Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 3, Issue, 11, pp.163-173, October, 2011

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

FEASIBILITY OF LOW CARBON ENERGY TECHNOLOGIES FOR GRID INTERACTIVE POWER GENERATION FOR INDIA

[1]Rahul Kumar and [2]Mahesh Pal

Technology Information, Forecasting and Assessment Council (TIFAC), New Delhi, India

ARTICLE INFO

Article History:
Received 26th July, 2011
Received in revised form
29th August, 2011
Accepted 15th September, 2011
Published online 5th October, 2011

Key words:
Low Carbon Technologies (LCTs),
Renewable energy technologies,
Carbon Capture and Sequestration,
Emission reduction.

ABSTRACT

Low Carbon Technologies (LCTs), have an important role to play in reducing emissions of carbon dioxide and to move towards a low carbon energy economy. Developing countries like India and China need to plan for an early development and deployment of LCTs for meeting emission targets and for sustenance of increasing energy demand. The migration of global energy systems to low carbon pathways therefore depends upon successful technical, environmental and cost effective deployments of LCTs for grid interactive power generation. Low Carbon Technologies, identified globally as means of energy production in a renewable manner, reducing carbon emissions and a mean to support carbon capture and storage are classified as - clean coal technologies, carbon capture and sequestration technologies and renewable energy technologies. This paper investigates and analyzes the techno-economic and environmental feasibility of low carbon energy technologies for grid interactive power generation for India in the future. Inclusion and Exclusion matrix indicate that nuclear energy, wind energy (onshore and offshore) and solar thermal energy has the potential to become main source of power for India in the years to come with decreasing reserves of coal and gas and favorable policy environment.

INTRODUCTION

Scenario post Copenhagen is different. Though developing countries including India, China, South Africa and Brazil were against any legal binding on emission cut, they accepted to take possible measures to reduce emissions parallel with their developmental agenda. This as India says, is its concern towards Kyoto Protocol. This is required more so because countries least responsible for the growing accumulation of greenhouse gases, particularly the developing ones, are likely to be amongst the most heavily impacted ones. Projected implications will be on diverse sectors like agriculture particularly food production, and water supply, biodiversity & ecosystems, health, energy security etc. Only possible option is to reduce implications through mitigation of emission from key development sectors like power, industries, transport etc and enhancement of adaptation measures. India and counterpart China and other industrialized countries had expressed their willingness to reduce the carbon emission as per their capabilities. With tremendous pressure to curb its emissions, India, has recently announced voluntary and unilateral targets to reduce the emission intensity by about twenty to twenty five percent by 2020. Predicted to be one of the worst climate change affected regions in near future, India is already on its toes with various Indian states putting together their Action Plans to tackle increasing affects of change in climate due to anthropogenic carbon emissions by taking the lead in implementation and use of green / low carbon energy technologies at centralized and decentralized levels. To reduce emissions, India would need a coherently synergized strategy for deployment of potential commercially feasible low carbon energy options to evolve a mutually consistent and environmentally sustainable energy scene for near future to meet its target. The first step certainly has taken place in the right direction, exploring and compiling various climate change mitigation measures existing locally. Other missions targeting global warming by achieving enhanced energy efficiency, promoting a sustainable habitat, efficient use of water, sustaining the Himalayan ecosystem, increasing forest cover, adapting to sustainable agriculture, and developing strategic knowledge on climate change.

Need for LCTs

India is in the top four emitters in carbon emissions after China, United States, Europe and Russia. But India is concerned because climate change poses a threat to the very existence of the human species, and India is poised towards its National Development Goals and its people.

***Corresponding author:** ahul9731@yahoo.co.in;mahesh1965@gmail.com

guided by the following factors:

i. Sustained economic growth and Food security
ii. Energy security
iii. Rising investment pressure &
iv. Sustainable environment

Economic Growth & Food Security

High economic growth in India has led to a rise in energy demand, which in turn has led to an increase in overall carbon dioxide emission, as vast majority of its energy has been supplied by fossil fuels. Combustion of fossil fuels is the largest single contributor to carbon dioxide and to the total greenhouse gas (GHG) emissions and, of all major sources, has grown the most rapidly over the period from 1970 to the present times. The growth of carbon emissions over time has shown substantial variation. The relation between this growth and changes in various structural factors in the economies, such as the energy intensity, share of fossil fuels in total energy consumption, as well as of the growth of the economy itself is the major area of focus.

Energy Security and Climate Change

Existing economic growth scenarios project total power generation capacity in India to increase manifolds in future. As a result of climate change, it is estimated that approximately 1.5% more power generation capacity will be required (U. Aswathanarayana, 2008). Increased energy demand and subsequently an increase in primary energy consumption may arise from a number of sources. Increased demand for energy can increase greenhouse gas emissions that contribute to climate change, creating a feedback effect. The fuel mix for the power sector in India is largely driven by coal, although the share of natural gas and oil continues to grow at a steady rate. The extent to which increased energy demand alters climate change scenarios will be influenced by the types of fuels used. Rise in energy supply due to increased demand would mean more power generation which would largely increase the consumption of coal in thermal generating plants in case the effects of change happens earlier than commercial development of other alternative energy sources. Figure 1 shows the additional energy that would be required in future due to change in climate (FICCI, 2007). Between 1990 and 2004 and after opening up of the Indian economy in 1991, there was an 88% increase in total carbon emissions in India as compared to increase of 67% in China, 19% in US and 6% in Europe (Windham, Worldwatch, 2006). More of India's carbon emissions come from the burning of fossil fuels for supplying power of which the most significant proportion is by the power sector followed by steel, transport, cement, chemicals etc. Figure 2 depicts the sectoral greenhouse gas emissions in India (FICCI, 2006).

Power/Energy Requirement and Investment Pressure

India plans to build more coal-fired power stations to meet its increasing power requirements. India coal-fired power plants are not only responsible for high emissions but are among the least efficient in the world. Apart from increasing the production of coal and washing, it is important to raise the

technologies like supercritical, ultra supercritical and integrated gasification combined cycle. Where a habitation is too far from the grid, resource has to be decentralized. Future power-generating capacity is projected to grow from its present level to 146–255 Giga Watt in 2015, and 522 Giga Watt in 2030 (U. Aswathanarayana, 2008). The International Energy Agency in 2007 has estimated that during the period 2006–15, India would need to make an investment of Rs 50 lakh crores, including the infrastructure of about Rs 40 lakh crores in the energy sector (World Energy Outlook 2007). With this requirement and goals already set for future with such heavy investments, any additional investment due to increased power requirement because of changes in climate is unlikely and will only burden the economy putting plans of economic growth at the back foot.

Technology Prioritization

To reduce dependence on coal, decrease anthropogenic fossil based carbon emissions, mitigate changes in climate and to increase the energy resource diversity, Indian policymakers are increasingly interested in promoting energy efficiency and renewable and low carbon sources of energy and technologies. Prime-facie these resources and technologies have the potential to reduce annual liberated emission of GHGs. Their promotion is motivated much more by the need to increase the security of energy supply and to meet the country's escalating fuel requirements in a sustained manner. But, before an action plan for mass scale deployment and generation be finalized and direction for future decided, it is important that the gamut of such available technologies and resources, be thoroughly investigated to establish feasibility for Indian conditions; as adoption, deployment and use/generation would be factored among others by technology readiness and suitability for commercial deployment, viability of economics and scale (order of investment) and potential for emission reduction. Prospects, constraints/barriers and specific needs/requirements to be identified and tackled before hand to avoid future hindrances and getting the desired results. Table 1 shows the gamut of available green / low carbon technologies for all sectors:

METHODOLOGY

In this paper identification and analysis technical, economic and environmental aspects of low carbon energy technologies is undertaken which have proven or potential capability to be integrated to grid. Inclusion and exclusion is performed among the various options of low carbon energy technologies based on potential to generate large amounts of energy at site (central grid integration) as the first consideration and response to parameters like resource availability, economic viability, emission reduction, technological feasibility and current stage of development and time period for implementation; to ascertain that the technology will be viable in future for large grid interactive power.

Technology Assessment

Assessment and analysis is performed for potential and available low carbon energy technologies in the Indian context. Those having prime facie proven potential and scope in this study paper:

i. ***Clean coal technologies***: Integrated Gasification Combined Cycle (IGCC) and Underground Coal Gasification with and without carbon capture and sequestration
ii. ***Renewable energy technologies***: Wind energy both onshore and offshore, Solar energy both thermal and photovoltaic (PV), Biomass energy and Small hydro
iii. Nuclear energy

Clean coal technologies

Coal Reserve and Status in India

The present coal reserve is 2, 57,381.55 million tonnes. Recoverable reserve has been estimated as 95,866 million ton, only 37.8% of total reserves (Geological survey of India, 2007). Figure 3 shows the coal consumption pattern of India. While domestic production of coal might become limited in the future, its demand is likely to increase dramatically. Already, coal demand has been outstripping supply. Over the last two decades, demand has increased at an average annual rate of 5.7%, while production has only increased at 5.1% (Tenth Five year Plan, Planning Commission, 2002). Longer term scenarios from the Planning Commission have indicated that annual coal consumption by the power sector might range between 1 to 2 billion tons by 2031-32 (Integrated Energy Policy, Planning Commission, 2006). With increase in coal demand in near future in the power sector as well as rising carbon emissions, technologies like IGCC and UCG etc, which have potential for efficient utilization of coal and emission reduction capability, are needed.

Integrated Gasification Combined Cycle (IGCC)

After combustion, gasification is the next most important pathway for utilizing coal for electricity generation. IGCC is a hybrid between the traditional coal combustion- powered steam-based electricity generation and the natural-gas-based combined cycle electricity generation. IGCC is an innovative electric power generation concept that combines modern coal gasification technology with both gas turbine (Brayton cycle) and steam turbine (Rankine cycle) power generation.

Status

There are only four operating coal-fired IGCC plants in the world, two in the United States both which use petroleum coke and not coal as the fuel source. Other IGCC projects in the U.S. were built as small scale demonstration projects with substantial government funding and some faced such severe operating problems that they never reached commercial operation. Even the facilities that did achieve commercial operation have not met projections for cost, efficiency, reliability, and environmental performance. The "next generation" of IGCC plants with higher power capacities is currently in development stage. A key consideration in the context of India arises from the high ash content of Indian coal. Indian coal need to be blended with better quality imported coal or petroleum coke. Blending with other types of imported coal may hike the cost further. The capital costs, operation and maintenance (O&M) costs will also be higher Worldwatch, 2006). In India limited amount of testing of IGCC has been done with Indian grade coal. There is lack of data on how these technologies would perform if applied to Indian coals and also lack of international information sharing on IGCC, which is ultimately hampering the development of IGCC.

IGCC and Greenhouse Gas Emissions

The largest contributor to greenhouse gas emissions from IGCC power generation is the production of CO2 from the carbon originally contained in the fuel fed to gasifier. The production of other GHG emissions, such as N2O and NH3, are small compared with CO2. Although CO2 emissions are higher than natural gas-fired plants, IGCC's improved efficiency reduces CO2 emissions relative to conventional PC plants. On an average, an IGCC plants produce CO2 at a rate of about 1.85 lb/kWh, while PC plants yield about 2 lb/kWh (Asian Development Bank, 1998). IGCC has two major advantages that it can be exploited to capture CO2 more efficiently than with the Pulverized Coal (PC) combustion technology. The syngas has a high CO2 concentration, which can be further increased by converting CO to CO2 prior to combustion (while simultaneously producing more hydrogen).

Economics and Technical Performance of IGCC and Conventional Coal Power Plants with Carbon Capture

The performance and cost of carbon capture is an important element for deciding the choice of base technology for new green-field projects, and for deciding if (or when) to install capture technologies as retrofits to existing power plants. Estimated performance and costs of carbon capture vary widely by different sources, primarily because of different assumptions regarding technical and financial factors chosen. Technical factors such as plant size, net efficiency, fuel properties, load factors, etc., can affect capital cost, and financial factors such as fuel cost, cost of labor and construction, interest rates, debt-to-equity ratio, discount rates, etc., can affect the cost-of-electricity). Specifically for carbon capture, there are several sources of differences and variability

1 Choice of capture technology
2 Choice of base power generating technology
3 Whether the capture technology is a retrofit or a green-field project
4 Whether the costs include costs of CO2 compression and transportation (pipelines, etc.)
5 Timeframe and assumed maturity level of technologies (first of a kind or nth plant), and use of different metrics for assessing capture costs – capital cost, cost of avoided CO2, cost of CO2 captured, cost of electricity, etc.

Table 2 (IPCC, 2005) shows the current best understanding of the performance and cost of carbon capture is by the IPCC Special Report. The cost of capturing CO2 from new PC power plants using post combustion capture which is generally more expensive and requires greater energy input than that of pre-combustion capture in IGCC plants. The plant efficiency drops nearly 10% for PC plants with and without capture, compared to about 7% for IGCC (IPCC, 2005). The increase in cost of electricity in PC plants ranges between 42-66%, whereas for IGCC it is 20-55%; the cost of CO2 captured is

2005). Hence, there has been a considerable focus on commercially deploying IGCC for this reason. However, for low-rank coals (high-moisture, sub-bituminous coals), the economics of post-combustion capture in PC plants is similar to, or cheaper than, the economics of carbon capture in IGCC plants.

Underground Coal Gasification

Underground coal gasification (UCG) is receiving increasing attention as a way to utilize unmineable coal seams. The key technology process involves drilling injection and production wells into coal seams, and injecting an oxidant (oxygen or air) and steam, if necessary, into the coal to produce a low-temperature, high-pressure syngas. The transport of gases from the injection and outlet boreholes controls the reactions. Today development in UCG is mainly focused on enhancing the connections between the boreholes, controlling gasification processes, and scaling up of operations. The gas composition of UCG-syngas is very similar in calorific value to that produced in surface gasifiers, but with higher methane content. Although process controllability and consistency of product from UCG remains big concern, there are several advantages (Friedmann, 2005).

1 The use of unmined and unmineable coal deposits with obstacles to mining such as high fault frequency, volcanic intrusions and other complex depositional and tectonic features.
2 No large-scale environmental impact, especially when compared with impacts of coal mining. There are, however, the problems of subsidence (as with underground coal mining) and possible alterations of underground hydrology, especially for UCG at shallow depths.
3 No need for ash or slag removal and handling, since inert material mostly remains underground.
4 No production of SOx, since most of the sulfur in coal is converted to H2S, which can be removed using standard techniques.
5 Little or no production of NOx (especially if oxygen is used as oxidant rather than air) because of low gasification temperatures and low quantities of organic nitrogen in coal.

Renewable Technologies

Wind

Status and Resource (Onshore)

From 1997 to 2008, global installed wind power capacity increased by an average of 35% per year and the annual market has grown from1.5 GW to 20.1 GW at the end of 2008, an average annual growth rate of about 29% (European Wind Energy Association, 2008). In India, the sector has an installed capacity of grid interactive renewable power of 10,242.50 MW cumulative as on 31st March 2009 (MNRE, Annual Report 2008). In terms of wind power installed capacity, India ranked 4th in the World. Today our country is a major player in the global wind energy market, which is expected to grow at an average rate of 24% annually for the Energy Association has estimated that with the current level of technology, the 'onshore' potential for utilization of wind energy for electricity generation is of the order of 65,000 MW (IWEA, 2010). This unexploited resource has the potential to sustain the growth of energy sector to some extent in India in the years to come. The offshore wind potential is also enormous considering the wind patterns around the country periphery and the advantageous geographic location.

Offshore

The total installed capacity of offshore wind power is 1,471.33 MW worldwide (EWEA, 2009). Figure 4 shows a breakdown of installed capacity as a percentage of the total capacity country wise. Denmark and the United Kingdom have large share of installed capacity which uses Danish turbine technology. India hasn't realized the offshore potential. Bounded by sea on all three sides, and blessed with prevailing strong monsoonal winds in the summer India has sheer advantage. Potential coastal locations situated near the shoreline at the eastern as well as at the western ghats of India shows that there are many locations having potential enough to harness wind for power with currently available indigenous turbines. The Offshore Potential farther into the sea at about 5-10 Km from the shore will be comparatively more because as we go inside the sea the mean wind speed increases by 20% and Wind Power Density multiplies (Soren Krohn, 2002). This is attributed to considerable decrease in areal and surface roughness factors as we go farther into the sea. Figures 5 & 6 shows the potential speeds at different coastal locations at 20/25 m mast height which indicates speeds ranging from low wind regimes (less then 5 m/s) to moderate (more then 5 m/s) and even higher (more then 7 m/s) (Rahul Kumar, Manish Kumar and S. Deswal, 2009).

Economics of Wind Power

About 70% of the electricity cost of wind farms is determined by the initial investment costs, which mainly consists of wind turbines, foundations, internal and external grid connections and installation as shown in Table 4 (H.J.T. Kooijman., Md. Noord, C.H. Volkers, L.A.H. Machielse, F. Hagg, P.J. Eecen, J.T.G. Pierik and S.A. Herman, 2001). Obviously, fluctuating fuel costs have no impact on power generation costs. Thus a wind turbine is *capital-intensive* compared to conventional fossil fuel fired technologies such as a natural gas power plant, where as much as 40%-70% of costs are related to fuel and O&M.

Competitive Economics with Conventional Power

Case 1: Figure 9 shows the results of the reference case (2007) when crude oil price by the World Energy Outlook, 2007, is $ 63/barrel and projected price in 2010 being $ 59/barrel, assuming that the two conventional power plants are coming online in 2010. As the main advantage of renewable power is the potential towards emission reduction so, extra cost of carbon is included in the conventional plants based on 2007 price of Euro 25 / ton. Figure 7 shows that with crude oil price of 2007, in the year 2010 the cost of wind power by coastal plant will be about Euro 5/MWh costlier then conventional power and about Euro 8-9/MWh costlier then included. The inland power including the regulation cost also will be about Euro 18/MWh costlier then conventional. The difference between coastal power and conventional with tax rebates and generation subsidy from the Govt. being a renewable source would make both the costs comparable. Case 2. The sensitivity analysis is presented in figure 8. The natural gas price is assumed to double as when the oil price will reach around \$100 - \$120/barrel in the near future. Following the same it is assumed that the coal price will also increase by say about 50% and the price of CO_2 to increase to 35€/ton (from 25€/ton in 2007) by 2010-2011. In this scenario, the competitiveness of wind-generated power increases significantly with rising fuel and carbon prices; costs at the inland site become lower than generation costs for the natural gas plant and around 10% more expensive than the coal-fired plant. On coastal sites, wind power produces the cheapest electricity of the three.

Technical Feasibility

Generation of power from wind turbine installations has already attained a commercial status worldwide. India till date has no large wind park producing grid interactive power. The technology is a proven one with some large wind power projects ongoing in different parts of the world. Of the basic infrastructural components for a wind power plant; turbine and foundation (platform) are important and most expensive. Figure 9. shows the technology development of the average sized wind turbine in important wind power countries (EWEA, 2009). The average commercial size of turbines has increased significantly over the last 10-15 years, from approximately 200 kW in 1990 to 2 MW in 2007 in the UK, with Germany, Spain and the USA not far behind.

Solar Power

Resource Potential

Solar resource is available in plenty round the year at least in tropical and subtropical countries. India is endowed with enormous solar energy due to its tropical position on the globe. The total installed capacity of grid interactive solar power as on date in the country is only 2.12 MW (MNRE, Annual Report 2008-09). India has realized both thermal & photovoltaic routes of solar energy in decentralized applications in the form of street and home lighting systems, solar lanterns, solar water heating systems, solar cookers etc. In countries like US, central grid connected concentrating solar trough plants generates power. There are nine solar parabolic trough based power plants in the Mojave Desert with a combined capacity of 354 MW supplying power to the electricity grid (Environment News Service, 2007). In grid connected Photovoltaics (PV) power generation, Portugal and Germany are leaders. Installed PV capacity in Germany has risen from 100 MW in 2000 to approximately 4,150 MW at the end of 2007 (Market Buzz, 2008). US have seen rapid growth recently due to various incentive programs and local market conditions. China has also entered in the list with the announcement to build a 2 GW photovoltaic system in Ordos City, Inner Mongolia, China in four phases consisting of 30 MW in 2010, 970 MW in 2014, and another 1000 MW by 2019 (Wall Street Journal, 2009).

Technical feasibility of solar thermal and photovoltaic systems for decentralized applications had already been established in India. Table 4 shows solar thermal power generation options available today. Recently developed indigenous technology 'Concentrated parabolic fresnel dish' called ARUN 160 can provide high delivery temperatures to about 350 degree centigrade and an efficiency of 40% (Shireesh Kedare, 2006). Power generation from large solar installations be it thermal or PV is yet a grey area in the country. In the light of world status of large power installations based on concentrating troughs and PV modules and arrays, the potential can be realized at places like Gujarat and Rajasthan where intensity of solar radiation is quite high. The PV technology is still in its early stage of development in India. The problems are low efficiency, high cost of silicon based cells and availability of semiconductor grade highly pure silicon. Single crystalline/ multicrystalline and amourphous silicon PV cells has entered the market and currently used for decentralized energy systems for limited power back up requirements. The need is to build low cost high efficiency thin film solar PV and organic/plastic cells for better market penetration and competitiveness.

Economic Viability and Emission Reduction Potential

The economic viability of renewable energy technologis needs to be considered in the light of energy security, renewable nature and environmental advantages (emission reduction capacity) even if the energy/power from renewable is priced higher than conventional power in the present energy price scenario. In the long run when fossil fuel resources will deplete and their corresponding prices will increase as a result of gap between demand and supply, the price of energy from renewable will reach breakeven point and will prove to be cheaper than the conventional power from coal, gas, and oil. Table. 5 (European Commission, 2008) shows a comparison between power from renewable energy resources and conventional technologies and the corresponding emissions considering a moderate fuel price scenario. The current production price of onshore wind is about twice that of pulverized coal power and about 20% -30% higher than natural gas power price. Similarly, small hydro is about 10%-15% higher than coal power price. Power from solar thermal is about 4 times and power from PV about 13 times higher than pulverized coal power price as of now. Power production prices from nuclear fission is competitive with the conventional fossil based power prices making nuclear fission the best option for the near term. Though power prices for renewable are higher currently compared to conventional, but this is more then covered by the high emissions reduction capacity and low fuel price sensitivity of renewable.

Power from Biomass and Hyrdo

Biomass: Biomass energy can be utilized either in the form of solid biomass like briquettes and pellets, liquid biofuels like biodiesel, ethanol, bio-oil etc, or through gaseous route like gasification of biomass/biomass waste i.e. agri residues, bagasse etc. India being largely an agricultural country had put all these methods of energy generation to practicality from the very past, in the form of rural soild briquettes for household jatropha, pogamia etc to light the house etc. Even, gasification of biomass is an ongoing utilization process through biomass bagasse based cogeneration gasifiers in many sugar industries for captive power generation thorough steam boilers. Waste to energy projects like municipal waste to energy also has been commercially developed on megawatt scale in Andhra Pradesh. No doubt biomass energy is an alternative source of energy and need to be exploited for commercial energy supply, but there are a number of issues and limitations involved:

1. Availability of biomass round the year for bio-gasification plants cannot be guaranteed eg: monsoons.
2. Composition keeps on varying round the year.
3. Liquid fuels from biomass like biofuels, bioethanol are better suited for transport sector then large scale power generation.
4. Composition of municipal waste varies. Segregation and moisture content are major parctical problems with Indian waste.
5. Direct gasification for power production though turbines and gasification for syngas production and ultimately hydrogen are two possible routes of large power generation through biomass. But syngas purification for carbon capture and hydrogen production, its storage and use involve many practical problems which are still under investigation. Direct gasification through combustion of biomass in incinerators/boilers for steam generation is used for captive power generation. For grid connected supply, large gas turbines above 2-5 MW may be needed.
6. Also, energy/power from biomass is susceptible to fuel (biomass) price volatility.

Before biomass power can be realized to its full potential, resource estimation for biomass need to be undertaken to ascertain the ready availability for long term for generation plants. Till that time it is suited for only decentralized applications and not for commercial scale power generation.

Hydro Power

For large scale commercial use, the technology is proven in the country and many large hydro power projects are producing power for the country. Small hydro upto 25 MW is considered renewable in India. The potential is about 15,000 MW and realization of 2,429.67 MW of grid connected power has been achieved (MNRE, Annual Report 2008-09). Before full realization it has to cross hurdles like:

1. Estimation of resource and micro-siting for generation (small hydro potential is concentrated mostly in hilly regions).
2. Performance and efficiency of small hydro turbines and their integration to the grid.
3. Variability of flow of water with respect to time and change of course of small distributaries and falls due to human generated hindrances.

Integration to grid is another issue with small hydro which will be expensive considering the remote and inaccessible locations of small hydro sites in hilly areas. Small hydro can be put to the best use in India through decentralized power

Providing integrated power to the grid will be a far option until the network of grid connection is established and above issues tackled.

Nuclear Fission

The fission technology is well established. India has now 17 operational reactors, which generate 3% of the country's electricity. The important benefit of nuclear power is that it is environmentally friendly as far as gaseous emissions are considered. Another advantage is while the coal-fired thermal power stations have to be established at pitheads in order to save on transportation costs, and hydroelectric power stations have to be set up at dam sites, a nuclear power station is not subject to such constraints. Besides, small amount of nuclear fuel can provide enormous energy, so the fuel inventory is reduced in this case. Presently, cost of nuclear fuel in India is roughly twice the global price. The price will go down depending on access to the international uranium market through the Nuclear Suppliers Group. Being a cost effective and non – polluting option, power from nuclear presents a powerful case for large scale deployment in future. Barring few issues like security of plant, radiation leakage etc, nuclear is a very feasible option for a country like India to meet near term as well as increased long term energy and power needs.

RESULTS

Inclusion and Exclusion Matrix

On the basis of the above discussion and considering the present Indian conditions, an *'Inclusion and Exclusion Matrix'* is prepared as shown in table 6 for the comparative assessment for all possible low carbon energy technologies. The techno-economic and environmental potential are analyzed to generate responses (+ve, moderate, -ve) for present and future contribution to the central grid. Those qualifying the criteria of analysis with capability of large grid connected power generation include:

1. Integrated Gasification Combined Cycle (IGCC) power plant carbon capture
2. Wind power – Onshore and Offshore
3. Solar Thermal power
4. Nuclear power

It may be seen from table 6 that responses from IGCC, wind-onshore & offshore, solar thermal and nuclear are positive. Though, solar PV shows high tendency towards positive response; owing to its ample resource and high emission reduction potential, but the technology is currently not advanced enough for grid connected power generation and is still extremely costly. Technologies like geothermal and UCG are still in their preliminary stages of development and may take many years before the first economically feasible venture. Small hydro has an already proven technical and economic viability in India with high emission reduction potential, being a renewable source. In this case, there is a limitation to the power generation capacity at one site. Due to this grid connection will become a costlier affair. Also the micro-sites data that is available shows the in accessible nature of this resource in hilly regions. This makes it even more difficult to exploit commercially with central grid. Small hydro may be more suitable for decentralized energy uses to satisfy local needs.

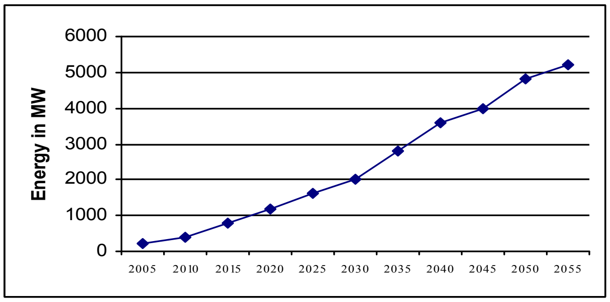

Fig. 1. Additional Energy Requirement Due to Climate Change

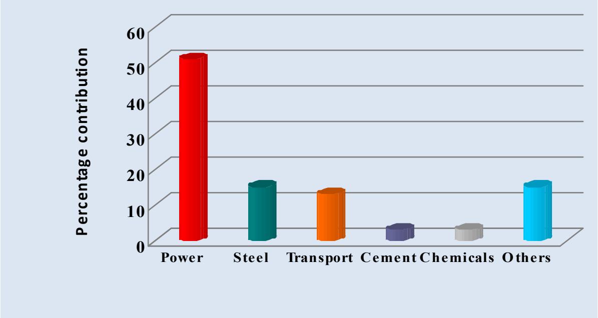

Fig. 2. Sectoral GHG Emission in percentage

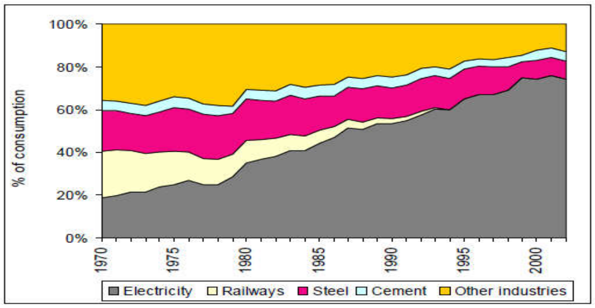

Fig. 3: Coal consumption by consumers (1970-2002)

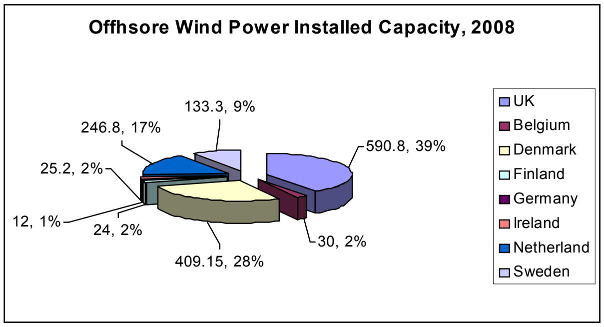

Fig. 4. Offshore Wind Installed Capacity Worldwide, end of 2008

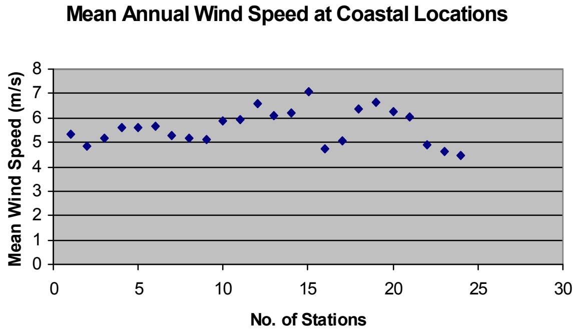

Fig. 5. Wind Speeds at Selected Indian Western Coastal Locations

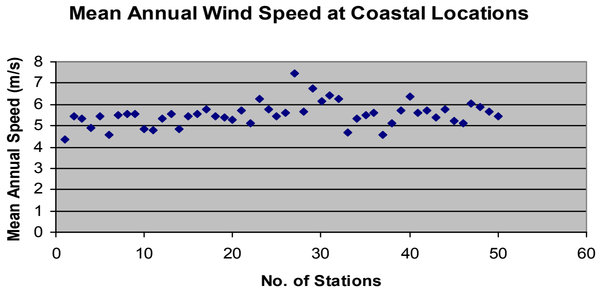

Fig.6: Wind Speeds at Selected Indian Eastern Coastal Locations [28]

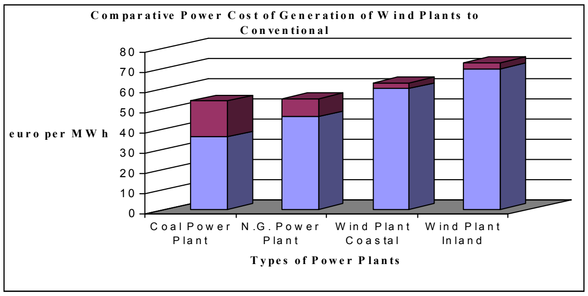

Fig. 7. Cost of Generation of Wind Plant to Conventional Power Plants with 2007 Crude Oil Price

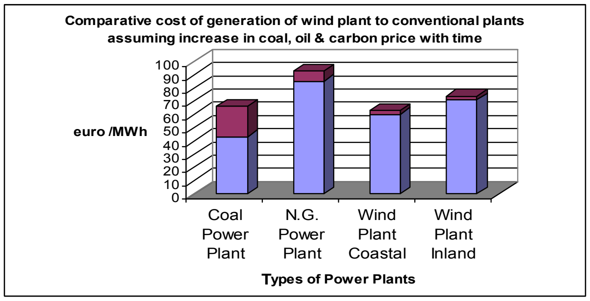

Fig. 8. Cost of Generation of Wind Plant to Conventional Power Plants Assuming Rising Crude Oil Prices upto $ 100-$120/ barrel, in 2010-2011

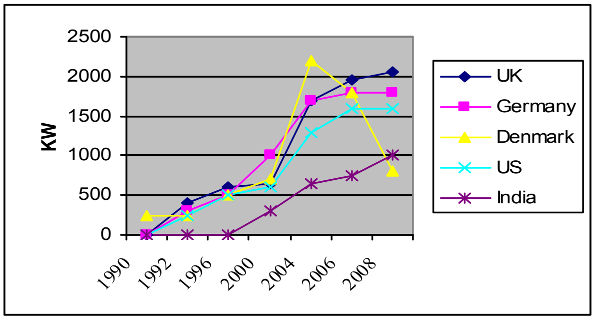

Fig. 9. Turbine Capacity Development from 1990 to 2007

Energy from biomass through gasification route will be an option to be looked at once the technology for few MW power generation will be in place and techniques for low cost and controlled purification of syngas are commercially available for hydrogen production. Till that time bagasse based co-generation below MW scale for industrial captive power and bio-fuels for blending with diesel for transport sector are more suitable. Nuclear energy by fission of uranium is the best possible option technically, economically and environmentally for present as well future energy needs of India. It has sure advantages like enormous energy generation from fewer

Table 1: Low carbon energy technologies for different sectors

Sector	Technologies
Power/ Energy Generation & Energy Supply	Carbon Capture and Storage (CCS) for gas, biomass and coal-fired electricity generating facilities, liquefaction of coal, supercritical combustion of coal, IGCC.; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar, and thin film , organic / plastic solar Photovoltaic modules and arrays
Transport	Biofuels, second generation biofuels, hydrogen from biomass, bioreactors fro hydrogen; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries, ultra and super capacitors.
Industry	Advanced energy efficiency; absorption refrigeration; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminum manufacture.
Buildings	Efficient lighting and daylighting, more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation ; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases.
Waste Utilization	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use

Table 2. Performance and cost of carbon capture in new power plants: All costs are for capture only, and do not include transport and storage costs

Performance and Cost Measures	New PC Plant Range		New IGCC Plant Range		New NGCC Plant Range	
	low	high	low	high	low	high
Emission rate without capture (kgCO2/MWh)	736	811	682	846	344	379
Emission rate with capture (kgCO2/MWh)	92	145	65	152	40	66
Percent CO2 reduction per kWh (%)	81	88	81	91	83	88
Capture energy requirement (% more input / MWh)	24	40	14	25	11	22
Plant efficiency without capture, HHV basis (%)	39	43	37	45	50	52
Plant efficiency with capture, HHV basis (%)	29	34	30	38	42	45
Total capital requirement without capture (US$/kW)	1161	1486	1169	1565	515	724
Total capital requirement with capture (US$ /kW)	1894	2578	1414	2270	909	1261
Percent increase in capital cost without capture	44	74	19	66	64	100
COE without capture (US$/MWh)	43	52	41	61	31	50
COE with capture only (US$/MWh)	62	86	54	79	43	72
Increase in COE (US$ / MWh)	18	34	9	22	12	24
Percent increase in COE	42	66	20	55	37	69
Cost of CO2 captured (US$/tCO2)	23 - 35		11 - 32		33 - 57	
Cost of CO2 avoided (US$/tCO2)	29	51	13	37	37	74

Table 3. Cost share of different components in onshore and offshore wind installations

Total turnkey investment cost	Onshore 800-1100 Euro/KW	Offshore 1200-1850 Euro/KW
Wind Turbine	65-70%	30-50%
Foundation	5-10%	15-25%
Internal grid and grid connection to shore	10-15%	15-30%
Installation*	0-5%	0-30%
Others**	5%	8%

Table 4. Comparison of Performance of Solar Thermal Energy Generation Systems

Solar thermal technologies	Max. delivery temp. (Deg. Centigrade)	Cost (Rs. per meter sq)	Efficiency	Concentration ratio
Evacuated tube with heat pipe system	120	15	0.7	0.7
Parabolic trough concentrators	300	20	0.7	100
Scheffler cooker	120	11	0.8	150
ARUN parabolic dish	350	20	0.65	440

Table 5. Cost and Performance of Different Power Generating Technologies

Source	Technology	Cost of production (Euro/MWh)	Projected cost, 2020 (Euro/MWh)	Direct Emission (kg CO2/MWh)	Indirect Emission(kg CO2/MWh)	Lifecycle emission(kg CO2/MWh)	Fuel price sensitivity
Natural gas	Open cycle gas turbine	65-75	90-95	530	110	640	Very high
	Combined cycle gas turbine	50-60	65-75	350	70	420	Very high
Oil	I.C. Diesel	100-125	140-165	595	95	690	Very high
	Combined cycle oil fired turbine	95-105	125-135	505	80	585	Very high
Coal	Pulverized coal combustion	40-50	65-80	725	95	820	Medium
	Fluidized bed combustion	45-55	75-85	850	110	960	Medium
Nuclear	Fission	50-85	45-80	0	15	15	Low
Biomass	Solid biomass	80-195	85-200	6	15-36	21-42	Medium
	Biogas	55-215	50-200	5	1-240	6-245	Medium
Wind	Onshore	75-110	55-90	0	11	11	Nil
	Offshore	85-140	65-115	0	14	14	Nil
Hydro	Large	35-145	30-140	0	6	6	Nil
	Small	60-185	55-160	0	6	6	Nil
Solar	PV	520-880	270-460	0	45	45	Nil
	Concentrating thermal	170-250	110-160	120	15	135	Low

Table 6. Inclusion and Exclusion Matrix for Low Carbon Energy Technologies

Low Carbon Technology	Proven resource availability	Economic viability	Technology feasibility & stage of development	Emission reduction potential	Time for implementation	Response / Reason
IGCC with carbon capture	Coal reserves ample for next 50 years	Yet to be established but high investment required. Cost is still high will come down with CCS incorporation.	Technology feasibility established at pre commercial and commercial level.	High potential for emission reduction. About 5 times less then coal fired power plants	> 10 years	**+ve** for long run **INCLUDED** 1.Emission considerations & international pressure 2.Coal reserves ample 3.Additional advantages of carbon storage like EOR 4. Fuel price sensitivity - medium 5. Efficiency comparable to PCC and N.G. plant
Wind Energy (On shore)	Wind resource ample	Viability already established and commercial production on for onshore wind power. In India price is still high which is currently covered by Govt. incentives	Technology for small stand alone turbines of the range of 5 MW established. Wind parks already generating power for commercial grid connection	High potential	Immediate	+ve **INCLUDED** 1. Renewable alternate energy/power option for grid supply 2. Resource availability enormous 3. Direct emission zero 4. System efficiency good 5. Not sensitive to fuel price 6. Generation cost to be competitive with rising fossil fuel price
Offshore	Ample resource	Viable over the lifetime	Technically feasible. Commercial production underway with grid integration. For India studies on platform & power supply inland & small barrier removal required	Very High potential	3-5 years (near future)	**+ve** **INCLUDED** 1. Resource ample 2. Long term viability 3. Production to be high as offshore wind speed is high 4.Direct emission zero 5. Suitable for island power requirements adjoining India
Solar PV	Ample resource	Economics currently not favorable owing to high silicon price	Technology feasible for small power. For grid supply integration of modules/arrays and Balance of Systems need to be proven. Space constraints	High potential	5 years (near term)	**+ve** but with reservations **EXCLUDED** 1. Efficiency low 3. Price very high 4. Currently suitable to decentralized stand alone applications 5. Some fuel price sensitivity owing to silicon supply limitations
Solar Thermal	Ample resource	Commercial production on	Technology feasibility established for concentrating trough and paraboloidal dishes for large power generation. Space constraints	High potential	> 5 years	**+ve** **INCLUDED** 1.Ample resource 2. Suitable for grid connected power 3.Low sensitivity to fuel price 4.High emission reduction potential 5.Policy favourable with launch of Solar Mission

Clean coal gasification (UCG)	Resource establishment still on. Unmineable coal seams are major sites	Experimental stage	Yet to be established	Potential is there	> 8-10 years	**-ve** right now **EXCLUDED** 1.Resource yet to be established 2.Experimental dev. stage 3.Env. issues involved like leakage, submergence, hydrology etc
Nuclear	Resource ample	Established	Established	High potential	Immediate	**+ve** **INCLUDED** 1.Ample uranium 2.Tech. fully established for grid connected power 3.Emission reduction potential high 4.Large energy from small fuel amount 5.Economicaaly viable with power cost less then diesel power & open cycle gas turbine power
Geothermal energy	Resource sites to be determined	Very expensive	Yet to be established	Potential is there	Long term and may be more	**-ve** **EXCLUDED** 1.Resource availability not established 2. Expensive in current scenario 3. Experimental stage of dev.
Large Hydro	Ample resource	Established & viable	Established	High potential	Immediate	+ve **EXCLUDED** 1.Not considered under renewable
Small Hydro	Resource available. Exact resource location to be established.	Established & viable	Established but need for high efficiency micro turbines	High	Immediate after micrositing	**+ve** **EXCLUDED** 1.Micrositing required 2.Suitable for decentralized power
Biomass	Resource ample but no exact estimation at place	Established but high	Establsihed for small applications like biogas, bagasse gasifier etc. Syn gas power route under investigation	High	5 Years	**Moderate** **EXCLUDED** 1.Currently suitable for decentralized use . Biofuels suited to transportation 2.Large scale biomass gasifiers ranging 1 MW yet to be developed

amounts of fuel, non polluting and independence of the preferred location.

Conclusion

Climate change is a global problem it needs a global solution as well as national prerogative. Development and deployment of cost effective low carbon energy technologies for energy security and sustainable environment is the need of the hour. India is willing to stand with the global community towards the low carbon economy. Already several concrete actions have been taken at the national level to mitigate the adverse impacts of CO_2 accumulation and change in climate. Several low carbon energy technologies and sources such as IGCC, Wind, Solar Thermal and Nuclear energy generation technologies have been found to be technically, economically and environmentally feasible for production of large scale power through centralized grid in the Indian conditions. Some of these technologies like solar thermal, onshore wind and nuclear are already ready for implementation on a large scale. The requirement is to bring these technologies into the national deployment agenda just as is for hydro and coal based power. Other technologies like IGCC and UCG however, have enormous emission reduction potential but their development and deployment at commercial level presently seems to be too far because of associated high capital cost and other technical constraints. Though at present, implementation of some of these low carbon technology options would appear to be financially burdening the economy because of already set societal and development goals, but with increasing international pressure and rising energy demand there is no other way round then to follow the low carbon pathway. The need is to build an international consensus and support mechanism towards knowledge sharing at the global level

REFERENCES

The Thaindian news, February 18th, 2008, 'Low carbon economy key to sustain competitiveness: R K Pachuri', retrieved on 3rd Feb. 2010. Web: http://www.thaindian.com /newsportal/india-news/low-carbon-economy-key-to-sustain-competitiveness-dr-pachauri_10018625.html

Aswathanarayana, U. 2008, 'A low-carbon, technology-driven strategy for India's energy security', *Current Science,* Vol. 94, No. 4, p. 440-441.

FICCI, 2006. Impacts of Climate Change on Indian Industries', a report published by Federation of Indian Chambers of Commerce and Industries, New Delhi, pp. 31-32.

Windham, 2006. Green house gas emissions and global warming'. Worldwatch, retrieved on 29th Jan. 2010, p. 9.

World Energy Outlook, 2007, International Energy Agency, Paris.

GSI, 2007. Indian Coal Resource as on 1st April 2007', Geological Survey of India, GOI, retrieved on 2nd Feb. 2010.http://www.portal.gsi.gov.in/gsiImages/information /N_India_coal_resource_07.pdf

Planning Commission, 2002b, Tenth Five-Year Plan Report by Planning Commission, GOI, New Delhi http://planningcommission.nic.in/

Planning Commission, 2006. Integrated Energy Policy, Planning Commission, GOI, New Delhi

Windham, 'Green house gas emissions and global warming'. Worldwatch (2006), retrieved on 29th Jan. 2010. Website: www.flcv.com/green.html

Asian Development Bank, (1998), 'Climate Change in Asia: India country report and Asia Least-Cost Greenhouse Gas Abatement Strategy', retrieved on 29th Jan, 2010. http://www.adb.org/Documents/Reports/ALGAS/ind/default.asp#instructions

IPCC, 2005, 'IPCC Special Report on Carbon Dioxide Capture and Storage: Technical Summary'. http://www.ipcc.ch / activity/srccs /index.htm

Friedmann, S.J., 2005, 'Underground Coal Gasification in the USA and Abroad' Senate Foreign Relations Committee Hearings, Washington. (November 14th, 2005).

Ministry of Coal, 2006, 'US – India Energy Dialogue: Coal Working Group Work Plan', retrieved on 2nd Feb. 2010. http://fossil.energy.gov/international/Publications/us_india_workplan_0406.pdf

GOI, 2007, 'Status Report on Underground Coal Gasification, Prepared by the Working Group on Underground Coal Gasification', pp.15-23.

http://psa.gov.in/writereaddata/11913281701_ucg.pdf

European Wind Energy Association', March, 2008, 'Pure Power - Wind Energy Scenarios upto 2030' website: www.ewea.org.

EWEA, 2009, 'Economics of Wind Energy' A Report by European Wind Energy Association', Belgium, p. 28-77.

MNRE, Annual Report 2008-09, Table 1.1, 'Details of Estimated Renewable Energy Potential and Cumulative Achievements under Different Programmes', Ministry of New and Renewable Energy, India. http://mnes.nic.in /annualreport/2008-09EN/overview.htm

Suzlon Energy India, 'Growth of Wind Energy Market in India', , retrieved on 15th Jan. 2010.

Website: www.suzlonenergyindia.com

IWEA, 'Potential of Wind Resource in India', Indian Wind Energy Association, retrieved on 1st Feb. 2010. Website: http://www.inwea.org

Soren Krohn, "Offshore Wind Energy: Full Speed Ahead", Danish Wind Industry Association, October, 2002.

Rahul Kumar, Manish Kumar and S. Deswal, 2009, 'Analysis of Long – term energy option in Offshore Wind: An investigation of Environmental and Techno- economic feasibility', Paper published in proceedings of World Academy of Science and Technology, Vol. 36, pp.394-401, March, 23-25, 2009, Hong Kong, China.

Kooijman., H.J.T., Md. Noord, C.H. Volkers, L.A.H. Machielse, F. Hagg, P.J. Eecen, J.T.G. Pierik and S.A. Herman, 2001, 'Cost and Potential of Offshore Wind Energy on the Dutch part of the North Sea in 2001', European Wind Energy Conference and Exhibition, Copenhagen, Denmark.

Md. Noord, 1999, 'Large-scale offshore wind energy: Cost analysis and integration in the Dutch electricity market', ECN, Petten, The Netherlands, p.72.

Soren Krohn, 'The energy balance of modern wind turbines', Background Information Note, Wind Power, 16th December, 1997, Copenhagen K, p.12.

Utility-Scale Solar Plant Goes Online in Nevada', Environment News Service, 4th June, 2007.

Marketbuzz 2008, 'Annual World Solar Pholtovoltaic Industry Report', solarbuzz. http://www.solarbuzz.com /Marketbuzz2008-intro.htm

Wall Street Journal, 'First Solar To Build 2-Gigawatt Solar Power Plant in China', 2009. http://blogs.wsj.com/ environmentalcapital/2009/09/08/first-solar-to-build-2-gigawatt-solar-power-plant-in-china.

Shireesh Kedare, 'Solar Thermal Systems for Induustrial Applications', Presentation held at RENET Workshop, IIT-B, Sept., 21-22, 2006.

European Commission, 2008, 'Energy Sources, Production Costs and Performance of Technologies for Power Generation, Heating and Transport', 2nd Strategic Energy Review, Brussels, U.K.

****