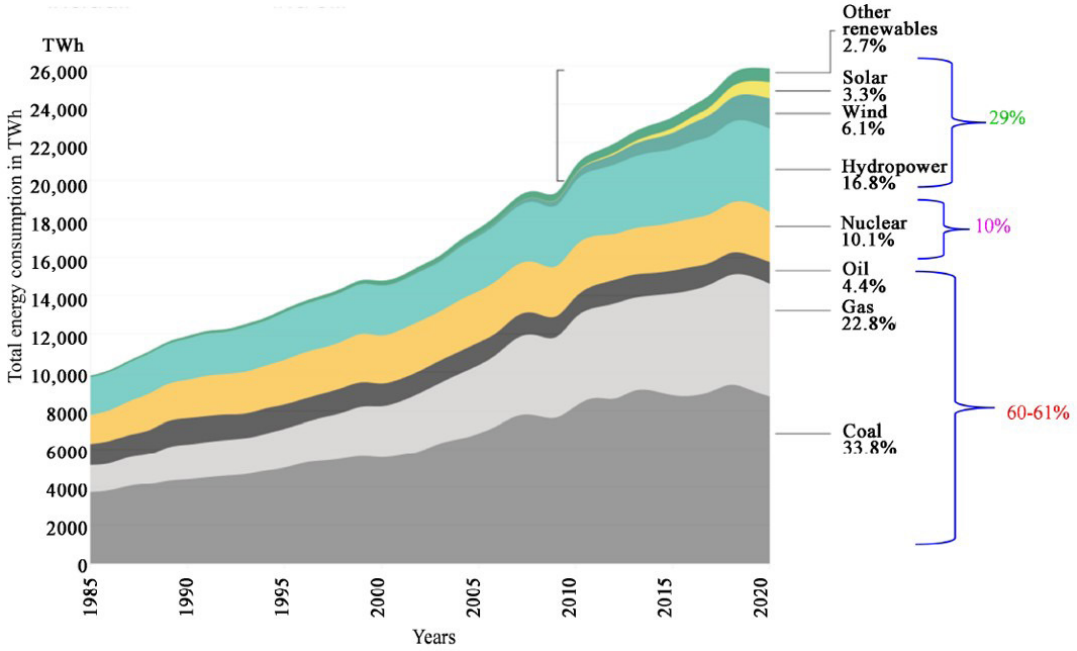

Figure 1: The total energy uses in terawatt-hours worldwide from 1985 to 2020
Source: IEA, 2021

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Even though the world really needs to change how it gets its energy, using renewable energy like solar and wind in different parts of the economy is still happening slower than it could. This means we really need to speed up and plan better for using these clean energies everywhere.

Over the last 50 years, the total amount of energy used around the world has kept going up, often very quickly. It's now at levels we've never seen before. And most of this energy still comes from burning old-fashioned fossil fuels. While renewable energy is only a small part of the total energy we use right now, it has a huge potential to grow and be used in all sorts of ways. This is becoming more and more important for the health of our planet. The fact that the world's population is growing and that industries are getting bigger in many countries has made the demand for reliable and cheap electricity even higher. And this demand is likely to keep growing in the future. Smart predictions and models suggest that the total amount of energy produced globally will increase a lot by the middle of this century. Renewable energy sources are expected to become the main way we make energy, especially with well-developed technologies like wind turbines and solar panels.

Because it's becoming more and more important to cut down on the greenhouse gases and other harmful pollution that humans are putting into the air, the world will need to focus on making the whole energy system more efficient. This includes how we first make the energy, how we move it around, and how we use it in our homes, factories, and everywhere else. Reliable and affordable electricity is really key for helping countries grow their economies and improve people's lives everywhere. Because of this, developing countries are working hard on big plans to expand and update their power plants and energy systems. Unlike nuclear power, which has its own environmental problems and waste issues, renewable energy offers a supply that will basically never run out and can be found in many different places. This means it can sustainably and fairly meet the world's energy needs now and in the future. This changing energy situation around the world clearly shows that we need to really study and start using the many future possibilities and environmental benefits that come with renewable energy. This is especially true for countries like Bangladesh as they try to grow their economy in a sustainable way, make sure they have energy security for the long term, and create a healthier environment for their people.

LITERATURE REVIEW

The world needs more energy. Burning old fuels makes the planet sick. So, lots of smart people are looking at clean energy. This paper looks at what might happen with clean energy in the future, especially for Bangladesh. It also talks about how it can help the environment there. What we know now says old fuels will run out. Burning them is bad for the air and for us. That's why we need to switch to energy that lasts. When you look at Bangladesh, they don't have much of their own gas or oil. But they need more power. So, scientists are checking out things like sun power, wind power, water power, and energy from plants. They want to see if these things can work for Bangladesh, if they cost too much, and if they'll help the country get more power without buying so much from other places. Bangladesh has a lot of sun. They also have a lot of leftover stuff from farming. That could be good for clean energy.

A lot of studies talk about how clean energy is good for the planet. It means less of those gases that cause climate change. It also means cleaner air and water, which is better for our health. If you compare clean energy to burning old fuels, clean energy is way better for the environment over the long run. Plus, using more clean energy can help the country grow its economy, create new jobs that are good for the environment, and get power to more people, even in the poor parts of Bangladesh.

Looking ahead, everyone thinks clean energy will get bigger, in Bangladesh and everywhere else. New technology will help. It will get cheaper. And governments might make rules that help clean energy. Scientists are trying to figure out what's stopping Bangladesh from using a lot cleaner energy. Maybe they don't have the right equipment. Maybe it costs too much at first. Maybe the rules are confusing. They're also looking at how to connect things like solar panels and windmills to the power lines they already have. And they're thinking about batteries to store energy for when the sun isn't shining or the wind isn't blowing. This paper just gives a basic idea of what we know now about clean energy in Bangladesh and what the future might hold. It also points out some things we still need to figure out and what the government might need to do.

MATERIALS AND METHODS

The way this research was done was based on a careful and organized look at all the studies and papers that already existed. These studies talked about what renewable energy might look like in the future and how it could help the environment, especially in Bangladesh. To really understand what was currently known, a specific search plan was used in major online libraries and research collections. These included places like Scopus, Web of Science, Google Scholar, and the special libraries of certain organizations.The search words were chosen carefully to find many relevant publications. The papers that were found then were examined closely to pick out the important information that directly related to what the research wanted to find out. Also, the lists of books and articles mentioned in important papers were looked at closely. This was done to find even more useful sources through a method of checking which papers cited which other papers.

The information that was put together in this research was taken only from existing sources. This involved reading a lot of scholarly materials that were available online and in physical archives. The different kinds of sources that were consulted included academic books, detailed reports

that were published by government and international groups, science papers that had been checked by other experts, and trustworthy information that could be found on the internet.

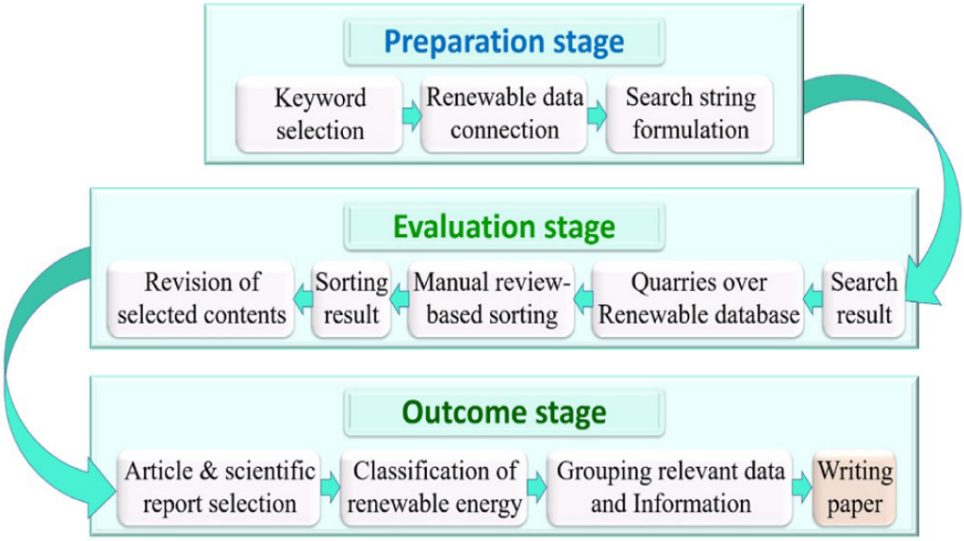

Figure 2: Review Methodology
Source: Abdullah-Al-Mahbub & Islam, 2023

The information that was taken from these existing sources was thought about carefully, was compared with other information, and was combined to create a solid base for the analysis and discussion presented in this study. This analysis and discussion concerned the future possibilities and environmental advantages that are linked to using renewable energy technologies specifically in Bangladesh.

Energy Sustainability for Development

Access to modern energy is a must for development and ending poverty. European countries relied a lot on fossil fuels to grow after the Industrial Revolution. We now know about the environmental damage and the dangers to the world's climate that followed. The problem is getting worse as developing countries try to grow their economies by using the same old energy methods. Because of this, it's more important than ever to push for renewable energy and find ways to save energy everywhere.

Developed countries have a big responsibility to create the technology for a sustainable energy system for the whole world. It would be a good idea to encourage developing countries to join in this global effort. When we think about it, many developing countries have natural advantages that would make it easier to use renewable resources. For example, Bangladesh has a lot of sunlight for solar panels, wind energy from the Bay of Bengal, and hilly areas for other renewable options.

Using electricity made from renewable energy in a spread-out way offers the most advantages. It can create new chances for poor rural areas where building a traditional electricity network wouldn't make economic sense. This can help reduce poverty. Many developing countries could also rely less on expensive fossil fuels they have to buy from other countries. Renewable energy sources can help them avoid the financial problems caused by unstable fuel markets.

An Outline of Bangladesh's Energy

Bangladesh relies on a mix of energy sources, including its own natural gas, imported oil and gas (LNG, LPG), coal, and some hydroelectricity. Biomass makes up about a quarter of the total energy used. The country's own natural gas is the biggest single source, but a significant amount of energy also comes from imported fuels. Coal is important for brick factories and power plants. To increase electricity production, Bangladesh is using solar home systems and biomass gasification, though these produce a small amount of power currently. The country's energy use is expected to grow by about 6% each year. While everyone in Bangladesh has access to electricity, the amount of energy used per person is still lower than in some neighboring countries. Renewable sources like hydroelectricity, solar, and wind make up a very small part of the current energy mix, but biomass has a significant share.Looking ahead, Bangladesh has good potential to use wind and small-scale hydroelectric power. A positive step is the increasing use of solar-powered irrigation pumps, which can reduce the need for traditional fuels (Akash *et al.*, 2024).

Between 2021 and 2022, the total energy used in Bangladesh hit 85,607 Gigawatt-hours (GWh). That's quite a bump, almost 5200 GWh more than the year before. And get this, they're expecting their energy use to keep climbing by about 7% every year(Rabbani *et al.*, 2024). Looking down the road, they're figuring they'll need to generate an extra 5700 Megawatts (MW) of electricity by 2040 just to keep pace with everyone's needs.

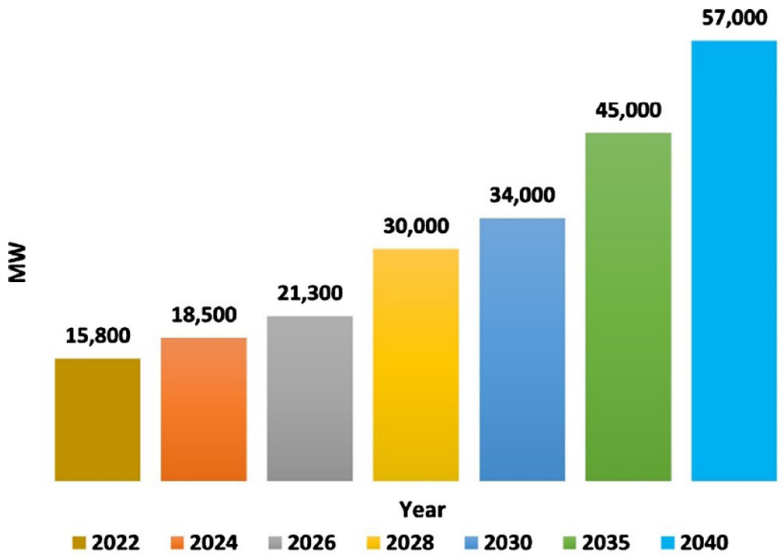

Figure 3: Bangladesh's electricity consumption forecast till 2040
Source: BPDB. 2022; Rabbani et al., 2024

Now, if you take a look at all the power-making stations they had up and running by June 2023, they've got the capacity to produce a hefty 26,007 MW (SREDA, 2022). They're using a mix of things to get that power going – you've got natural gas, coal, that thick, heavy furnace oil, and diesel. But, you know, those cleaner energy options, like solar and wind, are starting to contribute a bit more to the mix. On a typical day, the whole country churns out around 12,500 MW of electricity, but they've even hit a high of 14,800 MW at times. The thing is, when that summer heat really kicks in, everyone cranks up their air conditioners, and the demand for power goes through the roof. Even though they've got the potential to make a lot more electricity, they're only actually producing a little over half of what all their plants could do (SREDA, 2022). They're just not getting enough of the raw materials – the oil, the gas, the coal. So, a bunch of the power plants can't even operate at their full strength.

The State of Renewable Energy Worldwide at the Moment

Renewable energy sources are those that are essentially endless, meaning they will never run out. They can be easily and constantly replenished by nature. These include things like sunshine, wind, flowing water, ocean tides, ocean waves, the Earth's heat from inside, plants (biomass), and fuels that can be regrown (like certain crops). These natural resources can be turned into electricity, which can then be stored and moved to our homes, offices, or factories for us to use. This electricity is called renewable energy.Using renewable energy sources is very important for reducing our need for fossil fuels. It can also play a key role in making sure Bangladesh has a secure energy supply. Renewable energy can be used to power our transportation, generate electricity, and produce heat.

The world's energy use is growing very quickly, even faster than the number of people on Earth. Global business growth and a rising population will likely lead to about 30% more energy being needed as the world tries to achieve its Sustainable Development Goals by 2030. Renewable energy can be crucial in meeting this demand. In 2017, about a quarter of all the electricity produced in the world came from renewable sources. In 2021, the total amount of renewable energy the world could produce was 3146 GW. This was up by 306 GW from the year before, when the capacity was 2840 GW. Hydropower was the biggest source, making up about 38% of the world's total renewable energy production with a capacity of 1195 GW. Wind and solar power accounted for about 27% and 30% respectively, with capacities of 845 GW and 942 GW. Other renewable sources, like energy from burning plants, heat from the Earth, concentrated solar power, and ocean power, made up the remaining 143 GW. In 2019, more than 272 GW of new renewable energy production capacity was added. Most of this new capacity came from solar power (about 58%), followed by wind power (about 29%), hydropower (about 8%), bioenergy (about 4%), geothermal energy (about 0.5%), and concentrated solar thermal power (about 0.5%). It's worth noting that solar and wind energy together made up most of the new renewable energy added (about 87%), while the growth of hydropower was very slow. The total global renewable energy production capacity increased from 1222 GW in 2010 to about 3146 GW in 2021, including hydropower, wind, solar, bioenergy, geothermal, and marine energy (Abdullah-Al-Mahbub & Islam, 2023).

Renewable Energies

Renewable energy comes from sources that nature refills over time. This includes things like sunlight, wind, flowing rivers, and heat from inside the Earth. While big renewable energy projects get a lot of attention,

they can also work well for small towns, faraway places, and countries that are still developing. Often, renewable energy is used to make electricity, which is handy because it's clean when you use it.

Between 2011 and 2021, renewable energy grew from supplying 20% to 28% of the world's electricity. Nuclear power became less important, and fossil fuels still provided most of the electricity, but less than before (REN21, 2022). Hydropower's share went down a bit, but solar and wind power became much more common. Geothermal energy and energy from burning plants also grew slightly. Even though many countries have laws about renewable energy, there's a lot of renewable energy capacity working in many of them. In 2021, China produced about half of all the new renewable electricity in the world (IEA, 2022b). Renewable energy is becoming a big part of all the new power plants being built worldwide, and it's getting better, cheaper, and making up a bigger share of the total energy we use. In many places, building new solar panel farms or wind farms is now the cheapest way to make electricity.

Lots of countries already get more than 20% of all the energy they need from renewable sources, and some even get over 50% of their electricity this way (Ritchie *et al.*, 2020). The market for renewable energy in countries around the world is expected to keep growing fast in the 2020s and beyond. Studies suggest that it's possible, both with current technology and without spending too much, to switch to 100% renewable energy for everything – heating, electricity, transportation, and even making fresh water from saltwater (Bogdanov *et al.*, 2021).

Using energy-saving technologies and renewable energy gives a big boost to the economy, makes our energy supply safer, and helps fight climate change. However, the growth of renewable energy is being slowed down by the fact that governments still spend a lot of money supporting fossil fuels. When people around the world are asked what they think, they overwhelmingly like wind, solar, and other renewable energy sources. The International Energy Agency said in 2021 that we need to do much more to promote renewable energy if we want to reach zero carbon emissions. They said we need to increase the amount of renewable energy we produce by about 12% every year until 2030 (Rabbani *et al.*, 2024).

Renewable Energy Prospects

For any country to achieve the goals set by the UN Millennium Declaration, it's vital to grow and develop a good energy supply system. Emerging nations can reach these goals by using renewable energy sources and technologies that use energy efficiently. These things make it possible to have energy access in a spread-out way, so even in rural areas, not having enough energy won't stop development. By using these instead of fossil fuels, many countries can become less dependent on buying energy from other nations, which can be a big economic burden (IEA, 2003).

Burning coal, natural gas, and oil also harms the environment and the world's climate. In the future, the world's energy must come from more sustainable sources. It needs to meet the basic needs of the world's poor without using up all the Earth's limited natural resources and putting current and future generations at risk. We can do this by using energy more efficiently and depending on clean energy sources like wind power, hydroelectric power, solar energy, and geothermal energy. Right now, renewable energy sources provide about 30% of the world's total energy needs. The sun gives the Earth enough energy to theoretically meet all our energy needs 15,000 times over. The challenge now is to use some of this potential to help people. Experts predict that by the year 2050, renewable energy sources could supply almost half of the world's energy needs (Rabbani *et al.*, 2024) . There are many kinds of renewable energy, from huge hydropower dams and windmills to small solar panel setups that power single homes or small villages (often called solar home systems) or run water pumps without being connected to the main power grid. Geothermal energy offers a cost-effective way to heat buildings and generate electricity. It's widely known that many developing and newly industrialized countries haven't had enough energy up to this point. Large areas don't have a national electricity network. Many people in these countries traditionally get their energy from natural resources, mostly wood. Because the soil loses its protection when trees are cut down, this leads to deforestation, which causes serious environmental problems in many places. This is a major obstacle to these countries' economic growth (Martinot *et al.*, 2002).

Sustainable Energy Sources to Address Global Warming

Producing electricity and heat stands out as the biggest single thing making carbon dioxide, a major greenhouse gas- it's responsible for nearly a third of all of it. Burning fuel to get around, in cars and trucks and planes, adds another significant chunk, about fifteen percent. Farming contributes a bit less, around eleven percent. But when you add it all up, almost three-quarters of all the gases that trap heat come from how we make and use energy in every way. Because of this, businesses that don't actually make physical products – the service industry – have a real opportunity to influence how their customers, their workers, and everyone else they deal with acts. And getting people to change their behavior is key to stopping the worst consequences of climate change (Martinot, 2006).

Think back to when factories first started popping up; ever since then, we've been steadily pumping more and more gases into the air. The way we currently get our energy has some serious downsides for the environment, and you can see those laid out pretty clearly in various reports. Also, if you look at where in the world the most carbon dioxide is coming from, it paints a picture of who's contributing most to the problem (Bilen *et al.*, 2008).

The widespread burning of coal, oil, and natural gas in industrialized nations has pumped massive amounts of carbon dioxide into our atmosphere. This has caused the

average global temperature to creep up by about half a degree Celsius over the last century, and we're seeing more and more intense weather events like droughts, floods, and huge storms. Scientists predict that by the end of this century, the amount of CO_2 in the air could be three times what it was before the Industrial Revolution. The Intergovernmental Panel on Climate Change (IPCC) warns that temperatures could climb by as much as 5.8 degrees Celsius in the next hundred years (Hasegawa *et al.*, 2016; IEA, 2002).

Many developing countries rely heavily on farming. These nations could face serious economic trouble because of wild weather and changing climate patterns. For the developing countries we're talking about, climate change poses a real threat to their very existence, especially for the poorest people (IEA, 2002; Rabbani *et al.*, 2024). The richer, industrialized countries are largely to blame for this mess. They urgently need to switch to making energy from renewable sources that don't produce CO_2. Investing in ways to use energy more efficiently is also a really important part of tackling climate change.

Estimated Availability of Non-Renewable Energy Sources in Bangladesh

Bangladesh's utilized commercial energy resources encompass locally sourced natural gas, coal, crude oil acquired from international markets, Liquefied Petroleum Gas (LPG), Liquefied Natural Gas (LNG) obtained through importation, electricity purchased from neighboring countries, and hydroelectric power. Roughly 27% of the nation's overall energy consumption is met by biomass, while the larger 73% is supplied via these commercial channels. Within the realm of commercial energy, natural gas stands as the dominant source, contributing 62%, with a notable 8% of this amount originating from imported LNG. Annually, Bangladesh procures approximately 8.5 million metric tons of crude oil and refined petroleum products from abroad.

In the domain of renewable energy, Bangladesh's power generation includes about 401.26 MW derived from solar installations and an additional 1.03 MW produced by a biogas facility situated at a dairy farm. The total annual energy consumption for the nation hovers around 55.50 Million Tons of Oil Equivalent (MTOE), and this demand exhibits an annual growth rate of approximately 6%. On an individual basis, the average energy consumed per person in Bangladesh is about 334 kilograms of oil equivalent (kgoe), and the per capita electricity generation reaches 512 kilowatt-hours (kWh), with roughly 97% of the population having access to electrical power (Hasan, 2022).

Natural Gas

Bangladesh's first gas field was discovered in 1955. Since then, 26 gas fields have been discovered in Bangladesh, with 24 in the onshore and 2 in the offshore. 20 of the gas fields in Bangladesh are currently being produced from, and one field located in the sea was closed after 14 years of production, and many more gas fields with smaller reserves exist in Bangladesh. 40.09 Trillion Cubic Feet (TCF) of gas was estimated to be held by Bangladesh by June 2020. Of this, 17.79 TCF gas has been extracted, and 12.26 TCF gas reserves are assumed.At present, the average production of natural gas in Bangladesh is recorded at 2978 Million Cubic Feet per Day (MMcfd). In the 2019-20 financial year, 994 billion cubic feet (BCF) gas was produced, of which 46% was utilized in power generation, 15% was utilized in capacitive power, 16% was utilized in industry, 13% was utilized in domestic work, 4% was utilized for CNG, and 5% was utilized in agriculture. 71.80% of Bangladesh's electricity generation is fueled by natural gas. The role of gas is considered essential for the industrial development of a country. About 13% of the total population of Bangladesh uses natural gas for cooking through pipelines. Gas is used for the operation of motorized vehicles, the number of which is 504,293 (Hasan, 2022).

Bangladesh is completely depended on LNG imports. Around 1000 MMcfd LNG has to be imported by the government every year. An LNG terminal is needed to import LNG. An LNG terminal has been constructed in MaheshkhaliUpazila of Cox's Bazar district.The demand for natural gas has been steadily rising for the last few decades. The development of a country, and the contribution of everything depends on natural gas. At present, the demand for natural gas is 3508 MMcfd as against the supply of 2978 MMcfd, which shows that a supply shortage of about 530 MMcfdexists. It is also expected that by 2030, the demand will reach 4622 MMcfd (Hasan, 2022).

Oil Sector

The job of bringing in, cleaning up (refining), and sending out crude oil belongs to the Bangladesh Petroleum Corporation, or BPC. Think of BPC as a part of the government's power and energy department, specifically the bit that deals with resources like oil. Right now, both the government of Bangladesh and some non-government groups are involved in getting oil from other countries and making it usable. When they say "oil" here, they usually mean things like diesel for trucks and buses, petrol for cars, octane (another type of fuel), and kerosene. When you look at all the energy Bangladesh uses commercially, about one-fifth of it comes from oil. Making sure the country has enough of these liquid fuels is really important, no matter what. Every year, Bangladesh buys about 1.26 million metric tons of crude oil from other countries. On top of that, they also import another 4.04 million metric tons of oil that's already been refined and is ready to use (Hasan, 2022). The main ways they use this imported oil are for transportation (like cars and trains), making electricity, in farming, and in factories. If you break it down, here's roughly how much each sector uses: transportation uses the most, around 63%, then agriculture uses about 20%, power generation uses around 7%, industry uses about 6.5%, homes use about 3%, and everything else uses a little over 1%

(Hasan, 2022). So, when you look at the whole picture, Bangladesh's oil needs are completely met by what they bring in from other countries.

Coal

Energy is a key indicator of how well a country's economy is doing and a really important basic thing needed for social and economic progress. Right now, Bangladesh uses a lot of natural gas for its energy. But if we keep using it up so fast, we might run into a serious shortage down the road. That's why coal could be another option for energy. Right now, only a tiny bit of our electricity, like 2.55%, comes from coal, and all of that coal is dug up from our own mines.

Bangladesh has five coal mines, all located in the northwestern part of the country. Interestingly, the coal we get in Bangladesh can produce high temperatures, and it doesn't release a lot of sulfur when it's burned, which is a good thing. They've been commercially digging coal out of the Bara Pukuria mine since September 10, 2005. They get about a million metric tons of coal from it each year. The Power Development Board of Bangladesh uses coal from this mine to generate 250 MW of electricity. That's a big chunk, about 65%, of all the coal they take out. The other 35% of the coal ends up being used in brick factories and for other household purposes. To give you an idea, they've dug up 808,358 metric tons of coal from this mine, and they've also brought in a massive 6,828,032 metric tons of coal from other countries (Hasan, 2022).

Available Renewable Energy Sources in Bangladesh

Renewable energy brings a lot of good things to the table – for the environment, the economy, and for people in general. When it comes to the environment, it really cuts down on the greenhouse gases that cause climate change. Things like solar, wind, and water power make the air and water cleaner, which means a healthier planet for everyone. Economically, the renewable energy industry creates jobs, helps the economy grow, and makes a country's energy supply safer by using different sources. Because resources like the sun and wind will never run out, renewable energy is a long-term solution and reduces our need to rely on limited fossil fuels. Plus, when local communities are involved in and even own renewable energy projects, it gives people a sense of ownership and pride. And because the technology in this sector keeps getting better, it's helping us find more efficient ways to use energy and manage our power grids. Basically, switching to renewable energy is a big step towards a cleaner world and can really boost our economies and improve people's lives.

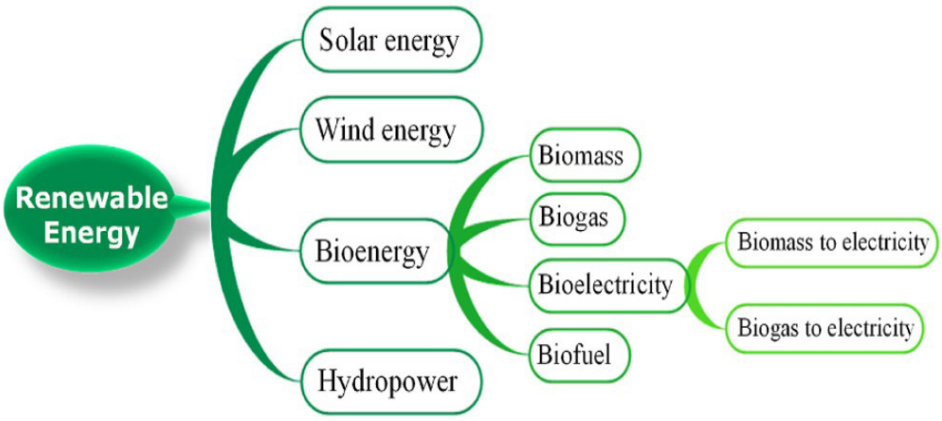

Figure 4: An overview of Bangladesh's present renewable energy resources
Source: Abdullah-Al-Mahbub & Islam, 2023

Keeping the lights on all the time is a real challenge for a developing country like Bangladesh. Right now, they mostly rely on natural gas for their energy, but everyone knows that stuff won't last forever. A huge chunk of all the energy they use – like almost three-quarters of it – comes from natural gas. And when it comes to making electricity, it's even more – over 80% of their power comes from burning natural gas. So, it makes a lot of sense for a country like Bangladesh to really start making good use of energy sources that can be renewed. Things like sunshine, wind, energy from plants, and biogas – these are all options that don't run out. The government, private companies, groups that are partly government-run, and even charities in Bangladesh have all started making long-term plans to try and use this renewable energy properly. They're looking at ways to tap into these sources so they can have a more secure and sustainable energy future.

Hydropower

even just a little bit of moving water, like a slow river or a gentle wave in the ocean, can actually create a surprising amount of power. And get this- water is like the superstar of renewable energy when it comes to turning that natural movement into electricity. It's super-efficient, like almost 90% efficient (Ang *et al.*, 2022). In the old days, they built these huge things – reservoirs and dams – to get power from water, which is called hydroelectric energy. Think of those massive projects like the Itaipu Dam, built together by Brazil and Paraguay, or the Three Gorges Dam in China on the Yangtze River. These big hydroelectric plants can usually churn out up to 50 MW of power. And who's the biggest in the world when it comes to making electricity with water It's China, with a crazy number – over 45,000 – of those smaller hydroelectric setups (Rabbani *et al.*, 2024). At present, the sole hydroelectric power generation

facility within Bangladesh is the Karnafuly Hydroelectric Power Station, possessing a power-producing capability of 230 MW. The operational oversight of this plant rests with the Bangladesh Power Development Board (BPDB). Looking ahead, BPDB has formulated strategies aimed at expanding the station's current capacity to 330 MW (Hasan, 2022).

Bioenergy

Since Bangladesh is largely an agricultural nation, there's a significant amount of biomass readily available. This includes things like cow manure, leftover bits from farming, chicken droppings, water hyacinth, and rice husks. These materials can be used to generate electricity. Biogas plays a really important role in Bangladesh. The government, various non-government organizations, and NGOs are all actively involved in helping to produce biogas (Hasan, 2022). Biogas is composed of a mixture of gases, in which methane (CH_4), ranging from 40% to 70%, and carbon dioxide (CO_2), ranging from 30% to 60%, are dominant. Water vapor (H_2O), present at 1% to 5%, nitrogen (N_2), found at 0% to 5%, and trace amounts of ammonia (NH_3), hydrogen sulfide (H_2S), and carbon monoxide (CO) are also included (Abdullah-Al-Mahbub & Islam, 2023).

Energy that comes from living things or materials that were once living is called bioenergy. You can turn bioenergy into heat (by burning wood or biogas directly), bio power (by burning biomass directly, or changing it into gas or oil to make electricity), and biofuels (to power vehicles). Biofuel is any fuel – gas, liquid, or solid – that you get directly or indirectly by changing biomass. Good examples are bioethanol made from sugarcane or corn, charcoal made from wood chips, and biogas made when waste breaks down without air. You can also make biofuels from lots of different plants, like Jatropha, castor bean, sunflower, sugarcane, mustard, corn, rapeseed, soybean, canola, and even algae (Abdullah-Al-Mahbub& Islam, 2023).

Wind Energy

Wind energy is considered one of the promising renewable technologies. The operation of wind turbines can be achieved by air flow. Modern utility-scale wind turbines have rated powers that range from around 600 kWh to 9 MWh. Since the power produced by the wind is determined by the wind speed, the turbine's power output reaches its maximum level as the wind speed climbs (EWEA, 2004). Wind farms are typically located in locations with stronger, more consistent winds, such as coastal and high-altitude areas. The typical annual full load periods for windmills range from 16% to 57%; however, they may be greater in particularly advantageous offshore areas (Kaltschmitt *et al.*, 2003).

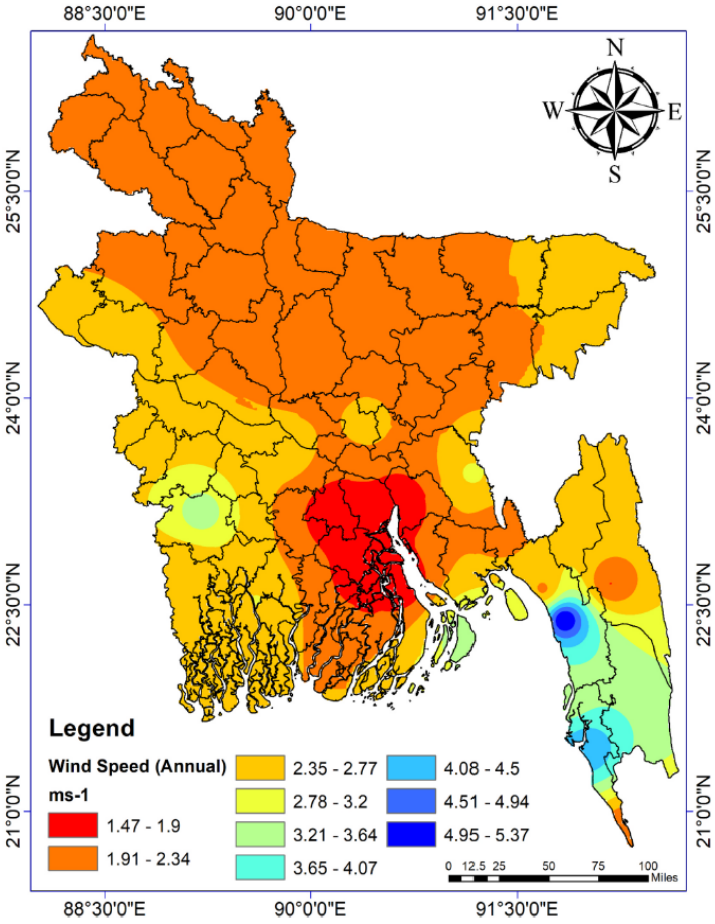

Figure 5: The distribution of average yearly wind speeds across Bangladesh
Source: Akash et al., 2024

Right now, the government in Bangladesh is really putting its attention on making electricity using wind power. They see a lot of promise in it. With that long coastline they have, about 724 kilometers, they figure they could get around 2000 MW of electricity just from the wind blowing along the shore. The problem is, it's not so easy to communicate with those coastal areas, which makes using that wind power tricky right now. Even with these challenges, the government has made up its mind to go for wind energy and is working on getting the infrastructure in place (Hasan, 2022). The people at the Bangladesh Power Development Board have even figured out that making electricity with wind costs less than setting up solar power plants to get the same amount of juice per kilowatt.

Solar Energy

Bangladesh gets a whole lot of sunshine every year – think about 19,000 units of energy hitting every square meter. If you break that down to a single day, it's like getting 4 to 6 and a half of those energy units on the same patch. Right now, all the solar panels in Bangladesh can produce about 229 megawatts of electricity. But the government has some really big plans for the future. They want to boost that solar power production way up to around 40 gigawatts by the year 2041. And they're expecting that a big chunk of all that new solar energy, maybe as much as 40%, will come from panels that people put right on top of their houses and buildings (Hasan, 2022).

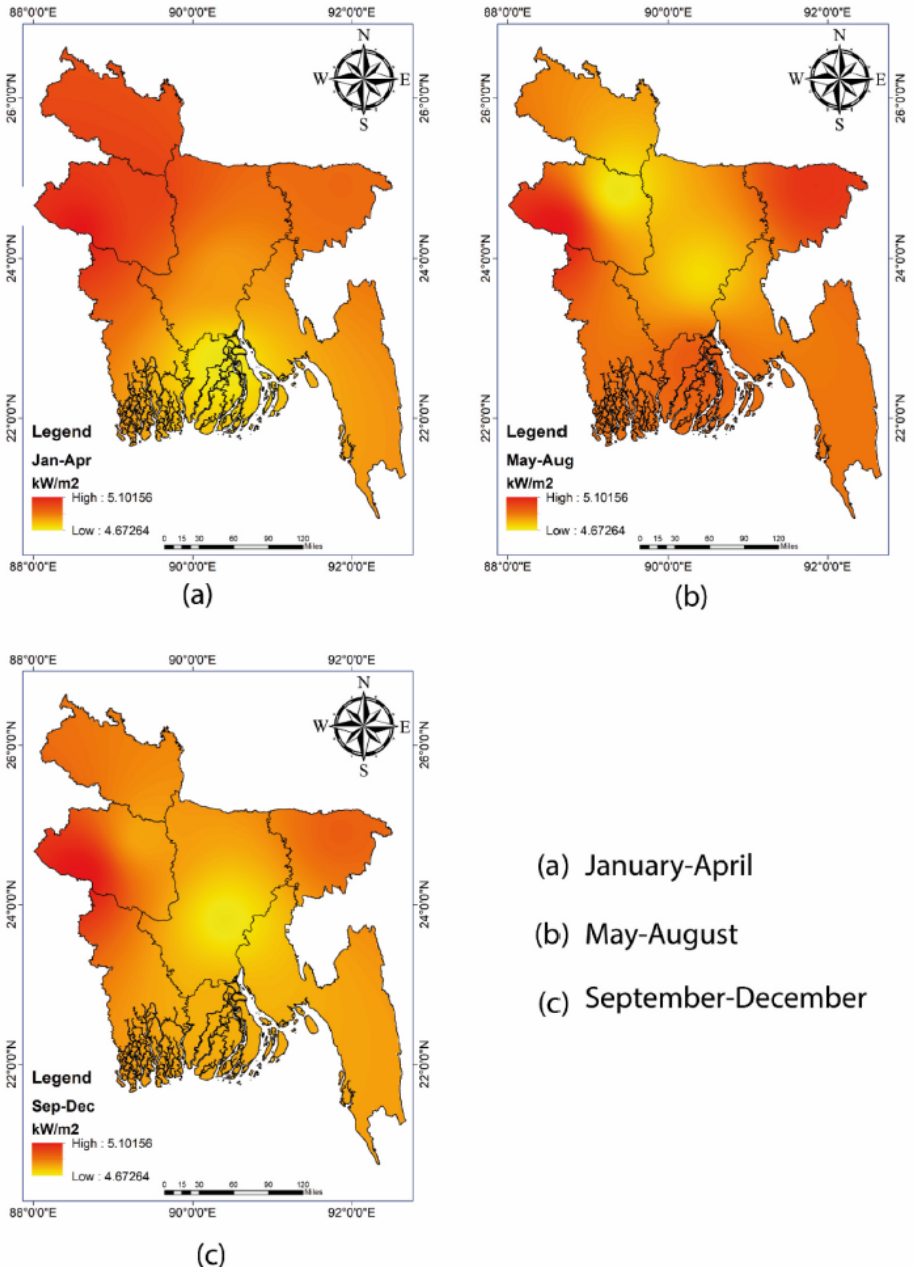

Figure 6: The yearly radiation levels in Bangladesh, calculated from the country's five largest cities (Dhaka, Bogura, Rajshahi, Sylhet, and Barishal

Source: WashimAkram et al., 2021; Akash et al., 2024

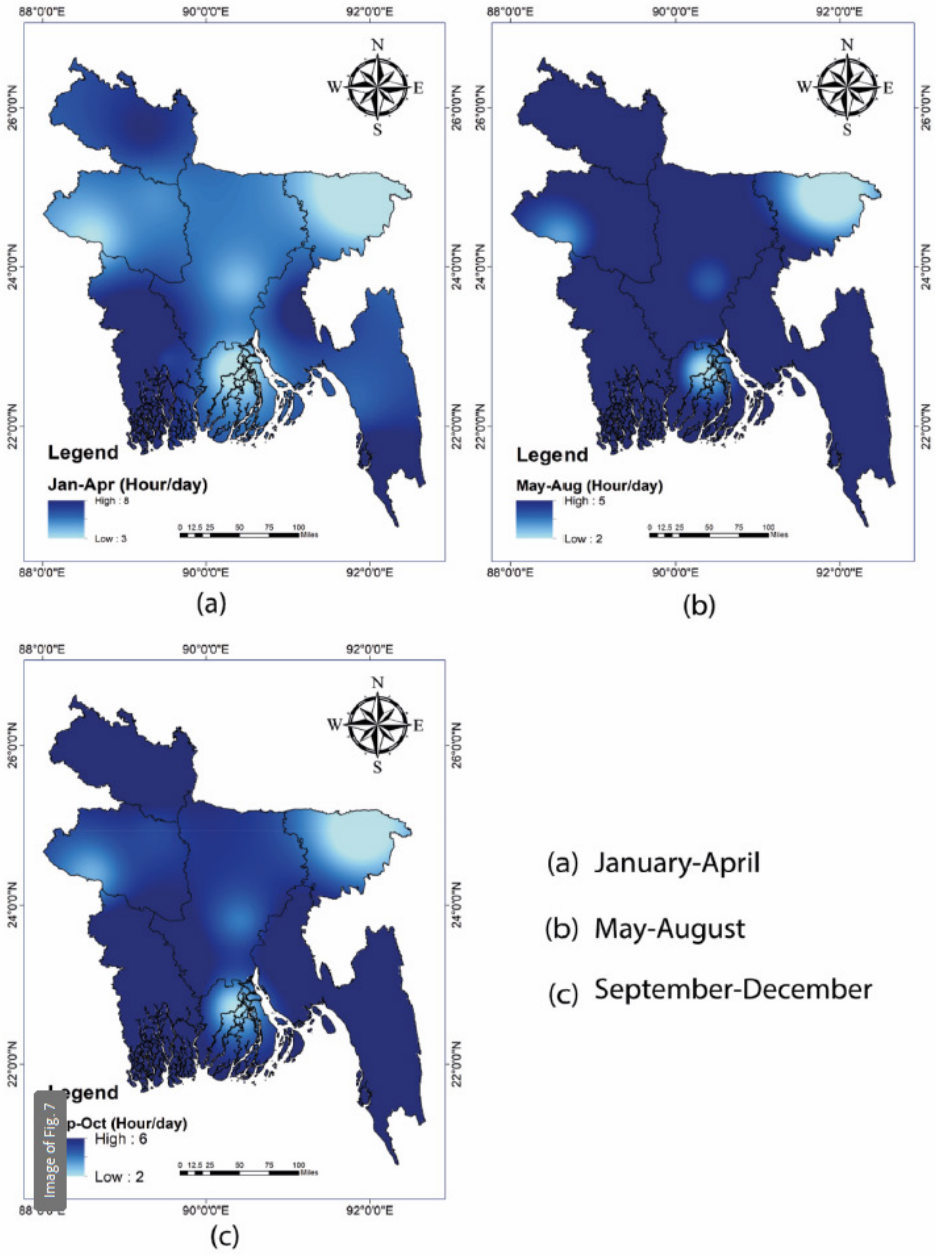

Figure 7: Sunlight hours in Bangladesh
Source: B.M. Department. 2023; Akash et al., 2024

The Multifaced Advantages of Renewable Energy Adoption In Bangladesh

Bangladesh is at a turning point in its growth, with its traditional energy sources becoming less viable and its energy demands rising. Adopting renewable energy is not just a wise decision for the country's environment; it offers a host of complex benefits ranging from long-term sustainability to social justice to economic prosperity. Bangladesh may move toward a more secure, wealthy, and resilient future by strategically pursuing solar, wind, bioenergy, and cooperative hydropower projects (Unb, 2025). The improvement of Bangladesh's energy security is among the most compelling benefits of adopting renewable energy. The country is susceptible to price swings and supply interruptions because to its reliance on limited indigenous natural gas sources and the unstable international market for imported fossil fuels. Bangladesh may lessen its reliance on outside sources and promote more energy independence and stability by diversifying its energy mix with domestic renewable resources. This independence results in stable energy prices, protecting the economy from the unpredictabilities of the world energy scene and enabling better long-term planning (Issue-I, 2022).

There are a lot of economic prospects for expansion and employment generation in the renewable energy sector. Investments in the creation, production, installation, and upkeep of renewable energy technology have the potential to boost regional economies and create jobs for workers of all skill levels. Large-scale solar and wind

farm projects, the installation of decentralized bioenergy systems, and the growing rooftop solar market are just a few examples of how the renewable energy sector can significantly boost economic growth, especially in rural areas where there are frequently few new opportunities (Karim, 2025). Renewable energy also provides a way to achieve more equitable access to electricity. Many renewable energy technologies, like solar home systems and biogas digesters, are decentralized and modular, which makes them perfect for electrifying underserved and remote communities where expanding the traditional grid infrastructure is frequently prohibitively expensive (Raftery, 2025). Greater social inclusion and a reduction in regional inequities can result from this increased access to clean and dependable electricity, which can also empower people, raise living standards, ease education, and open up economic prospects in formerly underserved areas (Energy Asia 2025, 2023). Making the switch to renewable energy has significant environmental benefits, especially for a country like Bangladesh that is particularly susceptible to climate change. Bangladesh can greatly reduce its greenhouse gas emissions by lowering its dependency on fossil fuels. This would help the world fight climate change and safeguard itself from its destructive effects, which include rising sea levels, harsh weather, and agricultural disruptions. Additionally, when operating, renewable energy sources emit very little air and water pollution, improving public health and creating a cleaner environment for all residents (United Nations, n.d.). In addition to these immediate advantages, using renewable energy can improve Bangladesh's reputation abroad and encourage technological advancement. Bangladesh may establish itself as a regional leader in sustainable development and draw in foreign investment and partnerships by adopting renewable energy technologies (Amir, 2023). In this quickly expanding global industry, the necessity to modify and enhance renewable energy technology for the local environment can also encourage innovation and the growth of local knowledge. In Bangladesh, adopting renewable energy has numerous, interrelated benefits. The shift to a renewable-powered future presents a revolutionary chance for the country to achieve sustainable progress and create a more resilient and prosperous society for future generations, from enhancing energy security and boosting economic growth to fostering social equity and protecting the environment. Bangladesh can propel its progress towards a cleaner and more promising future by wisely utilizing its wealth of renewable resources and cultivating a policy environment that supports them.

Bangladesh's Current Renewable Energy Technological Challenges

Bangladesh has enormous unrealized potential for using renewable energy, just as China and India. However, there are many obstacles in the way of RETs' global expansion. As listed below, a number of obstacles stand in the way of advancement. Figure 08 summarizes these problems with renewable energy.

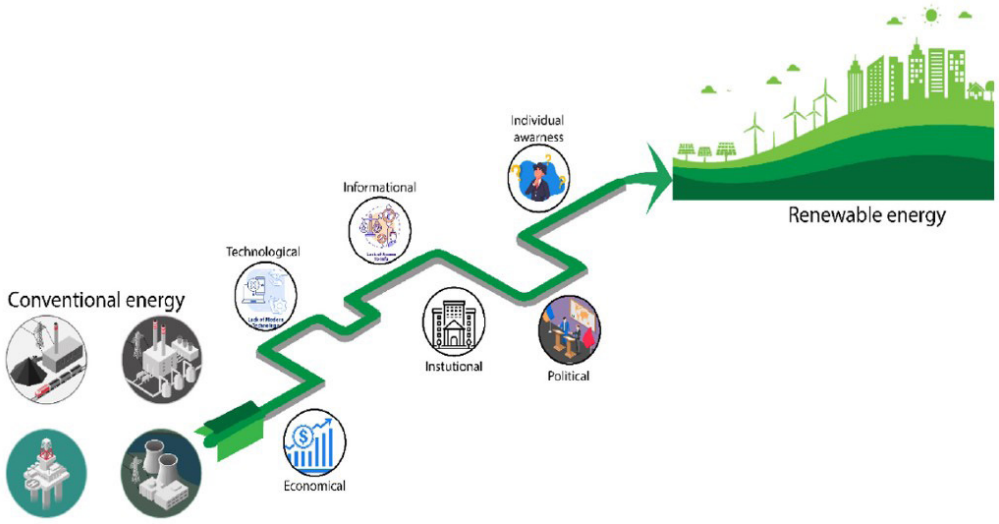

Figure 8: A summary of renewable energy's difficulties
Source: Akash et al., 2024

Bangladesh is aware of how important Renewable Energy Technologies (RETs) will be to the country's energy landscape in the future. However, there are a number of important obstacles in the way of broad adoption. The successful integration of RETs into the national energy strategy is hampered by inconsistent and shortsighted policies. Uncertainty and a lack of solid foundational support are caused by frequent policy changes and obstruct industry advancement. Moreover, the execution of RET programs frequently suffers from an excessive dependence on financial resources. Because RET projects must compete for scarce public financing against other urgent national goals like healthcare and education, this dependence causes delays and uncertainty. The necessity for more varied and sustainable finance methods for the growth of renewable energy is highlighted by this

financial limitation. Indirect subsidies that continue to support traditional energy sources also make RETs less economically competitive. Legislative support and specific financial incentives for RETs are necessary to level the playing field and promote investment in cleaner alternatives. A major obstacle to the broad adoption of RETs in Bangladesh is their high upfront prices, which require for financial assistance or subsidies in order to make them profitable for both consumers and companies. Although RETs provide viable lifecycles and long-term cost reductions, the high initial outlay needed may put off prospective users because of the delayed returns, which are made worse by current market interest rates. The potential of creative financing options is highlighted by the success of micro-credit models, as evidenced by Grameen Shakti's efforts to lower the cost of RETs (Akash *et al.*, 2024).

Bangladesh's greater transmission and distribution losses in comparison to developed countries present another significant obstacle. Since a sizable amount of the clean energy produced is lost before it reaches end consumers, these power infrastructure inefficiencies reduce the overall practicality and economic feasibility of RETs. Maximizing the advantages of renewable energy generation requires addressing these infrastructure flaws. Notwithstanding these challenges, Bangladesh has shown a strong commitment to the integration of renewable energy, as seen by the ambitious goals set forth in its Nationally Determined Contribution (NDC), which was submitted at COP26. A firm vision for a greener energy future is demonstrated by the goal of achieving 4100 MW of renewable energy capacity by 2030. However, significant improvements to the national grid infrastructure and extensive regulatory reforms are necessary to turn these goals into real action, especially from the private sector's point of view. Bangladesh must put a high priority on developing an environment that encourages strong private sector participation through extensive infrastructure and regulatory reforms if it hopes to fully realize the enormous potential of renewable energy. To achieve Bangladesh's goals for renewable energy and ensure a sustainable energy future, it is critical to address the policy inconsistencies, financial limits, indirect subsidies, high upfront costs, and infrastructure limitations (Akash *et al.*, 2024).

Bangladesh: Looking Towards a Renewable Energy Future

Here's a breakdown of what the future holds for renewable energy in Bangladesh:

Solar Power: Lots of Sunshine Ahead

Perfect Spot

Bangladesh's location on the globe means it gets a ton of sunlight almost all year round.

Big Potential

They get a good amount of solar energy every day, enough to really make a difference.

Government's Plan

The government is already putting up solar projects and has some really ambitious goals for how much solar power they want to produce in the future.

Wind Power: Tapping the Coastal Breeze

Windy Coasts

The areas along the coast have strong winds that are perfect for making electricity.

Huge Possibilities

There's the potential to generate a massive amount of power from both onshore and offshore wind farms (Figure 09).

Need to Build Up

They need to improve the infrastructure to really take advantage of this wind power.

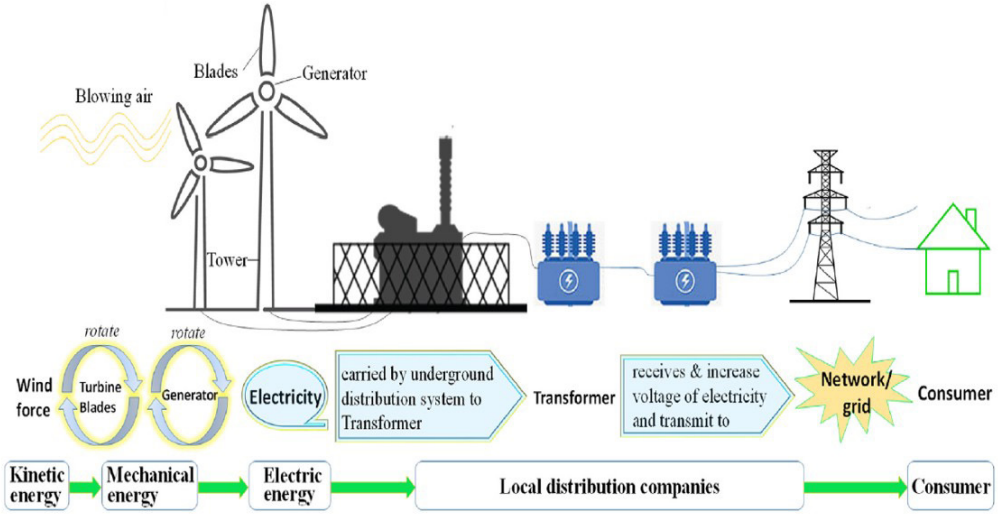

Figure 9: Wind power system, from generation to consumption
Source: Abdullah-Al-Mahbub & Islam, 2023

Bioenergy: Power from Plants and Waste
Rice Power
Because Bangladesh grows a lot of rice, there's plenty of rice husks that can be turned into electricity and other useful stuff.

Biofuel Hurdles
Making traditional biofuels like ethanol might be tough because there are a lot of people and not much spare land. Algae might be a better way to go.

Old and New Biomass
People in rural areas have always used things like wood for fuel. Biogas, made from waste, is a cleaner and more efficient option.

Animal Power (Biogas)
With so many chickens and cows, there's a lot of manure that can be used to make biogas.

Hydropower: Borrowing from Neighbors
Limited Local Rivers
Bangladesh doesn't have a lot of places for big hydroelectric dams.

Getting Power from Friends
Nearby countries have a lot of hydropower potential, and Bangladesh is looking to import some of that clean energy.
Bangladesh has a real chance to use renewable energy sources like solar, wind, and bioenergy to power its future. Bangladesh might also be able to get clean hydropower from their neighbors.

A New Beginning: The Promise of Renewable Energy for a Cleaner Bangladesh
Bangladesh is experiencing a serious energy crisis. The stability of its traditional sources of energy, i.e., natural gas, is declining, and the country is burdened with high costs of importing fossil fuels. This situation provides a strong argument for emerging energy solutions that are sustainable. Renewable energy sources offer an appealing prospect to secure energy while simultaneously saving the environment.The shift to renewable energy is central to the fight against climate change. Fossil fuels, upon combustion, release greenhouse gases, such as carbon dioxide, into the environment, and this is mostly to blame for global warming. Renewable energy sources, such as solar, wind, and hydropower, generate electricity with little or no direct release of these gases, and therefore, they are pivotal in the fight against climate change.
In addition to combating climate change, renewable energy also improves air and water quality. Traditional power plants that burn fossil fuels release harmful pollutants into the air and water, resulting in human health issues and environmental degradation. Renewable energy is a cleaner form of electricity generation, which reduces pollution-related health issues and prevents environmental degradation.Furthermore, renewable energy is sustainable. Unlike fossil fuels, which are finite and can be exhausted, renewable resources like sunlight and wind are constantly replenished. This ensures a long-term and stable energy supply in the future.In a word, the utilization of renewable energy is a vital choice for Bangladesh. It addresses the country's energy issue and saves the environment at the same time. The transition can lead to less greenhouse gas emission, cleaner air and water, and a sustainable future of energy for the nation.
The combustion of fossil fuels, as highlighted, is a primary driver of climate change due to the release of greenhouse gases, predominantly carbon dioxide (CO_2). The Intergovernmental Panel on Climate Change (IPCC) has unequivocally linked increasing atmospheric CO_2 concentrations to global warming and its associated impacts, such as sea-level rise and extreme weather events, which disproportionately threaten low-lying countries like Bangladesh. Renewable energy sources like solar photovoltaic (PV) and wind turbines operate without direct greenhouse gas emissions during electricity generation, thus mitigating climate change. Hydropower, while renewable, can have indirect emissions from reservoir construction and decomposition of organic matter. Furthermore, the text accurately points out the detrimental effects of fossil fuel combustion on air and water quality. Burning coal and natural gas releases pollutants such as particulate matter (PM2.5 and PM10), sulfur dioxide (SO_2), and nitrogen oxides (NOx), which are scientifically linked to respiratory illnesses, cardiovascular problems, and acid rain. Renewable energy technologies, excluding biomass combustion (if not managed sustainably), produce significantly fewer of these harmful pollutants, leading to improved public health outcomes and reduced environmental damage.
The sustainability argument is also scientifically sound. Solar irradiance and wind energy are virtually inexhaustible on human timescales. While the manufacturing of renewable energy technologies requires resources and energy, life cycle assessments consistently show significantly lower environmental impacts compared to fossil fuel-based energy systems over their operational lifetime. The long-term stability of energy supply offered by renewables contrasts sharply with the finite nature of fossil fuel reserves and the geopolitical vulnerabilities associated with their importation. In conclusion, a transition to renewable energy in Bangladesh is scientifically justified. It presents a pathway to reduce greenhouse gas emissions, improve air and water quality, and establish a sustainable energy future, aligning with global efforts to combat climate change and promote environmental sustainability.

Future Research Directions for Renewable Energy in Bangladesh
Optimising the integration of variable renewable energy sources, especially solar and wind, into the current national grid is a crucial area for future research because of the intermittent nature of these resources. Given

this, research should concentrate on advanced grid management techniques, such as smart grid technologies, load forecasting, and demand-side management strategies tailored to Bangladesh's unique energy consumption patterns. The preceding analysis highlights the compelling case for Bangladesh's transition towards a renewable energy-centric future, opening several crucial avenues for future research. Additionally, it is essential to investigate and modify economical and effective energy storage options, such as battery technologies and maybe pumped hydro where geographically possible, in order to guarantee grid stability and dependability with a large penetration of renewables. Developing and using bioenergy resources sustainably is another important area of research. Although it is clear that agricultural waste, such as rice husks, have promise, further research is required to maximize conversion technologies, increase energy yields, and evaluate the overall environmental impact, taking into account land use and greenhouse gas emissions. A intriguing avenue for research, given the constraints of conventional biofuel production, is the viability and sustainability of advanced biofuel production methods, such as algae-based biodiesel, in the Bangladeshi setting.

In light of Bangladesh's limited capacity for large-scale hydropower, future studies should examine the viability and economics of smaller-scale run-of-river hydroelectric projects as well as other cutting-edge hydrokinetic technologies appropriate for the nation's river systems and coastal regions. In order to provide a steady and varied energy supply, it is imperative to do research on the technical, political, and economic facets of regional energy cooperation for importing hydropower from nearby nations. Analyzing the legal frameworks, infrastructure needs, and geopolitical factors related to international energy trading is part of this. Furthermore, it is crucial to conduct study on the socioeconomic effects of Bangladesh's deployment of renewable energy. This involves evaluating the potential for job creation along the whole renewable energy value chain, the effect that decentralized energy access has on rural livelihoods, and the degree to which renewable energy technologies are accepted and known by the general population. A successful transition will depend on an understanding of the social and economic obstacles to adoption and the creation of practical solutions.

Lastly, ongoing research and development is required to optimize and adapt renewable energy technology for the Bangladeshi context. This entails assessing how well various solar PV modules and wind turbine designs perform in the local climate, creating long-lasting and reasonably priced off-grid renewable energy solutions for isolated locations, and investigating cutting-edge uses of renewable energy in industries like water purification and agriculture (such as solar-powered irrigation). For a thorough grasp of the environmental impact of the many renewable energy technologies used in Bangladesh and to pinpoint areas in need of development, life cycle assessments are also essential. In conclusion, Bangladesh needs a strong and diverse research agenda in order to make the transition to renewable energy in the future. Research should be focused on a number of important topics, including addressing grid integration issues, optimizing the use of bioenergy, investigating regional energy cooperation, comprehending socio-economic implications, and localizing technologies. The evidence-based knowledge gathered from these research projects will be used to inform policy choices, spur technical advancement, and guarantee Bangladesh's energy transition is egalitarian, sustainable, and seamless.

RESULT AND DISCUSSION

Bangladesh stands at a critical juncture in its energy development. Facing the depletion of domestic natural gas reserves and burdened by the escalating costs of imported fossil fuels, the nation urgently needs to chart a sustainable energy future. The preceding analysis underscores the technical and economic viability of renewable energy sources, aligning with global trends and presenting a compelling solution to the country's energy challenges while simultaneously offering significant environmental advantages. The current reliance on a fossil fuel-dominated energy mix, with natural gas forming the cornerstone of both energy consumption and electricity generation, is demonstrably unsustainable. The widening gap between domestic gas supply and increasing demand necessitates a strategic diversification of the energy portfolio. The economic strain of importing oil and liquefied natural gas (LNG), coupled with the well-documented environmental consequences of their combustion, highlights the pressing need for cleaner alternatives. While coal represents a smaller fraction of the current energy supply, its potential expansion carries substantial environmental risks associated with emissions and land use, making it a less desirable long-term solution.

In contrast, Bangladesh has a significant amount of unrealized potential for renewable energy. The high levels of solar irradiance experienced across the country offer a robust foundation for both centralized and decentralized solar power generation. The government's ambitious targets for solar capacity expansion are technically sound, particularly given the declining costs of photovoltaic technology. Furthermore, the assessment by the Bangladesh Power Development Board indicating the cost-effectiveness of wind power along the extensive coastline presents a strong economic argument for investment in this sector. The consistent wind speeds in coastal regions offer a reliable energy source, though the development of grid infrastructure in these areas remains a key challenge. Beyond solar and wind, bioenergy presents a readily available and environmentally responsible option, leveraging Bangladesh's significant agricultural sector. The conversion of agricultural waste and animal manure into biogas offers a decentralized energy solution, particularly beneficial for rural electrification and contributing to improved waste management practices. While large-scale biofuel production may face land constraints in a densely

populated nation, exploring alternative pathways such as algae-based biofuels warrants further investigation. The limited domestic hydropower potential necessitates exploring smaller-scale projects and fostering collaborative relationships with neighboring countries possessing greater hydroelectric resources. The global energy landscape is undergoing a profound transformation, characterized by the rapid growth and declining costs of renewable energy technologies. The significant proportion of new global power generation capacity additions from solar and wind sources underscores their technological maturity and economic competitiveness. The increasing share of renewables in the global electricity mix serves as a testament to their viability and provides valuable lessons and technological transfer opportunities for Bangladesh. This global momentum reinforces the strategic importance of embracing renewable energy as a key component of Bangladesh's energy future. The environmental imperative for transitioning to renewable energy is unequivocal. The scientific consensus linking fossil fuel combustion to climate change necessitates a fundamental shift towards energy sources with minimal operational greenhouse gas emissions. For Bangladesh, a nation highly vulnerable to the impacts of climate change such as sea-level rise and extreme weather events, this transition is not merely an environmental consideration but a matter of national resilience. The reduced air and water pollution associated with renewable energy will also yield significant public health benefits and contribute to a healthier environment.

To effectively navigate this energy transition, Bangladesh must adopt a multifaceted approach. Prioritized and sustained investment in both large-scale and distributed solar and wind power infrastructure is crucial, accompanied by necessary upgrades to the national grid to ensure stability and accommodate the variable nature of these energy sources. Supportive policy frameworks, including financial incentives and clear regulatory guidelines, are essential to attract private sector participation and accelerate the deployment of renewable energy technologies. Simultaneously, a focused effort on harnessing bioenergy resources through biogas and waste-to-energy initiatives can provide decentralized energy solutions and address waste management challenges. Exploring regional energy cooperation to access clean hydropower from neighboring countries can further diversify the energy mix and enhance energy security. Underpinning these efforts must be a commitment to research and development, particularly in areas such as energy storage, smart grid technologies, and sustainable biofuel production. Investing in capacity building and raising public awareness about the benefits of renewable energy will also be critical for a successful and enduring energy transition. The evidence overwhelmingly supports the assertion that a significant shift towards renewable energy is not only environmentally imperative for Bangladesh but also a strategically sound and economically viable pathway to secure its energy future. The nation's inherent renewable energy resources, coupled with global technological advancements and the urgent need to mitigate climate change, present a unique opportunity for Bangladesh to emerge as a leader in sustainable energy adoption within the region, paving the way for a cleaner, more secure, and prosperous future.

CONCLUSION

The detailed analysis shows a clear direction for Bangladesh's energy future, with renewable energy sources being most important. Bangladesh is at a key point as it tries to meet growing energy needs while knowing that relying on old fossil fuels is no longer a good long-term plan. The findings of this study strongly support a change to a more varied energy plan based on renewable sources. One important point is that Bangladesh is in a good position to use solar power. Because of its location, it gets a lot of sunlight throughout the year. This makes solar power a leading option for producing a lot of electricity and a good replacement for the fossil fuels that have been used. Using solar technology in different ways, from large power plants to individual rooftop panels, can help provide energy to more people, especially in rural areas that have not had good access before. Also, it would mean the country would not need to depend so much on fuels from other countries. The study also highlights the great potential of wind energy, especially along Bangladesh's long coast. Building wind farms, both on land and offshore, offers a big chance to use different energy sources and make the country's energy supply more secure. However, to really make this happen, they will need to invest wisely in things like better infrastructure to reach coastal areas, connect to the power grid, and store energy.

The research also looks at how much bioenergy could add to Bangladesh's energy sources. Using farm waste, like rice husks, to create power is a clean way to do it. It also helps with waste disposal and could help the rural economy. However, the study also warns against simply copying how traditional biofuels like bioethanol are made, mainly because Bangladesh has a large population and other important uses for its land. Finding a good balance is important, focusing on making sure there is enough food and looking into other biofuel options that do not use as many resources, like biodiesel made from algae. Besides solar, wind, and bioenergy, the study also considers hydropower. While it notes that there is not much space for large hydropower projects within Bangladesh itself, it points out how important it is to work with neighboring countries to import hydropower. This means that the country's overall energy plan needs to include both its own renewable energy projects and these partnerships with other nations. Basically, this research provides a solid plan for Bangladesh to move towards a future that is cleaner, greener, and where energy is more secure. Using the right renewable energy technologies, specifically chosen for the country's unique situation and what resources it has, is not just good for

the environment; it also makes sense economically and socially. By really focusing on developing renewable energy, Bangladesh can deal with climate change, reduce air and water pollution, make energy more available, boost economic growth, and build a future that is more sustainable and resilient for everyone.

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