

IMPACT OF POPULATION ON CARBON EMISSION: LESSONS FROM INDIA

*Chandrima Sikdar and Kakali Mukhopadhyay**

The global population is more than seven billion and will likely reach nine billion by 2050. As India is home to 18 per cent of the world's population, but has only 2.4 per cent of the land area, a great deal of pressure is being placed on all of the country's natural resources. The increasing population has been trending towards an alarming situation; the United Nations has estimated that the country's population will increase to 1.8 billion by the 2050 and, by 2028, it will overtake China as the world's most populous country. The growing population and the environmental deterioration are becoming major impediments in the country's drive to achieve sustained development in the country.

In this backdrop, the present study develops an econometric model to explain the causal relationship between carbon dioxide (CO₂) emission and population, given the population structure, industrial structure and economic growth in India. Based on this modelling exercise, the paper estimates the energy consumption and generation of CO₂ emission in 2050. The study projects that the total CO₂ emission in India will be 3.5 million metric tons in 2050.

JEL classification: J11, Q5, Q54.

Keywords: CO₂ emission, population, population structure, India, STIRPAT model.

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I. INTRODUCTION

Research and interest on population dynamics and environmental change was given renewed impetus by the United Nations Conference on Environment and Development in its Agenda 21, which was adopted in Rio de Janeiro, Brazil, in 1992. In Agenda 21, the development and dissemination of knowledge on the links between demographic trends and sustainable development, including environmental impacts, was recommended (United Nations, 1993).

The global population exceeds seven billion and is expected to reach nine billion by 2050. According to recent United Nations estimates, the global population is increasing by approximately 80 million — the size of Germany — each year. India is home to 18 per cent of the world's population, but it has only 2.4 per cent of the total land. Based on this, pressure on the countries resources is expected to persist.¹ The increase in population in India has been trending towards an alarming situation. According to the United Nations, the population of India will increase to 1.8 billion by 2050, which would make the country the most populous country in the world ahead of China.

The world's energy consumption is forecast to increase by 37 per cent during the next two decades, amid the rising global population and growing demand from Asian markets. While renewables will account for 8 per cent of the energy mix, up from its current level of 3 per cent, and fossil fuels will continue to meet two thirds of the increase in energy demand, according to the benchmark study. However, continued demand for fossil fuels means the world will not be able to reduce greenhouse gases in the atmosphere to about 450 parts per million of CO₂, which is the so-called 450 Scenario and seen as crucial for capping the rise in global temperature by 2°C, as outlined by the International Energy Agency (IEA, 2007). CO₂ emissions from fossil fuel combustion and industrial processes contributed a major portion of total greenhouse gas emissions during the period 1970-2010.² CO₂ emissions are expected to be 18 billion tons above the IEA 450 Scenario by 2035

¹ Over the past century, population and economic production increased about twentyfold, along with the demand for natural resources.

² The Intergovernmental Panel on Climate Change (IPCC) in its recent report – the Fifth Assessment Report (AR5), published in 2014 — has observed that, there has been an increasing trend in the anthropogenic emissions of greenhouse gases since the advent of the industrial revolution, with about half of the anthropogenic carbon dioxide (CO₂) emissions during this period occurring in the last 40 years. The period 1983-2012 is likely to have been the warmest 30-year period of the last 1,400 years. The change in the climate system is likely to have adverse impacts on livelihoods, cropping pattern and food security. Extreme heat events are likely to be longer and more intense in addition to changes in the precipitation patterns. Adverse impacts are likely to be felt more acutely in tropical zone countries, such as India, and within India, the poor will be more exposed.

(BP Energy Outlook, 2015). Specifically, India is one of the most important transitional and growing economies in the world.³ Over the last three decades, India has sustained impressive gross domestic product (GDP) growth, with an average rate of 5.4 per cent per year. This economic growth is likely to be associated with greater energy use and increased air pollution. Industrial growth in the country has, in terms of the long-run trend, remained aligned with the GDP growth rate. The long-term average annual growth of industries comprising mining, manufacturing, and electricity, during the post-reform period between 1991-1992 and 2011-2012, averaged 6.7 per cent as against GDP growth of 6.9 per cent. Inclusion of construction in industry raises this growth to 7.0 per cent. The share of industry, including construction, in GDP remained generally stable, at about 28 per cent, in the post-reform period. The share of manufacturing, which is the most dominant sector within industry, however, did not show an impressive increase. It remained around the 14-16 per cent range during this period.

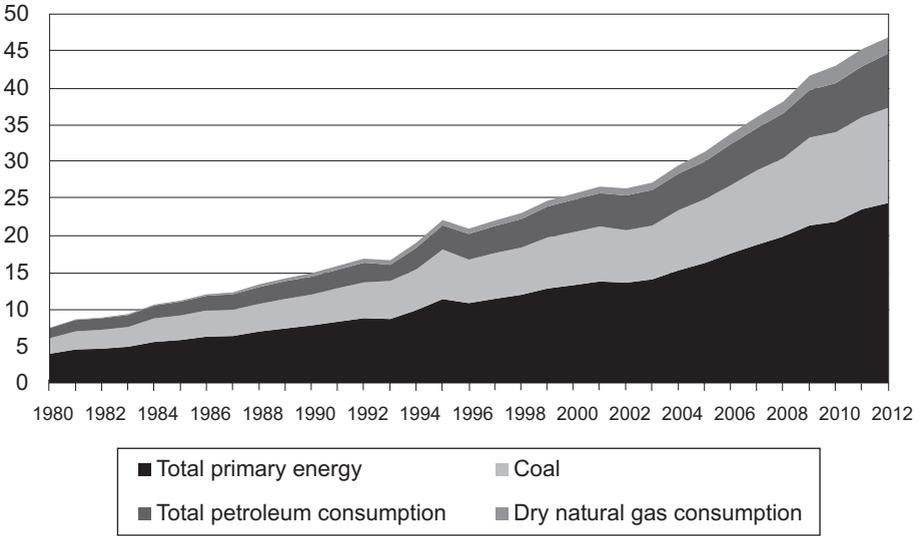
The development of a diversified industrial structure in India based on a combination of large and small-scale industries and the growing populations in both urban and rural areas have put pressures on the environment, as reflected in the growing incidence of air, water, and land degradation. India is currently highly reliant on fossil fuels to meet its energy needs. The country's production of total primary energy, including coal and lignite, crude petroleum and natural gas, has increased from 3.1 quadrillion British thermal units (BTU) in 1980/81 to 15.9 quadrillion BTU in 2011/12, an increase of five times, while consumption increased almost seven times (figure 1). In 2007, coal and oil together accounted for two thirds of the primary energy, with the remainder being predominantly biomass and waste. To develop further, India requires reliable access to increasing supplies of energy.

Energy security is, therefore, a primary concern for India, but there are several reasons why attention has also turned to climate issues in recent years. One of them is that India is vulnerable to climate change, which could have a number of negative effects, such as decreased yields of wheat and rice (two of its major exports) and increased sea level and water stress. The main concern related to air pollution at present is greenhouse gas emissions,⁴ owing to their role in contemporary global climate change. Greenhouse gas emissions, which are derived mainly from combustion and CO₂ emission levels, have climbed quickly in the current century (figure 2). Industrial pollution is concentrated in such industries as petroleum

³ India is still poor by global standards, with a gross national income (GNI) per capita of about \$5,350 (in PPP) in 2013, compared with \$53,750 for the United States of America (World Bank, 2015).

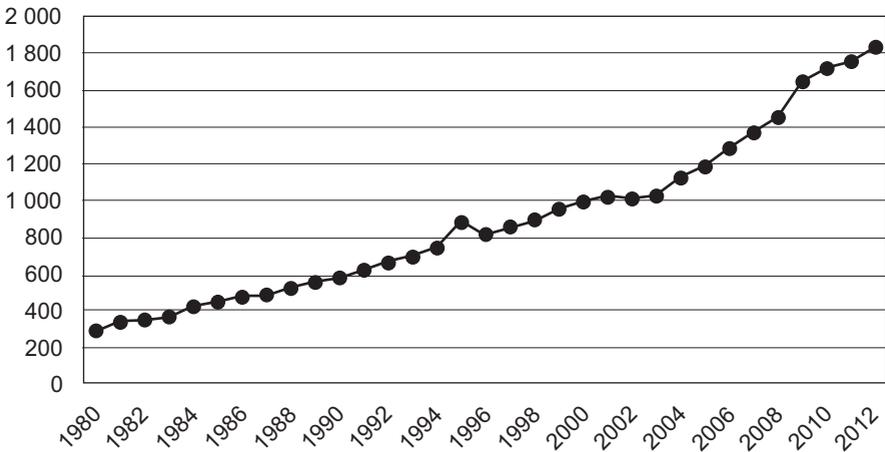
⁴ The major greenhouse gas is carbon dioxide, released to the atmosphere mainly by fossil fuel burning (80 per cent), but also by burning of forests (20 per cent).

Figure 1. Energy consumption in India in quadrillion British thermal unit (1980-2012)



Source: EIA (2015).

Figure 2. Carbon dioxide emission from energy consumption in India (1980-2012) in million metric tons



Source: EIA (2015).

refineries, textiles, pulp and paper, industrial chemicals, iron and steel, and non-metallic mineral products. Small-scale industries, especially foundries, chemical manufacturing, and brick making, are also significant polluters. In the power sector, thermal power, which constitutes the bulk of installed capacity for electricity generation, is a significant source of air pollution. As long as smokestack, chimney, and tailpipe emissions are unregulated, or ineffectively regulated, and as long as technological change does not fundamentally affect pollution levels, population remains a crucial variable for such countries as India. Therefore, policies and investment must encourage more efficient use of resources, the substitution of scarce resources and the adoption of technologies and practices that minimize environmental impact. Fortunately, the Government of India has already made some positive moves in this direction.

Thus, the major challenge for India with regard to controlling carbon emission levels is its population growth. This is because the country's population is projected to increase to a level that will lead to an overall scarcity of resources, which will, in turn, result in greater fossil fuel combustion and also carbon emissions. A general question that arises from this is: What would be the impact of this population growth on the carbon emission levels in India? To answer this question, the present paper uses a STIRPAT model, a framework widely used in literature to study the environmental impacts of population and affluence in an economy. However, to show a more complete and accurate impact of population change on carbon emission levels, along with GDP per capita, which is used as an indicator of affluence, the present paper incorporates two more variables in the STIRPAT modelling framework: household size and industry value added in GDP. Using time series data for the Indian economy for the period 1980-2012, the impact of population change on carbon emissions is quantitatively assessed and analysed. Based on this analysis, the paper attempts to project the extent of carbon dioxide emission in India in 2050.

The organizational structure of the paper is as follows: section II presents a brief review of literature. Section III discusses the model. Section IV provides the data, the data sources and statistical testing of data. Section V elaborates the estimation technique to arrive at the estimated coefficients and provides the projection for carbon emissions in India during 2050. A detailed discussion of the results obtained is carried out in section VI. Section VII finally concludes the paper with a summary of the main findings and the policy implications.

II. LITERATURE REVIEW

As the effect of population on carbon emissions is wide ranging, identifying the relationship between them is a truly challenging exercise. In terms of population

characteristics, key demographic factors, such as population size, its structure and distribution, are constantly changing, making the effect of these changes on carbon emission extremely complicated and varied. Researchers around the world have, thus, been much engaged in analysing the relationship between population growth and increasing carbon emission levels on one hand and analysing the impacts of changing population characteristics on emission levels on the other.

A large volume of literature has already contributed to this field. According to Birdsall (1992), population growth in developing countries results in large greenhouse gas emissions because of increased energy demand for power generation, industry, and transport, which, in turn, leads to increased fossil fuel consumption. However, he notes that a reduction in population growth matters, but is not the key factor in levelling off carbon emissions. Knapp and Mookerjee (1996) explore the nature of the relationship between global population growth and CO₂ emissions using the Granger causality test on annual data for the period 1880-1989, as well as more comprehensive error correction and cointegration models. The results suggest lack of a long-term equilibrium relationship, but imply a short-term dynamic relationship between CO₂ and population growth. Using decomposition analyses, Bongaarts (1992) shows that population growth is a key factor in greenhouse gas emissions growth.

The effect of changes in household size and urbanization on carbon emissions is another research focus. Dalton and others (2007) incorporate household size into the population-environment-technology model to stimulate economic growth, as well as changes in the consumption of various goods, direct and indirect energy demand, and carbon emissions over the next 100 years. Jiang and Hardee (2011) discuss the impact of shrinking household size on carbon emissions and argue that households, rather than individuals in a population, should be used as the variable in analysing demographic impact on emissions. This approach is favourable considering that households are the units of consumption, and possibly also the units of production in developing societies. Poumanyvong and Kaneko (2010) empirically investigate the effects of urbanization on energy use and CO₂ emissions. In the investigation, the authors consider different development stages using the STIRPAT model and a balanced panel dataset that covers the period 1975-2005 and includes 99 countries. The findings suggest that the impact of urbanization on carbon emissions is positive for all income groups, but that this effect is more pronounced in the middle-income group than in the other income groups. Barido and Marshal (2014) investigate empirically how national-level CO₂ emissions are affected by urbanization and environmental policy. They use statistical modelling to explore panel data on annual CO₂ emissions from 80 countries for the period 1983-2005. The results indicate that on the global average the urbanization-emission elasticity value is 0.95

(a 1 per cent increase in urbanization correlates with a 0.95 per cent increase in emissions). Several regions display a statistically significant, positive elasticity for fixed- and random-effects models: lower-income Europe, India and the subcontinent, Latin America, and Africa. Bekhet and Yasmin (2014) examine the causal relationship among economic growth, CO₂ emissions, energy consumption and urbanization in Malaysia for the period 1970-2012. The bounds F test yields evidence of a long-run relationship among per capita carbon emissions, per capita energy consumption, per capita real income, and urbanization. The results show that an increase in energy consumption results in an increase in per capita carbon emissions and urbanization in the long run. These results support the validity of the “Urban Transition Theory” developing stage in the Malaysian economy. This means that the level of CO₂ emissions is still increasing with the rapid urbanization process in Malaysia and that the expanding sprawl of the cities will harm the environment in the country in the long run in Malaysia.

A large number of studies analysed the impact of population and population structure on the environment, in particular on carbon emission using the IPAT/STIRPAT models. Shi (2003), using IPAT exercise, analyses CO₂ emissions in 93 countries between 1976 and 1995. He submits evidence that emission level rises disproportionately with population, the other variables in the model are GDP per capita, percentage of manufacturing in GDP, and percentage of population in the work force. He also finds that population elasticity of CO₂ is higher in developing than in developed countries. Fan and others (2006) analyse the impact of population, affluence, and technology on total CO₂ emissions of countries at different income levels at the global scale over the period 1975-2000. The results show that the working age population (15-64 years) has less of an effect on CO₂ emissions than do population size, affluence, and technology.

MacKellar and others (1995), covering the years 1970-1990 at the world scale, attribute roughly one third of CO₂ emissions to population, a percentage that more than doubles when population is represented by number of households rather than by individuals. Engelman (2010) similarly deduces from the simultaneous decrease of per capita emissions and increase of total emissions that the number of emitters must be a significant factor. Raskin (1995) suggests that from an environmental point of view, population stabilisation in wealthier countries should take priority over that in poorer countries. Satterthwaite (2009) negates the population factor after noting the low per capita greenhouse gas emissions of the world's two billion poorest people. Dalton and others (2008) incorporate population age structure into an energy-economic growth model with multiple dynasties of heterogeneous households to estimate and compare the effects of ageing populations and technical change on the baseline paths of United States energy use and CO₂ emissions. The authors show that an

ageing population reduces long-term emissions by almost 40 per cent in a low-population scenario, and that the effects of the ageing process on emissions can be as large as, or larger than, those of technical change in some cases, given a closed economy, fixed substitution elasticity, and fixed labour supply over time.

Zhu and Peng (2012) examine the impacts of population size, population structure, and consumption level on carbon emissions in China from 1978 to 2008. Using a STIRPAT exercise, the study finds that changes in the consumption level and population structure are the two major factors that affect carbon emissions. Population size is not important. Regarding population structure, urbanization, population age and household size have distinct effects on carbon emissions. Urbanization increases carbon emissions, while the effect of age acts primarily through the expansion of the labour force and consequent overall economic growth. Households, rather than individuals, are a more reasonable explanation for the demographic impact on carbon emissions. Liddle (2014) summarizes the evidence from cross-country, macro-level studies that demographic factors and processes, specifically, population, age structure, household size, urbanization, and population density, influence carbon emissions and energy consumption. Higher population density is associated with lower levels of energy consumption and emissions.

Thus, while contemporary researchers around the world have extensively studied the impact of population growth on the environment, carbon emission levels, in particular, similar studies that focus on India are limited. Some of the recent studies on the Indian economy were conducted by Ghosh (2010); Martínez-Zarzoso and Maruotti (2011); Mukhopadhyay (2011); Ozturk and Salah Uddin (2012), and Yeo and others (2015).

Ghosh (2010) examines the carbon emissions and economic growth nexus for India. Using a multivariate cointegration approach, the study fails to establish a long-run equilibrium relationship and long-term causality between carbon emissions and economic growth; however, it establishes the existence of a bidirectional short-run causality between the two. Martínez-Zarzoso and Maruotti (2011) do a STIRPAT modelling to primarily analyse the impact of urbanization on CO₂ emissions involving a sample of ninety-five developing countries, of which India is one of them, from 1975 to 2003. India is classified as a low-income country in the study. Results of the study show that the emission-population elasticity is greater than one for all upper-, middle- and lower-income countries. However, the emission-urbanization elasticity is greater than unity for upper-income countries. For the other groups of countries, it is 0.72. Mukhopadhyay (2011) estimates the emissions of carbon dioxide, sulfur dioxide, and nitrogen oxide in India during the period 1983-1984 to 2006-2007. Using input-output structural decomposition analysis, he investigates the changes in emissions and the various factors responsible for those changes. He finds that industrial emissions of air

pollutants have increased considerably in India during 1983-1984 to 2006-2007 with the main factors for these increases being changes in the final demand, changes in intensity and changes in technology. Ozturk and Salah Uddin (2012) study the long-run causality among carbon emission and energy consumption and growth in India and reports that there is feedback causal relationship between energy consumption and economic growth in India, which implies that the level of economic activity and energy consumption mutually influence each other; a high level of economic growth leads to a high level of energy consumption and vice versa.

Yeo and others (2015) identify and analyse the key drivers behind the changes of CO₂ emissions, particularly in the residential sectors of two emerging economies, namely India and China, during the period 1999-2011. Five socioeconomic factors, namely, energy emissions coefficients, energy consumption structure, energy intensity, household income and population size, are identified as the key factors driving the CO₂ emission levels in India. Using the logarithmic mean Divisia index (LMDI) method to decompose the changes in the emission levels, the study finds that from 1990 to 2011, the biggest contributor to the rise in emissions has been the increase in the country's per capita income level followed by the increasing population and changes in the energy consumption structure. The increases in emission levels brought about by these factors are 173 MtCO₂e, 65.9 MtCO₂e and 60.7 MtCO₂e, respectively. On the other hand, changes in energy intensity followed by changes in the carbon emission coefficient have been the main factors behind lower carbon emission levels in the country during this period. While the energy intensity decreased the emission by 86.1 MtCO₂e, the carbon emission coefficient lowered it by 14.4 MtCO₂e. Thus, the stable economic growth and expansion experienced by the country during the two decades primarily resulted in increased energy demand and hence higher levels of CO₂ emission, while improved energy intensity by the way of investments for energy savings, technological improvements and energy efficiency policies were effective in mitigating CO₂ emissions in India.

These studies identify economic growth, rising income levels, population growth, urbanization and real investment as factors driving CO₂ emission levels in India. Some of the earlier works of Mukhopadhyay (2001; 2002), Mukhopadhyay and Chakraborty (2002; 2004), Gupta (1997) and Murthy, Panda and Parikh (1997) also point to similar such factors behind carbon emissions in India. In particular, they have found that economic growth and growing income levels have been the main contributing factors to emission levels over time.

The Intergovernmental Panel on Climate Change (IPCC) indicates that the key driving forces of CO₂ emissions in any economy are demographic changes, socioeconomic development and the rate and direction of technological change. As pointed out by different studies, in India, the key driving forces of CO₂ emissions are

similar, namely economic growth, demographic profile, technological change, energy resource endowments, geographic integration of markets, institutions and policies (Shukla, 2006). Shukla (2006) constructs emission scenarios for India for the medium run (2000-2030) and the long run (2000-2100) based on the IPCC SRES⁵ framework (IPCC, 2000) and finds that it is the endogenous development choices that will play a significant role in shaping the emission pathways in each of these scenarios. For both medium-run and long-run time periods, he predicts that the carbon emission trajectories in India under all of the scenarios are more or less linear, indicating a sustained rising emission trend throughout the century in all possible scenarios.

Thus, some researchers have focused on studying carbon emission levels in India and the factors that influence them while others have projected the trajectories for carbon emission in the country under different development scenarios for hundred years from 2000 to 2100. However, none of these studies look at population and population structure closely as the driving factors. With a population projection of 1.8 billion for the country by 2050, a careful study and understanding of the impact of this likely population growth on carbon emission levels is absolutely important, particularly in view of the country's pledge to support the Durban Platform for Enhanced Action to improve cooperation aimed at reaching a global agreement on climate change to be effective by 2020 (Gambhir and Anandarajah, 2013). The present study seeks to contribute to this research gap.

III. THE MODEL

STIRPAT modelling is a research framework for the stochastic estimation of the well-known IPAT identity model of environmental impact. The IPAT identity (Ehrlich and Holdren, 1971) is an equation that is usually used to analyse the impact of human behaviour on environmental pressures. It is given as:

$$I = PAT \quad (1)$$

Where I denotes environmental impact, P denotes population, A denotes affluence and T denotes technology.

Equation (1) is an accounting identity in which one term is derived from the value of the other three terms. The model requires data on only any of the three variables for one or some observational units and these can be used to measure only the constant proportional impacts of the independent variables on the dependent

⁵ SRES stands for Special Report on Emissions Scenarios.

variable. Thus, the multiplicative identity framework of IPAT is problematic for empirical analysis. Dietz and Rosa (1997) recognized this and reformulated the equation (1) into a stochastic model as under

$$I = a P^b A^c T^d \varepsilon \quad (2)$$

Where, I, P, A and T are the same as in IPAT equation (1); a, b, c and d are the coefficients and ε is the error term.

With this reformulation as in equation (2), the data on I, P, A and T can be used to estimate a, b, c, d and ε using the regression methods of statistics. Thus, with the reformulated version, the IPAT accounting model is converted into a general linear model, to which statistical methods can be applied and the non-proportionate importance of each influencing factor may be assessed.

Given in logarithmic form (York and others, 2003b) equation (2) is as under:

$$\ln I = \ln a + b (\ln P) + c (\ln A) + d (\ln T) + \varepsilon \quad (3)$$

Equation (3) presents an additive regression model in which all variables are in logarithmic forms. This natural logarithmic forms allow the terms to be estimated as elasticities (York and others, 2003b), where coefficients are given as percentage change. Thus, coefficients b, c and d in equation (3) are respectively the population, affluence and technology elasticities. Any coefficient closer to unity imply unit elasticity and represent proportional change in dependent variable due to change in independent variable; while coefficients greater than one denote more than a proportional change in the dependent variable brought about by a change in independent variables.

STIRPAT analysis usually begins with this basic framework and goes on to add or eliminate variables in an attempt to test different model specifications at different scales and regions. Total population size and GDP per capita are the most commonly used metrics in literature for P and A, while CO2 emissions or similar derivative metrics, such as global warming potential (GWP) and CO2 equivalents, are usual units used for I. Many studies eliminate "T" altogether and estimate only P and A and hence avoid the difficulty of operationalizing "T". According to York and others (2003a) and Wei (2011), "T" should be included in " ε ", the error term and not treated separately in an application of the STIRPAT model. This is for consistency with the IPAT model where "T" is solved to balance I, P and A.

To capture the complete comprehensive impact of population changes in India on the country's carbon emission levels, the present paper proposes the STIRPAT model of the following form:

$$\ln I = \ln a + b_{Iva} (\ln I_{va}) + b_h (\ln AHHS) + b_A (\ln A) + \varepsilon \quad (4)$$

Where, I denotes CO2 emissions per capita (in million metric tons)

I_{va} denotes the share of industry value added as per cent of GDP

AHHS denotes the average household size

A denotes the GDP per capita

a denotes the constant

ε denotes the error term.

In equation (4), the impact (I) is measured as CO2 emissions per capita while A is the usual affluence term of an IPAT identity. To this identity, the present study incorporates variables – I_{va} and AHHS.

With 18 per cent of the world's population on 2.4 per cent of its land area, India already is putting a great deal of pressure on all its natural resources. Furthermore, with the estimated increase in population, it is obvious that this pressure will increase manifold in years to come, leading to increased resource scarcity and fossil fuel combustion and hence higher levels of carbon emissions. Therefore, to understand a more comprehensive impact of the population growth, the present study uses emission per capita rather than total carbon emission as the dependent variable.

Average household size is an indicator of population structure. Given a fixed population size, a change in the number of households brought about by a change in average household size can influence the scale and structure of consumption in a large way and thereby significantly affect carbon emission levels. In addition, in an economic structure, such as in India, often households rather than individuals in the population are the units of energy consumption. Studies on relations between population structure and carbon emission levels have often used the working age population (15-64) as an indicator of population structure. However, such a broad age structure is likely to be related to total population. A more disaggregated age structure (Liddle and Lung, 2010; Liddle, 2011; Roberts, 2014) would probably reflect better the demographic impact on emissions, but because of the lack of available data on disaggregated age structure for India, average household size is used as a metric of population structure in the present study.

Industry value added in GDP is used as a metric for industrial structure. This is in line with the literature. As pointed out in section I, manufacturing, the most dominant area of the industrial sector, did not show much increase in its GDP share. In fact, the manufacturing value added of 16 per cent of the 1980s declined to

15.8 per cent in the 1990s and further to 15.3 per cent from 2000 and 2009 (World Development Indicators).⁶ However, the long-run growth trend of Indian industries did stay aligned with the GDP growth rate. Moreover, the industrial structure has diversified into large and small-scale industries and have been reportedly putting pressures on the environment, as reflected in the growing incidence of air, water and land degradation. Furthermore, the Indian economy now is at a major turning point. With the current initiatives of the Government of India, such as Make in India⁷ and Startup India,⁸ the industrial sector is expected to emerge as a major sector. This, in turn, has its implications on energy use and consequent carbon emissions in the country.

IV. DATA AND STATISTICAL TESTS FOR DATA

The data required for the empirical implementation of the STIRPAT model are:

- Annual data for CO₂ emissions (CO₂) from energy consumption in metric tons per capita for India from 1980 to 2012 obtained from the World Development Indicators;
- Annual data for real GDP per capita (in millions) in India for the period 1980-2012, also obtained from the World Development Indicators;
- The industry valued added as per cent of GDP for India for the period 1980-2012, also obtained from the World Development Indicators;
- Average household size for India for the period, which is available from the Ministry of Statistics and Programme Implementation, Government of India.

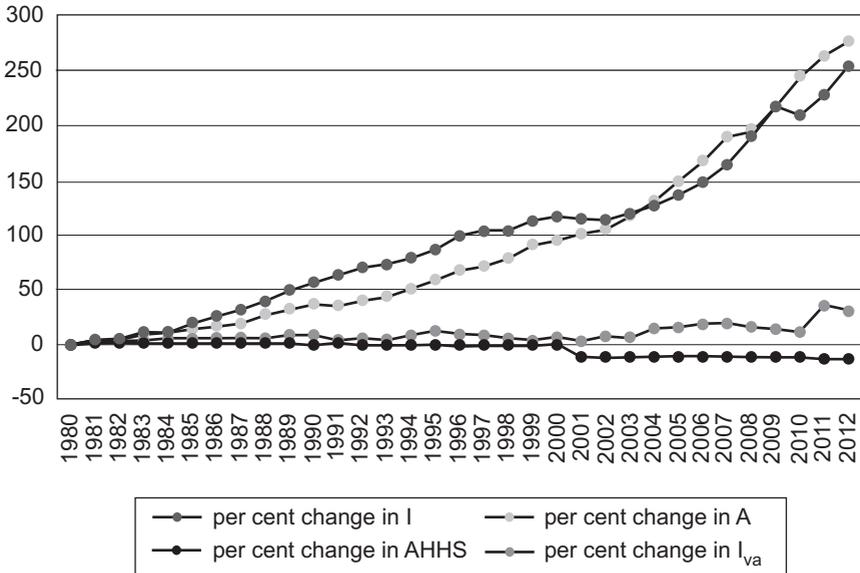
Figure 3 presents the changing rates of all the variables of the model with 1980 as the base. As is observed, almost all the variables appear to be non-stationary with either a continuous uptrend or downtrend during the period. Of all the variables, carbon emission shows the most rapid growth rate, followed by GDP per capita, population and industry valued added. Average household size has shown negative

⁶ World Bank, World Development Indicators database. Available from <http://data.worldbank.org/data-catalog/world-development-indicators> (accessed 20 April 2015).

⁷ Make in India is an initiative of the Government of India to encourage multinationals and domestic companies to manufacture their products in India. This initiative was launched by Prime Minister Narendra Modi on 25 September 2014.

⁸ Startup India campaign is an initiative of the Government of India to boost entrepreneurship and encourage startups with job creation. It was launched by Prime Minister Narendra Modi on 16 January 2016.

Figure 3. Rate of change in carbon emission per capita, gross domestic product per capita, population, and population and industrial structure in India during the period 1980-2012



Source: Authors' calculation based on the data used in the model.
 Note: AHHS, average household size.

growth during the time period. This non-stationarity of the variables needs to be taken care of to come up with precise and reliable estimates for the coefficients of the model.

Thus, the study of the causal relationship between carbon emissions and population changes in India involves the following steps:

Test for stationary

Test for stationary – estimation involving time series data set should be first checked for stationarity; without this initial test, the results of the regression can be highly misleading, as time series data may contain a trend element. A deterministic trend in estimation involving time series data may be taken care of by including a trend variable in the estimating model. But accounting for stochastic trend requires a more detailed exercise of conducting number of tests before proceeding with the estimation. In the absence of such tests, the estimation may be spurious.

Thus, an important econometric task is first to test if a time series data set is trending. If it is found to be trending, then some form of trend removal should be applied.

Trend in time series data is usually accounted by removing or de-trending the series. Two common de-trending procedures are first differencing and time trend regression. Unit root tests are used to determine if the trending data should be first differenced or regressed on deterministic functions of time so as to render the data stationary. Thus, unit root tests that consider the null hypothesis in which at least one unit root exists determines if the data are non-stationary against the alternative hypothesis that the series is stationary.

The most popular of those tests are the Augmented Dickey Fuller (ADF) and the Phillips-Perron (PP) unit root tests. The tests differ mainly on how they treat the serial correlation in the test regression. The test regression equation involving the series lnl is given as

$$\Delta lnl_t = \alpha + \beta t + \delta lnl_{t-1} + \sum_i^k \beta \Delta lnl_{t-i} + \varepsilon_t \quad (5)$$

Where, α is the constant, β is the coefficient of trend; δ is the coefficient of the lagged variable lnl_{t-1} and ε_t is the error term. k is the length of the lag and it makes the error a stochastic variable. The unit root tests of ADF and PP test the null hypothesis with two more formulations of the test regression equation – one where $\alpha = 0$ but $\beta \neq 0$ and the other where both $\alpha = 0$ and $\beta = 0$. The series lnl is considered stationary if any one of the three formulations of the test regression equation rejects the null hypothesis $H_0: \delta = 0$, i.e. the series has at least one unit root.

The results of the unit root tests for the variables of model (as in equation 4) are presented in table 1.

The ADF and PP results (refer to column 8 of table 1) indicate that all the variables – CO2 emissions per capita, industry value added, average household size and affluence, as measured by GDP per capita, are non-stationary and integrated of order (1).

Once variables of a model are classified as integrated of order I(1), and so on, it is possible to set up models that lead to stationary relations among these variables, thereby making standard inference possible. However, the necessary criterion for stationarity among non-stationary variables is called cointegration. Testing for cointegration is a necessary step to check if the modeling exercise undertaken yields empirically meaningful relationships. Thus, the next step is to conduct the cointegration tests.

Table 1. Results of unit root tests

Variables	Unit root tests	Difference order	Exogenous (α, β, k)	t-statistic	Significance level	Test critical value	Verdict
<i>lnl</i>	ADF	1	$(\alpha, \beta, 0)$	-4.63	5%	-3.56	I(1)
	PP	1	$(\alpha, \beta, 2)$	-4.64	5%	-3.56	I(1)
<i>lnl_{va}</i>	ADF	1	$(\alpha, 0, 0)$	-6.96	5%	-2.96	I(1)
	PP	1	$(\alpha, 0, 7)$	-7.63	5%	-2.96	I(1)
<i>lnAHHS</i>	ADF	1	$(\alpha, 0, 0)$	-6.01	5%	-2.96	I(1)
	PP	1	$(\alpha, 0, 2)$	-6.02	5%	-2.96	I(1)
<i>lnA</i>	ADF	1	$(\alpha, 0, 0)$	-4.20	5%	-2.96	I(1)
	PP	1	$(\alpha, 0, 0)$	-4.20	5%	-2.96	I(1)

Source: Authors' calculation based on the data used in the model.

Notes: ADF – Augmented Dickey Fuller; PP – Phillips-Perron.

Cointegration test

The variables CO2 emissions per capita, industry value added (as per cent of GDP), average household size and GDP per capita are all non-stationary and integrated of order (1). Hence, these variables satisfy the precondition for conducting a cointegration test and hence if there is a stable and non-spurious long-run relationship between these variables (Ramirez, 2000). Given a number of non-stationary variables of the same order, the number of cointegrated vectors, involving these variables, can be determined by the Johansen cointegration approach. The results of the Johansen maximum likelihood test of cointegration are shown in table 2. The trace test statistics of the null hypothesis of no cointegration vector against the alternative hypothesis of one cointegrating vector as provided in table 2 suggests that there is one cointegrating vector. The maximum eigenvalue test statistic also indicates the same.

The results of the unit root tests and the cointegration tests support the existence of long-run equilibrium relationships among the variables of the model as presented in equation (4). The next step is to obtain the long-run estimates of the model. For this, the Fully Modified Ordinary Least Squares (FM-OLS) estimation procedure is used.

Table 2. Johansen cointegration test

Hypothesized number of cointegrated equation(s)	Trace statistic	0.05 per cent critical values	Maximum Eigen statistic	0.05 per cent critical values
None	55.48*	47.86	28.6*	27.58
At most 1	29.26	29.79	14.28	21.10
At most 2	14.99	15.49	11.41	14.26
At most 3	3.57	3.84	3.57	3.84

Source: Authors' calculation based on the data used in the model.

Notes: Trace test and Max-eigenvalue test indicates 1 cointegrating equation(s) at the 0.05 level.

*Denotes rejection of the hypothesis at the 0.05 level.

V. FULLY MODIFIED ORDINARY LEAST SQUARES ESTIMATION

In time series data, once the cointegration tests establish the existence of a long-run relationship among the variables, the ordinary least square (OLS) technique, if used to estimate the parameters of the model, comes up with super-consistent estimates of the parameters, for example, the estimators converge at rate equal to the sample size of the model. Furthermore, if a problem of endogeneity among the independent variables exists, then the limiting distribution of the OLS estimators is said to have the so-called second order bias terms (Phillips and Hansen, 1990). In the presence of these bias terms, inference becomes difficult. Thus, to investigate the long-run relationship among variables, various modern econometric techniques were introduced. These techniques propose modifications of OLS that result in zero mean Gaussian mixture limiting distributions that make the standard asymptotic inference feasible (Vogelsang and Wagner, 2014). One such method is the fully modified OLS (FM-OLS) approach. This method, which was introduced and developed by Phillips and Hansen (1990), uses the "Kernel" estimators of the nuisance parameters that affect the asymptotic distribution of the OLS estimator. FM-OLS modifies the least squares so as to account for the effect of serial correlation and presence of endogeneity among the independent variables (brought about by the existence of cointegration among the variables) and thereby ensures asymptotic efficiency of estimators. Thus, the FM-OLS method gives reliable estimates and provides a check for robustness of the results. Table 3 contains a report of the estimated results of the FM-OLS approach.

Table 3. Fully modified ordinary least squared regression results for extended STIRPAT model as in equation (4)

Variables	Coefficient	t test	P values
$\ln I_{va}$	-0.39 (.359)	-1.10	0.28
$\ln AHHS$	1.87* (.51)	3.67	0.00
$\ln A$	1.14* (0.09)	12.00	0.00
Constant	-12.68* (1.21)	-5.83	0.00
Observations			32
R^2			0.967
Standard error			0.06

Source: Authors' calculation based on the data used in the model.

Notes: Dependent variable: $\ln I$.

Standard errors are in parenthesis.

Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.1$.

The FM-OLS results in table 3 reveal that the average household size and the real GDP per capita are statistically significant in explaining variations in the level of CO₂ emission per capita. In particular, both of these variables have a significantly large positive effect on the emission level. Industry value added is not statistically significant. The adjusted R^2 value is 0.967, which indicates a very good fit. The diagnostic tests reveal that the estimated residuals are $I(0)$ and the test for serial correlation for residuals based on Q statistic reveal that there is no serial correlation present.

The FM-OLS estimates are accepted as estimators for the extended STIRPAT model (equation 4) and are used for predicting CO₂ emission in India for 2050. Based on the estimates of the model, the future total CO₂ emission is estimated to be 3,516.2 million metric tons in 2050. The estimate obtained is also in line with what is suggested by IPCC research on CO₂ levels. The IPCC reports suggest that both population and level of affluence can be significant factors in greenhouse gas emission trends in poorer countries. That is highly applicable for India as well. The present model also finds that affluence (measured as real GDP per capita) is an important variable influencing per capita carbon emission levels in India. Additionally, average household size is also found to be an important variable, resulting in higher per capita emissions in the country. Thus, based on the ongoing economic development momentum in India and a population projected to reach 1.862 billion by 2050, carbon emission levels are expected to rise sharply in the country.

As indicated by the coefficients corresponding to the independent variables, which are statistically significant in table 3, the factors affecting carbon emission per capita in India may be ranked (in terms of higher to lower in importance) as follows:

- Average household size – contribution ratio of 1.87 implying that a 1 per cent increase in average household size is likely to increase carbon emission per capita by 1.9 per cent;⁹
- Per capita GDP – contribution ratio of 1.14 implying that a 1 per cent increase in per capita GDP is likely to raise carbon emission per capita by 1.1 per cent.

The figures above present the contribution of each of the two identified drivers of per capita carbon emission in India for the entire period 1980-2012. However, it would be interesting to understand if these contributions have remained the same over the entire three decades or if they have changed over time. To do this, the same proposed model as in equation (4) is run separately for three different time periods: the first one for period 1980-1990, the second one covering the period 1990-2000 and the third one for the period 2000-2012. The results of these three models are reported in table 4.

Table 4. Fully modified ordinary least squared regression results of extended STIRPAT model as in equation (4) for three time periods, 1980-1990, 1990-2000 and 2000-2012

Period	Change in carbon emission per capita		$\ln I_{va}$	$\ln AHHS$	$\ln A$
	Per cent	Million metric tons			
1980-1990	57.9	0.261	2.46 (1.39)	2.12 (1.85)	0.84** (0.33)
1990-2000	37.7	0.268	1.14 (0.67)	1.51 (3.31)	0.896* (0.13)
2000-2012	63.1	0.618	-0.34 (0.19)	0.57*** (0.28)	0.89* (0.06)

Source: Authors' calculation based on the data used in the model.

Notes: Dependent variable: $\ln I$.

Standard errors are in parenthesis.

Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.1$.

AHHS, average household size.

⁹ Given natural log transformation of both per capita carbon emission and average household size, the coefficient of 1.87 against natural log of average household size is interpreted as a 1 per cent increase in average household size multiples per capita carbon emission by $e^{1.87 \times \ln(1.01)} = 1.0188$, i.e. a 1 per cent increase in average household size increases per capita carbon emission by a 1.9 per cent. The coefficients corresponding to other independent variables are interpreted similarly.

Table 4 shows the changes in per capita carbon emission levels over three decades from 1980 to 2012 and the respective roles of share of industry value added in GDP, average household size and per capita GDP in driving that change. Carbon emission per capita increased by 0.261 million metric tons from 1980 to 1990. This figure increased to 0.268 during the period 1990-2000. Thereafter, from 2000 to 2012, it still increased and more than doubled to stand at 0.618 million metric tons. Increasing per capita GDP has been the most important driver throughout and its influence has remained more or less constant over time. Influence of average household size became important only in the recent years. Industry value added turns out to be statistically insignificant in explaining variations in emission levels over these shorter time periods, as well. Thus, increase in GDP per capita explains the increase in the emission per capita not only for the entire period from 1980-2012 but also during the three shorter periods in between. Though the elasticity of per capita carbon emission with respect to average household size is highest for the longer period from 1980 to 2012, during the shorter periods considered, it is only in the last one and a half decade that much of the increase in the emission level has been due to an increase in the average household size. Thus, real per capita GDP has always been one of major drivers of per capita carbon emission in India.

VI. DISCUSSION

Based on the results in table 3, the rising per capita GDP and the average household size were the most important drivers of carbon emission in India over the last three decades. In particular, the influence of per average household size was the most important driver and even more influential in the recent one and a half decade.

Household size

Family and households hold a prominent place in the social life of any population as the most potent socioeconomic institution. Any change in the household size has a serious social, economic and demographic implication. The national census 2011 drew attention to falling household size during the last three decades, which is becoming an all India phenomenon, while the number of households increased at a phenomenal rate. The rate of growth of the households was close to 30 per cent during the 2001-2011 decade (Nayak and Behera, 2014). The carbon emission elasticity with respect to average household size in India is given to be 1.4 (table 3) for the entire period 1980-2012, indicating that an increase in household size is likely to have caused increased emission levels. This result varies from most of the results obtained by other researchers (Cole and Neumayer, 2004; Liddle, 2004). Though the national census 2011 drew attention to falling household sizes during the last three decades, the rural households still continue to be relatively

large. Sixty-eight per cent of the population of India lives in rural areas (in 2013, according to World Development Indicators). Thus, given the results of the model, the rising household size in rural India may have been one of the major reasons for increased carbon emissions in the country. A comparison of census data of 2011 to 2001 indicates that there has been a major change in the energy consumption pattern of rural households. To meet their fuel requirement for cooking, these households have embraced the substitution of traditional fuel type (firewood, cow dung, leaves and twigs, branches, straw and rice husk) by more fossil fuel-based cooking fuel. The number of rural households using electricity also has risen substantially in recent years (55.3 per cent of the rural households used electricity as their primary energy source for lighting in 2011 as against a 43.6 per cent of the rural households in 2001 (TERI, 2013). This, together with large household sizes in these rural areas, have significantly contributed to energy demand and consequently to the levels of carbon emissions in the country.

Urban households undoubtedly may have larger energy demand as compared to rural households. Be it for cooking, water supply, sewerage network, transportation, information and communication technology or the provision of social infrastructure to enhance quality of life, energy in the form of electricity, oil and gas is an inescapable necessity for the urban population. Yet, there are some positive results pertaining to energy used by the urban population. First, over the years, urban families have moved towards more fuel efficient sources for residential use. In addition, a significant part of the educated urban middle and upper class practice energy conservation as it is a learned habit and to save money (Jain and others, 2014). Second, as the present study points out, it is the larger household size that results in larger emissions. The fact that urban household sizes have fallen over the years is thus a welcome change.

Gross domestic product per capita

The relationship between economic development and environmental pressure resembles an inverted U-shaped curve. India belongs to the middle-development range and, as such, there are likely to be strong pressures on the natural environment, mostly in the form of intensified resource consumption and the production of waste. Furthermore, higher levels of income tend to correlate with disproportionate consumption of energy and generation of greenhouse gas emission (Hunter, 2000). An increase in income and affluence in the country, as measured by GDP per capita over the years coupled with the increased population and the changing population structure, has directly affected the national level CO₂ emission through increased consumption and production activities. There is an obvious increase in consumption demand among the affluent Indians who, in turn, engage in production activities to

satisfy their consumption needs. Ghosh (2010) supports the result that higher economic growth, which leads to more affluent members of the population, stimulates energy demand in end-users sectors, namely industry, transport, commerce, households and agriculture. The majority of commercial energy in India comes from coal, which generates the highest carbon dioxide emission in the country.

Share of industry value added

CO₂ emissions from manufacturing industries and construction contain the emissions from the combustion of fuels in industry. Industry valued added in GDP in India rose on average from 1980 to 2012, though the country did shows signs of deindustrialization during the period 2000-2009. The share of industry, particularly manufacturing in CO₂ emissions averaged about 26 per cent annually. While it ranged from 29 per cent to 34 per cent in the 1980s, more recently during the period 2000-2012, it stayed in a range of 19 to 25 per cent. However, as the model results indicate, the variations in value added of industry in GDP contributed to variations in per capita carbon emissions in the country.

VII. CONCLUSION AND POLICY DIRECTIONS

The present paper attempts to study the impact of population on carbon dioxide emission levels in India and to project the extent of emission in the country in 2050. Using an extended STIRPAT model with FM-OLS estimation techniques on data obtained from World Development Indicators and the Ministry of Statistics and Programme Implementation of the Government of India from 1980 to 2012, the CO₂ emission in India for 2050 is estimated to be 3,516.2 million metric tons. It is found that the average household size and per capita GDP are important factors in determining the level of per capita carbon emission levels in the country. The elasticity of per capita carbon emissions to changes in real GDP per capita was 1.14 for the entire thirty two-year period from 1980 to 2012. When reviewed by decade, it was about 0.84 in 1990s and increased to 0.89 thereafter. Average household size caused emission levels to rise only in the last decade, but the elasticity of per capita carbon emission with respect to average household size for the entire period was much higher at 1.87. Industry value added and variations in it over this period did not appear to have had an impact on emission levels.

Gross domestic product per capita at purchasing power parity (PPP) in India averaged \$3,074.12 from 1990 until 2013, reaching an all-time high of \$5,238.02 in 2013 and a record low of \$1,176.44 in 1991. The GDP per capita, in India (PPP) is equivalent to 29 per cent of the world's average (World Development Indicators). The GDP per capita has been growing at the rate of 5.6 per cent annually. Thus, as the

growing affluence in the country in general is leading to an increased level of consumption and production activities, it is important to ensure energy conservation and emission reductions in fields of production. At the same time, the likely impact of increasing affluence, urbanization, and movement towards nuclear family system on increased per capita use of residential energy cannot be ignored. Policies need to be designed to prevent waste and encourage conservation. The policies should be structured to balance emission control and improved standards of living.

Though rural households remain relatively large in size, the median household size in urban India has been falling for some time and is now less than four for the first time in history (India, Ministry of Home Affairs, 2011). This trend coupled with the growing rate of urbanization in the country is undoubtedly good news as far as carbon emission levels are concerned. However, the larger size of rural households along with the shift in their energy consumption pattern in favour of fossil fuel based energy continues to be one of the major challenges in controlling carbon emissions in India. While a change in the consumption pattern away from traditional types is positive, the larger size of households is an unfavourable feature that unfortunately is not likely to change in the short run. Therefore, it is absolutely necessary to ensure that these rural households get increased disposable income through additional income-generating opportunities, so that they can afford more modern and efficient fuel types. At the same time, the availability and accessibility of clean fuel types in rural areas need to be ensured. The Government of India has already taken an initiative in this direction by seeking to increase the distributorship of liquefied petroleum gas (LPG) in the rural areas, but it needs to work on the affordability of rural households for using these alternate fuel types. Lastly, efforts must be made to educate rural households on the advantages of energy conservation.

With a current population growth rate of 1.58 per cent, the most serious impact on carbon emission levels in India, is undoubtedly its population size. The population grew from 868 million in 1990 (2 per cent per annum) to 1.04 billion in 2000 (1.7 per cent per annum) and further increased to 1.2 billion in 2010 (1.2 per cent per annum). The population of India represents 18 per cent of the world's total population, which arguably means that one in every six people on the planet is a resident of India. With the population growth rate at 1.58 per cent, India is predicted to have more than 1.5 billion people by the end of 2030. Every year, India adds more people than any other country in the world, and, in fact, the individual population of some of its states is equal to the total population of many countries. Some of the reasons for the country's rapidly growing population are poverty, illiteracy, the high fertility rate, a rapid decline in death rates or mortality rates and immigration from Bangladesh and Nepal.

Thus, while the growing population is obviously expected to raise the country's carbon emission levels to alarming levels, the important result that the present study comes up with is that along with the growing population, the increasing GDP per capita and changing household size magnifies the problem even more.

India, therefore, faces the enormous challenge of curbing greenhouse gases (CO₂ emissions: 2.6 billion tons in 2013) as its population and economy expands and its population structure undergoes change. In 2010, India voluntarily committed to a 20 per cent to 25 per cent cut in carbon emissions relative to economic output by 2020 against 2005 levels. Under current policies, its carbon dioxide emissions will double by 2030, according to the International Energy Agency. Thus, policies that would help to reduce emissions are undoubtedly curbing population growth, but most importantly, large households in rural areas leading to greater emission levels needs to be addressed urgently. Policies towards reduced and efficient use and waste reduction with respect to both residential and commercial use of energy will definitely help in the short run.

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