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A Developing Country Changes Course: A Study of Sustainable Electrification for Bangladesh

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ABSTRACT

The two greatest problems facing many developing nations are the issues of extreme poverty and vulnerability to the effects of climate change. Bangladesh is no exception and in fact is considered a least developed country. They are one of the most densely populated nations in the world while at the same time consuming one of the lowest amounts of energy per capita. Their situation is further complicated by the geographical features of the country. Over 17 million people live on land that is less than one meter above sea level making them very susceptible to the rising oceans caused by climate change.

The Bangladesh government has developed an energy plan to fully electrify the country by 2020. This plan calls for the expansion of their current electricity grid by adding new natural gas and coal plants. The fuel resources to carry out this plan are available in Bangladesh but these fuels are not sustainable and will run out at some point in the future.

This report takes this energy plan and attempts to meet the same goals for electricity demand in the same time frame only in a sustainable way. The energy analysis program LEAP was used to model: the current situation in Bangladesh, the plan laid out by the government with natural gas and coal (the Reference scenario), and three alternative scenarios that implement the sustainable technologies of solar power, biogas, and municipal solid waste incineration through distributed generation. The alternative scenarios are (1) 100% Renewable technologies; (2) Resource limited renewable technologies; (3) Resource limited renewable technologies with a reduced Reference scenario.

The economic and environmental analysis of these four scenarios revealed that the third alternative is the most feasible, environmentally friendly option. Unfortunately, it is only able to provide 25% of the needed electricity generation through renewable technologies, the remainder comes from natural gas, but it is able to reduce the green house gas emission by 30% when comparing it with the Reference scenario. Its cost is 60% higher than the Reference scenario but will benefit Bangladesh by extending the lifespan of the natural gas and coal reserves until other technologies become available. Although this scenario does not meet the demand through 100% renewable technologies it is important to remember that poverty alleviation is important to Bangladesh and this scenario would accomplish this while also beginning a renewable technology movement in their energy sector.

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1 INTRODUCTION

A clear and defined relationship has emerged concerning the two global crises of climate change and extreme poverty. This association is manifested through the expansive, intertwined and detrimental effects of both phenomena. The Intergovernmental Panel on Climate Change (IPCC) recently claimed that “projected climate changes can exacerbate poverty... especially in developing countries, which are the most dependent on natural capital” (IPCC 2007). Projections from this report indicate that extreme climatic alterations will continue throughout the foreseeable future, further worsening the plight of those whose daily routines already force them to endure dreadful conditions. However, this kinship among climate change and poverty is not solely confined within the negative context. The authors of this last year’s UN Development Report (UNDP) issued a rallying call to the world: “We must see the fight against poverty and the fight against the effects of climate change as interrelated efforts. They must reinforce each other and success must be achieved on both fronts jointly <...>” (UNDP 2007/2008). Thus, as the symptoms of these great challenges are related, so is the cure, Sustainable Development.

Grounded in two of The United Nations’ Millennium Development Goals (UNMDG), “Eradicate Extreme Poverty” and “Ensure Environmental Sustainability” (UNEP 2008), the practical philosophy of Sustainable Development provides a two pronged attack strategy that combats the root of both global dilemmas. The “Brundtland Report” describes Sustainable Development as, “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (WCED 1987) Implied in this philosophy is the utilization of renewable resources for energy production as well as active participation in environmental conservation. These two principles directly impact the targets of the UNMDG in several critical ways. As affirmed by the Expert Group Meeting on Integration of Energy and Rural Development Policies Programs, “Sustainable energy development [was identified] as the *Missing Link* in rural poverty alleviation and environmental conservation.” (IERDP 2003) The International Institute for Sustainable Development (IISD) asserts; “For the poorest third of humanity, the capacity to cope with climate change is synonymous with sustainable development.” (IISD 2004). These statements bear evidence that an ideological awareness is emerging which has the potential to improve humanity’s standing as both anthropological brethren and terrestrial stewards.

1.1 Approaching the Problem

From a global perspective, the problems of climate change and extreme poverty appear obvious. The IPCC, in no uncertain terms, claims that the threat of climate change is real, imminent, and anthropologically influenced. The UN's member states have pledged through the UNMDGs, "to free our fellow men, women and children from the abject and dehumanizing conditions of extreme poverty." It is this pandemic poverty that is widely considered the root cause of humanitarian crises around the world. However, these broad statements struggle to illicit a critical connection with individuals. It is easy to talk about climate change and poverty as critical global issues; but when doing so from the comfort of a warm sitting room, the sense of urgency these problems should convey is often underwhelming. For this reason, it is useful to examine each issue in a more concentrated manner. An increasingly personal story should emerge that will help frame such discussions from the perspective of those who are most in peril. With any luck, this new perspective will provide the catalyst for active participation in finding solutions, rather than continued debate over what will happen if we don't.

The intention of this paper is to show that proper energy planning, utilizing renewable energy sources and sustainable practices, can be a major driving force for economic development. Perhaps more importantly, this development may be realized while simultaneously preserving and restoring the natural environment for future generations. In order to illustrate this argument, a case study and scenario planning analysis will be carried out regarding the People's Republic of Bangladesh. This analysis will specifically focus on the electrical energy sector. It will include a "business as usual" scenario projection as well as "alternative scenarios" with proposals for possible sustainable development strategies. These models should be relevant to government entities, international organizations and domestic grassroots movements currently engaged in ongoing electrification efforts. It is hoped that the conclusions reached will offer an alternative energy growth strategy for Bangladesh that would allow it to bypass or "leapfrog" the traditional reliance upon non-renewable fossil fuels evident in much of the developed world today. Ideally, this alternative strategy will be relatively repeatable for similarly characterized developing nations posed to embark on ambitious electrification operations of their own.

Thus, the research presented here has been conducted with respect to the following question:

How can Bangladesh provide adequate electricity to its populace while avoiding a reliance on fossil fuels by emphasizing sustainable development through the use of local renewable energy resources?

1.2 Defining the Problem

The following sections will clarify the greater issues of climate change and extreme poverty by focusing on the immediate dilemmas faced today by the people of Bangladesh. Additionally, it will be made clear just how vulnerable this nation is to the impending effects of climate change in relation to poverty and development. Finally, the advantages of adopting sustainable practices for reducing these vulnerabilities and improving Bangladesh's overall standard of living will be presented.

1.2.1 Extreme Poverty

In 2005, Nelson Mandela made an abject comparison: "Massive poverty and obscene inequality are such terrible scourges of our times—times in which the world boasts breathtaking advances in science, technology, industry and wealth accumulation—that they have to rank alongside slavery and apartheid as social evils." (HDR 2005) Mandela's statement is a rebuke of the world's gross and ever growing status of inequalities. For instance, according to the UN Human Development Report (HDP), 2005: "One-fifth of humanity live in countries where many people think nothing of spending \$2 a day on a cappuccino. Another fifth of humanity survive on less than \$1 a day and live in countries where children die for want of a simple anti-mosquito bed-net." They further state, "The world's richest 500 individuals have a combined income greater than that of the poorest 416 million. Beyond these extremes, the 2.5 billion people living on less than \$2 a day—40% of the world's population—account for 5% of global income. The richest 10%, almost all of whom live in high income countries, account for 54% (Figure 1-1)." (HDR 2005) These statements are extraordinary in their description of the world's abhorrent poverty gap.

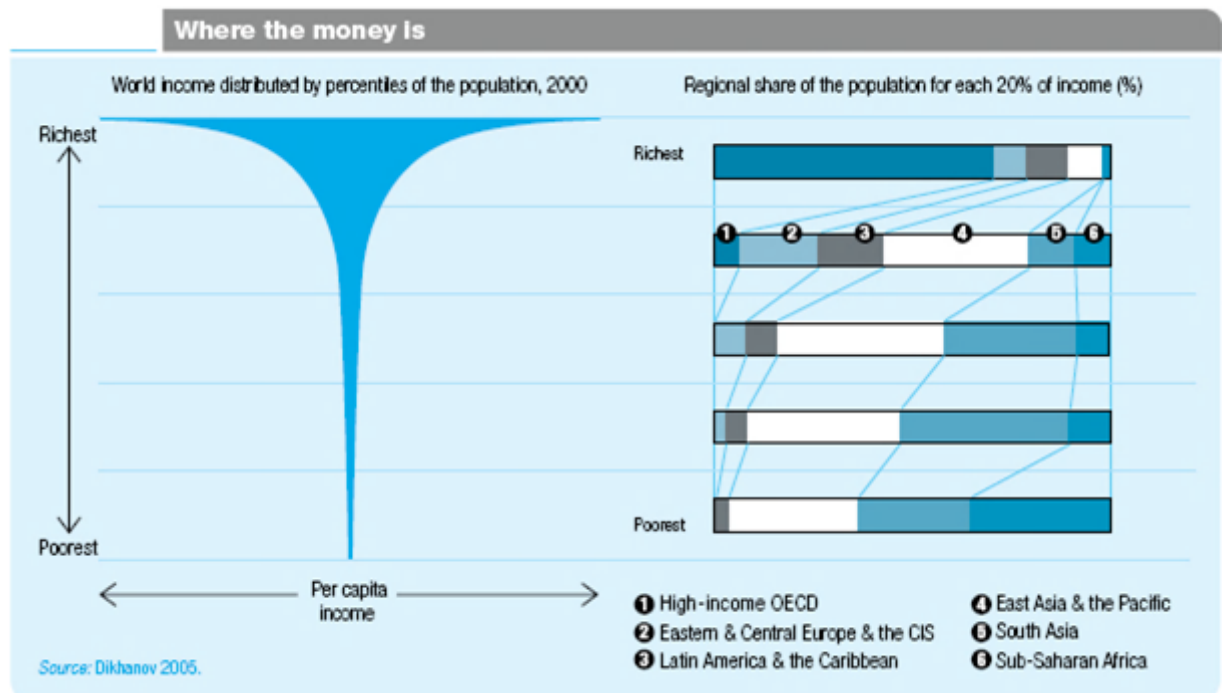


Figure 1-1: Global distribution of wealth by region (HDR 2005).

Remark: CIS – Commonwealth of Independent States.

OECD – Organization for Economic Co-operation and Development.

Compounding the vast size of this gap is the cyclical nature of the problem, poverty breeds poverty. The inability to improve one's own life inherently prevents this life from improving. While this seems blatantly simple, it is a problem at the heart of the global poverty pandemic. These people are not only unable to help themselves; they are actually worsening their own situation by fighting the basic battle for survival. In order to cook and stay warm, most impoverished people rely on indigenous biomass for fuel. This is particularly true for rural areas in developing nations where 90% of total energy is supplied by biomass resources, often leading to significant deforestation (Importance of Rural Bioenergy for Developing Nations, 2007). Scarcity of food, loss of wildlife habitat and competition for limited natural resources are growing areas of concern throughout the third world. As affirmed by the UN Department of Economic and Social Affairs, "The enormity and complexity of the poverty issue could endanger the social fabric, undermine economic development and the environment, and threaten political stability in many countries." (UNDESA 2008)

Bangladesh has endured many of these hardships. The United Nations considers Bangladesh a Least Developed Country (LDC). Also referred to as the "Fourth World", the categorization of LDC is reserved for those nations which exhibit the lowest indicators of socioeconomic development as defined by the following UN criteria (UN-OHLLS 2008):

- Three year average Gross National Product (GNP) under \$ 750 per capita;
- Human resource weakness including nutrition, health, education and adult literacy;
- Economic vulnerability based on instability of agricultural production, instability of export industry, economic smallness handicap and population vulnerability to natural disasters.

The same UN body describes Bangladesh thusly: “Despite sustained domestic and international efforts to improve economic and demographic prospects, Bangladesh remains a poor, overpopulated, and ill-governed nation.” The non-profit poverty alleviation advocacy group, International Development Enterprises (IDE), attests that Bangladesh has seen modest improvement in its poverty situation in the last decades; however, at the turn of the century, 50% of Bangladeshi people remained mired in poverty with a full third of the total population considered to be living in extreme poverty. The geographic breakdown of economic distribution is stark, with 85% of poor Bangladeshis living in rural areas (IDE 2008).

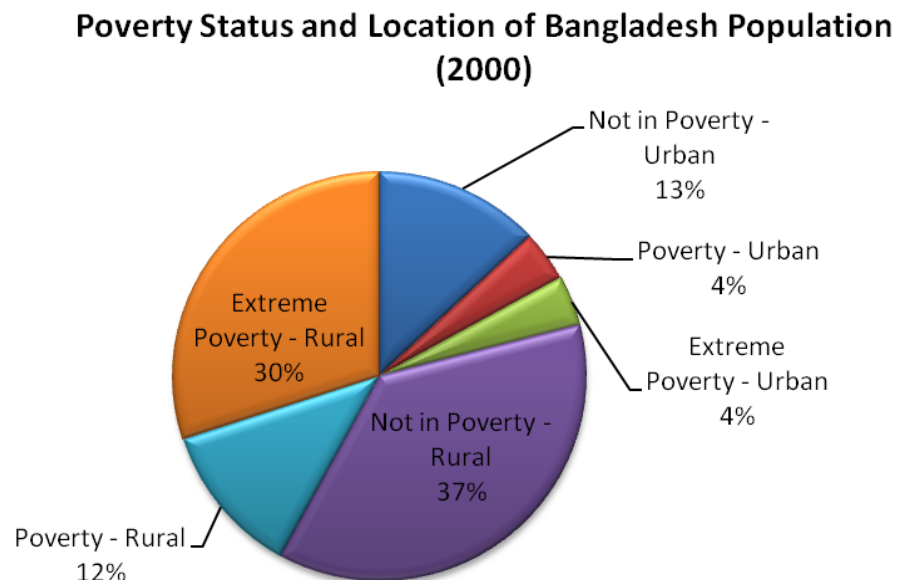


Figure 1-2: Poverty distribution in Bangladesh (IDE 2008)

Poverty – insufficient resources for food and basic necessities.

Extreme Poverty – insufficient resources even for food.

The UN’s LDC description of Bangladesh reinforces this assessment by stating that “although half of Gross Domestic Product (GDP) is generated through the service sector, nearly two-thirds of Bangladeshis are employed in the agriculture sector, with rice as the single-most-important product.” (UN-OHLLS 2008) Again, the IDE provides a snapshot of this rural situation in the following Table 1-1, detailing the percentage of landless agricultural workers in relation to poverty:

Land Ownership category	Percentage of Rural Population	Incidence of Poverty
Functionally Landless (own less than 0.05 ha)	48%	65%
Small Farmers (owning 0.2 – 1.0 ha)	40%	49%
Medium and Large farmers (owning more than 1.0 ha)	12%	22%

Table 1-1: Breakdown of rural land ownership and percent of each category that live in poverty (IDE 2008).

The fact that so many make their meager living through subsistence agriculture is a telling indicator of Bangladesh's overlying poverty dilemma; that its rural population is cut off from modern energy and associated economic possibilities, as evidenced by its paltry 22% rural electrification rate (M. Islam 2006). It is no wonder then that Bangladesh has maintained its status as an LDC.

Providing power to Bangladeshi citizens currently without would help them achieve significant improvements in their daily lives. The most basic modern technology, electric lighting, allows people to read, write and work after sunset. A pleasure most of the world takes for granted, the introduction of affordable lighting greatly increases a person's productivity. A survey of Grameen Shakti program implementers regarding the success of Solar Home Systems (SHS) units in rural households revealed the following (Tania 2008):

- 100% of SHS recipients said their quality of life improved, including opportunities for entertainment and increased working and studying hours;
- 87% thought the solar lighting program created more local jobs;
- 40% said they used the system for direct income generation.

The simple introduction of electric lighting into these homes has indelibly improved the life of each family. Increasing the scope of rural electrification projects will lead to further achievements in poverty reduction throughout Bangladesh. It will allow industries to grow where it was once impossible, creating jobs and productive income in place of the daily struggle to eat. However, it is important to consider the means with which Bangladesh provides this modern energy. As will be shown below, expansion of the status quo system of fossil fuel powered energy will ultimately exacerbate the plight of Bangladesh's impoverished population.

1.2.2 Climate Change

The UN Development Report declares that “climate change is the defining human development challenge of the 21st Century.” (UNDP 2007/2008) Though long overdue, it appears that the world’s leaders have finally taken this statement to heart. Debates which previously concerned scientific validity and proof of anthropogenic influence are now distinctly focused on strategies for mitigating and adapting to the world’s rapidly altering climate. However, admitting one has a problem is merely the first step; recovery is a long and arduous process. The response posed by the world must be swift and decisive, time is not a luxury. Echoing this sentiment, the UN Development Report declares: “Increased exposure to droughts, floods and storms is already destroying opportunity and reinforcing inequality. Meanwhile, there is now overwhelming scientific evidence that the world is moving towards the point at which irreversible ecological catastrophe becomes unavoidable. Business-as-usual climate change points in a clear direction: unprecedented reversal in human development in our lifetime.” (UNDP 2007/2008)

An often overlooked dimension to the greater issue of climate change is the unbalanced vulnerability of varied peoples to these adverse effects. As asserted by the UNDP: “While there is potential catastrophic risk for everyone <...> The distributional challenge is made particularly difficult because those who have largely caused the problem— the rich countries—are not going to be those who suffer the most in the short term. It is the poorest who did not and still are not contributing significantly to green house gas emissions that are the most vulnerable.” (UNDP 2007/2008) The inability of developing nations to rapidly respond to natural disasters is a distinct vulnerability not shared by developed countries. This disparity is made evident by the IPCC which claims that “more than 90% of the deaths related to natural disasters occur [in developing nations]”. (IPCC 2007)

Bangladesh is particularly susceptible to the effects of climate change. The IPCC projects a “high frequency of extreme climatic events for Bangladesh <...> Anticipated adverse impacts of climate change include primary impacts on human lives from high sea level rises, sea surge from severe storms, consecutive floods, drought, and heavy rainfalls as well as secondary impacts from resource constraints and the redirection of development assistance toward rebuilding basic infrastructures.” (N. Uddin 2008) Outlined in Section 1.2.1 (Extreme poverty), the majority of Bangladeshi people are heavily reliant upon agriculture and naturally occurring resources for survival. This reliance on nature, in combination with limited financial resources, magnifies the dangers faced by Bangladesh and similar LDCs around the world. As the adverse effects of climate change worsen, the most visible impacts for Bangladesh may include any or all of the following:

- Loss of habitable land: for both humans and wildlife;

- Rapid population relocation;
- Increased spread of communicable diseases;
- Unpredictable crop productivity;
- Malnutrition and possible starvation;
- Resource deficits;
- Political instability;
- Increased human fatalities.

The Bangladeshi people's reliance on indigenous natural resources for survival propagates a common syndrome in developing nations. As they consume resources for basic necessities they are progressively destroying the very carbon sinks that serve as mitigating factors to both the cause and effects of climate change. In addition to the increased atmospheric CO₂ concentrations brought on by the loss of these sinks, the substitution of old growth plant life with agricultural fields reduces the land's natural ability to cope with hydrological events; groundwater percolation is depleted while natural water flow barriers are removed. These result in increased quantity and velocity of surface water runoff, which in turn leads to greater frequency and severity of floods (Wikipedia 2008 d). However, arguably the greatest danger posed by climate change is the potential rise in sea levels. 17 million people, over 10% of Bangladesh's total population, live on land that is less than 1 meter above the sea (CAR 2006). While estimates vary, a modest ocean rise of a few meters could prove catastrophic for Bangladesh. To cope with this challenge, massive investment in levee and dike infrastructure would be required, assuming this response is even technologically possible. More likely, a rise in sea level would lead to the displacement of millions of Bangladeshi people.

While it is unclear what effect, if any, a drastic shift in global policy will have in reducing the impacts of climate change, without this shift there is little doubt. As it stands today, developing nations around the world, including Bangladesh, will suffer intensely from the expected consequences of climate change. The choice is obvious, the world must respond.

Looking to the future, no country—however wealthy or powerful—will be immune to the impact of global warming. There is a window of opportunity for avoiding the most damaging climate change impacts, but that window is closing: the world has less than a decade to change course. Actions taken—or not taken—in the years ahead will have a profound bearing on the future course of human development. The world lacks neither the financial resources nor the technological capabilities to act. What is missing is a sense of urgency, human solidarity and collective interest. (UNDP 2007/2008)

1.2.3 Sustainable Development and International Benchmarks

The IISD has published a report detailing the importance of decentralized renewable energy (DRE) in the context of climate change mitigation. They also claim that sustainable development using DRE can be a driving force in achieving the UNMDGs.

Summarily, IISD claims that poverty and environmental degradation are intertwined. Figure 1-3 displays the IISD's simplified flowchart detailing this synonymous relationship.

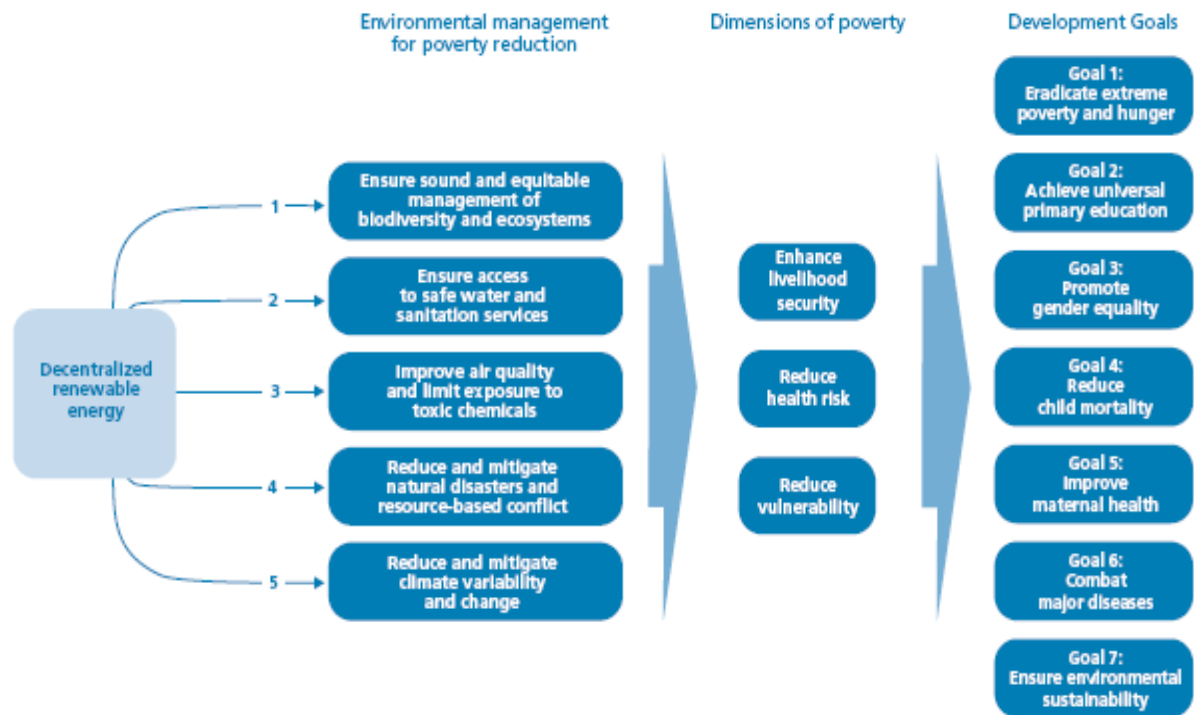


Figure 1-3: Linkage between DRE, environmental management and development goals in relation to poverty (IISD 2004).

As shown above, the principles of environmental management for poverty reduction intrinsically influence the UN's defined dimensions of poverty, therefore impacting the world's ability to achieve the UN's Millennium Development Goals. The IISD report from which Figure 1-3 can be found goes on to detail the role of DRE in improved environmental management techniques.

Environmental and Poverty alleviation benefits of decentralized renewable energy:

- A. Improved management of and cohabitation in the natural environment. They enhance agricultural productivity per land used by powering improved irrigation techniques thus reducing deforestation due to the need for more subsistence based agricultural land.

- B. Greater access to safe, fresh water. Pumps powered in off-grid locations can access deeper, cleaner groundwater for drinking or sanitation purposes.
- C. Reduce local and global air pollutants. Incorporating efficient renewable energy in place of oil fired combustion generators as well as more efficient use of biomass will reduce air emissions of all types. Local inhabitants will be exposed to fewer toxic chemicals during domestic practices.
- D. Reduce impacts of natural disasters. Assuming adoption of DRE helps to reverse deforestation in developing nations, the associated increase in biomass will attenuate flood and drought impact by reducing runoff and increasing deep groundwater percolation.
- E. Reduce impact of rural energy on climate change. As renewable energy sources, DRE's do not emit CO₂. Additionally, improved use of biomass and biogas can reduce methane emissions from livestock.

The IISD further provides linkages between DRE and the Millennium Development Goals, though these won't be listed here. The main point being that sustainable development using distributed generation and renewable energy provides improved methods for general electrification to the local populace. By improving environmental management techniques, poverty alleviation will be enhanced. Additionally, access to clean water and improved air quality will result in an increase in rural standards of living.

1.2.4 Potential Roadblocks for Distributed Generation and Sustainable Development

Conversely to the developed world, the major limiting factor for renewable energy implementation in third world nations is the lack of financial capital. While the price of alternative technologies is consistently decreasing, they are still not on even ground with simple fossil fuel power generators. As these developing nations are constantly strapped for cash, it is difficult to validate greater initial investment in sustainable energy, despite the savings that could be realized further on down the road. Political instability provides a second roadblock, creating anxiety and fear in potential foreign investors who might otherwise be willing to help fund renewable energy projects. Stabilizing the government, producing clearly defined energy policies and adhering to said policies would greatly enhance a developing nation's chances of receiving international aid for development projects, particularly those involving long term infrastructure improvements.

2 RESEARCH METHODOLOGY

Following the “wisdom-generating” planning framework described in “The Missing Link in Sustainable Energy” (Blarke 2008), the research presented here has been guided by the following questions:

1. What is the problem, who is affected by it?
2. What is the objective of examining the problem?
3. What is the current situation and what are the major contributing factors?
4. Where will the current trends lead?
5. What are the options for change?
6. What are the consequences with respect to these options and who will be affected?
7. What should be done regarding the original problem, anything?
8. What is the intent of this action (non-action), is it congruous with our stated objectives?

Section 1 addresses the first two questions by identifying our main areas of concern, specifically electricity sector development in relation to socio-economic (poverty) and the environment (climate change). These are initially described in broad contextual terms followed by a focused discussion of the specific vulnerabilities experienced by the people of Bangladesh in relation to these issues.

Section 3 answers the third planning question by describing the relevant history and current conditions in Bangladesh. Situational factors are identified in terms of demographic and geographic data while direct contributing factors include: general energy and specific electricity demand and production; resource availability and consumption; methods and technologies currently employed within the energy sector.

Section 4 introduces the scenario modeling process beginning with key assumptions made for each developed scenario. The Power System Master Plan (the Master Plan) (Nexant 2006) describes the official strategy for electricity development and serves as the basis for our scenario platform. Using the computer modeling program LEAP (Long Range Energy Analysis Program), a “current account” reflecting the data from the Master Plan and section 3 was constructed. Answering question four of the planning framework, a “reference scenario” has been projected to the year 2025 that reflects our interpretation of the current energy development trends.

Section 5 addresses question five by identifying the best fit renewable energy options for sustainable, decentralized electricity expansion as determined by our case study and literature research. Three “alternative scenarios” were constructed in LEAP that each emphasize varying amounts of renewable and “reference” technologies to meet expected growth in electricity demand.

Sections 6 and 7 provide a comparative analysis of each alternative scenario versus the reference. Particular attention is paid to whether or not Bangladesh’s electricity requirements are met, what the economic implications of each electrification strategy are, and finally the environmental factors associated with each scenario. Impacts on the Bangladeshi people and institutions are considered. This will lead into a discussion about what, if anything, Bangladesh authorities should do to amend their electrification agenda. Our recommendations will be framed from the dual perspectives of poverty alleviation and climate change mitigation while keeping in mind the government’s distinct intentions for electricity expansion.

Section 8 will conclude the report with a summary of conducted research and provide an answer to our research question based on our best educated assessment.

The following diagram Figure 2-1 provides a visual representation of the research methodology and structure followed throughout this project:

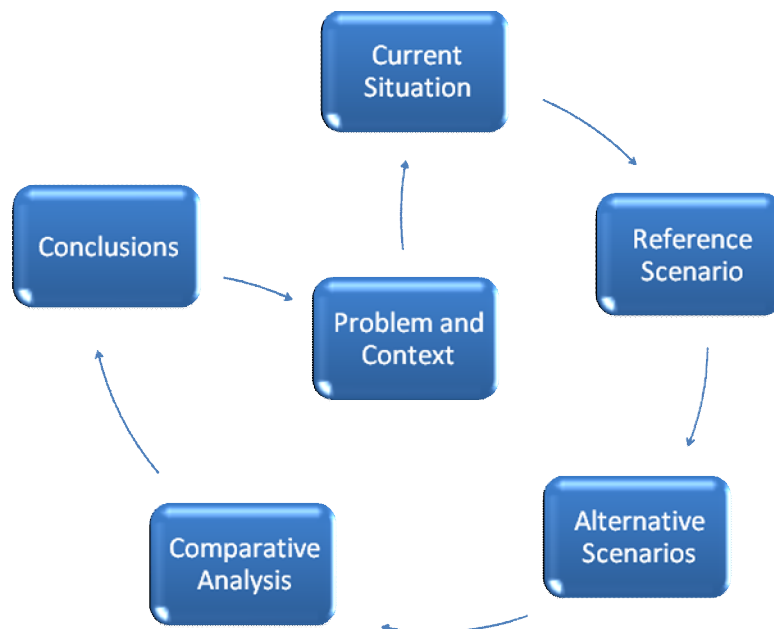


Figure 2-1: Research methodology structure

This project is primarily a case study and scenario modeling endeavor focused on the Bangladeshi energy system. Based on the established government agenda, Power System Master

Plan, Bangladesh plans to meet 100% of its electricity demand by the year 2020 (Nexant 2006). The objective of our report is to provide a realistic development strategy that will allow Bangladesh to achieve this goal by utilizing sustainable, renewable resources. This strategy will be developed through the formulation of reference and alternative scenarios describing the next 20 years of energy development in Bangladesh.

The first step for this project consisted of defining a problem and identifying key driving forces. The broad issue of energy in relation to climate change and socio-economic development provided the motivational basis for this project. Bangladesh was then selected as the target case study based on the following set of criteria:

- Current energy situation: large percentage of populace without access to electricity
- Current economic situation: LDC nation showing signs of economic improvement
- Political situation: relatively stable government with capacity to implement policy initiatives
- Availability of data: recent, credible, accessible data exists

The remaining activities were devoted to integrating a traditional case study analysis with a fluid scenario planning approach. This process began by creating a “current account” of Bangladesh, including a general overview of the demographics, economy and political situation as well as an in depth analysis of electricity production and consumption. To design this present model, data was collected from publications found in research journals and official documents from the Government of Bangladesh. Additionally, reports were examined from international organizations active in Bangladesh’s energy sector such as International Energy Agency (IEA), the United Nations (UN), Energy Information Administration (EIA) and several others. Background information such as geography, demographics, economic indicators, and political conditions were used to frame the general situation while specific energy indicators established the working variables to be altered in the scenario modeling stage. Main indicators include:

- Primary energy supply
- Fuels and technologies used for electricity production including efficiencies and costs
- Fossil fuel reserves
- Renewable energy potential
- Emissions data related to energy production
- Planned future installations
- Transmission and distribution grid data
- Electrification rate as well as geographic distribution of electricity access

After constructing the current account, the software program LEAP (Long-Range Energy Analysis Program) was used to create a “business-as-usual” development scenario for Bangladesh. LEAP then extrapolated the impacts of the scenario parameters to the year 2025. The scenario was then analyzed in regards to a number of relevant outputs corresponding to those defined in the current account. Significant additions include:

- Population growth
- Energy demand and consumption growth
- New electricity generation technologies
- Transmission infrastructure expansion
- Costs associated with each investment over the scenario lifespan
- Environmental effects such as greenhouse gas emissions and other toxic chemicals
- Resource depletion

Accompanying the reference scenario are several alternatives. These emphasize the use of sustainable practices and renewable energy for achieving domestic electrification. Information gathered during the literature search regarding potential renewable energy resources and technologies applicable to the geographic and economic conditions in Bangladesh provided guidelines for the construction of these alternative scenarios. Again, LEAP was used to extrapolate these models to 2025. The same characteristic outputs were analyzed as in the reference scenario with advantages and disadvantages highlighted.

The final step is to establish recommendations based on the scenario models developed as to how Bangladesh can best fulfill its electrification goals. It is hoped that feasible alternatives will be found that emphasize the sustainable and renewable development objectives stated in the beginning of this report.

3 BANGLADESH FROM ABOVE

3.1 Bangladesh: Demographics, Politics, Economy

The People's Republic of Bangladesh (further just Bangladesh) is a country in South Asia. The major neighbor that this country borders is India, it almost surrounds Bangladesh. Still, there's a small border with Myanmar to the far southeast and the Bay of Bengal to the South. Bangladesh is divided into administrative divisions and each of them is named after their respective divisional headquarters: Barisal, Chittagong, Dhaka, Khulna, Rajshahi, and Sylhet (CIA 2008, a).

Geographically the country straddles the Tropic of Cancer and the fertile Ganges-Brahmaputra Delta, however it is struggling with natural calamities, such as floods, tropical cyclones, tornadoes, and tidal bores that occur almost every year, combined with the effects of deforestation, soil degradation and erosion. The government created the Ministry of Food and Disaster Management to statistically track and give aid to those affected by these commonly occurring disasters.

17 million people live on land that is less than 1 meter above sea level, most parts of Bangladesh are less than 12 meters (Wikipedia 2008, a) above the sea level. The highest point in Bangladesh is Keokradong 1,230 meters above sea level (CIA 2008, a) and the lowest – Indian Ocean 0 meters (CIA 2008, a). A major part of the coastline comprises a marshy jungle, the Sundarbans, the largest mangrove forest in the world and home to diverse flora and fauna, including the Royal Bengal Tiger. In 1997 (Wikipedia 2008, a), this region was declared endangered.

Its tropical climate with a mild winter from October to March, a hot, humid summer from March to June and a warm and humid monsoon season from June to October, which supplies most of the country's rainfall, is subjected to extremities. The average annual rainfall is 2540 mm (Bangladesh Statistics 2006), although it varies from a maximum of 5,690 mm (Bangladesh: Rainfall & Weather 2008) in the northeast of the country to minimum of 1,110 mm (Bangladesh: Rainfall & Weather 2008) in the west. Average annual temperature is 26 °C (Bangladesh Statistics 2006).

3.1.1 Population and history

With a population of almost 154 million (July 2008 est.) (CIA 2008, a) it is one of the most densely populated countries in the world. With a total land area of the country is 144,000 sq km, of which water covers 10,090 sq km and land 133,910 sq km (CIA 2008, a). So the (CIA 2008, a) giving a population density of 1067 persons per sq km. Capital, Dhaka, is one of the biggest cities in South

Asia with over 12 million inhabitants (2007 est.) (Bangladesh Statistics 2006). Life expectancy at birth for total population is 63.21 years (male - 63.14 and female - 63.28 years (2008 est.) (CIA 2008, a). In comparison, the population density in Denmark is 128 persons/sq km and total life expectancy at birth for total population – 78.13 years (male - 75.8 years and female - 80.59 years (2008 est.)) (CIA 2008, b).

About 98% of the Bangladesh people are Bengalis and use the official Bengali language. Minorities include all the tribal population of Bangladesh's, about 1 million people. They include people such as the Biharis numbering of 250 000 (Virtual Bangladesh 2008) and the Chakma being most numerous in number. They live primarily in the Chittagong Hills and in the regions of Mymensingh, Sylhet, and Rajshahi. The majority of the tribal population (778,425) (Virtual Bangladesh 2008) live in rural settings, where shifting cultivation is mostly practiced. These minorities differ from the rest of the country in their social organization, marriage customs, birth and death rites, food, and other social customs. They also speak Tibeto-Burman languages because most of tribal people are of Sino Tibetan descent.

Bangladesh became independent from West Pakistan in 1971 (CIA 2008, a). And now it is a parliamentary democracy with Islam (89.7 %, 96 % of them are Sunni) (Wikipedia 2008, a) as the state religion, with the number of 130 million Muslims (Bangladesh Statistics 2006). Hinduism compiles only 9.2 %, Buddhism (0.7%, mostly Theravada), Christianity (0.3%, mostly Roman Catholic denomination), Animism and believers in tribal faiths (0.1%) (BANBEIS 2006).

3.1.2 Government

The President is the head of state, a largely ceremonial post elected by the parliament. The Constitution of Bangladesh was drafted in 1972 and has undergone fourteen amendments. The highest judicial body is the Supreme Court. Laws are loosely based on English common law, but family laws such as marriage and inheritance are based on religious scripts, and therefore differ between religious communities.

3.1.3 Economy

45 % (2004 est.) (CIA 2008, a) of country's population is below the poverty line, though unemployment rate (includes underemployment) estimated in 2007 is only 2.5 % (CIA 2008, a). Almost two-thirds of Bangladeshis are employed in the agriculture sector, with rice as the most important product. Beside inefficient state – owned enterprises, insufficient power supplies, delays in exploiting natural gas, slow implementation of economic reforms, the economy has grown 5-6 %

(CIA 2008, a) over the past few years. Bangladesh remains a poor, overpopulated, and inefficiently-governed nation. However, more than half of the Gross Domestic Product (GDP) is generated through the service sector. The GDP purchasing power parity is $\$208.3 \cdot 10^9$ (2007 est.) (CIA 2008, a), GDP is $\$72.42 \cdot 10^9$ (2007 est.), this amount of money shows the GDP as official exchange rate, which is the home-currency-denominated annual GDP figure divided by the bilateral average US exchange rate with that country in that year (CIA 2008, a). GDP per capita is $\$1,400$ (2007 est.) (CIA 2008, a), while in Denmark it is $\$37,200$ (2007 est.) (CIA 2008, b).

3.2 Energy situation in Bangladesh

In this chapter an overview of the current energy situation is given. These include the current electricity crisis, the energy production, power facilities, and fossil fuel reserves. The energy statistics quoted in this article are the most recent, publicly available data from 2005. According to the significant data for the scenario modeling, most information are attributed to the Power System Master Plan (PSMP) updated 2004, this will be referred to in this paper as the Master Plan.

3.2.1 Current electricity crisis

Currently there is fluctuation in the electricity supply especially urban areas. The high electricity demand cannot be covered through the low available electricity generation capacity. According to this shortage of electricity, the available power is allocated by load shedding (Uddin and Taplin 2008, a). In 2004, the maximum load shedding was about 700 MW. At this time the average of maximum daily power demand is 5,000 MW and natural gas demand is about 1,900 million cubic feet ($0.054 \text{ million m}^3$) compare to an effective power generation capacity of 4,000 MW and daily gas supply of 1,750 million cubic feet (0.05 million m^3) (Energy Bangla 2008, a). Uddin and Taplin presented the reasons for low electricity generation by aging power plants, unprofessional maintenance and shutdowns because of overloading (Uddin and Taplin 2008, a). Though, Energy Bangla maintained that the main fault lies with the government because they didn't establish an Energy Authority of competent and honest energy professionals to manage the whole energy sector in a more sustainable way (Energy Bangla 2008, a).

3.2.2 Power demand

The biggest concentrations of power demand in the country are regions of most developed and most populated cities. Dhaka's region demand made 47 % of the national total 3,952 MW

(including estimated load shedding) in 2004 (Nexant 2006). Other regions ranked as follows in Table 3-1.

The Southern Region (including Chittagong)	20 %
The Western Region (including Khulna)	12 %
The Northern Region	12 %
The Central Region	8 %

Table 3-1: Power demand concentration

The Rural Electrification Board (REB), in their summary report about rural consumer information, states that the demand from 2003 to 2006-2007 (July 06 – December 06) grew from 1,293 MW to 1,874 MW (REB 2005)

The forecasts of electricity demand in Bangladesh are usually made according to GDP growth rate, as it is historically known as proper linkage between economic activity and electricity demand for a developing country. The last 10 years (1996 – 2006) GDP average growth rate of 5.1 % was accompanied by 8.1 % (Nexant 2006) rate of net electricity demand growth as an average per annum. Last year's Bangladeshi economy rate was increasing, for example in 2003 it was 4.40 %, while in 2007 – 6.60 % (CIA 2008, a).

3.2.3 Institutions and authorities of Power sector

Bangladeshi demand of electricity is divided into urban and rural electricity demand. Therefore power generation, transmission and distribution authorities were (and still are) created relating to these circumstances. Although Bangladesh has been independent for 36 years, the power sector still needs a lot of reforms and investment to improve the amounts of producing power, the distribution lines and reduce losses. Changes and developments are already being made by the government in planning, managing and implementation of new projects, regulations and institutions. The government of Bangladesh outlined a reform process of the power sector focusing on institutional issues in a paper "Power Sector Reforms in Bangladesh" in 1994 which gave specific direction on physical planning of the power system. This encourages splitting loads of electricity generation, transmission and distribution with respect of creating new authorities and companies to manage them. The current structure of the Power Sector is shown in Figure 3-1 and more detailed explanations of the authorities and companies are listed below.

Bangladesh Power Sector: Current Structure

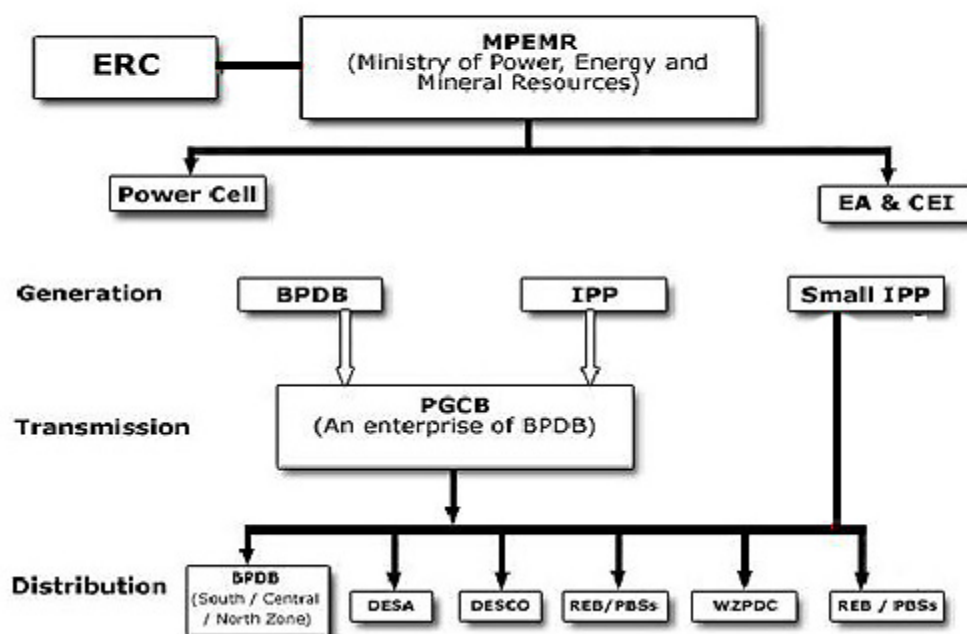


Figure 3-1: Bangladesh Power Sector current structure.

Remark: ERC – Energy Regulatory Commission;

EA & CEI - Office of the Chief Electrical Inspector & Electrical Adviser.

Bangladesh Power Development Board (BPDB) was created in 1972 as a public sector organization to boost the power sector. Then the Rural Electrification Board (REB) was established in 1977, as the semi-autonomous government agency, which is still the most important authority for electrification of rural areas of Bangladesh. REB is reporting to the Ministry of Power, Energy and Minerals Resources.

As Dhaka grew in population and became a metropolitan city, the need for its own electricity grid management was obvious, this led to the creation of the Dhaka Electric Supply Authority (DESA) in 1991. It was implemented to operate and develop the distribution system and bring about improvements in customer service, collection of revenue and lessen the administrative burden of BPDB. After a decision by the government, Dhaka Power Distribution Company Ltd. (DPDCL) has taken over DESA activities from the 1st of July 2008. This is part of the overall power sector reform aimed to unite the energy system and produce a more competitive, reliable and efficient system.

To bring about a commercial environment in the energy sector by introducing an increase in efficiency, the establishment of accountability and dynamics, the Power Grid Company of Bangladesh

(PGCB) was created. It was established under the restructuring process and incorporated in 1996. Entrusted to own the national power grid and to operate and expand the same with efficiency. In the end of 2003 PGCB completed taking over and operating all the transmission assets from BPDB and DESA. PGCB is a public limited company and 76.25 % of it is owned by BPDB, the remaining portion, 23.75 %, is owned by the general public (PGCB 2008).

Creation of the Dhaka Electric Supply Company (DESCO) was part of the reforms being initiated by the government. It was created as a public sector company, incorporated under the Companies Act 1994 as a subsidiary of DESA. However, in the future, shares of the company will be offered to the private sector, other power sector entities and the general public to make the DESCO's management more responsive to its consumers.

As for creating opportunities of improving agricultural production and improvements in standard of living and quality of life by means of electrification in rural areas REB today has 70 operating rural electric cooperatives called Palli Bidyut Samity (PBS). These cover more than 90% (REB 2008) of effective area for rural electrification. It brings service to approximately 7,200,000 new connections and constructing more than 14,000 km of line each year.

Generation, transmission and distribution of electricity have been opened to foreign and private sector involvement, although both sectors remain dominated by state-owned entities. Power Division was established in 1998 under the Ministry of Power, Energy and Mineral Resources. It is entrusted with the responsibility of overall management of the power sector in Bangladesh.

Power Cell has been created by the government under Power Division, Ministry of Power, Energy & Mineral Resources under the "TA [Technical Assistance] for Implementation of Bangladesh power sector reform" project to carry forward the Power Sector reform activities of the government of Bangladesh. The Bangladesh Energy Regulatory Commission Act was enacted in March 2003 and Bangladesh Energy Regulatory Commission has been made functional since April 2004. The Commission has a mandate to regulate the electricity, gas and petroleum sector and has been fully functional since the year 2008. It has been established with the vision "To make provisions for the establishment of an independent and impartial regulatory commission for the energy sector". (BERC 2008)

3.2.4 **Energy production**

Bangladesh had in 2005 a total primary energy consumption of 24.19 MTOE (million tons of oil equivalent) that corresponds to a per capita consumption of 158 kgOE (kilogram of oil equivalent) (IEA 2005, a) Thus it was one of the lowest per capita consumption within the Indian subcontinent

compared to 491 kgOE for India, 490 kgOE for Pakistan, 477 kgOE for Sri Lanka and 453 kgOE for South Asia, and it was far below the world average of 1,796 kgOE (World Bank 2005). The share of the total primary energy supply was estimated with biomass 34.3%, natural gas 44.7%, oil 19.1%, coal 1.4% and hydro 0.5% as illustrated in Figure 3-2 (IEA 2005, b).

Electricity is generated from natural gas (82 %), oil (9 %), hydro (4 %) and coal (5 %). The total installed capacity of power generation is 4,458 MW which is not achievable due to the electricity crisis (see 3.2.1) (Energy Bangla 2008, b). In 2006 only 42.09 % of the population was served with electricity and per capita electricity consumption is only 169.92 KWh (BPDB 2006). Reasons for the low electricity accessibility are the high transmission and distribution costs, transmissions losses and high prices (Uddin and Taplin 2008, a). The demand of electricity in 2004 was about 20,300 GWh.

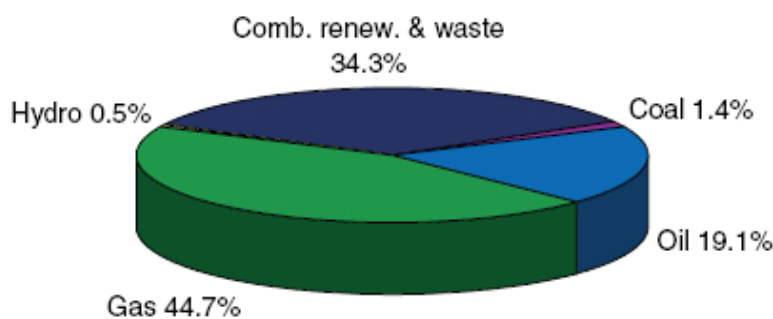


Figure 3-2: Share of Total Primary Energy Supply of 2005 (IEA 2005, b)

Among biomass and hydro there is several renewable energy systems used in Bangladesh that are more common in rural areas. Current renewable energy technologies include solar photovoltaic (PV) as solar home systems (SHSs) for solar cookers, dryers, water heaters and tunnel dryers for crops, biogas, biomass briquetting machines and improved cooking stoves (Uddin and Taplin 2008, a). In Bangladesh over 3,000 kW of solar PV applications (M. Islam 2006) and over 45000 SHSs are in operation. Also there are over 19,500 biogas plants operating and a wind power generation capacity of 50 kW (Uddin, N. and Taplin, R. 2008, b)

	Coal	Crude Oil	Petroleum Products	Gas	Hydro	Combustible Renewables and Waste
Supply						
Production	0	98	0	10,806	111	8,296
Imports	350	1,070	3248	0	0	
Exports	0	0	87	0	0	0
Consumption						
Electricity Plants	0	0	534	4,682	111	0
Petroleum Refineries	0	1,488	1,418	0	0	0
Own Use	0	0	63	0	0	0
Distribution Losses	0	0	0	688	0	0
Industry sector	350	0	234	1,526	0	0
Transport sector	0	0	1,759	0	0	0
Other sectors	0	0	1,479	1,869	0	8,296
Non-Energy Use	0	0	486	2,041	0	0

Table 3-2: Energy supply and consumption of Bangladesh 2005 (in thousand tons of oil equivalent (IEA 2005, a).

3.2.5 Power Transformation

Power Facilities

As mentioned before the total installed capacity of power production is 4,458 MW. There are different types of power plants which generate electricity and synchronize it with the national grid. At remote places and islands which are not connected to the national grid there are diesel engines in operation. The power facilities are operated by the public Bangladesh Power Development Board (BPDB) and the private Independent Power Producers (IPP). (BPDB 2007)

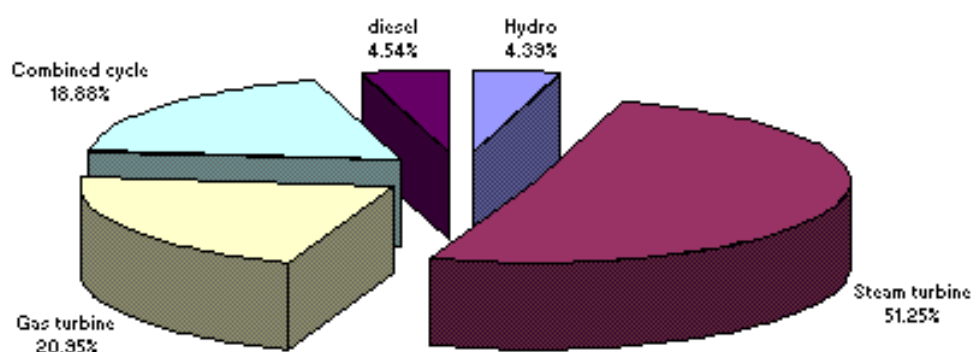


Figure 3-3: Share of total installed capacity by plant type (BPDB 2006)

Figure 3-4 illustrates the classification of the total installed capacity to fuel types in percentage. In 2006-07 the public sector produced 62.84 % and the private sector 37.16% of the total energy consumption (Ministry of Finance 2007).

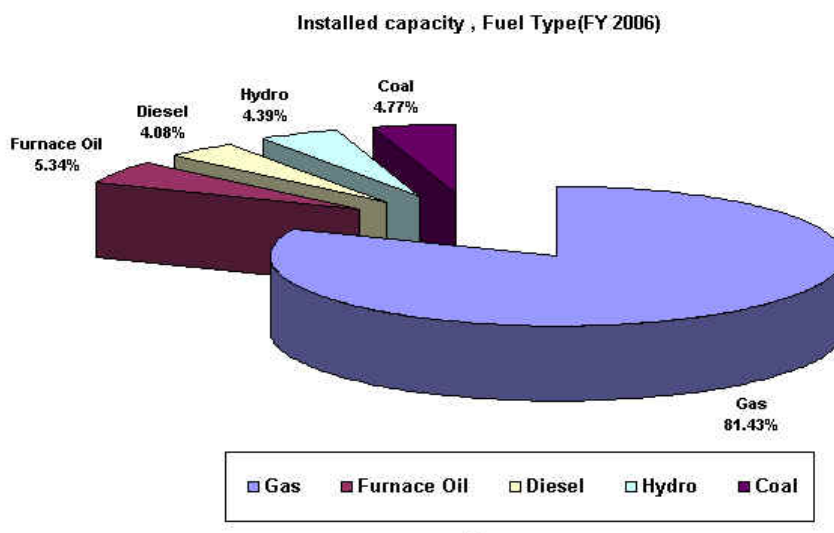


Figure 3-4: Installed capacity according to primary energy source (BPDB 2006)

Furthermore, with the committed capacities the total net installed capacity increase up to 6,966 MW by 2010. These facilities are predominantly based on natural gas which raises the share of the primary energy source from 82% to 86 %. The existing and committed facilities can be found in the Power System Master Plan (Nexant 2006). Here the generation facilities specific terms such as net capacity, heat rates, fuel costs, operations and maintenance costs, operating days and so on can be viewed. Table 3-3 illustrates the existing and committed capacities in 2004 with the primary energy input.

	Primary Energy Input						TOTAL
	Fuels						
	Natural Gas	Domestic Coal	Imported Coal	Diesel	Heavy Fuel Oil	Hydro	
Total National Existing Capacity, [MW]	3,486	0	0	158	246	230	4,120
% of National Total June 2004	85%	0%	0%	4%	6%	6%	100%
Total National Committed Capacity, [MW]	2,515	230	0	0	0	100	2,845
% of National Total	88%	8%	0%	0%	0%	4%	100%
TOTAL NATIONAL EXISTING AND COMMITTED CAPACITY, [MW]							
	6,002	230	0	158	246	330	6,966
% of National Total	86%	3%	0%	2%	4%	5%	100%

Table 3-3: Primary Energy Resources for Existing and Committed Capacity (Nexant 2006)

Present Generation Technology

This section focuses on the generation technology within the different power plants, especially which are using natural gas and coal. Furthermore, it portrays the power generation based on renewable energy resources.

Steam Turbine

Steam turbines are the most common technology for electricity generation in the world. When considering the availability, reliability and performance of the present steam turbine technology the efficiency has reached a high value. The turbines are made in a variety of sizes but the performance of electricity generation units can obtain more than 1 GW. Steam temperature and pressure for the process are up to 650°C and 375 bars respectively. To increase the efficiency within the power facility more stages are integrated and therefore the efficiency lies between 40 % and 48 % (DEA 2005).

Simple Cycle Combustion (Gas) Turbine (SCGT)

In the combustion turbines the fuel is burned and the generated kinetic energy moves the generator. It has a lower efficiency than the steam turbine due to worse utilization of the energy. The electrical efficiency factor lies between 29 % and 42 % and the size of the combustion turbine unit has progressed to more than 300 MW (DEA 2005).

Combined Cycle Gas Turbine

The combined cycle gas turbine is a combination of the simple cycle combustion turbine and the steam turbine. In the gas turbine fuel is burned and the hot exhaust gases are used to generate steam for a steam turbine. For this process an efficiency of up to 60 % can be achieved (DEA 2005).

Table 3-4 represents different generation units with specific terms, attributes and costs.

Unit Type	Net Unit Capacity (At Grid)	Thermal Parameters	Equipment Cost \$/kW	Installation Cost \$/kW	Total Project Cost \$/kW	Construction Time Per Unit, Months	Plant Life, Years	Minimum Load, % of Capacity	Net Heat Rates at Grid, kcal/KWh			Weeks/year Sched Maint	FOR, %	O&M Cost	
									At 100% Power	At 75% Power	At 50% Power			Fixed \$/kW-month	Variable \$/MWh
Steam (coal) with FGD	500	Note 1	896	215	1,111	60	30	50%	2,154	2,198	2,268	8	8%	0,58	1,8
CC (natural gas)	300	Dual Pressure	438	232	670	36	25	50%	1,720	1,856	2,023	6	6%	0,42	2
SCGT (natural gas)	100		238	163	401	24	20	50%	2,687	2,986	3,161	4	4%	0,42	2,5
Steam (natural gas)	500	Note 1	579	211	789	60	30	50%	2,109	2,152	2,220	6	6%	0,58	1,6
Diesel (diesel fuel)	10	Medium Speed			450	24	15	50%	2,900	3,050	3,200	3	15 %	0,83	3
Note 1: Superheat, Single Reheat, 165 bar/538 deg C/538 deg C															

Table 3-4: Generation Units Options (Nexant 2006)

Remark: O&M Cost – Operation and Maintenance Costs;

FOR – Forced Outage Rate.

Electricity Grid – Transmission and Distribution

From different power plants generated electricity is transmitted by the national grid system through its 230kV and 132kV transmission lines. The electric grid system, transmission and distribution lines, is annually increasing in size. In 1996 the total lengths of 230 kV and 132 kV transmission lines were 838 ckt (circuit) km and 4,755 ckt km respectively which increased to 1466 ckt km and 5,577 ckt km respectively in 2006 – 07. The total lengths of the Distribution system, 33 kV, 11 kV and 0.4 kV raises from 35,962 km in 1995-96 up to 47,479 km in 2006-07 (Ministry of Finance 2007). The losses of the transmission and distribution system are a part of the energy sector that requires a solution. In the last years a reduction of losses has been achieved but more improvements are essential. The distribution losses decreased from 30 % in 1994 to 21 % in 2004. Transmission losses dropped from 4.7 % to 3.5 % in the same period.

Table 3-5 gives the existing transmission system. It shows the existing, under construction and planned 230 kV and 132 kV transmissions lines. Dashed lines represent the planned facilities, dotted lines the facilities under constructions and solid lines the existing transmission lines.

Currently, there is only one 230 kV line that connect the eastern and western part of the country. To improve the reliability of the transmission system there is a second 230 kV line under construction that connect East and West.

The Bangladesh power development plan intends to intensify the power generation. To handle these large power flows there are already committed transmission lines. For a higher reliability, stability and voltage flow there is a 400 kV line in the area of Dhaka. A list of the committed transmission facilities, length of existing transmission lines, existing 230 kV/132 kV transformers can be found in the Master Plan document (Nexant 2006). According to the Power System Master Plan, transmission and distribution lines will reach 12,000 km and 477, 558 km respectively by the year 2020. That expansion shall ensure an electricity accessibility of 100% after the same period. Table 3-5 shows the costs of transmission lines and system components.

Transmission lines	Thousand \$/km	Transmission devices	Thousand \$/unit
400 kV, double circuit	291	¹⁾ 400/230 kV, 375/375 MVA	4,178
230 kV, double circuit	189	¹⁾ 230/132 kV, 225/225 MVA	1,857
132 kV, double circuit	102	¹⁾ 230/132 kV, 125/125 MVA	929
400 kV, single circuit	189	400 kV circuit breakers	1,162
230 kV, single circuit	123	230 kV circuit breakers	789
132 kV, single circuit	66	132 kV circuit breakers	325
		1) Transformers	

Table 3-5: Costs of Transmission System Components (Nexant 2006)

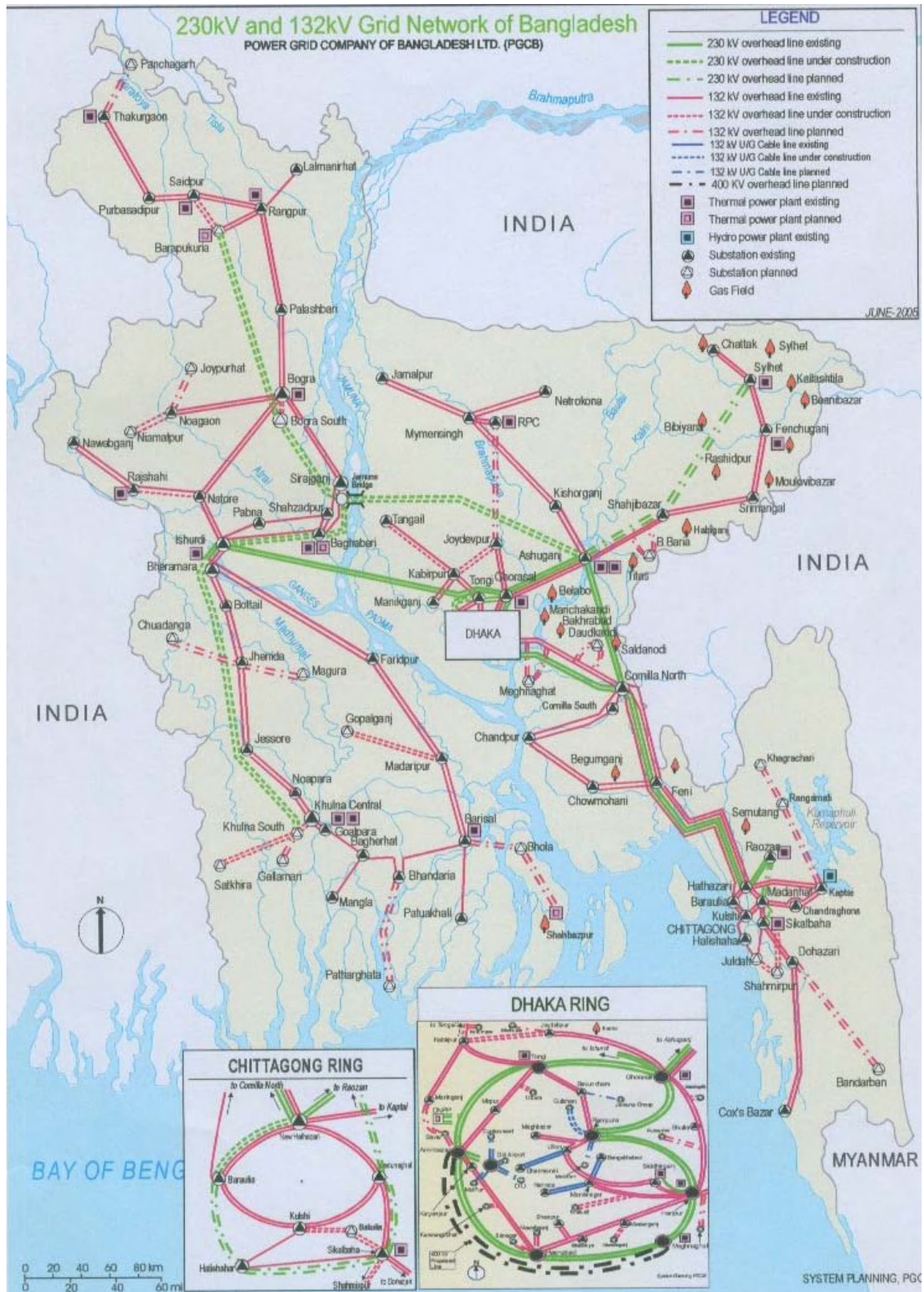


Figure 3-5: Map of Electricity Grid (Nexant 2006)

3.2.6 Resources

Gas Reserves

In 2004 the proven and probable gas reserves from 22 gas fields (21 in East zone and 1 in West zone) was about 20 trillion cubic feet (Tcf), of which about 5 Tcf has so far been used. The natural gas production was 463 billion cubic feet (Bcf), up from 429 Bcf in 2003 (EIA 2006, a), out of which the power sector accounted for 40%. The end users of natural gas are power plants, fertilizer factories, other industries (e.g. brick factories, tea processing plants, steel mills and textile factories), commercial organizations (e.g. offices and business centers) and the domestic sector (Hossain and Badr 2005)

FIELD	Recoverable = Proven + Probable [BSCF]	Cumulative Production [BSCF]	Net Remaining Recoverable, [BSCF]
A. PRODUCING			
1. Bakhrabad	1,002	624	378
2. Beanibazar	170	23	147
3. Habiganj	3,854	1,089	2,765
4. Jalalabad	879	158	721
5. Kailashtila	1,931	317	1,614
6. Meghna	111	32	79
7. Narshingdi	77	47	30
8. Rashidpur	1,401	307	1,094
9. Sangu	734	247	490
10. Saldanadi	140	32	108
11. Sylhet	479	172	307
12. Titas	5,110	2,179	2,931
B. NOT IN PRODUCTION			
13. Begumganj	32	0	32
14. Bibiyana	2,202	0	2,202
15. Fenchuganj	283	0	283
16. Kutubdia	603	0	603
17. Simutang	122	0	122
18. Shahbazpur	465	0	465
19. Maulavibazar	350	0	350
C. PRODUCTION SUSPENDED			
20. Chattak	332	26.5	305.5
21. Feni	116	39.51	76.49
22. Kamta	27	21.1	5.9
TOTAL [TCF]	20.42	5.31	15.11

Table 3-6: Natural Gas Reserves of Bangladesh (Nexant 2006)

According to the base forecast of Power System Master Plan the total quantity of natural gas required from 2005 to 2025 is about 9.5 Tcf. The fuel requirement is polled to meet electricity demand reliably. This is about 63% of present remaining gas reserve of 15 Tcf. Therefore, to realize

the base power development plan it is essential to discover gas fields to raise the reserve level up to 20 Tcf. Figure 3-6 illustrates the annual natural gas and coal requirement corresponding to the electricity generation during the period 2005 – 2025. Not included within Figure 3-6 are major consumers such as fertilizers factory, other industries, commercial organizations and the domestic sector.

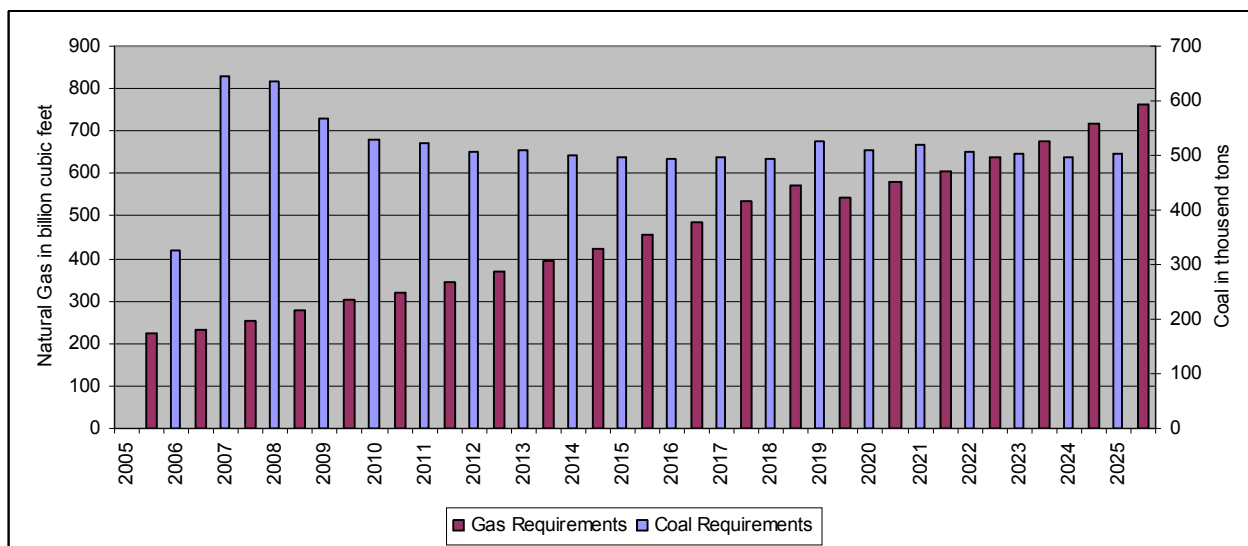


Figure 3-6: Gas and Coal Requirements during 2005 – 2025 (Nexant 2006)

Coal Reserves

The coal reserves are estimated to 2,514 million tons. The major coal deposits are at Jamalgonj, Barapukuria, Phulbari and Khalashpir which are located in the North-West of the country. The locations with their proven coal reserves as well as the depth of coal deposit are shown in Table 3-7.

Location / Field	Depth (meter)	Proven Reserve (million tons)
Barapukuria	118-509	390
Khalaspir Rangpur	257-483	685
Phulbari Dinajpur	150-240	386
Jamalganj Joypurhat	640-1,158	1,053
Dighipara Dinajpur	328-407	Not yet estimated

Table 3-7: Estimated Coal Reserves in 2003 (Nexant 2006)

It is assumed that the estimated coal reserves are adequate to supply coal power plants with a capacity of 4 GW (until 2025). However, currently in operation are the two 115 MW units at Barapukuria and the Reference Scenario consider only these two units (230 MW) with an annual coal requirement shown in Table 3-7. The expected coal production in Barapukuria is 1.0 million tons

annually could be supplying three such units. The coal at Phulbari has a high quality with low ash, low sulphur product, highly suitable for export markets and power generation. Furthermore, the coal at Jamalganj lies at a depth of more than 1,000 meters and currently the mining is not economically feasible.

Oil Reserves

In January 2006 Bangladesh had proven oil reserves of 28 million barrels. In 2005 Bangladesh produced approximately 4,000 barrels per day (bbl/d) of oil and the consumption was estimated to 91,000 bbl/d. Based on the low production and reserves of oil Bangladesh is dependent on oil-imports (EIA 2006, b).

3.3 Renewable Resources

Bangladesh is endowed with plentiful supplies of key renewable energy resources. The most abundant of these are direct solar energy, biomass, and biogas. Biomass currently accounts for about 60% of total primary energy supply; however, this is almost entirely in the form of crude domestic or industrial fuel used for cooking and heating (M. Islam 2006). To date, little progress has been made incorporating renewable energy into the national electricity system. Bangladesh does have limited large scale hydro power potential, but most experts agree the 230 MW Kaptai dam has already harnessed the majority of this resource (M. Islam 2006). There is some speculation that micro-hydro installations could prove valuable for some rural communities, particularly those situated in the southeastern hilly regions of the country, though the extent of this resource is unknown. Wind is not considered a particularly viable energy source for much of the country with the exception of some coastal and offshore sites. Based on a preliminary assessment of the most abundant and feasible renewable resources, the following sections will provide detailed information regarding current utilization practices and remaining energy potential of solar, biomass and biogas.

Solar Resource Potential

Bangladesh receives an average daily solar radiation of 4-6.5 kWh/m² or about 1700 kWh/m² per year nationally (M. Islam 2006). As an inexhaustible and abundant source of energy, the sun's solar rays could provide huge amounts of power. However, this considerable amount of energy goes largely unused. The most common method of solar utilization is through direct use, low technology applications such as domestic and agricultural drying. In terms of electricity generation, there have been some successful, all be it small scale, solar photovoltaic (PV) applications. The Grameen Shakti

project provides power and lighting to rural households using Solar Home Systems (SHS). These units typically include a 50 Watt PV panel, battery for energy storage, charge controller to regulate battery operation, fluorescent tube lights, installation kits and connecting devices (Climate Change Corp. 2008). SHS are primarily used for lighting houses and shops, powering TVs or radios and operating computers (Barua 2001). Using a micro financing scheme, Grameen Shakti has provided over 42,000 small SHS units. However, a compiled list of all small scale solar components, including those from Grameen Shakti, indicates that solar PV accounts for a paltry 3.01 MW, less than 0.1 %, of total installed capacity in Bangladesh (M. Islam 2006). While it hasn't happened yet, widespread implementation of solar PV technologies could provide massive quantities of electricity to the entire country.

Figure 3-7 shows some examples of small scale PV units currently operating in Bangladesh:



Figure 3-7: Solar PV installations in Bangladesh (Rahman 2006)

Solar PV used for rural electricity generation can provide power to the following sectors (Rahman 2006):

A. Agriculture and Water usage:

- Pumping stations for irrigation and drinking water;
- Water purification units;
- Salt water desalination units;
- Water circulation for fish farms.

B. Health care systems:

- Lighting in rural clinics;
- Refrigeration storage units;
- Sterilization units.

C. Remote communication systems

- TV and radio receivers;
- Weather measuring equipment;
- Charging stations for mobile communication equipment.

D. Infrastructure and Transportation aids:

- Road and sign lighting;
- Railway signals;
- Runway lighting;
- Navigation buoys.

The major limiting factor for harnessing solar energy has traditionally been prohibitive financial costs associated with PV units. To address this issue, Grameen Bank through its Grameen Shakti project, has developed a “micro financing” model that provides low-interest loans for a solar home system with an expected lifetime of 25 years. According to the “One World, South Asia” publication, “the customer can choose to pay 10% to 25% upfront and the rest in 24 to 42 monthly installments at a flat service charge of 4% to 6% <...> The total cost of a 50 watt solar home system – the most popular size – is \$ 400. A 50 watt solar system can power four to six low-energy lamps, radio, TV and mobile phone charger.” (Climate Change Corp. 2008) Grameen Shakti is currently installing SHS units at a rate of 5,000 per month with a goal of one million SHS installed by 2015. As stated by Dipal Barua, managing director of Grameen Shakti, “we plan to achieve this through promoting local entrepreneurs who will market, install, and carry-out repair and maintenance activities at the local level on behalf of Grameen Shakti” (Climate Change Corp. 2008). Considering the massive quantity of solar radiance, significant benefits of small scale PV implementation and

improved methods of micro financing, solar energy should play a central role in providing basic levels of electricity and associated economic growth to a large portion of rural Bangladesh.

Biomass

The aforementioned access to large quantities of direct solar energy, in combination with a robust wet season, provides Bangladesh with large quantities of biomass. This resource is manifested in the form of agricultural and process residues, fuel wood, and animal waste. An analysis of biomass resource potential and consumption in Bangladesh concluded the following: "In 2003, the total annual generation and recoverable rates of biomass in Bangladesh were 148.983 and 86.276 million ton/year, respectively <...> Using the lower calorific values of the individual biomass components, the energy potential of the annually recoverable 86.276 million ton of biomass is estimated at 1125.4 PJ, which is equivalent to 26.795 mtoe or 312.613 TWh <...> Considering the present national consumption of biomass, total available biomass resources potential for electricity generation vary from 183.865 to 223.794 TWh." (A. Hossain 2007)

Annual generation and recoverable rates of biomass from different sources in Bangladesh

Biomass resource	Rate of generation (Mtonne/year)	Waste recovery rate (Mtonne/year)	Waste recovery rate (Mtonne dry matter/year)
Crop residues			
Field residues	75.035	26.261	22.704
Process residues	15.732	15.732	13.168
Animal wastes and poultry droppings	34.552	20.619	20.619
Human wastes and MSW	14.793	14.793	10.177
Forests and forestry industry	8.871	8.871	7.461
Total	148.983	86.276	74.129

Table 3-8: Annual generation and recoverable rates of biomass from different sources in Bangladesh (Prospects of Renewable Energy Utilization for Electricity generation in Bang).

Figure 3-8 breaks down the type of fuel used and the sectors which consume biomass within Bangladesh. As seen, crop residues constitute almost two thirds of biomass use followed by fuel wood and animal waste. Crop residues can be divided into field residues, those coming directly from the raw plants on agricultural plots, and process residues, those left over from industrial or domestic processing of crops. There is an established limit of 35% for field residue removal, extracting more than this has been shown to have adverse effects on future crop yields. On the other hand, 100% of process residues can be utilized as they would otherwise be treated as waste (A. Hossain 2007).

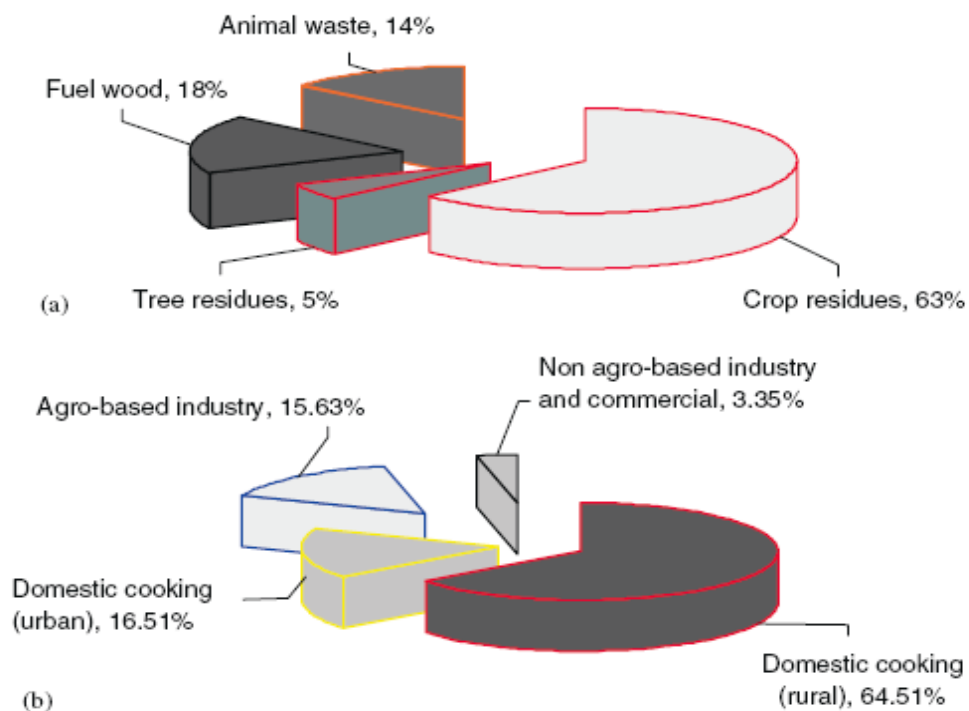


Figure 3-8: Biomass consumption for energy in Bangladesh: (a) according to biomass source; and (b) according to consumer sector (A. Hossain 2007).

In order to more efficiently utilize biomass resources and further the integration of biomass into the electricity market, specific technologies and management methods must be introduced or expanded in Bangladesh. These are varied and plentiful including the following:

- A. Sustainable resource management: This is absolutely essential to the continued use of biomass as a traditional energy source as well as a fuel for electricity generation. It is a difficult issue to describe quantifiably, however, as the practical application must be carried out on a local level. National policies for forest preservation and efficient land use can establish the required methods, but without cooperation of the individuals involved these methods will bear no fruit.
- B. Cooperative resource exchanges: Efficient utilization of local resources can be enhanced by coordinated material exchanges with neighboring municipalities. Following the concept of specialization, each region and locality should produce and maintain that which is ideally suited to their particular circumstances. By doing this and by adhering to fair exchange practices, it should be possible to provide the basic necessities for each region while maximizing production efficiency on the micro level.
- C. Improved cook stoves for domestic use: Several organizations are leading efforts throughout the developing world to improve domestic cooking practices as this constitutes the majority of rural energy use and contributes significantly to respiratory illness in women and children. The Bangladesh Council of Science and Industrial Research (BCSIR) produces cook stoves that are purported to save 40-60% of fuel compared to traditional mud and clay models (M. Islam 2006). The widespread dissemination of these stoves would dramatically reduce biomass

consumption throughout Bangladesh. The saved fuel could be transferred over to electricity generation or recycled into the environment as part of a sustainable land use plan.

- D. Biomass briquetting: This technique, practiced in many countries for a number of years, provides greater ease of transportation, better handling, cleaner and more efficient combustion and increased volumetric energy value of biomass fuel. Briquette densities can be up to three times more than that of loose biomass. This reduction in volume leads to significant savings in transportation and storage costs. As of 2003, Bangladesh had 906 “piston press” briquetting machines in operation (A. Hossain 2007).
- E. Biogas utilization: Due to vast numbers of agricultural livestock in Bangladesh, biogas is a distinct option for electricity generation. The following section will provide a detailed assessment of this technology.

Municipal solid waste (MSW), considered in this paper to be a form of biomass, is generated in urban Bangladesh at a rate of about 0.5 kg/capita/day and about 0.15 kg/capita/day in rural areas (A. Hossain 2007). Basing his figures on 2003 data, Hossain contends that by considering a 100% recoverable rate of human MSW, the total waste available nationwide is about 14.8 Mton/year or around 10.2 Mton/year of dry matter. Table 3-9 shows this data as attributed to the rural and urban populations in Bangladesh.

Generation and recoverable rates of human waste and MSW in Bangladesh in 2002 [48,49]

Biomass	Rate of generation ^a		Waste recovery rate (Mtonne/year)	Moisture content		Waste recovery rate (Mtonne dry matter/year)
	(kg/ capita/ day)	(Mtonne/ year)		(% by mass)	Reference	
Human waste	0.09	4.537	4.537			4.537
MSW						
Urban	0.4	4.312	4.312	45.0	[49]	2.372
Rural	0.15	5.944	5.944	45.0	[49]	3.269
Subtotal		10.256	10.256			5.641
MSW						
Total		14.793	14.793			10.177

^aCalculation of human waste generation rate is based on dry matter.

Table 3-9: Human waste recovery potential for Bangladesh by area (A. Hossain 2007).

Sustainable development using biomass can and should be a major contributor to rural economic growth as well as climate change mitigation. Local entrepreneurs have already seen a modest boon with the emergence of about 60 private enterprises in Bangladesh that utilize modern techniques to transform rice husks and saw dust into efficient biomass briquettes for commercial sale (A. Islam 2006). Another program within Grameen Shakti is promoting sustainable forest management by requiring each of its SHS recipient households to plant 5 new trees on their land

(Climate Change Corp. 2008). Hossain contends, "If grown in a sustainable manner, the production and utilization of biomass create no net accumulation of CO₂ in the atmosphere. During the next century, biomass energy is expected to offer cost-effective and sustainable opportunities with the potential to meet 50% of world energy demands and the requirement of reducing carbon emissions from fossil fuels. Biomass energy systems can play an important role in a country's or region's development, i.e. education, employment and economic growth through business expansion (i.e. earnings), direct and indirect effects on GDP, support of traditional industries, rural diversification and community empowerment." (A. Hossain 2007) With proper management and efficient utilization, biomass can remain a primary source of energy for Bangladesh as they transition to an industrialized economy.

Biogas

Biogas is produced during the biological breakdown or fermentation of organic matter in anaerobic conditions. Derived from biomass such as animal and industrial waste products including dung, fatty byproducts and oil rich agricultural residues, biogas could be a versatile and abundant renewable resource in Bangladesh. It can be used in nearly every capacity as that of natural gas; including as a fuel for traditional cooking or heating purposes, for use in combustion engines or as a fuel for gas powered electric turbines. After extracting biogas, it is possible to redistribute the used biomass to farmers as high quality fertilizer. An added benefit in many developing communities is improved sanitary conditions as well as increased employment opportunities due to the systematic handling and processing of waste. Biogas is considered a net zero carbon emitter because, like all bio-fuels, the CO₂ emitted during combustion was originally sequestered in the organic matter from the atmosphere, thus completing the carbon life cycle. As a final contribution to climate change mitigation, the methane content of biogas is prevented from reaching the atmosphere; as methane is a more potent GHG than CO₂, this represents a reduction in total GHG emissions throughout the process (Engler n.d.).

The biogas potential for Bangladesh is driven by huge populations of agricultural livestock including 24 million cattle and roughly 200 million chickens (M. Islam 2006). Islam calculates that domestic cattle produce nearly 185 million kg dung per day. He further states that 1 kg can produce 0.037 m³ biogas and that the total available cattle dung in Bangladesh could provide 2.5 billion m³ of biogas per year. In energy terms, this amount of biogas is approximately equivalent to 1.28 million tons of kerosene or 2.56 million tons of coal (M. Islam 2006). Goat and poultry animal waste is also fairly significant, raising the estimated biogas production from 2.5 to about 3 billion m³ per year (A.

Islam 2006). Table 3-10 shows the number of livestock present in Bangladesh and the waste residues available as of the year 2000.

Number of livestock and their residues production in 2000			
Livestock type	Heads	Dung yield (kg/animal/day)	Residues (tons/year)
Buffalo	828,000	8–12	3,022,200
Cattle	23,652,000	5–10	64,747,350
Goat	33,800,000	0.25–0.50	4,626,375
Sheep	1,121,000	0.25–0.50	153,436.87
Chicken	200,000,000	0.1	7,300,000
Total			79,849,361.87

Table 3-10: Livestock and waste per year in Bangladesh (M. Islam 2006).

In addition to animal wastes, it is possible to extract biogas from human waste. It is estimated that human excreta amounts to about 0.09 kg/capita/day (A. Hossain 2007).

At present, more than 25,000 household size biogas digesters (fixed dome style) have been installed by the Institute of Fuel Research and Development (IFRD) across Bangladesh. There are also some institutional and commercial biogas facilities operating via various agencies, both domestic and international. Of IFRD units, approximately 75% use cow dung, 20% use poultry and a further 5% utilize other biomass including human excreta (M. Islam 2006). Table 3-11 provides a summary of current biogas installations in Bangladesh. An ongoing program within the Grameen Shakti project is helping rural villages install small scale biogas digesters. As part of Grameen Shakti goals for 2015, they intend to have 1 million biogas units installed utilizing local labor and operators. Current biogas plants are reported to cost between \$ 215 and \$ 1,400 through the Grameen Shakti financing scheme and typically provide enough energy for a cluster of homes (Climate Change Corp. 2008). Complimenting the work of IFRD and Grameen Shakti, the Netherlands Development Corporation has announced plans to set up an additional 36,450 biogas plants by 2009 (M. Islam 2006). To encourage continued installation of these small scale biogas digesters, the Bangladeshi government has established a \$ 120 subsidy for plants producing approximately 3 m³/day gas (N. Uddin 2008). While biogas is primarily used as a direct fuel for cooking and lighting, the potential for electricity generation should not be ignored.

Summary of biogas plant installation by different organization in Bangladesh

Organizations	Type of systems installation	Number	Capacity (cft/day)
LGED	Family biogas plant	1164	120-420
	Community biogas plant	02	Up to 2000
IFRD of BCSIR	Phase-I	4664	100-200
	Phase-II	17194	120-420
BRAC	Family biogas plant	1200	120-420
	Power generating unit	02	Each of 800 Wp
Grameen Shakti	Family biogas plant	300	120-420
Proshika and others	Family biogas plant	476	120-420
Total		25,000	

Table 3-11: Biogas plant installations according to their parent organization in Bangladesh (M. Islam 2006).

A recently completed feasibility study on commercial poultry biogas plants conducted by the German institution (GTZ) and the Bangladesh Center for Advanced Studies (BCAS) claims that poultry biogas plants of moderate and larger sizes are financially viable with moderate farms suitable for heat production while larger farms could also sustain electricity production. The authors recommend that similar studies be undertaken in commercial biogas plants based on other feed stocks. As a final statement, the study contends that “there is a huge potential for commercial biogas plants for other uses” (M. Islam 2006).

4 MODELING THE FUTURE ELECTRICITY SYSTEM

Thus far the current energy situation has been described, emphasizing problems and available resources for various technologies. It has also been mentioned that the national goal is 100% electrification by the year 2020. A future expansion plan, referred to as the Master Plan, has been developed by the Bangladesh government that achieves this goal in a quick, cheap, and non-sustainable way by utilizing the natural gas reserves (Nexant 2006). Of the scenarios that will be created and described later, this Master Plan is the reference, or business-as-usual, scenario of the model created for this report. Alternative scenarios will then be created and presented utilizing the renewable resource potential. The goal is to determine if the energy system can be expanded to 100% electrification in a sustainable, environmentally friendly way that is economically feasible for the country.

The modeling software tool implemented for this task is LEAP (Long range Energy Alternatives Planning system). This section will explain important assumptions that were made to construct the platform that each scenario was built around, including the Current Accounts data and Future Projection data that was input in LEAP. Then the current trend of the electricity system, called the reference scenario, will be described and the results from LEAP shown.

4.1 Scenario Platform: Current Account Data

In order to develop a future electricity plan for Bangladesh the current situation must be understood and accurately input in LEAP. However, data of this nature takes time to compile and requires making assumptions when data is not available. A large portion of the data that makes up the platform is taken from the Master Plan and begins in the year 2004 (Nexant 2006). The analysis of the model begins with the current year, 2008, and goes through 2025. Although 2004 is not always the most recent data available one advantage to starting a few years in the past is the ability to check the assumptions of the model against reality. The data from 2004 creates the Current Accounts scenario, laid out in section 3.2, in LEAP and includes raw data for population, GDP, existing power plants, committed power plants and consumption. There are no inputs for future years in the current accounts, only data for the energy system as it stands in 2004.

The following data was input in the Key Assumptions area in LEAP for the Current Accounts:

- Total population: 135 million
- Total Households: 25.5 million (assuming 5 person per household)

- GDP: 54 Billion US Dollars
- Income (per capita): 363 US Dollars

(M. Islam 2006)

The distribution of electrified and non electrified people in both urban and rural areas, in 2004, is shown in Figure 4-1.

Population Electrification Status

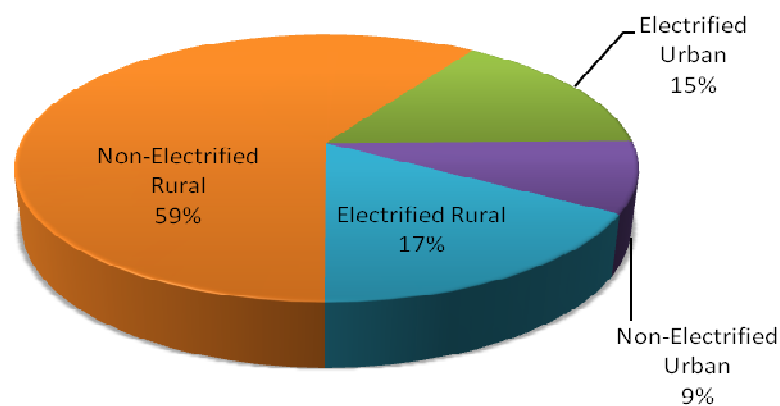


Figure 4-1: Electrification of Bangladesh in 2005.

The power generation facilities are perhaps the most important part of the Current Accounts. The Master Plan has a detailed listing of the facilities and their specifications that were operational in 2004. From this listing the full cost, exogenous capacity, and operation and maintenance (O&M) costs were input to LEAP. However, there was no information in the Master Plan on the efficiency or maximum availability of the facilities. Therefore, these were determined through literature research. The efficiencies for each technology were presented in a range in the 3.2.5 of this paper. To set a value for the efficiencies it was assumed that due to the poor maintenance of the facilities that the lower end of the range would be chosen, see Figure 4-2.

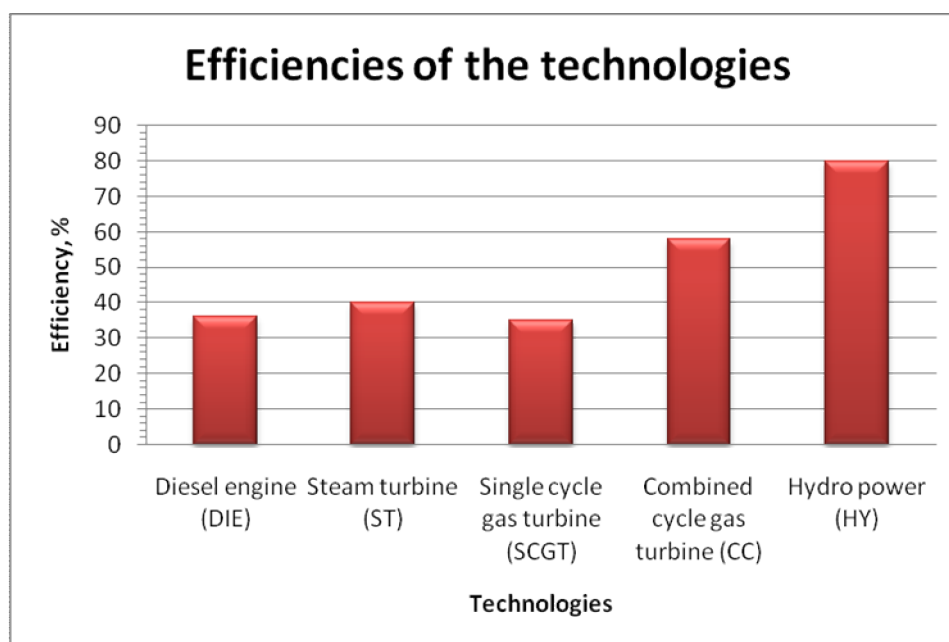


Figure 4-2: Technology efficiencies that were input into LEAP.

The maximum availability, the percentage of hours in a year that a facility is expected to be operational was generated with the following calculation:

$$\text{Maximum Availability} = 100\% - \% \text{ of scheduled annual maintenance}$$

4.2 Scenario Platform: Future Projection Data

The future projection data of the scenario platform refers to the data that is common to all the scenarios and based on growth percentages or projected values from the Master Plan. These values are imperative to developing an accurate model of the energy system in LEAP. It is possible to develop our own growth predictions; however it is our goal to develop alternative scenarios that can be directly compared with the current electricity plan.

4.2.1 Load Forecasting

An essential piece in developing an electricity plan is predicting what future loads will be required from an electricity system. The common approach to this problem is relating the GDP to the electricity demand. In a paper by the Ministry of Finance it was said, “Reduction of poverty to a moderate level calls for GDP growth rate at 7-8% and achieving this growth rate requires increased electricity supply which should be in the region of 1.5 times growth rate” (Ministry of Finance 2007). In the case of Bangladesh their economy has been doing well and it was assumed in the Master Plan that they would continue to do so. It was taken into consideration that as the economy gets larger it

becomes more difficult to maintain the high grow rate. The base case, and therefore our reference, has the following forecasted growth rates: 2004-2005 is 5.3%, 2006-2010 is 6%, 2011-2015 is 5.5%, 2016-2020 is 5%, and 2021-2025 is 4.5% (Nexant 2006). These numbers are low compared to what the Ministry of Finance says they should be. However, the main goal of the Master Plan is to electrify the entire country, not reduce poverty.

Also linked to the GDP is the anticipated population growth. This was determined through interpolating the population in 2005 with the population in 2008. This returned a 3% growth rate and was assumed to be constant for the entire model.

These growth rates are applied to the annual energy demand and multiplied by an electrification elasticity factor. This factor when over 1 indicates a growth rate greater than the GDP, less than 1 indicates a growth rate that is less than the GDP and a value of zero indicates a constant value for the electrification. In 2004 the initial energy demand was 20,272 GWh and with this forecast the demand in 2025 grew to 100,083 GWh (Nexant 2006), see Figure 4-3. This required an elasticity of 1.47 that was obtained through interpolation.

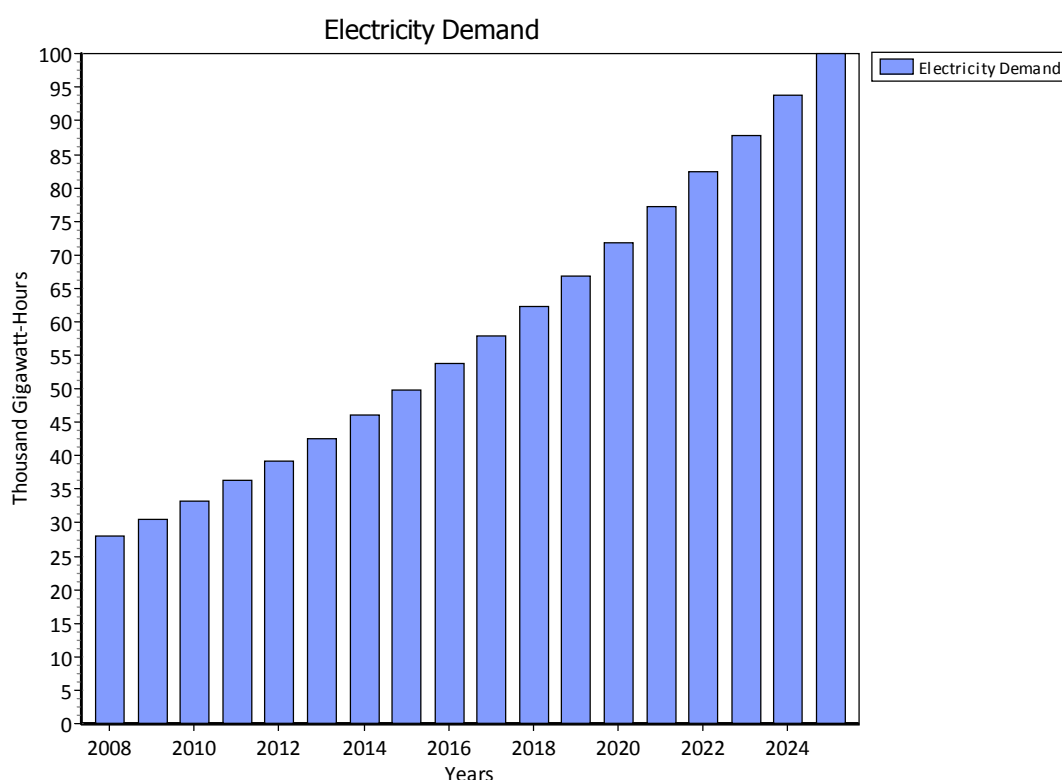


Figure 4-3: Annual electricity demand projected by the Master Plan, in thousand GWh (Nexant 2006).

4.2.2 Power Plants

Each power plant that was defined under the current accounts has a limited operational life time that must be considered for an accurate installed capacity. The retirement years for all existing power plants was input to LEAP. The committed power plants anticipated activation date is input. These are plants that are not operational but are far enough along in the planning or construction phases to be considered a guaranteed source of power at a later date. The result is the yearly installed capacity for Bangladesh if no new plants are built beyond the current plan, Figure 4-4.

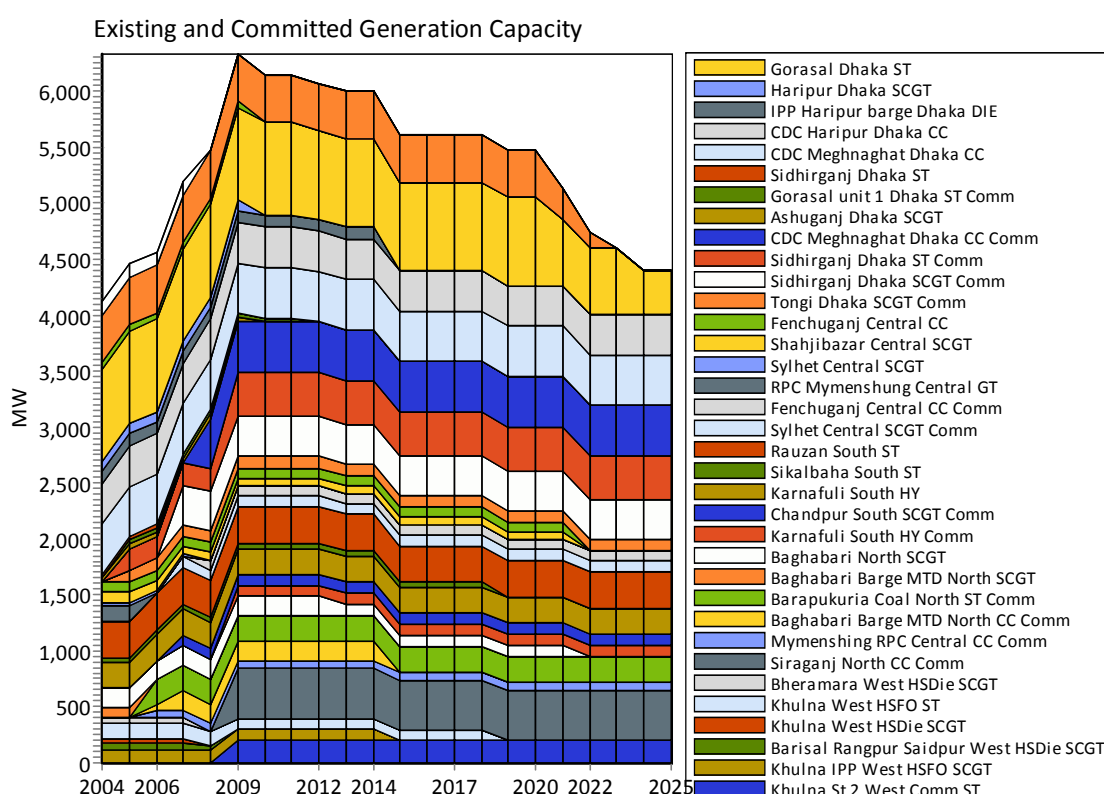


Figure 4-4: Installed Capacity of all the existing and committed generation facilities for the entire timeline of the model, in MW.

4.2.3 Reserve Margin

The reserve margin can be defined as “a measure of the generating capacity available over and above the amount required to meet the system demand requirements” (Nexant 2006). It can also be written in terms of installed capacity and peak load:

$$(Total\ Installed\ Capacity - Annual\ Peak\ Demand) / Peak\ System\ Demand$$

The goal is to have a large enough reserve margin that if your largest power plant is forced offline then the remaining plants can cover the demand and no customers lose power. Currently, they have issues with the demand being greater than the generation capabilities causing the power companies to load shed. The Master Plan adds in capacity for a reserve margin because without this there is no hope for a reliable system. The reserve margins used in the reference scenario can be seen in Figure 4-5.

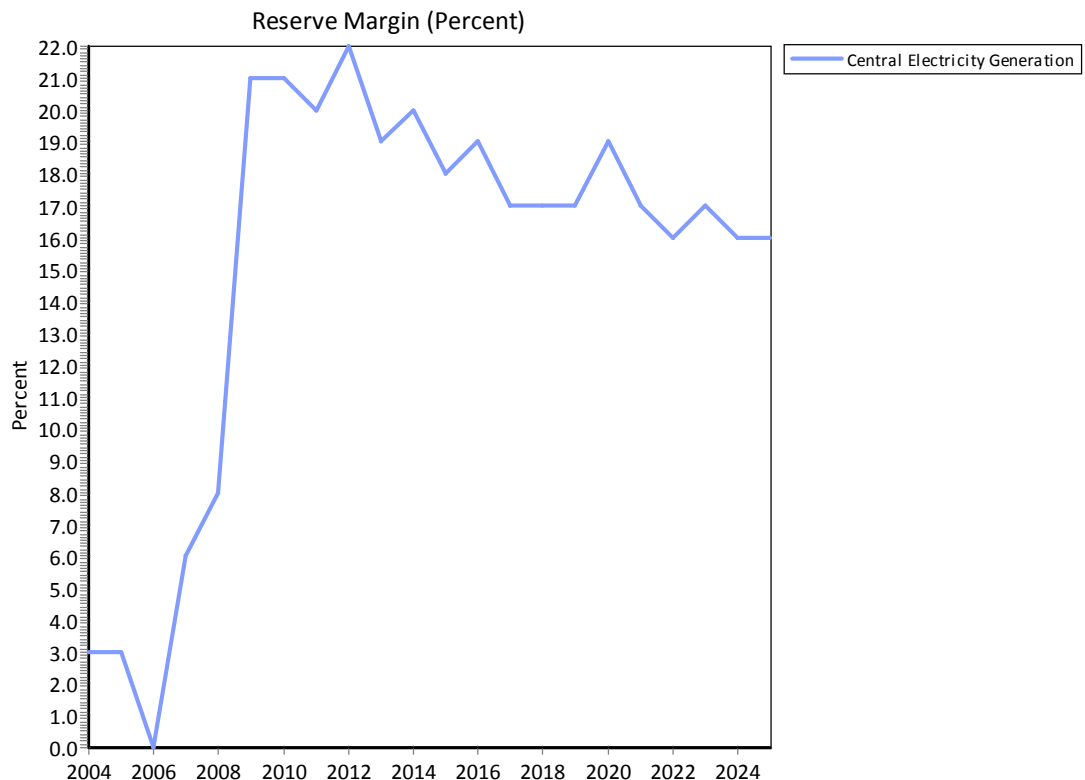


Figure 4-5: Reserve margin percentages desired by the Master Plan (Nexant 2006).

Central Electricity Generation refers to all of the existing and committed power facilities stated in the Master Plan.

4.3 Current Trend: Reference Scenario

The Reference Scenario refers to the existing energy expansion plan Bangladesh has developed for its future. As with all the scenarios of the model it is based on the scenario platform. The only addition to the platform is how this scenario will meet the projected electricity generation

demand and reserve margin. The method of this scenario is to meet the demand by installing natural gas plants at a rate pre-determined by the base case of the Master Plan.

4.3.1 Added Capacity

As can be seen in Figure 4-4 the installed capacity will begin decreasing during the next 20 years. However, the projected electricity demand increases considerably according to Figure 4-3.

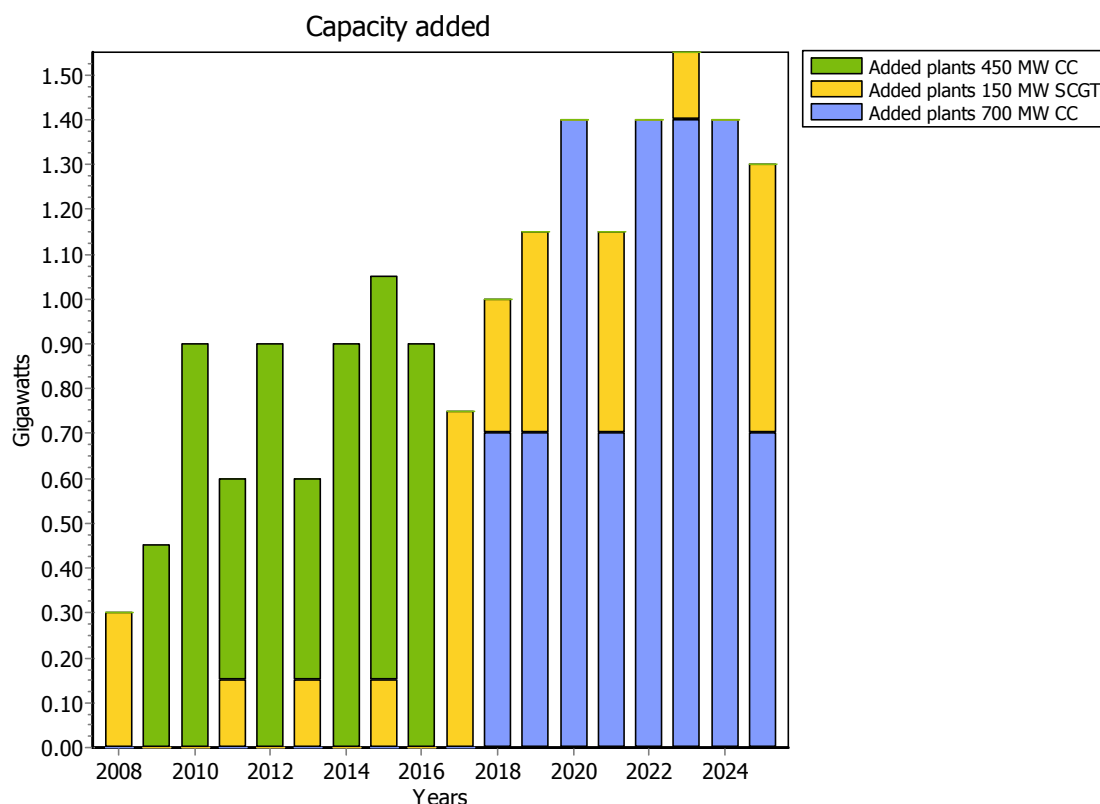


Figure 4-6: Added generating capacity to meet the demand in the reference scenario, in GW.

This increase is met through the installation of three types of natural gas plants: 150 MW single cycle gas turbine (SCGT), 450 MW combined cycle gas turbine (CCGT), or 700 MW CCGT. The Master Plan optimized these three units to cover the energy demand with a few assumptions. First, no plants were installed until after 2007 because time is required to plan and install power plants. Secondly, the 700 MW plants were not installed until after 2017 because they are more complicated and the developers believe that Bangladesh needs to progress in a technological sense before building these plants. Their optimization resulted in the number of plants to be installed each year; a yearly break down is shown in Figure 4-6.

4.3.2 Results of the Reference Scenario

Combining the added capacity with the existing and committed power plants completes the reference scenario, Figure 4-7.

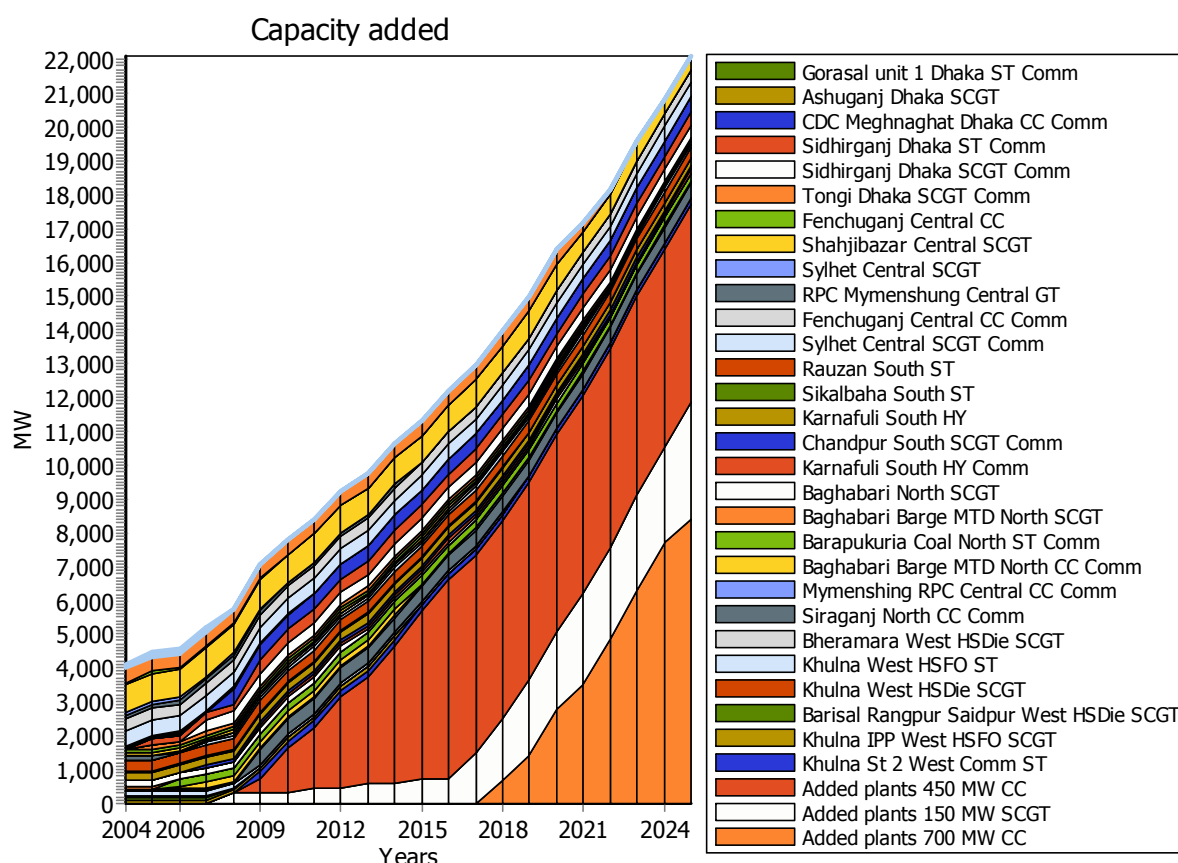


Figure 4-7: Total installed capacity of the reference scenario meeting all of the demand, in MW.

4.3.3 Costs

Determining costs for an electricity grid can be very complicated and tedious to properly develop. However, for our analysis between the reference scenario and the alternative scenarios, introduced in the following section, the costs can be simplified to a few key areas. The itemized costs for the electricity generation facilities that are analyzed later are the capital costs of the added capacity and the fixed and variable O&M costs for all the power plants, see Figure 4-8.

For Transmission and Distribution (T & D) only the costs of installing more transmission were considered. These costs are the investment costs including: connecting generation at new or expanded existing sites to the main transmission system, adding new transformers and circuits, and

placing reactive support where it would be most effective (Nexant 2006). The same amount of distribution lines was assumed to be needed in both the reference scenario and the distributed scenario and therefore could be left out of the model. The total costs of the electricity system are shown in Figure 4-9.

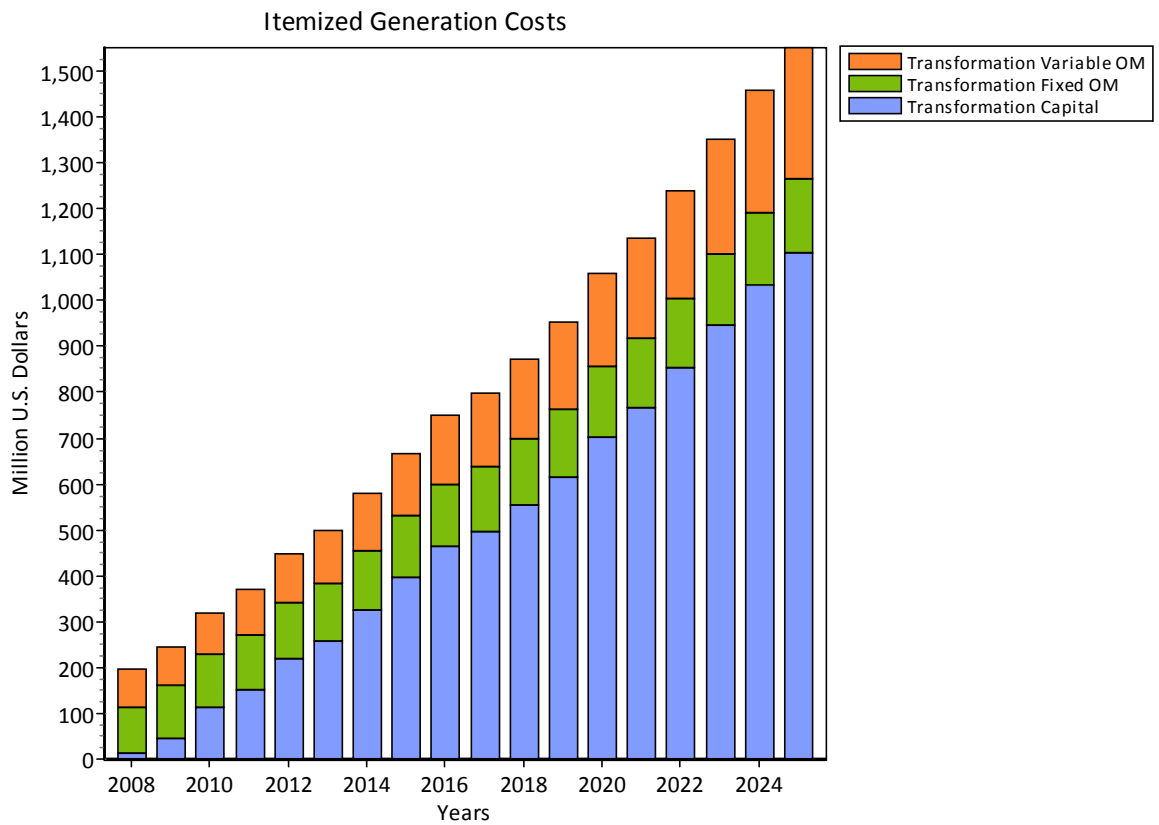


Figure 4-8: The itemization of generation costs for the reference scenario, in million USD.

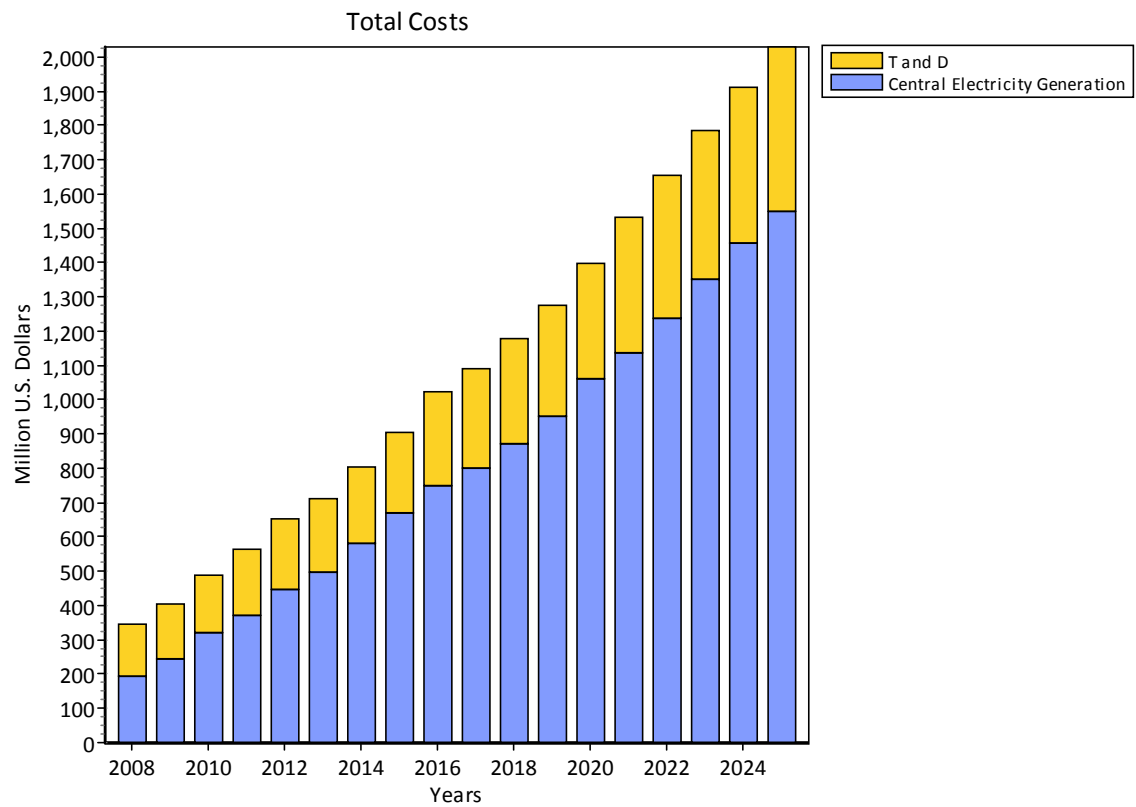


Figure 4-9: Total costs of the reference scenario, including the transmission lines that will be installed, in million USD.

4.3.4 Environmental Impacts

With the use of LEAP it is simple to show estimates for the CO₂ released by the fuels, see Figure 4-10. The default emission factors set in LEAP and suggested by the Intergovernmental Panel on Climate Change (IPCC) for each technology were used for this calculation. These include pollutants such as: Carbon Monoxide Non Biogenic, Carbon Monoxide (CO), Methane (CH₄), Non Methane Volatile Organic Compounds, Nitrogen Oxides (NO_x) and Sulfur Dioxide (SO₂).

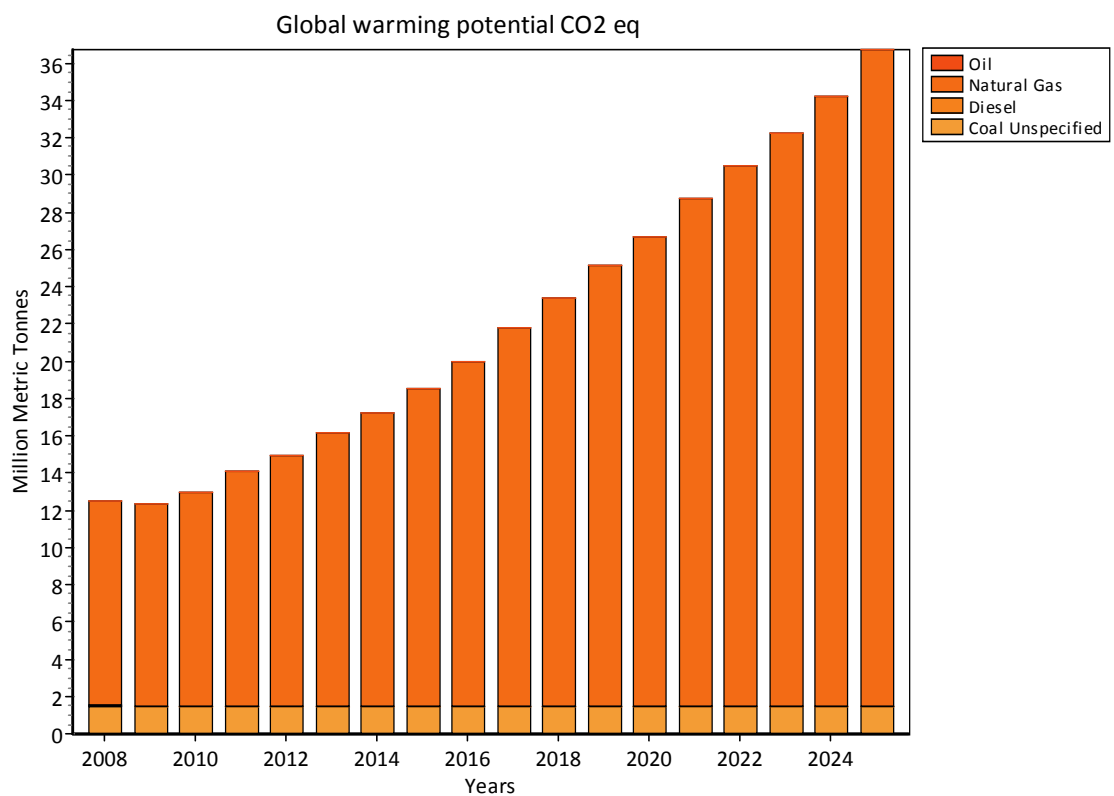


Figure 4-10: Environmental impact of each fuel used in the reference scenario, in million metric tons.

5 ALTERNATIVE SCENARIOS WITH DISTRIBUTED GENERATION

This section includes a description of the theories and technologies that form the basis of the three Alternative scenarios. The main concept of the alternatives is that of distributed generation. The three technologies implemented are solar photovoltaic, municipal solid waste incineration and biogas combustion engines. Each scenario is accompanied by a description of the assumptions and methods used to create the scenario model followed by a results section.

5.1 Distributed Generation

Distributed or decentralized generation (DG) incorporates several concepts of power production that are not unilaterally agreed upon within the scientific community. For the purposes of this paper, and using a contextual framework based on the Bangladeshi situation, the following definition should be applied: any method of energy production that is decentralized (not controlled or operated by a central transmission system manager); located at or near the point of consumption; is directly connected to a distribution network, but not necessarily a larger regional or national grid (this local network could be as small as one user); is not limited to, but prioritizes renewable energy sources (Pepermans 2003). Additionally, as Peperman purports, DG is normally thought of as small scale generation; however, this criteria is inconsequential for this report.

5.1.1 Techno-Economic Advantages of Distributed Generation

Advantages of a renewable distributed generation strategy are numerous; they include, among others, the following key points:

- Greater access to electricity. Rural and isolated locations can receive increased electrification by incorporating off-grid, stand-alone systems such as solar PV, micro-hydro, wind turbines, and sustainable biomass. These technologies can provide electricity without the need for a redundant, expansive centralized energy grid.
- Insulation from unreliable central power facilities. Many developing countries' energy grids are underserved and overwhelmed. This imbalance, commonly combined with the use of aging and poorly maintained power plants, leads to an environment of energy insecurity. Blackouts are frequent and unpredictable, making it more difficult to secure foreign or domestic industrial investment.
- Component scalability. Renewable energy systems can range from extremely small (a few watts) to massive (several hundred mega watts), the only major difference being overall size of the installation. This allows communities to incrementally increase their supply of

energy as immediate demand increases. Such flexibility precludes the need for huge initial investment. Additionally, as these systems are scaled up, the components can be placed directly at the point of consumption, thus eliminating costly transmission or complicated distribution networks.

- Fuel independence and price stability. By utilizing local sources of energy these regions can excuse themselves from the uncertainty and dependency that characterize global fuel markets. This is a distinct advantage when implementing long range development strategies by precluding the need to make dangerous assumptions regarding future fuel prices. Fluctuations in these can be rapid, violent and potentially fatal to an economy that is unalterably dependent on these energy sources.

5.2 Technologies

The three technologies described below are those proposed for development in Bangladesh in the following alternative scenarios. They are small biogas engines, small scale solar units, and moderate sized municipal solid waste incineration power facilities.

5.2.1 Biogas utilization

There are four main options for the utilization of biogas; direct combustion, electricity generation, fuel for vehicles and chemical product. However, for the electricity generation the two most common technologies are the gas combustion engine and the gas turbine (Appels, et al. 2008). The heat incurred through the process can be used for district heating, digester heating and so on that corresponds to a combined heat and power plant (CHP).

In general there are two types of combustion engines, the dual fuel engine and the spark ignition engine; the latter is used for biogas utilization and the size varies up to 8 MW. Gas engines and gas turbines both have quick start-up durations while it is possible to use gasses with lower heating value and higher contents of impurities in engines than in turbines. A disadvantage is that engines cannot utilize considerable amounts of high-pressure steam like the gas turbines do. Furthermore, the gas engine emits more CO₂-equivalents than other technologies, due to the unburned methane.

In the past few years the efficiency of the gas turbines were improved significantly by increasing the turbine inlet temperature. Based on this preheating the gas turbine becomes more competitive in the lower performances (< 100kW) compared to the combustion engine (DEA 2005).

Table 5-1 illustrates the differences like efficiency, availability, lifetime and costs between the best available combustion engines and gas turbines. It compares the small (micro) and the medium scale facilities of these two technologies. In the range up to 5 MW the engine has in all departments the better value than the turbine.

	Combustion engine		Gas turbine	
Energy/technical data				
Generation capacity for one unit [MW]	0.001 - 0.020	1 - 5	0.01	0.1 - 5
Total efficiency [%] net		88 - 96		70 - 75
Electricity efficiency [%] net – 100% load	< 25	40 - 44	15	30
75% load		40 - 43		28
50% load		38 - 40		25
Availability [%]		95		>90
Technical lifetime [years]		20 - 25		10
Financial Data				
Specific Investment [M\$/MW]	3.48	0.96– 1.44	1.2	1.32 – 2.04
Total O&M [\$/MWh]	15.6 – 32.4	7.2 – 10.8	12 – 18	> 8.4
Source: DEA, 2005				

Table 5-1: Specific comparison between Combustion Engine and Gas Turbine

Remark: Prices were converted from Euro's to US dollars according 2004-2005 currency exchange rate according European Central Bank information.

Costs of biogas plants

For the scenario planning specific costs for biogas plant, production, and utilization have to be defined. In the references no examples were found for a relevant size of biogas plant in Bangladesh that could provide energy for a small village. Therefore the installed capacity for one biogas power plant was assumed with 50 kW. This size installation should be sufficient to provide electricity for a medium sized village in which each household requires low levels of electricity (approx. 50-150W). The specific capital costs of a biogas power plant were fixed on 2.4 million \$ per MW (DEA 2005). For the fixed and variable operation and maintenance (O&M) costs it was taken into account only the total O&M of the combustion engine in Table 5-1. Basically, the combustion engine has the better efficiency and lower costs compared to the gas turbine. The chosen performance (50kW) is not in the presented range of the engine in Table 5-1 (0.001 – 0.02 MW; 1 – 5 MW) and therefore the total O&M costs were assumed with 13.2 \$/MWh. (DEA 2005)

5.2.2 Solar PV

The solar technology used in the alternative scenarios is based directly on the SHS units described in 3.3. These are specifically intended for basic rural electrification. The costs used for solar installations were calculated based on the figures from the Grameen Shakti program as \$ 400 per 50

W unit including batteries and all connecting equipment. This corresponds to an \$ 8 million/MW installation cost. This is actually higher than the previously listed general price of \$ 5 million/MW. The extra expense is assumed to be for the auxiliary equipment. Using LEAP it was difficult to account for the financing scheme used in Bangladesh that makes it possible for the rural poor to afford these units, so all costs were simply input as capital costs. The prices are assumed to decline as the technology progresses. The World Energy Outlook report claims that the cost of PV cells will decline by 50% by the year 2030. Figure 5-1 shows this assumption along with several other technologies.

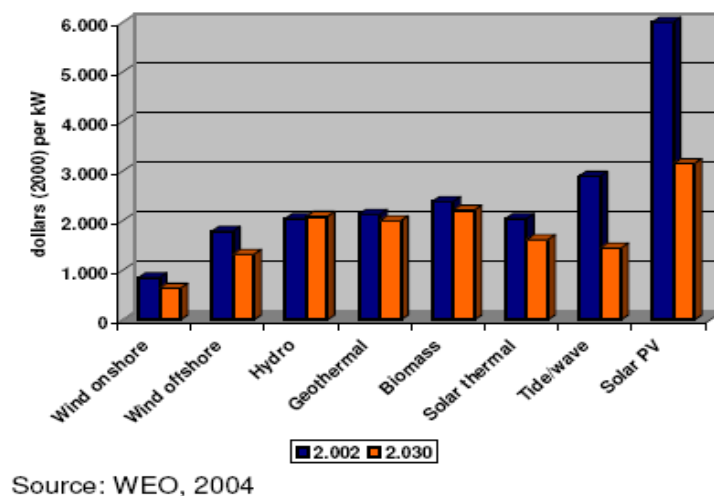


Figure 5-1: Price projections for renewable energy capital costs (IEA 2008).

For the alternative scenarios, the capital cost for solar was assumed to fall 10% in 2010, 25% in 2015 and 35% of original price by 2020. The efficiency of Solar PV cells is assumed to be 11% for the 50 W panels.

5.2.3 Municipal Solid Waste Incineration

Incineration is a waste treatment technology which can reduce the volume of the original waste by 95-96 % (Rambol 2006). It involves the combustion of organic materials, therefore incineration and other high temperature treatment systems are described as “thermal treatment.” Heat is the primary product of the incineration process and it can be used to generate electricity. Aside from useful heat, there is incinerator bottom ashes, flue gases and particulates left after combustion, which are the main issues of the whole process.

Incineration with energy recovery is called waste to energy (WtE) technology. The whole technology is based on the incinerator, which is a furnace for burning waste. Currently they are

improved by pollution mitigation equipment such as flue gas cleaning. Incinerators themselves can be of four various types:

1. Moving grate.

It is used for typical incineration plants and sometimes referred as Municipal Solid Waste Incinerators. Moving grate enables the movement of waste through the combustion chamber and makes the combustion process more efficient and complete. Usually, one boiler can handle up to 35 tons (metric) (Wikipedia 2008, c) of waste per hour and operate 8,000 hours per year (Wikipedia 2008, c) with only about 1 month stop for inspection and maintenance.

Heat is transferred to steam in the super heaters where the flue gases are cooled. Steam reaches 400 °C typically at a pressure of 40 bars.

2. Fixed grate.

The older and simpler type of incinerator it is a brick – lined cell with a fixed metal grate over an ash pit. It has two openings: one in the top or side for loading and another one in the side or bottom for removing incombustible solids called clinkers. Many small versions of these incinerators found in apartment houses are now replaced by waste compactors.

3. Rotary – kiln.

Used by municipalities and large industrial plants. These incinerators have two chambers. The primary chamber consists of an inclined refractory lined cylindrical tube, there, conversion of solid fraction to gases, through volatilization, destructive distillation and partial combustion reactions takes place. Movement of this cylinder on its axis makes waste to move. The secondary chamber works as “afterburner” and completes the combustion process.

4. Fluidized bed.

The strong airflow seeps through the sandbed until a point is reached where the sand particles separate to let the air through and mixing and churning occurs, so a fluidized bed is created. Then fuel and waste can be introduced. Keeping sand, pre-treated waste and/or fuel suspended on pumped air currents, lets them take on a fluid-like character. The bed is thereby violently mixed and agitated keeping small inert particles and air in a fluid-like state. This allows the mass of waste, fuel and sand to be fully circulated through the furnace.

Modern municipal incinerator designs include a high temperature zone, where the flue gas is ensured to sustain a temperature above 850 °C for at least 2 seconds (Wikipedia 2008, c) before it is

cooled down. They are equipped with auxiliary heaters to ensure this at all time. These are often fueled by oil or natural gas and normally only active for a very small fraction of the time.

The World Bank Technical Paper on MSW (2000) lists the technical and financial data for an incineration plant with capacity of 960 metric tons/day. The electrical output for sale is rated at 265 GWh/year. Assuming an availability of 85 % operation over each year the plant will have an installed capacity of 35.3 MW. The total investment is \$ 145 million or \$ 4.1 million/MW installed capacity and total annual operating costs of \$ 266,000/MW/year. Converting these figures to 2005 values as are used in the models, the investment is \$ 4.5 million/MW while O&M costs are \$ 290,000/MW/year. The efficiencies of typical waste incineration facilities range from 15 – 30 % for electricity generation while combined heat and power can recover up to 80% of the thermal energy in the fuel (World Bank 2000). The efficiency used for LEAP calculations is 19.5 % as described by the Danish Technology catalogue for waste incineration facilities (DEA 2005).

5.3 Alternative Scenarios

The following alternative scenarios produce different results when implementing three renewable technologies: solar, biogas and municipal solid waste incineration, in various ways to meet the expected electricity demand laid out in the Master Plan. The added capacity also includes covering a reserve margin to eliminate the load shedding that has been a historical problem with the Bangladesh electricity system. It is assumed that no biogas or municipal solid waste plants can be added until 2010 allowing time for bureaucracy and construction. There are already programs working on installing solar panels on homes to help with electrification and it is the goal of this scenario to expand this program. This allows for solar installation to be included from the beginning year of the model, 2004. The basis of the Alternative scenarios is the reference scenario with some alterations. These include eliminating the cost of transmission lines and inserting the three renewable technologies as means to generate electricity. Table 5-2 shows the costs, efficiencies and generation capacities used for each technology in LEAP.

Renewable Technology	Capital Cost (\$/MW)	Fixed O&M (\$/MW)	Var. O&M (\$/MWh)	Efficiency, %	Unit Capacity
Solar Home Units	2004: 8,000,000 2010: 7,200,000 2015: 6,000,000 2020: 5,200,000	560,000	0	18	50 W
Biogas	2,400,000		Total O&M 13.2	30	50 kW
Municipal Solid Waste	8,160,000	326.4	30	19.5	10 MW

Table 5-2: Renewable Technology data entered into LEAP for the alternative scenarios.

5.4 Alternative Scenario I: 100% Renewable Technologies

5.4.1 Description

The first distributed generation scenario examines the possibility of only using the renewable technologies. The three renewable technologies will fill the needed capacity of the overall electricity system so that the total demand is met, not taking into account the annual resource limitations of each technology. The capacity of the three renewable technologies was evenly distributed by LEAP through the endogenous capacity function. The reason for choosing an even distribution of the technologies is because there is no easy way of determining adequate added capacity proportions. On a technical note, the LEAP endogenous function is only capable of adding each technology in a user-defined, consecutive order: solar, biogas, municipal solid waste. LEAP then adds each technology with their set capacities, cycling through the technologies, until the needed capacity is met.

The annual generation capacity of Bangladesh under this scenario is shown in Figure 5-2. This shows that if each renewable technology would be evenly distributed each year to cover the demand then by 2025 there would need to be approximately 4.5 GW of each technology installed. This far exceeds the maximum capacity of each technology when limiting them against their available resources; see Appendix A for these limit calculations. The maximum cumulative added capacities for the technologies are as follows: solar – 1.9 GW, biogas- 657 MW, and MSW – 1.9 GW. It should be noted that the total capacity generated in this scenario is not quite the same as the reference scenario. According to these calculations there are a few years that have unmet capacity

requirements. The unmet requirements range between 3-4 % of the total capacity for those years. This is simply a problem in LEAP with the endogenous capacity function.

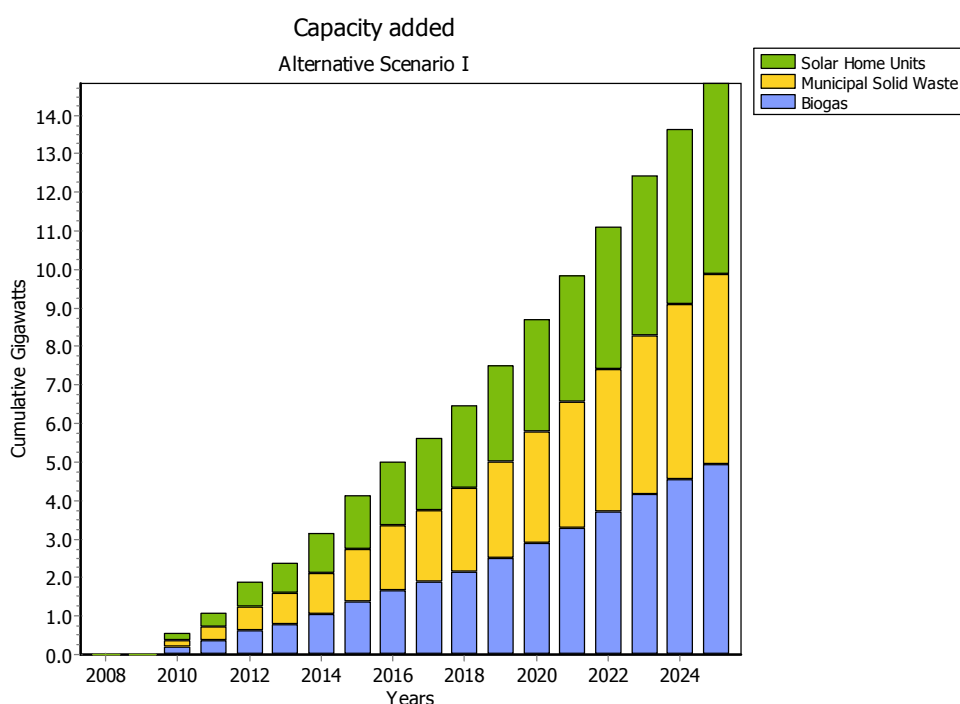


Figure 5-2: Cumulative added generation capacity of the 100% renewable scenario, in GW.

5.5 Alternative Scenario II: Resource Limited Renewable Technology

5.5.1 Description

This alternative scenario builds off the previous scenario, however it only adds in each renewable technology to its annual resource capacity. For biogas and municipal solid waste the annual resource grows with the population and these growths were accounted for in LEAP. There is assumed to be no fluctuation over the years in the solar power that lands on Bangladesh. The solar resource is assumed to be infinite because the solar radiation is so large there is no way it can be completely extracted and turned into electrical power. Therefore, the solar capacity was limited by the number of households and a reasonable growth rate of installed capacity, see Appendix A. These capacities were added into LEAP with the exogenous function, meaning the annual capacities added for each technology were defined and LEAP did not add any additional capacities to meet the demand. These additions are shown in Figure 5-3.

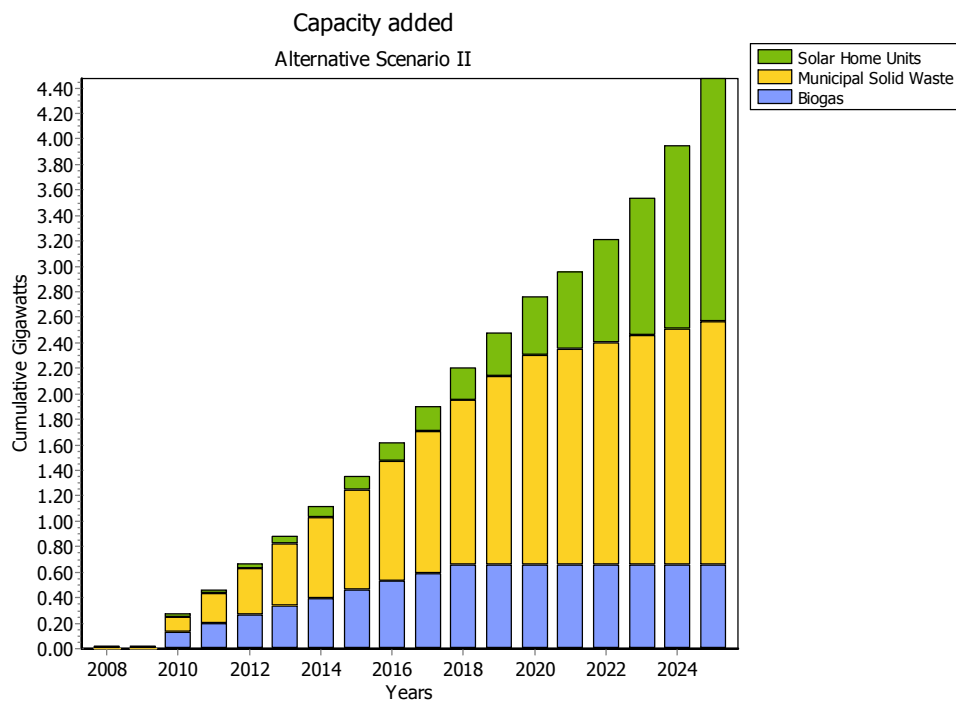


Figure 5-3: Cumulative added generation capacity of the resource limited scenario, in GW.

5.6 Alternative Scenario III: Renewable Technologies combined with a reduced Reference Scenario Solution

5.6.1 Description

This scenario is a combination of Alternative scenario II and the Reference scenario. The difference in this scenario is the same three natural gas plants as the Reference scenario are added endogenously in LEAP to fulfill the electricity demand that was not met in previous scenario. The cumulative added electricity generation capacity is shown graphically in Figure 5-4. Once again there is a problem related to the added endogenous capacity from LEAP.

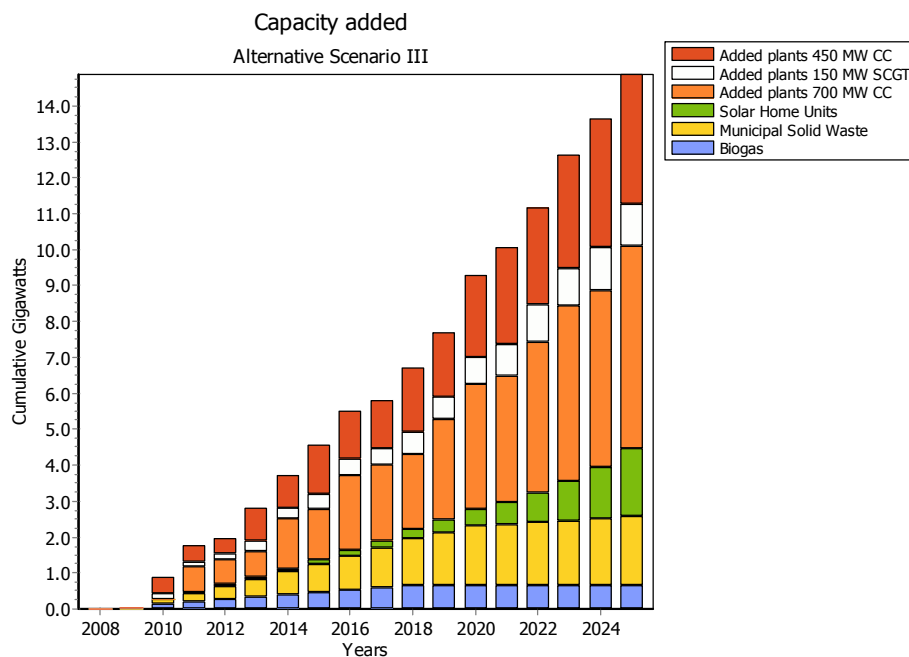


Figure 5-4: Cumulative added electricity generation capacity of the Mixed scenario, in GW.

5.7 Results

The results for the costs and global warming potential are shown here. The cost graphs include the investments, fixed O&M, variable O&M, and transmission costs (Reference scenario only). Each is displayed in millions of USD. The Global Warming Potential graphs show the emissions of each fuel in millions of metric tons. The legends for the graphs are presented below.

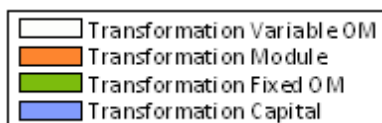


Figure 5-5: Reference Scenario Total Costs

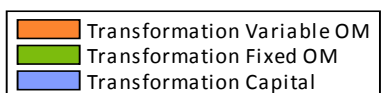


Figure 5-6: Alternative Scenarios Total Costs

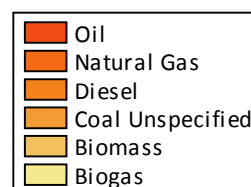


Figure 5-7: Reference and Alternative Scenarios Global Warming Potential

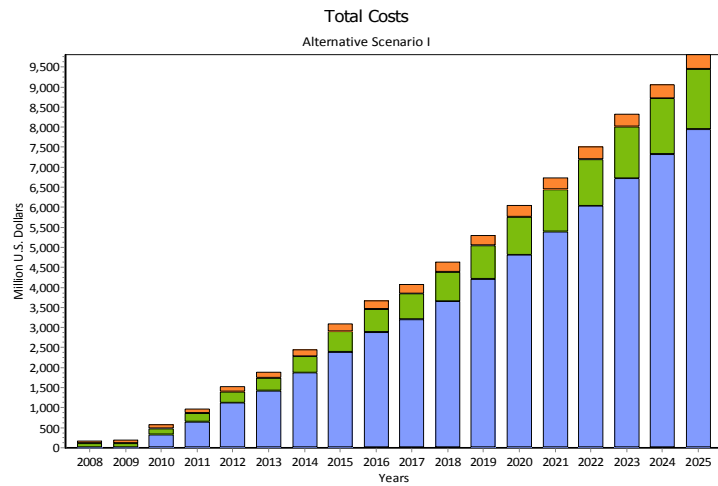


Figure 5-8: Alternative Scenario I

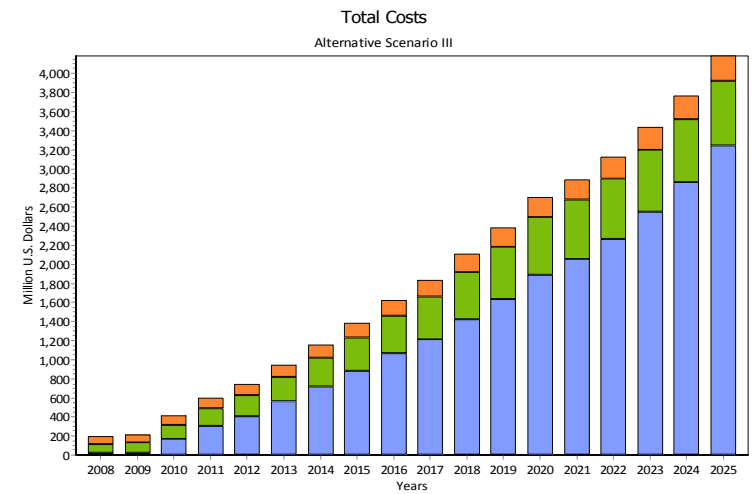


Figure 5-10: Alternative Scenario III

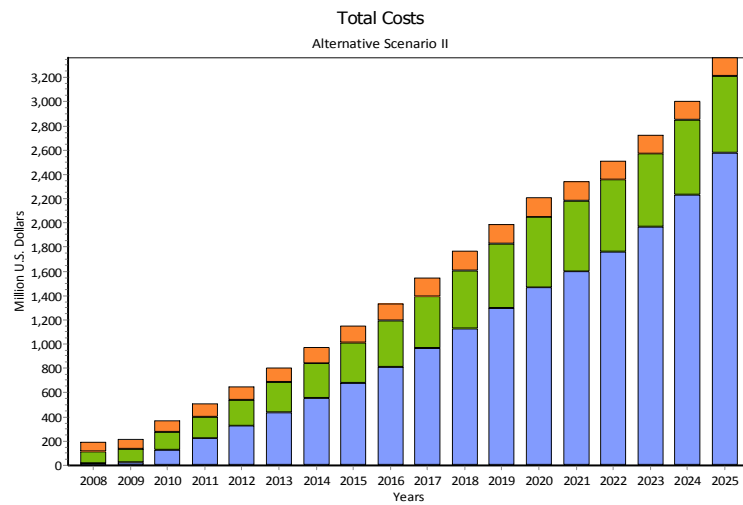


Figure 5-9: Alternative Scenario II

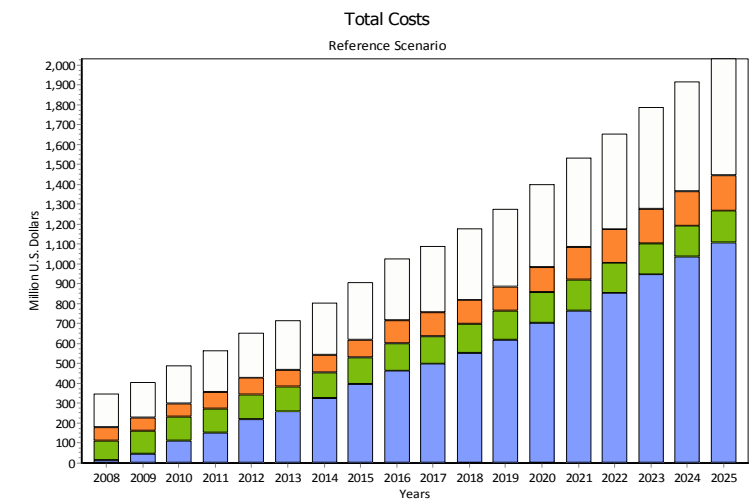


Figure 5-11: Reference Scenario.

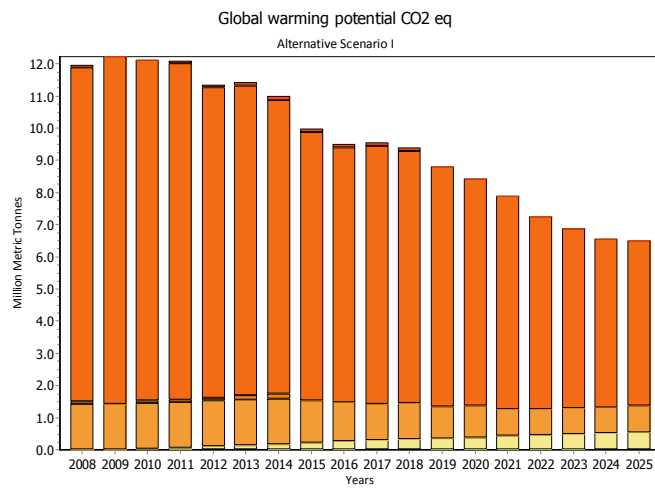


Figure 5-12: Alternative Scenario I

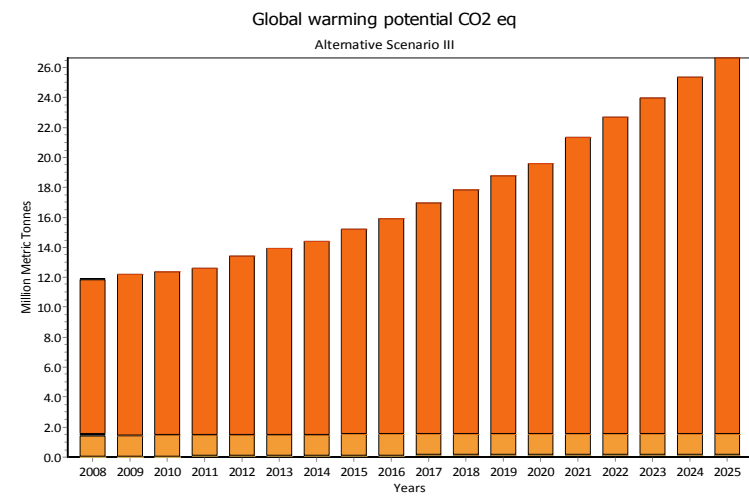


Figure 5-14: Alternative Scenario III

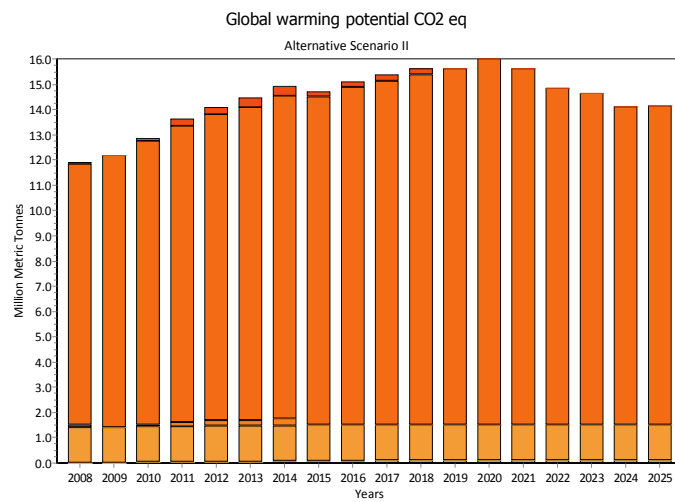


Figure 5-13: Alternative Scenario II

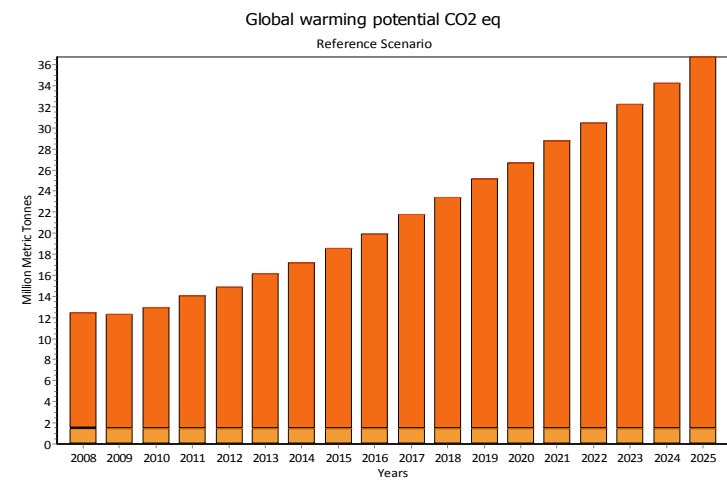


Figure 5-15: Reference Scenario

6 SCENARIO COMPARATIVE ANALYSIS

This section will provide comparative analyses of the significant results for each scenario based on the economic, environmental, and energy context involved.

6.1 Cost Comparison

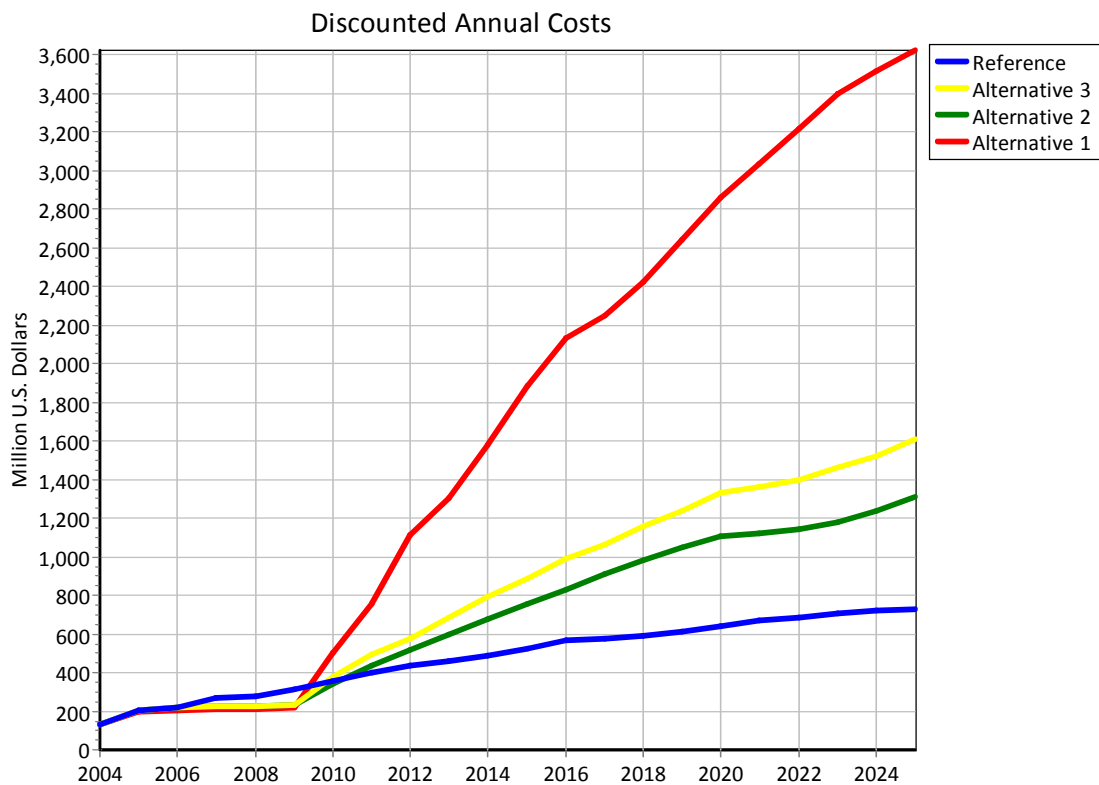


Figure 6-1: Total Net Present Value (NPV) costs per year for each scenario (discounted at 5% per annum).

The following graphs represent the costs associated with each scenario. Figure 6-1 displays the costs accrued each year while Figure 6-2 shows the total cumulative costs by transformation process in the last year of the planning period, 2025. The amounts are discounted at 5% per year and shown in 2004 US dollars.

Alternative I, 100% Renewable Technologies, is significantly more expensive than any other scenario with a total cumulative net present value (NPV) of just under \$ 38 Billion compared to a total reference NPV of almost \$ 11 Billion. Alternatives II and III incur moderate total costs,

approximately \$ 15 and \$ 18 Billion NPV respectively, in relation to the other two scenarios. The high cost of alternative I is due to significantly higher capital and fixed O&M costs associated with producing renewable electricity than with the reference technologies as evidenced by Figure 6-2. Solar and MSW installations are particularly capital intensive, though the solar costs are expected to fall; MSW has extremely high O&M costs. The transformation module cost included in the reference scenario represents the costs associated with expansion of the central electricity transmission system. These costs are only present for the reference as they are considered unnecessary for distributed generation systems which are the cornerstone of the alternative scenarios. It could be argued that alternative III should include some transmission costs because a scaled down version of the reference scenario is used; however, our argument remains consistent in saying that the majority of renewable technologies would be implemented in off grid areas, thus significantly reducing the need for transmission expansion.

6.2 Criticisms and Benefits

While the reference scenario appears to be the hands-down winner on an economic basis, there are several factors that could alter this perception. Due to limitations in the modeling software, it was unable to include the costs for fuel consumed in each scenario. The inclusion of these prices could significantly alter the final financial results. It is expected the reference to be impacted significantly more than the alternatives due to the use of commodity based natural gas as the primary fuel. However, follow up analyses using an updated version of LEAP should be completed before this can be verifiably stated.

A second factor to consider is the potential for Bangladesh to recover costs for renewable energy expansion through international programs. These may include the CDM or carbon credit trading systems that are in place through the UN or European Union. The amount of financial windfall possible through these routes is also a subject for further investigation, but would undoubtedly reduce the discrepancy between each alternative and the reference.

Finally, the costs associated with central grid expansion and long distance transmission may not be accurately represented through LEAP. The benefits of distributed generation discussed in section 5 would relieve Bangladesh authorities of the immediate need to invest in large scale transmission infrastructure, allowing them to focus more clearly on providing power where and in the appropriate quantities for which it is needed. The financial impact of this advantage is not specifically known, though again, it should benefit the comparison between each alternative and the reference scenario.

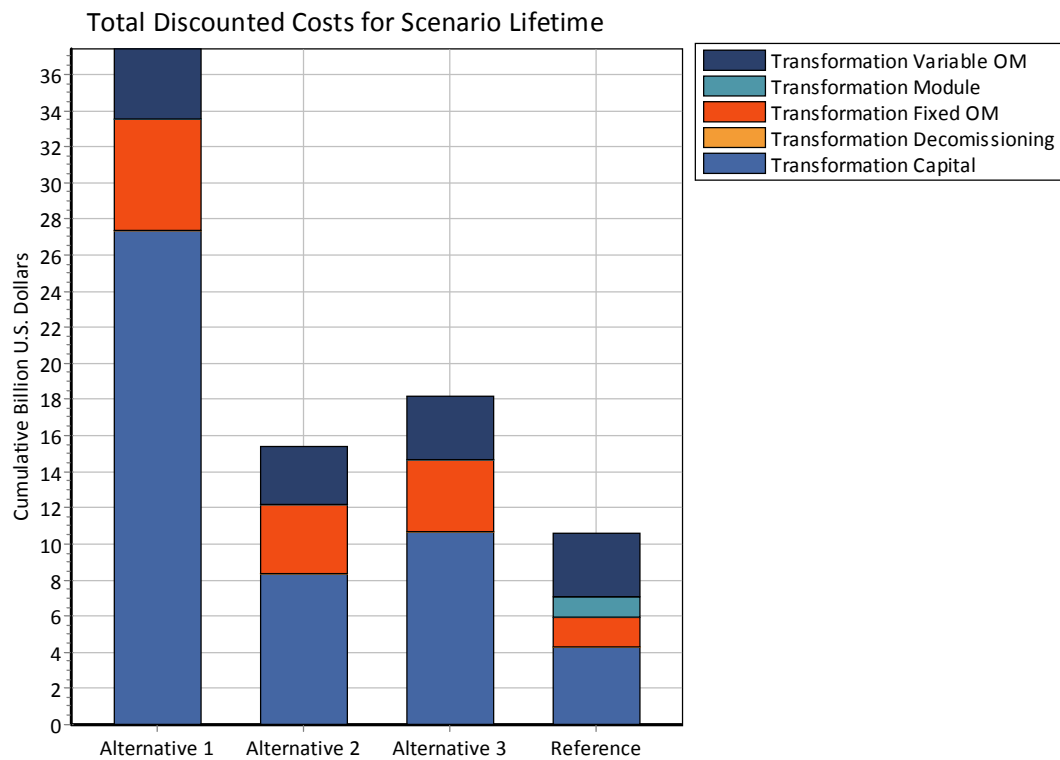


Figure 6-2: Total NPV costs over the entire scenario planning period (discounted 5%).

6.3 Global Warming Impact Comparison

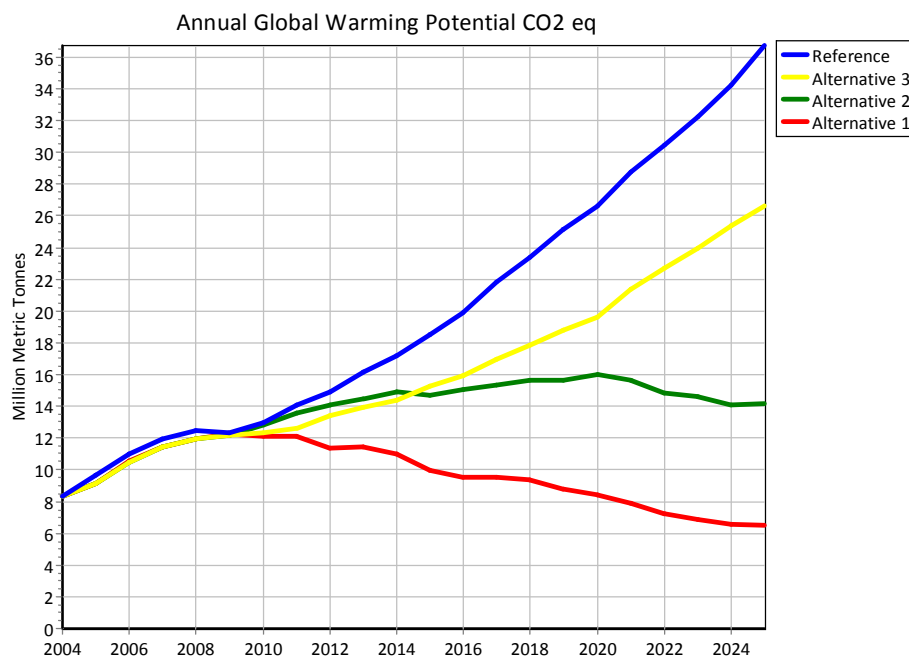


Figure 6-3: Annual global warming potential CO₂ equivalent.

The Figure 6-3 illustrates the annual global warming potential of each scenario. Alternative I and II have the lowest values. Alternative II rises at a modest rate up to 14 million tons. The line of alternative I expires at a level of around 6 million tons which means a decrease of GHG emissions and of the global warming potential of 50% from its peak.

Alternative II GHG emissions grow fairly constant over the scenario period. This is related to unmet electricity demand starting in 2010 which requires all plants to operate at maximum capacity at all times equating to a consistent GHG output from the existing power facilities present in the current accounts model. Alternative I does not reflect this trend because the added renewable capacity allows the existing facilities to power down during periods of low demand, thus emitting significantly less GHGs.

The blue line represents the current plan, reference scenario, in which massive amounts of central power in the form of natural gas is installed. This is not ideal in a world that is dealing with a global climate crisis because the CO₂ that is emitted from these power facilities are only adding to the problem. As it is seen on the graph after the expansion of the electricity system in 2025 the annual global warming potential of the electricity sector increases from 8 million tons in 2004 to nearly 37 million tons equating to an increase of over 450%. The alternative scenario 3 has a rise in emissions as well; however, the implemented renewable energy sources reduce the overall global warming effect versus the reference by approximately 30% over the last decade of the analysis. Therefore, in 2025 the alternative III produce about 10 million tons less CO₂ equivalent emissions than in the reference plan. This scenario shows the most environmentally friendly way of reaching the goals of the master plan.

6.4 Resource Availability and Consumption Comparison

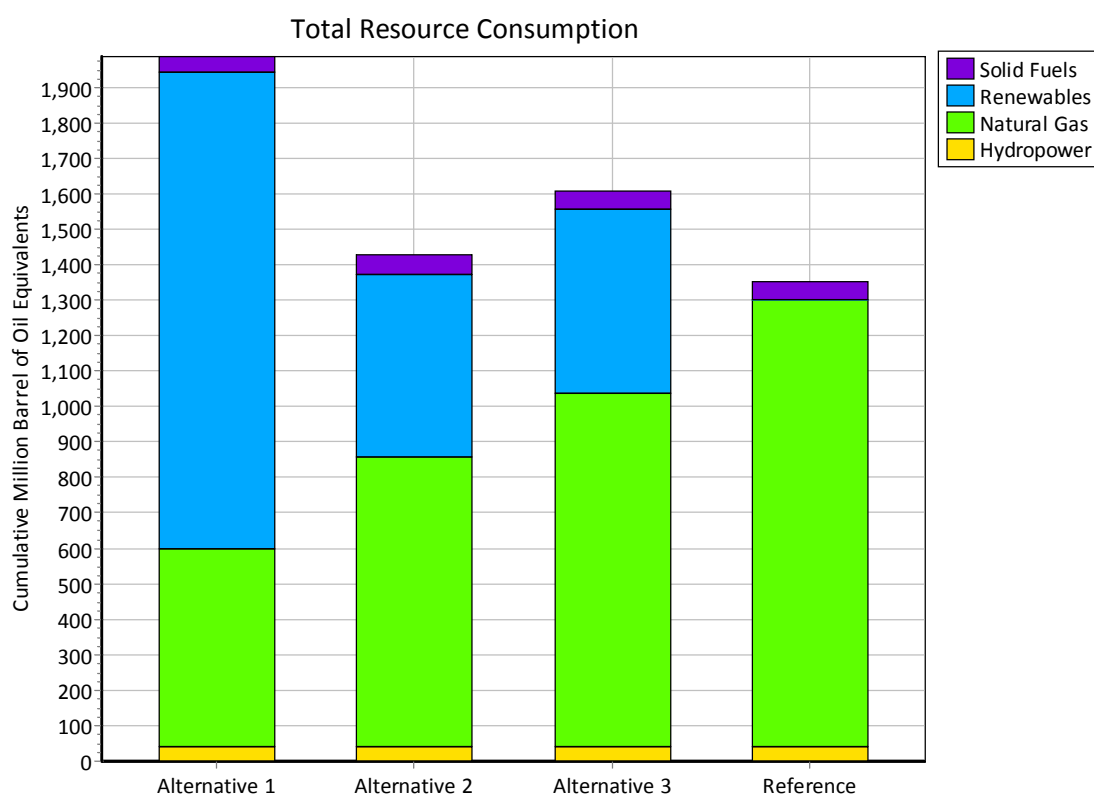


Figure 6-4: Total primary fuel input compared to each scenario.

The bar chart in Figure 6-4 shows the total primary fuel input in oil equivalent compared to each scenario. With the exception of alternative II, each plan has the same electricity output. The large consumption of renewable resources shown in the graph represents the lower efficiency of the renewable energy technologies versus the natural gas turbines used in the reference scenario. Alternative I needs about 650 million barrel of oil equivalent fuel input more than the reference scenario. That is almost equal to half of the total resource consumption in the reference scenario. However, the excessive resource inputs in the alternatives compared to the reference are renewable energy resources and are therefore sustainable (excepting alternative I which exceeds available MSW and biogas resources).

Additionally, natural gas is a limited fossil fuel, as shown in 3.2.6, the Master Plan predicts that they will use 9.5 Tcft or 63% of the 15 Tcft of total proven gas reserves by 2025. At this rate of consumption the domestic reserves would not last another 15 years, forcing Bangladesh to either switch technologies or begin importing natural gas. This potential dependence on foreign fuel

supplies should be avoided if at all possible. If Bangladesh were to use renewable technologies as prescribed by the alternative scenarios, a portion of this gas reserve could be saved for future use internally, or sold to other nations to help fund the renewable technology investments.

6.5 Energy Demand Satisfaction

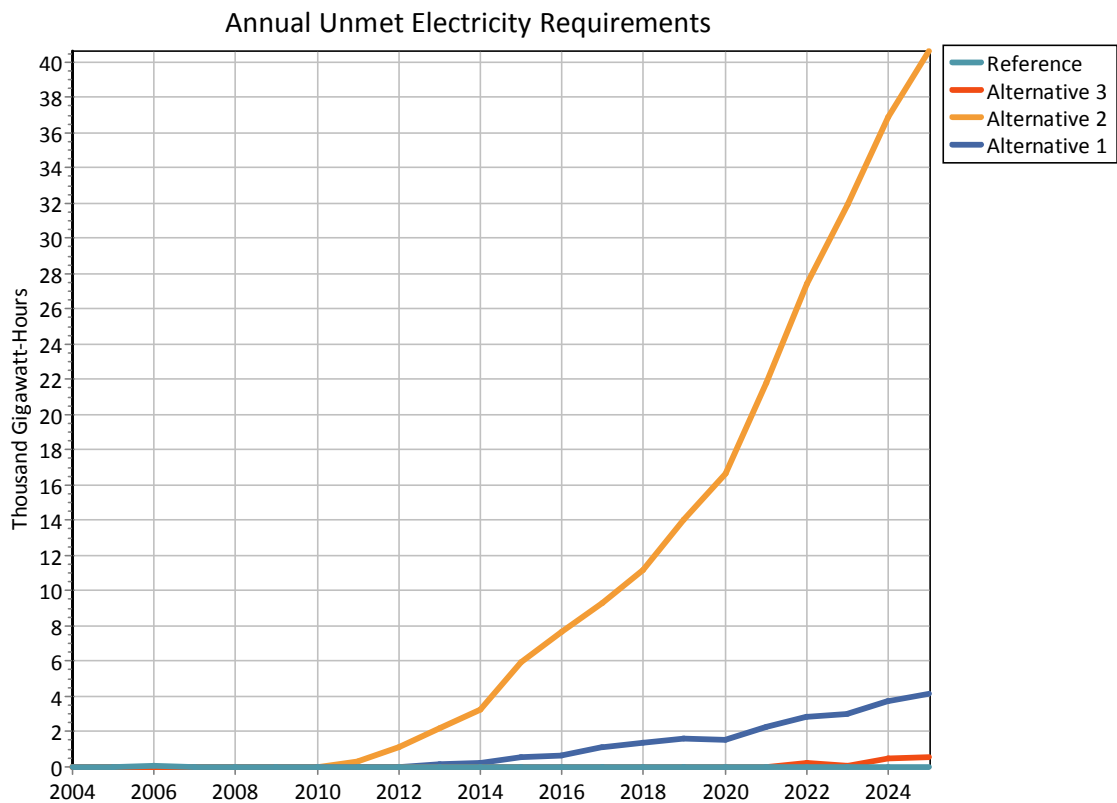


Figure 6-5: Unmet electricity requirements for each scenario.

Figure 6-5 shows the unmet electricity requirements based on implementation of each scenario. Alternative II is the significant result here showing that large sections of projected demand will remain unmet. This is due to the scenario parameters which were designed to limit the capacity expansion to reflect the renewable resources and implementation time scale considered feasible for Bangladesh (Appendix A). This gap amounts to about half of total system demand, therefore making alternative II unacceptable as long as the expected electricity demand growth remains consistent. The small deficits in alternative I and III are due to software discrepancies involved in the endogenous capacity function and should therefore be ignored during scenario comparison.

6.6 Discussion

Alternative scenario I, utilizing 100% renewable energy to meet all future electricity demand, is by far the best solution in respect to climate change mitigation. However, it is not only impossible based on a resource availability standpoint, but it is also prohibitively expensive without massive foreign aid mechanisms. Alternative II and III implement identical amounts of renewable technologies amounting to about a quarter of total electricity demand, 4.5 GW. Alternative III also includes over half the reference scenario natural gas additions, about 10 GW, to meet the remaining demand. While alternative II is cheaper, the unmet demand would leave significant portions of the country without electricity assuming consistent demand growth, making it an unacceptable alternative for Bangladesh's electrification agenda.

Therefore, alternative III is the most feasible of the alternative scenario options. While costing about 60% more than the reference scenario, Bangladesh would meet its 100% electrification goal within the desired time frame. Additionally, the inclusion of 25% decentralized renewable energy into the national system should bolster overall energy security in terms of fuel supply; reduce the intensity of infrastructure development responsibilities; and reduce vulnerability to cascading blackout effects due to natural disaster or load shedding. Alternative III would extend the lifespan of domestic natural gas reserves due to reduced consumption versus the reference. Furthermore, it is reasonable to assume that there could be significant financial benefits for Bangladesh based on an international carbon credit system or through the Clean Development Mechanism (CDM).

Acceptable levels of increased costs compared with long term sustainability are issues that the government of Bangladesh and related development investors will have to decide. It is the recommendation of this report that serious consideration be given to alternative III as a substitute for the reference scenario plan based on the reasons listed above.

7 RECOMMENDATION

The recommendation of this report is that Bangladesh attempt to implement the third alternative scenario, mixed renewable and traditional technologies. In this scenario they can achieve their goal of 100% electrification in the most sustainable way possible based on domestic renewable resources. Though the major fuel source will still be non-renewable natural gas, it is the best case for such rapid and massive expansion of electricity access in Bangladesh. The long term benefits gained from immediate inclusion of renewable resources into the electricity sector should outweigh the added capital costs associated with the technologies discussed in the alternative scenarios. Additionally, Bangladesh would be eligible for international development aid based on established and expected CDM protocols. Though these are not discussed in detail in this report, further work should be done to establish the exact potential of such development mechanisms.

Specifically, small scale solar units similar to those already used (50 W SHS) should be used to provide basic power levels to many rural households. Biogas programs should be expanded, in tandem with the introduction of biogas engines to replace diesel generators in rural areas. The size of these engines could vary considerably to accommodate single households (50-200 W) or entire villages (1-100 kW). An organizational system may need to be established among local farmers for areas that employ larger scale biogas generators in order to supply adequate amounts of biogas from multiple small scale digesters. These recommendations would require cooperation between local municipalities and the central government. Financing schemes are already in place, like the Grameen Shakti program, that provides models of effective electrification methods in poor areas. With substantial support from federal or international agencies, these programs could greatly expand current electrification to the levels described in the mixed renewable and traditional technologies scenario. MSW incineration would require substantial investment from government authorities as well as significant organizational methods to collect and treat the waste. Though the costs are significant, Bangladesh would be well served to use this technology as it could provide almost 2 GW installed capacity by year 2025. The expected improvements in waste handling and associated public health would also be of great benefit to overpopulated urban areas.

With reservations, it is also the recommendation of this report that Bangladesh should meet its remaining electricity needs with the government proposed natural gas facilities. Though these are not sustainable, nor renewable, the goal of electrification and poverty alleviation is significant and should not be ignored. The expansion of natural gas facilities is not considered a long term solution by this report due to the limited domestic gas supplies and the impending vulnerability to climate change that could affect large infrastructure expansion.

8 CONCLUSION

The two greatest problems facing many developing nations are the issues of extreme poverty and vulnerability to the effects of climate change. The concept of sustainable development was identified as an essential element in combating both issues. Due to geographic and economic conditions, Bangladesh has been shown to be particularly vulnerable to these issues. The key limiting factor for economic and social development as well as the capacity to cope with climate change was determined to be the limited availability of electricity. In order to address this predicament, the government of Bangladesh has established a Power System Master Plan for electrification that relies on the implementation of large centralized natural gas power facilities in combination with a robust expansion of the national electric grid. This plan incorporates several policies that were deemed counterintuitive to the adoption of sustainable development strategies identified in this paper as the following:

1. Long term commitment to non-renewable fossil fuels of which domestic supply is relatively small (40 years maximum at projected rate of consumption).
2. Expansion of central grid infrastructure across vast rural areas requiring high investment costs.
3. Vulnerability to fuel supply and cost fluctuations.
4. Reduced energy security with respect to natural disasters due to centralized production and transmission system.
5. Increased impact on climate change

To address these issues and propose alternate development strategies, several scenarios were created with the modeling software LEAP extrapolating to the year 2025. These included a “business as usual” or reference scenario followed by three alternative scenarios, each one employing different strategies to electrify Bangladesh.

The results of this analysis show that the economic costs of implementing each alternative scenario are significantly higher than for the reference. The recommended alternative is approximately 60% more expensive than the Reference scenario. However, it is unclear as to the impact each scenario may have on alleviating extreme poverty due to the varied effects of rural electrification strategies as well as the domestically driven renewable technology industry expected to accompany the alternative scenarios. The environmental assessment revealed a much clearer picture than the economic analysis as the reference scenario drastically increases Bangladesh GHG emissions compared to each alternative. The Reference scenario releases 30% more CO₂ than the

recommended alternative and even more for the other alternatives. Though not shown quantifiably in this paper, the impacts of a sustainable energy policy on environmental management and climate disaster mitigation are discussed. In terms of energy (in our case only electricity) requirements, the reference as well as first and third alternative scenarios all meet the expected demand over the planning period. However, the first alternative is not feasible due to limited domestic renewable resources; therefore the third alternative is the only one that Bangladesh could realistically consider as a substitute for their current Power System Master Plan.

In relation to the dilemmas of climate change and poverty, Bangladesh would be well served to consider the third alternative scenario. By incorporating all reasonably available solar, biogas, and MSW based electricity generation they could meet approximately 25% of the expected rise in electricity demand over the next 20 years. Meeting the remaining 75% with natural gas powered central electricity, while not ideal environmentally, should provide significant economic stimulus for a nation in desperate need of a secure electricity supply. The 25%, about 4.5 GW by 2025, renewable energy would be a major accomplishment for an industrialized nation, as Bangladesh intends to be by that date. It is also reasonable to assume that this effort towards sustainability could provide significant collateral on the global stage to influence international climate treaties.

It is the opinion of this paper that the Bangladeshi authorities have hastily decided upon the “path of least resistance” in choosing natural gas turbines as their dominant power generating technology. It is clear to us that further investigations concerning renewable development options should be conducted. Given more time to become acquainted with LEAP as well as Bangladesh’s internal objectives and limitations, this study could be considerably more inclusive and focused. The inability to include fuel costs, due to software limitations, could be very significant for the economic analysis. Additionally, the disparity in capital costs between the reference and alternative scenarios could be altered in either direction by quoting alternative figures for the renewable technology costs.

This report has taken an existing energy plan and tried to adapt it in a sustainable manner. While on paper this is the ideal solution, reality may disagree. It is possible that the government already looked into sustainable options but came to the conclusion that the current energy plan is the best option for their country. Their priorities maybe to first become a developed country as quickly as possible and worry about sustainability later. While it seems irresponsible to proceed in this manner it is the quick and inexpensive option. Clearly changes in the country’s ideology need to occur for the sustainable option to be implemented and there needs to be complete backing by the Bangladesh government. They need to develop a new energy plan and establish new institutions that specifically deal with sustainable development. These institutions can be government panels to

create regulations, sustainable research institutions creating more efficient technologies or public education on how to live in a sustainable way. Sustainability cannot be achieved without the co-operation of both the people and the government.

In closing, the model provided by Bangladesh should they adopt the mixed renewable and reference alternative development tactic, if successful of course, would be highly valued among other developing nations as a guideline as they construct Master Plans of their own. It is reasonable to assume that the local populace of these nations would benefit similarly in socio-economic terms to the people of Bangladesh. Furthermore, the global impact on climate change could be significantly lessened if these nations adopt a sustainable pathway from the outset of their industrialization efforts. This trend towards sustainability would constitute a significant step in breaking the pandemic addiction to fossil fuels that plagues the developed world today.

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APPENDIX A

Maximum renewable capacities based on resource limitations

Maximum capacities for each of the alternative scenario technologies were determined based on an analysis of resource availability in Bangladesh. This maximum resource availability corresponds to the amount of livestock manure to be used in biogas facilities and the amount of MSW produced in Bangladesh at any given year (see section 3.3 Renewable Resources). Using a 15 ton per hour usage in MSW facilities (DEA tech catalogue) corresponding to 10 MW capacity, the total maximum capacity was established. For biogas, a conversion rate of 1kg dung to 0.04 m³ biogas was used (Renewable Energy resources and tech practices) to calculate a maximum yearly production of 3.2 billion m³. Using our established efficiency for biogas engines, a maximum generating capacity was calculated for each year.

An introduction factor was included for each technology to account for the difficulties of bringing new technologies online in an established electrical system. This factor was determined based on a percentage of the calculated maximum possible capacity. For MSW, the maximum capacity is dependent upon the amount of waste generated in Bangladesh. This figure rises significantly as the population increases through the years. An introduction factor of 10 %, or 112 MW, was chosen with a first installation date of 2010 to allow for planning and construction period. The factor was then increased by 10 % each year until reaching 100 % in year 2017 at 1.9 GW total installed MSW capacities. Biogas was introduced in year 2010 at a 20% factor, 131 MW, and increased by 10 % each year until maxing out at 657 MW in year 2016.

For solar PV, the only real limiting factor is the high capital cost and availability of PV cells. Growth rate was established based on the actual growth rate of solar power in Bangladesh. The current plans are to bring 3 MW of new rural SHS systems online each year equating to a growth rate of 100% in 2005, 50% in 2006, and 33% in 2007 (Renewable Energy Resources and Tech practices). Assuming a growth rate of 33% from then on would reflect increased government assistance for solar installations leading to a significant increase in solar capacity by the end of the scenario planning period of 1.9 GW. This calculation is highly dependent on external factors such as technology pricing, government support and international clean development aid.