

Prospects of Nuclear Energy for Sustainable Energy Development in Bangladesh

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Abstract

Crisis of power is one of the major problems in Bangladesh. At present, electricity production in Bangladesh is mostly based on the existing reserve of conventional energy sources as fossil fuel like gas, coal, oil etc. which is not sufficient to meet the present and near future power demand. A comparative study between power generation from different energy sources and world energy consumption indicates that power generation from nuclear energy will facilitate to optimize energy mix and diversify country's energy source to get out of the chronic power shortage problem, sustaining the power development in Bangladesh. Considering the global trends to nuclear power, electricity generation from nuclear power plant could be the best option for Bangladesh to cope up with the growing demand and overcome energy and power crisis.

Keywords

Power Crisis, Power Sector, Sustainable Energy, Nuclear Energy, Nuclear Power Plant

Introduction

Electricity is the key source of power for socio-economic development of any country. Resources of fossil fuels are plentiful, which eventually will limit the use of these fuels. Often per capita consumption of electricity and energy is considered as one of the development indications of a country. In the Reference Scenario, global electricity generation (by fuel type) is shown in Fig. 1.

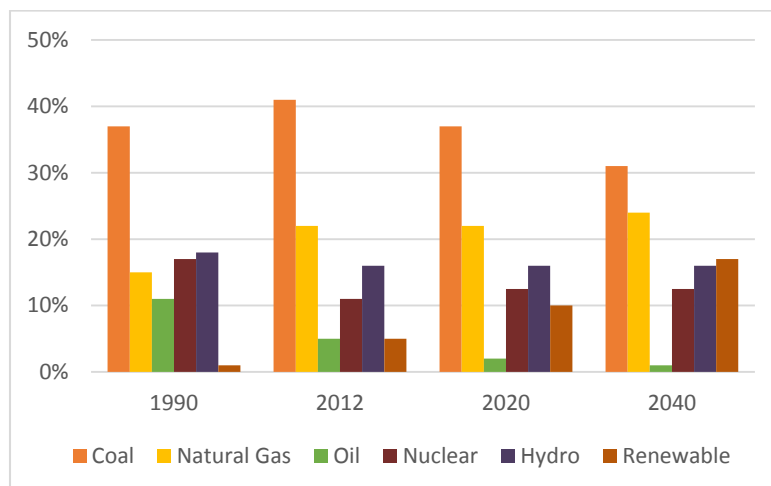


FIG. 1. WORLD ELECTRICITY GENERATION, 1990-2040 (SOURCE: IEA).

The per capita energy consumption in Bangladesh is one of the lowest (321 kWh) in the world. In Bangladesh, commercial energy consumption is mostly natural gas (around 62%), followed by oil, coal and hydropower. According to Bangladesh Power Development Board (BPDB), in the year 2014 against a peak electricity demand of 8349 MW, the maximum production of electricity was only 6675 MW [1]. Bangladesh's installed electric generation capacity was 11683.00 in August 2015 [1, 2]. Only 62% of the population has access to electricity with a per capita availability of 321 kWh per annum. Nowadays, the sustainable development is one, which does not have diverse effects on the environment and natural resources. However, all forms of electricity generation are unavoidable for

a sustained economic development. Generation of electricity from fossil fuels is costly and more significantly polluting the environment. Moreover, power generation from renewable energy will not be enough to fulfil the huge shortage of power. It is very essential for Bangladesh to give top priority on large scale power generation from other sources. Fossil fuels like petroleum and coal have been blamed as being responsible for greenhouse gases while nuclear power generation is generally regarded as clean in that standard [3]. Nuclear power can make a major contribution for meeting energy needs and sustaining the world's development in the 21st century, for a large number of developed and developing countries. According to IAEA, Nuclear power was projected to increase to 17% share of the world's electricity production by 2020. As of July 2015, 30 countries worldwide are operating **438** nuclear reactors for electricity generation and **67** new nuclear plants are under construction in 15 countries. It is projected to raise the number of nuclear power reactors to 200 to 400 during the next quarter century [4]. The projection of world net electricity generation from nuclear power, by region, 2006-2030 [5] is shown in Fig. 2.

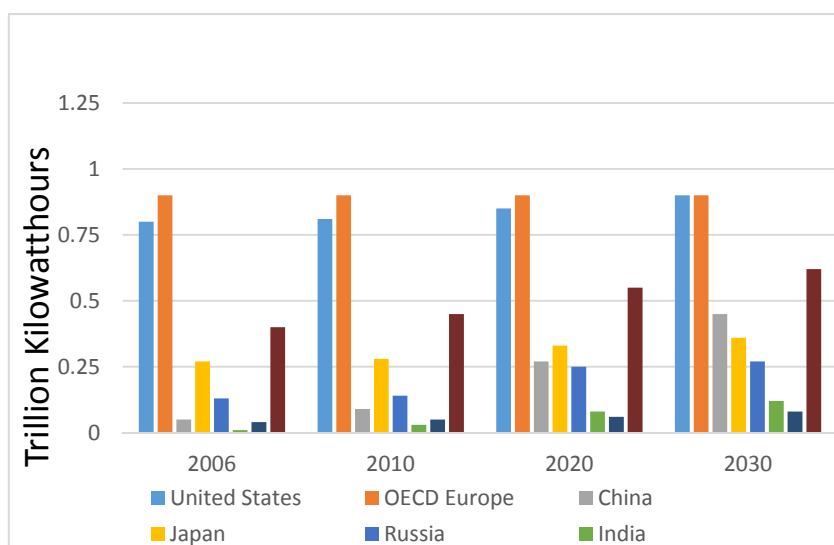


FIG. 2. WORLD NET ELECTRICITY GENERATION FROM NUCLEAR POWER, BY REGION, 2006-2030.

Bangladesh government is now planning for generation of electricity from nuclear power plant and recently they have taken a project called Rooppur Nuclear Power Plant Project (RNPP). This paper presents the feasible contributively share of electricity generation from each energy resources. This includes the economical feasibilities and all demographic projections involved in forecasting methodology, which explicitly reflect on overall national power demand projection in the energy prospects of Bangladesh till 2030. The energy demand and reliability are presented with a view to elaborate on significant role and required capacity of Nuclear Power Plants (NPP) towards fulfilment of an energy mix policy in the country. To keep pace with the increasing demand, it needs a source that can produce much more electricity than the present production. Such a breakthrough in electricity production can only be achieved through the introduction of nuclear energy in power generation system of Bangladesh. Nuclear energy is produced by fission reaction of fissionable fuel in a nuclear reactor. The amount of energy produced from nuclear reaction is gigantic compared with the energy produced from other primary resources. On the other hand, a nuclear power plant produces very little amount of greenhouse gases, so it is much safer [3, 4].

Electricity Scenario in Bangladesh

Primary Energy Resources

Bangladesh has very few natural resources which are being used to produce electricity, such as- coal, natural gas, furnace oil, diesel and hydro. The share of power plants in nominal capacity and electricity generation is shown in

Fig. 3. From the Fig. 3, it is clear that most of power plants in Bangladesh is using natural gas as fuel about 61.97 % of the total capacity. Other power stations are based on 21.46% furnace oil, 8.18% diesel, 1.97% hydro and 2.14% coal.

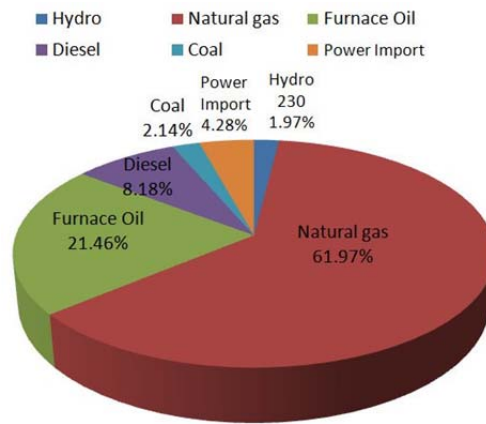
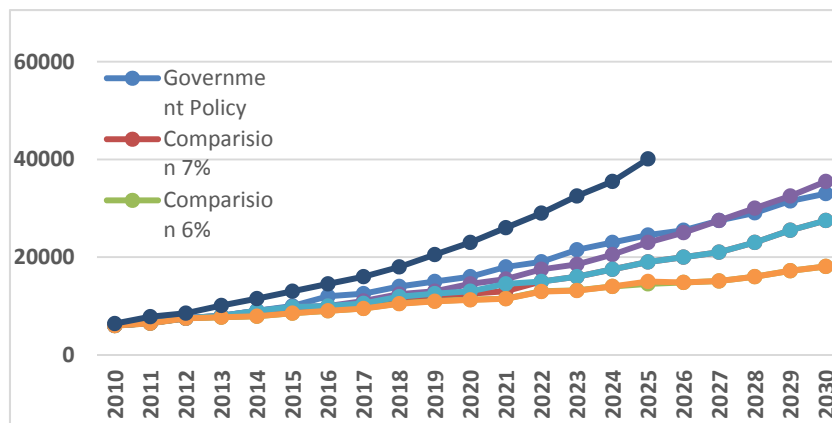


FIG. 3. INSTALLED CAPACITY AS ON AUGUST 2015 (BY FUEL TYPE)
TOTAL INSTALLED CAPACITY: 11683 MW (SOURCE: BPDB WEBSITE)

Coal is harnessed from coal mines situated in the northern portion of Bangladesh and there are several gas fields lying all around the country. But it is not possible to harness enough coal from the mines because of negative effects of it on nature and gas fields have limited balance of gas left in them. Bangladesh has to import furnace oil and diesel from abroad. According to Bangladesh Power Development Board (BPDB), the total installed capacity as on August 2015 is about 11,683 MW [2]. The net production capacity of Electric Power Plants of this country has reached 10445 MW in the year 2015 in August. It is well known that there is a direct relation between electricity consumption and economic growth. Therefore, electricity sector has to be developed to sustain this growth [4]. More electricity generation in thermal power plants will increase fossil fuel consumption, which subsequently results in an increase in emissions.

Problems with Present Electricity Scenarios

To make a proper power generation master plan, it is required to make a proper speculation of the speed at which the demand is increasing. According to the Power System Master Plan (PSMP) 2010, demand forecast made by Government of the People's Republic of Bangladesh is based on 7% GDP growth rate (Fig. 4). Based upon this study the peak demand would be about 17,304 MW in FY2020 and 25,199 MW in 2025. The electricity development is required to be accelerated to increase access and attain economic development. Therefore, Bangladesh is in the immediate need of manifold increase of existing electricity generation capacity.



SOURCE: PSMP STUDY TEAM.

FIG. 4. POWER DEMAND FORECAST 2010-2030 IN BANGLADESH.

Bangladesh has to import furnace oil and diesel from abroad. At the current rate of natural use in Bangladesh, the current estimated proven reserves would last 45 years. Even if the present rate of use increased at 10% per year, these reserves would last about 17 years (source: Wikipedia). Power sector ranks the highest (44%); fertilizer sector ranks the second (28%); and industry, domestic, commercial and other sectors together rank third (22%) in gas consumption. This speculation is made on the basis of a fixed GDP. So an increasing GDP will definitely increase the demand much more. To fulfil such a great demand of electricity in the future, present production needs to be

incremented greatly which can only be done with nuclear power plants. There is a huge gap between supply and demand which is increasing day by day. Since maximum power plants are gas based and proven gas reserve is reducing and no new gas reserve has been discovered yet. This huge gap cannot be met by renewable energy. In that case, nuclear power may be the alternative option for generating electricity. Nuclear power could be a reality to bridge between the huge gaps between supply and demand. In the modern world, nuclear power has already been proved as cheap, reliable and safe. Government of Bangladesh has made vision and policy statement regarding power sector improvement. For that purpose, Govt. issued its vision and policy Statement on power sector reforms with the following objectives:

1. Bringing the entire country under electricity service by the year 2025 in phases.
2. Making the power sector financially viable and able to facilitate economic growth.
3. Introducing new corporate culture in the power sector entities and increasing the sector's efficiency.
4. Improving the reliability and quality of electricity supply.
5. Ensuring reasonable and affordable price for electricity by pursuing least cost options.

Impact on Environment

Conventional Energy Sources

These days one of the biggest concerns of the world is the greenhouse gas emission. The burning of fossil fuel emits harmful gases like carbon dioxide, carbon monoxide, sulphur dioxide, sulphur trioxide, etc. in the atmosphere altogether known as the greenhouse gases. These gases raise the temperature of the atmosphere trapping the heat radiated from the earth making the world a vulnerable place to live in. The sources of emission free-electricity are shown in Fig. 5. The average greenhouse gas emission from coal based electricity production is about 1100 grams of CO₂ per kWh and from nuclear power plant; it is about 15 grams of CO₂ per kWh. So nuclear power plants are much healthier for the earth. However, fossil has still various irreplaceable roles and uses in society. Thus, most countries have a mix energy policy covering non-renewable, new, and renewable energy sources with different composition depending on their unique situations relating to various factors, e.g. population and economic growths, life-style, country's potency on domestic energy sources, etc. to secure the sustainable energy supply. Introducing solar, wind and other new energy sources is also an extremely efficient means of reducing CO₂ emissions. At present, however, these new energy sources still have issues of supply stability (energy cannot be generated on rainy days or when the wind does not blow), economic feasibility, etc. Under the present conditions, the power output of systems using natural energy such as solar power generation and wind power generation is prone to fluctuation, so backup power sources are essential.

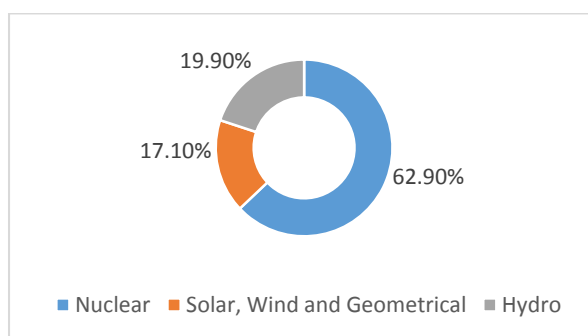


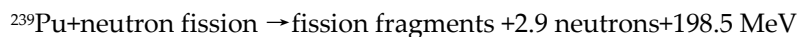
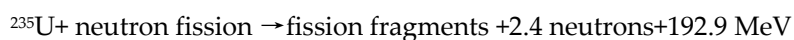
FIG. 5. SOURCES OF EMISSION-FREE ELECTRICITY IN 2014.

SOURCE: [HTTP://WWW.NEL.ORG/CORPORATESITE/MEDIA/IMAGES/INFOGRAPHICS/SOURCES-OF-EMISSION-FREE-2014-01.PNG?WIDTH=1500&HEIGHT=1125&EXT=.PNG](http://www.nel.org/corporatesite/media/images/infographics/sources-of-emission-free-2014-01.png?width=1500&height=1125&ext=.png)

The Alternate Energy Source

With such a sharp increase of demand and a decrease in the reserves of primary resources for electricity production, the perfect alternative is the introduction of nuclear based power production. Nucleus, one of the fundamental particles inside an atom releases energy when some special atoms are combined together to form

large atom or some special large atoms are split to form smaller ones. In nuclear fission, atoms are split apart to form smaller atoms, releasing energy. Nuclear power plants use nuclear fission reaction to produce electricity. Usually in commercial production of nuclear energy, special isotopes of Uranium and Plutonium are used. The general reaction is figured out below-



This massive energy is not produced in open places like the burning of fuels. This production needs an isolated and controlled environment.

Advantages of Nuclear Energy Based Electricity Production

Bangladesh needs a stable and powerful source which will be able to supply energy continuously for a very long period of time. Nuclear Energy can be the best solution to this problem. Primary sources of energy can't provide that much of energy as Nuclear Energy. Also the lifespan of a typical nuclear power plant is much higher than any other plant. Uranium is also abundant, and technologies exist which can extend its use 60-fold if demand requires it. World mine production is about 60,000 tonnes per year, but a lot of the market is being supplied from secondary sources such as stockpiles, including material from dismantled nuclear weapons. Practically all of it is used for electricity. For comparison, the typical heat value of various fuels is given in Table 1.

TABLE 1. TYPICAL HEAT VALUES OF VARIOUS FUELS

Firewood (dry)	16-18 MJ/kg
Brown coal (lignite)	10 MJ/kg
Black coal (low quality)	13-23 MJ/kg
Black coal (hard)	24-30 MJ/kg
Natural Gas	38 MJ/m ³
Crude Oil	45-46 MJ/kg
Uranium - in typical reactor	500,000 MJ/kg (of natural U)

(MJ = Megajoules)

Source: <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Introduction/Energy-for-the-World---Why-Uranium/>

It is seen that the source of nuclear energy- natural uranium can provide about 10000 times more energy than crude oil- the second highest heat value provider. The difference in the heat value of uranium compared with coal and other fuels is important since it directly affects the amount of wastes that each fuel produces. For instance, a single 1000 MW coal-fired plant produces over 300,000 tons of ash, 44,000 tons of sulphur dioxides, 22,000 tons of Nitrous Oxide and 6 million tons of carbon. In contrast, a 1000MW of nuclear power plant produces a mere 3 cubic meters of wastes after reprocessing the spent fuel, 300 tons of radioactive wastes and 0.20 tons of plutonium. There are also different transport requirements for both nuclear fuel and fossil fuels in the context of Bangladesh. Transportation costs are higher for coal and oil systems at 20000 train cars or 10 super tankers, in relation to a nuclear plant at just 3-4 trucks.

Nuclear Energy in Bangladesh

In 1963, the Rooppur site was selected for the establishment of the first nuclear power plant of this country. In 2001, Bangladesh adopted a national Nuclear Power Action Plan. On 24 June 2007, Government of People's Republic of Bangladesh announced planned to build a nuclear power plant to meet electricity shortages. In May 2010, Bangladesh signed a civilian nuclear agreement with the Russian Government. Bangladesh also had framework agreements for peaceful nuclear energy applications with the US, France and China. In February 2011, Bangladesh reached an agreement with Russia to build the 2,400 megawatt (MW) Nuclear Power Plant with two reactors, each of which will generate 1,200 MW of power. The nuclear power plant will be built at Rooppur, on the banks of the Padma River, in the Ishwardi sub district of Pabna, in the northwest of the country. The RNPP (Rooppur Nuclear Power Plant) is estimated to cost up to US\$14 billion (for 2 units of each 1200 MWe), and start operating by 2024/2025. The inter-governmental agreement (IGA) was officially signed on 2 November 2011. The Bangladesh

Atomic Energy Commission (BAEC) is responsible for implementation of RNPP project. For the development of nuclear sector, BAEC created necessary infrastructure to conduct the following major activities:

- o Obligations under nuclear power plant and non proliferation including establishment of state system of accounting and control.
- o Implementation and enforcement of safeguards legislations and relevant safeguards procedures.
- o Physical security of nuclear materials and performing all regulatory activities.

Though many issues relating to cost, financing and safety are yet to be resolved but Govt. is trying to solve all obligations regarding nuclear power. For this purpose, it is required that:

- o BAEC should develop basic technological infrastructure and manpower to set up Nuclear Power Plant (NPP).
- o Manpower for operation and maintenance of the nuclear power plant may be trained in cooperation with the plant suppliers and a team on design aspects could be planned as part of overall contract with the main supplier.
- o Fresh professionals should be appointed for RNPP which will be available to general Universities, Universities of Engineering and Technology and Technical Institutes during implementation phase.

Human Resource Development

BAEC has trained up a good number of professionals in various branches of nuclear technology to be involved in different implementation of phases of RNPP. Present manpower for “Rooppur NPP” Project is about 55 with 28 professionals-

- o Project Planning & Contract Negotiations: 7
- o Sitting and Development: 9
- o Nuclear Technology: 7
- o International Coordination & HRD: 5

A new department “Nuclear Science and Engineering” has opened for undergraduate and postgraduate students under the Military Institute of Science and Technology (MIST). Nuclear Science and Engineering Department started the first academic session on 5th February 2015 for B.Sc. Engineering (40 students) as commitment of MIST to develop skilled manpower for the first nuclear power project of Bangladesh. This Department also started the first academic session on 18th October 2015 for M.Sc. Engg./M. Engg, (26 students) and Ph.D.(3 students) programme to meet challenges of healthy and prosperous human resources for Bangladesh in the field of nuclear science and engineering.

Energy Security

Dependence on energy imports carries a large risk of disrupted power supplies. Nuclear fuel may also have to be imported and transported. However, because of the high energy density of nuclear fuel, it is possible for countries to stockpile sufficient imported uranium to operate their nuclear supply systems for many years on the once-through fuel cycle and thus weather any realistic supply interruption. Other energy resources, such as coal, could also be stockpiled, but uranium has significant advantages: the cost is low (about one- tenth that of coal for equivalent energy); storage is easy (more than four orders of magnitude less mass than the mass of coal for equivalent energy); and uranium, unlike coal, will not degrade in storage.

Global Climate Change

In 1990, a major environmental concern merged-the potential for climate change due to rising greenhouse gas (GHG) emissions that trap heat from the sun. That same year, the United Nations Framework Convention for Climate Change was convened and signed in Rio de Janeiro.

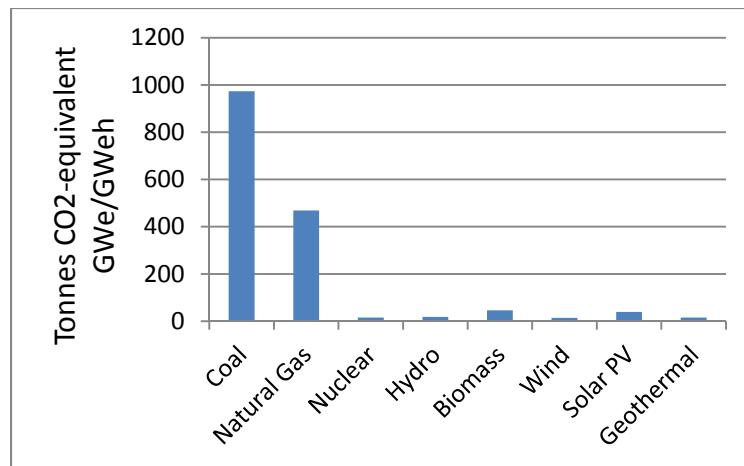


FIG. 6. LIFECYCLE EMISSIONS FOR VARIOUS ELECTRICITY GENERATION TECHNOLOGIES.

SOURCE: [HTTP://WWW.ZDNET.COM/ARTICLE/NUCLEAR-LESS-CO2-THAN-SOLAR-HYDRO-BIOMASS/](http://www.zdnet.com/article/nuclear-less-co2-than-solar-hydro-biomass/)

To implement the convention, the Kyoto Protocol was then negotiated, signed, and ratified by many countries. Although the United States—until recently, the world's largest emitter of greenhouse gases (superseded by China in 2008)—withdrew its signature in 2001, the protocol was eventually ratified by the required number of countries and went into effect in 2005. Like renewable energy sources (hydro, wind, solar, biomass, and geothermal), nuclear power is a low-GHG emitting technology. Indeed, GHG emissions from nuclear and renewable technologies are between one and two orders of magnitude below corresponding emissions from fossil fuel energy chains. In a life cycle analysis (Fig. 6), nuclear power is among the lowest of all forms of electricity generation in CO₂ emissions. It illustrates how many tonnes of CO₂ are emitted per gigawatt hour of electricity generated by different generating technologies. The figure 6 is a "lifecycle" analysis that takes into account of CO₂ emitted not only during electricity generation, but also by the mining, manufacturing, construction and other processes it is taken to get a power plant up and keep it running.

Reducing Air Pollution

Nuclear power has significant environmental benefits compared with fossil fuel generation. Under normal operations, nuclear power plants produce almost no airborne pollutants. Small quantities of radioactive gases are regularly emitted under controlled conditions imposed and supervised by regulatory authorities and pose no significant threat to plant workers or surrounding populations. By contrast, emissions from fossil fuel plants pose significant threats to human health and the environment. The main emissions from fossil fuel plants are particulate matter, sulphur dioxide, nitrogen oxides, and a variety of heavy metals—mercury being the most prominent. Thus, nuclear power almost entirely avoids the environmental effects of fossil fuel pollutants.

Changing Public Attitudes

Public opposition to nuclear power started in earnest in the early 1970s. As the memories of the Three Mile and Chernobyl accidents fade and the security of energy supplies and need to cut greenhouse gas emissions come to the fore of public concerns and debates, attitudes toward nuclear power have gradually changed. A public opinion survey was carried out toward nuclear power between 1983 and 2008 in the United States. A survey conducted in September 2008 indicated that a record-high 74 percent of Americans favoured nuclear energy, with only 24 percent opposed. Those who strongly favoured nuclear power outnumbered those who strongly opposed by almost four to one. The favourability mark in September was 11 percentage points higher, and the unfavorability level 9 percentage points lower than was the case just five months before [6]. Similar survey has been carried out in Bangladesh in 2010 [7]. A survey conducted in March 2015 indicated that 70% of Bangladeshi people favoured nuclear energy, with only 30% opposed. In 2010's survey it was 62% [7].

Safety Risks and Perceptions

A unique hazard of nuclear plants is the potential for exposing the public to radiation. A major health hazard would be resulted, for example, if a significant portion of the radioactive inventory in the core of a nuclear reactor

was released to the atmosphere. Such releases are obviously unacceptable, and steps are taken to ensure that they never occur. Various techniques are used, including conservative designs, safety equipment, and physical barriers to radiation releases if all other measures fail. Physical barriers include the containment structure, a large steel and concrete structure enveloping the nuclear reactor and many of its systems. Although objective estimates of safety levels can be made using physical laws and probability theory, setting safety criteria is often difficult and subjective. Such standards must take into account the public's view of how safe is safe enough. As a result, absolute guarantees of safety are sought. But a policy based on that premise overlooks the fact that every human activity entails some risk. In this context, it is useful to examine the effects on human life of various electricity generation technologies and to compare the effects per unit of electricity produced. A number of studies cover this subject. A 1998's study by Switzerland's Paul Scherrer Institute examines the external costs of electricity production [8,9]. Comparing deaths based on one terawatt-year, coal caused 342, hydropower 883, natural gas 85, and nuclear power just 8 (Fig. 7). Given that, nuclear power currently generates about 2500 TWh a year, and 8 deaths would occur every 3.5 years-while providing 16 percent of the world's electricity.

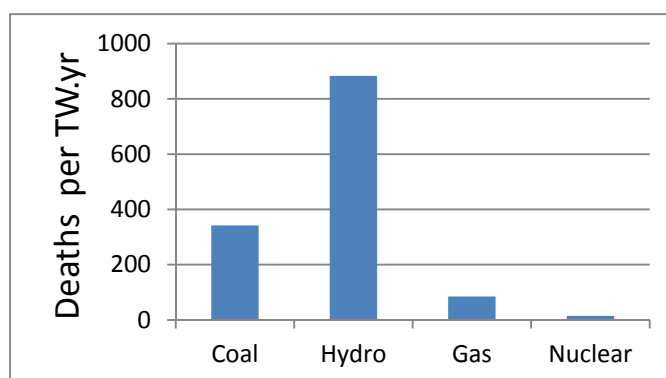


FIG. 7. FATALITIES ASSOCIATED WITH FULL ENERGY CHAINS (DEATHS PER TERAWATT-YEAR).

SOURCE: [HTTP://WWW.WORLD-NUCLEAR.ORG/INFO/ECONOMIC-ASPECTS/ENERGY-SUBSIDIES-AND-EXTERNAL-COSTS/](http://www.world-nuclear.org/info/economic-aspects/energy-subsidies-and-external-costs/)

Current Status and Expansion Plans for Nuclear Power

Nuclear power's share [8] of worldwide electricity production rose from less than 1 percent in 1960 to 16 percent in 1986, and that percentage has held essentially constant for almost two decades from 1986 to 2005. In 2006, nuclear power's share dropped to 15 percent and in 2007 it dropped another percentage point to 14 percent. In June 2009, the nuclear power industry comprised [8]:

- o 438 plants in operation in 30 countries with a total net installed capacity of 372 GW of electrical output.
- o 45 power reactors were under construction in 14 countries which will increase current capacity by 10.7 percent; and 131 were on order or planned, equivalent to 38 percent of present capacity.

Electricity generation from nuclear power is projected to increase from about 2.7 trillion kilowatthours in 2006 to 3.8 trillion kilowatthours in 2030. The strongest growth in nuclear power is projected to occur in non-OECD Asia (Fig. 2). In China and India, for example, electricity generation from nuclear power is projected to grow, from 2006 to 2030, at an average annual rate of 8.9 and 9.9 percent respectively. Outside Asia, the largest growth among the non-OECD nations is projected for Russia, where nuclear power generation is projected to increase by an average of 3.5 percent per year. One of the attractions of nuclear power to Asia has been a perceived contribution to "Energy Security". Energy security means many things to many people. Thus any delay in constructing NPP in such countries will have the following negative impacts:

- o lower allocation of oil export,
- o increase of oil prices in the international markets,
- o energy security lowers in the international markets,
- o no accessibility to energy mix to meet energy security,
- o more contribution to greenhouse gases,
- o more contribution to acid rains,

- o negative impacts on health and hygiene,
- o unsustainable development,
- o increase of social and environmental costs of power generation.

According to the present analysis, the diversification of energy generation by various energy sources is a secured method of planning national energy policy in which, the NPP hold a substantial unavoidable share. Based on this study, 15000 MW NPP is predicted as a prospect of NPP to be constructed within 30 years to secure a sustainable energy development in Bangladesh.

Nuclear Reactor Technologies

Because of its perceived advantages, nuclear power has attracted renewed interest from policymakers, energy planners, utilities, and investors. Reflecting this interest, improved designs for nuclear reactors have emerged which are addressing many of the public health and safety risks that plagued the industry since 1979. The design improvements fall into two broad categories:

- o evolutionary (known as Generation III and III+ reactors) and
- o revolutionary (known as Generation IV). Indeed, Generation IV designs may ultimately offer much larger benefits in terms of safety, cost, and sustainability.

Generation III and III+ Reactor Designs

The main reactor designs [10-12] that are being actively considered for construction in the world are the following:

- o Pressurized (light) water reactors AP600 and AP1000: Westinghouse and its partners have submitted two pressurized water reactor designs for licensing to the US Nuclear Regulatory Commission. The first, the AP600—an advanced passive reactor with gross electrical output of 600MW—received its final design approval from the Commission in 1998 and its design certification in 1999. But a subsequent design, the AP1000 (with output of 1000 MW), has superseded the AP600 because its larger size which is considered more appropriate for the US market. The AP1000 also has a lower capital cost per unit of installed capacity, a major concern to future investors.
- o Evolutionary power reactor (EPR): to combine their technical know-how and strengthen its commercial posture, the French firm Areva bought the rights to Siemens reactor designs and now offers the EPR. EPR is a pressurized water reactor with net electrical output of about 1600MW. According to Areva, the evolutionary power reactor's innovative features include safer operations, competitive costs, and environmentally sustainable development.
- o Economic simplified boiling water reactor (ESBWR): this is a Generation III+ evolutionary design in a long line of boiling water reactors built by General Electric in the United States and overseas. The design of the ESBWR aims to increase plant security and safety, reduce capital costs, and improve operability and maintainability-which ultimately increase plant availability. Its simplified design well serves safety improvements and cost reductions, the latter through a shorter construction period and lower costs for pipes and other components. Incorporation of passive features dramatically reduces the chance that active systems will fail when called on to intervene. The core damage probability and frequency of radioactive released into the atmosphere are calculated as being very low.
- o ACR700: Atomic Energy of Canada Limited has developed an advanced natural uranium reactor, known as the ACR700, that it considers an evolution from the Canadian deuterium (natural) uranium reactor (CANDU) - the line of Canadian reactors already operating in several countries. The ACR700 has been aggressively marketed - boasting low prices, short construction times, and favorable financing.
- o VVER-1200: the VVER's are the Russian counterpart of Western European and US versions of the pressurized water reactor (PWR) designs. Like all other reactors utilizing light water technology, the VVER design uses water to cool the reactor and to generate steam. A third generation VVER-1200 of AES-2006 design. This is largely an evolutionary development of the VVER-1000 reactor plant, with longer design life (50 rather 30 years), greater power, and increased efficiency (36.6 percent instead of 31.6 percent). Its design

incorporates significant passive features completely independent operation without operator's intervention for at least 24 h [10].

- o Other designs: a number of other reactor designs have been proposed, but do not seem to have the same potential for commercial realization as those above. Some of them may have a potential for countries with small electricity markets. These include: (i) the pebble-bed modular reactor (PBMR), promoted by South African utility ESCOM; (ii) the gas- turbine modular helium reactor (GT-MHR) promoted by the US firm General Atomic; and (iii) and the 4S reactor, designed and promoted by Toshiba of Japan.

Generation IV reactor designs

The Generation IV International Forum is a US-led association of 13 nations that seeks to develop a new generation of commercial nuclear reactor designs by 2030. Criteria for equal-valued fixed revenue delivered over the life of the asset's generating profile would cause the project to break even. Criteria for reactor design consideration by the initial sustainable energy (extended fuel availability, environmental impact), competitive energy (low costs, short construction times), safe and reliable energy (inherent safety features, public confidence in nuclear energy safety), and proliferation resistance (does not unduly add to unsecured nuclear material) and physical protection (security from terrorist attacks).

There are six main reactor types in use around the world. The various designs use different concentrations of uranium for fuel, different moderators to slow down the fission process, and different coolants to transfer heat. A comparison of basic characteristics of common civilian reactors is shown in Table 2.

TABLE 2. COMPARISON BETWEEN PWR, BWR, PHWR/CANDU REACTOR

	PWR	BWR	PHWR/CANDU
No. of nuclear reactor	264	94	44
% of reactor	61	31	8-10
Reactor designer/ manufacturer	USA, Japan, France, Germany, Russia, China, Korea	USA, Japan, Sweden, Switzerland	Atomic Energy Canada Limited. Used in Brazil, China, South Korea
Size/Rating	300-1400 MW	Medium size	600-700 MW

Cost Estimation

Assessing the relative costs of new generating plants utilizing different technologies is a complex matter and the results depend crucially on location. Nuclear power plants are expensive to build, but relatively cheap to run. In many places, nuclear energy is competitive with fossil fuels as a means of electricity generation. The **levelized cost of electricity (LCOE)** is a measure of a power source which attempts to compare different methods of electricity generation on a comparable basis. It is an economic total cost to build and operate a power its lifetime divided by the total power output of the asset over that lifetime. The levelized cost is that value for which an equal-valued fixed revenue delivered over the asset's generating profile would cause the project to break even. This can be roughly calculated as the net present value of all costs over the lifetime of the asset divided by the total electricity output of the asset.

The levelized cost of electricity (LCOE) is given by:

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

Where,

I_t : investment expenditures in the year t ,

M_t : operations and maintenance expenditures in the year t ,

F_t : fuel expenditures in the year t ,

E_t : electrical energy generated in the year t ,

r : discount rate,

n : expected lifetime of system or power station.

In 2013, the US Energy Information Administration published figures for the average levelized costs per unit of output for generating technologies to be brought on line in 2018, as modeled for its Annual Energy Outlook. The Levelized Cost of Energy for new power plants from various energy sources showing that for new construction, natural gas and nuclear are the two cheapest sources of electricity generation in the near-future (Fig. 8). The actual capital cost of nuclear is about the same as coal and very much more than any gas option. The 2015 edition of the OECD study on *Projected Costs of Generating Electricity* showed that the range for levelised cost of electricity (LCOE) varied much more for nuclear than coal or CCGT with different discount rates, due to its being capital-intensive. The nuclear LCOE is largely driven by capital costs. At 3% discount rate, nuclear was substantially cheaper than the alternatives in all countries, at 7% it was comparable with coal and still cheaper than gas, and at 10% it was comparable with both.

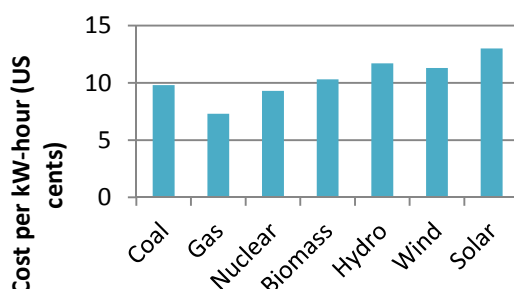


FIG. 8 LEVELIZED ENERGY COSTS FOR NEW POWER PLANTS (SOURCE: DATA FROM IER 2015 REPORT)

The projected nuclear LCOE costs for plants built 2015-2020, \$/MWh is shown in Table 3 for different discount rates.

TABLE 3. PROJECTED NUCLEAR LCOE COSTS FOR PLANTS BUILT 2015-2020, \$/MWH

Country	At 3% discount rate	At 7% discount rate	At 10% discount rate
Belgium	51.5	84	116.8
China	25.6-30.8	37.2-47.6	48.8-64.4
Finland	46.1	77.6	109.1
France	50.0	82.6	115.2
Hungary	53.9	89.9	125.0
Japan	62.6	87.6	112.5
South Korea	28.6	40.4	51.4
Slovakia	53.9	84.0	116.5
UK	64.4	100.8	135.7
USA	54.3	77.7	101.8

Reactor Technology for Bangladesh

Based on technical information and proven technology, Bangladesh should go GEN3/GEN3+ reactor system. With a consideration of system simplicity, economic competitiveness, economic benefits, economic liability, safety consideration, digital instrumentation and control system, compliments for the latest safety code for the consideration of severe accidents are given like Chernobyl and Fukushima disaster, physical protection and issues of nuclear security and safeguards. Based on proven technology records, Russian VVER-1000 MW/VVER-1200 MW nuclear power systems can be considered for RNP project to be operated by 2024/2025.

Conclusions

Electrical energy plays a vital role in the development of civilization. The advancement of a country is measured in terms of per capital consumption of electrical energy. Nuclear energy these days are safe, reliable and on the context of Bangladesh capable of reducing the gap between demand and production significantly. The 3rd Generation Pressurized Water Reactors with automated and in-built safety features make Nuclear Energy a reliable source of massive electricity production. On the basis of present energy scenario of Bangladesh, nuclear energy based power production should be the best solution to the overall energy crisis as well as sustainable energy development [12].

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