Nuclear power-an inevitable option for most vulnerable countries from the perspective of environmental degradation

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***Abstract*—Global warming has become the greatest problem of the world in the last few decades. Many efforts have already been made in some international treaties, but due to many limitations the success achieved so far is very minimal. The whole civilization depends on industrialization, which is making the environmental scenario worse day by day because of unavailability of green technology. Industrialization is important but Trading off between the carbon emission reduction and industrialization is more challenging task in hand. Though the developing nations are less industrialized and emitting less carbon, but they are suffering more for environmental degradation. The whole world has seen the developing nations being victimized by the tsunami disaster recently. To fight this situation, the whole world is looking for sustainable green technology in all sectors. This paper presents an idea of installing more nuclear power plants in developing nations to reduce carbon emission. Technical feasibility of building nuclear power plants has been proved and prioritizing energy sector over other sectors to implement green technology has been justified. Economic feasibility of the proposal has also been proved from the statistics and global governance and monitoring system has been proposed to overcome global skepticism about building nuclear power plants.**

***Index Terms*—Nuclear power plant, Environment, Global warming**

I. INTRODUCTION

Global warming is the rise in the average temperature of Earth's oceans and atmosphere. Increased amount of greenhouse gases in the air is responsible for this. Burning fossil fuel is the main cause behind this environmental degradation. Industrialization, traction and power generation are major three areas where fossil fuels are burnt thus providing the air with more and more carbon. As it is a global problem, so it is affecting the whole world. But the developing nations are the worst victim of this situation. They are emitting the least amount of carbon in the air but they are affected more as their development or industrialization is not up to the standard of developed country.

Top 5 countries who are worst hit by climate risks from 1990-2008 are Bangladesh, Myanmar, Honduras, Vietnam and Nicaragua all of which are least developed nations. In this paper, we showed the example and statistics related to Bangladesh only to describe the situation as the prevailing situation in other developing countries is more or less same. Section 2 demonstrates the effect of global warming in developing nations, section 3 explains the possibility of reducing carbon emission in power sector within the shortest possible time, section 4 describes the challenges in the way of establishing more nuclear power plants, section 5 proves the economic and technological feasibility of building nuclear power plant and finally section 6 draws the conclusion.

II. EFFECT OF GLOBAL WARMING IN DEVELOPING NATIONS

A. Bangladesh

In all, 654 events were registered worldwide in 2008, which caused around 93,700 deaths and economic losses of more than $123 billion. Only around a third had been insured primarily in developed countries. The fact that no further peak catastrophe has happened in Bangladesh, like in 1991 when 140,000 people died, is partial proof that it is possible to better prepare for climate risks and prevent larger-scale disasters [1].

B. Myanmar

In Myanmar, more than 95 per cent of the damages and fatalities occurred in 2008 because of cyclone Nargis. Cyclone Nargis killed as many as 100,000 people. One million people were rendered homeless. Many towns and villages have been washed away [2].

C. Honduras

Honduras has been hit by severe tropical storms and hurricanes over the years. Hurricane Mitch, which hit the country in 1998, changed the landscape of Honduras. In 2008, about 200,000 people were affected by severe flooding caused by heavy rains, and 20,000 people have been forced to flee their homes [3].

D. Vietnam

Over the last decade, the frequency and severity of droughts and floods have intensified, increasing their impact on living conditions. Many people have been affected by cyclones and hailstorms [4].

E. Nicaragua

Nicaragua has been often hit by earthquakes, hurricanes, floods and volcano eruptions.

At present the global climate change has affected the world population with a substantial hit in particular on the developing countries. These countries have become vulnerable to catastrophic natural disasters such as floods, cyclones, hurricanes, earthquakes, droughts, volcanic eruptions, landslides, avalanches, etc. Increasing death tolls and financial losses are of severe concern to these countries. The report shows the 5 top countries with climate risks from 1990 – 2008. High death tolls and huge financial losses are evident from such statistics obtained for developing countries. It is of utmost importance that the low GDP rate of these 5 countries is an indication of their inability to combat such rising climate risks. It is also evident that the issue of CO_2 emission is largely responsible for the global climate change. However, accounts for the increased climate risks and natural disasters. All of the above factors add up to the current power crisis in the developing countries. They are largely dependent upon the fossil fuels like coal and oil for their generation of power which is the major sources of CO_2 emission. Thus, the following extracts carefully analyses the opportunities of introducing nuclear energy in the developing countries as an environment friendly alternative taking into consideration the challenges at hand.

Table 1: Climate related casualties in the developing countries

Countries	Climate Risk Index	Annual death toll due to extreme climate	Total Losses	Losses per unit of GDP
Bangladesh	8	8241	$2,198 million	1.81%
Myanmar	8.25	4522	$707 million	2.55%
Honduras	12	340	$660 million	3.37%
Vietnam	18.83	466	$1,525 million	1.31%
Nicaragua	21	164	$211million	2.03%

All the above statistics show very clearly how much terribly the developing countries and their people are affected by the global environmental damage. The most dangerous part is that those countries do not have enough resources to fight the situation.

III. Focusing on the Power Sector to Reduce Carbon Emission

The generation of power in the developing countries is largely dependent on fossil fuels especially oil and natural gas. These two are the major contributors of CO_2 which is evident from the following chart:

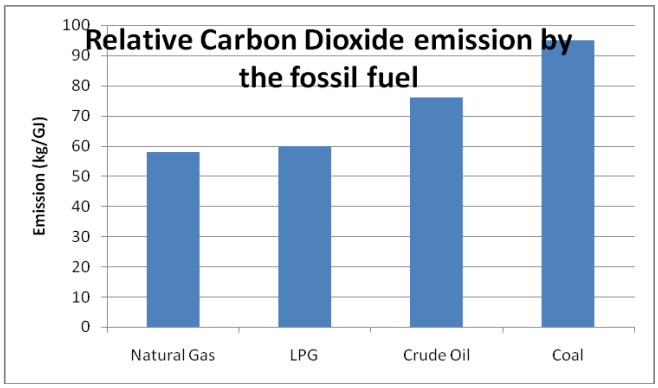

Fig 1: Relative carbon Dioxide emission by the fossil fuel

Moreover, in developing nations the usage of fossil fuel powered electric power plant is increasing [5]. The following figure demonstrates the situation

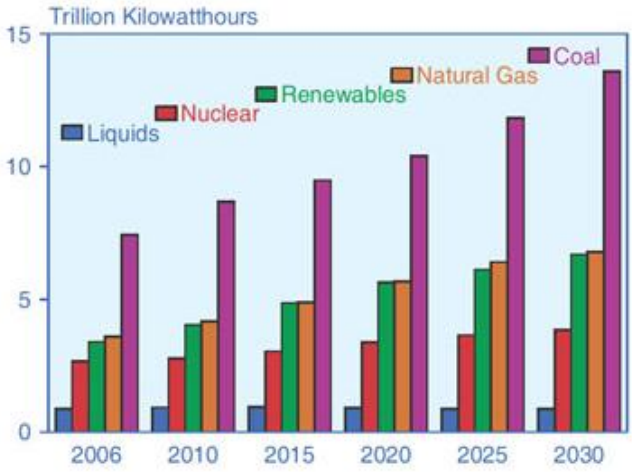

Fig 2: World Electricity Generation by Fuel [source: EIA 2006 & 2009]

Table 2: Peak demand of Electrcity in Bangladesh

Year	**Peak demand (MW)**
2005	4308
2006	4693
2007	5112
2008	5569
2009	6066
2010	6608
2011	7148

In such a situation, the gap between power demand and generation is also increasing in developing countries [6]. The table shows the example of Bangladesh:

The table 2 shows Bangladesh Power Development Board's peak demand and generation capacity PSMP-2005 base forecast. Starting from 2005, the chart shows that the peak demand and net generation capacity shows gradual increase for each year. For 2011, peak demand is 7148 MW and generation capacity is 4568 MW [6] which is almost half of the predicted value and is similar to the value of the year 2005. Whereas, in practice the peak demand has increased immensely but the generation capacity did not increase as expected. There is a continuous gap between demand and generation of power.

For the developing countries, the major sectors of CO_2 emission are the power plants, industries and transport system. The industries and transport system is subdivided into private and public sectors. Taking into consideration the vastness of such sectors and the technological drawbacks of these countries it is difficult to introduce environment friendly alternatives and implement immediately throughout all the developing countries. On the other hand, it is feasible to meet the power demand of the developing countries from the nuclear power plants which can play a vital role for the significant reduction of CO_2 emission. Establishing few nuclear plants will meet the demands as well.

Table 3: Fatalities of different energy sources

Energy Option	Fatalities
Coal Mine disaster	0.34
Oil	0.02
Capsizing refinery fire during transportation	0.08
Natural gas	0.17
Hydropower	1.41
Nuclear power	0.03

The critics of nuclear power plant try to portray it to be a very dangerous method of power generation since any accident can lead to major loss of lives along with severe damage to the environment. To refute this let us consider the fatality rate of various method of power generation [7]. But, their claims are disproved by statistics.

IV. Major challenges in the way of building nuclear power plant

Whether in developed or developing countries, nuclear power faces problems in its bid to be part of the global energy mix [8]. Let us tackle these issues first before coming to the problems faced by nuclear power specifically in the developing countries.

The problems faced globally by nuclear power are: cost, safety, waste disposal and proliferation. Let us discuss these one by one.

A. Capital cost and electricity generation cost of nuclear power stations

The University of Chicago carried out a study entitled "The Economic Future of Nuclear Power" in August 2004 primarily to study the economic factors affecting the future of nuclear power in the United States. Below is a summary of the comparative costs of nuclear and fossil fuels from that study (in 2003 prices):

Table 4: Comparative cost of fuels

Different cost in $/KWe	Nuclear	Coal	Gas Turbine Combined Cycle
Capital cost ($/KWe)	1200-1800	1189-1338	590
Busbar generation cost (Cents/KWh)	4.7 - 7.1	3.3 - 4.1	3.5 - 4.5
Busbar generation cost with carbon control tax of $ 50-250 per ton of carbon (Cents/KWh)	4.7 - 7.1	8.3 - 9.1	5.8 – 6.8

Nuclear capital cost varies from $ 1200/KWe for Mature Design FOAKE Costs Paid, to $ 1500/KWe for New Design FOAKE Costs Not Yet Paid, to $ 1800/Kwe for Advanced New Design FOAKE Costs Not Yet Paid. FOAKE stands for "First Of A Kind Engineering".

Capital costs for coal-fired plants vary from $ 1189/Kwe for Pulverized Coal Combustion, to $ 1200/Kwe for Circulating Fluidized Bed, to $ 1338/Kwe for Integrated Gasification Combined Cycle; it is evident from the above that nuclear is a clear choice once a carbon tax is imposed on coal and gas fired stations.

Further, nuclear industry is optimistic of reducing the NPP cost through learning-by-doing of the new advanced modular designs incorporating passive safety features and, more importantly, reducing its period of construction and going into operation time by streamlining legislation [8].

Besides the near-carbon-free nature of nuclear energy mentioned earlier, one further point needs to be noted in its favour, that is, its very low fuelling cost. Once a NPP has been built, its per kwh cost becomes almost fixed as the fuel cost comprises only about 10% of its total cost compared to about 50-70% for a coal or gas-fired station. As a result, if for example the price of natural gas is doubled, its per kwh cost will rise by approximately 75%, while similar doubling of uranium price will result in only 2-5% increase in its per kwh cost [9].

B. Safety

Nuclear electricity first flowed to a grid in 1954 from the Obninsk 5 Mwe RBMK station in Russia. As of 31 Dec 2007, there are 439 reactors in operation worldwide supplying 14.2% of world electrical energy in 2007 [10]. To date only two major power reactor accidents have occurred: Three Mile Island (TMI) Babcock & Wilcox PWR reactor #2 on March 28, 1979 and at the Chernobyl RBMK reactor #4 on April 26, 1986. In both these cases the accidents would not have occurred had the operators not disabled the reactors' safety systems. Nevertheless, reactor vessel remained intact and no major radioactivity was released from the TMI due to its robust containment and no death occurred. However major release of radioactivity occurred from the Chernobyl, due to its partial containment, as the reactor blew its top and 56 people died. Chernobyl type reactors were not built outside the old Soviet block countries. Where possible, these reactors are

being phased out. Following the accidents, improvements have been made in the design and operational procedures of both reactor types to prevent its recurrence. Concern for nuclear reactor safety is therefore more of perception problem for the general public. Nevertheless, a strong regulation and inspection system is needed independent of the operators. No industry can be trusted to regulate itself when the consequences of failure extend beyond the industry and the country.

C. Waste Disposal

Below is a summary of the study of this problem (and its probable solution) carried out by Nobel Laureate Physicist Professor Burton Richter of the Stanford University:

Table 5: Radioactive waste percentage

Components of spent reactor fuel	Uranium	Fission fragment	Long-lived component
Percent of total	95	4	1
Radioactivity	Negligible	Intense	Medium
Untreated required isolation time (yrs)	0	200	300,000

The uranium that makes up the bulk of the spent fuel is not radioactive enough to be of concern. It could be input for enrichment, or could even be put back in the mines from which it came.

The vast majority of the fission fragments have to be stored for only a few hundred years. Robust containment that would last the requisite time is simple to build.

The problem comes mainly from the last 1% of the spent fuel that is composed of plutonium and the minor actinides: neptunium, americium and curium (collectively, the actinides). For some of the components of this mix, the toxicities are high and the lifetimes are long. There are two general ways to protect the public from this material: isolation from the biosphere for hundreds of thousands of years, or destruction by neutron bombardment.

Long-term isolation is the principle behind the "once through" system as advocated up to now by the United States for weapons-proliferation-prevention reasons. However for a greatly expanded nuclear power programme, it would require a very large number of repositories. For example, if the U.S. nuclear capacity increases by mid-century to the 300 GWe as projected in the MIT study , a new Yucca Mountain Waste Repository would have to open every six or seven years. However, this would be quite a challenge since the first one has not been opened, although the initial study on it was started in 1958.

The alternative to "once-through" is a reprocessing system that separates the major components, treating each appropriately and doing something specific to treat the component that produces the long-term problem. The most developed reprocessing system is that of France. The French make mixed oxide fuel, MOX, by separating out plutonium from spent fuel and mixing it with an appropriate amount of uranium from the same spent fuel. (The extra uranium from the spent fuel not used for MOX goes to an enrichment facility.) The fission fragments and minor actinides are embedded in glass (vitrification) for eventual emplacement in a repository. The glass used appears to have a lifetime of many hundreds of thousands of years in the clay of the proposed French repository.

MOX fuel plus vitrification solves part of the problem but not all of it. The next question is what to do with the spent MOX fuel. The plan is to keep it unreprocessed until fast-spectrum reactors are deployed commercially. These fast-spectrum reactors burn a mix of plutonium and uranium-238 and can, in principle, burn all of the minor actinides as well, that is not possible in the present generation of reactors. It is possible to create a kind of continuous recycling program where the plutonium from the spent MOX fuel is used to start the fast-spectrum system, the spent fuel from the fast-spectrum system is reprocessed; all the plutonium and minor actinides go back into new fuel, and so forth. In principle, nothing but fission fragments goes to a repository and these only need to be stored for a few hundred years.

This sounds good in principle, but there's much work to do before putting it into standard, commercial practice. Clearly a coherent international R&D program is the best way to move ahead rapidly.

D. Proliferation suspicion

So deep and widespread is the current mistrust between the developed and the developing world that, even if a developing country can overcome the above-noted hindrances for introducing a NPP in its energy mix, it still faces the daunting task of convincing the NSG countries that its intention is purely for peaceful use of nuclear energy.

V. OUR PROPOSAL OF BUILDING MORE NUCLEAR POWER PLANTS AND ITS ECONOMIC AND TECHNOLOGICAL FEASIBILITY

A developing country embarking on its first NPP often lacks the necessary legal and regulatory structure to ensure proper design, construction and safe operation of its nuclear facility. Since the consequences of failure of a nuclear facility can go well beyond its national boundaries, one cannot let the operator of such a facility to regulate itself. On the other hand, it is not practical to ask a developing country to set up a totally independent regulatory body to monitor its first NPP. The compromise that is often made is to set up a separate group within the atomic authority to implement the regulatory aspects. A developing country can however seek IAEA's assistance not only in training of its personnel but in receiving advice from IAEA experts panel on milestone events like site selection, bid evaluation, granting construction permit, operation license etc. Once the developing country matures in its nuclear power program and embarks on its second and subsequent NPPs, it should set up a wholly independent regulatory body. In the interim period, the developing country can adopt the IAEA's Safety Standards for guidance.

So deep and widespread is the current mistrust between the developed and the developing world that, even if a developing country can overcome the above-noted hindrances for introducing a NPP in its energy mix, it still faces the daunting task of convincing the NSG countries that its intention is purely for peaceful use of nuclear energy. So what can a developing country do alleviate the cloud of suspicion?

First and foremost will be confidence-building measures like joining the NPT and signing and implementing the Full-Scope Safeguards Agreement and the Additional Protocol with the IAEA. Having done that, the recipient country still faces the stumbling block: what to do with the spent fuel?

If the supplier country agrees to take back the spent fuel, it is well and good. But it is very unlikely until the supplier country finds a satisfactory solution to waste disposal itself.

For a new entrant to NPP, it is prohibitively expensive to consider a reprocessing plant and a waste disposal site as a means of solving the waste problem.

A. Regional, Multi-lateral or international fuel cycle centers

For developing countries, particularly the small ones, the way out of the quagmire of proliferation suspicion, waste disposal and finding suitable waste disposal sites is to participate in the internationalization of the nuclear fuel cycle. Much theoretical work has been done on it particularly by the IAEA. However for the developing countries to benefit from this carbon-free technology and to ensure world peace and prosperity, it is imperative that the world takes this proposal seriously. Under this scheme, enrichment and reprocessing will be carried out in the nuclear supplier countries. The rest are users. This will benefit the small countries enormously where enrichment and reprocessing on small scale is not economic and waste repository with proper geology may not be available. However to allay the fear of the developing countries of being cut off from nuclear fuel supply on political or flimsy grounds, the facilities need to be located in geographically and politically diverse set of supplier countries.

One however has to be realistic and not expect the above international regime to materialize in the near future. In the interim period, the developing countries can try to negotiate with the reactor supplier country to take back the spent fuel and failing that, to store the spent fuel in ponds till a long-term waste solution is arrived at internationally. Once a developing country has overcome the problems stated above and succeeds in implementing its first NPP, subsequent expansion of its nuclear power program should be a lot easier.

B. Raising the necessary capital

Raising the necessary capital cost of a nuclear power plant (NPP) is the single biggest problem for a developing country. As we have previously noted, NPPs are capital intensive and the initial capital required may constitute a large chunk of a developing country's budget. For example, a 300 or 600 Mwe NPP may cost in the range of $ 0.5 to 1.0 billion. Because of competing needs for the same money in a developing country for more pressing issues, e.g. in the health, education, infrastructure etc. sectors, supporters of nuclear often lose out. Investment in a NPP in a developing country requires political will of the government in power who should be convinced of its many spin-off benefits. In the Republic of Korea, for example, high first-of-a-kind nuclear power costs were accepted as part of a long-term national energy strategy that anticipated (and subsequently realized) both eventual cost reductions from 'technology learning' and spin-off economic benefits by developing the country's high technology sector. A recent study estimated these economic spin-off benefits from nuclear power at about 2% of the country's GDP. Developing countries, if they cannot raise the capital cost of a NPP from their own resources, can try to raise the same from the international market through open tender or ask the vendors to do it based on Build, Own, Operate (BOO) or Build, Own, Operate, Transfer (BOOT) schemes. For this to succeed, a stable (preferably democratic) government, good law and order, good investment climate are necessary pre-requisites. Ensuring "Energy Security" should also weigh-in in favor of a NPP if a developed or developing country lack or have scarce natural resources. Japan, France and South Korea are excellent examples. France, by producing 78% of its electricity needs from nuclear energy is now benefiting as a model of GHG reduction. Compared to world average of 0.56 kg CO2 per $ GDP, its contribution is exactly half at 0.28. By diversifying its energy mix (through construction of a NPP or NPPs), a developing country also derives the benefit of conserving its precious natural resources for future generations or for more optimal use. For example, Iran with its enormous hydrocarbon resources still is justified to invest in NPPs as it will help to prolong the life its fossil reserves. Further, burning hydrocarbons to produce electricity is a very short-sighted strategy because so many useful chemicals can use hydrocarbons as feed material. Think of natural resources underground as your buried and secure capital [11].

VI. CONCLUSION

In drawing a conclusion it is important to note the following predictions:

- By 2030, the developing countries will overtake the industrialized countries in primary energy use.
- By 2050, global energy demand will double. Contribution from carbon-free energy sources will have to increase 7 times to keep CO2 levels below 450 ppm or 5 times to keep the same below 550 ppm.

It is obvious that the contribution from nuclear energy on a large scale, which will be a major contributor to reduce the GHGs, will need to come not just from the developed countries but increasingly from the developing countries if we are to save this planet from environmental disaster.

In this paper we proved the inevitability of the nuclear power plant in the developing nations from the perspective of environmental degradation. We justified the reason of prioritizing energy sector over other sectors to handle the issue of carbon emission. We demonstrated the technical and economic feasibility of our proposal. We also proposed the monitoring system and global governance by creating international fuel cycle centers and also the possible way for the developing nations to raise fund for installing more nuclear power plants. We also discussed the way of removing proliferation suspicion. In short, this paper validated the concept of building nuclear power plants more in developing nations to fight environmental degradation, proved economic and technical feasibility and showed the way of removing skepticism prevailing in the international political arena about nuclear power plants.

ACKNOWLEDGMENT

The author wants to acknowledge "Bangladesh Atomic Energy Commission" for all sorts of technical help that they have provided us with.

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