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Third Industrial Revolution and India's Approach to Sustainable Energy Development

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The Abstract

The productive forces of the first and the second industrial revolution were triggered essentially by the discovery and development of fossil fuel energy resources of coal followed by hydro carbons and their later transformation into electricity. The development of concerned new energy technologies converged upon newly emerging technology of transport and communication which had radically transformed human society by reducing special distance and effecting wide diffusion of knowledge, information and technology. However, fossil fuel based economic development has given rise to the alarmingly large accumulation of unabsorbed wastes and pollution in the ecosystems of the earth resulting in global climate change and many other adverse consequences.

The need for transforming the global economy and society to control climate change and clean up the environment at local and global level has led to the development of the vision of a new era of Third Industrial Revolution. It is being envisaged that the third revolution would revolve around the development of renewables and hydrogen to replace fossil fuel in the electricity and the transport sector. The development of IT on the other hand would lead to the emergence of technology of both way flows of energy and information between the source of generation and consumption of energy, so that energy can be widely shared through an energy internet of smart grid of power and the efficiency of the energy system can be vastly enhanced.

The paper outlines the vision of the third revolution and describes how this remains still an important but distant goal for G- 20 countries particularly of India as of today. It focuses on the current energy scenario of India with reference to energy efficiency and fuel mix and discusses the potential of her renewable resources and the state of its cumulative realization as of now. It also gives in this context some long run projections of how far India's economic growth can become low carbon by utilizing such opportunities in the time frame of 2030-31.

Finally, the paper points out the major challenges that India and the global community will have to face in order to make the apparent distant goal of the Third revolution realizable in a shorter time horizon and what kind of responsibilities would be involved upon G- 20 forum to facilitate such transition to the new revolutionary era.

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1. Energy and Industrial Revolutions

Rifkin, proponent of the concept of the Third Industrial Revolution, envisioned it to be a regime which would transform the economies and society and effect some fundamental changes through the introduction of a new energy regime along with the convergence of an accompanying new communication technology. Each of the Industrial Revolutions has revolved around the introduction of a new energy resource and associated technology. The first one revolved around coal and steam power and the second one around hydrocarbons – oil and gas – and electricity, the latter as a converted clean highly efficient energy for final use as fuel. The first industrial revolution gave us coal and steam power which led to the emergence of railways and factory economy. The steam powered printing technology with rollers and later rotary press and linotype technologies caused an explosion of print materials in the forms of newspapers, books, journals, magazines and led to the emergence of a print literate work force capable of organizing the complex operations of railways and factory economy.

In the second industrial revolution hydrocarbons led to the innovation of the internal combustion engine and this converged with the development of electrical communication. The two together brought out the automobile revolution and the use of clean electric power replacing the steam power in the industry, commerce and transport vastly raising efficiency of the ultimate use of energy resources. While the automobile revolution led to the development of highways of Europe and North America, and locational reorganization of production and human habitats, the development of electrical communication technologies led further to the emergence of power grid, telecommunication networks of telegraph, telephone, radio, television etc. having a vast impact on the organization and efficiency of society and economy in delivering human welfare.

Both the first and the second revolution had thus an important impact on the mobility and communication, which contributed to the expansion of options or opportunities of betterment of life and thereby the scope of human capability development on the one hand, and raised enormously the efficiency of energy resource use in converting the natural ecosystem resources into economic products, on the other.

However both revolutions have been driven by the development of fossil fuels and accompanying print and electrical communication technologies respectively. The fossil fuel resources are nonrenewable in human time scale and involve high intensity of pollution arising due to essentially the highly entropic nature of economic processes of production. In view of the implications of climate change, desertification, physical and chemical degradation of soil and water bodies, the facts of emission of greenhouse gases, nitric and sulfur oxides, suspended particulate, hydrocarbons and arising of solid waste and liquid polluted effluents of such fossil fuel based development have created the problem of ecological sustainability of our global development process. Such ecological sustainability is of critical importance for the life support to the humans and other species on the one hand and eco-service support to the human economic system.

In order to save the world and humanity from the adverse impact of the fossil fuel based economic order, the search and thrust of research in science and technology are now for the discovery and development of carbon free or carbon neutral renewable resources and that of communication technology like internet which can ultimately permit phasing out of the fossil fuel and greenhouse gas and other harmful emissions altogether in a Third Industrial Revolution. The Third revolution would essentially involve shifting from fossil fuel to renewable energy resources of solar, wind, geothermal, tidal, biomass, water, etc. and organizing such energy production in a decentralized manner in small and medium scale enterprises and sharing the energy output through a wide network of energy internet. The latter would require the development of a wide network of a smart grid aided by wide information flow through internet and their digitized co-ordination for demand supply matching and automated energy sharing. According to Rifkin, the Third industrial revolution is visualized as a construct resting on five pillars of energy resource and technology development as follows:

1. Every building/ home/ factory etc., to be developed or turned into a virtual power plant by appropriate redesigning and change of technology of building material and construction, and share excess energy output with others in shortage through the power grid.

2. Power to be produced mainly out of renewable resources of wind, solar, biomass and wastes, geothermal, etc.

3. Such energy resource development is to converge with the development of internet and information technology to convert the power grid into smart grid of energy internet for energy sharing and efficient use of energy resources at the systems level. Such grid would rest on both way flow of both electricity and information along the network.

4. Automobiles are to be driven by electricity using plugging in or fuel cell technology replacing hydrocarbons, internal combustion engine.

5. Hydrogen and fuel cell are to be developed to provide the technology of storage of energy and release of electricity as per the requirement particularly in transport. Renewable energy may be used to create hydrogen to be stored in the vehicle to power fuel cell and to release in turn electricity for the supply of motive power for the vehicles.

The development of electronics and IT would further lead to the following distinctive feature of this new era as an associated fall out.

(1) Digitization of manufacture to guide the operations by automated control.

(2) Development of new and complex material by the use of new technologies like 3D printing and others.

The consideration of efficiency would be no longer perceived in the new era to be dependent on large scale mass production of a predefined product and the logic of concentration of capital on that ground would be weakened. The development process in the new era would be visualized as one of widely distributed capitalism, inclusive growth, economization of energy used by the vast increase in the energy system efficiency. The cost of production of energy as well as digitized material products and complex materials would be reduced, carbon emission would be phased out and climate change mitigated.

2. Energy Development of G-20 countries in the perspective of Third Industrial Revolution

While clean energy production and use are growing fast in recent years, the world is still grappling with the problems of the second industrial revolution and resolve them mainly by focusing on energy efficiency both in its end use in the non-energy sectors (energy conservation) and in the supply of primarily electrical energy by reducing conservation loss, auxiliary loss and T&D losses. The other way by which that the countries are trying to get out of the current problem of pollution and unsustainability of fossil fuel use has been by reducing the share of fossil fuel (coal an oil) in the gross electricity generation, and by raising that of the natural gas or coal bed methane (cleanest of the fossil fuels), nuclear, micro-hydel, biomass and wastes and other abiotic renewables like wind, solar, geothermal, tidal, etc. People are resisting the development of new hydro-storages which can otherwise produce carbon free electrical energy because of its adverse impact on the river ecosystems and human settlements. The development of bio-liquids and electric vehicles has also been initiated in some countries and the governments are setting goals to support the advancement of new vehicle market. Although the growth of deployment of clean technologies in the first decade of the present century shows the growth rate to be varying mostly in the range of 27% to 56% as per GCCSI data base 2011, the world is still largely dependent on fossil fuels to satisfy the growing energy demand. In the last decade fossil fuel has supplied 50% of the new energy demand, oil has supplied 94% of the total fuel requirement of the transport sector and non-hydro power from renewables has supplied only 3% of the final energy produced in 2009 in the world. All these have resulted in the steady rise in the CO_2 emission by G-20 countries and the world over the last decade. In spite of a slight decline in 2009 due to global recession, the emission level in 2010 reached a record high of 30.6

giga tonne - 5% more than the previous peak in 2008. Besides, it is to be noted that 80% of the projected emissions are to arise from the infrastructural investments already made.

The G-20 countries today account for 80% of the energy related CO_2 emission although per capita CO_2 emission widely varies cross countries in the range from 1.4 to 17.7 tonnes as was found in 2009. It is also to be noted that some of the Afro-Asian countries including India are still energy poor. In India about 35% rural households have no access to reliable supply of electricity and about more than 80% of the rural households are primarily dependent on unclean unconverted polluting biomass for meeting their cooking fuel need posing a big problem of health hazard due to serious indoor air pollution (66th Round of NSS). In order to alleviate energy poverty by removing the supply side bottlenecks, there has to be rise in the supply of modern clean energy of electricity and natural gas in countries like India implying an upward pressure on CO2 emission. To ensure the control of GHG emission the G-20 countries need to co-operate and give special thrust to the following sets of issues:

(a) Energy conservation by raising efficiency of end use of energy

(b) Raising the efficiency of energy resource conversion into electricity and its distribution

(c) Raising the share of carbon free or carbon neutral resources in electricity generation

(d) Carbon capture and storage as and when technology stabilizes and attains maturity

The ushering of a third industrial revolution as conceptualized and described above at an early date induced by deliberate policy initiative and co-ordination at international level can of course contribute substantively to the above objectives. This would be achieved mainly through the accelerated introduction of non-hydro renewables, development of energy internet for energy sharing through a smart grid and through the digitization of manufacture and infrastructure.

3. Sustainability of India's Energy System

It is still really a far cry for India to reach the stage of ushering in of the third industrial revolution. While there has been the emergence of the renewables as beginning to play a more than negligible role in supplying the growing new power demand, the most challenging task in the revolutionary era is going to be the development of energy internet through that of smart grid of power and information flow. The development of new renewables has been particularly significant as a source of off-grid power generation and power in remote areas as it could save the transmission and distribution cost of supply. India has, however, made an important progress in conserving energy by raising the end-use efficiency and the efficiency of energy conversion and supply and also in reducing thereby the carbon intensity of GDP in its approach to the basic objectives of sustainable energy society of the Third industrial revolution in spite of her slow progress on the front of the renewables.

3.1 Energy Resource Mix

The energy system of India primarily consists of the energy carriers – fossil fuel, hydro and nuclear resources, biomass, the combustible biomass and wastes which are largely non-traded resources having a share of 24.6 % in the total primary energy supply. There are also other new renewable resources whose current use has a negligible share in the total energy balance, but which can emerge as significant resources in India's future energy balance if greening process is given due priority. As of 2010 the following has been the composition of the total primary commercial energy supply of 522 million tonnes of oil equivalent:

Table 1: **Composition of Primary Commercial Energy**

Coal	55.2
Oil	31.1
Natural Gas	10.1
Total Fossil Fuel	96.4
Hydro	1.9
Nuclear	1.3
New Renewables	0.38
Total Carbon	3.58
Total	100

Source: IEA 2012: Energy Balances of Non-OECD Countries, OECD, Paris.

Since cost economization has to be one of the important determining factors in these days of open global competitiveness, the pattern of energy resource use and that of fuel choice as above have been bound to be primarily driven by the energy resource endowment of a country as determined by the ecosystem characteristics. However, high dependence on coal is involving increasingly such risks of energy security in Indian context due to supply side uncertainties for various reasons that lead to the emphasis on the strategy of energy conservation and enhancement of energy supply efficiency for green development.

3.2 Energy Efficiency

3.3 (a) Macro-view : In developing countries like India there exists enormous scope of energy conservation by upgrading technology, equipment and appliances in a wide range of areas of application — furnace, motors, insulation system, automobile engine, cooking burner, power generating system, and innumerable others. However, it is first of all important to note that India's energy consumption per capita is very low being only 565 equivalent kg in 2010, a share of 24.6% of which was supplied in the forms of unclean unconverted inefficient combustible biomass and waste. The use of electricity per capita which is the cleanest and most efficient form of final energy has also been 778 kwh only in 2009 while the world average in that year has been 2964 kwh. It is also important to note that at the macro level, India's efficiency of energy use has been lower than that of USA and high income countries but higher than that of China and marginally lower than the world average (See Table 2).

Table 2: Energy Use and Energy Efficiency Indicators for Selected Regions kgoe: kilogram oil equivalent

Country	Purchasing Power Parity Gross National Income (Per Capita $) (2010)	Energy per capita Koe (2009)	Energy Intensity of GDP (Koe/PPP 2005$) (2009)	Share of Biomass in total Primary Energy (%) (2009)	Gross electrical energy gen per capita (2009)
Brazil	11000	1243	0.087	31.6	2408.36
China	7640	1695	0.270	9.0	2775.74
India	3400	560	0.196	24.5	778.49
Japan	34610	3700	0.126	1.4	8158.30
Russia	19240	4561	0.333	1.0	6976.74
South Africa	10360	2921	0.312	9.8	5006.08
USA	47310	7051	0.169	3.9	13568.07
World	11066	1788	0.181	10	2963.64

Source: World Development Indicators, (2011& 2012)

A disaggregated sectorial level econometric analysis of energy consumption behavior during the post reform period as estimated by this author, however shows such partial GDP (income) elasticities and partial (real) price elasticities of final energy demand that indicates that indicate that India has already been moving along a final end use commercial energy conserving trajectory. These also indicate that raising energy and fuel prices would have significant energy conserving impact on the demand side enabling the attainment of higher energy efficiency at macro level. An individual industry level econometric analysis further reiterates such energy and fuel saving impact of own price increase for seven most energy intensive industries of India (e.g.: steel, aluminum, cement, paper, chlor- ackali, fertilizer, textile). While the cross price elasticities do not always confirm the common perception that energy conserving move through price rationalization would necessarily be capital intensive. So far as the scope of conservation is concerned, Table 1 and 2 give illustrative estimates of energy savings potential for selected manufacturing and infrastructural sectors as estimated respectively by the current author and energy experts.

Table 3: Potential of Energy Saving in % of the actual consumption in 2007-08

Name of Industry	Range of Saving in %
1. **Textile Industry**	**46 – 88**
2. **Paper & Pulp Industry**	**43 – 94**
3. **Iron & Steel Industry**	**51 – 92**
4. **Fertiliser Industry**	**26 – 94**
5. **Chlor-Alkali Industry**	**37 – 95**
6. **Cement Industry**	**30 – 84**
7. **Aluminium Industry**	**9 – 58**

Source: Author's own calculation

Table 4: Energy Saving Potential in Infrastructure

Intervention	Sector	Potential Energy Savings (in %)
Various motors, drives capacitors, etc. for energy intensive industries like steel, cement, aluminum, glass, etc. building	Cross-cutting	10 to 20
Lighting	Commercial/industrial/institutional	50 to 60
Efficient Pumpset	Agriculture	30

Source: Suki Lenora (2010) which obtained from Bureau of Energy Efficiency (BEE) and India Renewable Energy Development Authority (IREDA).

For the realization of these potentials it is important to remove the barriers which arise essentially due to high initial cost of new appliances and devices, inadequate dissemination of information regarding life-cycle cost and benefit of such energy conserving investment and high discount rate of the energy consumer. Energy policies need to address these issues as well. However, transport and electricity are the two major sectors which are responsible for a large share of primary commercial energy consumption and CO_2 emission and other pollution. While electricity sector consists mainly of large stationary point sources of pollution and fuel use, transport sector describes the fugitive sources of pollutant emissions. While the intercity transport offers substantive scope of energy conservation through modal switch from road to rail, energy consumption in the urban transport can be significantly reduced by switch from a private to public transport in India, particularly mass rapid transport by electric traction. Apart from fuel efficiency of transport, the up-gradation of petroleum fuel quality and that of transport logistics for reducing congestion would have also significant environmental benefits which should also deserve attention in the context of energy policy to lead us to the cleaner world which the Third industrial revolution envisages.

(b) Efficiency of Electricity Industry

While electricity is a high quality clean efficient fuel used widely across every segment of the economy and society, the power sector causes substantial material and energy loss and pollution in the process of its generation, transmission and distribution. The total energy loss as a share of throughput energy has been of the order of 78.5% in 2009 in India. The economization of such losses is of critical importance for the supply side efficiency improvement in the power sector. This can be achieved through higher boiler efficiency of coal fired subcritical units and oil based thermal units up to 35 to 38% efficiency and also by up-gradation of CCGT gas turbines to the range of 45 to 60% Apart from raising the conversion efficiency, the reduction of auxiliary losses from 6.8% on the average for all types of plant technologies to 5% and the transmission and distribution losses from 25.8% in 2005 to 15 should be easily achievable by 2031. The power sector reforms are supposed to provide an enabling legal and institutional framework so that the unbundled generating and distributing companies can work efficiently following the commercial principle of efficiency and the regulatory commissions can rationalize the power tariff structure in India. However, the persistence of regulatory regime in power sector particularly in the distribution sector, political interference in tariff fixation in the states of India and cross subsidization of power for agriculture and household sectors are standing in the way of inadequate investments for up gradation and growth of the power sector.

4. Macroeconomic and Environmental Unsustainability of the pattern of India's Energy Resource Use:

Apart from energy conservation and raising efficiency of use of energy resources in the energy industry, the replacement of fossil fuel by carbon free renewable resources has been considered to be the other important strategy for greening the energy sector development of India, although the progress of India in this direction has been disappointing. The high dependence on fossil fuel has become unsustainable not only because of high share of carbon footprint in the total ecological footprint, but also because of (a) other adverse environmental externalities from which all the energy resources suffer to a larger or smaller extent and (b) macroeconomic unsustainability due to heavy financial requirement for imports arising from the growing eco-scarcity of the fossil fuel resources.

The shares of import in the total apparent consumption of coal, oil and natural gas have risen over time and reached the levels of 16.4%, 76.0% and 19.5% respectively in 2010 – 11. This implied a high share of import of 35.9% in the total apparent consumption of all fossil fuels together in oil equivalent unit in the same year. Meanwhile, the unit price of total fossil fuel per unit of oil equivalent kg has increased in nominal rupees and dollar terms at the rates of 10.23% per annum and 5.75% per annum respectively in the last two decades. These resulted in the growth of India's total net import bill of energy at an alarming rate of 19.92% per annum in nominal rupee terms. The total energy import bill has also been growing over time as a percentage share of India's total export which reached 38% in 2010-11. This has become a source of concern for the macro-economic sustainability of such pattern of growth of energy use in India, particularly in view of the sharp decline in the rate of growth of IT related service export earnings to 10% per annum and of the slowing down of inflow of foreign direct investment.

5. Role of carbon free and carbon neutral abiotic conventional energy resources: Hydro and Nuclear

Nuclear and hydro resources in large storage are two options which can contribute to green development of energy. The prospect of nuclear route of energy development depends on our success at the stage of breeder reactor and that in developing thorium – uranium cycle so that we can use our huge stock of thorium reserves. It is too early to assess the situation, but we need to engage in trade in uranium and light water reactor market so that we are in a position to successfully experiment with uranium – thorium reactor. So far as large hydroelectric projects are concerned the option is fraught with too many socio – political and political economic problems of environmental externalities arising from too much disturbance in the local and regional ecosystems as well as from the destabilization of human settlements.

6. Role of Renewables

6.1 Biomass

Biomass constitutes about a quarter of the total primary energy supply even as of today in India. In 2009, the total primary energy supply in the form of combustible biomass and wastes in India was 164.278 mtoe (which was been 24.45%) of the total primary energy supply. It is only a negligible fraction (0.69% approx. in 2009) of such biomass including wastes that was converted into electricity. Most of such biomass fuel is used in conventional country chullah (oven) for cooking causing problems of serious health hazards for women and children in the households of the lower income groups who are exposed to such emissions.

Besides, valuable time and effort are devoted by mostly women and children for biomass fuel collection at a high opportunity cost of earning from productive employment or that of education. In India, a case study points out that 85 million households spend 30 billion hours annually in fuel wood gathering (Parikh, et. al 2005).

Over harvesting of biomass, particularly fuel wood as collected from forests has also the adverse impact of deforestation. In poorer regions of India, particularly in the Himalayan regions where access of the people to commercial energy is limited, there has been degradation of forests due to such overuse (Baland et. al 2006). A decrease in forest area or its degradation due to the lowering of crown density would adversely affect the carbon sequestration and would contribute further to the global warming.

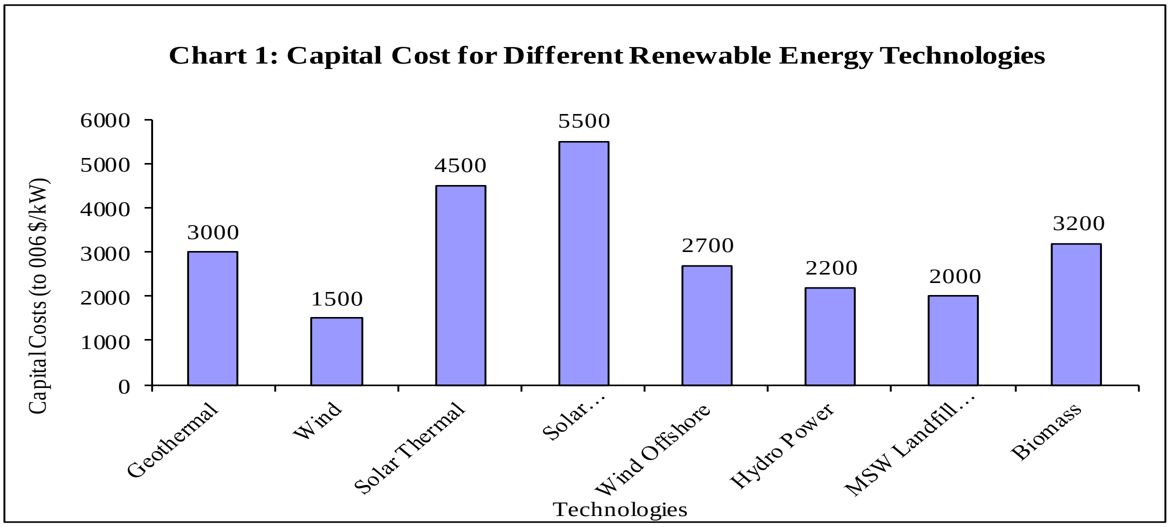
These biomass resources themselves can however be converted into clean gas fuel like biogas by way of gasification in bio digest. Such gaseous fuel can be further converted into electricity to meet the requirement of household or agricultural operation of the rural sector. It is possible to organize for example, both family sized and community sized plants if a critical minimum dung of animals or other biomass can be mobilized for the plant involving voluntary cooperation of all the stakeholders in an incentive compatible way (Parikh and Parikh 1977). However, such biogas based electricity constituted only 0.22% of total gross generational electricity.

6.2 Bio- liquids:

So far as biotic renewables are concerned, bio-liquids in the form of bio-diesel and bio-ethanol are important substitute fuels for petroleum particularly for the security of transport energy. In both the cases energy security may conflict with the issue of food security as there may be diversion of land use from food to energy cultivation, like jatropha replacing food grain production. However, government policy in this regard, has been that such cultivation of jatropha would be confined to waste land only. There is however a problem regarding the estimate of availability of waste land for the use of such purposes as the estimates widely varies across the reports of different expert agencies. There also remains the problem of regulating land use in a market driven system as international oil prices may raise the ground rent of land for such use of energy cultivation. (see Singhal and Sengupta, 2012). This points to the importance of fuel switch from hydrocarbons to electricity so far as transport sector is concerned. Hydrogen and fuel cell technology have therefore to play an important role in making Indian transport system ecologically sustainable.

6.3 Abiotic Source of New Renewable Energy

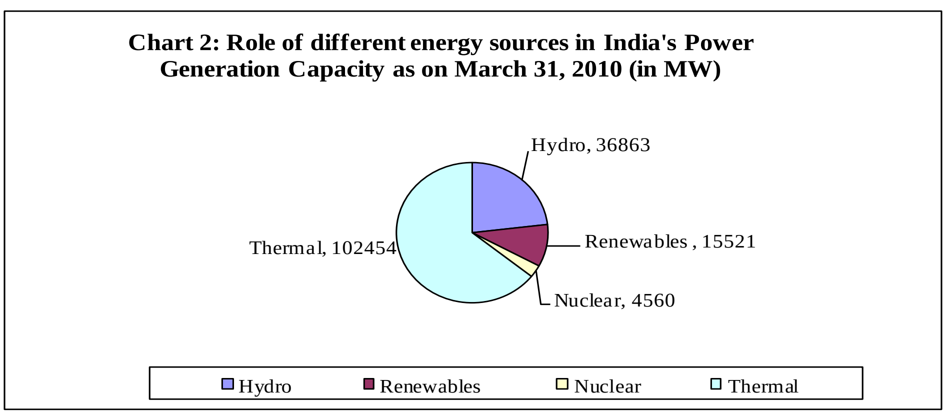
Finally, it is the abiotic energy resources of wind and solar radiation, geothermal heat and tidal waves which would constitute the major energy resources in the new era of Third industrial revolution. In India, wind power can be generated from the energy potential of on shore wind flow but only at a low load factor of about 20%. The solar thermal, on the other hand, is at the moment an economically feasible option mainly for water heating. The solar power has been a high cost option, with cost per unit varying in the range of Rs.15 to 20/kwh although the cost is coming down fast converging towards Rs.12/kwh with increasing deployment of technology and R&D efforts overtime. However, India has substantive potential of wind and solar energy as indicated later in Table 5.1. For wind energy, the estimates of such potential would depend on the hub height and spatial distribution of strength of the wind flow which would determine the power generation potential per unit of land area across the different regions of India. While the land requirement for wind power does not cause any major land use diversion, the solar power generation would involve such use of land for constructing the solar panels that may cause diversions of land use. The potential of solar power would therefore depend on the temporal and spatial distribution of strength of solar radiation and the land availability for solar power for other than roof top generation, solar pumping etc



Source: Adapted from Garg et al, 2010

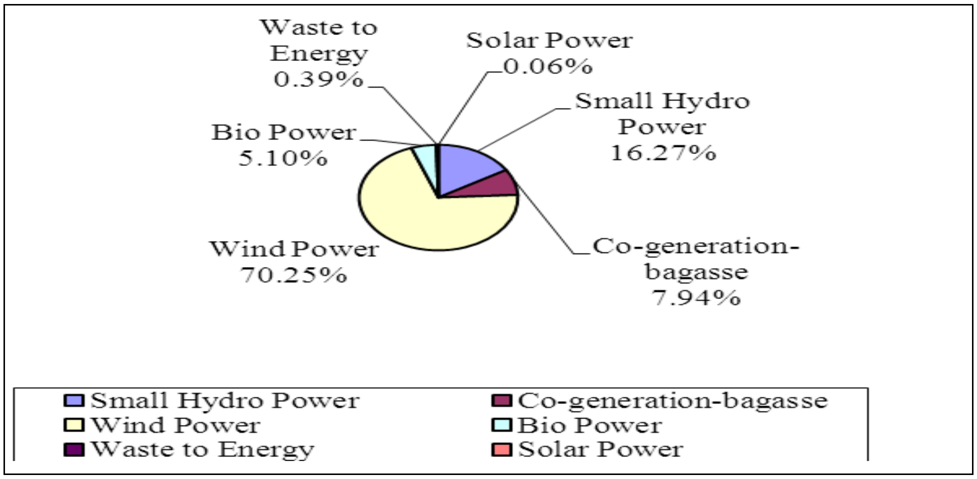
Chart 1 shows in fact the position of relative capital costs per Kw in 2006 for the alternative renewable technologies showing the wind to be the cheapest option and solar PV the costliest one. As there is little material fuel involved in any of the options the relative capital costs would be the major determining factor of competitiveness of the new renewable technologies (Garg et. al 2010).

The Chart 2 shows the shares of different energy resource based technologies in total power generation capacity of India, installed capacity of new renewable energy based power (i.e., excluding large storage based hydel power) technology being 15521 MW in a total of about 1,60,000 MW system (i.e. a share of 9.7%) on March 31, 2010. Chart 3 shows further the distribution of share of grid interactive alternative renewable energy capacities in India as on the same date. These show wind power to be the dominant technology having 70% of the new renewables based grid connected power capacity and the solar photo-voltaic having the least share of 0.06% in such grid connected systems. These are consistent with the findings of relative capital cost ordering of these technologies (Garg et. al 2010).



Source: Adapted from Garg et al, 2010

Chart 3: Share of different technologies in Grid- Interactive Renewable energy capacity in India as on March 31, 2010



Source: Adapted from Garg et al, 2010

Table 5.1 shows the estimated potential of power capacity from all the major biotic and abiotic energy resources and the cumulative achievement of realizing such potential as on 31 March 2007 as per the Eleventh Plan document and alternate assessments obtained by the author from other sources. The Table also shows the potential of generation of electricity in energy unit to be achievable for certain PLF assumption for each type of the new renewable options. It is really the relative high cost of some of the options like solar photovoltaic as already noted which is the main reason for such low utilization of potential, while subsidies at times act as a barrier to cost reduction. However, the lack of entrepreneurship in the deployment of such capital and technology, lack of institutional support at the grass root level, poor focus on training and management for using and maintaining such new technologies and the lack of awareness of rural community have been important additional factors which all together contributed to the poor achievement in this direction. Table 5.2 gives the technology wise estimates of both capital cost per MW of capacity as well as the unit costs of generation.

Table 5.1: Estimated Medium Term (2023) Potential and Cumulative Achievement

Source	**Units**	**Estimated Potential**	**Cumulative Achievements as on 31.03.2007**	**Capacity Factor**	**Potential Generation (Bkwh)**
Power from Renewables					
Grid Interactive Renewable Power					
Bio power from agro residues etc.	MW	16881	524.8	60%	88.72654
Wind Power	MW	45195	7092	25%	98.97705
Small hydro (<25 MW)	MW	15000	1975.60	20%	26.28
Cogeneration (Bagasse)	MW	5000	615.83	60%	26.28
Waste to Energy	MW	7000	43.45	60%	36.792
Solar	MW	50000	2.92	20%	88.72654

Source: Eleventh Plan Document (Planning Commission), Expert Group on Low Carbon Strategies for Inclusive Growth of the Planning Commission (2011) and Interview with World Institute of Sustainable Energy (WISE) in 2012.

Table 5.2: Capital Cost and the Typical Cost of Generation of power from Renewable Sources

Source	Capital Cost (Rs. Per MW)	Estimated Cost of Generation per Unit (Rs. Kwh)
Small hydro power	5.00 to 6.00	1.50 to 2.50
Wind power	4.00 to 5.00	2.00 to 3.00
Biomass power	4.00	2.50 to 3.50
Bagasse cogeneration	3.5	2.50 to 3.00
Biomass gasifier	1.94	2.50 to 3.50
Solar photovoltaic	26.5	15.0 to 20.0
Energy from waste	2.50 to 10.0	2.50 to 7.50

Source: Eleventh Plan Document (Planning Commission)

In spite of all the limitations of the new and renewable energy resources the total potential of generation of electrical energy from such sources is thus really huge while only a miniscule fraction of it has been really exploited. While the Eleventh Plan document shows the wind power potential to be 45195 MW as assesses on 31st March 2007, this has been reassessed by the Centre for Wind Energy Technology (C-WET) to be 49130 MW in 2010 at 50 m hub height, with productivity of wind strength as 9 MW/km^2 land and 2% of land availability for such purpose for all states other than the Himalayan ones and 0.5% land availability for others. The Lawrence Berkeley Laboratory under a study "Reassessing Wind Potential Estimates for India- Economic and Policy Implications" put the estimates to be 2006 GW at 80 meter hub height and 3121 GW at 120 meter hub height and higher land availability in the range of 7% to 11% in various states of India. For higher capacity utilization factor with greater than 25 MW units, the potential would however be in the range of 543 GW to 1033 GW. The offshore wind potential can further provide an additional 15 GW at less than 60 meter hub height in India.

The solar power potential was set at 45.195 GW in the Eleventh Plan document of the Planning Commission. Most parts of India however receive solar radiation of 4 to 7 Kwh per square meter per day. As several parts of India receive good radiation, the Expert Group on Low Carbon Strategies for Inclusive Growth of the Planning Commission set the solar potential at over 500 GW assuming 1% of land area of India. There are other expert views like that of World Institute of Sustainable Energy (WISE) which puts the estimate of potential in the range of 700 to 1000 GW assuming the additional possibility of setting up grid connected solar power capacity in several states, roof top solar power generation and solar pumping of water facility.

7. Projections on Primary Commercial Energy Requirements and CO_2 Emissions of India in the Long Run

In view of the potential of power generation by the alternative resources of solar, wind and other new renewable energy technologies and the sectoral energy consumption behavior, the long run projections of requirements of gross generation of electrical energy (see Table 6) and of the total primary energy resources were worked out by the present author for alternative combinations of growth rate, real energy price inflation and shares of new renewables in power generation. These projections were based on some higher achievable supply side efficiency and two alternative distributions of fuel mix of gross electrical generation – a baseline one of fuel mix of generation as per the National Action Plan for Climate Change (NAPCC) and the other one of accelerated introduction of renewables in the fuel mix. Any increase in the share of the new renewables has been assumed to take place at the cost of coal thermal power generation in these projections (see Tables 7and 8). The implications of these projections in respect of primary commercial energy intensity and CO2 emission intensity of GDP are indicated in (Tables 9 and 10). The result of all such projections will indicate the range of variation of primary commercial energy use and its intensity of GDP, CO_2 emission volume as well as CO_2 intensity of GDP of India in the coming decades conditional upon the realization of the alternative combination of assumptions as described above. These projections are not predictions of India's future energy scenario, but represent certain alternative energy scenarios which may be considered to be quite feasible for India to attain and which would indicate how low carbon and sustainable India's growth and energy development can be within the time horizon up to 2031.

Table 6: Gross Generation of Electricity (in Bkwh) for 8% GDP growth

	With 0% Energy Price Rise			With 3% Energy Price Rise		
Year	Gross Generation (in Bkwh)	Per Capita Gross Generation	Installed Capacity Requirement (MW)	Gross Generation (in Bkwh)	Per Capita Gross Generation	Installed Capacity Requirement (MW)
2009	979.87	811.33	186429	979.87	811.33	186429
2021	1537.28	1096.58	292481	1356.25	967.45	258038
2031	2577.99	1679	490485	2057.70	1340.15	391495

Source: author's calculation

Table 7: Share of Fuels in Electricity Generation- Baseline Growth in Electricity from Renewables Scenario

Year	Coal	Gas	Fuel Oil	Hydro Electricity	Nuclear	Renewables
2009	70%	11.5%	1.7%	13%	2.3%	1.5%
2021	65%	14%	1.7%	13%	2.3%	4.0%
2031	60%	16%	1.0%	13%	2.3%	7.7%

Source: Author's Own Calculations

Table 8: Share of Fuels in Electricity Generation- Accelerated Generation using Renewables

Year	Coal	Gas	Fuel Oil	Hydro Electricity	Nuclear	Renewables
2009	70%	11.5%	1.7%	13%	2.3%	1.5%
2021	60%	14%	1.3%	13%	2.3%	9.4%
2031	50%	16%	1.0%	13%	2.3%	17.7%

Source: Author's Own Calculations

We however, present the results only for the following selected five Scenarios out of all possible combinations of policy assumptions regarding pace of growth, energy pricing and choice of fuel mix for power generation.

Scenario 1(Baseline): 8% GDP growth rate, 0% annual rise in real energy price over the base line of 2009 , baseline use of
New renewables as per NAPCC
Scenario 2: 8% GDP growth rate, 3% rise in real energy price per annum, baseline use of
New renewables as per NAPCC
Scenario 3: 8% GDP growth rate, 0% rise in real energy price per annum, Accelerated use of
New renewables
Scenario 4: 8% GDP growth rate, 3% rise in real energy price per annum, Accelerated use of
New renewables
Scenario 5: 6% GDP growth rate, 0% rise in real energy price per annum, baseline use of new
Renewables as per NAPCC

Table 9: Primary Commercial Energy Intensity of GDP (goe/ rupee)

(2009-10 constant prices)

Year	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
2009	9.89	9.89	9.89	9.89	9.89
2021	6.65	5.60	6.67	5.61	7.37
2031	5.23	3.74	5.27	3.78	5.92

Source: Author's Own Calculation

Table 10: CO_2 Emission Intensity of GDP (g/rupee)

(2009-10 constant prices)

Year	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
2009	63	63	63	63	63
2021	38.3	33.1	36.6	31.7	43.1
2031	27	20.5	24.6	18.6	31.6

Source: Author's Own Calculations

Given the above projections, it is quite clear that the Indian economy will be on an energy conserving and low carbon growth trajectory in the future as per the extrapolation of the pre-existing trend of declining primary energy intensity and CO_2 intensity of GDP. However, the extent of use of primary commercial energy which is the ultimate determinant of the pressure of the ecosystem in terms of carbon foot print would depend on the policy scenario that is adopted as a strategy for the growth of the energy system.

It is interesting to observe that raising energy price is possibly marginally more effective than accelerated introduction of new renewables as considered to be feasible in reducing primary commercial energy intensity as well as CO_2 intensity of GDP. The reduction of the growth rate of GDP is on the other hand clearly counterproductive for the purpose of low carbon intensity of economic growth.

8. Concluding Remarks

Given the present landscape of industry and technology and the ground reality in India, the vision of the Third industrial revolution is more of the nature of a distant goal than an objective for action of immediate implementation. However, it is the short and medium run policy initiatives which would influence our attainment of the goal in the long run. The long run perspective of development would be therefore important to define our road map and basic approach of energy and environment policies for all time frames. The Indian ecological resource system provides adequate potential for the realization of the long term goal that the Third revolution envisages. It is thus important to realize what the constraints or barriers in the ways of achievement of such goals as of third revolution are and how to remove them. There are in fact big challenges that are to be faced in approach to the Third revolution from the present state of fossil fuel based global energy and economic development.

One major issue in this context would be the cost effectiveness of transition to the new industrial order of the Third revolution through the technological and socio economic transformation.

The new technologies which would constitute the five pillars of the third revolution as described in the first section of this paper would in fact be highly knowledge intensive. As the patented knowledge market is highly imperfect and monopolistic, the capital cost of such transformation process may become quite high, standing in the way of cost effectiveness and the redistribution of capitalism in the new order. So far as the inclusiveness of the development process is concerned, wide sharing of knowledge, transfer of technology and control of price of the knowledge capital by governmental intervention become important for the sharing of the benefit of the new industrial revolution both between the rich and the poor and between the developed and the developing countries. Co-operation among G-20 countries in joint research on science and technology and in sharing and transferring technologies across borders would only enable the developing countries to leapfrog to a higher stage of development characterized by the Third revolution. The intellectual property right regime would be of critical importance in such knowledge sharing and delivering the R&D output to the users at affordable prices and in converting the knowledge into a global public good at the earliest. G-20 countries forum can play an important role in effecting such policies.

It is however to be further noted that all the renewable energy resources like solar radiation, wind flow, tidal wave, micro hydel and storage hydroelectricity which are to replace fossil fuels are ultimately solar powered. However, the maximum of solar radiation reaching the earth is a finite, non-storable and dilute form of energy. The potential of electric power generation from the wind or tide or micro hydel water resource flows in any given geographic region is limited and the time distribution of their availabilities is determined exogenously for the human economy by the ecosystem behavior of the nature. The divergence between the time distribution of the demand for electric power and that of availability of such non-storable basic energy resources creates the problem of full utilization of opportunities as well as that of meeting the demand unless there is a grid connection with such power supply. If the grid connectivity be imperative for the best utilization of such abiotic resources like solar and wind whose supply may widely fluctuate at times, it would require the support of quite a strong and wide transmission and distribution network which may be high cost to make the system viable.

As the new energy scenario in the era of third industrial revolution envisages electricity to be supplied mostly from new renewables, it is also difficult to conceive how the supplies from a large number of small to medium scale power generation units or stations can be synchronized with the large demand of the industrial sources like steel, aluminum, paper, railway traction etc. unless the industrial landscape of the economy drastically changes to be one of cottage and small to medium scale units. Can digitization and automated control of production processes and new material based technologies effect such a transformation of the industrial economy? Even if it can, one needs to assess carefully the socio economic implications of such changes in terms of impact on employment, capital intensity and nature of participation of the people in the new order of the third revolution.

However, in the context of short to medium run policy for sustainable energy development it has already been noted above that, of all the non-conventional or new energy options, the hydro, wind and dung based biogas have the advantage of no significant land use diversion. On the other hand, the solar power and any biotic plant based fuel would require land use which may involve high social opportunity cost of diversion if it impinges specially on the food security of the country. The exploitation of such options for greening the energy scenario would therefore require careful land use planning for maintaining inter sectoral balance and social distributive equity of assets for maximizing the social welfare of the people. The issue is important for our long run planning as land use has become politically and economically a sensitive issue in a high intensity overpopulated developing country like India.

The government of India has however, recently given a new thrust on the development of renewables for power generation particularly, for the development of solar power. As part of the National Action Plan on climate change the government has mandated certain share of new renewable energy in the total annual electrical energy supply to the meet requirements over the time horizon 2009-10 to 2016-17 starting with 5% in 2009-10 and ending up with 12% share in the terminal year of 2016-17. However, the actual capacity addition of new renewables is falling short of the requirement to implement such mandates as their exist great uncertainties regarding their implementability in view of the unwillingness of the energy of distributors to buy such high cost power in a regulated regime of fixed tariffs.

The process of transition to the third revolution through the development of renewables, resources and hydrogen along with the fuel cell technology, IT based energy internet for energy sharing and digitization of manufacture and infrastructural operations among others are likely to require large mobilization of capital for financing and would pose a big challenge for the process. Both the state policy initiative and international cooperation are imperative for meeting the challenge if the world intends to effect the transition fast. The cooperation between the developed and the developing countries in R&D and knowledge sharing can significantly reduce some of the financial costs in the long run. It has to be noted here that the economic reforms of the kind introduced in India to induce greater competition in the energy industry and to ensure flow of financial resources to meet the need of this infrastructural sector have not met with the expected success. The marketization for spinning competition and the emergence of regulatory regime as witnessed in the power sector in India have unfortunately not been able to deliver the objectives. The political interference in tariff fixation by regulators, poor quality of governance, lack of appropriate legal order and finally lack of political will, have in fact been responsible for the poor rate of transformation our energy economy. A transition to the third industrial revolution and India's becoming a partner in guiding and participating in the transition process would demand long range vision and political will of the leaders and policy makers and substantive development of our institutional capability.

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