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Differential Carbon Footprint in India – An Economic Perspective

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Abstract: It is a matter of apprehension that wealthy countries are contributing huge to global emission and more responsible for producing greenhouse gases in the atmosphere. There is direct intervention of economic activities like industrialization, urbanization and infrastructure development over carbon footprint across the world and economically developed nations tend to have higher footprints as compared to less developed countries. India, the second largest populous nation is facing dual challenges, one hand, the need to fulfill the energy requirement for development and on the other hand, the global climate challenge. The country is third largest emitter of CO_2 and fifth largest economy by nominal GDP in the world. But its per capita emission is much lower than that of developed countries and even it is below the average per capita emission of many developing countries. The present paper is an attempt to map the carbon footprints across the country in respect to the economic status. The paper reveals that there exist huge disparities of economic resources and developmental activities, and based on these the carbon footprint is also varied widely. The footprint is significantly high in developed and urbanized states across the country. Economically developed western and southern part emits more than the underdeveloped region of Bihar, Uttar Pradesh, Jharkhand and Odisha. A correlation has been drawn to map the carbon footprint per capita in respect to poverty ratio and a negative relationship exists among most of the districts, as higher carbon footprint has been reported in the lower poverty stricken districts. The overall low per-capita carbon footprint of the country is due to its huge population is living with nominal amount of energy. The fossil fuel is the major source of energy in the country and for equitable economic development, the huge energy is needed. Hence, to meet the global climate challenge, the country can accomplish the energy requirement by reducing emission of conventional sources and look forward for renewable energy resources, so that the development should not be hindered.

Keywords: *Carbon footprint, Climate challenge, GSDP, Per capita emission, Poverty ratio, Urbanization*

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1. Introduction

There is a long debate between economic development and environmental conservation across the world. Economic development of a country is evident preference and developmental activities, particularly development of physical infrastructure affects environment adversely. As priority, the development certainly comes first to meet the basic requirement of people and infrastructural prospects of a country, whereas environmental conservation and sustainability issues are not treated as equal importance.

The economic progress achieved in the past few decades, along with a rapid population explosion, has come with a huge environmental cost across the globe. As per the United Nations Conference on Trade and Development (UNCTAD) the global GDP per capita has nearly tripled since 1960, the CO_2 emissions have quadrupled during the same period. The world's top three emitters (China, United States, and India) account for more than 50%, and the world's top 10 emitters account for 70% of global CO_2 emissions (Crippa et al., 2020). However, instead of total emissions, per capita emissions of countries reveal an important perspective on the global CO_2 challenge. As it shows that the developed countries along with some high-income oil-producing developing countries having higher emissions per capita (Mott et al., 2021). Climate change is inextricably linked to economic inequality as the poorest half of the global population are responsible for only 10% of total global emissions attributed to individual consumption, yet live overwhelmingly in the most vulnerable countries (Gore, 2015). Though, some emerging economies like China, India, Brazil and South Africa have high and rapidly rising emissions, but their richest citizens remain some way behind that of their counterparts of developed countries.

Environmentalist generally find the cause and consequence of environmental hazards, degradation, impact assessment of new developmental projects on natural resources and conflict of human intervention with nature. Often they measure the state of environment by different indices like environmental performance index (EPI), environmental sustainability index (ESI), vulnerability index (VI), etc. While economist measure the country's wealth and productivity as aggregation measures like gross domestic product (GDP), gross national product (GNP), gross national income (GNI) or relative income measure (like per capita income) as development indices. But economic and infrastructure development cannot be achieved without hampering the environment of a country or region and this should be assessed and acknowledged. This is not only required for economic development of the country but also for preparing country's developmental roadmap by minimizing environmental degradation. The focus should be on achieving economic development with sustaining environment. The present paper is an attempt to study the differential carbon footprint generated by developmental activities across the region/states of the country. The impact of footprint on the socio-economic status of the state is varied widely, which is mainly due to infrastructure development and urbanization.

The carbon emission threatens the environment universally. But its resilience impact and distress is how much location specific is needed to be studied. It is a general trend across the world that the per-capita carbon footprint is higher in comparatively rich/economically developed countries (Oo, & Thin, 2022). Though India a low per-capita income country, the per-capita emission is also low, but during last few decades the footprint has increased significantly. The economic perspective of this increase has been assessed, whether economically developed regions has more share for these footprint? Or environmentally sustainable states have the more resources to combat emission in the long run. The economic perception of carbon footprint with the level of poverty across the districts of the country is also assessed to find out any possible correlation among them. The objective of present study is to assess the carbon footprint across the state/regions of the country and indicate whether the distribution is skewed to some regions of the country or evenly scattered across the states. The intention of the study is to depict the distribution of economic resources along with carbon footprint of the country and not to comments on cause and consequences of carbon footprint due to developmental activities.

Carbon footprint is the total greenhouse gas (GHG) emissions and is calculated by summing the emissions from every stage of a product/process or service's lifetime by individual or institutional events. The major source of emission are household emission, industrial emission, transportation & food and emitted GHGs include carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), and nitrous oxide (N_2O) etc. The emission of GHGs trends to trap heat in the atmosphere, while carbon sequestration is the long-term storage of carbon through artificial or biological methods, which is treated as an option to reduce carbon emissions. The goal of both, the carbon capture and the carbon sequestration is to mitigate climate change by reducing GHGs emission globally.

Carbon neutrality or 'net zero' means not adding new emissions and continued emissions will be balanced by absorbing an equivalent amount from the atmosphere. The 'net zero' is a proposed climate action of United Nation (UN) which is aimed at cutting GHGs emission to as close to zero as possible, with any remaining emissions re-absorbed from the atmosphere (by oceans and forests for instance). As per the UN Climate Change Conference (at Paris in 2015) a large number of countries are making commitments to achieve carbon neutrality, or 'net zero' emissions within the next few decades. However, the wealthy countries are continuing to contribute more per capita to global emissions and more responsible for producing GHGs in the atmosphere (Ritchie, 2019; ECCC, 2022; Gumel, 2022). So, the cutting the emissions of these countries will be more significant for the world to achieve the net zero target.

India is the fifth-largest economy by nominal GDP and one of fastest growing economy in the world (IMF, 2022). It shares more than 17% of world population and home of about one forth of global poor. It is the third largest emitter of CO_2 and contributes about 7% of global emission (EDGAR, 2022). Though the per capita CO_2 emission of India has grown 2.7 times in last 3 decades but still its emission is much lower than the global average (4.8T per capita/year). The scope of present article is to compile, quantify and assess the emission and regional distribution of carbon storage & emission in the country. Economic parameters like state-wise GSDP, poverty index has been considered to relate the emission with these parameters. However the paper does not to comment on cause and consequences of carbon footprint across the states of the country to meet the global climate challenge. State/union territory (UT) wise distribution of projected population, urbanization, populous (million plus) polluted cities, carbon emission and level of poverty have also been compiled. An attempt has been made to show the distribution of carbon footprint of Indian districts in respect to the poverty ratio, whether the differential carbon footprint in India is merely based on location or there is a role of economic activities behind its uneven distribution.

Though the effect of climate change realizes globally, but the contributing factors affecting climate and environmental degradation are not equally distributed across the world. Several studies have revealed that climate variability is inextricably linked to economic inequality. As per the OXFAM report (2015), it is a crisis that is driven by GHGs emission of the 'haves' (economically privileged) that hits the 'have-nots' (economically deprived) the hardest. The lifestyle consumption emissions of citizens of these countries are far lower than those of their counterparts in the rich OECD countries (Gore, 2015). South Asia and Sub-

Saharan Africa, the two regions together account for 85% of world poor and about half of the extreme poor of global population live in the country like India, Nigeria, Congo, Ethiopia & Bangladesh and also happen to be most populous countries of the region. India alone is the home of 24% of global poor (Roy and Wadhwa, 2019) and more than 35% of people is remain poor in four populous states of the country (NITI Aayog, 2021).

Poorest people are the most vulnerable for the adversity of climate change and less responsible for the GHGs emission across the countries. Though, there is a difference in average lifestyle consumption footprint among countries, and the emission varies widely among different segment of society and also among regions of a country. Individual consumption is responsible for lion share of global emissions followed by government consumptions in investments (in infrastructure sector) and all means of transport. A recent World Bank study found that poor people are more exposed to droughts, floods, heat waves and other climate related hazards across the world. In India more than 150 districts are vulnerable to agricultural drought and more than 55 districts are exposed to high flood prone, cyclone and coastal flooding (Nandy, 2021). The preparedness to cope with these adverse climatic calamities is not uniform among states/regions of the country. Several studies indicate that the poorest people are most vulnerable to the consequences climate change, as the struggle of surviving is the obvious priority for them (Oxfam, 2022; Chancel, 2021). These people live in hand to mouth and not equally prepared to cope of adversity of natural calamities. Such un-equal risks of adversity to the inhabitant is horizontal as well as vertical; based on gender, inhabitation, social groups, ethnicity etc. For example woman facing greater risks than men, rural communities often more exposed to natural calamities than the urban ones and marginalized groups due to race, ethnicity and sects are disproportionately affected (Bhadra, 2017;Yavinsky, 2012)

Misra (2019) has carried out a study for the long term relationship between economic growth and carbon emission in India during the period 1970 to 2012. The study compared emission and GDP growth of India with other large emitting countries like USA, European Union (EU) and China. The results reveal that there exists a unidirectional causality from energy consumption and GDP to carbon emissions. The study has also finds that there exists a long run relationship between these variables whereas in the short run, there is no relationship between the variables. The finding implies that any attempt to reduce carbon emissions without bringing the energy efficiency will adversely affect the economic growth of the country. State-wise analysis of carbon storage and emission has been carried on by Ramachandra and Shwetmala (2012) and estimated about 1000 Tg of CO2, CO and CH4 emission per year. And 7.35% of total carbon emissions get stored either in forest biomass or soil in India. The analysis has shown Maharashtra, the highest emitter of CO_2 followed by Andhra Pradesh, Uttar Pradesh, Gujarat, Tamil Nadu and West Bengal while its storage mainly concentrated to Arunachal Pradesh, Madhya Pradesh, Chhattisgarh and Odisha.

To achieve the climate target by near future, India needs to chart its development plan rooted in green initiatives. As per the World Bank report India is the home of world largest poor population and also rank bottom line (101 out 116 enumerated nations) of global hunger index (2021). In 2020 iteration of human development index (HDI), India ranks 131 amongst 189 nations with HDI scores of 0.645 implying medium level of human development. This puts immense pressure on developing nation like India by compelling them to confront the trade-off between development and environment. Several studies indicate a direct relationship between human development and CO_2 emission among countries, as development of physical infrastructure affect the environment adversely. This relative inelastic response of HDI implies a large cost in terms of CO_2 emission, for a small increase in the human development quotient (D'Souza, 2021). However, such relative proportional measure of HDI has limited implication and also depends on various factors, such as the energy use activities for human development is lower; limited focus on primary health and education sector etc. Also, heavy reliance on coal has a negative impact on human development, as coal-linked emission causes several health hazards.

There are apparent research gaps between environmental studies and its economic impacts. Scatter evidences are there, but there exist a noticeably knowledge gap between economic impact on environmental degradation. Though several studies have been carried out on carbon footprints across the world but economic aspects of it have not been clarified exclusively. So there is need of further studies on economic impact of carbon footprint spatially. This will not only meet the information gap but also support the decision/policy makers for location specific environmental friendly sustainable economic development.

2. Materials and methods

The present study is based on (or derived from) secondary sources collected from Census of Inda, United Nation (UN) population estimate, NITI Aayog, Central Pollution Control Board (CPCB), the World Bank, and Reserve Bank of India (RBI), etc. The available data in various parameter like, human population, urbanisation, carbon storage/emission and socio-economic indicators like gross state domestic product (GSDP), poverty index, human development, etc. have been compiled state-wise and presented for statistical inferences. District-wise carbon footprint per capita in respect to poverty ratio has been mapped to find out the possible trend or relationship between economy and carbon emission. State and district boundaries (as on 2011 census) have been used to integrate these attributes with the spatial data (state/district boundaries) using GIS software. While presenting state-wise data, district boundaries have been dissolved and

State IDs have been used to shown the geographical distribution on the map.

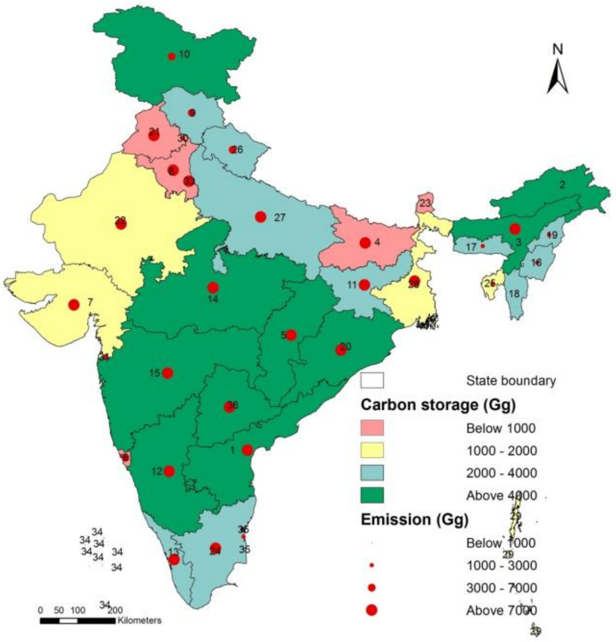

Figure 1: Distribution of carbon storage and emission by Indian state/UTs (Figures within state boundary indicated state ID, which is used in Table 2 and Figure 3)

3. Results and discussion

India's CO_2 emission has increased about 3 times during last two decades (2001-2021) against 2.1 time increase in per capita CO_2 emission. During the same period the GDP of the country has increased by 6.5 times against per capita GDP about 5 times. Thus the annual average growth rate of CO_2 emission is about half of the annual growth rate of GDP.

Seven large states namely Uttar Pradesh, Maharashtra, Bihar, West Bengal, Madhya Pradesh, Rajasthan and Tamil Nadu contribute about 60% of country's total population. Out of these states the poverty index of Bihar is more than half and Uttar Pradesh & Madhya Pradesh is more than one third as per the NITI Aayog estimate (Table 2). So, the issues like environmental performance, sustainability, carbon policy, etc. are the least priority for these states. On the other hand less populous north-eastern states like Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Tripura and UT of Andaman & Nicobar Islands has shown negative emission (carbon absorption exceeds the emission). This is due to the huge forest cover and less developmental activities has been carried out in these states. Economically developed states like Maharashtra, Tamil Nadu, Gujarat and Karnataka are highly urbanized. Very high rate of carbon emission has been recorded in most urbanized and economically well-developed Delhi and Chandigarh. Adjoining Punjab and Haryana are also among highly emitting states with minute carbon storage.

Urbanization has aggravated economic growth but rapid urbanization has several adverse environmental impacts, apart from the emission of GHGs and air pollution. The estimated percentage of urban population in India is about 35.4% (in 2021) against the recorded urban population 31.15 % (in 2011). Indian urban areas have experienced an unprecedented growth rate over the last 40 years. The decadal growth rate of urban population is quite high (about 3%) in India during last four decades (1981-2021). Due to rapid urbanization number of million plus cities has increased to 63 (Table 2), which will be around 70 within a couple of years. In these big cities, several climate-induced challenges also remain neglected. Most of the metropolitan cities in India are confronted with a serious threat of environmental pollution, acute housing crisis, and deterioration in the living conditions of slum and squatter settlements (Nandy, 2015). In the uncontrolled situation it is very tough for city/town planners to monitor the urban sprawl processes and assess the environmental impact of it. These areas are very prominent in several cities (or part of cities) where CEPI (Comprehensive Environmental Pollution Index) score is more than 60 as per the estimate of Central Pollution Control Board (CPCB). In consequence of global warming the coastal cities have experienced sea-level rise and enhanced flooding, which leads to changes in the spatial distribution of formal and informal settlements.

Table 1: Comparison CO_2 emission among three largest emitter

Country	Percentage global share of the country (2021) in		GDP PPP 2021* (constant 2017 international $, USD)	CO_2 emission (Mt/year) in last 30 years			Per capita CO_2 emission (tones per capita/year)		
	CO_2 emission	Population		1990	2005	2021	1990	2005	2021
China	32.93	18.15	24861	2426	6338	12466	2.069	4.796	8.727
USA	12.55	4.24	20932	5067	5951	4752	20.067	20.163	14.237
India	6.99	17.32	9301	600	1215	2649	0.690	1.062	1.895
World	100	100	131682	22718	30162	37858	4.264	4.614	4.811

*Gross Domestic Product (GDP) expressed in Purchasing Power Parity (PPP) as per World Bank estimate.
Data source: Census of India, Emission Database for Global Atmospheric Research (EDGAR, 2022)

Table 2: Economy and carbon status of Indian state/UTs with million plus populous & polluted cities

ID	NAME	Population (in million) and % of urban population @	GSDP (2019-20) Rs in crore (at current price)	Poverty index (2020) in %	Carbon storage (Gg)	Emission (Gg)	Million plus populous cities#
1	ANDHRA PRADESH	52.79 (35.27)	971224	12.31	6115	86509	Visakhapatnam*, Vijayawada*
2	ARUNACHAL PRADESH	1.53 (25.17)	28046	24.27	10038	621	-
3	ASSAM	35.04 (15.32)	335238	32.67	4900	11808	Guwahati
4	BIHAR	123.08 (12.12)	594016	51.91	853	20494	Patna
5	CHATTISGARH	29.49 (26.48)	344955	29.91	7067	51178	Raipur*, Durg-Bhilainagar
6	GOA	1.56 (73.65)	74828	3.76	366	3926	-
7	GUJARAT	69.79 (47.74)	1630240	18.60	1604	81328	Ahmedabad*, Surat, Vadodara*, Rajkot*
8	HARYANA	29.48 (40.92)	780612	12.28	341	36035	Faridabad*
9	HIMACHAL PRADESH	7.39 (10.27)	162816	7.62	2436	5618	-
10	JAMMU AND KASHMIR	13.71 (30.18)	170382	12.58	4283	6764	Srinagar
11	JHARKHAND	38.47 (25.83)	321157	42.16	2265	47268	Jamshedpur*, Ranchi, Dhanbad*
12	KARNATAKA	66.85 (43.45)	1628928	13.16	6167	56606	Bangaluru, Mysore, Hubli-Dharwad
13	KERALA	35.49 (71.01)	854689	0.79	2927	26808	Kozhikode, Malappuram, Thrissur, Kochi*, Thiruvananthapuram, Kannur, Kollam
14	MADHYA PRADESH	84.52 (28.77)	937405	36.65	9842	49923	Indore*, Bhopal, Jabalpur, Gwalior
15	MAHARASHTRA	124.44 (47.98)	2818555	14.85	6419	109011	Greater Mumbai*, Pune*, Nagpur, Nashik*, Vasai Virar, Aurangabad*, Solapur
16	MANIPUR	3.17 (31.88)	31790	17.89	2927	1123	-
17	MEGHALAYA	3.29 (20.56)	34716	32.67	2589	2146	-
18	MIZORAM	1.22 (54.53)	25149	9.80	2093	852	-
19	NAGALAND	2.19 (42.92)	29536	25.23	2376	2631	-
20	ODISHA	45.70 (18.47)	547959	29.35	6759	30974	Bhubaneswar
21	PUNJAB	30.34 (41.1)	539687	5.59	432	46525	Ludhiana*, Amritsar, Jalandhar*
22	RAJASTHAN	79.28 (26.33)	998999	29.46	1877	56420	Jaipur*, Jodhpur*, Kota
23	SIKKIM	0.68 (44.93)	30809	3.82	382	446	-
24	TAMIL NADU	76.40 (52.79)	1797229	4.89	2612	73777	Chennai, Coimbatore*, Madurai, Tiruppur*,

							Tiruchirappalli, Salem
25	TRIPURA	4.07 (36.97)	55857	16.65	1295	1221	-
26	UTTARAKHAND	11.40 (34.96)	253666	17.72	3796	5314	-
27	UTTAR PRADESH	230.91 (23.74)	1687818	37.79	3086	85724	Lucknow, Kanpur*, Ghaziabad*, Agra*, Meerut, Varanasi*, Prayagraj (Allahabad), Bareilly, Aligarh*, Moradabad*, Saharanpur
28	WEST BENGAL	98.13 (35.95)	1207823	21.43	1733	73244	Kolkata, Asansol*, Siliguri
29	A&N ISLANDS	0.40 (42.95)	9719	4.30	1187	634	-
30	CHANDIGARH	1.21 (99.7)	43674	21.81	1	1495	Chandigarh
31	DADRA & N.HAVELI	0.61 (67.09)	-	27.36	36	1466	-
32	DAMAN & DIU	0.47 (94)	-	6.82	2	851	-
33	DELHI	20.57 (99.35)	830872	4.79	17	23778	Delhi*
34	LAKSHADWEEP	0.07 (96.78)	-	1.82	5	108	-
35	PUDUCHERRY	1.57 (69.88)	38004	1.72	3	2877	-
36	TELANGANA	37.73 (46.11)	957207	13.74	-	-	Hyderabad

@ Projected figures from Population Projections for India & States 2011-2036, Census of India, New Delhi; Figure within parenthesis ( ) indicate percentage share of urban population of the respective state/UTs
# Cities are arranged in order of estimated population (as on 2021) within each state.
*Industrial clusters of critically or severely polluted areas (CEPI>60 as per CPCB) of the city or part of the city like Nazafgarh drain basin of Delhi, Chembur, Navi Mumbai of Greater Mumbai and Pimpri-Chinchwad in Pune etc.

Data sources: Economic Survey 2021-22, Govt. of India; National Multidimensional Poverty Index (MPI) Report 2021, NITI Aayog, New Delhi; Comprehensive Environmental Assessment of Industrial Clusters, CPCB, New Delhi.

It is a general trend across the world that carbon footprint is high where vigorous developmental activities are going on, and as a result the per capita footprint of developed nations are generally high. India has also shown higher carbon footprint in the urbanized regions having several developmental projects. The economically deprived regions have shown a lower footprint while less poverty stricken districts have shown higher carbon footprint. Most of the districts in India have shown a negative relationship between poverty ratio and carbon footprint, as the districts having a lower poverty has shown a higher carbon footprint per capita (Figure 2). A fair R-value of correlation shows a moderate relationship between poverty and carbon footprint in India. Districts like Mumbai (Suburban), Thiruvanathapuram, Kottayam, Bangaluru, Dakshina Kannada, Ludhiana, Bathinda, Patiala, North-West Delhi, Chennai has shown a very high carbon footprint having relatively lower poverty. Most of the poverty stricken districts of Bihar, Uttar Pradesh, Jharkhand and Odisha have shown a low carbon footprint. The relationship between economy and emission also support the fact, where there is low level of economical development and significant percentage of people are poor, has a minimal contribution in the carbon emission in the country (Figure 3).

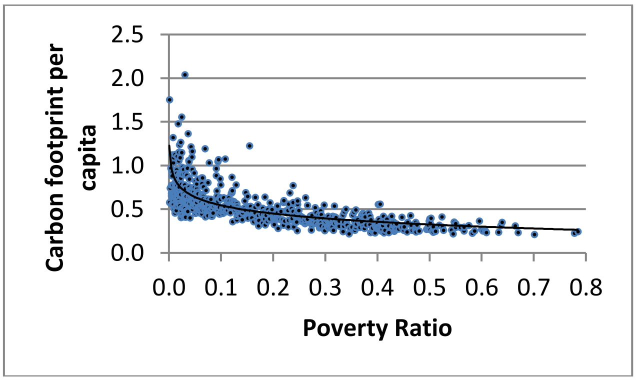

Figure 2: Carbon footprint per capita of Indian districts in respect of poverty (Data source: Lee et al., 2021)

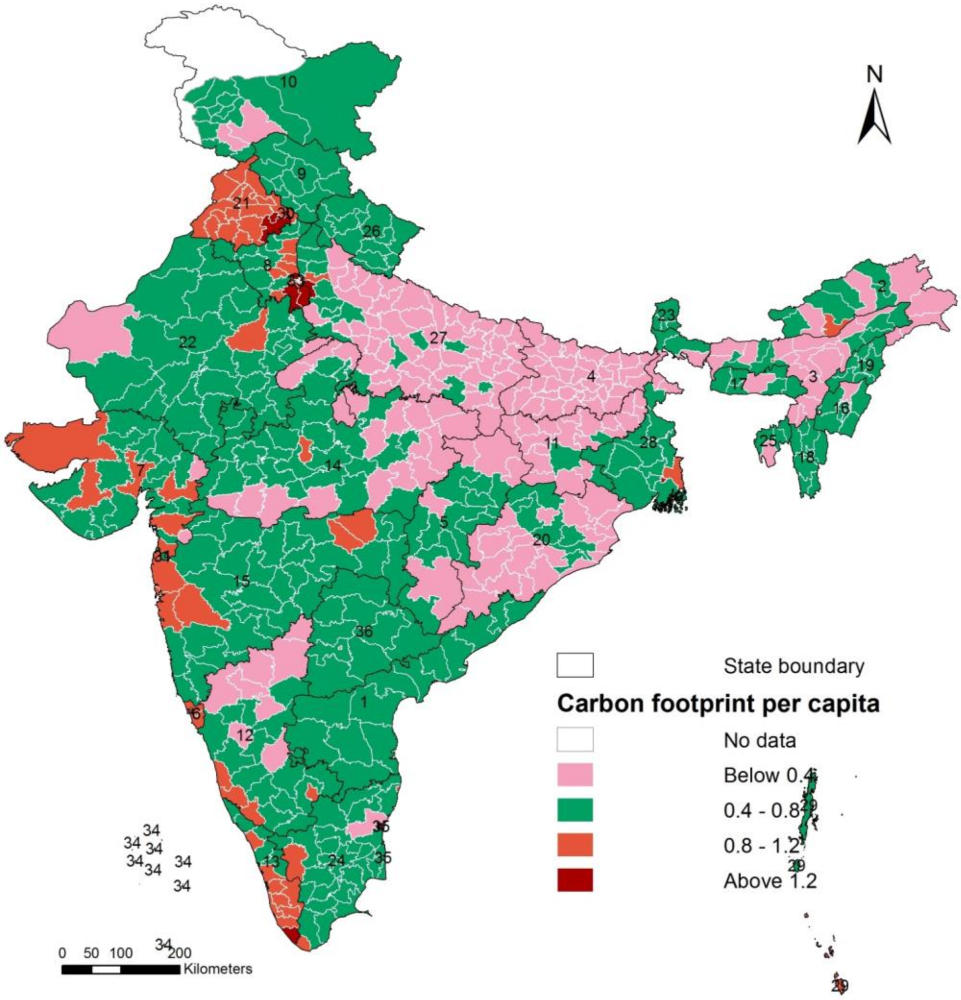

Figure 3: Distribution of carbon footprint across the districts in India

4. Conclusion

After China and USA, India is the third largest emitter of CO_2 in the world; though the per capita emission of India is remain low, as huge populations is still living in smaller amount energy. The per capita emission of the country is 4.6 times lower than China and 7.5 times lower than USA and below the average of per capita emission of many developing countries. So there is a need to detailed study on the energy requirement of India and how to meet it from different sources by limiting emission towards achieving the global climate challenge. The information presented in this paper is based on (or derived from) secondary sources collected from various agencies/departments and the availability of data in the same/uniform reference period is one of the major constraints. Further, the country has a diverse regional distribution of resources and comparison of states of different size on the same scale may lead to inaccurate estimation.

The dependence on the conventional sources of energy such as coal and oil is the major reason for the carbon emission as these sources are easy to acquire and relatively less expensive. Electricity generation, transport, cement and steel industries are among the top contributors of CO_2 and coal based power plants contribute about the half of the total CO_2 emission in India. As a policy measure, the government should reduce the usage of conventional energy and look for alternative renewable energy and promote them by giving incentives in the form of subsidies for the adoption of low carbon technologies. Further efforts must be taken to build a market for clean technology, along with robust financial system that encourages the adoption of low carbon technologies by various sectors in the country.

There is a need in allocate carbon budget to human development on long term basis and develop a roadmap to achieve this allocation. Greening initiative, such as renewable energy resources can be used to power educational and health care institutions for reducing the carbon footprint. Energy efficient electronic equipments may be promoted in education and medical care units. Low carbon technologies in electricity generation may be achieved by adopting fuel switching and reduction of transmission & distribution loss. Other issues like regional cooperation for hydro electricity trade, effective use of shared water resources among states and use of renewable, nuclear energy as an alternative of fossil fuel.

Energy plays a vital role for the development and economic growth of any economy. The growth of an economy is very important as it helps in reducing poverty and unemployment. The demand for energy due to rapid urbanization and economic development from various sectors has been rising and the country must fulfill the requirement. The focus would be equitable development with less pollution, limited emission and increasing clean, affordable energy for the poor. These goals can be achieved by bringing in energy efficiency and by adopting clean technology. Therefore the country must focus on the economy by adopting different measures of energy efficiency which can be achieved in short run, as adoption of clean technology requires huge investments and is achievable in long run. So the country should focus on fulfilling the energy requirement by reducing carbon emissions without compromising its economic growth.

Speedy economic growth could be achievable, but the environmental consequences due to the rapid developmental activities may persist for long run. To assess such environmental impact, a detailed long-term time-series environmental parameters are required. So there is need of further studies on developmental impact on environment and climate change. The present paper discusses the spatial distribution of carbon status in the country in respect to some economic parameters. It is an attempt to minimize the knowledge gap between economic aspects of emission and uneven development in the country. With the increasing realization of global climate, the planning of India's natural and biological resources is vital for its billion plus population. In this context this is a ready reference for policy/decision makers to take future course location specific action by assessing the global climate challenges.

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