Electrical energy scenario in India

: Looking into the sustainability of use of new renewables

Sovik Mukherjee[1]

Abstract

In this fast growing world where 82 per cent of energy supply in the world's twenty biggest economies still comes from fossil fuels it is difficult to be in line with the emission targets of the Paris Accord. India's emission targets, by far, are the most ambitious and close to the 1.5°C limit agreed. Having said that, the question that arises is — is it enough? Continuously for three years, investments in renewable energy have pinnacled past fossil fuel related power investments. But at the same time, India's ongoing expansion of coal is a worrisome factor. The Paris agreement of 1.5°C limit means that there needs to be a phase-out of coal in the power sector by 2040 at least, if not earlier. But, India at this point of time can not even stop the use of coal immediately. Here lies the jinx. There has to be a tradeoff between India committing on its long run goals of greenhouse gas emissions in such a way that it does not raise the short run cost to the development process in India in terms of not being able to fund the huge costs of using new renewables.

In this background, the paper discusses how the optimum fuel mix design should look like involving the use of using new renewables. We want to make it however, clear here that these projections are not predictions of India's future energy scenario, but represent certain alternative energy scenarios which may be considered attainable for India not only from the feasibility part but also from the financing part. We project the share of non-fossil power generation capacity to reach 450 GW in 2031 of the total capacity, corresponding to a 12% share of electricity generation. Though these results broadly support the targets of the present Government regarding the creation of generation capacity of new renewables based power, the paper argues that the rent domestically extracted through either coal or gas in not enough to finance these capacity requirements from use of solar or wind or other renewables in line with the carbon emissions intensity of GDP target of 33-35% in 2030.

Key words : Anthropocentrism, Coal, CO_2 Emissions, Emissions Intensity, Energy, Power

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[1] St. Xavier's University, Kolkata. Action Area III B, New Town. Kolkata – 700 160. West Bengal, India.
e-mail: sovik1992@gmail.com

1. Introduction

It is however, still really a far cry for India to reach the stage of ushering in of a third industrial revolution, unless it is supported by the kind of funding that would be available from some Climate Fund and global technological collaboration for its transfer. While there has been the emergence of the renewables, as beginning to play more than a 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 but the question of shouldering such a huge proportion of power demand still remains. To that extent, India has however, made an important progress in conserving energy by raising the end-use efficiency and the efficiency of energy conversion and supply by reducing losses. While such efficiency gain would make power sector economically sustainable, this would henceforth also contribute to the reduction of the carbon intensity of GDP and also to the saving of capital requirement in a capital scarce country like India (Sengupta, 2015). The energy system of India primarily consists of the energy carriers – fossil fuel, hydro, nuclear resources, biomass, combustible biomass and wastes – the last one being largely non-traded resource having a share of 32 % in the total primary energy supply in 2015. There are also other new renewable resources whose current use has a relatively small share in the total energy balance, but which can emerge as significant resources in not so distant future in India's future energy balance in view of the recent decline in their cost of investment and the trend in the growth of their capacity.

Table 1. Composition of Primary Commercial Energy as on 2016 for the entire Indian economy and Technology wise Gross Generation mix of Electrical Energy in 2016

Composition of Primary Commercial Energy as on 2016 for the entire Indian economy		
	Total Fuel in Ktoe	**Share %**
Coal	378.91	44.52
Oil	206.91	24.23
Natural Gas	43.21	5.08

Total Fossil Fuel*	628.31	73.82
Hydro	11.87	1.39
Nuclear	4.82	1.15
New Renewables	4.82	0.57
Total Carbon free fuel	196.35	23.07
Total	**851.1**	**100**

Technology wise Gross Generation mix of Electrical Energy in 2016

Fuel Resource	**Total Gross Generation Bkwh**	**Utility**	**Non-Utility**	**Composition (% share) of fuel mix of generation**
Coal	1032.061	895.340	136.721	77.25
Gas	68.205	47.122	21.083	5.11
Oil	8.963	0.551	8.412	0.67
Hydro	121.487	121.377	0.110	9.09
Nuclear	37.414	37.414	—	2.8
Other Renewables	67.827	65.781	2.046	5.08
Total	**1335.957**	**1167.583**	**168.372**	**100**

Source : Compiled by the author from Energy Balance of Non OECD countries

*Includes the share of non-utility in thermal power

The primary commercial energy supply of India has grown from 675 million tonnes of oil equivalent in 2009 to 851 million tonnes of oil equivalent in 2016 at an annual average rate of growth of 3.9 % as per the energy balance sheets of IEA for the different years to support the growth of GDP and population of India during this period. The growth of electrical energy on the other hand grew from 906 billion KWh in 2009-10 to 1336 billion KWh in 2016-17 at an annual average rate of 6.69 % as per the Energy Statistics of the Government of India for 2018. The composition of fuel mix of primary energy and that of energy resource mix for gross generation of electricity are given in the Tables 1 and 2 respectively for the year 2016-17.

The most important characteristic of this composition of mix for the overall energy system or the electricity generation in India has been the dominance of fossil fuel with high carbon footprint. The driving force behind the observed pattern of growth of the power sector, which provides the major opportunity of fuel substitution, has been energy security to provide support to India's high growth of GDP and to provide energy security to the households in terms of access to electricity by supply side initiatives in the energy industry. The relative endowments of availability of the alternative fuels and their cost competitiveness have been the key determinants of such choice of fuel composition. The environmental unsustainability has however led to the present policy thrust on the accelerated introduction of new renewables as alternative energy resources (Mallah & Bansal, 2010).

The Paris agreement of 1.5°C limit means that there needs to be a phase-out of coal in the power sector by 2040 at least, if not earlier. Surprisingly, 90 GW of planned coal-fired capacity under the National Electricity Plan (NEP) in 2018 will lead to an increase in emissions unnecessarily. But, India at this point of time can not even stop the use of coal immediately given the fuel composition she follows under the relative cost considerations. Here lies the jinx. There has to be a tradeoff between India committing on its long run goals of greenhouse gas emissions in such a way that it does not raise the short run cost to the development process in India in terms of not being able to fund the huge costs of using new renewables. The paper has been organized as follows. The second and third section introduces the background of India's power sector by arguing out that why conventional sources of hydro and nuclear are not tenable and the requirement of new renewables. In the quest for trying to find an answer to this, the author develops an econometric model for projection of growth[2] of energy demand by integrating both the sides of demand and supply of electrical power generation in the future. Also, the fluctuations in energy prices have been modeled based on a Brownian motion process as given in the appendix. Though these results broadly support the targets of the present Government regarding the creation of the generation capacity of new renewables based power, the paper argues that the rent domestically extracted from either coal or gas should be able to finance these capacity requirements from use of solar or

[2] The terminal years for the projection of our model are 2021-22 and 2031-32 with 2011-12 (actual) as the base at overall 6 per cent GDP growth.

wind or other renewables in line with the carbon emissions intensity of GDP target of 33-35% in 2030.

2. Why not Carbon free abiotic conventional energy resources in the road map to sustainable energy for India : Hydro and Nuclear?

It may however be noted here that nuclear and hydro resources in large storage are two options, which can contribute to green the development of energy. The prospect of nuclear route of energy development depends on India's 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. The availability of suitable site for nuclear reactors is an important constraining factor. The capacity forecasts for this sector have chronically erred grossly on the higher side than what could be achieved. The analysts of the Department of Atomic Energy claimed that the total capacity would require to be raised to 275 GW by 2052 from the current level of 4.78 GW in 2014-15 to wipe out all the shortages of power supply from all other sources together. This is unlikely to materialize unless there is a breakthrough in technology development and such application in the Indian nuclear industry. The recent projections based on the current ongoing nuclear project capacities gives an addition of 4.8 GW, while pre-project activities have started for 10.5 GW from domestic sources and for another 8 GW from the sources of foreign collaboration (particularly the case of Russian collaboration). In view of these developments the Twelfth Five Year Plan had boldly set the target of raising the share of nuclear in the gross electricity generated from 3.17% in 2011-12 to 5% in 2016–17 and 12% in 2031-32. While it is too early to assess the situation of successful prospect of nuclear development, we need of course 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 in the next phase of the cycle of nuclear power development.

So far as the hydro energy is concerned, India has a potential of generation 150 GW from large storage of hydro resources and another 15 GW of small hydro generation potential as per the assessment of Central Electricity Authority (CEA) and MNRE (WISE 2014, Chapter 11) respectively. The actual hydro capacity installed has however been 40.53 GW in 2013-14. The share of all kinds of thermal power (i.e. gas, diesel, etc) together in the total gross generation of power in the utility system increased from 51% in 1950 to 70.6% in 1990-1991, and 82% in 2011-12, and 83% in 2015-16 (including the shares of non-utility, while that of hydro-electricity declined from 49% in 1950 to 27.1% in 1990-1991 and 12.4% in 2011-012 and 9.09% in 2015-16. As the non-utility power generation has been mostly thermal based, there has thus emerged a serious imbalance of hydro-thermal mix from the point of view of efficiency for meeting the varying load of power demand, hydropower being known to be the most convenient and efficient resource in meeting fluctuating peak load by quickly ramping up or down the load generation.

The reasons of the declining share of hydro have been due to the long gestation lag of storage dam projects and various socio-ecological constraints of such projects like displacement of human settlements, degradation of the ecological landscape due to inundation of the catchment and dam area, disturbances in the riverine water flow with consequent adverse impact on flora and fauna in the upstream as well as the downstream ecosystem. These options are in fact fraught with too many socio–political and political economic problems (see Parikh & Parikh, 2011 for details) arising from too much disturbance in the local and regional ecosystems in terms of creating such environmental externalities as well as from the destabilization of the human settlements.

3. Overall Potential of New Renewables and Green Electrical Energy

If all the conventional sources of commercial energy resources have their limitations in providing environmentally and macro economically sustainable electrical energy supplies we have to look for other options of biotic and abiotic renewable resources for the purpose. Biomass constituted about 23% of the total primary energy supply in India as late as in 2015. It was only a negligible fraction of 0.69% approx. Of such biomass including wastes that was converted into electricity in 2009. Most of the biomass fuel is used in conventional country chullah (oven) for combustion for cooking causing a huge problem of indoor air pollution which constitutes a serious health hazard for women and children in the households of the lower income groups who are exposed to such emissions. The resource can alternatively be converted into biogas by way of gasification in bio-digest. Such gaseous fuel can be further 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 requirements of household or agricultural operations of the rural sector.

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 industrial era. Both biomass resources and abiotic wind, solar light energy and micro-hydroelectricity can provide not only to fill any shortfall of power supply from the conventional sources to meet the demand, but may constitute a major source of supply of electricity for supporting economic growth and universal access to electricity for all. The major shortcoming of our rural electrification programme for giving access to power for villagers in India has been the lacunae in the electricity distribution infrastructure, lack of strength of the grid extended to cover villages in large areas and also inadequate supply of power to flow along the distribution infrastructure. As the generation of power based on both biotic and abiotic renewable resources can be decentralised, these technologies may permit both supply to the grid in case such generation is grid connected or can provide off-grid supply to the local consumers if the grid development or extension to the concerned areas become infeasible due to physical or logistical constraint or be high costs. The new renewables can in fact be a source of not only greater energy security by providing the consumers wider access to power and thereby greater equity in its distribution but also facilitating an improvement in the quality of power supply in rural India leading to greater competitiveness and efficiency in the power industry (Das & Sengupta, 2015).

4. Future Projection of Energy Resource and Technology for Power Scenario of India : CO_2 emission implications for changing technology

Let us turn our attention to the changing fuel or resource composition of power technologies in the development of India's electricity industry. We present in this and also in the following sections scenarios of the Accelerated Share of Renewables (ASR) vis-à-vis the Business As Usual (BAU) are taken to be the same as that of the NITI AAYOG in its document of Energy Policy Draft 2017. To begin with, this projection model assumes the planning horizon to be the terminal years of 2021-22 and 2031-32 with 2014-15 (actual) as the base. The scenario assumes 6 per cent overall GDP growth and accelerated rates of introduction of carbon free new renewable fuels. The comparative scenarios will be ASR and BAU ones (see Table 2 and 3). The level of aggregate electricity generated (see Table 3) after taking care of the auxiliary and transmission & distribution losses have been derived using the energy demand model presented in the annexure based on the

Energy Balance data over the years from International Energy Agency's (IEA's) database and applying the shares of new-renewables vis-à-vis the conventional sources of coal, thermal, hydel power etc. in Table 3.

Table 2. Business As Usual_(BAU) vs. Accelerated Share of Renewables_(ASR) Share Comparison

Energy Fuels	**2021-22***	**2031-32#**	**2041-42***	**2021-22***	**2031-32#**	**2041-42***
	(ASR)	**(ASR)**	**(ASR)**	**(BAU)**	**(BAU)**	**(BAU)**
coal	62.600	51.76176	42.800	64.909	60.750	56.500
gas	6.500	6.500	6.500	5.444	7.500	4.000
nuclear	3.700	4.343961	5.100	3.488	3.000	3.500
hydro storage	9.000	7.937254	7.000	9.103	9.350	5.400
Solar PV	4.200	6.640783	10.500	4.211	4.643	9.100
Solar CSP	0.600	1.549193	4.000	0.468	1.150	2.300
Distributed Solar PV	2.300	3.108054	4.200	2.339	1.800	3.600
Total Solar	7.100	11.52259	18.700	7.018	7.593	15.000
Onshore Wind	5.500	7.074602	9.100	5.487	5.750	8.500
Offshore Wind	0.300	0.774597	2.000	0.255	0.650	1.300
Total Wind	5.800	8.023715	11.100	5.742	6.400	9.800
Other Renewables (including biomass)	5.350	6.861487	8.800	3.658	5.313	5.900
Imports	-	-	-	-	-	-
Total	**100.050**	**100.025**	**100.000**	**100.000**	**99.906**	**100.100**

Source : Compiled by the Author from Energy Policy Draft (2017)

: For 2031-32 for both the BAU and ASR scenarios, the value has been derived after taking the geometric mean of 2021-22 and 2041-42.

These are the shares in Table 2 with which the projected estimates in Table 3 have been derived. The main essence of carrying out this entire exercise, results of which are reported in Table 3 is to predict to what extent electricity generation is possible using new renewables and to what extent it can be sustained after taking care of the CO_2 emissions. Here comes the tradeoff between India committing on its long run goals of greenhouse gas emissions in such a way that it does not raise the short run cost to the development process in terms of not being able to fund the huge costs of using new renewables. In trying to answer this question and to comment on the choice of optimal fuel mix (see Table 3) and the consequent carbon emissions (see Table 4), we present the CO_2 emissions in million tonnes under both the scenarios in Table 4.

Table 3. Business As Usual_(BAU) vs. Accelerated Share of Renewables_(ASR) Electricity Generation Comparison in Twh*

Energy Fuels	2011-12	2021-22*	2031-32*	2021-22*	2031-32*
	(actual)	**(ASR)**	**(ASR)**	**(BAU)**	**(BAU)**
coal	729.403	1449.531	2590.998	1504.921	2984.441
gas	118.476	150.510	319.572	254.678	368.449
nuclear	27.816	85.675	216.326	57.881	147.379
hydro storage	148.353	208.399	393.320	307.929	459.333
Solar PV	2.060	97.252	358.904	4.283	228.070
Solar CSP	-	13.894	113.079	-	56.495
Distributed Solar PV	-	53.257	162.244	-	88.428
Total Solar	2.060	-	-	4.283	372.993
Onshore Wind	32.967	127.356	358.904	69.458	282.478
Offshore Wind	-	6.947	54.081	-	31.933
Total Wind	32.967	-	-	69.457	314.411
Other Renewables (including biomass)	47.390	123.881	349.071	109.419	261.009
Imports	5.151	-	-	-	-
Total	**1111.618**	**2316.703**	**4916.506**	**2308.572**	**4908.019**

Source : Author's calculations ;
* : refer to the annexure for the empirical model used

Table 2 shows that the total gross generation of new renewables based power will rise from 93.36 Twh in 2014-15 to 1055.0 Twh in 2031-32 and to 2855 Twh in 2041-42 as per the BAU scenario. The same will rise to comparatively higher levels of 1186 Twh in 2031-32 and to 2909 Twh in 2041-42 as per Scenario 4. Thus while the share of coal thermal generation as a % share of total gross generation will decline from 66% in 2014-15 to 60% in 2031-32 and 57.3 in 2041-42 as per the BAU scenario, the share of new renewables will rise from 7% share in 2014-15 to 21.5% in 2031-32 and further to 30% in 2041-42 in the same scenario. According to Scenario 4, the share of coal is supposed decline to a comparatively lower level 52.7% in 2031-32 and to 44% in 2041-42 while the share of new renewables should rise to a comparatively higher level of 28.4% in 2031-32 and 36.9% in 2041-42 in comparison with the BAU scenario. Given these breakups, what are the overall implications of the projection of such gross generation requirement of power in terms of requirement of capacity of different technology based plants and the related financial resource requirement to create such capacities on the one hand and in terms of CO_2 emission implications on the other? The results of projection indicate the relative physical benefit and financial cost of CO_2 emission reductions in Table 5 based on the CO_2 emission coefficients for the different generation technologies presented in Table 4. These coefficients have been assumed for the current emission to be as per CEA norm and that for the life-cycle emission to be as per IPCC norms for the generation technologies. Table 5 presents the total current CO_2 emissions for the different terminal years under the two scenarios of projection and the same for a total life cycle emission for the same terminal years and the same being represented in Figure 1.

Table 4. CO_2 emission coefficient (current and lifecycle)

Fuels	**Current**	**Lifecycle**
Coal	1.04	0.820
Gas	0.60	0.490
Nuclear	0	0.012
hydro storage	0	0.024
Solar PV	0	0.048
Solar CSP	0	0.048
Distributed Solar PV	0	0.048
Total Solar	0	0.048
Onshore Wind	0	0.012
Offshore Wind	0	0.012
Total Wind	0	0.012
Other Renewables	0	0.230

Source : Compiled from the World Bank Database

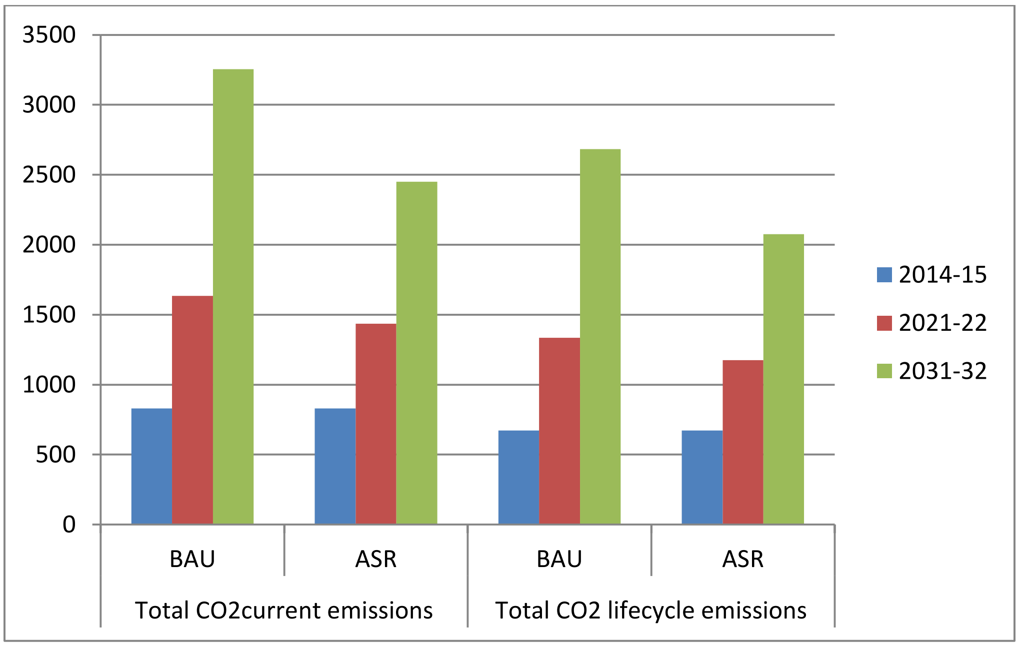
Table 5. Total CO_2 current and lifecycle emissions in million tonnes

Time Period	**Total CO_2 current emissions**		**Total CO_2 lifecycle emissions**	
	BAU	ASR	BAU	ASR
2014-15	829.711	829.711	671.984	671.984

2021-22	1633.812	1434.262	1334.493	1175.972
2031-32	3254.016	2450.959	2682.772	2075.592

Source : Author's own estimates

Figure 1. Total CO_2 current and lifecycle emissions in million tonnes



5. Financing out of Resource Rent based Climate Fund : Mapping it with CO_2 Emissions

The results in Table 3 show that temporally India can definitely switch over from the fossil fuel based sources to the new renewable based ones (as reported) of electricity generation. However, as mentioned in the outset, in the Indian context, fossil fuels are not a substitute for new renewables but rather the fuel mix has to be designed optimally so as to ensure that the transition from fossil fuel based regimes to the new renewables one happens smoothly consistent with the CO_2 emisions as reported in Table 5.

For any given generation scenario of our projection, the requirement of installed capacity would depend on the capacity utilisation factors (as reported in Table 6), which would vary across energy resources and technologies. The capacity utilisation factor further varies widely for the new renewables because of the uncertain time distribution of availability of energy resources vis-à-vis that of load demand. These capacity utilization factors of the different technologies are reported in Table 6 and the same set of values of such utilisation factors have been used for the purpose of projection of the installed capacity requirement for the different scenarios in the different terminal years.

Table 6. Capacity Factor, Investment and Generation cost

Technologies	**(1) Capacity utilization factor**	**(2) Capital Cost INR/MW 2016-17 prices**	**Capital Cost in US$ million/MW 2016-17**	**Unit cost of Generation Rs./KWh**	**Unit cost of Generation US cents/KWh**
Coal*	0.80	8.00	1.23	4	6.15
Gas	0.70	3.53	0.54	4.36	6.71
Oil	0.70	-	-	-	-
Hydro	0.20	10	1.54	5.51	8.47
Nuclear	0.60	8.8	1.36	2.35	3.62
Solar PV	0.20	5.3	0.82	2.44	3.75
All Solar	0.20	5.3	0.82	2.44	3.75
Wind	0.25	4.1	0.63	3.46	5.32
Other renewables	0.60	5.45	0.84	5.19	7.99
Small hydro, ocean, geothermal	0.20	5.45	0.84	5.19	7.99
The data in Table 8 has been derived after taking into account Column 1 and Column 2 of Table 6.					
*For super critical boiler the capital cost would be INR 15.7 crore per MW or US$ 2.42 Million$ per MW *Source :* Compiled from interviews of CEA personnel along with NITI Aayog's Draft Report of National Energy Policy (2017)					

These are reported for the for the new renewables based subsystem of generation in Table 7. The implications of these capacity projections in respect of financial resource requirements for the build up of the capacity over the different time horizons like 2012 to 2022, 2012 to 2032 have been presented in Table 8 in the units of INR Billion.

Table 7. Capacity Requirements of New Renewables and Wind & Solar (MW)

Time Period	Capacity Requirements _new renewables (MW)		Capacity Requirements _total (MW)	
	BAU	**ASR**	**BAU**	**ASR**
2011-12	9016.47	9016.47	254847.02	254847.03
2021-22	20817.98	21132.91	532187.07	628107.33
2031-32	49659.37	54487.01	1538749.69	1476761.07

Source : Author's calculations

Table 8. Requirement of funds for total capacity building (INR Billion)[4]

Time Period	Cumulative requirement of funds for capacity building (INR Billion)[3] given the capital cost per MW in million US$ in table 6	
	BAU	**ASR**
2011-12 to 2012-22	7087.796	6429.161
2011-12 to 2031-32	22320.449	24759.739

Source : Author's calculations

We want to make it however, clear that 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 under reasonable conditions in view of particularly the very high potential of abiotic new renewables resources that exist as indicated in the above sections consistent with the reduction in carbon emissions intensity. Besides our cost projections of the different scenarios include the share of investment for the purpose of energy conservation, which is definitely having a policy forcing in respect of energy efficiency improvement in our present model of power development. The financial burden of such energy conservation investment is

[3] The cost of using the different technologies like coal, hydel, solar, wind, etc. is taken as Rs. crore per MW of power at 2016-17 prices have been considered from NITI Aayog's Energy Policy Draft (2017).

however to be borne by the consumer sectors as the benefit of such investment would accrue to them[4].

Moving on to the estimation of resource rents, there exists a coal cess today imposed by the Government of India currently at the rate of Rs.400/- per tonne. This was originally introduced in 2010 at the rate of Rs.50/- per tonne and later enhanced in 2016 to the level of Rs.400/- per tonne. This was imposed as a carbon tax on the production and importation of coal, lignite and peat whose proceeds were to flow to National Clean Energy and Environment Fund. This was supposed to be a non-lapsable fund, the unutilised portion of the cess revenue being transferable to the following year in the same fund for utilization (Rajan, 2017). This will be routed through the Consolidated Fund of India but earmarked for clean energy development initiative. The fund is supposed to be utilised for financing research and innovative development projects in clean energy technologies. The cess had thus dual objective of penalising production and import of coal and its variants and encourage a shift towards renewables. Since this is thus supposed to serve the purpose of resource rent which we propose to be imposed as a resource rent tax to be mobilized for financing clean energy development, we give our observations and comments on the adequacy of this cess and discuss in that context the required rate and form of resource taxation required for the development of new renewables based green power as envisaged in the era of the Third Industrial Revolution.

However, after the introduction of GST (Goods and Services Tax) in India, a GST cess was introduced on some luxury or demerit goods for compensating revenue loss of states which suffer from the shift to GST from the earlier tax regime. The coal cess was abolished when this new GST cess was introduced and was supposed to be subsumed by it. This was followed by a transfer of the accumulated fund of the unutilised coal cess to the Consolidated Fund of India out of which most of the government expenditure are made. Although the fund of coal cess is supposed to be made available for the purpose for which it is set up, the actual historical record of fund utilisation for

[4]Energy conservation in any year being taken to be the saving in any sector or year as indicated by the comparison of final energy consumption between Business As Usual and Higher Efficiency in use for the same GDP. We take the projection of this to be the same as in NITI AYOG (2017) in the process of estimating the energy demand in the appendix coming from sectors like — building, industry, transport, pumps, telecom, cooking, etc..

this cess has been very poor. First of all, only a mere 37% of the total coal cess collected has been transferred to the National Clean Energy and Environment Fund. Out of this 81% has been used for financing projects for clean energy development. It is thus only a share of 30% of coal cess has been applied for the purpose for which it has been meant.

It is really an issue if the Government of India is serious about using coal cess fund for the objective of developing new technologies for clean energy. This is particularly important as the coal cess has been now subsumed under the GST cess and there has been siphoning of the unused money of the National Clean Energy and Environment Fund to fund GST compensation to industrially advanced states of the past to placate their disgruntlement over loss of revenue due to the regional redistributive impact of GST reform. Such diversion of use of fund of coal cess is surely immoral if not illegal.

However, one may raise the issue if the current coal cess of Rs.400/- per tonne is adequate as an eco-tax either for the purpose of internalising the environmental external cost of use of coal in the context of power sectors' use. Such coal cess would imply hike in the cost of power only by INR 0.30 in 2011-12 which will come down to Rs.0.26 in 2021-22 and Rs.0.23 in 2031-32 due to improvement in thermal power's generation efficiency as per our model. Table 9 shows, on the other hand, how coal cess at the rate of Rs.400/- per tonne would generate cumulative revenue of INR Billion 3094 for the time horizon up to 2021-22 and 8322 up to 2031-32, assuming a linear phasing of growth of cess revenue over time between the terminal years of any decade according to the baseline BAU. When these are compared with the requirement of financial resources for the cumulative generation capacity build up from the same base year 2011-12 as projected for the same scenario we find the cumulative coal cess revenue will meet only 43.66% of the capital requirement of creation of generation capacity in new renewables based power up to 2021-22, such coverage declining to 37.29% in 2031-32 and to 22.53% in 2041-42 (for the year 20141-42 we have not reported the data in details). For ASR, the level of adequacy of cess revenue is even lower for the different time horizons as compared to the one of BAU scenario in line with the emissions intensity (see Table 9).

Table 9. Coal Cess Revenue @ INR 400.00 per tonne of coal and its Adequacy

BAU. Business As Usual Scenario wrt energy efficiency and fuel mix					
Period	Coal Cess Revenue (Current) INRBilln.	Cumulative cess revenue from base year 2011-12(INR billion)	Cum.Cap. Resource Required up to the current year from 2011-12 (INR Billn.)	Cess Finance Avail in % that can be met at @ INR 400.00 per tonne of coal	Carbon Emissions Intensity of GDP, unit fall
2011-12	216.268	216.268	-		
2021-22	402.636	3094.520	7087.796	43.660	↓0.24
2031-32	723.452	8322.322	22320.449	37.286	↓0.32
ASR. High energy eff. Cum Accld. Intro. Of New Renewables					
Period	Coal Cess Revenue (Current) INR Billn.	Cumulative cess revenue from base year 2011-12 (INR billion)	Cum.Cap. Resource Required up to the current year from 2011-12 (INR Billn.)	Cess Finance Avail in % that can be met at @ INR 400.00 per tonne of coal	Carbon Emissions Intensity of GDP
2011-12	216.268	216.268	-		
2021-22	349.605	2829.364	6429.161	44.008	↓0.21
2031-32	540.507	6930.319	24759.739	27.990	↓0.40

Source : Author's own estimates

One may however argue that the existing coal cess was imposed with the limited objective of capital financing for only development of new technology and innovations possibly through R & D, and not for financing the building up of the entire new generative capacity embodying the new technologies. Besides the adequacy of resource rent as shown in Table 9 is not considering the transmission and distribution investment requirement for setting up new capacities in the new renewables and also resource rents extracted through gas. So bringing in gas might raise the coverage to a certain extent but will not cover the entire fund requirement. The focus here is on the importance of complementarity of fossil fuel based power and the backstop technology (new renewables) based power from the view point of meeting the challenge of financing the new technology development in power industry. India's emission intensity has reduced by 21% over the period 2005-2014 while total emissions continue to grow. Therefore, a review of our carbon intensity projections suggests that India's emission intensity reduction by 2030 is likely to be in the range of 32% - 40% below 2005 levels but adequacy of resource rent remains a challenge.

6. Challenges of Generation and Transmission of Power in the era of Renewables based Power

What would then be further required to introduce a big bang change in fuel policy for generating electricity by making a structural shift in technology in favor of new renewable resources?

Large Solar and Wind capacities need to be created for faster transformation of the India's fossil fuel based electricity industry into a green one. The development of new renewables would require large-scale availability of financial resources as is shown in Table 9. The financial requirements of energy conservation as envisaged for the concerned scenarios have also to be made available from the financial system to the industries at large to make the idea realizable.

In the area of research and development (R & D) for technology development, there is required a policy thrust in favor of development of CSP and off - shore wind energy development in the Indian context. India needs to accelerate her manufacturing capacity of equipment of new renewable based technologies and also provide high priority to human resource development for the new RE (renewable energy) industry through wider introduction of new renewables technology education as these are of crucial importance to make the potential of renewable energy (RE) capacity of India to be realizable.

The major challenge that arises from the abiotic renewables based power development is that both the power output as well as the energy resources like wind or solar irradiation are non-storable unlike the fossil fuels. In the conventional power system the demand for power fluctuates, but the fossil fuel resources like coal, natural gas, water in large hydro storage, or nuclear fuel are all storable and can be drawn upon as and when load of generation is to be raised at any point of time. In view of the intermittent nature of supply of wind or solar radiation due to varying wind speed or varying radiation depending on cloud or time of the day effect, the availability of these resources vary over both spatially and temporally.

In the interest of sustainability of power supply what needs to be targeted is to maximise the mobilisation and conversion of the resources like wind or solar irradiation whenever they are available into electric power and at the same time match the demand and supply of power along the network of the power grid serving the various load centres by dispatching power from the generation sources – both conventional and new renewables based ones. This challenge can be met in one of these following ways :

i. Storage devices :

(a) Storage of power when solar or wind power is available abundantly, for use at other time by storing it in a Battery Storage system. Some project is already being implemented in Puducherry, India where experiments are going on with alternative Battery technologies.

(b) Pump storage of hydro resources for storing water during off-peak hours using availability of solar or wind power, and using them for driving turbine releasing the pumped water during peak hours.

ii. Flexible Operation and balancing power needs :

This involves flexibility of load generation in a power plant with the aid of power electronics which can ensure automated control of production and supply of power. By technical change in power electronics the operation of a base load curve with such flexibility of load generation, thermal coal or gas based plant can be made flexible by ramping up or down the rate of load generation. The use of fossil fuel or nuclear or storage hydro resources and those new renewable resources can be complementary in power generation for meeting a load curve. In a situation of flexible plant operation, the system operator can ramp up generation by using the wind and solar radiations in their hours of availability and ramp down the rate of load generation by the other conventional plants. Similarly, in hours of non-availability of such new renewables, the operation of load generation rate in the conventional thermal or hydel plants can be ramped up to ensure meeting of the total load demand of the system. This would in fact minimise the fossil fuel use, but at the same time utilise the best wind or solar resources whenever they are available and control also the externalities of CO_2 emissions. This of course, requires comprehensive R & D work on technology alteration for making plants flexible by raising their ramp rate up or down with minimum damage to the plant life. The ramp rate is the rate at which the load generation as a percentage of capacity generation can be raised per unit of time. For a ramp rate of 5% of capacity per minute, the plant will take 20 minutes to reach the full capacity load generation which is an index of flexibility of operation. For a base load plant like coal thermal it is likely to remain low even after making R & D efforts to bring in flexibility. One of the real resource costs of such flexibility of operation may be the reduction of plant life because of higher rate of wear and tear due to such flexibility.

In India R & D activities are trying to promote flexibility of operation of plant with minimum damage impact on the available equipments and machineries for all the conventional power generation technologies. Besides, quite a large number of pump storage projects have been undertaken in different regions. For better utilisation of RE based power, economic incentives in the form of low or higher power tariff are to be introduced in the hours of high or low availability of RE based power, besides the investment in pumped storage development for better utilisation of the stranded gas based power plants in India for which there was over investment relative to the actual availability of gas at some time in the past due to wrong market signals. There remains also the possibility of setting up some new green field gas based plants for balancing the power need in times of low availability of RE power relative to demand.

Besides, it has to be noted that grid balancing requirement for meeting the high demand for power intensive industries like steel, aluminium, cement, paper, railway traction, etc. would in any case require some firm supply from large point sources of hydro power and natural gas which may only be supplemented by supply sources of new renewables based power which is intermittent in nature. The challenge of balancing load demand and supply is not also just a matter of resolving temporal mismatch of demand-supply, but also a matter spatial balancing of the same due to divergence between spatial distribution of load demand and that of supply of RE resources. All these require both grid scale storage and up-gradation of transmission and distribution system.

The up-gradation of the power grid for T & D into a smart grid is a pre-requisite for efficient utilisation of RE resources when introduced as grid connected. Such up-gradation into smart grid would essentially mean automated co-ordination for smooth two way flow of electricity and information regarding power demand and capacity of all kinds of power – both conventional and new renewables one. This is important for

(i) avoiding congestion while evacuating power from a large number of sources of renewables based generation.

(ii) the relevant co-ordination of activities of the power sector across regions and state boundaries in the context of transmission of power and load dispatches from the various nodal junctions.

Smart grid in fact represents an efficient and reliable power system with diverse energy resources for meeting fluctuating load demand, both supply and demand for load being independently given over space and time. The system includes a variety of operational and energy measures like introduction of smart meters and smart appliances for measurement and communication of demand and supply of load. It is essentially a system of electronic power conditioning, by automated control of production and despatch of power generated from various sources for supply to a wide range of load centres.

Such grid would, in India, require strengthening of the information system for energy for every 15 minutes if not, minute by minute power demand and availability of power capacity and basic RE resources. While the existing power system is quite geared to making load forecasting and managing supply accordingly, the forecasting of supply from fluctuating and uncertain sources of wind and solar energy poses challenge on demand-supply management.

The up-gradation of information system for efficient ways of electrical energy production and the sharing of power generated using renewable energy resources requires use of Telemetry, which is nothing but automated communications process by which measurements and other data are collected from remote or inaccessible points of locations and transmitted to receiving equipment for monitoring. A telemeter is in fact a physical device used to remotely measure any quantity. It consists of a sensor, a transmission path which may be wireless or hard wired, and finally a display, recording and control device. Government of India is setting up a National Optical Fibre Network – Bharat Net which would provide connectivity to 2.5 lakh Gram Panchayats which are spread over 6600 Blocks and 641 districts of the country, for facilitating data transmission regarding power load demand, renewable energy resources and power availability at all the nodes of the power network (NITI AAYOG, 2017). In fact, the objective is that all renewables based generated power plants should be connected with the optical fibre network which can ensure their transmission of real time data regarding generation and availability to the system operator. Such facilities of data can ensure two-way flow of information and power and upgrade India's power grid in different regions into smart grids. The latter would in turn enable the integration of a range of new renewable resources into our energy system which would contribute to sustainable development of the Indian economy by providing energy security, universal access of people of India to electricity and finally abatement of CO_2 emission which accompanies economic growth.

However, all these would involve extensive use of power electronic devices for smooth and reliable operation when the system integrates a range of alternative RE resources. A lot of work in the area is being done by the POWER GRID of India. Besides, the rolling out of smart grid technology has in fact essentially meant a fundamental re-engineering of the electricity servicing industry. Ministry of Power of the Government of India has allocated 14 smart grid pilot projects to be implemented by the various state owned distribution utilities in India.

It has to be further noted here that while we consider the balancing of power need and power supply from alternative sources – particularly renewables on the basis of the telemetric data capacity we need to meet such balancing not only on state level, but also on national level, if not including possibly some of the neighbouring countries. This issue becomes important because some of the renewable resource rich states may not have high power demand, while at a wider regional/national level these locally surplus resources can be best utilised by investing in long distance transmission arrangement of such power for its evacuation. The government is investing in the development of green corridors in RE rich states to evacuate power from solar parks or wind parks where particularly there is no pre-existing regular grid connectivity. These corridors are meant for transmitting the power from such RE based power plants and connect them to the main power grid. However, such investment cost should partly be socialised for power supply by pooling financial resources from the Central Government while rendering benefit due to some externalities of advantages to all the stake holder states. The government of course should weigh the cost-benefit of such corridor development vis-à-vis the option of off-grid power development with storage facilities near RE generator pooling station.

However, the efficiency of operation of such a power system involving the use of diverse RE technologies, would depend on the choice of models for forecasting on the supply side. There are not only problems of uncertainty but also of accuracy in the prediction of the new supply side variables. The larger the area of such forecasts and shorter the time horizon (gate closure time), the higher is generally the accuracy of forecasts.

Besides, one major issue in this context would be the cost effectiveness of the transition to the new industrial order through the technological and socio economic transformation. As new renewables based technologies would be knowledge intensive and as the patented knowledge market is highly imperfect and monopolistic, the capital cost may become finally quite high, standing in the way of cost effectiveness and the distribution 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 becomes important for both the sharing of benefit of the new industrial revolution between the rich and the poor and between the developed and the developing countries.

International co-operation among the member UNFCC 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 characterised by the new order. 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. The financial cooperation through UN Climate Fund at global, regional or national level would be such an arrangement which can be catalytic for such required cooperation.

7. Conclusion

The projections of investment requirement as presented above for the build up of renewables based power system capacity should not as such pose any big constraint in these days of globalization when global capital is crossing national boundaries with much greater ease. India plans to achieve 175 GW of renewable energy by 2022 through 100 GW of solar, 60 GW of wind, 5 GW of small hydro, and around 10 GW of biomass-based power consistent with our projections in Table 2 and 3. At 82.5 GW of installed renewable capacity as of September 2019, India is nearly halfway to meeting its 2022 target (Joshi, 2019). The recent 450 GW of renewable energy capacity, likely by 2030, signals a huge ambitious increase. It is over five times of India's current renewable capacity

(82.5 GW at present) and more than India's total installed electricity capacity from all sources (362 GW). Hon'ble Prime Minister of India's announcement is also consistent[5] with our results on the predictive targets of use of new renewables and carbon emissions intensity target[6].

However, India's renewable energy market has slowed this year. Challenges — import duties on solar panels, land availability issues, slow development of electricity evacuation infrastructure, uncertainty of power purchase agreements, and artificially low ceilings on solar tenders — are dampening market progress. The national government is working with stakeholders to get the market back on track. Currently, around 31.1 GW of renewable capacity is under various stages of construction, and another 39 GW likely to be constructed by 2021 is in the biding stage. Based on these projects, it is likely that India's 175 GW by 2022 may get extended amid the pandemic. But the real challenge would however arise in attracting entrepreneurship and fund in particular choice option of generation technology due to low credit rating of many of such projects in India at least to begin with. Such rating may be affected not only by the risk involved due to technology and business environment of the project, but also by the macroeconomic and country level policies in the context of attracting foreign capital. The alternative, as discussed, is resource rent extraction. There are studies in the literature which consider roughly 20 % of the oil linked price of coal or gas to be the resource rent component of the fuel price. But the question is that, is this enough? The problem is what should be the per cent of resource rent to be extracted. While the amount of rent extracted and the funds required for capacity build up need not balance, their comparison would tell us if and to what extent such resource rent can provide adequate finance for the capacity build up based on the new renewables over the same time horizons of planning in line with the carbon emissions intensity of GDP target of 33-35% in 2030. However, to overcome such constraints, if at all, it may be important to develop new initiatives for alternative sources of finance like, regional infrastructural banks, multilateral banks, and climate funds like the one proposed here besides the illustrative climate fund as proposed here.

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[5] https://www.thehindu.com/sci-tech/energy-and-environment/prime-minister-narendra-modi-addresses-the-un-climate-summit-in-new-york/article29492091.ece

[6] https://www.livemint.com/Politics/ZD2z2vwZktGNlzhrLujmyO/India-unveils-emission-targets-for-2030-in-UN-climate-submis.html
https://www.nrdc.org/experts/sameer-kwatra/india-announces-stronger-climate-action

All these measures for greening India's electricity industry would require substantive effort and financial resources in R & D activities and human resource development. However, the fuel substitution of fossil fuels by new renewables which is the driving force of the third industrial revolution is to be viewed not as a short term objective, but as a long term one to be achieved by way of conversion of the resources rent of the extracted fossil fuels into capital assets as emphasized in the earlier section, created for the development of knowledge, human resources, and infrastructural capital along with new kinds of plant and equipment which serve as the vehicle of technical progress ushering in a rise in the share of new renewables in the optimal fuel mix. Since the developing countries are very often constrained by their financial capability and resources of technology, global cooperation is essential for the required technology transfer and investment flows across boundaries of nations to bring about the basic transformation of the global energy system at the least cost of transition and structural adjustment.

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Annexure : The Model

For applying the Engel and Granger (1987) methodology of cointegration under single equation specification, we consider the following model,

$$\log(\Delta ED_i) = \beta log(\Delta GDP_i) + \gamma \log(\Delta REP_i) + \epsilon \ \ldots\ldots (1)$$

where, *i* represents different sectors - industry, agriculture, residential, transport and commercial. ΔED_i is the change in the energy demand of the i^{th} sector, integrated of order 1. ΔGDP_i is the change in GDP of the i^{th} sector, integrated of order 1. ΔREP_i is the change real energy price faced by the i^{th} sector, integrated of order 1. For characterizing the energy price determination process, let, REP_t denotes the energy price at time period *t* and the price formation function takes the form of a standard Geometric Wiener stochastic process, W_t with a drift μ and infinitesimal variance, σ[7].

$REP(t) = REP(0)e^{\left(\mu+\frac{\sigma^2}{2}\right)t+\sigma[W(t)]}$ where,

$\mu = \frac{1}{n}\sum_i \left(\frac{REP_{i+1}-REP_i}{REP_i}\right)$ and $\sigma = \sqrt{\frac{1}{n-1}\sum_i \left(\frac{REP_{i+1}-REP_i}{REP_i} - \overline{\left[\frac{REP_{i+1}-REP_i}{REP_i}\right]}\right)^2}$

have been drawn out of a normal distribution process. The model is estimated using data from 1990-2015 from the Energy Balances of the non-OECD countries published by International Energy Agency (IEA) GDP, PFCE (private final consumption expenditure is used as proxy for GDP under residential sector) and WPI are obtained from the National Account Statistics and Handbook of Statistics on the Indian Economy.

[7] See https://galton.uchicago.edu/~lalley/Courses/313/BrownianMotionCurrent.pdf

The cointegration results deriving the long run elasticity coefficients of sectoral energy demand and real energy price of different sectors have been reported in Table A1.

Table A1. Long run elasticity coefficients results

Variables (logarithm)	**Elasticity Coefficients**	**Probability**
Dep Var : Δ (INDUSTRY_Energy demand)		
Δ (INDUSTRY_GDP)	0.83	0.00*
INDUSTRY_Real Energy Price	0.03	0.00*
Dep Var : Δ (AGRICULTURE_Energy demand)		
Δ (AGRICULTURE_GDP)	0.75	0.00*
AGRICULTURE_Real Energy Price	0.12	0.06
Dep Var : Δ (RESIDENTIAL_Energy demand)		
Δ (RESIDENTIAL_GDP)	0.72	0.00*
RESIDENTIAL_Real Energy Price	-0.02	0.00*
Dep Var : Δ (COMMERCIAL_Energy demand)		
Δ (COMMERCIAL_GDP)	0.62	0.00*
COMMERCIAL_Real Energy Price	-0.38	0.00*
Dep Var : Δ (TRANSPORT_Energy demand)		
Δ (TRANSPORT_GDP)	0.88	0.00*
TRANSPORT_Real Energy Price	-0.08	0.00*

* denotes significance at 95 per cent level

In order to project the final energy demand at the original level, we make use of the following derivation from (1),

$$\log(\Delta ED_t) - \log(\Delta ED_0) = \beta[\log(\Delta GDP_t) - \log(\Delta GDP_0)] + \gamma[\log(\Delta REP_t) - \log(\Delta REP_0)]$$

$$\Delta ED_t = \left(\frac{\Delta GDP_t}{\Delta GDP_0}\right)^{\beta} \times \left(\frac{\Delta REP_t}{\Delta REP_0}\right)^{\gamma} \times \Delta ED_0 \ ; \ t = 2015, 2016, \dots\dots, 2041 \dots\dots (3)$$

Now, projecting the energy demand at 2021, we calculate (3) for t = 2015, 2016, 2017, 2018, 2019, 2020, 2021 and then add up these to get the total change from 2014 – 2021 and finally add it up with the base year value of 2014 to derive the final energy demand in the concerned year. Similarly, we do it for 2031.