Economic Development and CO_2 Emissions: A Household Level Study of Lucknow District in Uttar Pradesh

THESIS

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Under the Supervision of
Prof. Sanatan Nayak

Submitted by
Ekta Srivastava

DEPARTMENT OF ECONOMICS
SCHOOL OF ECONOMICS & COMMERCE
BABASAHEB BHIMRAO AMBEDKAR UNIVERSITY
(A CENTRAL UNIVERSITY)
Vidya Vihar, Raebareli Road, Lucknow-226025, (U.P.), India

Enrolment No: -699/18 Year 2021

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I hereby, declare that this thesis entitled **"Economic Development and CO_2 Emissions: A Household Level Study of Lucknow District in Uttar Pradesh"** submitted to Babasaheb Bhimrao Ambedkar University in fulfillment for the award of Doctor of Philosophy in Economics is my original work. It has not been submitted in part or full for any other diploma or degree of any other University. The indebtedness of the candidate to others has been duly acknowledged at relevant places.

This study is carried out under the supervision of Prof. Sanatan Nayak, Department of Economics, Babasaheb Bhimrao Ambedkar University Lucknow, Uttar Pradesh, India. This is also declared that the thesis is essentially free from all kinds of plagiarism.

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Ekta Srivastava
(Enrolment No. 699/18)
Department of Economics
Babasaheb Bhimrao Ambedkar University,
Lucknow, Uttar Pradesh

116/DE/BBAU/2021
Date - 27/09/2021

CERTIFICATE

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Date: 27.09.2021

Sanatan Nayak
Supervisor
अर्थशास्त्र विभाग/Deptt. of Economics
बी०बी०ए०यू०, लखनऊ/B.B.A.U., Lucknow

Sanatan Nayak
Head of the Department
विभागाध्यक्ष/HEAD
अर्थशास्त्र विभाग/Deptt. of Economics
ए०एस०एस०एस०/A.S.S.S.
बी०बी०ए०यू०, लखनऊ/B.B.A.U., Lucknow

बाबासाहेब भीमराव अम्बेडकर विश्वविद्यालय
(केन्द्रीय विश्वविद्यालय)
विद्या विहार, रायबरेली रोड, लखनऊ–226 025

BABASAHEB BHIMRAO AMBEDKAR UNIVERSITY
(A Central University)
Vidya Vihar, Raebareli Road, Lucknow-226 025

Letter No.-840/COE/BBAU/2020 Dated: 28/1/2020

Ph.D. Course Work Certificate

This is to certify that **Ekta Srivastava**, Enrollment No. 699/18 Ph.D. Research Scholar, Department of Economics of the University has successfully completed her Ph.D. Course work in the examination held during December, 2018.

Deputy Registrar (Exams.)

Gmail ekta srivastava <ektasri95@gmail.com>

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Ekta Srivastava
Research Scholar
Department of Economics
Babasaheb Bhimrao Ambedkar Central University
Lucknow

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Dedicated to

"Mother Earth"

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PREFACE

The basis for the study titled "**Economic Development and CO_2 Emissions: A Household Level Study of Lucknow District in Uttar Pradesh**" emerges from the current global crisis of climate change which is even more severe crisis for developing nations like India which are facing developmental challenges as well as high vulnerability to climatic changes.

As supply side interventions such as switching to renewable energy or green technology is a costly affair for many developing nations, it is advisable to search and implement cost effective demand side and behavioural interventions such as following the principle of 3R's (Reduce, Reuse and Recycle) along-with infrastructural changes.

This study, thus, is an attempt to understand the role of households as a causal factor as well as the mitigating agents of climate change.

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Abbreviations

ANCOVA	Analysis of Covariance
BASIC	Brazil, South Africa, India, China
BAU	Business As Usual
CAGR	Compounded Annual Growth Rate
CPR	Common Property Resources
ECM	Emission Coefficient Method
EKC	Environment Kuznets Curve
EU	European Union
GDP	Gross Domestic Product
GSDP	Gross State Domestic Product
GHG	Greenhouse Gas
GWP	Global Warming Potential
HCE	Household Carbon Emissions
IAM	Integrated Assessment Models
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquefied Petroleum Gas
NAPCC	National Action Plan on Climate Change
NATCOM	National Communication
OECD	Organization for Economic Cooperation and Development
RES	Renewable Energy Source
RF	Radiative Forcing
TEC	Transferable Emission Credit
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

Chapter 1

Economic Development and Environment: Debate and Methods

"Yes, we can save what is left. Yes, we can repair and make amends. We can reclaim nature and restore ourselves. There is a bridge at the edge of the world."

- James Gustave Speth (2008:13)

1.1 Introduction

Climate change is a global issue which is increasingly being manifested in the form of frequent natural disasters, melting glaciers, extremely varying rainfall patterns and increasing global temperatures[1]. It is a scientific phenomenon induced due to increasing concentrations of greenhouse gases which obstruct the path of infrared rays radiated back by the earth's surface. Rapid economic growth regardless of its resultant environmental impact is the main culprit of climate change (Hegerl 2007: 727). The rationality of economic growth and its relationship with environment has been a matter of research for over a century now. What is the relation between growth and environment? Is economic growth and environment always an issue of trade off or they can go hand-in-hand? Has the global growth process been sustainable? What are the social, economic, political and demographic factors which have led to a certain environment-economy relationship? A lot of issues have cropped-up since economic growth is highly multidimensional in nature. However, no consensus has been reached till date on this issue.

The following section elaborates upon the major viewpoints that have emerged in the environment economy debate.

1.2 Economic Development and Environment Debate: The Approaches

A very common view is that economic growth leads to environmental pollution. Economic development can be harmful to environment in generally two ways. One is by the extraction of natural resources like mining, deforestation and consequent biodiversity loss, etc. and the other

[1] https://www.climate.gov/news-features/understanding-climate/climate-change-glacier-mass-balance

is through the consumption of pollution intensive goods and services, due to access to high income. Post-World War, quest of Russia for economic growth led to the strangulation of Aral Sea and consequently to other related issues like vanishing fisheries and increased water salinity (McNeill and Engelke 2014: 156-157). In a similar way Mao's China destroyed forests and polluted the Mekong river, which led to alterations in the local climate and brought in more sharp cycles of drought and flood (ibid: 156 -159). A very interesting study on the impact of economic trends on air pollution (Davis 2012: 1951), observed that the air quality improves during economic downturn. A latest study on the effect on lockdown during COVID-19 on the air quality of Delhi found that PM_{10} and $PM_{2.5}$ concentrations reduced by about half compared to pre-lockdown period. Also, the air quality of heavy transportation and industrial regions improved by nearly 60% (Mahato et al 2020: 5).

Contradicting the earlier view, the Environment Kuznet's Curve (EKC) hypothesis, suggests that economic growth itself leads to improvement in environment quality, once a threshold level of income per capita is reached (Grossman and Krueger 1995: 353-377). This view believes that it is necessary to bear some environment degradation initially in order to get the benefits of economic growth (Ali and Oliveira 2018: 3). There could be a number of reasons for such inverted U-shaped relation. It may be due to improvement in technology overtime, increased focus of people on the quality of life and environment once their basic needs are fulfilled, or due to change in the structure of the economy from primary to tertiary, which is less polluting (Everett et al 2010: 17). A vast literature concludes that the EKC holds true in High and Upper Middle income group countries as they have access to energy efficient technologies, which are way too costly for low income countries (Al-Mulali et al 2015: 319). But this environment quality isn't solely due to their domestic environmental regulations and technology. Some studies found that owing to trade openness, the rich nations shifted the environmental burden to the poor developing nations who compete for international competitiveness and foreign investments[2] (Aşıcı & Acar 2015: 2; Schütz et al 2004: 55; Stern 2004: 1428). Also, Brock and Taylor (2003: 2) put forward the Environment Catch-up Hypothesis (ECH)[3], which states that initially poor countries experience greater environmental degradation than rich countries and worse environmental quality at all levels of income; despite this, differences in environmental quality between rich and poor diminish over time. A major drawback of EKC is that it may encourage the business as usual approach (BAU)[4], i.e., policy makers to pursue economic growth and assume good environment quality as natural outcome of it overtime (Arrow et al 1995: 520; Stern et al 1996: 1158; Stern 2017: 24).

Another dominant view emerged with the publication of '*The Limits to Growth'* by Meadows et al (1972: 17-185). Its central idea was that the 'earth is finite' and over- pollution will lead to the collapse of the economy itself. It developed a model to track the global environment economy, which suggested that if BAU continues, the world will collapse. This view believes that the technological advancement may act as substitute of and enhance the efficiency in the use of natural capital but the decline of basic environmental system itself, is an issue of concern (Kolstad 2011: 65-74). Early research studied resource depletion and pollution as separate issues (Ali and Oliveira 2018: 8). Later, scholars criticized this narrow approach. They saw environmental decline in terms of both resource depletion and pollution (ibid: 8). In their study of the long run impact of climate change on growth covering 176 countries over the time period 1960-2014, Kahn et al (2019: 44), found that the labour productivity was highly affected by temperature changes, although the impact of precipitation changes was not significant. They predicted that if average global temperature increases by 0.04°C per year, in the absence of mitigation policies, the world real GDP per capita will be

[2] "Pollution Havens Hypothesis" or "Race to the bottom"
[3] https://econ.ucalgary.ca/sites/econ.ucalgary.ca/files/taylor.pdf
[4] A scenario for future patterns of activity which assumes that there will be no significant change in people's attitudes and priorities, or no major changes in technology, economics, or policies, so that normal circumstances can be expected to continue unchanged.

reduced by 7.22 percent by 2100. OECD estimates[5] suggest that the impact of outdoor air pollution on labour productivity, health expenditures and agricultural crop yields, will lead to global economic costs that would gradually increase to 1% of global GDP by 2060. Apart from the health and productivity effects, environment pollution led loss of ecosystem services also leads to large economic loss. Beier et al (2017: 19-27) studied the impact of acid pollution in Adirondack region (USA). They found that acid-impaired hardwood forests had less than half the value of non-impaired forests. Also, acidification of lake water caused significant losses of value in recreational fisheries.

Yet another view is that pollution abatement will lead to loss in economic growth. For any pollution abatement measure, there is an opportunity cost, as the government could have used that fund for growth generation activities. Although the pollution abatement technology sector may generate some growth, there may be short term loss of economic growth (Ali and Oliveira 2018: 6). This is a major dilemma being faced by the developing nations recently. They face an economic growth and environment trade off. Paris Agreement 2015 came to their rescue by providing for a Green Climate Fund wherein the developed nations have to provide for $100 billion per year to support climate-resilient low-carbon growth in poor economies. The wealthy nations however, have failed to comply with it completely. In 2017, USD 71.2 billion were given to the fund, of which USD 13.3 billion (19%) was used for adaptation, USD 5.5 billion (8%) for cross-cutting activities and USD 52.4 billion (73%) for mitigation[6]. Dechezleprêtre and Sato (2017: 19) observed that in short run, environmental regulations have small, statistically significant adverse effects on trade, employment, plant location, and productivity in energy-intensive sectors (due to lack of innovation). But the scale of these

[5] https://www.oecd.org/environment/indicators-modelling-outlooks/Policy-Highlights-Economic-consequences-of-outdoor-air-pollution-web.pdf
[6] Climate Finance Provided and Mobilised by Developed Countries in 2013-17, OECD. https://www.oecd-ilibrary.org/docserver/39faf4a7-en.pdf?expires=1591872373&id=id&accname=guest&checksum=F5EBC95170C54C04140373686D6CABE4

impacts is very small. The Porter's hypothesis, using the example of Dutch Flower Industry, argues in a dynamic perspective that the environment regulations may lead to innovations which may more than fully offset the costs of complying with them (Porter and Linde 1995: 121).

The latest approach is that of a "circular economy". The theoretical background of this approach is very diverse and comprises of ecological economics, environmental economics and industrial ecology (Ghisellini et al 2016: 24). It was proposed by Boulding (1966: 3-14). Based on this article, Pearce and Turner (1990: 1-361) developed the concept of circular economic system. They disagreed with the traditional linear economic system and advocated recycling to attain a sustainable development path. European Commission (2015) defines a circular economy (CE) as the one in which "the value of products and materials is maintained for as long as possible; waste and resource-use are minimized, and resources are kept within the economy when a product has reached the end of its life, to be used again and again to create further value". Ellen MacArthur foundation (a non-profit organization launched in 2010), is one of the major advocates of circular economy. It strongly condemns the "take-make-waste" culture of the traditional linear economy. Geisendorf and Pietrulla (2017: 2-10) attempt to clarify the concept of CE by differentiating it with the other very closely related concepts of cradle-to-cradle, blue economy, regenerative design, closed supply chains, natural capitalism, industrial ecology, performance economy, bio-mimicry and reverse logistics. The CE cannot be surely a panacea to environment economy trade-off, as reduction in consumption will affect the human development by means of reduced employment opportunities. Also, even an efficient system may fail if Jevons paradox[7] comes into action (Ali and Oliveira 2018: 11).

[7] Jevons paradox occurs when technological progress or government policy increases the efficiency with which a resource is used, but the rate of consumption of that resource rises due to increasing demand, thus failing the purpose of increased efficiency.

While on the one hand many still refuse to accept climate change as a real problem, on the other hand the need for economic growth is questioned. Speth (2008: 111-114) questions whether *to grow or not to grow*? He suggests that an environment friendly growth is possible only if there is a sustained green technological revolution at a very high rate. On the contrary, he observes that, in reality, the governments all over the world are committed to growth and nothing much is done at the required scale on the green technology front.

1.2.1 CO_2 as the Focus of Climate Change Mitigation

A parallel research on environmental impacts was going on in the scientific field. It began with the work of Joseph Fourier in 1820s, who discovered the phenomenon of greenhouse effect. His work was carried forward by Eunice Newton Foote and John Tyndall in 1850s (Stern 2006: 7). They found that water vapour and hydrocarbons (methane, carbon dioxide, etc.,) despite constituting only 1% of the atmosphere, strongly blocked outgoing solar radiations (Jackson 2020: 105- 111). Revelle and Suess (1957: 18-27) found that oceans absorb CO_2 after nearly ten years of fossil fuel combustion and the CO_2 concentration is increasing continuously. Confirming their findings in 1958, Charles Keeling of the Scripps Institution of Oceanography, UC San Diego, began measuring carbon dioxide at Mauna Loa, initiating what is now known as the “Keeling Curve.” The curve shows that the CO_2 concentration has been continuously increasing in the atmosphere[8].

In 1970s, a new debate emerged among the climate scientists, i.e., ‘the global cooling’!! Mitchell (1963: 161-181) showed that between mid-1940s to mid-1970s, a dip in global average temperature was observed, giving rise to fears of coming ice-age. This post-World War II cooling was attributed to increase in the aerosol concentrations in the atmosphere. Bryson (1974: 753-760) predicted that aerosol cooling will dominate CO_2 warming, which may trigger

[8] https://keelingcurve.ucsd.edu/

an ice age. This trend, however, was not global, while the Northern Hemisphere was cooling, in the Southern Hemisphere, the temperature was increasing (Damon and Kunen 1976: 447). Peterson et al (2008: 1330), reviewed climate science literature from 1965 to1979 and concluded the cooling hypothesis to be a myth.

By the early 1980s, the cooling trend had stopped and global warming became more prominent. In 1988, summer was the hottest on record. 1980s also witnessed Vienna Convention (1985) and Montreal Protocol (1987) to reduce ozone depletion. Thus, a consensus on climate change due to global warming led by greenhouse gases emerged in 1980s. In 1988, IPCC (Intergovernmental Panel on Climate Change) was formed by WMO (World Meteorological Organisation) and UNEP (United Nations Environment Programme) to assess the science related to climate change. IPCC assessment reports identified, that the greenhouse gases are majorly emitted from anthropogenic sources (IPCC 2014: 4).

Carbon dioxide is the most important GHG. Other greenhouse gases have much greater Global Warming Potential[9] (GWP) than CO_2. For example, methane (CH_4) is estimated to have a GWP of 28–36 over 100 years and Nitrous Oxide (N_2O) has a GWP 265–298 times that of CO_2 for a 100-year timescale[10]. However, it is the abundance and long residence time (thousands of years) of CO_2, which makes it the most prominent greenhouse gas. CO_2 constitutes over 70% of the total GHG emissions, followed by methane and nitrous oxide. AR-5 of IPCC (IPCC 2014: 4) observes that "*between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 $GtCO_2$. About 40% of these emissions have remained in the atmosphere (880 ± 35 $GtCO_2$); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean.*"

[9] It is a measure of how much energy the emissions of 1 ton of a **gas** will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2).
[10] https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

Table 1.1:Contribution of GHGs in the World

Greenhouse Gases	1970[a]	1990[b]	2010[c]	2016[d]
CO_2	72	74	76	73
Methane	19	18	16	19
Nitrous Oxide	8	7	6	6
F-gases	1	1	2	2

Source: IPCC (2014) based on global emissions from 2010 for (a), (b), (c). Details about the sources included in these estimates can be found in the *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. For (d), find, https://www.pbl.nl/sites/default/files/downloads/pbl-2017-trends-in-global-co2-and-total-greenhouse-gas-emissons-2017-report_2674_0.pdf

Note: Figures are in percentage.

1.2.2 Sectoral Contribution to CO_2 Emissions.

The sector-wise global CO_2 emissions for the years 1990, 2000, 2010 and 2015 (Table 1.2) show that the highest contribution to CO_2 emission is from electricity and heat producers, followed by transport, industry, residential and other sectors.

Another observation made is that, the share of residential sector has declined from 9% in 1990 to 6% in 2015. The definition of emissions from residential sector includes all emissions from fuel combustion in households (IPCC Source/Sink Category 1A 4b). It covers only the emissions from cooking, heating or cooling in the households. The indirect emissions, emissions from transport used by a household, etc., are not included as a part of residential emissions in it.

Table 1.2: Sectoral Composition of Global CO_2 Emissions

Sector	1990	2000	2010	2015
Heat and Electricity production	37	40	41	41
Other energy industries	5	5	5	5
Industry	19	17	20	20
Transport	22	25	23	24
Residential	9	8	6	6
Commercial and public services	4	3	3	2
Agriculture	2	1	1	1

Source: Estimated from IEA CO_2 Emissions from Fuel Combustion https://www.iea.org/subscribe-to-data-services/co2-emissions-statistics.

Note: Figures are in percentage.

1.2.3 Household CO_2 Emissions

Households play an extremely crucial role in the GHG emissions by their consumption activities (Zhang et al 2015b: 874). Rapid urbanization-led increasing living standard has resulted into increased household energy consumption. The GHG emissions by households can be categorized as direct and indirect emissions. Direct or on-site emissions are related to direct household fuel use, such as electricity, heating, gas and other liquids. While, the embedded/embodied/indirect emissions, are those that are generated in the production and distribution processes of goods and services for households, such as emissions that occur in the manufacturing of food, clothes, furniture and services (Bin and Dowlatabadi 2005: 199; Zhang et al 2015b: 874; Druckman and Jackson 2016: 185).The direct and indirect household carbon emissions together are responsible for 60% to 80% of a countries total greenhouse gas emissions (Edgar et al 2009: 6417; Benders et al. 2006: 3612; Kok et al. 2006: 2746; Moll et al. 2005: 260). Thus, in order to meet global emission reduction targets, reduction in household carbon emissions is necessary (Zhang et al 2015b: 881). It is also crucial to estimate the GHG emissions as well as the factors responsible for GHG emissions by a household.

Earlier, most of the environmental policies targeted the supply side for reduction in emissions, but with increasing research on the role of households in GHG emissions, the demand side approach is gaining more and more attention (Kok et al 2006: 2744). Wynes and Nicholas (2017: 1), very aptly marked the gap in the current carbon mitigation policies. They highlighted the significance of individual behavior (demand side) in transitioning to a low-carbon lifestyle. Zhang and Wang (2017: 116-124) reviewed carbon abatement policies in 144 countries from demand side (carbon tax, feed in tariff, cap and trade, tradable renewable energy certificates, subsidies and loans and funds) and supply side (standards, targets and regulations, tendering and net-metering) perspective. Income level was found to be an important determining factor in a country's policy approach (ibid: 116-124).

The demand side must be held equally accountable for its environmental impact. The international climate policy is concentrating only on the technological innovations and economic incentives. It ignores the potential of behavioural changes in bringing down our carbon footprint[11] (Dubois et al 2019: 145). Therefore, a number of studies are being carried out all over the world in this regard.

Based on the above background at Introduction and subsequent sections, the study followed by a literature review of household carbon emissions, research gap, objectives,

[11] Amount of Carbon dioxide being emitted by an activity or an individual or an organization.

hypotheses, methodological framework and significance of the study. The last section briefs upon the chapter plan.

1.3 Literature Review

1.3.1 Determinants of Household Carbon Emission: International Experience

Kenny and Gray (2009: 263-266) carried out a survey of 103 households in Ireland in which they found that the household energy consumption becomes more efficient when occupancy rate increases. Olsen et al (2016: 586) attempted to study the carbon footprint of Norwegian household consumption during the period 1999–2012 using Multi-Regional Input Output model (MRIO). Expenditure on transport, housing and food was found to be contributing the most to the carbon footprint of households in Norway. Olaniyan et al. (2018: 23) studied the socio-economic factors responsible for direct household emissions in Nigeria. The study found household income, household size, motorisation and literacy rate to be the major factors that influenced the level of Nigerian household carbon emissions. In China, a large number of studies have been carried out on this issue (Wang et al. 2015: 257-272; Zheng et al. 2011: 761-792). The direct and indirect CO_2 emissions from household consumption accounted for more than 40% of total carbon emissions from primary energy utilization in China during 1992-2007 (Liu et al 2011: 1758). Li et al. (2015: 107-112) studied the impact of urbanization on direct and indirect household emissions in China during 1996-2012. They found that urban households had more carbon emissions from indirect sources, compared to the rural households.

Wang and Yang (2014: 6) studied the indirect emissions from rural and urban households in China during 1999-2010 by using Consumer Lifestyle Approach (CLA). They found declining Energy Ecological Footprint[12] (EEF) among rural households while the

[12] Land needed to absorb the pollution (CO2) caused by the combustion of fossil energy.

opposite trend was observed among urban residents. Dietz et al (2009: 18452-18456) applied a behavioral approach complementing engineering and economic approaches to estimate the achievable potential for near-term emissions reduction from behavioral change in US households. They found that nearly 20% reduction in emissions in the household sector is possible within 10 years if the most effective non-regulatory interventions are used.

1.3.2 Determinants of Household Carbon Emission: National Experience

A very limited number of studies are found in India on CO_2 emissions from household sources. These studies are largely based on secondary level data sources. Das and Paul (2014: 90-103) studied the CO_2 emissions from household consumption in India between 1993–94 and 2006–07 using input-output analysis. CO_2 emissions were found to have increased by 86% during this period. During 1993–94 and 2006–07, direct emissions from households have increased from usage of primary energy (6%) and secondary energy (171%). Rapid urbanization and changing lifestyles influenced the substitution of coal with diesel and electricity. Both Liquefied Petroleum Gas and electricity were being used for cooking. Increasing number of private vehicles led to rise in usage of petrol/motor gasoline for transport. Electricity usage for home illumination and entertainment has also gone up during this period. The study observed a switch towards cleaner energy sources. The results for indirect emissions from household consumption reveal that maximum increases have been brought about by consumption of "transport" (21%), followed by "food, beverage, tobacco and primary goods" (20%), "recreation" (12%) services, house building (5%) and other personal services (4%) followed next with lower increase in emissions. This has been mainly due to activity and population effect.

Further, Zhu et al. (2018: 1545–1552) carried out a structural decomposition analysis of India's carbon emissions and its intensity during 2007-08 to 2013-14 by using Input-Output model. It was found that India's carbon emissions were mainly driven by private consumption, followed by investment (or gross fixed capital formulation) and exports. The emissions embedded in private consumption were found to have increased from 417.50 Mt- CO_2 (metric ton) to 660.45 Mt- CO_2, but its share slightly decreased from 54.5% to 51.6% during this period. In contrast, the share of emissions embodied in investment remained stable, but that in exports increased from 14.0% to 18.1%. Particularly, the emissions embodied in exports doubled from 172.27 Mt- CO_2 to 349.53 Mt- CO_2 during the above mentioned period. The major contributors to emissions from private consumption in 2007-08 were agriculture, transport and communication services while those in 2013-14 were transport and communication services and food, beverages and tobacco products. Therefore, the findings of the study observed an increase in the consumption of transport and communication services and food products, with increase in income of the Indian households. The study suggests more efforts should to be put on household consumption behavior in order to reduce the CO_2 emissions in aggregate.

Both the studies made the common observation of increasing emissions from consumption of transport services and food products, with increasing population and income. Such studies give a glimpse of an aggregate picture, however for accurate and responsible policy formulations; more micro-level studies are needed. In line with this objective, Ramachandra (2012: 5828) developed a focused study on the state wise carbon emissions (CO_2, CO and CH_4), using region specific emission factors and state wise carbon sequestration[13] capacity. Domestic energy consumption (rural and urban consumption) was found to contribute 88.3 Teragram/year, 14.7 Tg/year and 0.6 Tg/year of CO_2, CO[14] and CH_4[15] respectively in the

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[13] Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change.
[14] Carbon mono-oxide
[15] Methane

year 2001. CO_2 emissions from this sector was found to be largest in Andhra Pradesh (14.6 Tg/year) followed by Uttar Pradesh (9.9 Tg/year), and Maharashtra (6.5 Tg/year).

Few more studies have attempted to bring out a further decentralized level of household CO_2 emissions in India. Ahmad et al. (2015: 11312-11318) used the micro-data of 60 largest cities of India to map the direct energy use of urban households in India and their GHG emission pattern and its determinants. The study found that income, access to electricity, and education level are driving forces of emissions, while emissions reduced with household size and population density. Delhi and Chennai were found to be the high emitting cities, while low-emitting cities were Bareilly and Allahabad. The study suggests renewable sources of energy, urban greening and increasing provision of public transport to reduce electricity consumption and mitigate emissions. Ramachandra et al (2014: 207-267) assessed the sector-wise carbon footprint across major cities (Delhi, Greater Mumbai, Kolkata, Chennai, Greater Bangalore, Hyderabad and Ahmedabad) in India. Under the domestic sector emissions, greenhouse gases emissions from electricity consumption in domestic sector and fuel consumption were accounted in the study. In Delhi during the year 2009, 11690.43 Gigagram of CO_2 equivalent was emitted from the domestic sector, which was the highest among all the cities considered. Hyderabad and Ahmedabad were found to have the lowest emissions from domestic sector. The above micro level studies are crucial in framing a region specific policy. However, most of the studies in this sector are based on secondary level data. In order to bring out the impact of behavioural and demographic factors, a primary level study is also needed.

1.3.3 Factors Affecting Household Carbon Emissions (HCEs)

Zhang et al. (2015b: 877-879) identified seven major factors influencing the household carbon emissions, including household income, size, age structure, gender of the head, education, location and rebound effects. All the studies worldwide conclude that HCEs rise with income. Different age groups, however were not found to have same impact in all the studies. Studies on the impact of the education level of household members on carbon emissions have produced varying results. While some of them claim that a higher education level leads to higher emissions, the others suggest vice-versa. The location of a household was found to play a key role in the energy consumption of the household. The role of gender was found to be important in case of indoor energy consumption only. Another important issue was rebound effect, which refers to the reduction in expected gains from new energy efficient technologies because of behavioral or other systemic responses. For instance, the low electricity consuming LED bulbs, might motivate some people to use them even when there is sufficient light, leading to unnecessary greater electricity consumption.

1.4 Methods to Estimate Household Carbon Footprint

Various methods have been used by researchers to estimate household carbon emissions (both direct and indirect). Reviewing these methods enables us to find out the most suitable methodology for our present study. Zhang et al (2015b: 875-877) reviewed the different methodologies used to quantify household carbon emissions (HCE). They stated four main methods used by the researchers to analyze HCE.

1.4.1 Input-Output Model (IOM)

Input–output economic analysis was developed by the 20th century Russian-born U.S. economist Wassily W. Leontief. Encyclopedia Britannica defines it as a table in which the interdependence of an economy's various productive sectors is observed by viewing the product of each industry both as a commodity demanded for final consumption and as a factor in the production of itself and other goods. Leontief (1970: 262-271) extended this approach to environment studies. Kok et al (2006: 2744-2761) applied the modified forms of IO approach to households in Netherlands, input–output energy analysis, based on national accounts (IO-EA-basic), input–output energy analysis combined with household expenditure data (IO-EAexpenditure), hybrid energy analysis, input–output analysis combined with process analysis (IO-EA-process).

1.4.2 Life Cycle Assessment (LCA)

Muralikrishna and Manickam (2017: 57-75) interestingly defined Life Cycle Assessment as, "a cradle-to-grave or cradle-to-cradle analysis technique to assess environmental impacts associated with all the stages of a product's life, which is from raw material extraction through materials processing, manufacture, distribution, and use." It is a standard methodology and its standards are provided by International Organisation for Standardisation (ISO) in ISO 14040 and 14044. ISO also describes the four main phases of an LCA viz., (i) goal and scope, (ii) inventory analysis, (iii) impact assessment and, (iv) interpretation.

1.4.3 Emission Coefficient Method (ECM)

This approach is based on the method used by IPCC (2006: 2.11-2.24). IPCC provides for three tiers of ECM, which are as follows.

Table 1.3: Approaches for Measurement of CO_2 based on ECM

Tier 1 approach	Emissions = Σ (Fuel consumption * Default emission factor)
Tier 2 approach	Emissions = Σ (Fuel consumption * Country-specific emission factor)
Tier 3 approach	Emissions = Σ (Fuel consumption * Technology-specific emission factor)

Source: IPCC 2006, Guidelines for National Greenhouse Gas Inventories

Note: Tier 1 fuel combustion from national energy statistics and default emission factors; Tier 2 fuel combustion from national energy statistics, together with country-specific emission factors, where possible, derived from national fuel characteristics; Tier 3 fuel statistics and data on combustion technologies applied together with technology-specific emission factors; this includes the use of models and facility level emission data where available.

1.4.4 Consumer Lifestyle Approach

Pointing out the limitations of sector based approach, Bin and Dowlatabadi (2005: 197-208) proposed Consumer Lifestyle Approach to study the relationship between consumer activities and their environmental activities in US. The basic premise underlying consumer lifestyle research is that by understanding consumers we can design better public policies.

Table 1.4: Comparative Chart on Methods on Measurement of CO_2

Methodologies	Advantages	Disadvantages
Input-Output Method	Provides a standard method of analysis that can be updated or applied to different populations in a uniform manner and can be easily combined with other methods.	Lacks reliability when forecasting long-run effects and assumes a fixed technology coefficient which cannot reflect technological improvements and elasticity.
Life Cycle Approach	Reflects the effects of the entire life cycle.	Data intensive and time consuming.
Emission Coefficient Method	Presents an easy calculation process.	The coefficient is difficult to estimate.
Consumer Lifestyle Approach	Considers the interacting factors that influence consumers. It combines the advantages of IOM and ECM.	The model application is complicated.

Source: Zhang et al. (2015b: 877),

Considering the various advantages and disadvantages of the household CO_2 estimation methods and given the limited data availability in case of India, emission coefficient method is taken to be the most suitable method for the present study.

1.5 Research Gap and Significance of the Study

1.5.1 Highly Uncertain Knowledge Stock in Social Sciences

The issue of climate change is well researched in physical sciences. However, studies on its socio-economic costs and appropriate mitigation policies are still in a novice phase. Most research has concentrated on uncertainties about the natural sciences (climate modelling and carbon cycle). According to William Nordhaus' Integrated Assessment Models[16], the uncertainties involving natural sciences comprise about 15% of the total quantified uncertainties, while those involving behavioural and social sciences account for about 85% of the value of better knowledge**.**

1.5.2 Unreliability/Unavailability of Data Sources

Maintaining an inventory of GHG emissions is a fundamental building block in a country's climate policy. However, there is no up-to-date stock of carbon emissions data at decentralized level in India at present. India's Second Biennial Update Report to UNFCCC (2018: 14) acknowledges, "India does not have any GHG monitoring and mitigation assessment-related domestic Measurement, Reporting and Verification (MRV) arrangements presently."

1.5.3 Geographical Research Gap

The researches on estimation of carbon cost and emissions have largely been limited to China, US and UK. Attention in this area is needed in India as well, as India is the fourth largest emitter of GHG in the world.

1.5.4 People's Willingness To Reduce Carbon Emissions is Unmeasured

Consumers are the major target group of the carbon emission reduction drive. More studies are needed to assess people's willingness to reduce their emissions, in view of their varying locations, income levels, education level, etc.

[16] https://www.nber.org/reporter/2017number3/integrated-assessment-models-climate-change

1.5.5 Lack of Research on Demand Side Approaches

The rise of fossil fuel led CO_2 emissions in 2018 was mainly driven by higher energy demand (Fawzy et al 2020: 2070). As the current global climate mitigation policy is primarily focused upon supply side approaches of reducing emissions, which are very cost intensive and difficult to implement for developing nations, it is important to see demand side policies as a potential alterative.

1.6 Objectives of the Study

- To assess the linkages of economic growth with various social, demographic and environmental factors among top twenty CO_2 emitting countries in the world during the period 1960-2017.
- To assess the extent of residential energy consumption, CO_2 emissions and their monetary value and the socio-economic factors impacting on total residential emissions in 22 major states in India for the year 2018-19.
- To estimate the total CO_2 emission by household fuel consumption and its economic value and the impact of socio-economic factors on the annual direct carbon emissions from households in Lucknow city.
- To estimate the extent and dimension of environment awareness, community participation and willingness to sacrifice in Lucknow city.

1.7 Hypotheses of the Study

- The socio-economic factors (population and per capita GDP) affect the level of CO_2 emissions in the top twenty CO_2 emitting nations.
- Per capita gross state domestic product and population density have positive and negative relationship respectively with the state’s CO_2 emissions.

- Households with higher income tend to emit more CO_2 as compared to households with lower income level.
- Household's environmental awareness does not ensure its environment-friendly actions.

1.8 Methodological Framework

1.8.1 Study Area

India comprises of 29 states and 7 union territories at present, which are highly diverse in socially, economically, demographically, climatically and geographically. Given such variations, each state shows a different response to the changes in climate. Mani et al (2018: 10) in a World Bank report on 'South Asia's Hotspots' found Chhattisgarh, Madhya Pradesh, Rajasthan, Uttar Pradesh, and Maharashtra to be the top five most vulnerable states to changes in temperature and precipitation. Also, there is a large variation in each state's contribution to CO_2 emissions, leading to climate change. Ghoshal and Bhattacharya (2008: 41-73) found Uttar Pradesh to be the leading CO_2 emitting state in the country during the period from 1980 to 2000, followed by Madhya Pradesh and Maharashtra. GHG Platform-India (2017) analyzed GHG Emissions in India from 2005 to 2013 and found maximum overall emissions to arise from the states of Uttar Pradesh, Andhra Pradesh, Maharashtra, Gujarat, and Odisha in 2013. Garg et al (2017: 117) had similar observations. They found UP, Maharashtra and Andhra Pradesh to be top three CO_2 emitting states in the country in the year 2013. Since, there have been a very limited number of studies on the CO_2 emissions scenario at state level in India to capture this diversity, the studies covered in this work suggest Uttar Pradesh to be one of the leading contributors to and also the most vulnerable state to climate change. Therefore, the study covers the state level analysis of CO_2 emission from domestic sector in chapter 4 and simultaneously, Uttar Pradesh is being chosen as the state under this study.

Uttar Pradesh is a state in northern India. It is the most populated state of India with fourth largest GSDP (constant 2011-12 prices) as of 2018-19 (Appendix Table 1.1A). According to Census 2011, Uttar Pradesh accounts for nearly 17% of India's population and has the fourth highest population density (829 persons per sq. Km) in India (Appendix Table 1.1A). It also has the largest number of households in India (i.e., 3.3 crore households) with largest mean household size (i.e. 6).[17] Further, 78% of its population resides in rural areas and 22% in urban areas. Uttar Pradesh has the highest rural population in India (18.6% of India's rural population) as well as the highest literate rural population[18].

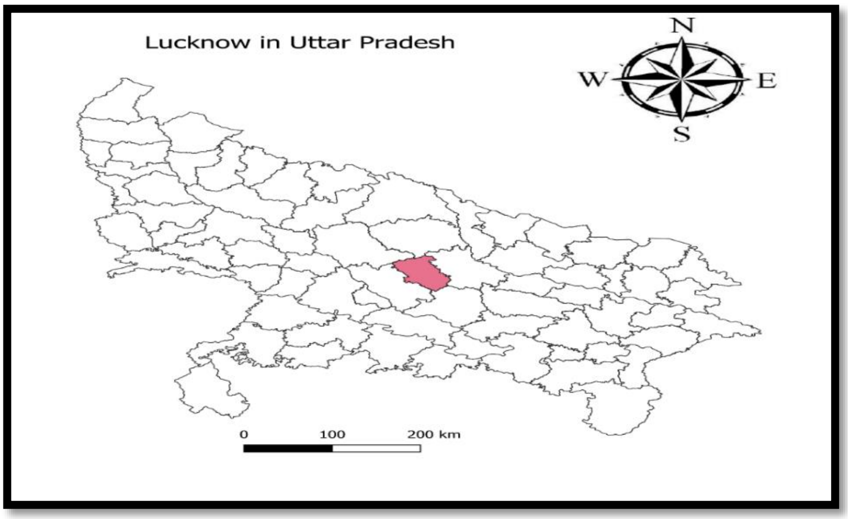
As of August 2020, Uttar Pradesh accounts for sixth largest installed capacity of power stations (7% of all India installed capacity), of which 79% is contributed by coal, 12% by renewable energy sources, 5% by gas, 1.7% by hydropower and 1.5% by nuclear energy[19]. As of 31st March 2016, Uttar Pradesh had third largest number of registered motor vehicles (10% of total) in India (Appendix Table 1.2A). Between 1980 and 2000, Uttar Pradesh was found to be the highest mean CO_2 emitting state in the country (Ghoshal and Bhattacharya 2008: 6). According to GHG Platform India (2017) analysis of GHG emissions from 2005 to 2013, Uttar Pradesh was the leading state in emissions from electricity generation, AFOLU and waste sector. These sectors together account for nearly 75% of total GHG emissions in India. Further, it is the third largest consumer of petroleum products (after Gujarat and Maharashtra) and fourth largest consumer of electricity (after Maharashtra, Gujarat and Tamil Nadu) as of 2018-19 (India Petroleum and Natural Gas Statistics 2019) (Appendix Table 1.2A). The above mentioned facts also indicate that Uttar Pradesh is one of the major contributors to CO_2 emissions. Thus, Uttar Pradesh plays an important role in determining the emissions in India.

[17] http://www.censusindia.gov.in/2011census/hh-series/HH-1/DDW-HH01-0000-2011.XLS
[18] https://censusindia.gov.in/2011-prov-results/paper2/data_files/india/paper2_1.pdf
[19] https://npp.gov.in/publishedReports

The state of Uttar Pradesh comprises of 75 districts. The present study has selected Lucknow as its study area. Lucknow district is the state head quarter of Uttar Pradesh covering an area of 2528 sq. km and the city is the capital of the state. As per 2011 census, Lucknow district accounted for third largest population and second highest number of normal households[20] (8.6 lakh households; 2.8 lakh rural households and 5.8 lakh urban households) in Uttar Pradesh. Average household size in Lucknow is 5.3 persons per household. Lucknow has nearly 34% rural population and 66% urban population (second highest in UP)[21]. Lucknow district has the fifth highest per capita income in Uttar Pradesh as of 2014-15 (Appendix Table 1.3A). The location of Lucknow district is almost in the center of the state.

As of 2017, Lucknow city has the highest number of registered motor vehicles (19.78 Lakh) in Uttar Pradesh (Road Transport Year Book 2019: 18). Further, as of March 2019, Lucknow city has the largest number of electricity consumers (9.9 Lakh) and third highest connected load (2763 MW) in UP (UPPCL, Statistics 2018-19: 139-140). Also, it is one of the top 10 most polluted cities in the world.[22]

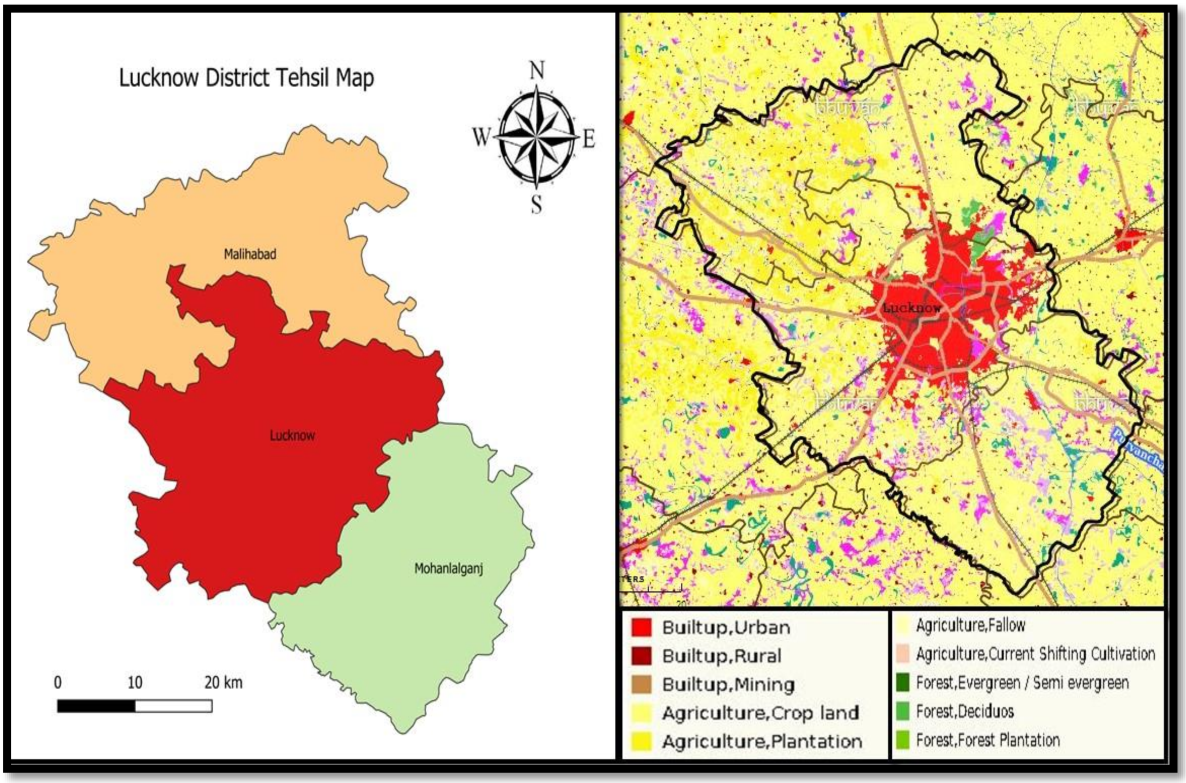
Figure 1.1: District-wise Map of Uttar Pradesh



Source: Author's adaptation using QGIS 3.10.3

[20] A 'household' is usually a group of persons who normally live together and take their meals from a common kitchen unless the exigencies of work prevent any of them from doing so.
[21] https://censusindia.gov.in/2011census/dchb/0926_PART_B_DCHB_LUCKNOW.pdf
[22] https://www.iqair.com/world-most-polluted-cities

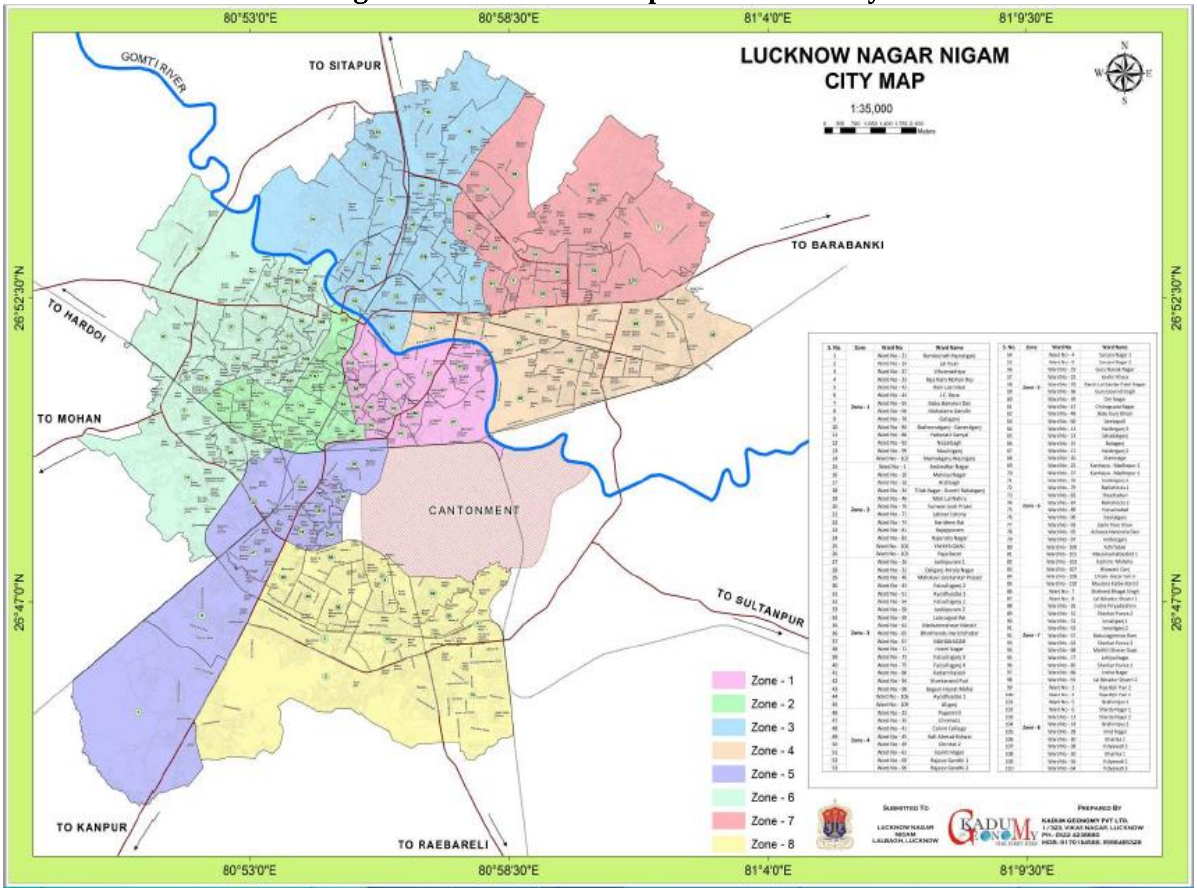
Figure 1.2: Lucknow District Tehsil Map and Land Use Map for 2015-16



Source: Author's adaptation using QGIS 3.10.3 and bhuvan.nrsc.gov.in

Since our unit of study is households, Lucknow city is selected to be the study area. It is located in Gomti basin with flat alluvial terrain. It has a warm humid sub-tropical climate with cool, dry winters. It is one of the most developed cities of Uttar Pradesh and has good connectivity (rail, road and air) to other major cities. As of May 2021, Lucknow has been divided into eight administrative zones. Figure 1.3 shows the zone-wise and ward-wise division of Lucknow city as of latest.

Figure 1.3: Zone-wise Map of Lucknow City



Source: Nagar Nigam Lucknow

1.8.2 Data Sources, Period and Variables

In the present study both secondary and primary level data has been used. Numerous volumes of secondary data are taken from World Bank, Maddison Project Database version 2018, Ministry of Statistics and Programme Implementation, Census 2011, Statistical Diary Uttar Pradesh 2017, etc. An international level study is undertaken, including top twenty CO_2 emitting nations for the period from 1960 to 2017. The linkages of economic growth (GDP growth, per capita GDP and sectoral contribution to GDP) with various social and demographic factors (population growth, dependency ratio, urban population, life expectancy, infant mortality, population density, literacy rate) along with environmental outcome such as CO_2 emissions (total and per capita CO_2 emission) among top twenty CO_2 emitting countries during the period 1960-2017 are outlined here.

A national level study comprising of major 22 states of India is carried out for the year 2018-19. State wise CO_2 emissions by the households and their monetary values are also estimated. Further the impact of population, per capita GSDP and population density on total emissions is assessed.

Lastly, a primary study is carried out in the city of Lucknow. Total CO_2 emission by the households and their monetary value is estimated, based on the consumption of electricity, vehicular use and cooking gas. Further, the impact of socio-economic factors such as caste, nature and size of family, house ownership and annual income on the annual direct carbon emissions from households and the respondent’s awareness, environmental concern and willingness to sacrifice is assessed.

1.8.3 Sampling Design and Size

In order to select a representative sample for the study, Multi-Stage Sampling Method is used for selecting area and households for data collection. In the first stage, Lucknow district is selected based on the above mentioned reasons (provide the justification above). In the second stage, Lucknow tehsil is selected (provide the reasons). In the third stage, all the zones are covered based on proportionate sampling method, i.e., sample size in each zone is proportion to the total population of respective zone. In the last stage, systematic sampling method is adopted to capture the household in the specific ward/locality (which is selected randomly) as mentioned in table 1.6.

According to UN World Population Prospects, the estimated population of Lucknow in 2020 approximately 3.6 million. Taking the average household size to be 5 persons per household (from census 2011), the number of households in Lucknow in 2020 is estimated to be 6.6 lakhs. Literature suggests following two methods of sample size calculation:

- Cochran's formula (1977) when population size is finite:

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}}$$

Where, n is the required sample size, n_0 is the sample size derived from Cochran's formula of sample size for unknown population and N is the total population.

- Yamane (1967:886) suggested the following formula:

$$n = N/(1 + N(e^2))$$

Where e is the margin of error and N is the population size.

Table 1.5: Estimation of Sample Size

	Population Size	Error Margin	Sample size		Population Size	Error Margin	Sample size
Cochran's method (95% confidence)	Unknown	5%	385	Yamane's Method (95% confidence)	6.6 lakh	5%	400
	6.6 lakh	5%	385		6.6 lakh	6%	278
	6.6 lakh	6%	267				

Source: Self estimation

Considering the results of Table 1.5 and other practical difficulties for primary data collection, a sample size of 270 households is taken to be appropriate for this study. In this study, one ward has been selected randomly from each zone (covering population in both old and new Lucknow and trans-Gomti and cis-Gomti areas of Lucknow), so as to ensure the representation of households from whole of Lucknow (Table 1.6). Number of households to be taken from each ward, which has been estimated by taking the population share in each zone. The primary survey has been carried out from January 2021 to March 2021. Within each household one adult (earning member/oldest member/one who has knowledge about household's details) is interviewed.

Table 1.6: Sample Distribution of the Study Area

Zones in Lucknow	Zone-wise Population share (census 2011)*	Wards selected for study	Locality selected for study	Number of Households selected from each locality
Zone 1	10.4	Basheeratganj-Ganeshganj (84)	Aminabad	28
Zone 2	9.3	Aishbagh (18)	Aishbagh	25
Zone 3	18.5	Jankipuram I (16)	Jankipuram	50
Zone 4	9.3	Gomtinagar (61)	Gomtinagar	25
Zone 5	8.5	Ramlilal-Sardar Patelnagar (29)	Alambagh	23
Zone 6	18.5	Balaganj (15)	Balaganj	50
Zone 7	14.1	Indiranagar (86)	Indiranagar	38
Zone 8	11.5	Ibrahimpur II (14)	Vrindavan Yojana	31
Total	100		Total Sample	270

Source: *Estimated from Revised City Development Plan for Lucknow City, Vol. 1, Lucknow Municipal Corporation, 2015.

1.8.4 Estimation Techniques

The secondary data have been statistically processed using STATA 13 version. Mean, Standard Deviations and Compounded annual growth rate (CAGR) have been used. Fully Modified OLS (FMOLS) and dynamic OLS (DOLS) panel data regression has also been carried out. Further, in order to estimate CO_2 emissions, emission coefficient method (Tier-2) has been used.

ANCOVA model has been used for the analysis. Lastly, index method based on Principal Component Analysis (PCA) based weighting approach has been utilized.

1.9 Chapter Plan

The thesis has been divided into seven chapters. The first chapter titled "**Economic Development and Environment: Debate and Methods",** which is the background of the study comprises of the general introduction, context of economic growth and environment debate and the relevance of CO_2 in mitigating climate change by literature review. The chapter brings out the organization of the research report including the research gap and its significance, objectives, hypotheses, and methodological framework of the study.

Chapter two, titled "**Economics of Climate Change: A Theoretical Background"** traces the origin of climate change debate and environmental issues in economic theory. The purpose of the chapter is to present the contemporary climate change debate and validate the objectives of the present study.

Chapter three titled "**Economic growth and Carbon Emissions: A Global Scenario"** gives the global picture of economic growth and carbon emissions tracing the history since the industrial revolution based on secondary data. It further presents the inter-linkages of socio-economic and demographic variables and CO_2 emissions in the top twenty CO_2 emitting countries of the world.

Chapter four titled "**State-wise Domestic Energy Consumption and CO_2 Emissions Scenario in India",** studies the energy consumption and CO_2 emission trends in 22 major states of India and analyses the various socio-economic factors affecting them based on secondary data.

Chapter five titled "**Assessment of Direct Household Carbon Emissions in Lucknow City",** deals with the analysis of primary data collected from the field survey. The chapter presents the socio-economic profile of the surveyed households. Lastly, their energy consumption behavior and consequent CO_2 emissions are analyzed.

Chapter six titled "**Impact of Environmental Awareness, Social and Personal Norms and Willingness to Sacrifice on Environmental Pollution",** presents the role of socio-economic along with psychological factors in causing as well as mitigating climate change. Based on survey data, an environment awareness index is constructed and analyzed.

Chapter seven titled, "**Major Findings and Conclusions",** includes the key findings and conclusions to the objectives of the thesis and also provide relevant suggestion and recommendation based on the results and finding of the research.

Chapter 2

Economics of Climate Change: A Theoretical Background

2.1 Introduction

Climate is usually defined as the average state of the weather patterns over an area. These patterns refer to the variations mainly in the temperature, pressure, wind and rainfall. Climate has never been static. It has been changing since the earth's formation due to natural drivers. However, changes in the global climate, post-industrialization, are mainly due to the anthropogenic emissions of greenhouse gases[23], mainly carbon dioxide, which have accumulated over past hundred years. The argument is validated by substantial scientific evidence including IPCC assessment reports.

Climate Change has been the most widely discussed and debated issue of concern for the whole world, especially in the last few decades. Despite this, the issue is marred with a lot of uncertainties regarding its cause (anthropogenic or natural), severity, time left to deal with, measurement techniques of its costs (control cost and abatement cost) and mitigation techniques.

The present study therefore, attempts to throw some light over the science and economics of climate change, followed by the various prominent global debates going on the matter and its relation with the modern economic theory. The study further elaborates upon the various mitigation approaches being followed and the Indian discourse on climate change. The last section concludes.

2.2 The Science of Climate Change

The economics of climate change is shaped by science (Stern 2006: iv). Therefore, it becomes necessary to first understand the basics of climate change science. The UNFCCC defines climate system as the totality of atmosphere, hydrosphere, biosphere, lithosphere and their

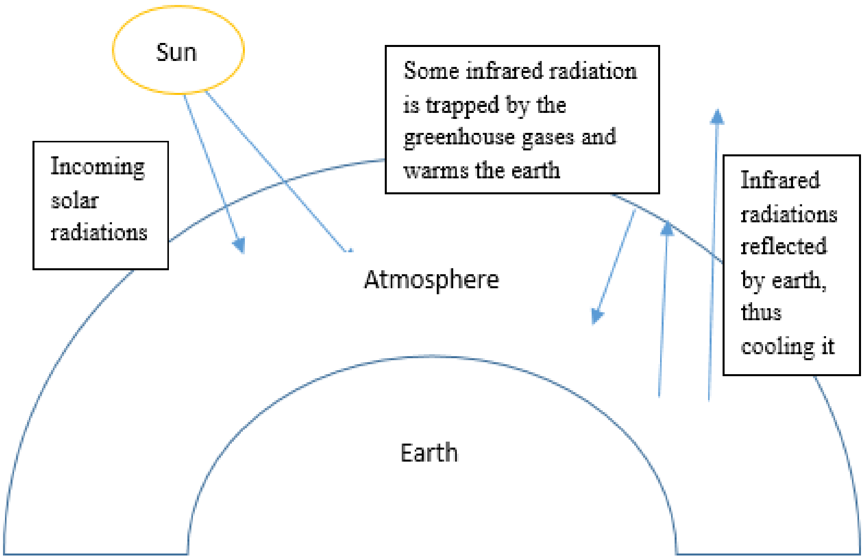
[23] Gases such as carbon di-oxide, methane, water vapour, etc., are transparent to the incoming solar radiation but opaque to the outgoing terrestrial radiation, giving rise to the phenomenon of greenhouse effect, i.e., warming of earth. These gases therefore, are referred to as greenhouse gases.

interactions. The earth's atmosphere mainly comprises of nitrogen (78.01%) and oxygen (20.9%). Less than 1% of air consisting of carbon dioxide, methane, nitrous oxide, ozone, particulate matter is responsible for global climate change[24]. According to the basic law of thermodynamics, as the earth absorbs energy from the sun, it must eventually emit an equal amount of energy to space. The difference between incoming and outgoing radiation is known as a planet's radiative forcing (RF). Thus, radiative forcing is the energy imbalance in the earth's climate system.

Radiative Forcing = Incoming Energy – Outgoing Energy

When incoming energy becomes greater than the outgoing energy, the earth will warm (positive radiative forcing) and when the opposite happens, the earth will cool down (negative radiative forcing). The greenhouse gases warm the earth's climate by not allowing the infrared radiations from the earth surface to escape to outer space. This phenomenon is scientifically known as greenhouse effect[25]. This is clearly reflected in the following Figure 2.1.

Figure 2.1: The Greenhouse Effect



Source: Self

[24]https://www.nationalgeographic.org/encyclopedia/atmosphere/#:~:text=Earth's%20atmosphere%20is%20composed%20of,up%20the%20remaining%200.1%20percent.

[25] https://www.britannica.com/science/greenhouse-effect

Greenhouse effect is a natural process, and is in fact crucial to keep earth's temperature suitable for sustaining life. However, it becomes detrimental when the concentration of the GHGs increases to a level which warms the climate beyond normal temperature levels (average 15^0C). Scientific evidence increasingly shows that it is the human activities which are largely responsible for global warming by means of GHG emissions (Table 2.1).

Table 2.1: IPCC's Attribution of Drivers of Climate Change

Sl. No.	IPCC Assessment Report	Attribution of global warming to human activities
1	IPCC (1992: 6)	"Largely due to natural variability and **little** due to human activities"
2	IPCC (1995: 4)	"**Largely** due to human activities"
3	IPCC (2001: 51)	"**Consistent** evidence for an anthropogenic signal in the climate record of the last 35 to 50 years"
4	IPCC (2007: 39)	"**Very likely** due to the observed increase in anthropogenic GHG concentrations"
5	IPCC (2014: 5)	"**Extremely likely** …… caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together"

Both natural and human activities lead to GHG emissions (Table 2.2). Natural sources include forest fires, earthquakes, oceans, permafrost, wetlands and volcanoes (Yue and Gao 2018: 244-248), while human activities are mainly related to energy production, industrial activities and those related to forestry, land use and land-use change (IPCC 2014: 44-49). It is however, the earth's natural system that can be considered as self-balancing while the anthropogenic emissions add extra pressure to the earth system (Yue and Gao 2018: 249). Carbon di-oxide is the principal anthropogenic greenhouse gas. It is the reference gas against which other greenhouse gases are measured and therefore it has a Global Warming Potential (GWP) of 1 (IPCC 1992: 16). Other prominent GHGs are methane (CH4) and nitrous oxide (N2O). These three gases viz. CO_2, CH_4 and N_2O, in total account for 80% of the total radiative forcing from well-mixed greenhouse gases (IPCC 1995: 8).

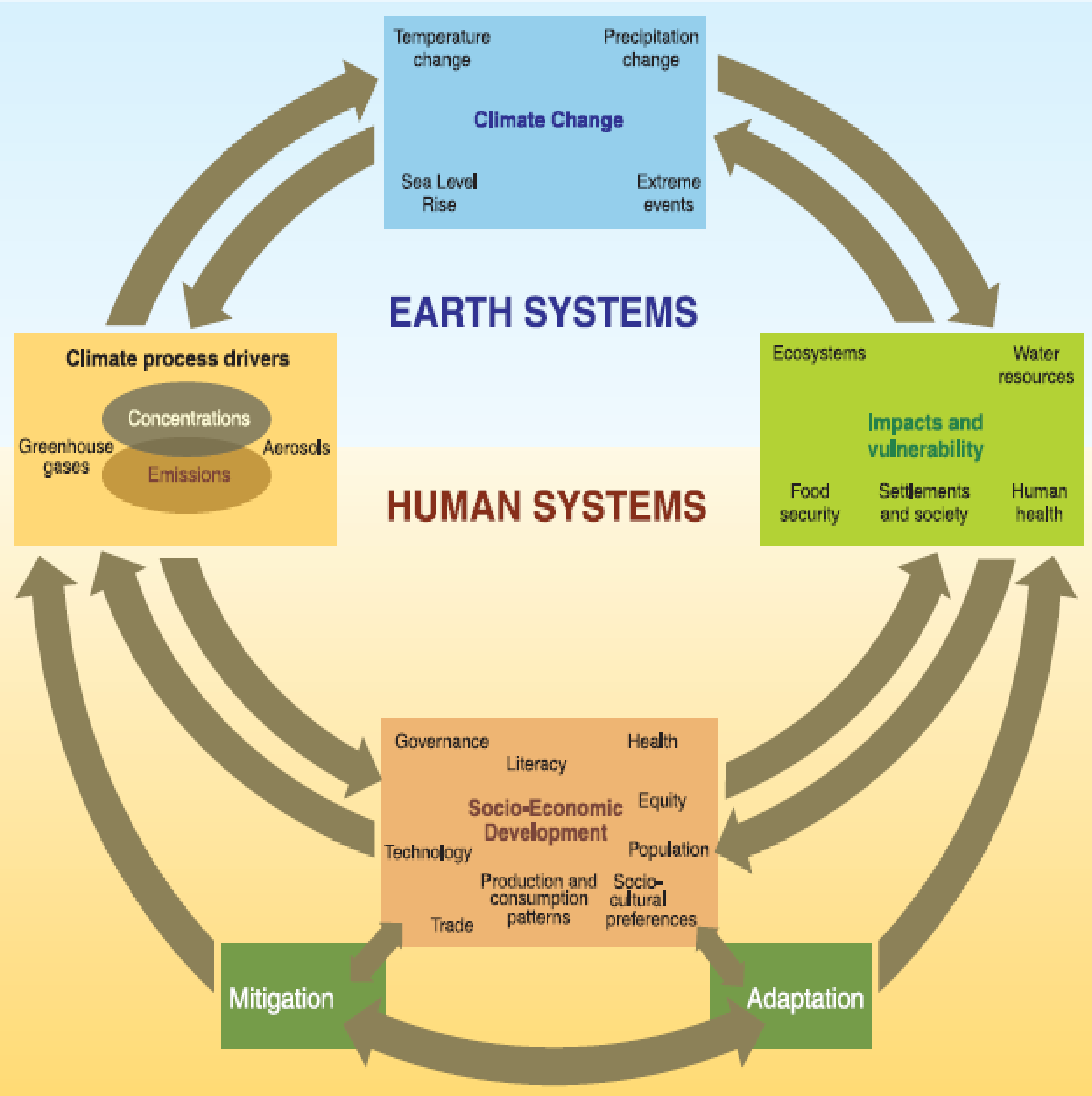
Table 2.2: Principal Greenhouse Gases and Their Sources

Principal GHGs	Natural Sources	Anthropogenic Sources
Carbon di-oxide	Organic decay; Forest Dioxide fires; Volcanoes	Fossil fuels burning; Deforestation; Land-use Change
Methane	Wetlands; Organic decay; Termites	Natural gas & oil extraction; Biomass burning; Rice cultivation; Cattle; Refuse landfills
Nitrous oxide	Forests; Grasslands; Oxide Oceans; Soils	Fertilizers; Biomass burning; Burning of fossil fuels.

Source: Adapted from IPCC (1992: 1-168)

As the process and drivers of climate change are well understood now, the question that arises is that, what implications does global warming has for human beings. The Figure 2.2 describes the linkage between the drivers of climate change, its impacts and responses. The global impacts of climate change are clearly visible in the form of rising global temperatures, melting of glaciers, rising sea levels, varying distribution of rainfall, species loss, decline in crop yields, declining coral reefs and increasing frequency of natural calamities. The IPCC 1.5^0 C Report released in October 2018, warns of the catastrophic effects of climate change and urges timely action by all the stakeholders. "*Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term* *changes in the climate system, such as sea level rise, with associated impacts*" (IPCC 2018: 1-12).

Figure 2.2: Link between The Drivers Of Climate Change, Its Impacts And Responses



Source: IPCC (2007: 26)

2.3 The Economics of Climate Change

2.3.1 Origin and Global Intellectual Discourse

The environment economy debate came into existence with the emergence of the discipline of economics itself. The classical economists accorded importance to the natural resources in determining the growth of a nation. While Malthus (1803: 1-597) focused on population control, Ricardo (1821: 1-483) emphasized upon land as a crucial factor of production. The classical school gave rise to 'limits to growth' approach. This approach was followed by neo-Malthusians, who regarded population, affluence and technology as the main culprit behind environmental damage. For neo-classical economists, environmental resources had no intrinsic value. Their economic value was based only on human preferences for them (Hussen 2013: 16). They rejected the 'limits to growth' hypothesis and believed that market and technological advancement will enable us to overcome any such physical limits. The Environment Kuznets' Curve by neo-classical economists further affirms their belief that higher income will automatically lead to environmental improvement (Grossman and Krueger 1991: 1-39).

The Neo-Classical era was followed by the emergence of the sustainability debate. World Commission on Environment and Development, Brundtland Report (1987: 17-25) defined sustainable development as "the development which meets the need of the present generation without compromising with the ability of the future generations to meet its needs". It talked about intergenerational equity with regard to nature and the natural resources. In 1992, the Framework Convention on Climate Change was signed at the Earth Summit in Rio de Janeiro. This attracted the intellectual interests of many economists in the field of climate change, with varying thoughts and suggestions.

Hussen (2013: 192) classifies these economic thoughts into three broad categories viz. the 'business as usual (BAU)' approach, the 'gradualist' approach and the 'precautionary' approach. The believers of BAU approach argue that the abatement costs of climate change are way too much, largely ignoring the damage cost of climate change (ibid: 192-193). While some question the rationality of spending for the future generations instead of spending for the well-being of present poor population (Mendelsohn 2007: 43), others disapprove of the phenomenon of climate change altogether citing the evidence of natural periodical warming and cooling of earth since ages (Sheehan 1996)[26]. Gradualists, on the other hand, follow a balanced approach by considering both damage costs and abatement costs in cost benefit analysis (Hussen 2013: 194). One of its proponents estimated that by the end of 21st century the damage cost of climate change will be average 3% of global GDP (Nordhaus 2008: 141). Thus, he avoids suggesting drastic cut in emissions as it would mostly affect today's poor and is not ethically feasible, since the future generations are expected to be much richer than today (ibid: 179). Unlike the gradualists, the believers of precautionary approach take a strict stand on actions needed to mitigate climate change. Considering the cumulative nature and long lasting impact of greenhouse gases, precautionists argue for a discount rate[27] as low as 1% (Cline 2004: 1-37). Complementing Cline's view, Stern (2006: 1-575), called for an immediate aggressive action to mitigate climate change internationally. The report, acknowledging the uncertainties involved, and taking the discount rate to be 0.1%, warned of a huge loss ranging from 5% to 20% of global GDP every year if no steps are taken to mitigate climate change. It further assures that the cost of mitigation will be around only 1% of global GDP every year. Thus, the benefits of climate change mitigation outweigh the cost involved (ibid: vi).

A major issue of contention in the climate change debate among economists, is the debate over discount rate or pure rate of time preference, which can in general, be understood as the rate of intergenerational discrimination (Heal 2008: 4-21). Weitzman (2007: 703-724), Nordhaus (2007: 686-702) and Mendelsohn (2007: 42-46) reviewed the Stern report and concluded that the uncertainty involved in deciding the optimal discount rate is the main reason behind their differential views. Thus, there has been no consensus on the seriousness of the climate change issue as well as on the extent of steps needed to mitigate it. This situation can be equated with that during COVID-19. Amidst wide uncertainty regarding the cause,

[26] https://www.ourcivilisation.com/aginatur/hot.htm
[27] The discount rate is the rate at which society as a whole is willing to trade off present for future benefits.

seriousness and cure of the corona virus, while some countries followed very strict precautions and experienced minimum loss of lives, others in the name of halting of economic growth took namesake measures and suffered severe consequences of their inaction (Pinto-Bazurco 2020: 1-2).

2.3.2 Modern Economic Theory and Climate Change

Market Failure: Climate as a Common Property Resource and GHG Emission Externalities

Climate is a global common property resource and is therefore subject to the free-rider problem. Adam Smith's invisible hand does not operate in the case of common resources, since their ownership is not defined. The economic theory thus, views climate change as one of the biggest global market failure caused by externalities associated with greenhouse gas emissions. It implies the costs which are not paid by those who emit greenhouse gases. Thus, the theory of public goods, externalities and market failure forms the basis of the economic theory of climate change (Stern 2006: 25). Alfred Marshall in one of his main works, *Principles of Economics* (Marshall 1890: 374-523), formulated the concept of externalities in his own words, external economies and diseconomies. Marshall's example of fisheries was the pioneering step to study the economics of common property resources (Sandmo, 2015: 52). The theory of externalities was further developed by Arthur C. Pigou in his '*The Economics of Welfare (1920)' and 'A Study in Public Finance (1928).*

Externalities refer to the uncompensated impact of consumption or production activities which are not reflected by the market prices. If such an effect is beneficial, it is known as positive externality and if such an effect is adverse, it is referred to as negative externality. Since the market prices do not account for externalities, the market becomes inefficient in the presence of externalities. This point is explained with the help of an example of a market for commodity X. Consider the first case (Figure 2.3 (a)) where externalities are not present. In this case, the market equilibrium is efficient.

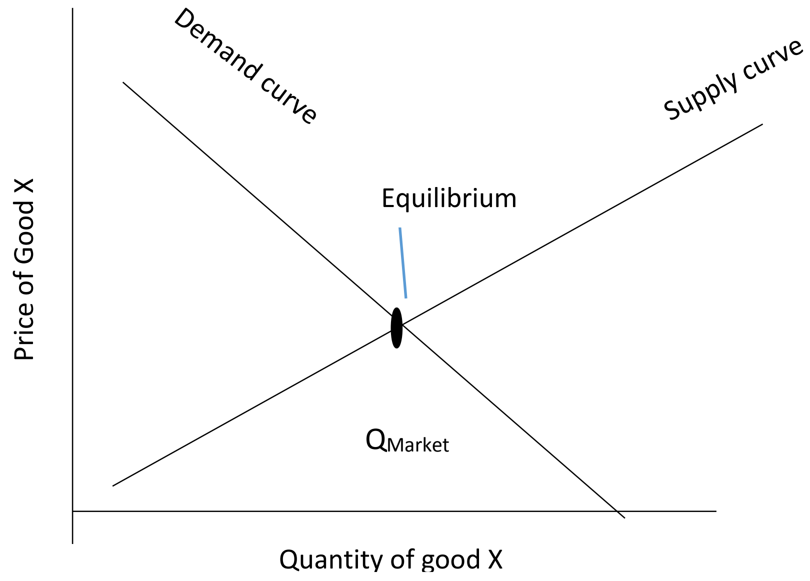


Figure 2.3 (a): Market Equilibrium in the absence of externalities

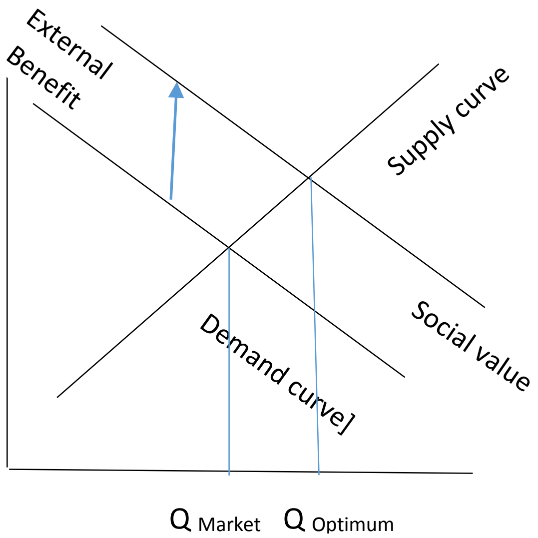


Figure 2.3 (b): Market Equilibrium with positive

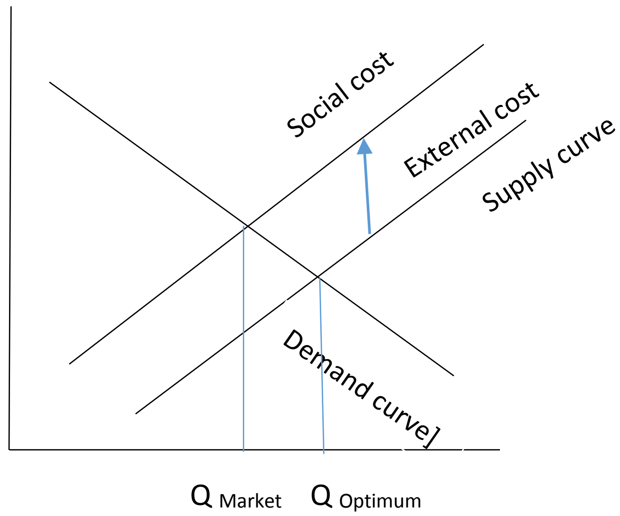


Figure 2.3 (c): Market Equilibrium with negative

From Figure 2.3 (b), we observe that in case of positive externalities markets produce a smaller quantity than is socially desirable. While in case of negative externalities (Figure 2.3 (c)) markets tend to produce a larger quantity than is socially desirable.

In case of positive externalities:

Social Benefit = Private benefit + External benefit, which implies that

Social benefit > Private benefit.

In case of negative externalities:

Social Cost = Private cost + External cost, which implies that

Social cost > Private cost

Thus in such cases, the markets fail to work efficiently and government intervention is needed to internalize the externalities. In case of climate change, the greenhouse gases, particularly carbon di-oxide, emitted in the process of production and consumption are the negative externalities which are not accounted for in the firm's supply cost.

GHG Damage Costs and Abatement / Control Cost

The discipline of climate change economics emerged with the recognition of the trade-off that exists between economic development and environment conservation or more specifically, between greenhouse gas (GHG) damage cost and greenhouse gas abatement cost. The GHG damage cost refers to the future expected damage to the economy, human health and the environment in monetary terms in the absence of any climate change mitigation policy. While the GHG abatement cost refers to the social costs arising as a result of implementing a climate policy resulting into reduction of GHG emissions.

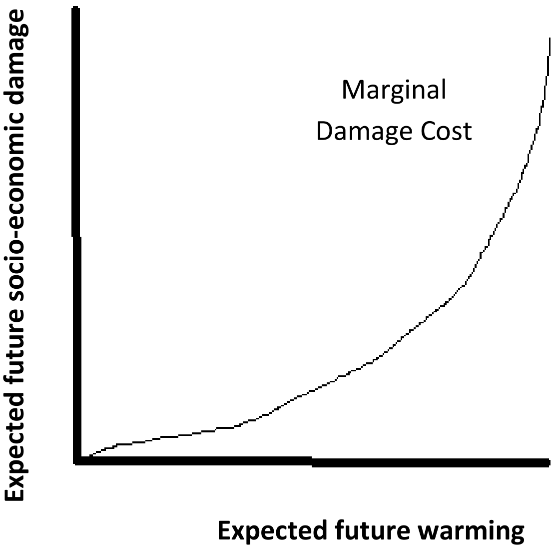


Fig. 2.4(a) Marginal Damage Cost Curve

Source: Hussen (2013: 73)

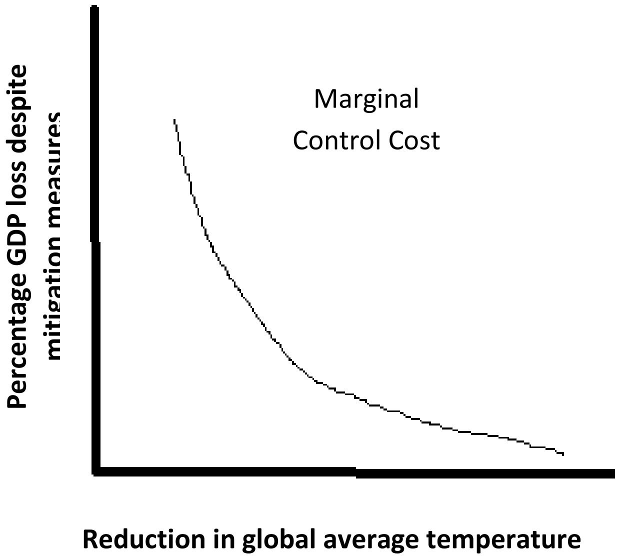


Fig. 2.4(b) Marginal Control Cost Curve

Source: Hussen (2013: 71)

From Figure 2.4(a), it is observed that as the future warming increases, the marginal damage cost increases in the absence of any climate change mitigation policy. Figure 2.4(b) shows the increasing marginal control cost as the global average temperature is reduced by some GHG emission reduction policy. This figure assumes a constant technology level. However, if the GHG emission abatement technology advances, the marginal control cost will go down. A dilemma arises here, since GHGs are stock pollutants. The damage and control costs associated with them have inter-temporal property. The damage costs arise not only because of present emissions but also because of past stock of GHG emissions. Further, the cost of present emissions will be imposed upon the upcoming generations who have no say in the present policy making. Thus, a lot of uncertainty is involved in assessing the social costs and damage costs arising out of climate change.

Stern (2006: 25) and Wagner and Weitzman (2015: 1-29) summarize the following unique features of climate change as a form of market failure, which necessitate the economic analysis to go much further. First, telekinesis property of the atmosphere, which refers to the quick movement of GHG emissions from one part of the earth to another. This results into climate change being global in both its causes and consequences. Second, its impacts are persistent and develop over time. Third, it is irreversible. Four, it involves considerable uncertainty. In order to address these complexities of climate change and measure its socio-economic impact, a number of models have been developed, which altogether, are known as 'Integrated Climate Assessment Models'. Further, CO_2 being the primary cause of global warming led climate change, these models attempt to measure the 'social cost of carbon'.

Social Cost of Carbon and Integrated Assessment Models

Any serious climate policy which intends to meet specific temperature targets, requires a careful assessment of the trade-offs between GHG damage cost and abatement cost. Global-climate-economy models have been developed to incorporate the inter-linkages and complexities involved in climate change, which are referred to as Integrated Assessment Models (IAM's). IPCC third assessment report defines Integrated Assessment as "*an interdisciplinary process of combining, interpreting, and communicating knowledge from diverse scientific disciplines in such a way that the whole set of cause-effect interactions of a problem can be evaluated*" (IPCC, 2001: 242). The interlinked chain of interactions can be understood in the form as follows. First, climate change is the result of GHG emissions by economic activities and the level of their atmospheric concentration. Climate science explains the impact of GHG concentrations on temperature, precipitation, wind, cloud formation and sea level rise. These changes in turn result in various physical, environmental and social changes, such as changes in crop yields, migration, specie loss, etc. These interactions can further be measured in monetary terms or processed through an economic model to measure the economic cost of climate change. The IAMs attempt to capture the dynamic nature as well as the uncertainties involved in the climate-economy model and primarily comprise of two key modules - climate module and economy module (Nikas et al 2019: 3).

Integrated assessment models of climate change originated from energy models in 1960s and 1970s. The earlier work of Tjalling Koopmans (Nobel prize winning economist) on the linear programming approach to production and Samuelson's principle of "markets as maximization," formed the intellectual base of energy models (Nordhaus 2017a)[28]. The 1992 ratification of UNFCCC with the aim of preventing "dangerous anthropogenic change to the climate system" led to huge increase in the number of IAMs (Schneider and Lane 2005: 44).

Various researchers have attempted to classify IAMs into different categories on varying basis (Goodess et al (2003: 145-171); Bahn et al (2006: 103-119); Stanton et al. (2009: 166-184)). Some of the major IAMs are, the Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) model (developed by Richard Tol and extensively by the IPCC), Policy Analysis of the Greenhouse Effect (PAGE) model (developed by Chris Hope and most prominently used in the Stern Review) and Dynamic Integrated Climate and Economy (DICE)/ Regional Integrated Climate Economy (RICE) model developed by William Nordhaus. DICE model is one of the earliest and most widely used IAM for climate change. It was developed in 1992 and undergone several revisions since then. The latest available version of DICE model is DICE-2016R. The DICE model was the first major attempt to investigate alternative approaches to slowing climate change. Most of the prior models followed the steady state approach. The extraordinary time lags involved in the reaction of the climate and economy to the greenhouse gas emissions were ignored. The DICE model incorporated both the dynamics of emissions and impacts and the costs of policies to curb emissions.

Climate Change Mitigation Approaches

Economics Theory suggests three basic approaches to deal with negative climate externalities such as Legal approaches (Liability Laws, Property Rights: Coasian Approach, Emissions standards/Command and control approach), Non-economic approach (Governing the

[28] https://www.nber.org/reporter/2017number3/nordhaus.html#N_2_

Commons: Elinor Ostrom), Economic approaches (Carbon pricing), Effluent Charges or Imposition of Taxation and Subsidies: A.C Pigou), Transferable Emissions Credits (TEC) (Hussen 2013: 79-113).

Legal approach to climate change mitigation is based upon legal rules and regulations. Liability laws, property rights, emission standards are some of its examples. The *liability law* states that any economic activity must be able to internalize its liability costs, and if not, it should not be in the market (Siebert, 1989: 2). Liability laws are strictly based upon polluter pay principle. *Property rights* approach was introduced by Coase (1960: 87-137), wherein, assuming zero transaction costs, he suggested to arbitrarily assign enforceable property rights to either the polluter or the pollute, so as to reach an optimal level of pollution by voluntary negotiation (bargaining) between private parties. *Emissions standards or command and control* approach is a centralized approach set and enforced through legally mandated laws. Emission standard is usually found in three major forms viz. quantity standard, performance standard and technology standards.

The discipline of economics suggests price mechanism to mitigate climate change. The two most widely used mechanism are, effluent charges and emission trading. *Effluent charges* or carbon taxes are price instrument in the form of taxes upon the polluters, per unit of waste discharged. This tool comes with a double dividend as it generates revenue while controlling pollution (Pigou 1920: 1-914). An *emissions trading* is a permit system which creates an artificial market for pollution rights, where the regulators allocate permits (credits) to the polluters and thereafter allowed them to freely exchange their pollution rights at the market established rates.

Non-economic Approach: Ostrom (1990: 1-217) demonstrated “how local property can be successfully managed by local commons without any regulation by central authorities or privatization." She supported bottom up approach of local management of Common Pool Resources (CPRs) without any central planning.

Along with the economic, legal and social approaches, there are various scientific approaches too, to reduce carbon emissions. Fawzy et al (2020: 2073) classifies these technologies into three categories, viz. *conventional mitigation technologies*, which include renewable energy, fuel switching, efficiency gains, nuclear power, and carbon capture storage and utilization; *negative emissions technologies*, which include bioenergy carbon capture and storage, biochar, enhanced weathering, direct air carbon capture and storage, ocean fertilization, ocean alkalinity enhancement, soil carbon sequestration, afforestation and reforestation, wetland construction and restoration, etc.; and lastly the most recent *radiative forcing geoengineering technologies* such as stratospheric aerosol injection, marine sky brightening, cirrus cloud thinning, space-based mirrors, surface-based brightening and various radiation management techniques.

Lastly, behavioural approach is also being suggested by the literature to reduce carbon emissions. Table 2.3 summarizes the various behavioural models, barriers to behavioural approach and needed policy interventions.

Table 2.3: Behavioural Models, Barriers and Policy Interventions to Reduce Emissions

Models	Barriers	Policy Interventions
•*Education models* (awareness creation) •*Extrinsic motivation models* (providing incentives or punishment) •*Intrinsic motivation models* (self motivation and concern) •*Information-processing-based models* •*Social models* (culture and social norms)	•*Individual (internal) barriers* (Social and psychological barriers, Knowledge-based barriers, Unconscious behavior, Demographic factors, Dwelling ownership) •*Societal (external) barriers* (Structural and physical barriers, Cultural barriers, Economic barriers, Institutional barriers, Regulatory barriers, Social barriers)	•*Motivation for voluntary mitigation* (awareness, nudges) •*Habits change* •*Economic incentives* (pricing, taxes, subsidies) •*Lifestyle change* (reduce, reuse, recycle)

Source: Adapted from Stankuniene (2020: 3-10)

2.3.3 Climate Change Discourse in India

In the year 1990, World Resource Institute (WRI), a private non-profit organization, based in Washington, USA, published a report in which it concluded that the developing nations together contribute to nearly half of the global warming issue. In response, Centre for Science and Environment (CSE) and The Energy and Research Institute (TERI) separately carried out an assessment of WRI report. Both the assessments, CSE's Agarwal and Narayan (1991: 81-91) and TERI's Pachauri, Gupta and Mehra (1992: 33-38) concluded that WRI's report was politically motivated and methodologically flawed. They emphasized that the global pressure of reducing emissions on developing economies was an excellent example of 'environmental colonialism'. This early scholarly treatment of climate policy in India had a lasting impact on India's early climate policy. India's climate change perception began as a global north-south inequality debate in 1991 (Dubash 2013: 192). India championed the cause of global south at international forums on climate issues by bringing up the issues of climate equity by focusing on per capita rather than total emissions, historical emissions responsibility on developed nations, common but differentiated responsibility (CBDR) calling for an institutional mechanism for climate funding for developing nations, and many more issues (Dubash 2013: 192; Thaker and Leiserowitz 2014: 108; Rastogi 2011: 129). This phase of active engagement was quickly followed by a quiescent period wherein India remained fixated on the issue of north-south contest and failed to develop its capacity on the understanding of climate science and its own vulnerabilities to climate change impacts (Raghunandan 2019: 191-192). Also erroneously, it aligned with the developed nations even at the cost of Kyoto protocol for short run profits ignoring the interests of other developing nations (ibid.:193). Indian business class earned substantially from Clean Development Mechanism (Dubash 2013: 193).

Post 1990s presented a very different scenario, where on the one hand high economic growth was making India at par with the developed nations while on the other hand poverty and low development related it more with the least developed nations. Higher economic growth came with higher total emissions, although the per capita emissions of India were still too low to be considered to be very significant. However, by its political negotiations, India seemed to identify itself more with the developed nations, thus inviting criticism from developing nations (ibid.: 193). Also swayed by its increasing importance on the global level and the desire to align with the only superpower (US), India failed to reconcile back with the LDCs and small island nations on its earlier stance of CBDR (Raghunandan 2019: 199).

The decade of 2000s is observed as a shift in India's policy stance to climate change (Rastogi 2011: 130; Dubash 2013: 194). In fulfillment of its commitment to UNFCCC, India submitted its first National Communication (NATCOM) to UNFCCC in 2004. In 2008, GOI launched the National Action Plan on Climate Change (NAPCC), which marked India's first concrete domestic action plan on climate change front. Further, the formation of BASIC[29] (Brazil, South Africa, India and China) in 2009 and India's pledge to voluntarily reduce its emissions intensity[30] between 20 to 25 percent below 2005 levels by 2020, without any international financial support indicated India's acknowledgement of its climate responsibility. In 2010, a Coal cess was imposed to fund the development of renewable energy[31]. Also, the release of the Fourth Assessment Report of IPCC in 2007 led to a growing interest on climate change among all groups including parliamentarians, trade unions, youth organizations, NGOs and business community (Dubash 2013: 194-195; Raghunandan 2019: 196). Thus, although equity remained the prominent issue of concern, but it was increasingly accompanied by demands for domestic mitigation actions, although not without any opposing voices (Thaker and Leiserowitz 2014: 108). A number of intra-country affairs, apart from global north-south

[29] Group of four large newly industrialized countries formed by an agreement on 28 November 2009, committed to act jointly at the Copenhagen climate summit.
[30] Emissions per unit GDP
[31] https://doe.gov.in/sites/default/files/NCEF%20Brief_post_BE_2017-18.pdf

contest, cropped up like, inter-class disparities in “luxury and survival emissions”, increasing awareness of climate impacts on various sectors like agriculture, coastal regions, islands, glaciers etc. (Dubash 2013: 196).

Ahead of the UN Conference of Parties on Climate Change, scheduled in December 2015 in Paris, India submitted its Intended Nationally Determined Contribution (INDC) to the UNFCCC, wherein it pledged to improve the emissions intensity of its GDP by 33 to 35 per cent by 2030 below 2005 levels, increase the share of non-fossil fuels-based electricity to 40 per cent by 2030 and also to enhance its forest cover which will absorb 2.5 to 3 billion tonnes of carbon dioxide by 2030. India has also decided to anchor a global solar alliance, INSPA (International Agency for Solar Policy & Application), of all countries located in between Tropic of Cancer and Tropic of Capricorn[32].

Climate Transparency Report (2020: 23) identifies the INDC of India alone to be 2^0 C compatible. The INDC of USA and Russia are marked as ‘critically insufficient’, China’s ‘highly insufficient’ and that of EU as ‘insufficient’. Solar capacity in India increased from 2.6 Gigawatts in March 2014 to 30 gigawatts in July 2019, achieving its target of 20 gigawatts four years ahead of schedule. Further, India claims to have reduced emission intensity of its GDP by 21% between 2005 and 2014 (BUR 2018: 11). Dubash et al (2018: 1-9) concludes that India’s current policy trajectory is consistent with meeting its INDCs.

2.4 Conclusions

The scientific evidence assures of the realness of climate change, although the time frame and severity of a drastic change to occur is yet uncertain. This uncertainty is the main reason behind the lack of consensus upon the scale of measures needed to mitigate climate change. While a

[32] https://pib.gov.in/newsite/printrelease.aspx?relid=128403

section (BAU) believes that far future (uncertain) should not be prioritized over present consumption, another section of intellectuals (gradualists) agree with the need to take measure to reduce emissions gradually. Yet another group (precautionary) advocates the need of strict timely actions, so as to reduce the coming catastrophe. Modern economic theory, which believes climate change to be a market failure, suggest an accurate measurement of damage and control costs of CO_2 emissions, so that an optimum strategy can be formed.

Of the various approaches to mitigate climate change, none alone is best for any nation. An optimum mix of these approaches need to be taken to all levels of the society i.e. global, national, local and even individual level. The behavioural approaches are fit to be followed at individual, household and even society level and it will also ensure the involvement and a feeling of connectedness with the problem.

India, a nation which is highly vulnerable to climate change due to its tropical location, poverty issues and largely rain-fed agriculture dependent economy, initially stood in favour of BAU and climate justice for developing nations. However, in the last decade, India has taken a lead in climate change mitigation policies, while still raising call for climate justice. Thus, it can be concluded that, gradually the dominant BAU approach is losing its hold, as with each passing year, the prominently visible changes in the climate and its extremities, are making the world realize that inaction is going to be harmful.

Chapter 3

Economic Growth and Carbon Emissions: A Global Scenario

"The western model of growth that India and China wish to emulate is intrinsically toxic. It uses huge resources- energy and materials – and generates enormous waste…it remains many steps behind the problems it creates. India and China have no choice but to reinvent the development trajectory."

\- *Sunita Narain*

3.1 Introduction

Environment and economic growth are inextricably linked with each other. It is the interplay of a number of historical, social, economic, political, cultural, demographic and technological factors which has shaped this relationship so far. The idea basically emerged out from a debate between Ehrlich and Holdren (1971: 1212) on one side and Commoner (1972: 343-363) on the other. Ehrlich and Holdren focused on rapid population growth (P) as the main culprit behind environmental crisis, while Barry Commoner emphasized upon the role of modern production technology (T) in deteriorating the environment (York et al 2002: 19). York et al (2002: 21) introduced the idea of factor plasticity[33], to measure the potential of each of the three factors to move in different directions (rate and range of variation) and thereby impact the environment. However, they suggest that environmental impact is the outcome of the multiplicative interconnectedness between population, affluence and technology, and no single factor alone can be held responsible for it. The idea of plasticity does not suggest the importance of one factor over the other, it rather, only brings out the fact that even if one factor remains constant, it will affect the absolute value of the total impact (ibid: 21-22). It will help to identify the factors that can be modified to reduce the impacts in a faster manner.

Waggoner and Ausubel (2002: 7861) reconceptualized the IPAT identity and renamed it as ImPACT. They predicted total CO_2 emissions (impact) to be equal to the product of population (P), per capita GDP (A), energy consumption per unit GDP (C) and CO_2 emissions

[33] The potential for each factor to vary, particularly because of purposive human action (e.g., policy) (York et al 2002: 21)

per unit of energy consumption (T). Consumers can lessen the impact by 'de-materializing' (reducing C) and producers can lessen the impact by innovating (reducing T). However, both IPAT and ImPACT identities could not be used for hypothesis testing. To remove this drawback Dietz and Rosa (1997: 175) developed the stochastic version of IPAT and renamed it as STIRPAT model.

Based on the above background the present chapter will focus majorly on the relationship between economic growth, social development and environment. The analysis will be divided into three sections. In the first section a brief outline of the economic growth process of the major CO_2 emitting countries is presented along-with its social and environmental consequences since sixteenth century. This section is divided into two time frames, i.e. from 1500 to 1800 and from 1801 to 1950. The second section deals with a more detailed statistical analysis of economic, social, demographic and environmental trends in the top twenty CO_2 emitting nations in the post-cold war era. In the last section, econometric modeling is carried out to bring out the drivers of CO_2 in the twenty nations.

3.2 Objective and Methods

3.2.1 Objectives

The present chapter aims to assess the impact of economic growth process on social development and consequently on environment at the global level and more specifically top twenty CO_2 emitting countries. In other words, the linkages of economic growth (GDP growth, per capita GDP and sectoral contribution to GDP) with various social and demographic factors (population growth, dependency ratio, urban population, life expectancy, infant mortality, population density, literacy rate) along with environmental outcomes such as CO_2 emissions (total and per capita CO_2 emission) among top twenty CO_2 emitting countries during the period 1960-2017 are outlined here. Further, it assesses the impact of various economic, social, demographic factors on environment across top twenty pollution emitting countries. These twenty countries have been responsible for over 70% of global CO_2 emissions since eighteenth century.

3.2.2 Period and Data Sources

The top twenty CO_2 emitting countries[34] as of 2018 are selected to understand the linkage of economic, social and environmental factors during 1960-2017. They comprise of high income, upper middle income as well as lower middle income group countries, as classified by the World Bank[35]. They encompass nearly all the continents viz. Asia, Europe, Africa, North America, South America and Australia. The study is based on secondary data. The main data source is World Bank. The data on sectoral share of GDP and employment, population, population density, birth rate, death rate, life expectancy at birth, age dependency ratio, fertility rate, urban population, sources of electricity generation, sectoral CO_2 emissions and energy use are all sourced from World Bank. The data on real per capita GDP (2011US$) is sourced from Maddison Project Database version 2018. Total GDP, and per capita CO_2 emissions data are sourced from 'Our World in Data'[36]. For descriptive statistical analysis of socio-economic variables, the period selected is 1960 to 2018. For econometric analysis, period from 1960 to 2015 is undertaken as energy use (one of the independent variable) data is not available after 2015.

3.2.3 Statistical Techniques and Methodology

The analysis of trends up to 1950 is mainly based on literature review and descriptive data analysis. Post 1950 trends are studied first through descriptive statistical and graphical analysis.

[34]http://www.globalcarbonatlas.org/en/CO2-emissions
[35]Countries having per capita GNI below 1,025 $ are defined as low income countries, Lower middle income countries have a per capita GNI ranging from 1,026 $ to 3,995 $. Countries with per capita GNI lying between 3,996$ to 12,375$ have been referred to as upper middle income countries and those having GNI per capita above 12,375 $, fall under the category of high income countries.
[36] https://ourworldindata.org/co2-emissions

For variables with absolute values, Compounded Annual Growth Rate (CAGR) is used, while for variables available in percentage form, mean is taken to study the trends. In the last section, panel data regression is carried out.

The IPAT identity is the most widely used method to study human impact on environment. The general form is:

$$I = PAT$$

Where I stands for environmental impact, P denotes population size, A stands for affluence (per capita consumption) and T denotes technology. A modified version of it, STIRPAT model is as follows:

$$I_i = aP_i^b A_i^c T_i^d e_i$$

York et al (2003: 354) refined the STIRPAT model by expanding their idea of plasticity to ecological elasticity, which measures the proportional change in environmental impacts due to a change in any driving force. STIRPAT could also be modified to include other factors as components of P, A and T. In log form STIRPAT can be easily used to determine the population and affluence elasticity of impacts using cross-sectional, time-series or panel data (ibid: 355). The present study develops a model based on this. Following Dietz and Rosa (1997), this study presents CO_2 emissions as a function of per capita GDP and population. CO_2 is a major GHG responsible for more than 70% of total greenhouse gas emissions. The model is written in the following way:

$$log\ CO2emi_{it} = log\ a_i + \beta_1\ log\ PCGDP_{it} + \beta_2\ logPOP_{it}$$

where CO_2emi refers to CO_2 emissions in tonnes, PCGDP refers to per capita real GDP (Constant at 2011 US$) and POP refers to the total population. To study the causal relationship between economic growth (per capita real GDP), population and CO_2 emissions, we present firstly the panel unit root analysis, the panel co-integration analysis, Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS). Finally, panel VECM (Vector Error Correction Model) model and Wald test is applied to check for long run and short run causality respectively.

3.3 Historical Background of Global Economic Growth and Environment: A Brief Review

3.3.1 Period up to 1800

The period from 1500 to 1800 witnessed some major events in the history of mankind, the American war of Independence, French Revolution, the age of Renaissance. World trade began in this era, when the European explorers connected the east and the west, but it was mostly imperial and exploitative trade and not truly global in nature (Ortiz-Ospina et al 2018; Vanham 2019). Most of the world population lived in non-urban areas till 18th century. Although a few cities emerged as a result of imperialism, however, large scale migration to urban areas occurred only after the Industrial Revolution in Europe. According to Paul Crutzen[37], in the late 18th century a new stage had begun in the earth's history, which he referred to as the "anthropocene" indicating the powerful influence of mankind on global environment. It also marked the beginning of the fossil fuel energy regime, with coal as the prominent fuel till early-19th century (McNeill and Engelke 2016: 8).

The emergence of the Industrial revolution in Britain led to major socio-economic, demographic as well as environmental changes across the globe. Based on the estimates by Maddison Database 2010[38], China and India were the largest economies in terms of GDP till 1820. In 1000 A.D., India's GDP was ahead of China's GDP, where the former had a GDP of 33,750 million and latter had a GDP of 27,494 million in terms of 1990 International Geary-

[37] A Dutch atmospheric chemist and Nobel prize winner in 1995
[38] https://www.rug.nl/ggdc/historicaldevelopment/maddison/data/md2010_horizontal.xlsx

Khamis dollars[39]. In 1500, both the countries had same GDP values i.e., nearly 61000 million 1990 GK$. India's GDP was 90,750 GK$ in 1700 A.D., afterwards China surpassed India, for all the subsequent years (Maddison Database 2010). For the entire period from 1000 to 1820 A.D., India and China together accounted for nearly half of the world's population and over 45% of the world's GDP, which confirms equality in income (Nayyar 2020: 8). This was so, since prior to industrialization**,** the economies of the world were largely agriculture dependent and there wasn't much technological innovation in production (Lin 1995: 269).The largest population centers were also the largest poles of economic production (Lin and Rosenblatt 2012: 173). The "great powers of west" were far behind India and China. The GDP of the then third largest economy, i.e., France was nearly one sixth and one fourth of India's and China's GDP in 1500 A.D. and 1700 A.D. respectively. In 1820, France's GDP was one sixth of the GDP of China and one third of India's GDP. United Kingdom, which was the tenth largest economy in 1500 (GDP twenty-one times less than that of India) became the third largest economy (leaving behind Germany, Italy and Japan) with GDP (a little above France) and had one third of that of India and one sixth of China's GDP (Maddison Database 2010). A historic question emerges from this scenario, that despite such state of prosperity in Asia (mainly India and China), the sustained industrialization occurred in North Western Europe or the question of "the great divergence[40]" in post 1800 A.D. In terms of GDP per capita, France, Italy, Germany and U.K. took the top four positions between 1600 -1700 A.D. Between 1000 A.D. and 1820 A.D., the per capita GDP of France, Germany, United Kingdom, United States and Italy increased three times. United States joined the top list in 1820 with per capita GDP of

[39] "Geary-Khamis (GK) dollars" are simply values that have been converted from local currency into U.S. dollars using PPPs calculated using Geary's and Khamis' method of aggregation.

[40]The Great Divergence or European miracle is the socioeconomic shift in which the Western world (i.e. Western Europe and the parts of the New World where its people became the dominant populations) overcame pre-modern growth constraints and emerged during the 19th century as the most powerful and wealthy world civilization, eclipsing Mughal India, Qing China, the Islamic World, Joseon Korea, and Tokugawa Japan.https://en.wikipedia.org/wiki/Great_Divergence.

1257 GK$ in 1990 A.D (Maddison Database 2010). India and China were not even in the top ten in terms of per capita GDP in 1820 A.D. This suggests that the high GDP in China and India could possibly be the result of large population rather than real economic prosperity and also that the divergence didn't suddenly came with industrialization, but was a long continuous process (Maddison 2005: 2).

During the Paris Conference in 2015, nations of the world agreed to hold "the increase in the global average temperature to well below 2°C of pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C"[41]. Clearly, if we're aiming to limit global warming to 1.5℃ or 2℃ above a certain point, we need a common understanding of what we're working from. However, "pre-industrial" scenario was not defined in the Paris Agreement. Over the past 800,000 years, the earth went through a number of fluctuations in the level atmospheric CO_2 concentrations due Milankovitch cycles[42]. CO_2 fluctuated between about 180 ppm during ice ages and 280 ppm during interglacial warm periods[43]. Before the Industrial revolution in the 19th century, global average CO_2 was about 280 ppm. However, it was only after the industrial revolution (nearly 300 years ago) that the concentration of CO_2 increased beyond 300 ppm which currently is over 400 ppm (Ritchie and Roser 2020). Being the leader of Industrial revolution, the global CO_2 emissions were completely contributed by United Kingdom up to 1785 (16869.06 kt of CO_2). In 1800, United Kingdom's share fell to 94.8%, while Germany contributed 2.83%, Poland 1.44% and United States 0.99%. Between 1785 and 1825, global CO_2 emissions increased by nearly 3.5 times, i.e., 60756.45 kilo tonne

[41]Adoption of the Paris Agreement FCCC/CP/2015/10/Add.1. UNFCCC; 2015.

[42] The long-term, collective effects of changes in Earth's position (eccentricity, obliquity and precession) relative to the Sun, which drive the long term climate of Earth.https://climate.nasa.gov/news/2948/milankovitch-orbital-cycles-and-their-role-in-earths-climate/

[43]https://www.esrl.noaa.gov/gmd/news/7074.html

of CO_2, comprising of 81.6% by United Kingdom, 7.1% by Germany, 6.5% by France, 2.2% by Poland and 1.87% by US Carbon Dioxide Information Analysis Centre (CDIAC[44]).

The above background shows that, it was only after the industrial revolution occurred, that the atmospheric concentrations of CO_2 increased unusually. As the industrial revolution emerged in European nations and later to United States, both regions are responsible for historical CO_2 emissions. Also, despite India and China were observed to be the largest economies before nineteenth century, their per capita income was too low to be considered as rich nations, owing to their large population.

3.3.2 From 19th Century to 1950 A.D.

Table 3.1 shows that, the period from 1820 to 1960 witnessed a new trend, where the share of 'the West' in world income nearly doubled from 37% to 73%, while the share of 'the Rest' declined by more than half from 63% to 27%. Of 'the Rest', the share of Asia in world income fell from 57% to 15% during the same period (Nayyar 2020: 9). Maddison (1995: 1) divided this period into three phases, viz., 1820-70, 1870-1913 and 1913-50. Between 1820 and 1870 A.D., Europe experienced both GDP and demographic expansion and the most rapid per capita growth than in any other period. Asia and Africa observed meager growth in this period (ibid: 2). The period from 1870 to 1913 was a peaceful period which witnessed growth in most of the regions. World GDP increased by 2.5 times between 1870-1913 as compared to 1.6 times between 1820 and 1870 (ibid: 3). This era came to an end with the outbreak of the First World War in 1914 followed by the Second World War, which ended in 1945.

During nineteenth century, there was high income equality between countries (Table 3.1). However, by the mid of the twentieth century the top four economies, United States,

[44]OWID based on the Global Carbon Project; Carbon Dioxide Information Analysis Centre (CDIAC); Gapminder and UN population estimates.

United Kingdom, France and Germany, which had 12% of the world's population, accounted for nearly 43% of the global GDP. United States emerged as the largest economy in this century, beginning from a mere 1.8% share in world GDP to 27% (Table 3.1). Also United States wasn't far behind in terms of CO_2 emissions. In 1820, United Kingdom, France and Germany contributed over 95% of global CO_2 emissions, whereas United States by 1950 turned out to be the largest emitter, contributing over 43% of CO_2 emissions of the world, as shown in Table 3.1. Thus, contrary to the expectation of the flow of the benefits of industrial revolution across the world by late nineteenth century and twentieth century, economic growth remained limited exclusively to the western nations, with the exception of Japan, till mid twentieth century. Also, the early 20th century was marred by the two world wars and the inter-war period great depression of the 1920s.

Table 3.1: Country-wise Share of Population, GDP and CO_2 Emissions

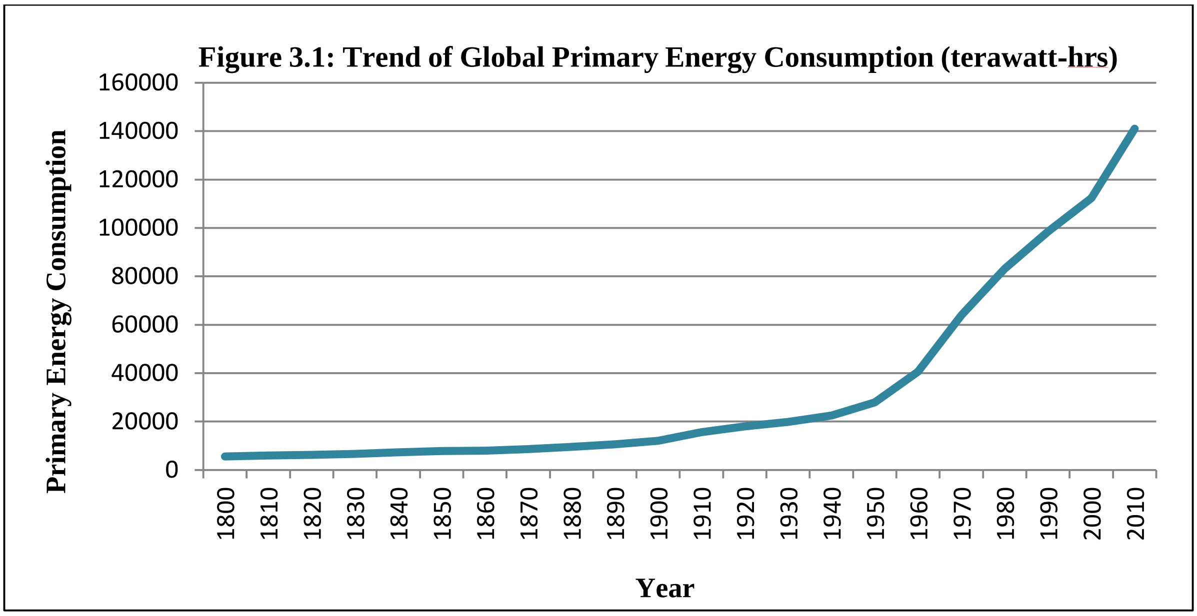
Year	**1820**			**1870**			**1900**			**1920**			**1950**		
Country	Pop*	GDP*	CO_2**	pop	GDP	CO_2	pop	GDP	CO_2	pop	GDP 1913	CO_2	Pop	GDP	CO_2
Australia	0.03	0.02	0	0.14	0.52	0.11	0.24	0.76	0.52	0.29	0.91	0.73	0.3	1.15	0.95
Brazil	0.43	0.42	NA	0.77	0.63	NA	1.15	0.62	0	1.47	0.7	0.1	2.1	1.67	0.34
Canada	0.08	0.11	0.01	0.3	0.58	0.27	0.35	0.81	1.05	0.47	1.28	2.4	0.6	1.91	2.66
China	36.6	32.9	0	28.1	17.1	0	25.6	11.1	0.01	25.3	8.83	0.76	21.6	4.59	1.36
Germany	2.39	3.9	6.67	3.08	6.5	14.4	3.48	8.23	16.7	3.27	8.68	12.2	2.7	4.97	8.83
France	3	5.1	5.72	3.01	6.5	9.49	2.6	5.92	6.62	2.09	5.29	4.33	1.7	4.13	3.5
India	20.1	16.1	0	19.8	12.1	0.13	18.2	8.64	0.67	16.4	7.47	1.08	14.2	4.16	1.15
Indonesia	1.72	1.58	NA	2.57	1.71	NA	2.88	1.61	0.06	2.95	1.65	0.24	3.3	1.24	0.17

Iran	0.63	0.56	0	0.66	0.55	NA	NA	NA	0	NA	0.4	0.15	0.6	0.53	0
Italy	1.94	3.25	0	2.19	3.77	0.5	2.15	3.05	0.71	2.01	3.49	0.51	1.9	3.09	0.72
Japan	2.98	2.99	0	2.7	2.29	0.01	2.82	2.64	0.99	3	2.62	2.12	3.3	3.02	1.77
South Korea	NA	NA	NA	0.76	0.53	NA	0.63	NA	0	0.63	0.34	NA	0.8	0.33	0.03
Mexico	0.63	0.72	NA	0.72	0.56	NA	0.87	0.94	0.05	0.8	0.95	2.17	1.1	1.26	0.53
Turkey	0.97	0.93	0	0.92	0.88	0.03	NA	NA	0.05	NA	0.67	0.04	0.8	0.64	0.16
Poland	1	0	1.47	1.32	1.44	3.13	1.58	1.93	3.24	1.29	1.7	2.18	0.98	1.14	1.94
Saudi Arabia	0.2	0	NA	0.18	NA	NA	NA	NA	0	NA	NA	NA	0.2	0.16	0.09
South Africa	0.15	0.09	NA	0.2	0.2	NA	NA	NA	0.12	NA	0.36	0.73	0.5	0.65	1.05
U.S.	0.96	1.81	1.56	3.15	8.87	18.5	4.89	15.8	33.9	5.74	18.9	49.5	6	27.3	43.8
U.K.	2.04	5.22	83.9	2.46	9.03	42.9	2.63	9.37	21.5	2.51	8.22	13.4	2	6.52	8.65

Source: *Estimated from Maddison Online Database; **Estimated from ANNUAL CO_2 EMISSIONS (GLOBAL CARBON PROJECT & CDIAC (2019)); Retrieved from https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

Note: Figures are in percentage.

Energy consumption has played a very crucial role in this global economic and environmental transformation. By the end of 19th century, coal replaced traditional bio-fuels as the major energy source (Smil 2016: 32-48). Figure 3.1 shows that the consumption of coal increased from 97.2 terawatt-hours to 5728 terawatt-hours (59 times) during 1800 to 1900, while the traditional bio-fuel consumption remained almost stagnant at an average value of 6515 terawatt-hours during the entire twentieth century (ibid: 32-48). The energy consumption doubled over nineteenth century, while in just first half of the twentieth century the consumption of energy increased by 2.3 times. In the second half of the 20th century, the energy consumption quadrupled[45].



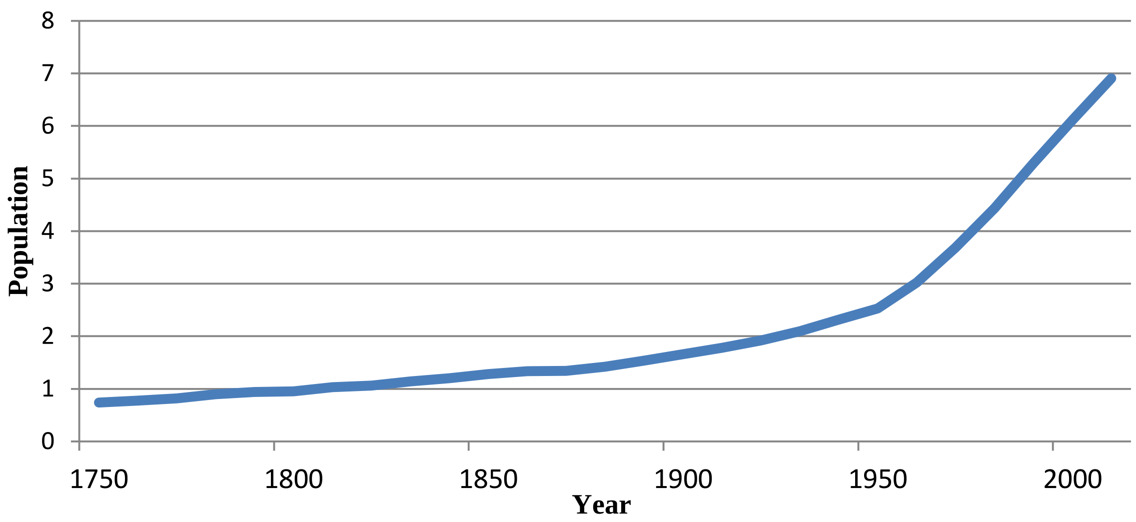
Source: Smil (2016). & BP Statistical Review of World Energy

3.3.3 Post Mid-Twentieth Century

The world population has more than tripled in the last 70 decades, with a sustained CAGR of over 1.5% from 1950 to 2000 (Table 3.2). This mainly happened because the fall in death rate out-weighted the fall in birth rate. From 1800 to 1950 global child mortality has declined from around 43% to 22.5% and since then, the mortality rate has declined by five times to 4.5% in 2015[46]. Between 1800 and 1900, global average life expectancy increased from 28.5 to 32 years, 46 years in 1950 and increased to over 71 years by 2015[47].

[45]https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html
[46]Roser et al 2013
[47]James C. Riley (2005) – Estimates of Regional and Global Life Expectancy, 1800–2001. Issue Population and Development Review. Population and Development Review. Volume 31, Issue 3, pages 537–543, September 2005., Zijdeman, Richard; Ribeira da Silva, Filipa, 2015, "Life Expectancy at Birth (Total)", http://hdl.handle.net/10622/LKYT53, IISH Dataverse, V1, and UN Population Division (2019)

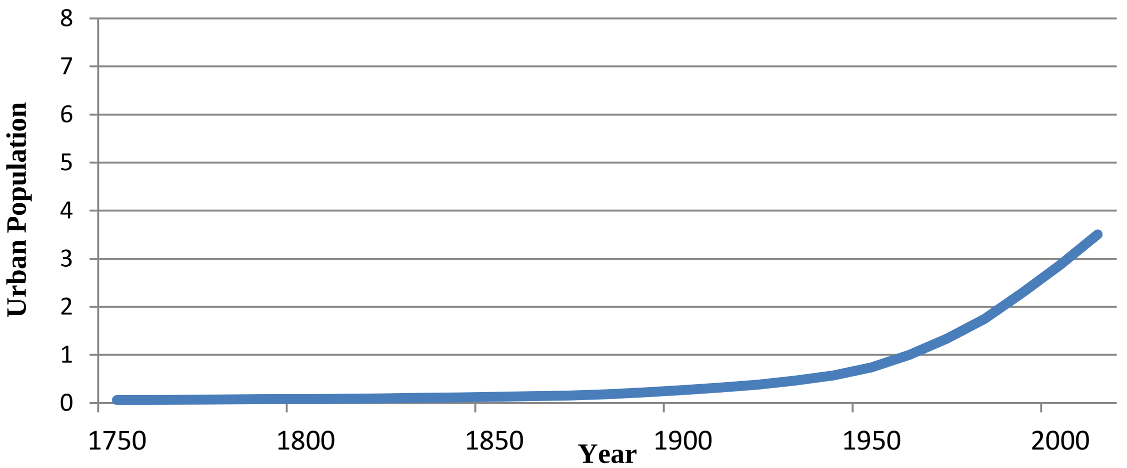
Figure 3.2: Trend of World Population



Source: Klein (2010). http://dx.doi.org/10.1177/0959683609356587

Figure 3.3 shows that the post-world war era also witnessed rapid urbanization, wherein the global urban population increased from nearly 730 million in 1950 (29% of world population) to 3.7 billion people (more than 50%) in 2015.

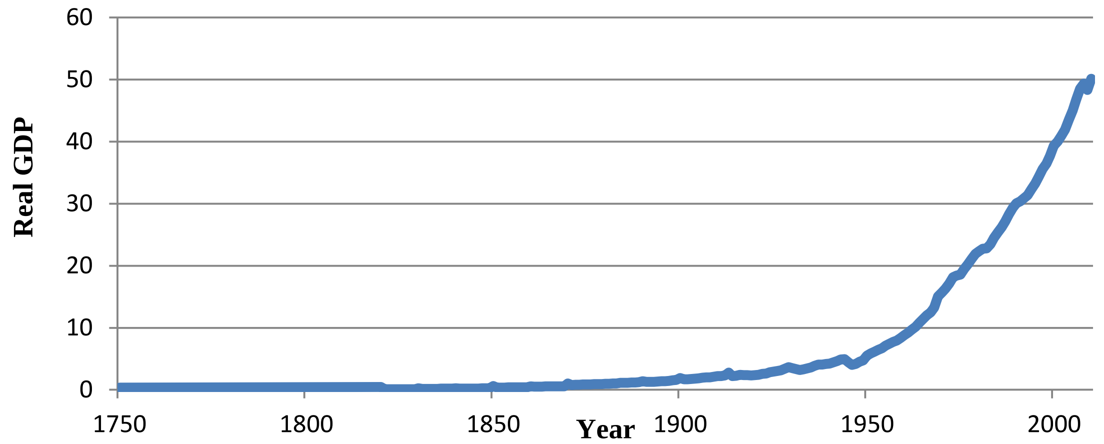
Figure 3.3: Trend of World Urban Population (billion)



Source: Klein (2010). http://dx.doi.org/10.1177/0959683609356587

The decades following the Second World War till the oil price hike of 1973 was referred to as the "golden age" or "the great acceleration" of economic growth (Maddison 1995: 13; Neill and Engelke 2016: 128). The period from late 1940s to early 1950s marks a major break from earlier trend. As in case of, global energy consumption, population and urban population, global real GDP also depicts a major break in 1950's, compare to the earlier trend (Figure 3.4).

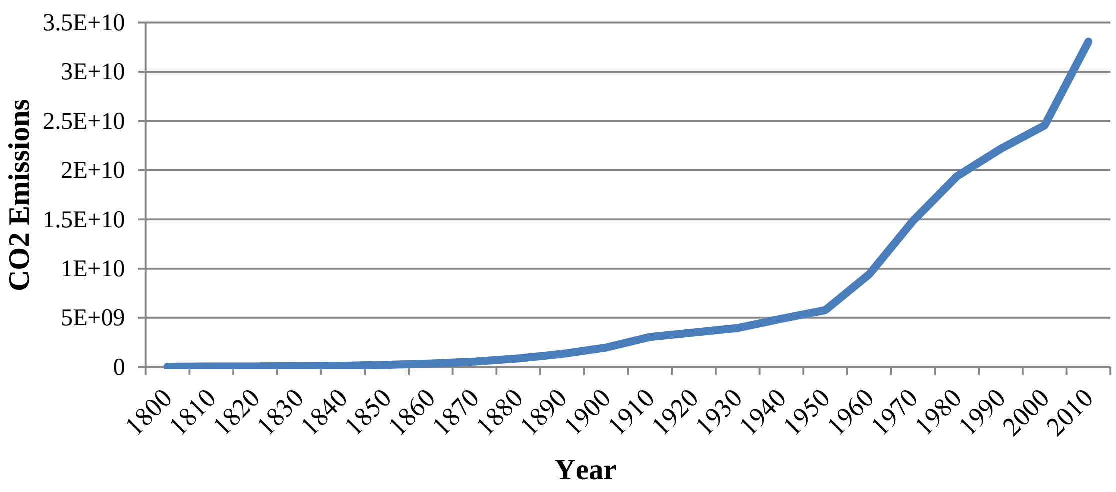
Figure 3.4: Trend of World Real GDP (trillion US $)



Source: Maddison 1995; M. Shane, Research Service, United States Department of Agriculture

Figure 3.5 further shows clearly that global CO_2 emissions was almost stagnant and it became significant only after 1870s. From 1870s to 1950 the emissions increased steadily, but after 1950s, a rapid increase in global CO_2 emissions is observed.

Figure 3.5: Trend of World CO_2 Emissions (tonnes)



Source: Annual CO_2 Emissions (Global Carbon Project & CDIAC (2019))

Table 3.2 shows that the CAGR of primary energy consumption stood at 3.8% and 4.7% during 1950-60 and 1960-70 respectively, which was the highest in the past one and half century.

McNeill and Engelke (2016: 38), regard the availability of cheap and abundant fossil fuel energy (coal and oil) as the most important consequential factor for environment in this modern growth period. By 1965, crude oil replaced coal as the major energy source followed by natural gas. The extraction, transport and combustion of fossil fuels led to land, air and water pollution and grave damage to human health and loss of lives. A number of coal mining accidents and oil spills during transport (English Channel in 1967 and 1978; Cape Town in 1983; Exxon Valdez in 1989; Persian Gulf in 1991; Niger Delta in 1998; Deep-water Horizon in 2010; Norilsk in 2020) took thousands of life and sharply damaged the marine ecosystem (ibid: 15-20). According to WHO, ambient (outdoor air pollution) caused by fossil fuel combustion, is a major cause of death and disease globally. The indirect effects of cheap energy include large scale deforestation, mechanized agriculture, exploitative fishing by trawlers, long distance travel and tourism, etc. All this transformed the scale, intensity, and environmental implications of human interaction with nature (ibid: 39). The search for alternative cleaner energy sources brought in nuclear and hydropower, but not without any risks. The nuclear disasters of the Three Mile Island in 1978, Chernobyl in 1986, Fukushima Daichi in 2011 and others, reduced the confidence in nuclear energy (ibid: 162-165). The large hydropower dams had their own drawbacks, mainly the large scale displacement of people. This has led to the search for alternative green energy sources. Still, as of 2018, fossil fuels constitute over 87% of world energy consumption[48].

Table 3.2: World Decadal Compounded Annual Growth Rate of Population, Urban Population and Primary Energy Consumption Since 1810

Year	CAGR Population	CAGR Urban Population	CAGR Primary Energy Consumption
1810-20	0.26	0.44	0.49
1820-30	0.75	1.21	0.60
1830-40	0.51	0.82	0.93
1840-50	0.62	1.19	0.65

[48]BP statistical review of world energy 2018

1850-60	0.44	0.97	0.27
1860-70	0.01	0.85	0.71
1870-80	0.58	1.51	1.03
1880-90	0.81	1.91	1.14
1890-1900	0.76	2.12	1.28
1900-10	0.72	1.84	2.58
1910-20	0.73	1.73	1.41
1920-30	0.90	2.07	0.99
1930-40	0.99	2.07	1.28
1940-50	0.89	2.55	2.19
1950-60	1.80	3.07	3.79
1960-70	2.01	2.95	4.67
1970-80	1.87	2.72	2.64
1980-90	1.77	2.73	1.71
1990-2000	1.46	2.28	1.33
2000-10	1.23	2.05	2.29

Source: Maddison Online Database; UN World Urbanization Prospects 2018 and others; Smil (2017); https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Note: Figures are in percentage.

However, even in this phase the Great Divergence between west and the rest continued. It began to be bridged only after late 1980s, while the developing nations like India, China, Russia, Brazil and Indonesia emerged as new growth centers, leading to multipolar growth in the world economy (Lin and Rosenblatt 2012: 171–194). The broad global level study however, hides the details about individual country growth process. Therefore, in the following section, we will deal with each of the nations in a detailed manner, which have the largest share in world population, GDP and CO_2 emissions.

3.3.4 Global Economic Growth and Environment in top Twenty Countries: Post-cold War Era

Table 3.3 shows that the top twenty CO_2 emitting countries selected for our study have been responsible for over 70% of global CO_2 emissions since eighteenth century. However, their respective shares in emissions have undergone significant changes. United Kingdom, which was responsible for over 90% of world's emissions in eighteenth century, holds a share of mere 1% in 2018 (Table 3.3). These countries have also accounted for more than half of the world's population and GDP since then. Thus, this group of nations is highly representative of global changes which came about in post-cold war era. The post -cold war era holds special importance due to the rapid rate of changes which occurred in socio-economic and environmental variables in these nations in a small period of 60 years (Figure 3.1, 3.2, 3.3, 3.4 and 3.5).

Table 3.3 gives a comparison of changes in CO_2 emissions, population and GDP shares of these nations between 1960 and 2018. The share of CO_2 emissions and GDP of China increased most rapidly in this period, while that of USA declined by nearly half. Saudi Arabia and South Korea depict massive rise in per capita emissions by nearly 13 times and 24 times respectively (Table 3.3). China, Japan, Iran and Australia also witnessed a significant increase in their per capita emissions by 6 to 9 times. In United Kingdom and Germany, the per capita emissions surprisingly declined over the period.

Table 3.3: Country wise Share of Land, CO_2, Population, GDP, and Per Capita CO2 in World

Country	Land Area (%)	CO_2 Share (%)		Population		GDP const. 2010 US $		Per capita CO_2 emission	
		1960	2018	1960	2018	1960	2018	1960	2018
China	6.30	8.27	27.5	22	18.33	1.14	18.64	1.18	6.98
USA	6.1	30.6	14.8	5.96	4.31	27.4	15.08	15.46	16.24
India	2	1.28	7.25	14.9	17.81	1.22	7.71	0.27	1.84
Russian Fed.	11	9.45	4.67	3.95	1.90	NA	3.11	7.42	11.75
Japan	0.2	2.47	3.17	3.05	1.67	7.1	4.11	2.48	9.45
Germany	0.27	8.65	2.07	1.54	1.09	NA	3.15	11.09	9.74
Iran	1.1	0.40	1.96	0.72	1.08	0.58	1.27	1.7	8.28
South Korea	0.1	0.13	1.8	0.82	0.68	0.21	1.57	0.5	12.08
Saudi Arabia	1.4	0.03	1.69	0.13	0.44	NA	1.37	1.43	19.27
Indonesia	1.2	0.23	1.68	2.9	3.52	0.54	2.57	0.24	1.84
Canada	6.1	2.05	1.55	0.59	0.49	2.82	1.35	10.76	15.64
Mexico	1.3	0.67	1.3	1.25	1.66	1.3	1.89	1.65	3.79

South Africa	0.8	1.04	1.27	0.56	0.76	0.70	0.58	5.6	8.05
Brazil	5.6	0.50	1.25	2.38	2.76	2.20	2.47	0.65	2.27
Turkey	0.5	0.18	1.17	0.91	1.08	0.78	1.73	0.61	5.55
Australia	5.2	0.94	1.15	0.34	0.33	1.78	0.94	8.56	16.89
UK	0.2	6.21	1.04	1.73	0.87	6.50	2.23	11.14	5.81
Poland	0.2	2.12	0.9	0.98	0.50	NA	0.90	6.74	8.56
Italy	0.2	1.16	0.9	1.66	0.79	4.90	1.79	2.19	5.99
France	0.4	2.9	0.9	2.4	0.88	5.42	2.19	5.91	5.48
Total	50.17	79.36	78.2	68.5	60.98		74.69		4.79*

Source: Estimated from https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions; https://ourworldindata.org/grapher/co-emissions-per-capita; https://ourworldindata.org/grapher/gross-domestic-product?tab=chart&year=earliest; https://data.worldbank.org/indicator/SP.POP.TOTL

Note: * denotes world average per capita CO_2 emissions.

3.4 Pattern of Change in Economic, Social and Environmental Variables

3.4.1 Economic Changes

Economic growth is attributed to be the most important cause of CO_2 emissions and consequent climate change. According to Maddison Project Database 2018, during 1960 to 2018, China's GDP increased by 109 times, which is the highest growth among all the twenty nations considered. It showed a remarkable jump from 14thlargest economy in 1960 to second largest economy in 2017, only behind United States of America. China is followed by South Korea, whose GDP increased by 53 times in total terms and 24 times in per capita terms. India and Indonesia were the next fastest growing economies with GDP increasing by more than 17 times (Maddison Project Database 2018). Thus, it was the developing Asian economies which had an edge in economic growth in this period. The growth in the earlier 'developed west' stagnated. As a result, the emissions from Asian economies particularly, India and China also increased.

The shift in the sectoral composition of the economy's GDP and employment is also expected to have impacts on environment. In advanced economies, economic growth is associated with transition from manufacturing to service sector economy. An economy is said to be a service sector economy when service sector dominates employment and value added shares. Kim (2006: 18) outlines four major views regarding the transition of an economy from manufacturing to service sector economy. Fisher (1935: 1-234) and Clark (1940) suggested a demand side theory based on 'hierarchy of needs hypotheses' (Schettkat and Yocarini 2005: 127-147) which states that as income increases, demand for services increases, because the income elasticity for goods is less than one, but that of services is greater than one. Contrary to this view, Baumol (1967: 415-426) put forward a supply side view, based on 'cost disease hypotheses', which suggests the productivity difference between the two sectors as the main reason behind shift to service economy. The relative price of high productivity manufacturing sector falls fast while the relative price of low productivity service sector increases by the productivity difference between the two. Another important view is the 'exogenous demand shock hypothesis', which considers structural changes in the economy, as responsible for the said transition. The last theory is the 'de-industrialization hypothesis', which believes that the labour - intensive manufacturing industry is transferred from advance nations to less developed nations, i.e., the developed industrial nations, shifted their pollution intensive manufacturing industries to less developed nations and imported such goods from poor nations, deteriorating their environment quality.

Post-1950, world witnessed a rise in the importance of service sector. Table 3.4 shows that all the Western nations and Japan, Russia, South Korea and Australia show nearly equitable distribution of sectoral shares in employment and GDP. Also these nations had shifted to service sector economy by 1990. However, among Asian nations like China, India, and Indonesia, in 1990s, agriculture contributed to more than half of the employment and more than 20% to their GDP. Manufacturing sector accounted for 15-20% of employment in these countries (Table 3.4). While in China 40% of GDP was contributed by manufacturing sector, in India, it held a share of only 26%. GDP share of service sector stood between 35-40% but in terms of employment it held a share of 20% in India and China and nearly 30% in Indonesia. In Indonesia, the share of manufacturing and service sector in GDP has remained nearly equal (approx. 40%) between 1980 and 2018. In 2018, service sector became the dominant sector in terms of GDP share in China and India (Table 3.4). But, in terms of employment, while the service sector dominates in China and Indonesia, in India, it is still the primary sector which accounts for more than 40% of employment. Thus, while the Indian economy transitioned directly from agriculture to service sector in 1970s, China's transition from manufacturing to service economy in GDP terms is recent (started with the beginning of 21st century). The transition of India remains unique in terms of employment share as well as its skipping the manufacturing stage, making it an 'agriculture dominated service economy'. Also, we must not ignore the fact that, in absolute terms the value of each of these sectors has increased over time.

Table 3.4: Country-wise Sectoral Composition of GDP and Employment

Country	Agriculture, forestry, and fishing, value added (% of GDP)		Employment in agriculture (% of total employment) (modeled ILO estimate)		Industry (including construction), value added (% of GDP)		Employment in industry (% of total employment) (modeled ILO estimate)		Services, value added (% of GDP)		Employment in services (% of total employment) (modeled ILO estimate)	
	1991	2018	1991	2018	1991	2018	1991	2018	1991	2018	1991	2018
Australia	3.18	2.46	5.46	2.62	27.74	24.12	23.83	19.89	61.14	66.56	70.71	77.50
Brazil	6.79	4.36	18.98	9.26	31.51	18.44	23.29	20.13	48.85	62.63	57.73	70.61
Canada	1.92	1.71	3.01	1.49	28.01	24.81	23.06	19.57	62.72	66.75	73.94	78.94
China	24.03	7.19	59.70	26.10	41.49	40.65	21.40	28.19	34.48	52.16	18.90	45.71
France	2.61	1.62	5.74	2.51	24.30	16.90	28.39	20.29	62.82	70.34	65.86	77.20
Germany	1.10	0.77	3.50	1.25	33.52	27.46	37.57	27.34	56.37	61.84	58.93	71.41
India	27.33	14.60	62.56	43.33	26.44	26.75	15.72	24.95	37.79	49.13	21.72	31.72
Indonesia	19.66	12.81	54.02	29.63	41.20	39.73	14.56	22.29	39.13	43.41	31.42	48.08
Iran	12.01	9.50	24.63	17.58	33.39	34.91	31.29	32.04	53.26	54.35	44.08	50.38

Italy	3.24	1.94	8.30	3.76	27.16	21.40	34.99	26.10	60.44	66.34	56.71	70.14
Japan	1.94	1.19	5.81	3.44	34.70	29.14	34.19	24.63	63.03	69.12	60.00	71.93
South Korea	6.82	1.98	14.61	5.00	36.49	35.12	36.82	25.20	47.45	53.56	48.57	69.80
Mexico	6.50	3.39	25.94	12.81	25.75	30.94	23.47	26.13	60.38	60.14	50.59	61.06
Poland	5.54	2.11	22.63	9.62	33.24	28.62	32.01	31.82	49.41	56.80	45.36	58.56
Saudi Arabia	5.43	2.22	7.84	2.52	48.84	49.54	26.13	24.79	46.16	48.37	66.03	72.69
South Africa	4.17	2.18	11.25	5.17	35.10	25.85	28.74	23.15	52.39	61.04	60.01	71.69
Turkey	15.25	5.82	47.81	18.43	31.54	29.47	20.16	26.66	49.69	54.26	32.04	54.90
UK	1.37	0.63	2.16	1.07	27.18	17.51	30.36	18.13	67.92	71.04	67.48	80.80
United States	1.34	0.92	1.75	1.43	23.13	18.21	25.11	19.73	71.81	77.37	73.14	78.85
Russia	13.77	3.15	14.24	5.88	45.86	32.07	39.96	26.81	36.71	54.12	45.80	67.31

Source: World Bank national accounts data, and OECD National Accounts data files and International Labour Organization, ILOSTAT database. Downloaded from https://data.worldbank.org

The important question arises here that, since service sector is generally believed to be less polluting, whether this global shift to service sector is a positive sign for environment? The idea that service sector is less polluting than manufacturing sector isn't true (Grove et al 1996: 58; Alcántara and Padilla 2009: 909-910). It is the backward linkage or supply chain effect or the pull effect of the service sector which leads to large emissions. The service sector requires a number of goods from upstream sectors. For example, the hotel services, tourism, health and other services involve large amount of material goods to serve their customers. The production of these goods involves large amount of energy consumption. Zhang et al (2015a: 93-103) used multi regional input output model to study the CO_2 emissions in the global supply chain of services. They found that the consumption-based emissions of the service sector are significantly greater than its direct emissions. In some countries direct emissions of the service sector were found to have decreased but their consumption-based emissions increased substantially during 1995–2007.

3.4.2 Socio-demographic Changes

Population is one of the most important causal factors behind CO_2 emissions (Wang et al 2012: 278; Wang and Zhao 2015: 187). Along with population size, other demographic variables like urbanization level, household size, age composition, population density, longevity etc., are potentially important determinants of greenhouse gas emissions (O'Neill and Chen 2002: 53; Liddle 2014: 286–304; Chikaraishi et al 2015: 302–317). Table 3.5 shows that, in all nations except Saudi Arabia, population growth rate is either declining or has stagnated. Mean life expectancy has increased in all the nations and has gone well above 70 years of age by 2018 in all countries except South Africa, where it still lingers little below 65 years. Rapid decline in birth rate is observed in all the nations (by nearly 50% and more) between 1960 and 2018 (Table 3.5). While the death rate has expectedly declined in all countries in the last 60 years, in case of Russia, Poland and Japan, it has actually increased. Population density as well as urban population has also increased (Table 3.5).

Further Table 3.5 shows that the age dependency ratio[49] in European nations like France, Germany, Italy and U.K. has more or less been the same. Japan shows a significant increase in age dependency ratio from about 48 to 63, suggesting rapid increase in dependent population. In rest of the nations, age dependency ratio is declining, signaling increase in the working age population. Zagheni (2011: 371-399) found that, in USA per-capita CO_2 emissions increased with age until the individual is in his or her 60s, and then emissions tend to decrease. Wang et al (2017: 322-330) carried out a regional analysis of China and found that in the eastern region of China, aging population increases emissions, while in the central and the western region it has opposite effect. Urbanization had positive impact on carbon emissions in the western region, negative effect in the central region and statistically insignificant in the

[49] Ratio of dependent population (in the age group 0-14 years and 65 years and above) to working age population (15-64 years)

eastern region. Gender has also been found to be an important factor influencing indoor energy consumption (Streimikiene and Volochovic 2011: 4119).

Table 3.5: Decadal Mean of Demographic Variables

Country	Year	Avg. Population growth rate	Mean Population Density	Mean Life expectancy at birth	Mean Age dependency ratio	Urban Population (%)	Country	Year	Avg. Population growth rate	Mean Population Density	Mean Life expectancy at birth	Mean Age dependency ratio	Urban Population (%)
Australia	1961-70	2.0	1.5	70.9	61.7	83.1	Japan	1961-70	1.2	272.4	70.5	47.9	68.2
	1971-80	1.6	1.8	72.8	56.7	84.9		1971-80	1.1	309.0	74.9	47.2	75.1
	1981-90	1.5	2.1	75.8	51.1	85.6		1981-90	0.6	334.5	77.8	46.0	76.8
	1991-2000	1.2	2.4	78.2	50.0	84.8		1991-2000	0.3	346.7	80.0	44.5	78.1
	2001-10	1.4	2.7	80.8	48.4	84.6		2001-10	0.1	351.9	82.2	51.1	86.1
	2011-18	1.6	3.1	82.3	50.8	85.7		2011-18	-0.2	351.1	83.6	62.8	91.3
Brazil	1961-70	2.8	10.1	56.8	86.8	51.5	South Korea	1961-70	2.5	300.3	58.6	87.1	33.7
	1971-80	2.4	13.0	61.0	77.7	61.2		1971-80	1.7	365.8	64.3	71.1	49.2
	1981-90	2.1	16.3	64.6	68.5	70.2		1981-90	1.2	420.7	69.1	51.8	66.0
	1991-2000	1.6	19.5	68.5	59.4	78.0		1991-2000	0.9	467.6	74.0	40.7	77.9
	2001-10	1.1	22.4	72.1	49.7	83.0		2001-10	0.5	501.0	78.4	37.8	81.2
	2011-18	0.9	24.4	74.8	44.2	85.6		2011-18	0.5	520.5	81.7	36.6	81.7
Canada	1961-70	1.8	2.2	72.0	67.9	73.0	Mexico	1961-70	3.1	23.1	59.6	100	55.3
	1971-80	1.4	2.6	73.8	53.0	75.7		1971-80	2.8	31.1	64.2	98.6	63.1
	1981-90	1.2	2.9	76.5	46.4	76.3		1981-90	2.1	39.5	69.0	84.8	69.2
	1991-2000	1.0	3.2	78.2	47.4	77.9		1991-2000	1.6	47.5	72.8	70.1	73.4
	2001-10	1.0	3.6	80.3	44.7	80.3		2001-10	1.4	55.0	75.1	59.5	76.5
	2011-18	1.1	3.9	81.8	46.9	81.2		2011-18	1.3	62.3	75.0	52.7	79.1
China	1961-70	2.0	78.9	51.0	79.8	17.6	Poland	1961-70	1.0	102.6	69.1	60.7	50.3
	1971-80	1.8	99.1	64.0	76.0	17.7		1971-80	0.9	111.5	70.5	51.6	55.5
	1981-90	1.5	116.1	68.4	57.1	23.3		1981-90	0.7	121.2	71.0	53.5	60.1
	1991-2000	1.1	132.6	70.1	49.2	31.5		1991-2000	0.0	125.5	72.2	50.6	61.5
	2001-10	0.6	142.1	73.1	39.3	43.2		2001-10	-0.1	125.4	75.1	42.2	61.4
	2011-18	0.5	149.4	75.8	37.9	54.9		2011-18	0.0	124.4	77.4	43.9	60.4
France	1961-70	1.1	89.1	70.9	60.9	67.3	Saudi Arabia	1961-70	3.6	2.3	49.0	89.8	40.0
	1971-80	0.6	96.2	73.0	59.5	72.7		1971-80	5.1	3.6	58.5	89.6	58.8
	1981-90	0.5	101.2	75.4	52.7	73.7		1981-90	5.2	6.2	66.6	82.5	72.6
	1991-2000	0.5	105.8	77.9	53.1	75.0		1991-2000	2.4	8.7	71.2	77.8	78.7
	2001-10	0.7	111.8	80.4	54.0	77.3		2001-10	2.8	11.3	73.3	57.4	81.1
	2011-18	0.4	117.3	82.4	58.6	79.5		2011-18	2.6	14.5	74.6	41.9	83.1

Country	Year	Avg. Population growth rate	Mean Population Density	Mean Life expectancy at birth	Mean Age dependency ratio	Urban Population (%)	Country	Year	Avg. Population growth rate	Mean Population Density	Mean Life expectancy at birth	Mean Age dependency ratio	Urban Population (%)
Germany	1961-70	0.7	219.3	70.2	55.0	72.0	South Africa	1961-70	2.6	16.2	50.6	83.5	47.3
	1971-80	0.0	225.8	71.6	56.5	72.6		1971-80	2.6	21.1	55.7	81.9	48.1
	1981-90	0.2	224.1	74.1	45.4	72.9		1981-90	2.5	27.3	61.2	80.4	50.0

	1991-2000	0.3	232.0	76.7	46.5	74.1		1991-2000	2.0	34.3	60.5	70.3	54.7
	2001-10	-0.1	233.4	79.1	50.0	76.1		2001-10	1.3	39.8	54.8	55.6	59.8
	2011-18	0.2	234.6	80.8	52.7	77.2		2011-18	1.5	45.3	61.9	52.3	64.6
India	1961-70	2.1	170.0	44.9	80.2	18.9	**Turkey**	1961-70	2.4	40.8	49.3	85.0	34.9
	1971-80	2.3	212.4	51.2	77.1	21.5		1971-80	2.3	51.7	55.7	81.8	41.6
	1981-90	2.2	266.9	56.0	73.7	24.5		1981-90	2.0	64.4	61.9	73.4	52.7
	1991-2000	1.9	327.4	60.5	68.1	26.7		1991-2000	1.6	76.7	67.3	61.8	62.4
	2001-10	1.6	388.8	64.8	59.7	29.4		2001-10	1.3	88.7	72.6	54.3	68.1
	2011-18	1.1	438.0	68.4	52.2	32.6		2011-18	1.6	101.2	76.3	50.5	73.3
Indonesia	1961-70	2.7	56.3	49.9	83.8	15.9	**United Kingdom**	1961-70	0.6	224.4	71.5	56.1	77.8
	1971-80	2.5	73.1	55.6	84.6	19.6		1971-80	0.1	231.9	72.8	59.2	77.8
	1981-90	2.1	91.9	60.5	73.7	26.6		1981-90	0.2	233.8	74.9	53.1	78.4
	1991-2000	1.5	109.4	64.4	60.3	36.7		1991-2000	0.3	240.0	76.9	54.2	78.4
	2001-10	1.3	125.8	67.6	52.7	46.4		2001-10	0.6	251.7	79.1	51.9	80.0
	2011-18	1.3	141.6	70.6	49.2	53.0		2011-18	0.7	271.3	81.1	54.6	82.5
Iran	1961-70	2.6	15.6	48.1	92.0	37.6	**United States**	1961-70	1.3	21.9	70.3	64.8	72.0
	1971-80	3.0	20.6	54.4	87.6	46.1		1971-80	1.0	24.1	72.5	55.7	73.7
	1981-90	3.8	29.7	57.1	94.0	53.6		1981-90	0.9	26.4	74.6	51.4	74.6
	1991-2000	1.5	38.0	68.2	79.5	60.6		1991-2000	1.2	29.2	76.0	52.7	77.4
	2001-10	1.2	43.1	72.2	47.3	67.8		2001-10	0.9	32.4	77.6	50.0	80.0
	2011-18	1.3	48.0	75.6	42.2	73.1		2011-18	0.7	34.9	78.7	51.1	81.6
Italy	1961-70	0.7	176.2	70.4	53.9	62.1	**Russia**	1961-70	0.8	7.7	67.6	55.6	58.6
	1971-80	0.5	188.0	72.9	56.4	65.7		1971-80	0.6	8.2	67.7	47.7	66.7
	1981-90	0.1	193.4	75.7	48.3	66.8		1981-90	0.7	8.8	68.4	48.2	72.0
	1991-2000	0.0	193.7	78.4	46.6	67.0		1991-2000	-0.1	9.0	66.1	48.7	73.4
	2001-10	0.4	198.0	81.0	51.1	67.8		2001-10	-0.3	8.8	66.6	40.9	73.5
	2011-18	0.2	205.1	82.7	55.0	69.4		2011-18	0.1	8.8	71.1	43.5	74.0

Source: Estimated from https://data.worldbank.org

Thus, we observe that economic growth has led to positive demographic changes as well as social development in all the countries under our study. However, the cultural as well as political factors also play a major role in shaping the demography of any country. For example, increasing age dependency ratio in Japan as a result low fertility rate due to changing lifestyle and delayed marriages. Similarly, one child policy in China has led to massive population growth control.

3.4.3 Environmental Externalities

CO_2 Emission Trends

Table 3.6 presents the decadal CAGR of per capita as well as total CO_2 emissions for 20 nations under consideration during the period between 1960 and 2017. During the decade from 1960-70, nearly all 20 nations witnessed a high CO_2 emissions growth rate in both total and per capita terms. But, the East Asian nations, Japan and South Korea and west Asian nations, Saudi Arabia, Iran and Turkey showed extremely high growth rates (Table 3.6). Since 1970s all the nations witnessed very slow emissions growth rate. In many European nations, in fact, emissions peaked and later declined continuously since 1970s. This decline was initially due to shift to less polluting energy sources (Le Quéré et al 2019: 215). Since 1990s, emission outsourcing via international trade also contributed to this reduction (Peters et al 2011: 8904; Davis and Caldeira 2010: 5688). As shown in Table 3.6, in Germany, France, U.K. and Poland, both total and per capita emissions are observed to be declining since 1980s. In Canada, Japan, Italy and US the decline is observed since 2000s. Another interesting fact is while all the countries were observing declining emissions growth rate since the beginning of 21st century, China, in sharp contrast shows a very high growth rate of 9% during 2000-10. In case of India the emissions growth rate has been in the range of 4 to 6 % since 1960s.

Table 3.6: Decadal CAGR of Total and Per Capita CO_2 Emissions

Country	Year	CAGR per capita CO_2 emissions	CAGR CO_2 emissions (tonnes)	Country	Year	CAGR per capita CO_2 emissions	CAGR CO_2 emissions (tonnes)
Australia	1961-70	2.9	5.0	Japan	1961-70	9.4	10.5
	1971-80	2.6	3.7		1971-80	0.7	1.7
	1981-90	0.5	1.9		1981-90	1.7	2.2
	1991-2000	1.3	2.3		1991-2000	0.6	0.8
	2000-10	-0.1	1.3		2000-10	-0.4	-0.3
	2011-17	-0.9	0.3		2011-17	-0.5	-0.7
Brazil	1961-70	4.0	6.6	South Korea	1961-70	11.7	14.0
	1971-80	3.9	6.1		1971-80	7.1	8.7
	1981-90	0.1	2.0		1981-90	4.8	5.9
	1991-2000	2.6	4.1		1991-2000	4.5	5.4
	2000-10	1.1	2.1		2000-10	2.0	2.4
	2011-17	0.7	1.5		2011-17	0.3	0.7
Canada	1961-70	4.1	5.8	Mexico	1961-70	2.8	5.7
	1971-80	1.1	2.3		1971-80	5.1	7.8
	1981-90	-0.3	0.8		1981-90	-0.7	1.1
	1991-2000	1.4	2.3		1991-2000	0.3	1.8
	2000-10	-1.1	-0.2		2000-10	-0.1	1.2

	2011-17	-0.5	0.3		2011-17	-1.0	0.1
China	1961-70	1.3	3.4	**Poland**	1961-70	3.0	3.9
	1971-80	3.6	5.3		1971-80	3.2	4.0
	1981-90	3.7	5.3		1981-90	-1.4	-0.8
	1991-2000	2.0	2.8		1991-2000	-1.7	-1.6
	2000-10	8.9	9.5		2000-10	0.6	0.6
	2011-17	0.2	0.7		2011-17	-0.2	-0.2
France	1961-70	3.6	4.6	**Saudi Arabia**	1961-70	21.7	28.9
	1971-80	0.4	0.9		1971-80	0.1	11.0
	1981-90	-1.7	-1.2		1981-90	1.8	0.6
	1991-2000	-0.6	-0.2		1991-2000	-1.6	1.0
	2000-10	-1.2	-0.7		2000-10	3.0	5.7
	2011-17	-1.0	-0.6		2011-17	N.A.	3.5
Germany	1961-70	1.5	2.1	**South Africa**	1961-70	1.4	3.9
	1971-80	0.7	0.6		1971-80	0.7	3.1
	1981-90	-0.5	-0.4		1981-90	-0.1	2.0
	1991-2000	-1.4	-1.2		1991-2000	-0.3	1.5
	2000-10	-0.9	-1.0		2000-10	1.4	2.4
	2011-17	-0.4	-0.2		2011-17	-1.5	-0.4
India	1961-70	2.1	4.1	**Turkey**	1961-70	7.1	9.4
	1971-80	2.1	4.3		1971-80	2.5	4.7
	1981-90	4.1	6.2		1981-90	4.4	6.3
	1991-2000	2.8	4.6		1991-2000	2.5	3.9
	2000-10	3.6	5.1		2000-10	3.1	4.3
	2011-17	3.4	4.5		2011-17	2.4	3.8
Indonesia	1961-70	0.8	3.2	**United Kingdom**	1961-70	0.5	1.0
	1971-80	6.9	9.3		1971-80	-1.4	-1.3
	1981-90	2.2	4.1		1981-90	0.5	0.7
	1991-2000	2.5	3.9		1991-2000	-1.0	-0.7
	2000-10	2.4	3.7		2000-10	-1.8	-1.2
	2011-17	-4.0	-3.0		2011-17	-3.3	-2.8
Iran	1961-70	7.1	9.7	**United States**	1961-70	3.1	4.2
	1971-80	-1.1	1.7		1971-80	0.0	0.8
	1981-90	2.9	6.4		1981-90	0.4	1.2
	1991-2000	3.6	5.0		1991-2000	0.7	1.7
	2000-10	2.5	3.6		2000-10	-1.1	-0.3
	2011-17	1.1	2.2		2011-17	-1.4	-0.8
Italy	1961-70	8.3	9.1	**Russia**	1961-70	4.0	4.7
	1971-80	1.7	2.2		1971-80	2.8	3.4
	1981-90	1.5	1.6		1981-90	1.4	2.0
	1991-2000	0.7	0.7		1991-2000	-4.6	-4.7
	2000-10	-1.5	-1.1		2000-10	0.9	0.8

	2011-17	-2.0	-2.1		2011-17	-0.2	-0.2

Source: Estimated from https://ourworldindata.org

Energy Structure and CO_2 Emissions

Energy plays a vital role in economic growth as a production factor. Of all twenty nations under consideration, except in Brazil, Canada and France, it is the heat and electricity production sector which is responsible for maximum CO_2 emissions. Table 3.7 shows that in most of the nations, except, Brazil, Canada and France, a major share of electricity production is produced by fossil fuels. More than half of electricity in Brazil and Canada is generated from hydropower. In Brazil, however, over 80% of power was sourced from hydroelectric sources till 2010. In just five years, fossil fuels contribution increased from 10% to nearly 25% in 2015 (Table 3.7). In Canada, the share of hydropower has continuously declined from over 90% in 1960 to little below 60% in 2015. India, Indonesia, Iran and Mexico show a very similar trend of continuously increasing divergence between fossil fuels (increasing from nearly 60% to over 85%) and hydroelectric (decreasing from nearly 40% to 10%) sources (Table 3.7). France presents a very unique scenario wherein, fossil fuels held a prominent share till 1979 but since then declined rapidly to below 10% by 2015, taken over by nuclear sources whose share increased from 0.1% in 1960 to nearly 78% in 2015. Energy production in France and Europe at the beginning of the 20thcentury, depended half on hydraulic channels and half on fossil fuels (Fiore 2006: 3334). In response to the oil shock of 1973, major industrialized countries like Japan, Germany, South Korea and France shifted to large scale nuclear energy to be self-sufficient in their energy requirements. However, only France was able to sustain it as a major energy source. In France, it was the State which developed nuclear energy, while in Germany, it was mainly by the private sector (Wiliarty 2013: 283). Both France and Germany face wide anti-nuclear protests in 1970s and the Three Mile Island accident (US 1979) added to it. Wiliarty (2013: 281-296) believed that it was the political opportunity structure which led to different outcomes in the two nations. While the French government heavily suppressed the protests, in Germany, the reactions were not very extreme. By early 1990s and 2000, South Korea and Germany respectively began to phase out nuclear energy. While Germany turned to becoming a leader in renewables, South Korea instead went back to coal and oil resources. Japan on the other hand expanded its nuclear power in 1990s. But the Fukushima accident 2011, accelerated the phasing out of nuclear power in both Germany and Japan. Germany and Japan had similar history of post war reconstruction, but Germany, despite being rich in coal developed renewable power while Japan being coal-poor increased the share of fossil fuel resources (Table 3.7).

Table 3.7: Share of Source of electricity production (1960-2015)

Country	Year	Renewable sources, excluding hydroelectric	Hydroelectric sources	Oil, gas and coal sources	Nuclear sources
Australia	1960	1.41	18.64	79.95	0.00
	2015	8.34	5.30	86.36	0.00
Brazil	1971	1.20	83.75	15.05	0.00
	2015	12.12	61.85	23.43	2.60
Canada	1960	0.00	92.09	7.91	0.00
	2015	6.27	56.74	21.07	15.55
China	1971	0.00	21.57	78.43	0.00
	2015	4.86	19.07	72.96	2.34
France	1960	0.00	54.47	45.33	0.19
	2015	6.20	9.66	6.06	77.63
Germany	1960	0.00	10.19	89.81	0.00
	2015	26.27	2.96	55.06	14.32
India	1971	0.00	42.22	55.98	1.79
	2015	5.36	9.98	81.89	2.79
Indonesia	1971	0.00	44.02	55.98	0.00
	2015	4.78	5.87	89.34	NA
Iran	1971	0.00	33.05	66.95	0.00
	2015	0.08	5.02	93.86	1.63
Italy	1960	3.77	81.90	14.33	0.00
	2015	22.51	16.17	60.25	0.00

Japan	1960	0.00	50.65	49.35	0.00
	2015	7.76	8.23	80.26	0.91
South Korea	1971	0.00	12.52	87.48	0.00
	2015	1.50	0.39	67.72	30.00
Mexico	1971	0.00	46.33	53.67	0.00
	2015	5.49	9.90	80.88	3.72
Poland	1960	0.03	2.16	97.80	0.00
	2015	12.69	1.11	86.08	0.00
Saudi Arabia	1971	0.00	0.00	100.00	0.00
	2015	0.00	0.00	76.21	NA
South Africa	1971	0.00	0.20	99.80	0.00
	2015	1.93	0.32	92.79	5.53
Turkey	1960	1.46	35.60	62.95	0.00
	2015	6.31	25.65	67.85	0.00
United Kingdom	1960	0.00	2.27	96.12	1.60
	2015	22.97	1.87	53.18	20.91
United States	1960	0.02	18.44	81.48	0.07
	2015	7.39	5.84	67.08	19.32
Russia	1990	0.01	15.33	73.16	10.93
	2015	0.09	15.76	65.48	17.02

Source: Estimated from https://data.worldbank.org

Note: Figures are percentage, as share of total electricity produced.

The transport sector is the next major emitting sector in all the countries except Brazil and France, where it is the leading emitting sector. The share of residential buildings is generally in the range of 1 to 20% for all the nations. This however, does not provide a true picture of household emissions. The definition of emissions from residential sector includes all emissions from fuel combustion in households (IPCC Source/Sink Category 1A 4b). It covers only the emissions from cooking, heating or cooling in the households. The indirect emissions, emissions from transport used by a household, etc., are not included as a part of residential emissions in it.

Table 3.8: Sectoral CO_2 Emissions

Country	Year	Manufacturing industries and construction	Residential buildings and commercial and public services	Electricity and heat production	Transport	Other sectors, excluding residential buildings and commercial and public services
Australia	1971	31.31	3.30	37.76	23.28	4.35
	2014	11.49	3.72	58.36	24.74	1.69
Brazil	1971	28.04	7.04	14.49	48.45	1.98
	2014	20.60	4.29	26.31	44.75	4.05
Canada	1971	22.84	27.94	23.40	24.77	1.06
	2014	12.04	14.52	38.73	31.79	2.91
China	1971	48.75	21.60	17.37	5.83	6.46
	2014	31.72	5.36	52.25	8.60	2.07
France	1971	31.88	26.37	25.89	14.29	1.57
	2014	15.70	23.40	13.80	42.41	4.70
Germany	1971	24.64	23.50	39.03	10.20	2.63
	2014	12.44	17.67	48.47	21.37	0.05
India	1971	35.14	15.09	21.55	24.26	3.97
	2014	26.41	5.49	53.61	11.48	3.02
Indonesia	1971	19.92	23.33	21.94	32.14	2.70
	2014	18.40	5.11	44.25	30.81	1.43
Iran	1971	22.94	25.74	26.95	19.36	5.01
	2014	16.66	21.94	34.35	24.93	2.13
Italy	1971	32.09	23.20	26.18	16.65	1.88
	2014	11.19	18.07	35.56	32.95	2.23
Japan	1971	34.92	10.25	37.72	13.81	3.30
	2014	19.18	9.98	53.10	17.54	0.21
South Korea	1971	29.69	38.65	18.51	12.26	0.89
	2014	13.66	8.13	60.49	16.28	1.45
Mexico	1971	29.48	9.49	25.31	32.24	3.49
	2014	13.45	5.32	44.07	35.09	2.07
Poland	1971	17.63	18.78	51.91	9.82	1.86
	2014	10.28	15.05	55.61	15.67	3.39
Saudi Arabia	1971	15.55	4.50	53.75	26.20	0.00
	2014	24.10	0.82	49.16	25.92	0.00
South Africa	1971	28.06	7.93	42.74	18.28	3.00
	2014	12.58	5.47	67.48	12.05	2.42
Turkey	1971	19.75	24.06	24.66	26.58	4.91
	2014	14.62	15.16	46.69	19.83	3.71
United Kingdom	1971	25.18	17.23	43.07	11.87	2.66
	2014	9.60	19.06	41.93	28.45	0.96
United States	1971	20.78	19.06	33.00	25.34	1.82

	2014	8.66	11.01	45.99	33.40	0.94
Russia	1990	11.61	13.32	56.92	13.81	4.33
	2014	12.32	9.17	61.11	16.24	1.15

Source: Estimated from https://data.worldbank.org

Note: Figures are in percentage, as share of total fuel consumption.

3.5 Factors Determining CO_2 Emissions: Panel Data Analysis

Unit root tests

Before analysis the results of panel results, it is necessary to check for the presence of unit roots in the data and to avoid spurious regression. Four unit root tests viz. Levin-Lin-Chu (LLC) test (Levin et al 2002: 1-24), Im-Pesaran-Shin (IPS) test (Im et al 2003), Fisher-ADF test and Fisher-PP test (Maddala and Wu 1999: 631-652), were used to check the stationarity of the variables. Table 3.9 shows that all variables were not found to be stationary at level, but at first difference, all the variables are stationary at 1% significance level, that is, all variables are I(1). So now we can perform co-integration tests.

Table 3.9: Panel Unit Root Tests Results

	Level				First Difference			
Variables	Levin, Lin & Chu	Im, Pesaran and Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-square	Levin, Lin & Chu	Im, Pesaran and Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-square
Log CO_2 emissions	-11.9*	-7.68*	187.83*	217.46*	-22.6*	-22.58*	490.29*	535.96*
Log population	-6.93*	-4.5*	104.64*	292.52*	-2.93*	-2.47*	63.4*	81.03*
Log per capita GDP	-4.22*	1.08	42.38	63.09*	-15.5*	-18.33*	385.28*	402.81*

Source: Esimated from https://data.worldbank.org

Note: * denotes significance level at 1%. ** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality. Automatic lag length selection based on SIC: 0 to 10.

Co-integration tests

To determine long run relationship between the variables, two cointegration tests were performed: Kao (1999) residual cointegration tests and Johansen fisher panel cointegration test. The results of both the tests suggest that there is the existence of long run relationship between the selected variables (Table 3.10 and Table 3.11).

a) Kao Residual Cointegration Test

Table 3.10: Results of Kao Residual Cointegration Test

	t-Statistic	Prob.
ADF	-3.561382	0.0002
Residual variance	0.005222	
HAC variance	0.005931	

Source: Estimated from https://data.worldbank.org

Note: Null Hypothesis: No cointegration; Automatic lag length selection based on SIC with a max lag of 10 Newey-West automatic bandwidth selection and Bartlett kernel.

b) Johansen Fisher Panel Co-integration

Table 3.11: Results of Johansen Fisher Panel Cointegration Test

Hypothesized	Fisher Stat.*	Fisher Stat.*
No. of CE(s)	(from trace test)	(from max-eigen test)
None	207.3*	155.8*
At most 1	92.38*	73.80*
At most 2	84.96*	84.96*

Source: estimated from https://data.worldbank.org

Note: * denotes significance level at 1%

Fully Modified OLS

After determining the long run relationships, the long run parameters, i.e., co-integration coefficients, are estimated using FMOLS and DOLS. FMOLS was developed by Phillipps and Hansen (1990). It accounts for serial correlation effects and tests for the endogeneity in the regressors that result from the existence of co-integrating relationships (Rukhsana and Shahbaz 2008). It also eliminates sample bias asymptotically. The DOLS procedure corrects potential simultaneity bias among the regressors and also exhibits superior performance in finite samples

(Stock and Watson 1993: 793). Table 3.12 shows that both variables are found to be significant. The importance of population in terms of the magnitude of its elasticity is found to be much greater than that of per capita GDP in both FMOLS and DOLS.

Table 3.12: Results of Panel Co-integration Coefficients

Variable	FMOLS Coefficient	DOLS Coefficient
LOG_PC_GDP	0.706240* [0.0411]	0.638* [0.052]
LOG_POPULATION	3.232615* [0.1663]	3.458* [0.1896]

Source: Estimated from https://data.worldbank.org

Note: * Significance level at 1%. Long-run covariance estimates (Bartlett kernel, Newey-West fixed bandwidth). Standard errors in [].

Causality Test: Long run and Short run

Panel Vector Error Correction Model is used to study the causal relationship between the variables. Firstly optimum lag is obtained using VAR lag order selection criteria. Optimal lag length is found to be 3 by Schwarz information criterion. Both long run and short run causality was found to exist between dependent and independent variables.

Also country wise long run elasticity was estimated using both FMOLS and DOLS to confirm the consistency of the results. All the countries have significant elasticity coefficients of per capita GDP in both FMOLS and DOLS model except India in DOLS (Table 3.13). Population elasticity is non-significant in France, Germany, India and Japan in both FMOLS and DOLS. Whereas, UK has non-significant population elasticity under DOLS. In all the countries, population elasticity is significant, its impact on CO_2 emissions is much greater than that of per capita GDP (Table 3.13). It suggests that the impact of small increase in population is much greater than the impact of a small increase in GDP and therefore population control and reduced consumption by population as well as the behavioural changes can have a big impact on reducing emissions.

Table 3.13: Country-wise Long Run Elasticity using FMOLS and DOLS

Country	FMOLS		DOLS	
	Per capita GDP	Population	Per capita GDP	Population
Australia	0.62***	3.902*	0.673***	3.617*
Brazil	1.019*	2.013*	0.924*	2.066*
Canada	0.907*	3.673*	0.97*	3.596*
China	1.291*	3.715*	2.163*	6.087*
France	1.45*	0.951	1.517*	-0.471
Germany	1.027*	0.592	0.85***	0.512
India	0.21***	1.942	-0.196	0.6339
Indonesia	0.273**	3.1*	0.38*	4.95*
Iran	0.689*	1.791*	0.689*	2.13*
Italy	1.769*	2.076***	1.972*	1.519***
Japan	1.46*	-1.68	1.16*	-0.374
South Korea	0.33*	5.065*	0.387*	5.65*
Mexico	0.342*	3.302*	0.387*	5.651*
Poland	0.712*	5.93*	0.826*	6.44*
Russia	0.457*	5.481*	0.43*	5.98*
Saudi Arabia	1.298*	5.131*	1.367**	5.875*
South Africa	0.566*	2.99*	0.493**	2.85*
Turkey	0.365*	3.199*	0.804*	2.03*
United Kingdom	0.699*	1.306***	0.704*	1.35
United States	1.318*	4.616*	1.063*	6.178*

Source: Estimated from https://data.worldbank.org

Note: * denotes significance level at 1%. ** denotes significance level at 5%. *** denotes significance level at 10%.

3.6 Conclusions

The chapter attempts to cover a broad range of issues reflecting the interplay of socio-economic, demographic and environmental factors. The industrial revolution, which emerged in the west, changed the global scenario by technological innovation, increased energy consumption, growth of world trade, shifting from agriculture to large scale manufacturing and urbanization. Another major milestone was the mid-twentieth century, which witnessed rapidly increasing, global population, GDP, energy consumption and consequent CO_2 emissions. This age also witnessed the prosperity of Asian nations as well as the transition of global economy to service sector economy. The study outlines the transition of United States from an economy with low share in both GDP and carbon emissions to the biggest economy with largest emissions. It also describes the journey of China and India from accounting for more than half of world's GDP and population, and negligible emissions in nineteenth century to nearly 20% of world's GDP, 30% of world's population and 31% of world's CO_2 emissions in 2018. Europe's shift from accounting for 100% of global emissions to nuclear energy and renewable energy leading to decline in CO_2 emissions has been depicted. Also, the environmental impact of sectoral transition of most of the countries to service sector is detailed upon.

The findings suggest that transition to renewable energy sources is crucial, however, not without any side-effects. Nuclear energy, hydro-power, etc. come with their associated risks (large scale displacement, huge investment, health hazards etc.). Thus, reduction in energy consumption by following a sustainable lifestyle along-with gradual shift to renewable energy seems to be a more lasting strategy. Also, the panel data regression proves that population is a more elastic variable than GDP in determining CO_2 emissions. Thus, population control with other environment friendly behavioural changes is the need of the hour.

Chapter 4

State-wise Domestic Energy Consumption and CO_2 Emissions Scenario in India

"It is not an investment if it is destroying the planet"

\- Dr. Vandana Shiva

4.1 Introduction

According to Carbon Brief (2020)[50] India is the third largest emitter of CO_2 in the world but well behind the top two emitters viz. U.S. and China in 2019. In per capita terms, India's emissions are too little, and ranked 140th in the world. India is the fifth most vulnerable country to climate change after Japan, Philippines, Germany and Madagascar, and has the largest death toll of 2081 people in 2018 due to extreme weather events (Eckstein et al 2019: 6). Having nearly 50 percent of its borderline surrounded by water and being the second most populated nation in the world with more than half of it dependent on agriculture[51], makes it even more vulnerable to climate change. Indian agriculture is highly risk prone as 51 percent of its net sown area is rain-fed and accounts for 40 percent of total food production[52]. Further, India is the fifth largest economy in the world in terms of robustness of GDP after USA, China, Japan and Germany (World Economic Outlook 2020: 101). Human Development Report (2020: 243) of UNDP, places India at 131st rank out of 189 countries in Human Development ranking. Also, the Global Hunger Index (2020: 9) places India on 94th position out of 107 countries and Global Multidimensional Poverty Index (Alkire et al 2020: 44) ranks it 62nd out of 107 countries.

The above facts very clearly bring out the complex state of India. Climate change is a multidimensional problem for India. It is more of a socio-economic and political issue rather than an environmental issue domestically. Keller et al (2020: 219-235) conducted an automated content analysis on *Times of India* and *The Hindu* news articles from 1997 to 2016. The most frequent themes found were, "Climate Change and Society", "Climate Politics", "Climate

[50] https://www.carbonbrief.org/the-carbon-brief-profile-india
[51] http://www.fao.org/india/fao-in-india/india-at-a-glance/en/#:~:text=Agriculture%2C%20with%20its%20allied%20sectors,farmers%20being%20small%20and%20marginal.
[52] http://agricoop.nic.in/divisiontype/rainfed-farming-system#:~:text=Rainfed%20agriculture%20occupies%20about%2051,highly%20diverse%20and%20risk%20prone.

Change Impacts", and "Climate Science". The study observed that media coverage of climate change issues has increased significantly over the period. However, most of the coverage was in the social and political context. There was less focus on the environmental impacts and climate science. Thus, it is observed that India's climate policy is in favour of mitigation and adaptation measures to the extent that they are consistent with its economic growth objectives, i.e., "sustainable development realist approach" (Dubash 2013: 197; Thaker and Leiserowitz 2014: 111). Given India's prominent stature on the global table, despite being a developing nation, India is expected to act responsibly on environmental front, while simultaneously battling with its developmental challenges.

In the face of such challenges households can come to rescue of the world by making changes in their energy consumption pattern. Households are responsible for 72% of total Greenhouse gas emissions in the world (Edgar et al 2009: 6417). Residential energy consumption (cooking, heating and lighting) account for 21% of total CO_2 emissions in USA (Shammin 2012: 173). Similarly in UK, domestic sector accounts for 26% of its total CO_2 emissions (Natarajan et al 2011: 2602). Urban resident's lifestyle (direct energy consumption) accounted for 30% of total CO_2 emissions in China between 1999 and 2002 (Wei et al 2007: 254). Both direct and indirect household CO_2 emissions accounted for 58% of total emissions in India in 2003-04 (Parikh et al 2009: 1030).

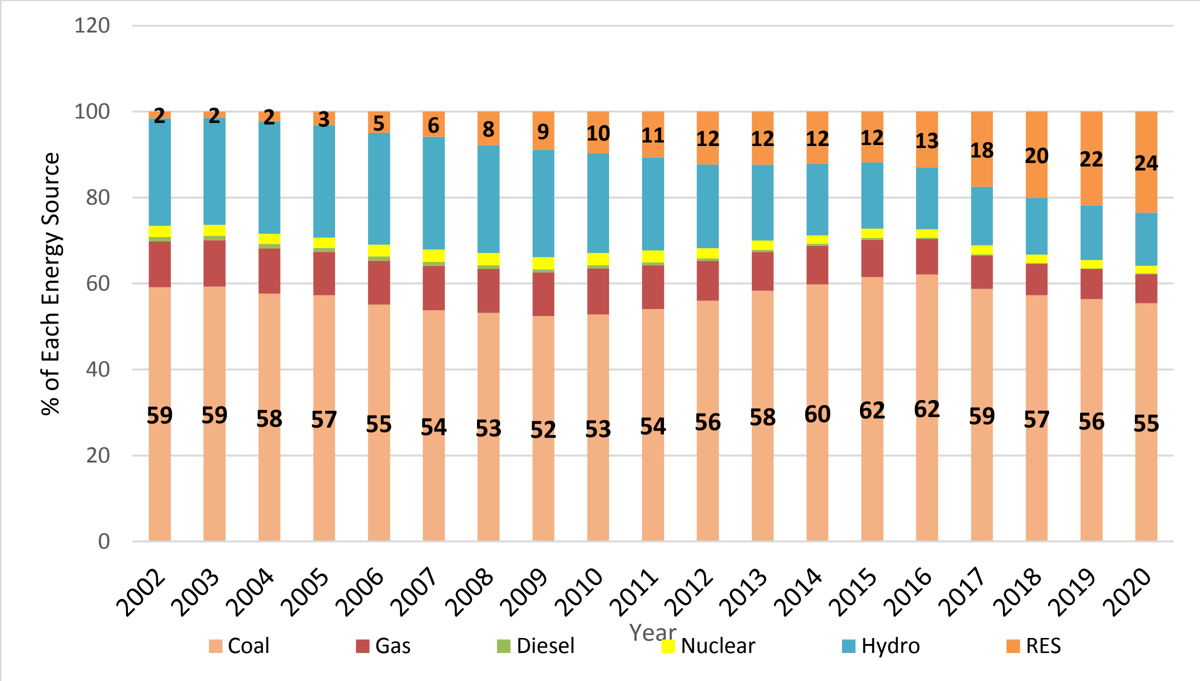
India being a party to UNFCCC, attaches great importance to the issue of climate change. Ministry of Environment Forest and Climate Change (MoEFCC) of Government of India, provides its GHG inventory at the national level periodically, for accurate policy formulations in this regard. Till date five reports have been published for the years 1994 (India's Initial National Communication to the UNFCCC 2004: iv), 2000 (India Second National Communication to the UNFCCC 2012: vi), 2007 (India: Greenhouse Gas Emissions 2010: ii), 2010 (Biennial Update Report (BUR) 2015: 17) and 2014 (BUR 2018: 8), providing the sectoral

CO_2 emissions in India. The reports suggest that the greatest contribution (over 80%) to CO_2 emissions has been from energy sector for all the years except in 2007, when it came down to 66% and the share of emissions from industrial sector increased to 27% (which normally lied between 7% to 12%). MoEF reports classify the energy sector into six major constituent sectors, such as energy industries (electricity production and petroleum refining industries) , manufacturing industries and construction, transport (road, rail, aviation and navigation), residential (firewood, LPG and kerosene), fugitive fuel emission and all other sectors (commercial/institutional, agriculture/fisheries). More than half of the total emissions emerged from energy industries. Since 1994, the contribution of energy industries emission has increased from 49% to 60% in 2014. This is mainly due to the high dependence on coal for electricity production in India in both utilities[53] and non-utilities (India Energy Statistics 2021: 56). Non-utilities account for 16% to 18% of total installed capacity of electricity generation and 13% of total electricity generated and comprise of 96% thermal and 4% Renewable Energy Sources (RES) and 98% thermal and 2% RES respectively in 2020. In utilities, contribution of coal in installed capacity decreased from 59% in 2002 to 53% in 2010. Between 2011 and 2016, coal contribution increased from 54% to 62% and again declined to 55.4% in 2020 (Figure 4.1). This decline is the result of the policies undertaken by the Government of India to meet its INDC submitted at Paris Agreement 2015, which aims to achieve 175 Gigawatts (GW) of renewable energy (installed) by 2022. All India installed capacity of electricity generation from gas and hydro sources from utilities has increased at a CAGR of 3.9% and 2.2% respectively, while that from non-utilities has increased at a CAGR of 5.9% and 6.6% respectively between 2010-11 and 2019-20 (India Energy Statistics 2021: 22-23). As of December 2019, India has reached halfway of its installed renewable energy target (88 GW)[54].

[53]A public utility (usually just utility) is an organization that maintains the infrastructure for a public service (often also providing a service using that infrastructure).
[54]Executive Summary on Power Sector, January 2020, CEA, Ministry of Power

As of 2021, India ranks third in Renewable Energy Country Attractiveness Index[55], after U.S. and China.

Figure 4.1: Source-wise All India Installed Generation Capacity from Utilities (in Percentage)



Source: Estimated from Annual CEA Reports, Ministry of Statistics and Programme Implementation, Government of India.

Note: *RES= renewable energy source excluding hydro.

While installed generation capacity refers to the maximum output of electricity that a generator can produce under ideal conditions, gross electricity generation, refers to the amount of electricity that is produced over a specific period of time. In case of electricity generation, share of coal increased by over 10% (66.4% to 76.4%) between 2010 and 2016, but later declined to 72% in 2020 (India Energy Statistics 2021: 38-39). Out of the net electricity available for supply, utilities accounted for more than 97% share since 2010 (Table 4.1). A matter of concern here is that the high transmission and distribution losses (India Economic Survey 2021: 300). Although T & D losses in India have declined from 24% in 2010 to 20.3% in 2020 (Table 4.1), it is still more than twice the world average (i.e. 8%).

[55]https://www.ey.com/en_in/recai

Table 4.1: Source-wise Gross Generation of Electricity from Utilities

Year	Net Electricity Generated from Utilities (GWh)	Purchases from Non-Utilities + Net Import from Other Countries (GWh)	Net Electricity Available for Supply (GWh)	% Sold to Ultimate Consumers & Other Countries	% Loss in transmission & distribution
2010-11	791796	19839	811635	76.0	24.0
2011-12	865952	15514	881466	76.4	23.6
2012-13	900380	20849	921229	77.0	23.0
2013-14	956488	17948	974436	77.2	22.8
2014-15	1040582	13773	1054355	77.2	22.8
2015-16	1088282	15947	1104228	78.2	21.8
2016-17	1154314	8977	1163290	78.6	21.4
2017-18	1221307	11198	1232505	79.0	21.0
2018-19	1288393	19291	1307685	79.3	20.7
2019-20	1298621	12554	1311176	79.7	20.3

Source: Estimated from India Energy Statistics 2021, Ministry of Statistics and Programme Implementation, Government of India.

Region-wise all India installed capacity analysis (Table 4.2) shows that the Southern region has the highest share of RES (40%) followed by Western region (20%) and Northern region (18.5%). The highest share of thermal source is in Eastern region (84%) followed by Western region (72.5%). The southern region excels in renewable energy production as both solar and wind energy are abundant in the South India, especially from the four states, viz., Karnataka, Kerala, Tamil Nadu and united Andhra Pradesh (CSTEP 2019).

Table 4.2: Region-wise Installed Capacity of Electricity Generation (Utilities) 2020

	Hydro	Thermal	Nuclear	RES	Total
North	21.75	57.96	1.78	18.52	100
South	11.18	45.38	3.15	40.29	100
East	11.93	84.43	0.00	3.65	100

West	5.84	72.46	1.44	20.26	100
North East	37.20	55.05	0.00	7.74	100
Total	12.35	62.31	1.83	23.51	100

Source: Estimated from India Energy Statistics 2021, Ministry of Statistics and Programme Implementation, Government of India.

Note: Figures are in percentage.

Based on above background, the present chapter is divided into four sections. Section one is the introduction, followed by objectives, data sources and methods in section two. The third section is the results section covering the domestic energy consumption scenario in India, state-wise CO_2 emissions from domestic energy consumption in India, the analysis of the impact of socio-economic factors on domestic CO_2 emissions and lastly the monetary value of total CO_2 emissions from direct household (HH) energy consumption is estimated for each state and compared with its Gross State Domestic Product (GSDP).The last section concludes.

4.2 Objectives, Data Sources and Methods

4.2.1 Objectives

The objective of this chapter is to (a) assess the extent of residential electricity and other fuel consumption sources under domestic consumption at state level in India, (b) estimate the extent of CO_2 emissions due to domestic consumption of fuels across states in India, (c) estimate the monetary value of CO_2 emissions by household (HH) fuel consumption, (d) find out the factors such as population, per capita GSDP and population density impacting on household emissions across major 22 states for the year 2018-19.

4.2.2 Data Sources

State-wise end use sale of electricity to ultimate consumer data for the year 2018-19 has been sourced from Central Electricity Authority[56] through Right to Information. State-wise

[56] **RTI filed** to **CEA on 3 December 2020, Registration No. CEATY/R/E/20/00341**.

combined emission factor for end-use consumption (Emission Factor for End-User Consumption with adjusted Import & Export of Electricity + Emission Factors for Aggregate Technical and Commercial (AT & C) Losses) provided by cBalance Solutions Pvt. Ltd: Electricity GHG Inventory Report 2009-10 (Appendix Table 4.1A) . State wise data on registered motor vehicles is sourced from Road Transport Year Book 2016-17 (Appendix Table 4.2A). State wise population and other demographic variables data for the year 2018-19 has been taken from Census 2011 population projections (Population Projections for India and States 2011 – 2036, 2019). GSDP 2018-19 at constant prices (2011-12) has been sourced from National Statistical Office of Ministry of Statistics and Program Implementation. LPG and Motor Spirit consumption data has been taken from India PNG statistics 2018-19 of Ministry of Petroleum and Natural Gas, Government of India.

4.2.3 Methods

Energy consumption and subsequent emission of CO_2 for domestic sector is defined as the combination of total electricity and cooking gas consumption, and use of vehicles. Further, the use of energy under above mentioned three sources and subsequent release of emission are estimated in the following sub-sections using Tier -2 methodology of IPCC (2006: 2.11) given as below.

$$Emissions_{GHG,fuel} = Fuel\ Consumption_{\ fuel} * Country\ Specific\ Emission\ Factor_{\ GHG,fuel}$$

Emissions from Domestic Electricity Consumption

Major 22 states account for 98% of total end use electricity consumption by ultimate customers in 2018-19. Using the state-wise combined emission factor for end-use consumption, the CO_2 emissions are calculated as follows.

$$CO2\ emissions\ from\ Domestic\ Electricity\ Consumption\ (Kg\ CO2)$$
$$= \Sigma\ (Electrical\ energy\ sales\ to\ ultimate\ consumers\ state - wise\ utilities\ \&\ non - utilities\ \ in\ kWh * Corresponding\ State's\ Combined\ Emission\ Factor\ for\ End - User\ Consumption\ (kgCO2e/kWh))$$

Emissions from Personal Vehicle Use

Road transport accounted for 90.1% of the total transport emissions, followed by civil aviation (5.6%), railways (3.1%) and domestic water-borne navigation (1.2%) (Biennial Update Report 2018: 8). According to Road Transport Year Book (2016-17: 1), non-transport vehicles accounted for 91% of total registered motor vehicles. Two wheelers accounted for 81% of total non-transport vehicles. Cars accounted for 12.43% of total non-transport vehicles in 2016-17 (ibid: 1). These 22 states accounted for 96% of total transport vehicles and 98% of total non-transport vehicles in 2016-17 (ibid: 15).

In 2018-19, end use of High Speed Diesel oil for road transport accounted for mere 3.3% of its total consumption and Light Diesel Oil accounted for mere 0.7% of its total consumption (India PNG Statistics 2018-19: 97-98). Therefore, petrol is the dominant source of energy for domestic vehicles. For the estimation of CO_2 emissions from personal vehicles, based on the above facts, it is assumed that the entire petrol consumption is for transport purpose. Further, state-wise share of non-transport vehicles is taken to be the representative of share of petrol consumed by personal vehicles. On the basis of above CO_2 emissions from personal vehicles is estimated as follows:

Step 1: Petrol consumption in TMT[57] is converted to litres using, 1 litre petrol = 0.71 kg of petrol

$$\text{Step 2: CO2 emissions form personal vehicles (Kg CO2)} =$$
$$[\text{Petrol consumption in litres} * \text{ Emission Factor of Petrol} * \text{Sate} - \text{wise share of non} - \text{transport vehicles (in \%)}]/100$$

Emissions from Domestic LPG Consumption

According to India PNG Statistics (2018-19: 94), domestic consumption accounted for 87.2% of total LPG consumption in India in 2018-19. Assuming that in all the states, only 87.2% of the total LPG consumed is used for domestic purpose, state-wise CO_2 emissions from domestic LPG consumption is calculated as follows.

$$\text{CO2 emissions from LPG consumption (Kg CO2)} = \Sigma\,(\text{LPG consumption (kg)} * \text{LPG Emission Factor} * 0.87)$$

Regression Model

The following equations are estimated in this study to understand the factors determining the emission of CO_2 from the respective energy sources used in domestic sector.

$$log\ CO2\ Emission\ from\ Electricity\ Consumption = log\ population + log\ per\ capita\ GSDP + log\ population\ density + e \qquad \text{----------- (1)}$$

$$log\ CO2\ Emissions\ from\ Personal\ Vehicle\ Use = log\ population + log\ per\ capita\ GSDP + log\ population\ density + e \qquad \text{------------- (2)}$$

$$log\ CO2\ Emissions\ from\ LPG\ use\ for\ Cooking = log\ population + log\ per\ capita\ GSDP + log\ population\ density + e \qquad \text{---------- (3)}$$

[57]**Thousand Metric Tons**

$$\log Total\ CO2\ Emissions = log\ population + log\ per\ capita\ GSDP + log\ population\ density\ + e \text{ ----- } (4)$$

Estimation of Monetary value of Carbon Emissions from Direct HH Energy Consumption

The state-wise monetary value of total CO_2 emitted from direct HH energy consumption is calculated by taking the value of CO_2 to be US$25/t-$CO_2$ per year (Garg et al 2014: 579).The value is based on the World Bank (2019: 15) report on the State and Trends of Carbon Pricing[58] in the world, of total 51 carbon pricing initiatives in the world, 41 initiatives price carbon in the range of US $1/ton CO_2e to US $25/t CO_2e. Further, Gross State Domestic Product (GSDP) of each state is converted into US $ from Rupees by taking the value US $ 1 = Rs. 71 for the year 2020.

4.3 Analysis of Results

4.3.1 Domestic Energy Consumption Scenario in India

Residential Electricity Consumption in India

In India, household electricity consumption is mainly used for lighting, appliances, cooking and water heating. Space heating is not a major component of household electricity consumption because India is having subtropical and tropical climate, where air conditioning is still a luxury confined to a small percentage of households (Dzioubinski& Chipman 1999: 5). The estimated total electricity consumption in India has increased from 6,94,392 GWh (Gigawatt hour) during 2010-11 to 12,91,494 GWh during 2019-20, showing a CAGR of 6.74% (India Energy Statistics 2021: 59). As on March 2019, 99.99% of the households have

[58] https://documents1.worldbank.org/curated/en/191801559846379845/pdf/State-and-Trends-of-Carbon-Pricing-2019.pdf

been electrified in India except few households in Left Wing Extremism (LWE)[59] affected Baster region in Chhattisgarh (Annual Report Ministry of Petroleum, 2019-20: 3). The electricity consumption by households in India has increased from 238000 GWh in 2015–16 to 310087.71 GWh in 2019-20 (India Energy Statistics 2021: 72), marking an increase of over 30% in the last five years. The share of domestic electricity consumption in total electricity consumption has doubled between 1970-71 and 1990-91 (Table 4.3). However, since the beginning of the twenty first century, domestic electricity consumption share has remained stable at nearly 24%. Although, in total terms, domestic electricity consumption has increased by 4 times since 2000-01 (Table 4.3). Between 2012-13 and 2018-19, all India per capita domestic electricity consumption has increased by 1.3 times. While in case of Puducherry, Chandigarh, Lakshadweep, Delhi, Arunachal Pradesh and Daman & Diu, it has actually declined (Appendix Table 4.3A). Bihar shows the highest increase in per capita domestic electricity consumption (2.14 times). In Uttar Pradesh a growth by 1.35 times is registered in per capita domestic electricity consumption between 2012-13 and 2018-19 (Appendix Table 4.3A).

Table 4.3: Domestic Electricity Consumption Scenario in India

Year	Domestic Electricity Consumption (GWh)	Annual growth rate of Domestic Electricity Consumption (in %)	Total Electricity Consumption (GWh)	Annual growth rate of Total Electricity Consumption (in %)	Domestic Electricity Consumption as % of total Electricity Consumption
1970-71	3840	-	43724	-	8.8
1980-81	9246	1.4	82367	0.9	11.2
1990-91	31982	2.5	190357	1.3	16.8
2000-01	75629	1.4	316600	0.7	23.9

[59] Naxalism affected areas

2010-11	169326	1.2	694392	1.2	24.4
2015-16	238876	0.4	1001191	0.4	23.9
2019-20	310151	0.3	1291494	0.3	24.0

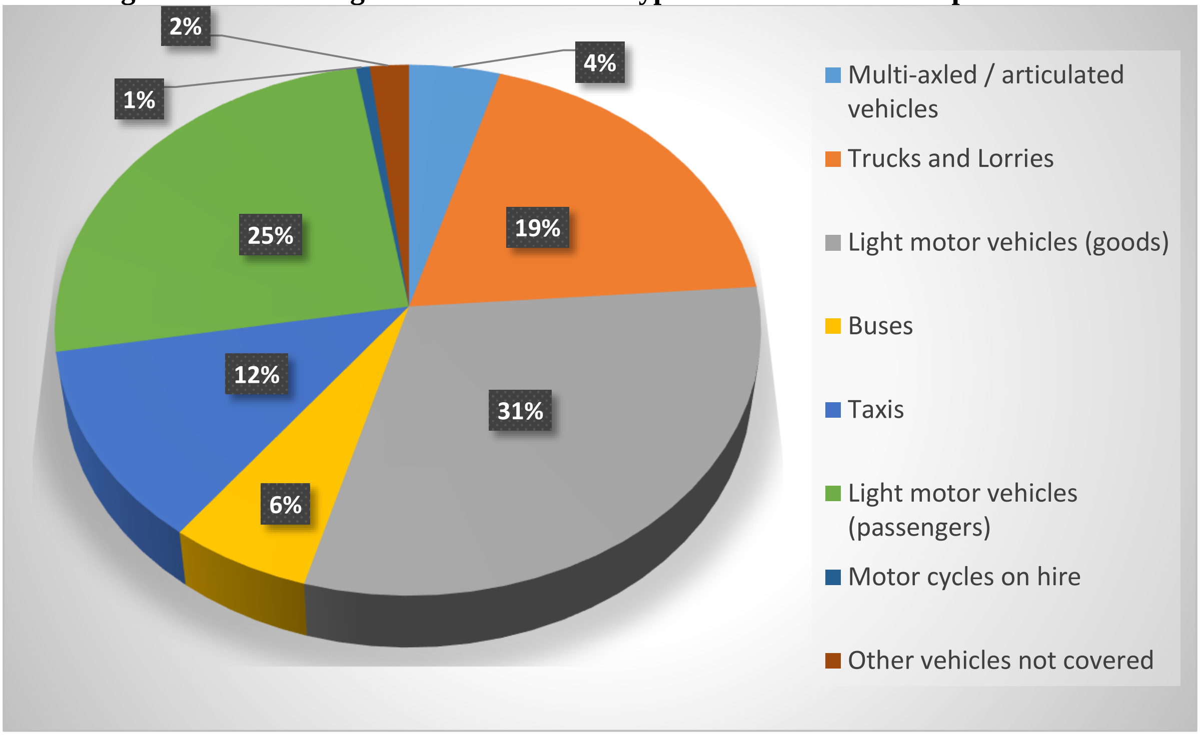
Source: India Energy Statistics, Annual Reports during 2008 to 2021, Ministry of Statistics and Programme Implementation, Government of India.

There has been a large increase in the use of cleaner commercial fuels, particularly LPG, and electricity in the household sector after 1990 (Pachauri 2007: 28). The proportion of households using electricity as major source of lighting has increased by 49% (from 24% to 72.7%) in rural areas and by 24% (from 72% to 96%) in urban areas from 1987-88 to 2011-12 (50th round 1997and 68th round 2015 of NSS). Domestic consumption of kerosene depicts a CAGR of -12.97% between 2010-11 and 2019-20 (India Energy Statistics 2021: 70).

Private Vehicle Usage in India

In India, vehicles are categorized as 'transport' (public service vehicles, both goods and passenger) and 'non-transport' (private vehicles) vehicles. According to Road Transport Year Book (2016-17: 1), the number of registered transport vehicles, were 22.539 million (8.9% of total registered vehicles) and non-transport vehicles accounted for the 91.1 % of total registered vehicles. Further, as Figure 4.2 shows, among the transport vehicles, light motor vehicles (goods and passengers) accounted for 56% followed by trucks and lorries (19%) and taxis (12%). Buses, which are an important source of public transport account for a very small share of 6% (Figure. 4.2). This suggests that the preference of people for personal vehicle in India is substantial and is also partly motivated by the lack of proper public transport.

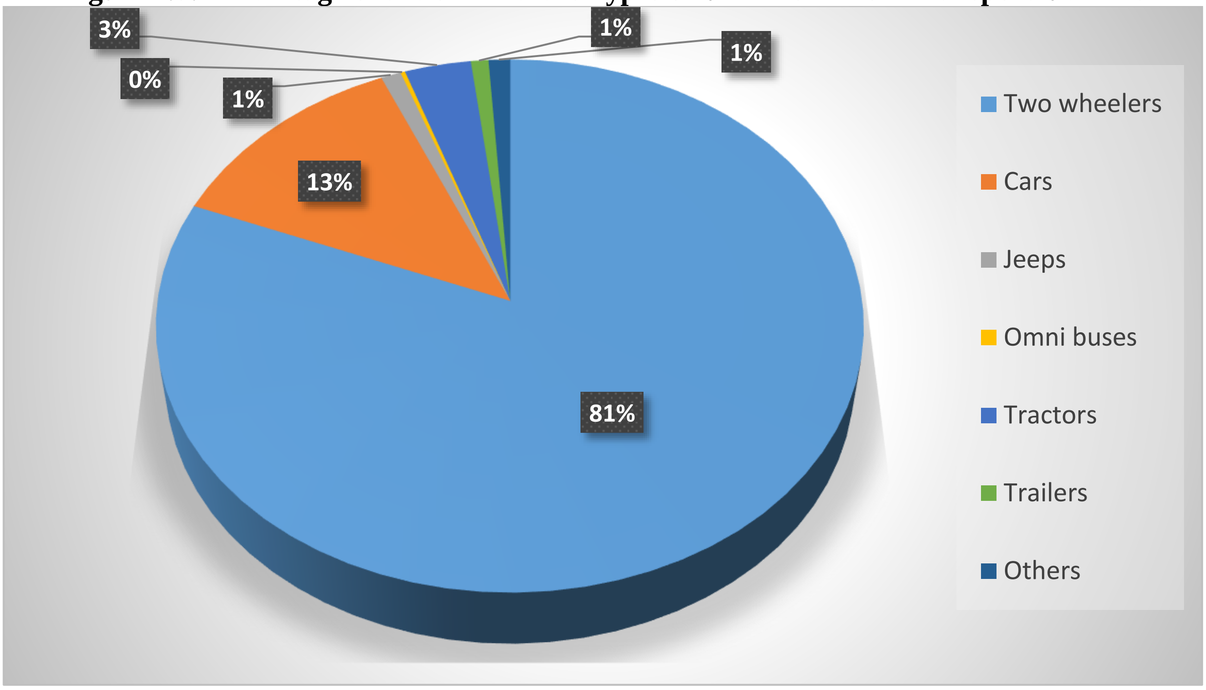
Figure 4.2: Percentage Share of Different Types of Vehicles in Transport Vehicles



Source: Road Transport Year Book 2016-17, Ministry of Road Transport and Highways, Government of India.

Unlike developed nations, where cars account for a major share of non-transport vehicles, in India, two-wheelers accounted for the largest segment of non-transport vehicles (81%), followed by cars (13%) (Figure 4.3). Out of the total registered motor vehicles up to 31st March, 2017 in India (253 million), Maharashtra accounted for the largest share (11.93%) followed by Uttar Pradesh (10.37%), Tamil Nadu (10.31%), Gujarat (8.70%) and Karnataka (7.06%) (Road Transport Year Book 2016-17: 47). These five States together accounted for nearly half of the total vehicles registered in the country. Also, the six states, Maharashtra (11.9%), Uttar Pradesh (11.1%), Tamil Nadu (9.2%), Karnataka (7.6%), Gujarat (7%) and Rajasthan (5.5%), alone accounted for more than half of the total petrol consumption (India PNG Statistics 2018-19: 102).

Figure 4.3: Percentage Share of Different Types of Vehicles in Non-Transport Vehicles



Source: Road Transport Year Book 2016-17, Ministry of Road Transport and Highways, Government of India.

Cooking Fuel Usage in India

LPG and kerosene are the two prominent fuels used for cooking purpose in India. In 2019-20, LPG (12.30%) and Kerosene (1.2%) accounted for 13.42% of total petroleum products consumption in India constituting nearly 214.13 million tonnes. Domestic consumption accounted for 87.6% of total LPG consumption (CAGR is 6.43% during 2010-11 to 2019-20) and 90.7% of total kerosene consumption (CAGR is -12.97% 2010-11 to 2019-20) in 2019-20 (India Energy Statistics 2021: 70). As on February 1, 2021, there were 280 million domestic Liquefied Petroleum Gas (LPG) consumers and 0.7 million piped natural gas domestic consumers in India[60]. The consumption of LPG for domestic use has nearly doubled between 2010-11 and 2019-20 (ibid: 68). The 22 states covered in the present study accounted for 97% of total LPG consumption in 2018-19. Uttar Pradesh (12.9%), Maharashtra (12.2%), Tamil

[60] https://www.downtoearth.org.in/news/governance/as-told-to-parliament-march-10-2021-280-million-lpg-consumers-in-india-75886.

Nadu (8.6%), West Bengal (6.9%), Karnataka (6.9%) and Rajasthan (5.3%) account for more than half of total LPG consumption in India (ibid: 102).

4.3.2 State-wise Emissions from Domestic Sector (Electricity, Personal Vehicle Use and Cooking) in 2018-19

Economic and Demographic Profile of the States

India is a large and highly diverse nation. It is home to varied weather conditions and topography in its different parts. Further, the socio-economic and political diversity makes it difficult to offer one size fits all policy for India. The same is true for the climate policy in India. An effective environmental policy in India must meet the needs of its diversity and thus has to be more decentralized. Therefore, it becomes crucial to look at the state level indicators of environment. Table 4.4 depicts a glance of the demographic profile of major 22 states of India. These states account for more than 95 percent of India's population. Age group wise distribution of population across all states is almost homogenous. On an average, among the 22 states considered, 24.4% of the population lies in the age group 0-14 years, 26.9% in 15-30 years, 28.5% in 30-49 years, 15.7% in 50-69 years and 4.5% in 70+ age group. Thus, more than half of the population in India lies in working age group and can be a huge asset for the nation if utilized properly. Table 4.4 shows that Delhi is the most densely populated region (13871) among the 22 major states considered in the study, followed by Bihar (1307) and West Bengal (1106). Distribution of male and female population is found to be nearly equal in all the 22 states. In Odisha and Kerala, female population is observed to have a greater share than male population i.e. 51.1% and 52% respectively (Table 4.4). Further, nearly all the states are found to be largely rural in nature, except Delhi, which is observed to be the highest urbanized region (99.1% urban population) followed by Kerala (66.5% urban population). Table 4.4

shows that Himanchal Pradesh has the lowest urban population (10.2%) followed by Bihar (12%).

Table 4.4: Demographic Profile of Major States in India

Sl. No.	States	Population ('000) 2018-19	Age group wise population share 2021 (%)					Population density (sq. Km.)	Male (%)	Female (%)	Urban (%)
			0 to 14	15 to 29	30 to 49	50 to 69	Above 70				
1	Andhra Pradesh	52221	20.5	25.1	31.1	17.7	5.5	329	50.0	50.0	34.1
2	Assam	34293	26.7	27.8	28.2	14.1	3.1	447	51.0	49.1	15.1
3	Bihar	119520	33.6	28.8	22.7	11.8	3.2	1307	52.0	48.0	12.0
4	Chhattisgarh	28724	27.8	27.7	26.7	14.3	3.5	218	50.2	49.8	25.8
5	Delhi	19814	21.8	28.2	31.2	15.0	3.7	13871	53.4	46.7	99.1
6	Gujarat	67936	24.7	26.4	28.8	15.8	4.1	356	52.4	47.6	46.7
7	Haryana	28672	25.0	27.8	28.6	14.2	4.5	667	53.0	47.0	39.7
8	Himanchal Pradesh	7300	20.6	25.1	30.3	18.2	5.8	133	50.7	49.3	10.2
9	Jammu and Kashmir	13203	23.6	29.3	28.5	14.5	4.0	82	52.5	47.5	29.5
10	Jharkhand	37403	29.1	29.1	25.4	13.1	3.4	483	51.2	48.8	25.5
11	Karnataka	65798	22.1	25.3	30.8	16.8	5.0	349	50.7	49.3	42.5
12	Kerala	35125	20.4	22.1	28.4	21.9	7.2	913	48.0	52.0	66.5
13	Madhya Pradesh	82232	29.4	27.7	26.1	13.5	3.5	274	51.6	48.4	28.6
14	Maharashtra	122153	21.7	26.1	30.5	16.6	5.2	404	52.0	48.0	47.4
15	Odisha	43671	23.6	25.4	28.7	17.2	5.0	283	48.9	51.1	18.1

16	Punjab	29859	20.3	26.2	30.5	17.3	5.8	602	52.6	47.4	40.4
17	Rajasthan	77264	29.2	28.7	25.5	13.0	3.6	232	51.5	48.5	26.0
18	Tamil Nadu	75695	19.9	23.2	31.3	19.8	5.8	587	50.0	50.0	51.9
19	Telangana	37220	21.5	26.4	31.2	16.0	4.9	337	50.3	49.7	45.0
20	Uttar Pradesh	224979	30.2	29.9	24.3	12.1	3.5	958	52.2	47.9	23.5
21	Uttarakhand	11141	23.7	29.2	27.6	14.6	4.9	213	51.2	48.8	34.0
22	West Bengal	96906	21.1	26.2	30.4	17.8	4.5	1106	51.1	48.9	35.1
	India	1332900	27.2	27.3	27.8	15.1	4.3	414	51.4	48.6	33.8

Source: Estimated from Census of India 2011, 2019. Population Projections for India and States 2011–2036

Table 4.5 shows that urban population and population density have high standard deviation, skewness and kurtosis. Rest of the variables do not show much variation and thus are not considered to be significantly affecting the energy consumption.

Table 4.5: Descriptive Statistics of Demographic Features of India

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
Population density	1097.8	380	13871	82	2871.2	4.27	19.54	317.94
Urban (%)	36.2	34.1	99.1	10.22	19.69	1.47	5.88	15.56

Source: Estimated from Census of India 2011, 2019. Population Projections for India and States 2011 – 2036

CO_2 Emissions by the States

According to India Second Biennial Update Report to UNFCCC (2018: 82), in 2014, energy sector emitted 1844705.03 Giga-grams of CO_2. Emissions from the transport sector are

250,172.79 Gg CO_2e[61], which is about 13% of the total GHG emissions from the energy sector in the country for the year 2014 (ibid: 82). Table 4.6 shows the state wise household emissions from electricity consumption, vehicle usage and LPG consumption. Maharashtra, Uttar Pradesh and Madhya Pradesh are the top three emitters in case of electricity consumption, accounting for 31.7% of total electricity emissions. While in case of personal vehicle emissions, Maharashtra, Uttar Pradesh and Tamil Nadu hold the top three positions, accounting for 32.8% of total emissions from personal vehicles. In case of LPG emissions, Uttar Pradesh, Maharashtra and Tamil Nadu top the list, accounting for 33.2% of total LPG emissions (Table 4.6).

In Bihar, the share of LPG emissions (5%), personal vehicular emissions (2.8%) and emissions from electricity consumption (3.1%) is estimated to be much lower than its population share (9.1%) (Table 4.6). This is probably because majority of Bihar's population is still dependent on fuel wood and other unclean sources of cooking fuel. According to the National Family Health Survey, Ministry of Health and Family Welfare, 2019-20, conducted in 17 states and five union territories, in five states, viz., Assam (42.1%), Bihar (37.8%), Meghalaya (33.7%), Nagaland (43%), and West Bengal (40.2%) accounted less than 45% of households use clean fuel for cooking. Vehicle ownership rate (number of registered motor vehicles per 1000 population) was found to be lowest in Bihar (48.01) and highest in Delhi (519.62)[62].

Further, in our study electricity consumption accounted for nearly 90% of total emissions, while cooking fuel and personal vehicle constituted nearly 5% each of the total

[61] CO2 equivalent: a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.
[62] Estimated using Road Transport year book 2016-17 and Census 2011 population projections. Vehicle Ownership Rate = (State-wise number of registered motor vehicles/State wise population projection 2016)*1000.

emissions in each state. The share of cooking fuel emissions is found to be too low because, fossil fuel based cooking sources are not considered here. Ahmad et al 2015 studied the emissions from domestic energy consumption in 60 largest cities in India and found that emissions from electricity usage account for about 66%, followed by emissions from cooking fuels (27%) and private transportation (7%).

As per estimates from Table 4.6, the direct all India household emissions for 2018-19 is 1587 million tonnes. As all India annual CO_2 emissions in 2019 is 2620 million tonne (Ritchie and Roser 2020), the direct household emissions are found to account for 60% (1587021 kilo tonne) of the total emissions, of which, electricity consumption alone accounts for 55% share (Table 4.6). The figure appears to be little greater than expected from literature review. This is probably due to the assumptions made in the study regarding energy consumption via electricity, personal vehicle and LPG use, as the actual state-wise figures are not available for households for the year 2018-19. However, it shows that the role of households in CO_2 emissions is extremely significant. Also, as of 2019, the per capita CO_2 emissions in India is 1.9 tonnes per capita (ibid) and as per estimates from Table 4.6, per capita CO_2 emissions from direct household emissions is found to be 1.2 tonnes. Further, Chhattisgarh (2.2), Haryana (2.1), Punjab (1.9), Delhi (1.8) and Gujarat (1.8) are found to be the top five CO_2 emitting states in terms of per capita direct household CO_2 emissions. While in case of Delhi, Gujarat, Punjab and Haryana, the results can be justified on the basis of their high per capita income (National Statistical Office, MOSPI, GOI), in case of Chhattisgarh high per capita emissions are the result of high value of combined emission factor for electricity (i.e. 1.37 kgCO_2e/kWh) (Appendix Table 4.1 A). The higher value of emission factor in Chhattisgarh is possibly due to the fact that among all sates in India, Chhattisgarh has highest dependency on coal (96%) in case of installed generation capacity as of 2021[63].

Table 4.6: State wise Annual CO_2 Emissions 2018-19

Sl. No.	States	From Electricity consumption		From Personal Vehicle Use		From LPG Use		Total Emissions		Per capita CO_2 emissions (tonnes)
		Value ('000 tonnes)	% share	Value ('000 tonnes)	% share	Value ('000 tonnes)	% share	Value ('000 tonnes)	% share	
1	Andhra Pradesh	57600	4.0	3227.6	3.9	2985.5	4.6	63813.1	4.0	1.2
2	Assam	10500	0.7	1159.6	1.4	1092.9	1.7	12752.5	0.8	0.4
3	Bihar	44500	3.1	2306.4	2.8	3206.2	5.0	50012.6	3.2	0.4
4	Chhattisgarh	61300	4.3	1691.5	2.1	708.7	1.1	63700.2	4.0	2.2
5	Gujarat	112000	7.8	5740.1	7.0	2868.7	4.4	120608.8	7.6	1.8
6	Haryana	56000	3.9	2825.6	3.4	2089.8	3.2	60915.4	3.8	2.1
7	Himanchal Pradesh	2380	0.2	608.0	0.7	428.4	0.7	3416.4	0.2	0.5
8	Jammu & Kashmir	7810	0.5	731.5	0.9	532.2	0.8	9073.7	0.6	0.7
9	Jharkhand	45000	3.1	1304.4	1.6	885.3	1.4	47189.7	3.0	1.3
10	Karnataka	52700	3.7	6211.0	7.5	4379.6	6.8	63290.6	4.0	1.0
11	Kerala	2900	0.2	4047.3	4.9	2567.5	4.0	9514.8	0.6	0.3
12	Madhya Pradesh	116000	8.1	4189.9	5.1	2583.1	4.0	122773	7.7	1.5
13	Maharashtra	176000	12.2	9799.4	11.9	7762.3	12.0	193561.7	12.2	1.6
14	Orissa	61800	4.3	2250.8	2.7	1425.3	2.2	65476.1	4.1	1.5
15	Punjab	50800	3.5	2393.6	2.9	2435.1	3.8	55628.7	3.5	1.9
16	Rajasthan	82000	5.7	4591.2	5.6	3356.7	5.2	89947.9	5.7	1.2
17	Tamil Nadu	111000	7.7	7689.3	9.3	5488.1	8.5	124177.4	7.8	1.6
18	Telangana	56100	3.9	3499.9	4.2	2500.0	3.9	62099.9	3.9	1.7
19	Uttarakhand	1500	0.1	918.4	1.1	747.7	1.2	3166.1	0.2	0.3

[63] https://npp.gov.in/publishedReports

20	Uttar Pradesh	164000	11.4	9551.3	11.6	8219.2	12.7	181770.5	11.5	0.8
21	West Bengal	64800	4.5	2616.0	3.2	4387.4	6.8	71803.4	4.5	0.7
22	Delhi	30600	2.1	2720.4	3.3	2141.8	3.3	35462.2	2.2	1.8
	Total (All India)	1440000	100.0	82360.5	100.0	64661	100.0	1587021	100.0	1.2

Source: Estimated from RTI to Central Electricity Authority, Road Transport year book 2016-17, India PNG Statistics 2018-19, Census of India 2011, Population Projections for India and States 2011 – 2036.

4.3.3 Factors Determining CO_2 Emissions in Domestic Sector in India

Multiple factors are affecting for domestic emission of CO_2 at all India level, however, we could identify based on the availability of data such as total population, per capita GSDP and density of population as significant factors. In order to understand the impacts of these factors on CO_2 emission, we have used multiple regression model and related steps are as follows.

Multicollinearity

The variance inflation factor (VIF) is used here to detect the severity of multicollinearity problem in the regression analysis. Generally, a VIF larger than 10 suggests that severe multicollinearity, which may influence the regression estimation results significantly (Wang et al 2013: 65–71). In our results, VIF is found to be much less than 10 for all the variables, therefore, it is observed that that there is no problem of multicollinearity (Table 4.7).

Table 4.7: Results of VIF

Variable	VIF	1/VIF
Log_Population	1.42	0.7024
Log_Per Capita GSDP	1.36	0.7347
Log_Population Density	1.18	0.8508
Mean VIF	1.32	

Source: Estimated from Census of India 2011, Population Projections for India And States 2011 – 2036

Regression Results

Robust regression is performed in order to avoid the heteroscedasticity problem. Based on the estimation of results as shown in Table 4.8, population and per capita GSDP have a significant positive relation with CO_2 emissions from electricity consumption, personal vehicle use, LPG use for cooking and other purposes and total emissions. Population density is observed to have negative but insignificant relation with CO_2 emissions from electricity consumption and vehicle usage (Table 4.8). While, in case of LPG emissions, population density is observed to have a significant positive relation.

As per estimates from Table 4.8, an increase in per capita GSDP by 1% leads to an increase of total emissions by 0.53%, electricity consumption related emissions by 0.47%, personal vehicle emissions by 0.89% and LPG emissions by 0.68%. An increase in population by 1% is found to lead to an increase of total emissions by 1.34%, electricity consumption related emissions by 1.44%, personal vehicle emissions by 1.03% and LPG emissions by 1.02%. The results suggest population to be a more elastic factor in case of CO_2 emissions. Available literature confirms a positive relation between population, income and emissions (Zhang et al 2015: 877; Duarte et al 2010: 179), as the increase in income leads to increased household consumption expenditure on transport, entertainment and other luxury comforts (Peters et al 2007: 5940). The same has been checked in next chapter by using the households, based on primary data collection. Some studies also suggest that as the household income increases, its direct emissions decline (due to decreased dependence on fossil fuels for cooking, lighting and heating), while its indirect emissions increase (Lyons et al 2012: 192; Golley and Meng 2012: 1867).The results are in agreement with those Chapter 3.

Further, Table 4.8 shows that since population density is observed to have a negative relation with all kinds of CO_2 emissions except that from LPG, an increase of population density by 1% is found to lead to a decrease in total emissions by 0.05%, electricity consumption related emissions by 0.07% and personal vehicle emissions by 0.04%. While an increase in population density by 1% is observed to lead to an increase in LPG emissions by 0.08%. Zheng et al (2011: 772) observed a negative relationship between carbon emissions and population density due to low vehicle ownership rate in dense areas. Chen et al (2008: 36) also suggested a negative relationship between population density and the domestic consumption of both electricity and natural gas in China. Ahmad et al (2015: 11316), using the data of 60 largest cities in India, found that urban population density is negatively correlated with emissions, except in the case of cooking fuel use.

Table 4.8: Regression Results on factors determining CO_2 emission from different sources in Domestic sector in India

	Dependent variable	Independent Variables				R sq. Value
		Log Population	Log Per Capita GSDP	Log Population Density	Constant	
Eq. (1)	Log CO_2 emissions from Domestic Electricity Consumption	1.44 (7.11)*	0.47 (1.56)	-0.07 (-0.37)	-5.96 (-1.12)	64%
Eq. (2)	Log CO_2 emissions from Personal Vehicle Use	1.03 (20.85)*	0.89 (12.42)*	-0.04 (-1.28)	-6.43 (-5.16)*	95%
Eq. (3)	Log CO_2 emissions from LPG use for Cooking	1.02 (16.93)*	0.68 (6.46)*	0.08 (2.06)**	-4.92 (-2.41)**	94%
Eq. (4)	Log Total CO_2 emissions	1.34 (8.4)*	0.53 (2.17)**	-0.05 (-0.39)	-4.89 (-1.09)	74%

Source: Estimated from Source: Estimated from RTI to Central Electricity Authority, Road Transport year book 2016-17 and India PNG Statistics 2018-19

Note: *Indicates significance at 1%, **Indicates significance at 5%, No. of observations= 22; Prob > F = 0.0000; (t-value))

4.3.4 Estimation of Monetary value of Carbon Emissions from Direct HH Energy Consumption

Table 4.9 shows that total CO_2 emissions from direct HH energy consumption account for nearly 2% (1.7 billion US $) of the average GSDP (88.5 billion US $) of the major 22 states. CO_2 emission from direct HH energy consumption in Chhattisgarh creates highest externality which is equal to massive 5% of its GSDP (Table 4.9) due to the fact that among all sates in India, Chhattisgarh has highest dependency on coal (96%) in case of installed generation capacity as of 2021[64]. Similarly, in case of Jharkhand and Madhya Pradesh, greater dependency on coal power generation leads to greater negative externality in terms of GDP loss. The values are seemingly small because only the direct emissions by the HHs are considered in this study.

Table 4.9: State-wise Price of Carbon Emissions from Direct HH Energy Consumption

State	GSDP 2018-19 in US $	CO_2 in US $	Value of CO_2 emissions as % of GSDP
Andhra Pradesh	87507239437	1600000000	1.8
Assam	32964492958	325000000	1.0
Bihar	52908629577	1250000000	2.4
Chhattisgarh	32560819718	1600000000	4.9
Gujarat	$1.671 * 10^{11}$	3000000000	1.8
Haryana	74800730986	1525000000	2.0
Himanchal Pradesh	16598673239	85000000	0.5
Jammu and Kashmir	15881033803	227500000	1.4
Jharkhand	31688214085	1175000000	3.7
Karnataka	$1.583 * 10^{11}$	1575000000	1.0
Kerala	78790416901	237500000	0.3
Madhya Pradesh	73522439437	3000000000	4.1
Maharashtra	$2.8719 * 10^{11}$	4750000000	1.7
Odisha	53833585915	1625000000	3.0
Punjab	56009784507	1400000000	2.5
Rajasthan	95412394366	2250000000	2.4

[64] https://npp.gov.in/publishedReports

Tamil Nadu	1.7117 * 10^{11}	3000000000	1.8
Telangana	86313832394	1550000000	1.8
Uttarakhand	27221518310	80000000	0.3
Uttar Pradesh	1.602 * 10^{11}	4500000000	2.8
West Bengal	1.0415 * 10^{11}	1800000000	1.7
Delhi	83178752113	875000000	1.1
Mean	88513752624	1701363636	1.9

Source: Estimated from National Statistical Office of Ministry of Statistics and Program Implementation, RTI to Central Electricity Authority, Road Transport year book 2016-17, India PNG Statistics 2018-19.

4.4 Conclusions

This chapter deals with estimating household induced CO_2 emission and its corresponding values as a share of GSDP across states in India. Households directly emit CO_2 by consuming mainly electricity and cooking gas, and using private vehicles. Electricity consumption by HHs in India has increased by 30% between 2015-16 and 2019-20 and holds a prominent share of nearly 24% in total electricity consumption since 2000. Both rural and urban HHs depict a shift to cleaner sources of energy. Personal vehicles accounted for 91% of total registered vehicles. Of the total personal vehicles, two-wheelers constitute the majority (81%). LPG is the most widely used cooking fuel in India. The share of kerosene for domestic consumption is quickly declining. In all the states under consideration, electricity consumption accounted for the highest share of CO_2 emissions followed by personal vehicle use and cooking. Maharashtra, Uttar Pradesh, Tamil Nadu, Madhya Pradesh and Gujarat are found to be the highest HH carbon emitting states in India. Chhattisgarh, Haryana, Punjab, Delhi and Gujarat are found to be the top five CO_2 emitting states in terms of per capita direct household CO_2 emissions. Per capita GSDP and population are observed to have significant positive relation with all kinds of sources (electricity, vehicle and cooking) of CO_2 emissions, while population density is observed to have a insignificant negative relation with all kinds of CO_2 emissions and a significant positive relation with LPG emissions. Further, the price of CO_2 emissions from direct HH energy consumption was found to be significant (approximately 2% of the mean GDP of the states considered) and therefore creating a large amount of negative externality.

Chapter 5

Assessment of Direct Household Carbon Emissions in Lucknow City

"Green is my sword to fight for a better living, make it yours too"

- Saalumarada Thimmakka

5.1 Introduction

Climate change is largely an anthropogenically generated phenomenon and thus its solution has to come from the human being itself (Singh 2020:1; IPCC 2018: 1-5). Climate change isn't only about austere thoughts of preserving the biodiversity, it has severe damaging consequences too. Climate change led disasters have cost an average economic loss of US $78 billion during 1980-2019 (Global Catastrophe Recap 2020: 6). Understanding the seriousness of climate change, countries of the world have come together through the enforcement of UNFCC in 1994 and have been meeting each year in different places, and have committed to reduce their Greenhouse Gas (GHGs) emissions. For example, EU committed 40% reduction in greenhouse gas emissions by 2030 (relative to 1990 levels) and has further adopted a resolution in November 2020 to set climate neutrality by 2050 as its long-term climate goal under the Paris agreement and to increase the emission reduction target to 55% by 2030[65]. China promised to reduce its emissions per unit of gross domestic product by 60% to 65% from the 2005 levels by 2030. In September 2020, China also updated its Paris targets by committing to reach peak emissions before 2030, followed by a long term target to become carbon neutral by 2060[66]. Similarly, United States of America (which earlier withdrew from Paris Agreement in 2015) has rejoined with UNFCCC in 2021 and has committed an economy-wide target of reducing its net greenhouse gas emissions by 50-52 percent below 2005 levels in 2030.[67] India targeted to reduce its emissions intensity of GDP by 33%-35% by 2030. Most of these targets are to be met by technological solutions including switching to cleaner sources of energy which

[65] https://ec.europa.eu/clima/policies/international/negotiations/paris_en
[66] https://climateactiontracker.org/countries/china/
[67] https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/United%20States%20of%20America%20First/United%20States%20NDC%20April%2021%202021%20Final.pdf

require large investments. A relatively less focused upon entity is the household which can be a potential complement to cost effective climate change solutions (Wynes and Nicholas 2017: 5; Dubois et al 2019: 153).

Carbon emissions produced by household energy use and personal travel (excluding international aviation) account for an average of 45% of the national carbon emissions in the major developed countries (Fawcett and Parag 2017: 330). In the developing nations, economic development and rising living standard has led to a considerable increase in the household's energy consumption (Zhang et al 2015b: 873). Consumption of electricity and cooking gas, and private vehicle induced fuel consumption are the three significant constituents of direct household CO_2 emissions. In India, the household carbon emissions (both direct and indirect) have increased by 66% between 1993–94 and 2006–07. While the increasing use of electricity and private vehicles have led to an increase of 171% in the emissions from secondary energy consumption by households, the indirect emissions too increased by 76% during 1993-94 to 2006-07 (Das and Paul 2014: 96). CO_2 emissions from direct household fuel consumption was responsible of 18% of total CO_2 emissions in 2006-07 (ibid: 91). Between 2007-08 and 2013-14 household's direct emissions in India increased from 251.70 Mt-CO_2 to 332.26 Mt-CO_2, or by 32.0% (Zhu et al 2018: 1548).

Emission Coefficient Method (ECM) is the most widely used method for estimating direct Household Carbon Emissions. IPCC guidelines (2006: 2.11) suggest this method to estimate carbon emissions. There are three tiers of ECM, where Tier 1 uses the default emission factors for each fuel at global level provided by IPCC. In Tier 2, country specific emission factors are used, which is more accurate, since the emission factors vary with the technology and climate of the country. Further, Tier 3 is the most accurate as it uses technology specific emission factors. However, due to lack of data, particularly in developing nations, it is the Tier 1 method which is most frequently used. A number of studies use emission coefficient method to estimate direct household carbon emissions (Golley and Meng 2012: 1864-1872; Wilson et al 2013: 880-891; Maraseni et al 2016: 179-192; Allinson et al 2016: 871-881; Miao 2017: 29-37). Literature suggests income, occupancy rate, age, occupation etc. to be the important factors determining household carbon emissions (Kadian et al 2007: 6195-6211; Kenny and Gray 2009: 259-272; Wislon et al 2013: 880-891).

There is scarce literature on HH carbon emissions in India. Further, none of the literature reviewed, has assessed the value of CO_2 emissions in monetary terms, with respect to the concerned country's GDP. The present study attempts to fill this gap. Further, it is also suggested by the literature that socio-economic and demographic factors play a key role in determining the HHs carbon emissions. Based on the above review, present chapter is divided into four sections. First section covers introduction along with review of few direct significant studies covering the extent of CO_2 emission in household sector and reasons behind it. The second section elaborates upon the objectives and methods followed. Third section deals with the analysis of the results, while section four concludes.

5.2 Objectives and Methods

This chapter aims to estimate (a) the total CO_2 emission of households based on the consumption of electricity, vehicular use and cooking gas in Lucknow, Uttar Pradesh; (b) economic value of CO_2 emissions from the household sector in Lucknow; (c) the impact of socio-economic factors such as caste, nature and size of family, house ownership and annual income on the annual direct carbon emissions from households due to cooking, lighting and use of personal vehicles in Lucknow using Tier -2 methodology (country specific emission factors) of IPCC (2006: 2.11).

Emission factor depends upon the carbon content of the fuel. Since the carbon content may vary significantly depending upon the composition of the fuel, the variability is reduced by converting it into energy units. As, a very small portion of fuel carbon is lost in combustion, it is assumed that 100% oxidation occurs. Default emission factor is then calculated as a product of carbon content and carbon oxidation factor (ibid: 2.11).

$$Effective\ CO2\ emission\ factor\ (kg/10^{12} Joule) =$$

$$Default\ carbon\ content\ (kg/TJ) * \ Default\ carbon\ oxidation\ factor (i.e.1) * 44/12$$

5.2.1 Methods of Estimation of CO_2

Emissions from Electricity

Combined emission factor for electricity for end-user consumption is the sum of emission factor for end user consumption with adjusted Import & Export of Electricity + Emission Factors for AT&C Losses. For Uttar Pradesh in 2009-10 its value was estimated to be 1.61 kg of CO_2e/kWh (cBalance Solutions 2009-10: 6). Since CO_2 is the most prominent GHG released from thermal power plants, it is assumed that emission factor for electricity is 1.61 kg of CO_2/kWh. Thus, emissions from electricity consumption by the households is calculated as follows:

$$\begin{aligned} &Emissions\ from\ electricity\ consumption\ in\ a\ year \\ &\quad = (Units\ of\ electricity\ consumed\ per\ month\ in\ winters \\ &\quad + Units\ of\ electricity\ consumed\ per\ month\ in\ summers) * 1.61 * 6 \end{aligned}$$

Emissions from Cooking

Emission factor for LPG = 2.984 kg CO_2/kg of LPG (IPCC 2006)

*Emissions from LPG per annum = Amount of LPG consumed per month (in Kg)*2.984*12*

Emissions from Personal Transport

Using the method as described in India Specific Road Transport Emission Factor (2015) report by India GHG Program, the emission factor for each vehicle is calculated as follows:

$$Emission\ Factor\ (Kg\ CO2/Km) =$$

$$(Fuel\ Emission\ Factor\ (Kg\ CO2/Litre))/(Fuel\ Efficiency\ of\ the\ vehicle\ (Km/Litre))$$

Table 5.1: Emission Factor for Fuels

Petrol (Motor Gasoline)	2.2719 kg CO_2/lit
Diesel	2.6444 kg CO_2/lit
CNG	2.6920 kg CO_2/kg

Source: India's Greenhouse Gas Emissions 2007, Ministry of Environment and Forest, Government of India 2010.

$$Emissions\ from\ personal\ transport\ per\ annum =$$

$$Total\ fuel\ consumed\ per\ month * Corresponding\ fuel's\ emission\ factor * 12$$

Total Emissions

To calculate the total emissions of CO_2 from all sources, the emissions are summed over all source categories.

$$Total\ CO2\ Emissions\ (kg) = \Sigma(Activity\ data * Emission\ Factor)$$

CO_2 Emissions in Monetary Terms

The state-wise monetary value of total CO_2 emitted from direct HH energy consumption is calculated by taking the value of CO_2 to be US $ 25/t-CO_2 per year (Garg et al 2014: 579). The value is also based on the World Bank (2019) report on the State and Trends of Carbon Pricing[68] in the world. Of the total 51 carbon pricing initiatives in the world, 41 initiatives price carbon in the range of US $1/ton CO_2e[69] to US $25/t CO_2e. Further, Gross State Domestic

[68] https://documents1.worldbank.org/curated/en/191801559846379845/pdf/State-and-Trends-of-Carbon-Pricing-2019.pdf

[69] CO2 equivalent: a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

Product (GSDP) of each state is converted into US $ from Rupees by taking the value US $ 1 = Rs. 71 for the year 2019.

5.2.2 Method of Analysis of Data

Firstly, a descriptive statistics analysis of the socio-economic and demographic profile of the HHs, their electricity consumption pattern, personal vehicle usage, LPG consumption and CO_2 emissions by each of these sources is carried out. The mean values of the considered variables is depicted on various aspects, viz. zone-wise, caste-wise, religion-wise, house ownership wise, family nature-wise and income level-wise. Descriptive statistics helps to understand the collective properties of the various elements of our sample HHs.

Later, in order to understand the causal relationship between the emissions from various fuel consumption categories (continuous variables) and the socio-economic features of the HHs (categorical variables) and HH size (continuous variable), analysis of covariance (ANCOVA) is performed. ANCOVA is an extension of ANOVA (Analysis of Variance) models. They consist of at least one categorical independent variable (also called as factor) and at least one interval natured independent variable (also called as covariates or control variables). ANCOVA model provides a method to statistically control the effects of covariates (Gujarati et al 2012: 302). ANCOVA model assumes normality of residuals, homogeneity of variances, homogeneity of regression slopes, linearity of regression and independence of error terms (Maneesha and Bajpai 2013: 337). As in our model, the independent variables comprise of categorical as well as continuous variables. Further, the regression model is based upon Wilson et al (2013: 880-891).

ANCOVA model used:

$$\text{Total Electricity Emissions} = \beta_1 + \beta_2 \text{ HH Size} + \beta_3 \text{Mean Age} + \beta_4 \text{HH Annual Income} + \beta_5 \text{House ownership1} + \beta_6 \text{ Family Nature1} + \beta_7 \text{ Caste 1} + \beta_8 \text{Occupation1} + \beta_9 \text{ Education1} \text{------ (1)}$$

$$\text{Total Vehicle Emissions} = \beta_1 + \beta_2 \text{ HH Size} + \beta_3 \text{Mean Age} + \beta_4 \text{HH Annual Income} + \beta_5 \text{House ownership1} + \beta_6 \text{ Family Nature1} + \beta_7 \text{ Caste 1} + \beta_8 \text{Occupation1} + \beta_9 \text{ Education1} \quad \text{------ (2)}$$

$$\text{Total LPG Emissions} = \beta_1 + \beta_2 \text{ HH Size} + \beta_3 \text{Mean Age} + \beta_4 \text{HH Annual Income} + \beta_5 \text{House ownership1} + \beta_6 \text{ Family Nature1} + \beta_7 \text{ Caste 1} + \beta_8 \text{Occupation1} + \beta_9 \text{ Education1} \quad \text{------ (3)}$$

$$\text{Total Emissions} = \beta_1 + \beta_2 \text{ HH Size} + \beta_3 \text{Mean Age} + \beta_4 \text{HH Annual Income} + \beta_5 \text{House ownership1} + \beta_6 \text{ Family Nature1} + \beta_7 \text{ Caste 1} + \beta_8 \text{Occupation1} + \beta_9 \text{ Education1} \quad \text{------ (4)}$$

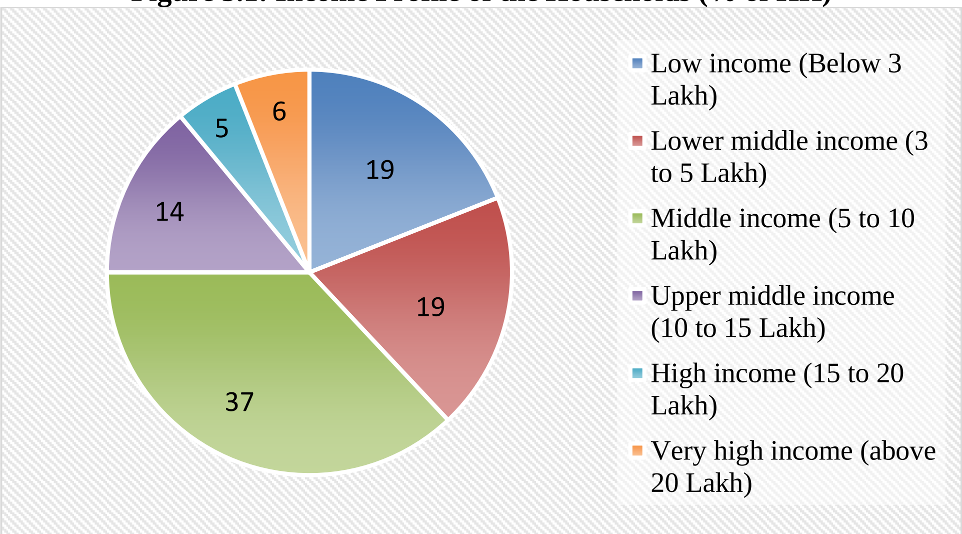
Where, HH Size refers to the Household Size, Mean Age is the Average age of all HH members, HH Annual Income is the Annual Income of the HH (in ’000 Rs.), House_Ownership1 means Own House, House_Ownership2 means Rented House, Family_Nature1 refers to Nuclear family, Family_Nature2 refers to Joint family, Caste1 refers to General category, Caste2 refers to Other categories, Occupation1 means HHs with at least one regular salaried member and Occupation2 refers to Others, Education1 refers to HHs with at least one member being graduate or above and Education2 refers to Others.

5.3 Analysis of Results

5.3.1 Socio-economic Profile of the Study Households (HHs)

The energy consumption pattern by the households has witnessed a shift to cleaner sources over time and it varies significantly by the socio-economic factors in India (Pachauri 2007: 28). Thus, it is important to understand the socio-economic profile of the households. Table 5.2 shows the socio-economic profile of the sample HHs in this study. Of the total 270 households covered in this study, 253 households (94%) belonged to Hindu religion, 11 households (4%) belonged to Muslim religion and rest 6 households (2%) belonged to Christian and Sikh religion (Table 5.2). In the caste category, 181 (67%) households belonged to General Category, 69 households (25%) to OBCs, 19 households (7%) to SCs and only 1 household of ST category. 181 households (67%) belonged to nuclear family and 89 (33%) belonged to joint family (Table 5.2). 215 households (80%) had their own home, while the rest 55 (20%) households lived on rented house. Table 5.2 shows that the SC&ST households have the highest average household size followed by OBCs and general category. To get a detailed distribution of income, household annual income of surveyed households has been categorized into six categories (Figure 5.1), wherein 52 (19%) households lie in low income category (0 to 3 Lakh), 50 (19%) households in lower middle income (3 Lakh to 5 Lakh), 99 (37%) households lie in middle income category (5 Lakh to 10 Lakh), 37 (14%) lie in upper middle income category (10 Lakh to 15 Lakh), 14 (5%) households lie in high income category (15 Lakh to 20 Lakh) and 18 (6%) households lie in very high income category. While 25% of the households own 54% of the total income, 75% of the households own only 46% of the total income (Figure 5.1). Top 6% of the households alone own 22% of total income. Thus deep inequality exists in terms of income distribution in Lucknow.

Figure 5.1: Income Profile of the Households (% of HH)



Source: Estimated from Field Survey Data, 2021

Further, Table 5.2 shows that zone 3, 4, 7 and 8 (belonging to new city region) are observed to have higher mean annual income as compared to old Lucknow city localities (zone 1, 2, 5 and 6). Caste-wise income status shows that the general category has the highest mean annual income (9.2 Lakh) followed by OBCs (7.2 Lakh) and SC&ST (5.7 Lakh). In case of religious groups, Sikh households have highest mean annual income followed by Christian households, Hindu households and lastly Muslim households. Households with own house have higher occupancy rate as well as higher mean annual income as compared to households living on rent (Table 5.2). The regular salaried households have higher mean annual income (9.2 Lakh) as compared to non-regular salaried households (7.8 Lakh). The education profile shows that in all the categories, majority of the households are graduate and above except, zone 2 and Muslim households. In case of graduate and above households, mean annual income (9.6 Lakh) is higher as compared to that of below graduate households (5 Lakh). Further the occupational status shows that majority of the households across all categories are non-regular salaried except in zone 3, zone 7, SC&ST households, Christian and Sikh households (Table 5.2).

Table 5.2: Socio-economic Profile of the Study Households

Basis	Categories	No. of HH	% of HH	Mean HH Size	Mean Annual Income (Lakh)	Education (% of HH)		Occupation (% of HH)	
						Below Graduate	Graduate and above	Regular Salaried	Non-regular salaried
Zone-wise	1	28	10.4	5.4	5.66	36	64	14	86
	2	25	9.2	4.6	5.79	52	48	44	56
	3	50	18.5	4.2	8.16	20	80	64	36
	4	25	9.2	4.9	9.12	36	64	28	72
	5	23	8.5	4.9	8.06	13	87	35	65

	6	50	18.5	4.7	7.38	30	70	48	52
	7	38	14.1	4.3	11.54	5	95	58	42
	8	31	11.5	5.1	11.16	26	74	33	67
Caste-wise	General	181	67	4.5	9.21	20	80	44	56
	OBC	69	26	4.9	7.23	39	61	41	59
	SC&ST	20	2.4	5.6	5.66	37	63	52	48
Religion-wise	Hindu	253	94	4.7	8.51	25	75	45	55
	Muslim	11	4	4.4	5.50	55	45	18	82
	Christian	3	1	3.7	10.33	0	100	67	33
	Sikh	3	1	5.7	11.52	33	67	67	33
House-ownership wise	Own	215	80	4.8	9.29	23	77	45	55
	Rented	55	20	4.2	5.11	38	62	43	57
Family Nature	Nuclear	181	67	4.1	7.86	23	77	46	54
	Joint	89	33	5.9	9.61	23	77	38	62

Source: Estimated from Field Survey Data, 2021.

Table 5.3 gives an overview of the usual activity and occupation profile of the HH members of the sample HHs. Of the total 1245 HH members 272 (22%) belonged to 0 to 18 years age group, 868 (70%) belonged to 19 to 60 years age group or working age group and rest 105 (8%) belonged to 61 years and above age group. In the working age group, 50% of the people were working while 29% were home-makers and 14% were pursuing higher education. Only 7% of them were unemployed. Of the total working population, 286 (63.5%) were employed in regular salaried category in both government and private sector (Table 5.3).

Table 5.3: Age-group wise Usual Activity Profile of the HH members

Age group	Usual Activity	Number	% of population in the given age-group
0 to 18	Student	228	84
	Non-school age going children	44	16
Total		272	100
19-60	Working	431	50
	Unemployed	61	7
	Home Maker	253	29
	Student	123	14
Total		868	100
61 and above	Working	19	18
	Home Maker	23	22
	Old/retired	63	60
Total		105	100

Source: Estimated from Field Survey Data, 2021.

5.3.2 Electricity Consumption by the Surveyed Households

The electricity consumption by the households was assessed by using their monthly electricity bill. Electricity consumption (kWh) in winters was found to be much less than that in summers across all the base categories (Table 5.4). In winters, the highest mean electricity consumption was observed in zone 7, followed by zone 8, zone 4 and zone 3. While in summers, the highest mean electricity consumption was observed in zone 4, followed by zone 8, zone 7 and zone 3. Caste-wise analysis shows that general category consumes highest mean electricity, followed by OBC and SC&ST HHs in both summer and winters. Religion-wise analysis shows that Sikh HHs consume highest average electricity in both winters and summers. Further, while in winters, Hindu HHs consumed second highest amount of electricity followed by Christians and

Muslims, in summers, Christian HHs consumed second highest electricity followed by Hindus and Muslims. HHs living on rent are found to consume much less electricity (nearly half) as compared to those having their own house (Table 5.4). Similarly, joint families consume much higher electricity than nuclear families. Income-wise analysis shows that as the income increases, average electricity consumed by the HHs also increases in both winters and summers. Both high and very high income HHs consume four times more electricity than low income HHs in both winters and summers.

Table 5.4: Monthly Mean Electricity Consumption by the Households (in Kilo-watt hour)

Basis	Categories	In Winter	In Summer	For entire year
Zone-wise	1	153.4	298.6	226
	2	187.6	304.6	246
	3	225.7	458.5	342
	4	248	509.6	379
	5	189.3	312.6	251
	6	152	291	221
	7	285.6	488.4	387
	8	262.9	499.6	381
Caste-wise	General	237.8	448.5	343
	OBC	173.2	311.2	242
	SC&ST	122	238.2	180
Religion-wise	Hindu	216.1	401.6	309
	Muslim	117.3	286.4	202
	Christian	183.3	420	302
	Sikh	306.7	473.3	390
	Own	236.9	438.1	337.5

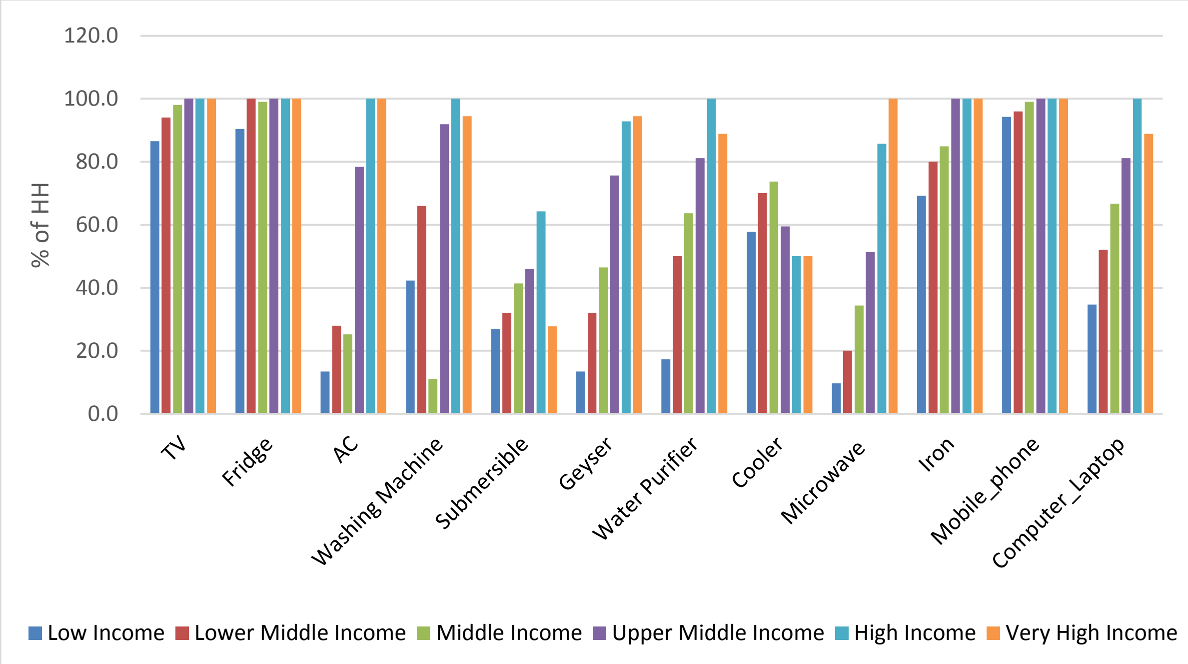
House-ownership wise	Rented	118.2	240.6	179
Family Nature	Nuclear	197.8	386.3	292
	Joint	242.9	421.4	332
Income -wise	Low Income	103.9	194.3	149
	Lower Middle Income	147.5	259	203
	Middle Income	215.4	388.4	302
	Upper Middle Income	273.9	554.2	414
	High Income	411.4	866.4	639
	Very High Income	412.8	738.3	575.6

Source: Estimated from Field Survey Data, 2021.

Appliance Ownership

Among the urban households, not only the greater connectivity, but also the wider penetration of electrical appliances is leading to increasing electricity consumption in India (Pachauri 2007: 29). Figure 5.2 shows that TV, fridge and mobile phones are the most commonly found appliances in the surveyed households (95-97%), followed by washing machine (77%) and cooler (65%). Geyser, AC and RO are found in 50-60% of the households. Whereas, the use of laptop is found mostly higher income category of households. Among all appliances, only the number of ACs is found to be highly correlated with the electricity consumption in summers (67%) as well as in winters (59%).

Figure 5.2: Income-wise Ownership of Assets by the Households



Source: Estimated from field survey data 2021.

5.3.3 Personal Transport Use by the Surveyed Households

Table 5.5 describes the personal transport ownership and usage scenario among the surveyed HHs. Two wheelers accounted for 74% of total motor vehicles (Scooty 34% and Bikes 40%) in all the HHs. In terms of distance covered per month, bikes account 141410 km or 40% of the total distance travelled, which tops the list followed by cars cover 125420 km or 36% of the total distance travelled and Scooty cover 24% of the total distance travelled. Further, Table 5.5 shows that 61% of the households have at least one fuel run vehicle. Further, it is found that 44% of the households have at least one of each type of vehicle such as bike, scooty and car. Zone-wise analysis in Table 5.5 shows that in zone 4, the mean distance travelled by Scooty (431.2 km) is highest followed by zone 3 and 2. Mean distance travelled by both bike and car is highest in zone 6 i.e., 848.4 km and 957 km respectively. General category has the highest average number of Scooty (0.7) and cars (0.6) as well the highest mean distance travelled by Scooty (330.7 km) and cars (479.5 km). In case of bikes, the OBC category excels with average 0.9 bikes and the highest average distance covered by Bikes per month (657.8 km). In terms of religious categories, Christian HHs have the highest average number of Scooty (1) and Cars

(1) as well the highest average distance covered by each of them. HHs with own house own greater average number of all the vehicles, as well the highest distance covered by each of them. Joint and nuclear family HHs have same average number of Cars and Scooty. Joint family HHs have greater number of bikes and they travel more than nuclear HHs (Table 5.5). The average number of cars as well as the average distance covered by it increases, as the income level of the HHs increases. In case of two-wheelers the situation is different. Very high income HHs have the lowest average number of bikes as well as the distance covered by it. It is the upper middle income HHs which have the highest average number of bikes and highest distance covered by it per month, followed by middle income and lower middle income.

Table 5.5: Mean of Vehicle Ownership by HHs and Distance Travelled Per Month (in Km)

Basis	Categories	No. of Scooty	Distance Travelled by Scooty (in Km)	No. of Bikes	Distance Travelled by Bike	No. of Cars	Distance Travelled by Car (in Km)
Zone-wise	1	0.6	183.9	0.7	278.6	0.1	67.9
	2	0.6	330.0	0.6	562.0	0.3	82.4
	3	0.7	395.8	0.6	399.6	0.6	352.5
	4	0.6	431.2	0.8	835.6	0.7	882.0
	5	0.7	239.1	0.9	583.0	0.5	158.9
	6	0.5	331.0	1.0	848.4	0.4	957.0
	7	0.7	271.1	0.6	234.2	0.7	473.4
	8	0.5	224.5	0.6	440.6	0.6	396.5
Caste-wise	General	0.7	330.7	0.7	499.3	0.6	479.5
	OBC	0.5	275.1	0.9	657.8	0.3	448.3
	SC&ST	0.6	222.5	0.5	282.5	0.4	385.0
Religion-wise	Hindu	0.6	309.0	0.8	529.9	0.5	465.7

	Muslim	0.1	90.9	0.5	445.5	0.3	327.3
	Christian	1.0	1033.3	0.3	166.7	1.0	1083.3
	Sikh	0.3	333.3	1.0	650.0	1.0	246.7
House-ownership wise	Own	0.6	325.1	0.8	550.5	0.6	533.1
	Rented	0.5	243.4	0.5	419.1	0.2	194.5
Family Nature	Nuclear	0.6	304.5	0.6	458.7	0.5	392.6
	Joint	0.6	316.4	0.9	655.9	0.5	609.6
Income-wise	Low Income	0.3	78.5	0.6	421.3	0.05	30.7
	Lower Middle Income	0.5	389	0.6	486.8	0.3	179.2
	Middle Income	0.7	261.7	0.8	590.9	0.4	447.5
	Upper Middle Income	0.8	599.2	0.9	742.2	0.8	750
	High Income	1	574.3	0.9	425	1.1	1421.4
	Very High Income	0.7	201.7	0.5	180.6	1.4	1267.2

Source: Estimated from Field Survey Data, 2021.

5.3.4 CO_2 Emissions from the Households

Table 5.6 shows that Jankipuram, Gomtinagar, Indranagar and Vrindavan Yojana areas hold the higher share in mean of CO_2 emissions (14 to 16%), while Aminabad, Aishbagh, Alambagh and Balaganj account for the lower share (9.5 to 10.6%). Total emissions in Zone 3, 4, 7 and 8 are 1.5 times greater than those in zones 1, 2, 5 and 6. This is apparently true that most of higher income group households do settle in the former category compared to latter category of locations. In all the areas, it is the average electricity consumption which is responsible for the highest contribution to CO_2 emissions (86 to 93.5%). The second highest contribution (8.5%) is from LPG consumption, followed by vehicular emissions (1.5%). Ahmad et al (2015: 11314) in their study observed that, in urban HH emissions electricity consumption is responsible for highest share of emissions, followed by emissions from cooking fuels and private transportation, due to unclean sources of cooking fuel like firewood, coal, etc. In this study however, nearly all the HHs had LPG connections but 39% of them had no fuel run vehicle. Also, there were 311 two wheelers (higher fuel efficiency) and 120 four wheelers (lower fuel efficiency). Zone 1, 2, 5 and 6 have a greater share in LPG resulted emissions (10.6 to 12%) while zones 3, 4, 7 and 8 have a smaller share (5.8 to 7.3%). Jankipuram and Balaganj have nearly same number of sample HHs and same number of vehicles, still the share of vehicular emissions from Balaganj (35.5%) is much higher than that of Jankipuram (13.3%). This is because, the mean distance travelled by all kinds of vehicles is highest in Balaganj. The same reason is found to be valid for Gomtinagar, where despite having half the number of sample HHs, as compared to Jankipuram, the share in vehicular emissions is high (19.6%).

Caste-wise analysis in Table 5.6 reveals that mean total emissions are highest for general category (43.6%) followed by OBC (31.8%) and SC&ST (24.5%). This is possibly due to the income differences among different caste groups. While the mean annual income of general category HHs is observed to be approximately 9.2 Lakhs, for OBC HHs 7.2 Lakhs and for SC&ST HHs mean annual income is found to be 5.6 Lakhs (Table 5.1). In SC&ST, LPG emissions form a greater share (13.7%) of their total emissions, followed by OBC (10.3%) and General category (7.7%) (Table 5.6). A possible explanation for this observation could be that the mean HH size for SC&ST HHs was found to be highest (5.6 persons per HH) followed by OBC HHs (4.9 persons per HH) and lastly general HHs (4.2 persons per HH) (Table 5.1). Sikh households account for the highest share in total emissions (31%), followed by Hindus and Christians (approx. 25% each) and lastly Muslims (17.6%). This finding can be explained by the highest mean annual income (11.5 Lakh) of Sikh households among all religious groups. Of the total emissions in each religious category, share from LPG emissions is highest among Muslim Households (13.2%), followed by Christians (10.2%), Hindus (8.4%) and lastly Sikh HHs (6.3%). In Table 5.6, mean emissions from HHs with own house is 1.8 times greater than those from HHs with rented house. Joint family HHs are observed to emit 1.15 times more than nuclear family HHs. Income-wise analysis in Table 5.6 shows that high and very high income category HHs emit more than half of the total emissions (52%), followed by upper middle income (18%), middle income HHs (13.5%) and lastly lower middle and low income HHs (7 to 9% each). Further, it is observed that, as the income increases, the share of LPG emissions out of total emissions in each income category declines (from 14.2% in low income HHs to 4.2% in very high income HHs), while that from personal vehicle use (from 0.3% in low income HHs to 1.6% in very high income HHs) and electricity consumption increases (from 85.3% in low income HHs to 94.2% in very high income HHs) (Table 5.6). The mean total CO_2 emissions from the sample HHs is estimated to be 6523.4 kg CO_2.

Table 5.6: Mean Annual Emissions of Surveyed Households (in Kg of CO_2)

Basis	Categories	LPG consumption	Personal Vehicles	Electricity consumption	Total
Zone-wise	1	590.2	14.4	4366.0	4970.6
	2	568.7	18.7	4754.7	5342.0

	3	526.3	48.6	6609.4	7184.3
	4	528.8	143.7	7318.4	7990.9
	5	630.1	28.1	4848.9	5507.1
	6	567.5	130.0	4279.4	4976.8
	7	608.8	66.1	7477.6	8152.5
	8	456.8	57.4	7366.5	7880.8
Caste-wise	General	561.5	68.4	6630.2	7260.1
	OBC	545.3	73.5	4679.5	5298.4
	SC&ST	559.3	43.6	3480.0	4082.9
Religion-wise	Hindu	554.4	67.6	5966.7	6588.7
	Muslim	600.9	58.7	3899.1	4558.8
	Christian	678.0	145.0	5828.2	6651.1
	Sikh	508.5	47.1	7534.8	8090.4
House-ownership wise	Own	574.7	77.4	6520.5	7172.6
	Rented	488.7	30.6	3466.2	3985.5
Family Nature	Nuclear	505.3	59.4	5642.8	6207.5
	Joint	662.7	85.2	6417.9	7165.8
Income-wise	Low Income	487.1	9.7	2881.3	3378.1
	Lower Middle Income	546.6	31.7	3926.8	4505.1
	Middle Income	594.8	67.1	5832.6	6494.4
	Upper Middle Income	597.8	101.3	7999.5	8698.6
	High Income	563.0	178.6	12344.1	13085.7
	Very High Income	494.3	186.2	11119.7	11800.3

Source: Estimated from Field Survey Data, 2021.

5.3.5 Cost of CO_2 Emissions

Table 5.7 shows the estimated value of CO_2 emissions by the HHs in money terms. The mean value of annual CO_2 emissions by all the HHs is observed to be Rs.11.6 thousand, which is approximately 2% of the mean annual income of all the surveyed HHs. Similar value is found in Chapter 4 in case of average monetary value of emissions from 22 major states of India. Income-wise analysis of the monetary value of CO_2 emissions shows that for the lowest income group the value of emissions as % of its mean annual income is the highest, i.e. 3.3%, however, the absolute values of CO_2 emission of higher income groups are more than those of lower income groups. As the income level increases the value of emissions as % of its mean annual income declines (Table 5.7). In caste-wise analysis SC&ST HHs are found to have the highest monetary value of CO_2 emissions as % of its mean annual income.

Table 5.7: Mean Annual Emissions of Surveyed Households in Monetary terms

Basis	Categories	HH Mean Annual Income (in Lakh Rs.)	Emissions (in Thousand Rs.)	Emissions as % of HH Annual Income
Zone-wise	1	5.6	8.8	1.9
	2	5.8	9.5	1.8
	3	8.2	12.8	2.1
	4	9.1	14.2	2.1
	5	8.1	9.8	1.3
	6	7.4	8.8	1.5
	7	11.5	14.5	1.8
	8	11.2	13.9	2.2
Caste-wise	General	9.2	12.9	1.8
	OBC	7.2	9.4	1.8
	SC&ST	5.7	7.2	2.3

Religion-wise	Hindu	8.5	11.7	1.9
	Muslim	5.5	8.1	1.5
	Christian	10.3	11.8	1.8
	Sikh	11.5	14.4	1.1
House-ownership wise	Own	9.3	12.7	1.9
	Rented	5.1	7.1	1.8
Family Nature	Nuclear	7.9	11	1.9
	Joint	9.6	12.7	1.7
Income-wise	Low Income	1.9	6	3.3
	Lower Middle Income	4.3	8	1.9
	Middle Income	7.4	11.5	1.6
	Upper Middle Income	12.8	15.4	1.2
	High Income	17.9	23.2	1.3
	Very High Income	28.4	20.9	0.7
Total		8.4	11.6	1.9

Source: Estimated from Field Survey Data, 2021.

5.3.6 Factors affecting CO_2 Emission in the Surveyed Households

Zhang et al (2015: 877) in their review study, found income, age, household size, education, gender and location to be the significant factors determining HH carbon emissions. Household income is observed to be the most important factor in determining a HH's CO_2 emissions (Duarte et al. 2010: 182; Han et al. 2015: 225). Meier and Rehdanz's (2010: 955) observed that, as the HH size increases, the residential energy demand and consequent emissions increase. Golley and Meng (2012: 1869) in their study of Chinese HHs, observed that more educated HHs tend to produce lower emissions, while Büchs and Schnepf (2013: 118) found that, in UK, more educated HHs tend to emit more GHGs. Thus, education alone cannot be said to be a decisive factor of CO_2 emissions.

In this study, four separate models have been estimated for each kind of HH CO_2 emissions to bring out the factors affecting each of them separately, in order to reach more detailed analysis. HH size, HH mean age and HH annual income are taken to be the control variables or covariates. General category, Hindu, nuclear HHs with own house and having at least one regular salaried member and at least one member being graduate or above is taken to be the benchmark category.

Multicollinearity

In order to check for the presence of multicollinearity problem in the regression analysis, Variance Inflation Factor (VIF) is used. Generally, a VIF greater than 10 suggests the presence of severe multicollinearity, which may affect the regression estimation results significantly (Wang et al 2013). Table 5.8 shows the result for VIF. VIF is found to be much less than 10 for all the variables, therefore, there is no problem of multicollinearity.

Table 5.8: Variance Inflation Factor

Sl. No.	Variable	VIF	1/VIF
1	HH Size	1.50	0.67
2	Mean Age	1.38	0.72
3	HH Annual Income	1.19	0.84
4	House Ownership1	1.25	0.80
5	Family Nature1	1.45	0.69
6	Caste1	1.09	0.92
7	Occupation1	1.12	0.89
8	Education1	1.22	0.82
	Mean VIF	1.27	

Source: Estimated from Field Survey Data, 2021

ANCOVA Regression Results

Table 5.9 shows the ANCOVA regression results. In case of CO_2 emissions from electricity consumption, caste, house ownership status and HH annual income are observed to be statistically significant. In case of vehicular emissions mean age and occupation are found to have a significant negative relation, while the HH annual income is observed to have a significant positive relation. This is so, because younger HHs tend to have more vehicles and travel more. Similarly, HHs with greater income usually own more personal vehicles. HH size and mean age are observed to be significant and positively related to LPG emissions suggesting that, as the number of people in a HH increase, its LPG consumption increases. The finding is in agreement with that in Chapter 4. Similar observation was made by Ahmad et al (2015: 11316), which observed that urban population density is positively related with emissions from cooking fuel use. Table 5.9 shows that an increase in HH size by 1 person is observed to cause an increase of 49.26 Kg of CO_2 emissions via LPG consumption in a year. Also, as the mean age of the HH increases, the LPG consumption increases, i.e. younger HHs consume less LPG. An increase in the average age of the HH by 1 year is found to increase its LPG emissions by 3.56 Kg of CO_2. HH size, annual income, caste and house ownership are found to be significant in case of total CO_2 emissions. Family nature and education are not found to be determining factors of a HH's CO_2 emissions. General category HHs and HHs with own house are observed to have a significant positive relationship with electricity emissions as well as total emissions suggesting that general category HHs and HHs with own house consume more electricity and emit more amount of CO_2. The main reason behind this observation is that the general category HHs and HHs with own house have greater annual income as compared to other caste groups and HHs livng on rent. Income is observed to be the important factor affecting emissions (Zhang et al 2015: 877; Duarte et al 2010: 179). This is because, as the income of the HH increases, its consumption expenditure on transport, entertainment and other luxury comforts also increases (Peters et al 2007: 5940). In Table 5.9, HH annual income is observed to have a significant positive relation with electricity and vehicular emissions but not with LPG emissions. This could be because higher income doesn't mean cooking more food or it may mean eating out more often, switching to induction, green gas or other non-LPG sources. An increase in HH annual income by Rs.1000, leads to an increase in electricity induced emissions by 3.25 Kg of CO_2, vehicle induced emissions by 0.07 Kg of CO_2 and total HH emissions by 3.3 Kg of CO_2.

Table 5.9: Factors Affecting CO2 Emission in the Surveyed Households

	Electricity induced CO_2 (Model I)	Vehicle induced CO_2 (Model II)	LPG induced CO_2 (Model III)	Total CO_2 (Model (IV)
HH Size	251. 6 (1.59)	-3.48 (-0.57)	49.26 (5.46)*	297.36 (1.87)
Mean Age	1.7 (0.06)	-2.41 (-2.19)**	3.56 (2.21)**	2.85 (0.10)
HH Annual Income	3.25 (9.25)*	0.07 (5.13)*	-0.01 (-0.92)	3.30 (9.31)*
House Ownership1	1605.47 (2.52)*	41.79 (1.69)	9.53 (0.26)	1656.8 (2.58)*
Family Nature1	391.2 (0.67)	-22.62 (-0.99)	-50.42 (-1.51)	318.24 (0.54)
Caste1	1481.8 (2.91)*	-12.58 (-0.63)	24.81 (0.85)	1494.1 (2.91)*
Occupation1	-796.8 (-1.45)	-47.09 (-2.20)**	18.76 (0.60)	-825.13 (-1.49)
Education1	611.8 (0.83)	31.49 (1.10)	71.80 (1.71)	715.13 (0.96)
Constant	-564.02 (-0.35)	107.1 (1.71)	150.58 (1.64)	-306.3 (-0.19)
R Sq.	36%	13%	21%	37%
F	18.27*	4.74*	8.77*	18.98*

Source: Estimated from Field Survey Data, 2021.

Note: The values in the parenthesis is the t-value of respective co-efficient. Further, * reflects significant at 1%; ** significant at 5% level.

5.4 Conclusions

This chapter attempted to estimate the CO_2 emitted by the households in Lucknow city based on their energy consumption of electricity, cooking fuel and personal vehicle usage. Electricity consumption (kWh) in all the HHs in winters was found to be much less than that in summers. HHs living on rent are found to consume half as much electricity as compared to the HHs having their own house. Joint families were found to consume much higher electricity than nuclear families. It is further observed that there is positive relationship exist between income and average consumption of electricity by the HHs in both winters and summers. TV and fridge are the most commonly found appliances in the surveyed households. Geyser, AC and RO are found in 50-60% of the households. Two wheelers accounted for the majority of total motor vehicles in all the HHs. As the income level of the HHs increases, the average number of cars as well as the average distance covered by it increases. In case of two-wheelers, very high income HHs have the lowest average number of bikes as well as the distance covered by it. It is the upper middle income HHs which have the highest average number of bikes and highest distance covered by it per month, followed by middle income and lower middle income. Electricity consumption is found to be responsible for the highest contribution to CO_2 emissions followed by LPG consumption and vehicular emissions. The mean monetary value of CO_2 emissions by all the HHs is observed to be Rs.11.6 thousand which is approximately 2% of the mean annual income of all the surveyed HHs. Further, as income of the household increases, the emission of CO_2 vis-à-vis absolute value of CO_2 also increases across households in the city. This observation is found to be true across all caste, religious and income groups. Therefore, annual income of the HHs is found to be the most important factor determining the CO_2 emissions in the survey region.

Chapter 6

Impact of Environmental Awareness, Social and Personal Norms and Willingness to Sacrifice on Environmental Pollution

"Ecology is Permanent Economy"

- *Sunderlal Bahuguna*

6.1 Introduction

There is extensive literature on economic and technological solutions to climate change, but the role of shifting to climate-friendly behavior in climate change mitigation is usually undervalued (van de Ven et al 2018: 854; Stankuniene et al 2020: 2; Safarzyńska 2017: 2).The existing macro-economic models are increasingly found to be inefficient in aiding to climate change mitigation policy due to large amount of uncertainty involved and sensitivity in fixing discount rates (Stern 2016: 408; Farmer 2015: 330). Thus, a need for alternative modelling approaches is increasingly being felt (Stiglitz & Gallegati 2011: 6). Behavioural economics models recognize the fact that humans have cognitive limitations and human decisions are not always rational (Stankuniene 2020: 2; Brekke & Stenman 2008: 280). Given the complexity of climate change mitigation policy, interventions are needed at every level, beginning with the households (HHs). Further, HHs, due to their energy consumption behavior, are responsible for 72% of the total greenhouse gas emissions globally (Hertwich 2009: 6417).

Behavioural economics offers a realistic view of human decisions and thus, is more accurate in assessing energy consumption behavior of the households. Faber et al (2012: 7-9) studied the GHG emission reduction potential of behavioural changes in European Union for the year 2020, 2030 and 2050. The study considered three aspects of behavioral change i.e., mobility (using fuel efficient vehicles in a fuel efficient way, switch to public transport, walking, cycling, etc., reduce travel distance by living near work place or work from home etc.), housing (optimized use of space heating, air-conditioning and water heating; turning off lights and fans when not needed, use of windows and doors for light and ventilation, etc.) and food and drink habits (vegetarian, local and seasonal food with minimum food wastage). Changes in mobility behavior, housing and eating habits were found to be able to reduce CO_2

emissions by 6% to 34%, 50% and 20% respectively in 2020. Dietz et al (2009: 18452-18456) in their study on HHs in United States of America found that with little or no reduction in household well-being and without introducing any new regulatory measures, only five kinds on behavioural interventions (Weatherization and Upgrades of Home Heating and Cooling Systems, Equipment Upgrades, Maintenance of Equipment, Adjustments of Equipment and Daily Use Behaviors) could save approximately 123 million tons of carbon per year in 10 years, which is 20% of household direct emissions or 7.4% of USA's national emissions.

People's behavior is influenced by a number of other factors apart from their economic interests, including the socio-economic conditions, social and personal norms, etc. (Farmer & Foley 2009: 685; Brekke & Stenman 2008: 281). Environmental awareness is found to be an important factor inspiring people to change their lifestyle and consumption habits (Brounen et al 2013: 49). However, awareness alone may not result into environment friendly behavior (Wang et al 2011: 3553). Socio-economic and cultural variables also affect an individual's decisions (Poortinga et al 2004: 85). Thus, there exists a gap between individual's awareness or concern and his/her actions, referred to as awareness behaviour gap (Liu and Bai 2014: 149). Further, Adam Smith in The Theory of Moral Sentiments (1759: 1-437) and The Wealth of Nations (1776: 1-393) has stated that human decisions are significantly affected by social and personal influences. Residential energy demand too is strongly related to the personal and social norms of the individuals of the household (Niamir et al 2020: 145; Chen and Zheng 2016: 22; Han et al 2018: 2127). The classical rational individual model assumes that each individual working for his self-interest will ultimately lead to the promotion of social interest. In case of externality ridden environmental problems, however, the self-interest theory leads to the 'tragedy of the commons'. The free-rider dilemma and the collective action problem are one of the important reasons behind environmental degradation, since the rational individual model motivates action leading to self-interest irrespective of the social-interest. The concept of Willingness to Sacrifice (WTS) suggests the contrary, wherein the individual altruistic behavior leads to the collective good, even at the expense of self-interest. The WTS behavior is explained by Norm-Activation theory proposed by Schwartz (1970: 127-141; 1977: 229-275). The norm-activation theory suggests that the helping behavior arises when the individual is aware of the impact of his/her actions/behavior on others, as well as when they ascribe the responsibility of helping others on themselves (Chen and Zheng 2016: 22). The WTS indicator was developed initially by Dietz, Stern, & Guagnano (1998: 458-466). Unlike the more popular concept of Willingness to Pay (WTP), which focuses mainly on the willingness of the people to contribute in the form of money, WTS covers people's willingness to sacrifice in terms of everyday behaviour and lifestyle changes along with monetary sacrifice (Chen and Zheng 2016: 20). Individuals who demonstrate greater WTS are also observed to demonstrate more environmentally responsible behaviour (Rahman & Reynolds 2016: 113; Han & Hyun 2017: 1252). This study takes the study by Dietz, Stern, & Guagnano (1998: 450-471) and Chen and Zheng (2016: 19-39) as the reference to measure WTS in Lucknow city. Sacrifice in terms of money and daily life behavioural changes are covered in the schedule.

Based on the above review, the chapter is divided into four sections. The first section is introduction followed by objectives and methods in the second section. The third section covers the results analysis through descriptive statistics, development of environmental indices and econometric modelling. The last section concludes.

6.2 Objectives and Methods

Based on the above literature, the present chapter attempts to assess, (a) the extent and dimensions of people's awareness on climate change, more specifically on emission of domestic induced CO_2, (b**)** the impact of people's awareness, and social and personal norms on willingness to sacrifice for controlling CO_2 emissions. The analysis of results is carried out in three phases, viz., (i) socio-economic profile and environmental awareness of respondents, (ii) development of environmental index across households in the study area, (iii) factors determining willingness to sacrifice (WTS) and Environmental impact assessment (EIA) through multiple regression analysis. The analysis of socio-economic profile and environmental awareness of respondents is done by using simple descriptive statistics such as simple percentage and graphical analysis to get a first-hand understanding on the survey data. The development of environmental index is accomplished to reflect the extent and dimensions of awareness of the respondents across zones and socio-economic behavior. The method of such index is as follows.

Development of Environmental Awareness Index (EAI)

The present study uses Hahn et al (2009: 74-88) and United Nations Development Programme (1990: 13) methodology to develop an environmental awareness index (EAI) using field survey data. The EAI is composed of three major components, viz., weather change awareness, community participation, and willingness to sacrifice. Each of these components comprise of several sub-components as shown in table 6.3.

As the sub-components are measured on different scales, it is necessary to standardize each of them as an index first (Eq.1). The equation used for this conversion is adapted from that used in the Human Development Index to calculate the life expectancy index (Watkins 2007:356):

$$\boldsymbol{X_i = (X_a - X_{min})/(X_{max} - X_{min})} \qquad \text{----- (Eq.1)}$$

Where $\boldsymbol{X_a}$ is the actual value of the sub-component, $\boldsymbol{X_{max}\ and\ X_{min}}$ are the maximum and minimum values of each of the sub-components respectively. For instance, in case of weather change awareness, the maximum value is 2 and minimum is 1, while in case of community participation and willingness to sacrifice, maximum value is 5 and minimum value is 1. All the indicators have a positive relationship with EAI.

After standardization, weights are generated through Principal Component based weighted approach, for each of the three major components of the EAI, weight is estimated separately, by using Eq. (2) and (3):

$$\boldsymbol{W_i = 1/\sqrt{Var}(X_i)} \text{ ------- (Eq. 2)}$$

$$\boldsymbol{K = 1/(\frac{1}{\Sigma_i^m \sqrt{Var(X_i)}})} \text{ ------ (Eq. 3)}$$

Where $\boldsymbol{W_i}$ is weight, m is the sample size i.e., 270 and $\boldsymbol{Var}(\boldsymbol{X_i})$ is the variance of $\boldsymbol{X_i}$. Weights thus generated, are then multiplied by corresponding sub-components and then the sub-components are summed up using Eq. (4) to calculate the value of each of the three major components, which is as follows.

$$\boldsymbol{Y_i = \Sigma_{i=1}^n W_i X_i} \text{ ------- (Eq. 4)}$$

Where $\boldsymbol{Y_i}$ stands for each of the three major components and $\boldsymbol{n}$ stands for each of the sub-components in each major component. In case of weather change awareness index, there are seven sub-components, while community participation index and willingness to sacrifice index have three sub-components each.

Further, to estimate the EAI, all the thirteen sub-components are taken together, standardized using Eq. (1) and weights are estimated using Eq. (2) and (3) and finally summed up using Eq. (4).

Factors Determining WTS and EAI

The following regression model has been employed for analyzing the gap between environmental awareness and the corresponding action. Equation (5) studies the relation between a household's willingness to sacrifice for environmental protection and their level of awareness and participation in community environmental programmes.

$$WTS = \alpha + \beta_1 Awareness + \beta_2 Community\ Participation + e \quad \text{----- Eq. (5)}$$

Equation (6) analyses the relationship between EAI and three component indicators.

$$EAI = \alpha + \beta_1 Awareness + \beta_2 Community\ Participation + \beta_3 WTS + e \quad \text{---- Eq. (6)}$$

6.3 Analysis of Results

6.3.1 Socio-economic Profile of the Respondents

Table 6.1 depicts the socioeconomic status of the sample households. The present study is conducted in eight zones of Lucknow city. Based on the socioeconomic characteristics, zones are classified into developed and under-developed. Zones 1,2,5 and 6 are located in the old city area of Lucknow having relatively higher population density, low access to basic amenities compared to other zones, hence, classified as under-developed. On the other hand, zones 3, 4, 7 and 8 are located in the well planned locations having better transportation and access of basic amenities, hence considered as developed. The results from Table 6.1 highlight the deprivation in the under-developed zones compared with developed zones. It is reported that population in the developed zones has relatively more employment security. In the developed zones, 49.31% of households are working in the secure sources of employment (i.e., regular salaried class), while only 37.30% of households working in under-developed zones. Further, education status is also relatively better in developed zones, i.e., 79.86% of households are having education-level above graduation. Marital status also is in favor of households belonging to developed zones. It is reflected in the Table 6.1 that 76.39% of households are married. Lastly, the mean longevity of respondents belonging to the developed zones is higher than that of respondents belonging to the under-developed zones.

Table 6.1: Socio-economic Profile of the Respondents

Categories	Indicators	Under developed	Developed
Usual Activity	Working	66.67	61.81
	Others	33.33	38.19
Occupation	Regular Salaried	37.3	49.31
	Others	62.7	50.69
Education	Below graduate	33.33	20.14
	Graduate and above	66.67	79.86
Marital Status	Married	61.90	76.39
	Unmarried	38.10	23.61
Mean Age (years)		36.2	40.7

Source: Field Survey Data, 2021.

Note: Figures are in percent.

6.3.2 Status of Environmental Awareness

Table 6.2 captures the status of environmental awareness in the sample households pertaining to Lucknow city. Responses on weather change, environmental degradation, and adverse impact of climate change on human ecology are collected. Majority of sample households perceived that weather pattern has been changing. The major changes such as increase in temperature, unprecedented change in rainfall distribution, and elevated levels of air pollution are causing several seasonal diseases to human beings. About 80% of households strongly perceive that anthropogenic factors are main contributors for changing climate, while only 8% of households perceive that natural factors are responsible for climate change (Table 6.2). Further, more than 70% of households perceive that by limiting use of natural resources and advanced technology, impact of climate change can be moderated in near future. Moreover, 80% of households perceive that climate change is changing rainfall pattern, which ultimately decreases the working efficiency of sample households.

Table 6.2: Status of Environmental Awareness

Awareness	Strongly Agree	Agree	Can't Say	Disagree	Strongly Disagree
Pattern of weather is changing during last few decades	98.9	0	0	1.1	0
Temperature is increasing since past 5 years	98.9	0	0	1.1	0
Rainfall pattern is changing over past 5 years	98.9	0	0	1.1	0
Air pollution is increasing over past 5 years	98.9	0	0	1.1	0
Climate change is actually happening	80	17.4	1.9	0.4	0.4
Human activity is responsible for climate change	72.2	21.9	1.9	3.7	0.4
Natural variability is responsible for climate change	8.5	42.2	18.1	21.5	10
Climate change is harmful	76.3	17.4	4.4	1.9	0
Climate change issue can be controlled	45.2	33	15.2	5.6	1.1
Recent floods and cyclones are due to climate change	50.7	34.1	10.4	4.4	0.4
Climate change is responsible for loss in work efficiency	38.5	36.3	11.9	15.2	1.9

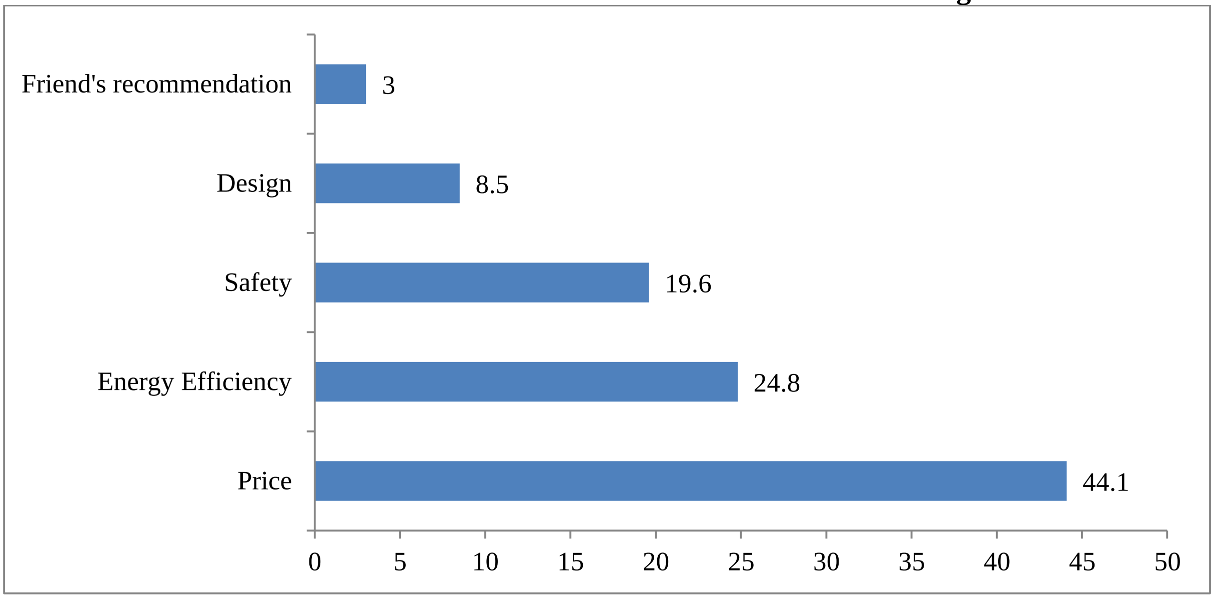
Source: Field Survey Data, 2021.

Note: Figures are in percent.

6.3.3 Criteria for Buying Vehicle

Figure 6.1 depicts households' preferences when buying a new vehicle. Five major factors such as price, energy efficiency, safety, design and friend's recommendation are covered keeping in center the environment. The results from Figure 6.1 reveal that about 44.10% of the households have given first preference to price, while only 24.80% of the households gave first preference to energy efficiency/mileage. This shows that majority of the households are giving preference to the prices while purchasing a vehicle than energy efficiency, safety and design of vehicles, even if they are well-aware of environmental consequences of low energy efficient vehicles.

Table 6.1: Various criteria of Households Preference for Purchasing a Vehicle



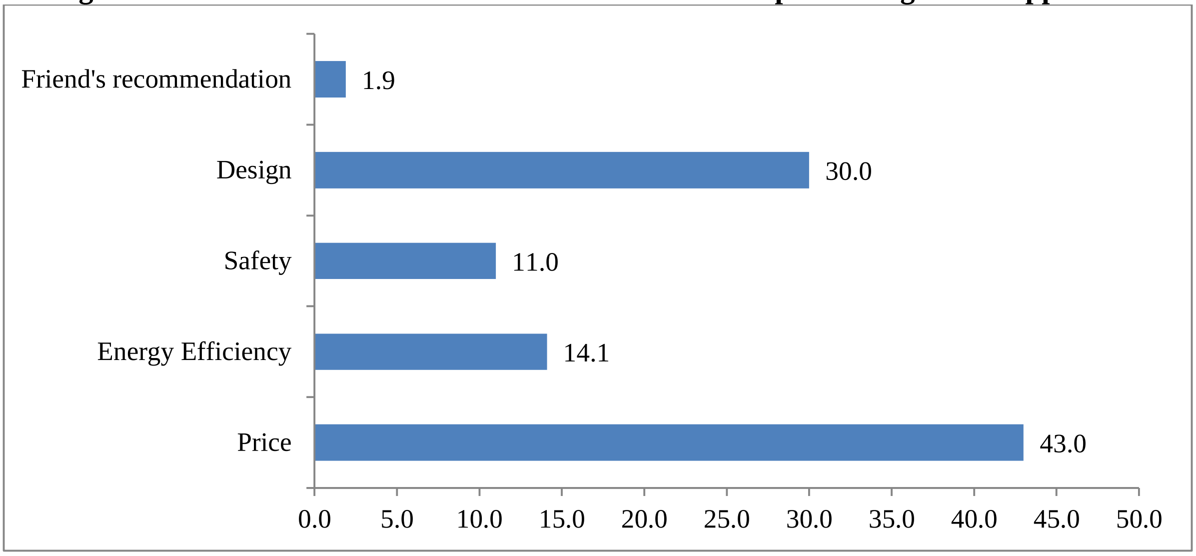
Source: Field Survey Data, 2021.

Note: Figures are in percent.

6.3.4 Criteria for Buying Home Appliances

Figure 6.2 depicts the households' preferences when buying home appliances. The above mentioned same five criteria are framed for purchasing of new home appliances. The result confirms that price of the home appliances is the first criteria compared to other features like design, safety and energy efficiency. In the informal discussion, households reveal that price is the key indicator for quality of the product, which is also environmentally friendly compared to others. For instance, highly energy-efficient rating appliances such as fridge and air conditioners are relatively costlier than low energy-efficient rating appliances. Further, 30% of households have given preference to the design, while 11% of household have given preference to safety.

Figure 6.2: Various criteria of Households Preference for purchasing Home Appliances



Source: Field Survey Data, 2021.

Note: Figures are in percent

6.3.5 Description of the Rational Indicators

A total of 13 rational indicators are selected for the development of Environmental Awareness Index (EAI) which covers three dimensions i.e., awareness, community participation, and willingness to sacrifice. Awareness indicators are covering the changes in weather pattern such as changes in rainfall and temperature, awareness of air pollution and its impact on human health. Community participation indicators cover the initiative for environmental protection that is taken at community level, willingness to sacrifice indicators cover household's willingness to sacrifice for environmental protection (Table 6.3).

Table 6.3: Rational Indicators for Environmental Awareness Index

Components	Indicators	Functional relationship with Environmental Index	Weight	Under-developed zones	Developed zones
Weather change Awareness	HHs are aware of pollution under control certificate (PUC)	+	3	79.37	81.25
	HHs perceive that weather pattern has been changed	+	13	99.21	98.61
	HHs perceive that temperatures have been increased	+	11	100	97.2

	HHs perceive that rainfall pattern has been changed	+	13	100	97.92
	HHs perceive that levels of Air Pollution have been increased	+	13	99.21	98.61
	HHs have participated in the environment awareness programmes	+	3	27.78	36.11
	HHs have planted trees to protect environment	+	3	68.25	83.33
Community Participation	HHs perceive that efficient use of energy at community-level will help in moderation of climate change effects	+	8	94.44	97.92
	HHs perceive that radical changes are done at community-level such as waste decomposition is needed to deal with climate change	+	7	92.86	91.67
	HHs perceive that moral aspect is vital for dealing with climate change	+	7	91.27	90.97
Willingness to sacrifice	HHs perceive that they prefer eco-friendly products to reduce ecological foot-print.	+	6	76.98	81.94
	HHs reveal that willingness to reduce material comfort to protect environment	+	8	86.51	89.58
	HHs are ready to pay additional tax for the protection of environment	+	5	69.84	71.53

Source: Field Survey Data, 2021. Note: Values are in Percent.

6.3.6 Zone wise Weather Change Awareness Index (WCAI)

The values of index on zone-wise weather change awareness are depicted in table 6.4. For the construction of weather change awareness index, indicators such as awareness of pollution under control certification, and households' perception on weather change, rainfall & temperatures change are used. The results from table 6.4 reveal that households belonging to the Zone-1 (Aminabad) are relatively more aware of weather pattern change and on the other hand, households belonging to Zone-5 (Alambagh) are relatively less aware of weather pattern change. The main contributing indicators for high level of awareness in Zone-1 (Aminabad) are air pollution and plantation of trees. In other worlds, households highly perceive that air pollution has increased in the past five years and to cope up with air pollution, households have planted trees. Further, planting trees not only helps in reduction of air population but also helps in reduction of temperature levels.

Table 6.4: Zone-wise Weather Change Awareness Index

Indicators/ Zones	Pollution under Control Certificate	Weather Pattern Change	Temperature Increase	Rainfall Pattern Change	Air Pollution Increase	Plantation of Trees	Weather Change Awareness Index	Rank
Zone-1 (Aminabad)	0.0000	0.0000	0.0000	0.0000	0.0250	0.0231	0.0527	1
Zone-2 (Aishbagh)	0.0000	0.0000	0.0000	0.0000	0.0235	0.0111	0.0411	4
Zone-3 (Jankipuram)	0.0025	0.0000	0.0000	0.0000	0.0157	0.0012	0.0285	7
Zone-4 (Gomtinagar)	0.0000	0.0000	0.0000	0.0050	0.0213	0.0099	0.0439	3
Zone-5 (Alambagh)	0.0000	0.0000	0.0000	0.0000	0.0097	0.0040	0.0180	8
Zone-6 (Balaganj)	0.0025	0.0022	0.0025	0.0025	0.0224	0.0080	0.0485	2
Zone-7 (Indranagar)	0.0033	0.0057	0.0066	0.0000	0.0147	0.0024	0.0336	6
Zone-8 (Vrindavan Yojana)	0.0000	0.0035	0.0000	0.0040	0.0199	0.0050	0.0387	5

Source: Field Survey Data, 2021.

6.3.7 Zone wise Community Participation Index

The values of Index on zone-wise community participation are depicted in table 6.5. Indicators such as efficient use of energy, waste decomposition at community-level and awareness on moral aspect are used for the construction of community participation index. The results from Table 6.5 reveal that households belonging to Zone-6 (Balaganj) have relatively higher participation in the community development programmes to protect environment and create awareness among the community members and on the other hand, households belonging to the Zone-1 (Aminabad) have relatively less participation. The cross-indicator analysis of community participation index shows that households belonging to the Zone-6 (Balaganj) are using relatively higher energy efficient home appliances and adopting better sustainable domestic waste decomposing habits than those of households belonging to the Zone-1 (Aminabad).

Table 6.5: Zone wise Community Participation Index (CPI)

Indicators/Zones	Efficient use of Energy	Sustainable Waste Decomposition Practice	Moral Aspects	Community Participation Index	Rank
Zone-1 (Aminabad)	0.0038	0.0026	0.0018	0.0082	8
Zone-2 (Aishbagh)	0.0127	0.0104	0.0108	0.0339	3
Zone-3 (Jankipuram)	0.0076	0.0059	0.0094	0.0230	6
Zone-4 (Gomtinagar)	0.0119	0.0118	0.0108	0.0345	2
Zone-5 (Alambagh)	0.0092	0.0153	0.0088	0.0333	5
Zone-6 (Balaganj)	0.0144	0.0130	0.0098	0.0372	1
Zone-7 (Indranagar)	0.0078	0.0097	0.0053	0.0229	7
Zone-8 (Vrindavan Yojana)	0.0082	0.0113	0.0141	0.0337	4

Source: Field Survey Data, 2021.

6.3.8 Zone wise Willingness to Sacrifice Index (WSI)

Table 6.6 depicts the values of willingness to sacrifice index (WSI) zone-wise. For the construction of WSI, indicators such as purchasing eco-friendly products, willing to reduce material comfort and willing to pay additional tax (environmental tax) to protect environment are used. It suggests that households belonging to the Zone- 2 (Aishbagh) have higher capacity of willingness to sacrifice than that of households belonging to the Zone- 8 (Vrindavan Yojana). The cross-indicator analysis reveals that households belonging to the Zone- 2

(Aishbagh) are using relatively higher eco-friendly products, ready to reduce material comfort and willing to pay additional tax to protect environment that that of households belonging to the Zone-8 (Vrindavan Yojna).

Table 6.6: Zone wise Willingness to Sacrifice Index

Indicators/Zones	Eco-friendly Products	Reduce Material Comfort	Willingness to Pay Additional Tax	Willingness to sacrifice Index	Rank
Zone-1 (Aminabad)	0.0162	0.0208	0.0145	0.0515	4
Zone-2 (Aishbagh)	**0.0220**	**0.0289**	**0.0265**	0.0774	1
Zone-3 (Jankipuram)	0.0156	0.0177	0.0178	0.0510	6
Zone-4 (Gomtinagar)	0.0175	0.0209	0.0167	0.0551	2
Zone-5 (Alambagh)	0.0141	0.0157	0.0158	0.0457	7
Zone-6 (Balaganj)	0.0175	0.0201	0.0173	0.0549	3
Zone-7 (Indranagar)	0.0145	0.0185	0.0181	0.0511	5
Zone-8 (Vrindavan Yojana)	0.0115	0.0188	0.0135	0.0438	8

Source: Field Survey Data, 2021.

6.3.9 Disaggregate-level Environment Awareness

Table 6.7 depicts the zone-level environmental awareness index values. Further, based on the socioeconomic characteristics, zones are classified into two categories i.e., under-developed and developed. The results from table 6.7 reveal that households belonging to the Zone-1 (Aishbagh) are relatively more aware of environmental protection than that of other Zones. On the contrary, households belonging to the Zone-5 (Alambagh) are relatively less aware of environmental protection. Further, aggregate-level analysis shows that households belonging to the under-developed zones are highly concerned/aware of environmental protection than that of households belonging to the developed zones, as the former are more exposed to the negative effects of climate change and are not capable enough to cope up with it.

Table 6.7: Zone wise Development of Environmental Awareness Index

Zone	Weather change Awareness Index	Community Participation Index	Willingness to sacrifice Index	Environment Awareness Index	Rank
Zone-1 (Aminabad)	0.0528	0.0082	0.0514	0.1125	5
Zone-2 (Aishbagh)	0.0411	0.0339	0.0774	0.1524	1
Zone-3 (Jankipuram)	0.0285	0.0230	0.0510	0.1025	7
Zone-4 (Gomtinagar)	0.0439	0.0345	0.0551	0.1336	3
Zone-5 (Alambagh)	0.0180	0.0333	0.0456	0.0969	8
Zone-6 (Balaganj)	0.0485	0.0372	0.0548	0.1405	2
Zone-7 (Indranagar)	0.0336	0.0229	0.0511	0.1076	6
Zone-8 (Vrindavan Yojana)	0.0387	0.0337	0.0438	0.1161	4
Under-developed	0.0424	0.0294	0.0569	0.1287	1
Developed	0.0347	0.0273	0.0502	0.1122	2

Source: Field Survey Data, 2021.

6.3.10 Socioeconomic Characteristics wise Environment Awareness Index

Table 6.8 depicts how socioeconomic characteristics shape households' awareness towards environment protection. It reveals that households belonging to the Other Backward Caste (OBC) have relatively higher environmental awareness than that of households belonging to the other social groups. Further, households belonging to the Hindu religion also have higher environment awareness than that of households belonging to the other religions. So far as gender is concerned, not much difference is observed among male and female respondents, except in the case of awareness. Male respondents have relatively higher awareness rate than that of females, as generally male members are more exposed to external environment, while females are usually observed to be confined to their domestic activities or they travel less frequently. Further, on the basis of education-level, households have been divided into two groups i.e., below graduation and above graduation. Households with at least one member being at least graduate or above are grouped as graduate or above, else below graduate. The calculated environment awareness index results confirm that households having education-level below graduation are having relatively higher willingness to protect and more aware and concerned about environment than households having education-level above graduation. This observation is contrary to the general expectation that greater education will lead to more aware and more environmentally sensitive generation. The field observation brings out a very important fact that environmental issues aren't simply an issue of being aware. The less formally educated people are found to be more involved with their natural surroundings and have traditional knowledge of a sustainable lifestyle which makes them to live in harmony with nature. In case of occupation, households with at least one regular salary earning member is categorized as regular salaried household, else non-regular salaried. Occupation does not seem to have a very relevant role in shaping household's thought and behavior on environmental issues except in case of awareness. Non-regular salaried households are observed to be more aware of climatic changes (Table 6.8). This is probably due to the uncertain nature of their work, as they are faced with greater challenges in their day to day life such as, very frequent travelling in all seasons, usually more exposed to regular weather changes, etc. In case of age-wise analysis, it is found that households having mean age between 31 to 60 years are more aware of climate change. However, it is the age group between 18 to 50 years which has higher community participation index, i.e., they are more actively participating in environmental protection activities, probably due to their young age. Further, the households belonging to the age group of 31 to 50 years have the highest willingness to sacrifice, as majority of the earning population belongs to this age group (Table 6.8). For deeper analysis, income wise (entire income range is divided into four categories, i.e., quintile) environmental awareness is estimated. The results from Table 6.8 reveal that households belonging to the 1st quintile (mean income Rs.2.56 Lakh) are relatively better aware on, and more willing to sacrifice for environmental protection than other households. Households belonging to the 4th quintile (mean income 18.12 Lakh) are observed to be least concerned as well as least willing to sacrifice for environmental protection.

The zone-wise analysis as well as the socio-economic status wise analysis lead to a very important observation that it is the less developed class (both economically and socially) which is more aware and more willing to sacrifice for environmental protection, as they are most exposed and vulnerable to, but least capable to cope up with climate change. While the affluent section which is contributing the most to environmental damage is less concerned with environmental issues. The above observation contradicts the classical school of thought with assumed poverty to be the leading cause of environmental damage (World Development Report 1992: 25-43) but confirms with the mainstream school of thought which believes that poverty alone does not lead to environmental degradation. There are various other factors which are at play, like, population growth, government policies, cultural factors etc. (Pearce and Warford 1993). It is, in fact, the poorer communities who are observed to develop a traditional system of resource management which enables them to reduce environmental damage (Jodha 1998: 2384-2389; Nayak 2014: 123-126).

Table 6.8: Socioeconomic characteristics and Environment Awareness Index

Indicators	Weather Change Awareness Index	Community Participation Index	Willingness to sacrifice Index	Environment Awareness Index
Social Group				
General	0.0383	0.0282	0.0540	0.1205
Other Backward Caste	0.0399	0.0316	0.0508	0.1223

Scheduled Caste and Scheduled Tribe	0.0328	0.0172	0.0559	0.1059
Religion				
Hindu	0.0388	0.0285	0.0526	0.1200
Muslim	0.0398	0.0217	0.0565	0.1180
Others	0.0140	0.0283	0.0771	0.1194
Gender				
Male	0.0392	0.0287	0.0531	0.1210
Female	0.0369	0.0274	0.0537	0.1180
Education				
Below Graduate	0.0481	0.0293	0.0552	0.1325
Graduate and above	0.0350	0.0279	0.0527	0.1156
Occupation				
Regular Salaried	0.0348	0.0286	0.0539	0.1173
Non-regular Salaried	0.0411	0.0280	0.0529	0.1220
Age				
18 to 30 years	0.0415	0.0274	0.0519	0.1208
31 to 50 years	0.0345	0.0308	0.0562	0.1215
51 to 60 years	0.0462	0.0255	0.0527	0.1244
Above 60 years	0.0343	0.0216	0.0444	0.1004
Income Quintiles (mean annual income)				
1st Quintile (Rs.2.56 Lakh)	0.0446	0.0291	0.0595	0.1332
2nd Quintile (Rs.5.52 Lakh)	0.0426	0.0305	0.0553	0.1284
3rd Quintile (Rs.8.34 Lakh)	0.0355	0.0287	0.0452	0.1095
4th Quintile (Rs.18.12 Lakh)	0.0296	0.0247	0.0519	0.1062

Source: Field Survey Data, 2021.

6.3.11 Relation Between Environmental Awareness and Willingness to Sacrifice

Table 6.9 shows the correlation between all the indices. WTS index and community participation index are found to be highly correlated with Environment Awareness Index. Weather change awareness index and community participation index are observed to be slightly positively correlated with WTS index.

Table 6.9: Correlation Matrix

	Environment Awareness Index	Willingness to sacrifice Index	Community Participation Index	Weather Change Awareness Index
Environment Awareness Index	1	-	-	-
Willingness to sacrifice Index	0.589	1	-	-
Community Participation Index	0.713	0.277	1	-
Weather Change Awareness Index	0.017	0.029	-0.058	1

Source: Field Survey Data, 2021.

Equation (5) is estimated as follows, where community participation is observed to be significant and positively related to willingness to sacrifice, while, awareness is not found to be a significant factor affecting willingness to sacrifice of the households. A unit increase in household's community participation activities and perception leads to an increment in their willingness to sacrifice by 0.33 units.

$$\boldsymbol{WTS = 0.22 + 0.08\, Awareness + \ 0.33\, Community\ Participation + e}$$ ----- *Eq. (5)*

t- value 15.19* 0.77 4.75*

$R^2 = 7.2\%$; F = 11.42*

(Note: * denotes significance at 1%)

Similarly, Eq. (6) is estimated as below, where community participation and willingness to sacrifice are found to be significant and positively related with Environment Awareness Index, while awareness is not observed to be significant. A unit change in community participation index and willingness to sacrifice index is observed to lead to an increase by 0.36 units and 0.22 units respectively in EAI.

$$\boldsymbol{EAI = 0.01 + 0.04\ Awareness + 0.36\ Community\ Participation + 0.22\ WTS + e} \quad \text{--Eq. (6)}$$

t- value 2.23** 1.14 16.44* 11.62*

R^2 = 67.3%; F = 185.20*

(Note: * denotes significance at 1%; ** denotes significance at 5%)

Thus, we observe that environmental awareness and concern or action do not have a significant causal relationship with each other. Similar observations have been made by various other studies (Klöckner 2013: 1035; Lillemo 2014: 250; Mei et al 2016: 673). Thus, all those who are aware about environment do not necessarily behave in an environment friendly way. This phenomenon is popularly referred to as the 'awareness - behaviour gap' (Li et al 2019: 30). The results are in line with the observations in Table 6.8, i.e., households having education-level below graduation are more willingness to protect and more aware and concerned about environment than households having education-level above graduation. Li et al (2021: 9) explained the existence of such gap on the basis of the dominant role of economic factors in guiding a person's consumption behavior. Lillemo (2014: 250) observed procrastination to be an important factor causing awareness-behavior gap, as, in case of environment-friendly actions, the short run or immediate gains are small but the long run benefits are significant. People usually prefer present benefits over future ones.

6.4 Conclusions

Household's awareness, concern and willingness to sacrifice for environment are assessed in this study. Majority of the households are found to be aware of the issue of climate change and its harmful consequences. However, this awareness is not found to be affecting their purchasing behavior much. Price of commodities (energy consuming home appliances including vehicles) remain the first priority of the households while purchasing these commodities. In vehicle purchase, people still care fairly about mileage as the fuel prices are a clearly visible fact. But in case of home appliances, energy efficiency is still not a major concern, as its benefits are accrued over long period in terms of low electricity bills, but the immediate price of energy efficient goods are little higher.

Further, the underdeveloped zones are observed to be more aware, concerned and willing to sacrifice for environmental cause as compared to the developed zones. This is probably because the well-off households can afford various comforts which do not make them realize the vagaries of environmental degradation, while the poorer households cannot do so, and thus, are more vulnerable to climate change consequences. This situation can be compared with the global scenario of developed and underdeveloped countries, where developed nations contribute more to climate change but care less about it due to their better adaptability capacity based on better socio-economic and technological well-being. Lastly, it is observed that, environmental awareness may not necessarily translate into environment friendly actions. Thus, along with awareness, various other socio-economic, cultural, psychological and other factors should be focused upon in order to promote environment friendly behavior.

Chapter 7

Major Findings and Conclusion

"When the last tree is cut, the last fish is caught, and the last river is polluted; when to breathe the air is sickening, you will realize, too late, that wealth is not in bank accounts and that you can't eat money."

- Alanis Obomsawim

7.1 Introduction

The fact that climate change is an upcoming global catastrophe to human civilization, created by humans themselves, is well-established. Numerous factors such as expansion of economic activities in the form of urbanization and various infrastructure in other areas for promotion of social, economic and demographic features are responsible for it. Further, the role of households in contributing to CO_2 emissions is also very important, given their demand for direct fuel consumption via electricity consumption, cooking and vehicle usage and also indirect demand via consumption of various goods and services which have substantial carbon footprint. The direct and indirect household carbon emissions together are responsible for 60% to 80% of a country's total greenhouse gas emissions (Benders et al. 2006: 3612; Kok et al. 2006: 2746). Edgar et al (2009: 6417) attempted to quantify the greenhouse gas emissions associated with final consumption of goods and services in 73 countries across the world, where, households were observed to contribute 72% of the total GHG emissions on the global level followed by investments (18%) and government consumption (10%). Thus, households can also play a vital role in reducing emissions by changing their lifestyle, consumption and energy demand behaviour. It is therefore necessary to understand the energy consumption behavior of the households and the factors affecting it.

With this background, the thesis attempted to study the various socio-economic dimensions of the households affecting their CO_2 emissions. Beginning with a global level study comprising of top twenty CO_2 emitters in the world, followed by a national level study comprising of twenty two major states of India and finally a primary level study of households in Lucknow city, a number of observations are made. The following section summarizes the major findings and conclusions of the study, followed by policy recommendation, limitations and further scope of the study.

7.2 Summary of the Study

Chapter 1 titled as **"Economic Development and Environment: Debate and Methods"** explores the environment-economy linkages, the reasons behind the focus on CO_2 in the climate change debate, sectoral contributions of CO_2 emissions more specifically households' CO_2 emissions at global and national level, and their measurement methods. Based on the review of existing literature, few important observations are as follows. Firstly, despite being accepted as a challenge for humanity by a large number of experts, climate change is still not unanimously accepted as a real problem by everyone. Second, nearly all government reports show that the energy sector is responsible for the highest share of emissions via electricity and heat production. As of 2015, heat and electricity production accounted for 41% of global CO_2 emissions, followed by transport (24%), industries (20%) and residential sector (6%)[70]. The residential sector emissions here, include emissions from electricity usage and cooking fuel usage. While households actually emit much more, given their personal vehicle usage, public transport and consumption of various goods and services like clothes, food, entertainment, cosmetics, etc. Third, income of the household is observed to be the most important factor in determining the household CO_2 emissions. Other relevant factors are the household size and urbanization. Fourth, Uttar Pradesh is found to be a leading contributor to CO_2 emissions, as well as the most vulnerable state to climate change. Thus, there is a need to focus on the role of households in causing emissions as well as in mitigating it. Therefore, using the emission coefficient method, the present study estimates the direct CO_2 emissions by the households via electricity consumption, cooking fuel and personal vehicle usage. The estimation of indirect

[70] https://www.iea.org/subscribe-to-data-services/co2-emissions-statistics

emissions requires the availability of secondary-level data. Given the limited data availability at decentralized level and primary nature on the study, the estimation has been limited to direct household emissions only. Further, household level survey is conducted comprising 270 sample households in the city of Lucknow to capture various dimensions of CO_2 emissions.

Chapter 2 entitled, **“Economics of Climate Change: A Theoretical Background”** traces the origin of climate change and environmental issues in economic theory. The debate on scientific and economic background of climate change is covered. The issue of environment and economics can be traced back to the origin of economic theory itself. First, beginning with the classical economists, Malthus and Ricardo suggested the ‘limits to growth approach’, i.e., the inability of the economy to grow infinitely due to limited natural resources. Whereas, Neo-Malthusians believed excess population, huge income and technology to be the prime culprit behind environmental damage. The Neo-classical school of thought however, believed that environment and economy work in coordination with each other. But, after witnessing the two world wars and the great economic depression, the debate on economic growth changed drastically, giving way to the concept of sustainable economic development. Later, years of intellectual discourse led to the emergence of sustainability debate which talked about inter-generational inequality in resource consumption and with the beginning of 21st century, economists agreed to the fact that climate change is real but differed on the degree of its seriousness. Hussen (2013: 192) classifies these economic thoughts into three broad categories viz. the ‘business as usual (BAU)’ approach, the ‘gradualist’ approach and the ‘precautionary’ approach. The believers of BAU approach argue that the abatement costs of climate change are too much, largely ignoring the damage cost of climate change (ibid: 192-193). Gradualists, on the other hand, follow a balanced approach by considering both damage costs and abatement costs in cost benefit analysis (Hussen 2013: 194). Unlike the gradualists, the believers of precautionary approach take a strict stand on actions needed to mitigate climate change.

Second, economists view climate change as a market failure problem caused by the negative externalities of human activities, considering climate to be a common property resource. An equilibrium in this situation can occur at a point where marginal damage cost equals the marginal control cost. A number of models referred to as Integrated Assessment Models and a number of approaches viz. economic, non-economic and legal approaches have been developed to analyze and solve the problem of climate change. Thus, the discipline of economics and environment is deeply connected with each other and economic solutions may help to mitigate the phenomenon of climate change. Lastly, India's stand on climate change issue has transitioned from being the leader of 'climate justice' debate, urging developed nations to pay for their historical emissions, to being a climate responsible nation pledging to improve the emissions intensity of its GDP by 33 to 35 per cent by 2030 below 2005 levels and being the only nation to have 2^0 C compatible targets (Climate Transparency Report 2020: 23).

The third chapter, **"Economic Growth and Carbon Emissions: A Global Scenario"** presents the inter-linkages of socio-economic and demographic variables with CO_2 emissions in the top twenty CO_2 emitting countries of the world. The economic growth and environmental history of the twenty nations are traced since 1000 AD till the 21st century, divided into four phases. Following observations are made from this chapter. First, for the entire period from 1000 to 1820 A.D., India and China together accounted for nearly half of the world's population and over 45% of the world's GDP, with India being ahead of China in terms of GDP till 1700 AD. Western powers were far behind India and China in terms of total GDP. However, in per capita GDP terms, India and China lagged behind, owing to their large population. The landmark event which occurred in the late 18th century in Britain, i.e., the Industrial Revolution, marked the beginning of a new era called as 'the Anthropocene Era'. Up to 1785, United Kingdom was responsible for 100% of the global CO_2 emissions. Later, France, Germany and Poland joined in the process of industrial revolution. Second, during the period from 1820 to 1960, the

Western world flourished. Asia and Africa observed meager growth in this period. Post World War-II, USA emerged as the largest economy. The top four economies, viz., USA, UK, France and Germany, which had 12% of the world's population, accounted for nearly 43% of the global GDP. USA by 1950 turned out to be the largest emitter, contributing to over 43% of CO_2 emissions of the world. The energy consumption doubled over nineteenth century sourced mainly by coal. Third, a rapid increase in global CO_2 emissions is observed after 1950s. World population increased by more than three times in the last seven decades. Global average life expectancy increased from 46 years in 1950 to over 71 years by 2015. Also, in the post-world war era, the global urban population increased from nearly 29% of world population in 1950 to more than 50% in 2015 and touched to 56% in 2020. After late 1980s, the developing nations like India, China, Russia, Brazil and Indonesia emerged as new growth centers. Fourth, between 1960 and 2018, the share of CO_2 emissions and GDP of China increased most rapidly, while that of USA declined by nearly half. Saudi Arabia and South Korea depict massive rise in per capita emissions i.e., by nearly 19 times and 12 times respectively. Fifth, other than the socio-economic and demographic factors, the shift to service sector economy in majority of the twenty nations and decline in the use of non-renewable energy sources has also impacted their emissions. Sixth, population and GDP are found to be the most relevant factors in determining a nation's CO_2 emissions. Increase in per capita income, literacy rate, gender empowerment, promotion of public health (such as life expectancy, reduction total fertility rate, maternal mortality rate, and child mortality rate) are the major targets through economic growth, which have resulted into heavy pressure on natural resources.

Chapter 4 entitled, **"State-wise Domestic Energy Consumption and CO_2 Emissions Scenario in India"**, explores the extent of residential electricity, cooking and private vehicle induced fuel consumption and the consequent emissions under domestic consumption at state level in India and assesses the impact of population, per capita GSDP and population density on household emissions across major 22 states for the year 2018-19. First, there has been a rapid increase in electricity consumption, with increasing shift to cleaner sources of cooking and lighting in India in both rural and urban regions. Second, people prefer personal transport over public transport, as understood from the fact that non-transport vehicles accounted for the 91.1 % of total registered vehicles in 2016-17. Further, two-wheelers comprise of over 80% of personal vehicles. Third, Maharashtra is the highest CO_2 emitting states from electricity consumption as well as personal vehicle usage, followed by Uttar Pradesh. In case LPG led emissions for cooking purpose, Uttar Pradesh tops the list, with Maharashtra at second rank. Fourth, the direct household emissions are found to account for 60% of the total emissions, which shows that the role of households in CO_2 emissions is extremely significant. Further, Chhattisgarh, Haryana, Punjab, Delhi and Gujarat, due to their high per capita income and greater dependency on coal for power generation, are found to be the top five CO_2 emitting states in terms of per capita direct household CO_2 emissions. Fifth, population and per capita GSDP are observed to have a significant positive relation with CO_2 emissions from electricity consumption, personal vehicle use, LPG use for cooking and total emissions. Population density, on the other hand is observed to have negative but not significant relation with CO_2 emissions from electricity consumption and vehicle usage. While, in case of LPG emissions, population density is observed to have a significant positive relation. Lastly, the monetary value of total CO_2 emissions from direct HH energy consumption is estimated be nearly 2% (1.7 billion US $) of the average GSDP (88.5 billion US $) of all the major 22 states.

The fifth chapter, **“Assessment of Direct Household Carbon Emissions in Lucknow City”** attempts to analyze the domestic fuel and electricity consumption by the households in Lucknow and their consequent emissions. The following observations are drawn from this chapter. First, large income inequality among the surveyed households is observed. While 25% of the households own 54% of the total income, 75% of the households own only 46% of the total income. Top 6% of the households alone own 22% of total income. Second, in case of electricity consumption, general category households consume highest average electricity. Further, households with own house and joint family households consume much higher electricity as compared to rented households and nuclear households respectively. Third, as the income of the household increases, its average electricity consumption also increases. Fourth, over 95% of the households have light, fan, TV and fridge. While the penetration of AC, geyser and RO is nearly 50-60%. Fifth, electricity consumption is responsible for the highest share of CO_2 emissions from the households, followed by LPG consumption and personal vehicle usage. Sixth, as the income of the household increases, its emissions via electricity consumption and personal vehicle use increases, while that from LPG consumption decreases. HH income is found to be the most relevant factor affecting a household's CO_2 emissions. Seventh, per household annual CO_2 emissions is observed to be 6523.3 Kg and the monetary mean value of annual CO_2 emissions by all the HHs is observed to be Rs.11.6 thousand which is approximately 2% of the mean annual income of all the surveyed HHs.

Chapter 6 entitled, **"Impact of Environmental Awareness, Social and Personal Norms and Willingness to Sacrifice on Environmental Pollution"** assess the extent and dimensions of household's awareness on climate change. Nearly all the households (99%) agreed that the pattern of weather and rainfall is visibly changing in last few decades and increasing temperatures are being witnessed. Over 80% of the households believed that climate change is harmful and could feel its side-effects in their day to day lives. In terms of purchasing behavior, 44% of the households kept price as their first priority, while purchasing any vehicle or home appliances. Energy efficiency is yet not a priority for majority of households. Only 14% of the households were concerned about energy efficiency while purchasing home appliances while only 25% of the households are concerned about mileage while purchasing vehicles. This observation suggests that most of the households prefer immediate gains over long run benefits or savings provided by eco-friendly appliances/vehicles. Few of the significant observations are as follows:

First, over 90% of the respondents agree that everyone should contribute to solve the issue of climate change. Nearly 51% of the respondents are ready to do their bit in protecting the environment, irrespective of what others do. 70% of the respondents believe that they still have time to beat climate change. 80% of the respondents express their fear of the consequences of climate change (CC). Over 80% of the respondents agree that they felt a moral duty to protect the environment and were actively aware of the issues of environment. They also agree that humans have no right to modify the environment as per their suitability. Further, 50% to 70% of the respondents agree that their family members, friends, neighbours and other close ones also have a positive attitude towards environmental issues and contribute to environmental protection is any possible way in their day-to-day choices and activities. 24% to 30% of the respondents are unwilling to make any personal sacrifice for environment and believed that their job is more important than environment protection even if it pollutes the surroundings. Thus, it is observed that majority of the people are concerned towards environmental issues but are not able to do much regarding it due to time and money limitations.

Second, as far as people's willingness to sacrifice is concerned, nearly 80% of the respondents are found to be willing to pay a higher amount to purchase environment friendly products. Further, 88% of the respondents are willing to make life comfort sacrifices for environment protection. However, only 70% of the respondents are ready to pay tax for environment protection. The main reason for this, is the low trust of people in the government on the actual allocation and utilization of the tax revenue. A more detailed analysis shows that only 17% to 27% of the respondents are strongly willing to make any kind of sacrifice for environment.

Third, the less developed zones are observed to be more aware, concerned and willing to sacrifice for environment protection, given their higher vulnerability to climate change due to lack of resources. Lastly, huge gap between environment awareness and action is observed, suggesting that awareness alone will not lead to the adoption of environment friendly practices. Various other factors need to come together to motivate people to come forward to take environment friendly initiatives, such as community participation and other means.

7.3 Hypothesis Testing

Table 7.1 presents a summary of the major objectives and hypotheses of the present study. It also shows the relevant literature and methodology adopted to test the hypothesis and sums up the major findings.

Table 7.1: Summary of Study Objectives and Results

Sl. No.	Objectives	Hypotheses	Literature adopted for methodology	Major Methodology	Findings	Remarks
1.	To assess the linkages of economic growth with various social, demographic and environmental factors among top twenty CO_2 emitting countries in the world during the period 1960-2017.	The socio-economic factors (population and per capita GDP) affect the level of CO_2 emissions in the top twenty CO_2 emitting nations.	Dietz and Rosa (1997:175); Rukhsana and Shahbaz (2008); Stock and Watson (1993: 793)	Panel data regression (FMOLS and DOLS)	Population and per capita GDP are found to have a significant positive relationship with CO_2 emissions.	Hypothesis is accepted.
2.	To assess the extent of residential energy consumption, CO_2 emissions and their monetary value and the socio-economic factors	Per capita gross state domestic product and population density have positive and negative relationship respectively with the state's CO_2 emissions.	IPCC (2006); Ahmad et al (2015); Garg et al (2014: 579);	IPCC Tier-2 methodology; Simple OLS regression.	CO_2 emissions are found to be positively related with per capita GSDP and negatively related with population density.	Hypothesis is accepted.

	impacting on total residential emissions in 22 major states in India for the year 2018-19.					
3.	To estimate the total CO_2 emission by household fuel consumption and its economic value and the impact of socio-economic factors on the annual direct carbon emissions from households in Lucknow city.	Households with higher income tend to emit more CO_2 as compared to households with lower income level.	IPCC (2006); Ahmad et al (2015); Garg et al (2014: 579); Wilson et al (2013)	IPCC Tier-2 methodolog; ANCOVA model.	Annual income of the HHs is found to be the most important factor determining the CO_2 emissions by the HHs and positively related to it.	Hypothesis is accepted.
4.	To estimate the extent and dimension of environment awareness, community participation and willingness to sacrifice in Lucknow city.	Household's environmental awareness does not ensure its environment-friendly actions.	Hahn et al (2009)	Weighted index based on principal component.	Despite being aware of environmental problems, respondents were not found to act in a environment-friendly way.	Hypothesis is accepted.

7.4 Conclusions

The present study attempts to bring out the various dimensions of household carbon emissions at the global, national, as well as local level. Beginning with the introduction to climate change debate and its theoretical origin in the discipline of economics, it is observed that despite climate change being a decades old phenomenon, it is still not accepted to be a reality by all.

Further, even if the acceptance of the issue has increased overtime, the degree of concern over its consequences varies a lot. Also, instead of being a global environmental concern, it has been more of a power-politics issue where the developed nations try to shift the burden of mitigating climate change on the lesser developed nations, leading to the call for climate justice.

In order to tackle the challenge of climate change, various economic (example - emission trading, carbon tax, etc.) and non-economic approaches (example - emission standard, liability laws, etc.) have been developed. The study suggests that none of the approaches alone can fix the issue. Also, along with these climate change mitigation approaches, a number of large-scale investments are needed to generate low-carbon development. Given the limited resource availability, developing nations look for low-cost alternatives to reduce their carbon emissions. As households are the primary sources of demand for direct and indirect energy consumption, changes in their consumption pattern can help to achieve lower emissions without much investments.

The study observes that, income is the most important factor affecting a household's emissions. It is further observed that it is the low income and more vulnerable households which are more aware and concerned about environment. Thus, just like the developed nations, it is the high income households which should be the center of behavioural policies intending to mitigate climate change.

7.5 Policy Recommendations

The findings of the study lead to the following important policy suggestions:

Firstly, in developing nations like India, which are faced with dual challenges of development and environment protection, the focus should be more on the cost-effective climate change mitigation policies, such as, promoting climate friendly daily life practices, encourage the use of energy efficient home appliances, public transport, etc. Secondly, mechanisms need to be developed to reward small environment friendly behaviours and to demotivate environment polluting behaviors. For example, giving certain incentives to people who buy five-star rating appliances or electronic vehicles, using social media platforms to reward individuals, households and companies with lowest footprints, etc. Thirdly, measurement of emissions at state-level, district-level and further decentralized levels should be done and published at regular intervals. This will help in the easy implementation of policies such as cap-and-trade among states as well as districts. This will also motivate low carbon development and will generate funds for those willing to reduce their emissions. Fourthly, people should be made to involve themselves more in community environment friendly activities like, tree plantation drives, or taking care of local water bodies, parks etc. Such activities should be made compulsory part of school curriculum as well as in higher education institutes and government and private offices too as it is well prevalent in Philippines. Lastly, but most importantly, as zero pollution is neither possible not desirable, none of the above policies should compromise with the basic living amenities required to lead a healthy life.

7.6 Limitations of the Study

There are a few limitations of the present study, which are as follows.

Firstly, only urban households are covered in the study. Emissions from rural households are of different nature and therefore should be studied separately as well. Secondly, along with emissions, households also contribute to creating sinks by maintaining gardens and other activities. This aspect has not been included in the study. Thirdly, only the direct emissions from the households are covered in the study due to limited data availability. Various indirect emissions such as from the household’s demand for food, clothing, footwear, cosmetics, entertainment, etc. are not included in the present study. Fourthly, the emissions in case of official and commercial vehicles possessed by a household have not been included in the study.

Lastly, few of the important variables such as floor area of the household, vehicle model, emissions from waste disposal, etc. have not been covered in the study.

7.7 Further Scope of the Study

There are very few studies on household emissions, and even fewer studies on household's emission behavior. Further, in case of India, the research is scanty. The residential sector is usually shown to account for a meagre share, as only the emissions from the heat and electricity consumed by the households are considered under residential sector emissions. Emissions from the use of personal vehicles and indirect emissions via the consumption of various goods and services by the households is not included in it. This emphasis on the supply side emissions and negligence of demand side emissions leads to undermining the role of households in CO_2 emissions. Also, measurement of CO_2 emissions at the most decentralized level is needed. Availability of accurate data will help in policy framing as well as getting benefits of approaches like carbon credit. Thus, a lot more studies on the quantitative as well as qualitative aspects of demand side carbon emissions are required, particularly in developing nations.

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Appendices

Table 1.1A: Socio-economic Profile of States in India

	Source: Census 2011 Population Projections			Source: National Statistical Office, MOSPI, GOI			Source: National Sample Survey Organisation, NITI Aayog.	
RANK	STATES/UTS	2018 POPULATION IN ('000)	RANK	STATES/UTS	GSDP 2018-19 AT CONSTANT PRICES (2011-12) (IN LAKHS)	RANK	STATES/UTS	2011-12 PERSONS BELOW POVERTY LINE[71] (MILLIONS)
1	Lakshadweep	67	1	Mizoram	1452439	1	Andaman and Nicobar Islands	0
2	Daman & Diu	385	2	Arunachal Pradesh	1667595	2	Lakshadweep	0
3	Andaman Nicobar	395	3	Nagaland	1764736	3	Daman & Diu	0.03
4	Dadra & Nagar Haveli	515	4	Sikkim	1872227	4	Sikkim	0.05
5	Sikkim	657	5	Manipur	1930041	5	Goa	0.08
6	Chandigarh	1165	6	Puducherry	2444221	6	Puducherry	0.12
7	Mizoram	1181	7	Meghalaya	2468196	7	Dadra & Nagar Haveli	0.14
8	Puducherry	1470	8	Chandigarh	3119198	8	Mizoram	0.23
9	Arunachal Pradesh	1489	9	Tripura	3696278	9	Chandigarh	0.24
10	Goa	1531	10	Goa	6253943	10	Meghalaya	0.36
11	Nagaland	2129	11	Jammu and Kashmir	11275534	11	Nagaland	0.38
12	Manipur	3073	12	Himachal Pradesh	11785058	12	Arunachal Pradesh	0.49
13	Meghalaya	3192	13	Uttarakhand	19327278	13	Tripura	0.52
14	Tripura	3953	14	Jharkhand	22498632	14	Himachal Pradesh	0.56

[71] Based on mixed recall period consumption, Tendulkar Methodology

15	Himanchal Pradesh	7253	15	Chhattisgarh	23118182	15	Manipur	1.02
16	Uttarakhand	11013	16	Assam	23404790	16	Uttarakhand	1.16
17	J&K	13392	17	Bihar	37565127	17	Jammu and Kashmir	1.33
18	Delhi	19435	18	Odisha	38221846	18	Delhi	1.7
19	Haryana	28266	19	Punjab	39766947	19	Punjab	2.32
20	Chhattisgarh	28340	20	Madhya Pradesh	52200932	20	Kerala	2.4
21	Punjab	29619	21	Haryana	53108519	21	Haryana	2.88
22	Assam	33918	22	Kerala	55941196	22	Andhra Pradesh	7.88
23	Kerala	34943	23	Delhi	59056914	23	Tamil Nadu	8.26
24	Jharkhand	36869	24	Telangana	61282821	24	Assam	10.13
25	Telangana	36967	25	Andhra Pradesh	62130140	25	Gujarat	10.22
26	Odisha	43490	26	Rajasthan	67742800	26	Rajasthan	10.29
27	Andhra Pradesh	51938	27	West Bengal	73952500	27	Chhattisgarh	10.41
28	Karnataka	65275	28	Karnataka	112442289	28	Jharkhand	12.43
29	Gujarat	67010	29	Uttar Pradesh	113746879	29	Karnataka	12.98
30	TN	75342	30	Gujarat	118637907	30	Odisha	13.85
31	Rajasthan	76256	31	Tamil Nadu	121530747	31	West Bengal	18.5
32	MP	81090	32	Maharashtra	203907396	32	Maharashtra	19.79
33	WB	96297				33	Madhya Pradesh	23.41
34	Bihar	117739				34	Bihar	35.82
35	Maharashtra	121011				35	Uttar Pradesh	59.82
36	UP	222015						

Table 1.2A: Energy Consumption Profile of States in India

	Source: India PNG statistics 2019			Source: GOI Ministry of Power Lok Sabha Starred Question No.73 To Be Answered on 21.11.2019			Source: Ministry of Road Transport and Highways	
Rank	States/UTs	Consumption Of Petroleum Products In TMT 2018-19	Rank	States/UTs	Total Electricity Consumption Kwh 2018-19	Rank	States/Uts	2016 Total Registered Motor Vehicles (000)
1	Lakshadweep	15	1	Lakshadweep	37118000	1	Lakshadweep	16
2	Sikkim	126	2	Andaman Nicobar	235815000	2	Sikkim	49
3	Mizoram	139	3	Sikkim	573561000	3	Dadra & Nagar Haveli	105
4	Nagaland	154	4	Mizoram	728677000	4	Daman & Diu	106
5	Andaman Nicobar	212	5	Nagaland	757924000	5	Andaman Nicobar	111
6	Daman & Diu	221	6	Dadra & Nagar Haveli	813185000	6	Mizoram	171
7	Tripura	235	7	Arunachal Pradesh	1046767000	7	Arunachal Pradesh	265
8	Manipur	241	8	Chandigarh	1139370000	8	Manipur	306
9	Arunachal Pradesh	248	9	Manipur	1140083000	9	Tripura	319
10	Dadra & Nagar Haveli	398	10	Tripura	2031842000	10	Nagaland	380
11	Chandigarh	435	11	Puducherry	2565150000	11	Meghalaya	558
12	Meghalaya	492	12	Meghalaya	2812152000	12	Chandigarh	837

13	Puducherry	542	13	Daman & Diu	2986830000	13	Puducherry	863
14	Goa	798	14	Goa	3481494000	14	Goa	1158
15	Jammu & Kashmir	1503	15	Himanchal Pradesh	10284754000	15	Himachal Pradesh	1176
16	Himanchal Pradesh	1559	16	Assam	11566038000	16	Jammu & Kashmir	1366
17	Uttarakhand	1725	17	Uttarakhand	16156071000	17	Uttarakhand	1888
18	Assam	2744	18	J&K	17704224000	18	Jharkhand	2477
19	Jharkhand	3409	19	Kerala	26451851000	19	Assam	2817
20	Chhattisgarh	4110	20	Delhi	30085380000	20	Chhatisgarh	4810
21	Delhi	4890	21	Jharkhand	34583122000	21	Bihar	5482
22	Bihar	5242	22	Bihar	36616829000	22	Orissa	5833
23	Odisha	5930	23	Chhattisgarh	55574740000	23	West Bengal	6488
24	Kerala	6339	24	Haryana	58849812000	24	Haryana	8633
25	Telangana	7000	25	Punjab	60600474000	25	Telangana	8709
26	Punjab	7063	26	WB	67696791000	26	Andhra Pradesh	8728
27	Andhra Pradesh	7820	27	Telangana	70089432000	27	Punjab	9064
28	Madhya Pradesh	8006	28	Odisha	70801720000	28	Delhi	9705

29	West Bengal	8789	29	Andhra Pradesh	76868240000	29	Kerala	10172
30	Haryana	10523	30	Madhya Pradesh	87901560000	30	Madhya Pradesh	11141
31	Rajasthan	11403	31	Karnataka	91123900000	31	Rajasthan	13632
32	Karnataka	13206	32	Rajasthan	97760192000	32	Karnataka	16292
33	Tamil Nadu	14421	33	Uttar Pradesh	1.34541E+11	33	Gujarat	20361
34	Uttar Pradesh	18180	34	Tamil Nadu	1.40588E+11	34	Uttar Pradesh	23936
35	Maharashtra	21017	35	Gujarat	1.5935E+11	35	Tamil Nadu	24203
36	Gujarat	21216	36	Maharashtra	1.7232E+11	36	Maharashtra	27870

Table 1.3A: Socio-economic Profile of Districts in Uttar Pradesh

Rank	Source: UP Statistical Diary 2017		Rank	Source: Census 2011		Rank	Source: Census 2011	
	District	PCI at 2011-12 constant prices in 2014-15		District	Population		District	Urban Population (%)
1	Gautam Buddha Nagar	325583	1	Allahabad	5954391	1	Ghaziabad	80.44
2	Hapur	70929	2	Azamgarh	4613913	2	Lucknow	66.21
3	Agra	68939	3	Lucknow	4589838	3	Kanpur nagar	65.83
4	Meerut	64836	4	Kanpur nagar	4581268	4	Gautam Buddha Nagar	59.12
5	Lucknow	54534	5	Jaunpur	4494204	5	Meerut	51.08
6	Kasganj	52591	6	Sitapur	4483992	6	Agra	45.81
7	Ghaziabad	51403	7	Bareilly	4448359	7	Varanasi	43.44
8	Bareilly	48925	8	Gorakhpur	4440895	8	Jhansi	41.7

9	Jhansi	47845	9	Agra	4418797	9	Moradabad	36.99
10	Kanpur nagar	46795	10	Hardoi	4092845	10	Bareilly	35.26
11	Amroha	46531	11	Kheri	4021243	11	Firozabad	33.35
12	Mahoba	45963	12	Bijnor	3682713	12	Aligarh	33.13
13	Sonbhadra	44219	13	Varanasi	3676841	13	Saharanpur	30.77
14	Etah	44027	14	Aligarh	3673889	14	Hapur	29.76
15	Rampur	43827	15	Ghazipur	3620268	15	Mathura	29.68
16	Bulandshahar	42976	16	Kushinagar	3564544	16	Shamli	29.39
17	Muzaffarnagar	42230	17	Bulandshahar	3499171	17	Muzaffarnagar	28.45
18	Baghpat	41661	18	Bahraich	3487731	18	Rampur	25.2
19	Mathura	41647	19	Saharanpur	3466382	19	Bijnor	25.13
20	Shamli	41569	20	Meerut	3443689	20	Amroha	24.93
21	Allahabad	40823	21	Gonda	3433919	21	Jalaun	24.79
22	Hathras	39860	22	Ghaziabad	3343334	22	Bulandshahar	24.79
23	Pilibhit	39600	23	Barabanki	3260699	23	Allahabad	24.74
24	Saharanpur	38759	24	Ballia	3239774	24	Etawah	23.16
25	Bijnor	37739	25	Pratapgarh	3209141	25	Mau	22.63
26	Aligarh	36211	26	Budaun	3127621	26	Farukkhabad	22.08
27	Hamirpur	35842	27	Moradabad	3126507	27	Sambhal	21.29
28	Moradabad	34644	28	Unnao	3108367	28	Hathras	21.26
29	Sambhal	34507	29	Deoria	3100946	29	Mahoba	21.16
30	Varanasi	33580	30	Shahjahanpur	3006538	30	Baghpat	21.11
31	Amethi	33026	31	Raebareli	2903507	31	Kasganj	20.06
32	Chitrakoot	32588	32	Muzaffarnagar	2829865	32	Shahjahanpur	19.76
33	Jalaun	32489	33	Mahrajganj	2684703	33	Hamirpur	19
34	Firozabad	32247	34	Fatehpur	2632733	34	Budaun	18.97
35	Etawah	32186	35	Siddharth nagar	2559297	35	Gorakhpur	18.83
36	Kheri	31991	36	Mathura	2547184	36	Pilibhit	17.3
37	Farukkhabad	31991	37	Firozabad	2498156	37	Unnao	17.1
38	Shahjahanpur	31984	38	Mirzapur	2496970	38	Auraiya	16.98
39	Lalitpur	30519	39	Faizabad	2470996	39	Kannauj	16.95

40	Basti	28920	40	Basti	2464464	40	Sonbhadra	16.88
41	Kanpur dehat	28717	41	Sultanpur	2431491	41	Mainpuri	15.44
42	Mainpuri	28607	42	Ambedkar nagar	2397888	42	Banda	15.32
43	Sultanpur	28051	43	Rampur	2335819	43	Etah	15.11
44	Budaun	27824	44	Mau	2205968	44	Sant ravidas nagar	14.53
45	Mirzapur	27608	45	Sambhal	2199774	45	Lalitpur	14.36
46	Fatehpur	27499	46	Balrampur	2148665	46	Mirzapur	13.92
47	Banda	27298	47	Pilibhit	2031007	47	Faizabad	13.77
48	Unnao	27074	48	Jhansi	1998603	48	Hardoi	13.24
49	Kushinagar	26396	49	Chandauli	1952756	49	Chandauli	12.42
50	Barabanki	24958	50	Farukkhabad	1885204	50	Fatehpur	12.23
51	Mau	24901	51	Mainpuri	1868529	51	Sitapur	11.84
52	Faizabad	24886	52	Amethi	1867678	52	Ambedkar nagar	11.71
53	Gonda	24602	53	Sonbhadra	1862559	53	Kheri	11.46
54	Gorakhpur	24418	54	Amroha	1840221	54	Deoria	10.22
55	Sitapur	24368	55	Banda	1799410	55	Barabanki	10.15
56	Kannauj	24368	56	Kanpur dehat	1796184	56	Chitrakoot	9.71
57	Raebareli	23810	57	Etah	1774480	57	Raebareli	9.69
58	Sant ravidas nagar	23327	58	Sant kabir nagar	1715183	58	Kanpur dehat	9.66
59	Hardoi	22768	59	Jalaun	1689974	59	Ballia	9.39
60	Mahrajganj	22586	60	Kannauj	1656616	60	Azamgarh	8.53
61	Kaushambi	22098	61	Gautam Buddha Nagar	1648115	61	Bahraich	8.14
62	Auraiya	21420	62	Kaushambi	1599596	62	Kaushambi	7.78
63	Ghazipur	21271	63	Etawah	1581810	63	Balrampur	7.74
64	Chandauli	21264	64	Sant ravidas nagar	1578213	64	Jaunpur	7.71
65	Deoria	20615	65	Hathras	1564708	65	Ghazipur	7.58

66	Ambedkar nagar	20202	66	Kasganj	1436719	66	Sant kabir nagar	7.49
67	Jaunpur	19720	67	Auraiya	1379545	67	Amethi	7.11
68	Siddharth nagar	19310	68	Hapur	1338311	68	Gonda	6.55
69	Ballia	19307	69	Shamli	1313647	69	Siddharth nagar	6.28
70	Azamgarh	18951	70	Baghpat	1303048	70	Sultanpur	6.04
71	Shrawasti	18608	71	Lalitpur	1221592	71	Basti	5.6
72	Pratapgarh	17917	72	Shrawasti	1117361	72	Pratapgarh	5.46
73	Balrampur	16986	73	Hamirpur	1104285	73	Mahrajganj	5.02
74	Bahraich	16891	74	Chitrakoot	991730	74	Kushinagar	4.72
75	Sant kabir nagar	16531	75	Mahoba	875958	75	Shrawasti	3.46

Table 4.1A: State wise Domestic Electricity Consumption by Ultimate Consumers 2018-19 and Emission Factors

Sl. No.	States	Electrical energy (GWh)	Emission Factor ($kgCO_2e/kWh$)	Sl. No.	States	Electrical energy (GWh)	Emission Factor ($kgCO_2e/kWh$)
1	Andhra Pradesh	63300	0.91	12	Madhya Pradesh	69200	1.68
2	Assam	8660	1.21	13	Maharashtra	139000	1.26
3	Bihar	21200	2.1	14	Orissa	70200	0.88
4	Chhattisgarh	44700	1.37	15	Punjab	52400	0.97
5	Gujarat	110000	1.02	16	Rajasthan	67800	1.21
6	Haryana	44100	1.27	17	Tamil Nadu	98300	1.13
7	Himachal Pradesh	9160	0.26	18	Telangana	61600	0.91
8	Jammu & Kashmir	9640	0.81	19	Uttarakhand	12500	0.12

9	Jharkhand	26800	1.68	20	Uttar Pradesh	102000	1.61
10	Karnataka	75300	0.7	21	West Bengal	50200	1.29
11	Kerala	22300	0.13	22	Delhi	29200	1.05
All India Domestic Electricity Consumption is 1210000 (GWh) and Emission Factor is 1.19 ($kgCO_2e/kWh$)							

Source: Estimated from RTI Reply from CEA and cBalance Solutions Pvt. Ltd: Electricity GHG Inventory Report 2009-10

Table 4.2A: State-wise Share of Registered Non-transport Vehicles up to March 2017

Sl. No.	State	% share	Sl. No.	State	% share
1	Andhra Pradesh	86.8	12	Madhya Pradesh	95.4
2	Assam	88.0	13	Maharashtra	91.2
3	Bihar	90.9	14	Orissa	90.6
4	Chhattisgarh	94.4	15	Punjab	85.1
5	Gujarat	90.8	16	Rajasthan	92.5
6	Haryana	90.3	17	Tamil Nadu	92.4
7	Himachal Pradesh	84.4	18	Telangana	91.2
8	Jammu & Kashmir	83.1	19	Uttarakhand	92.9
9	Jharkhand	83.7	20	Uttar Pradesh	95.7
10	Karnataka	90.6	21	West Bengal	90.4
11	Kerala	86.5	22	Delhi	94.1

Source: Estimated from India PNG Statistics 2018-19 and Road Transport Year Book 2016-17

Table 4.3A: State-wise Details of Per Capita Electricity Consumption (Kwh)

State/UTs/REG.	2012-13	2013-14	2014-15	2015-16	2016-17	2018-19
Chandigarh	1168	1133	1052	1112	1128	978
Delhi	1613	1446	1561	1557	1574	1548
Haryana	1722	1773	1909	1936	1975	2082
Himachal Pradesh	1380	1348	1336	1339	1340	1418
Jammu & Kashmir	1043	1066	1169	1234	1282	1322
Punjab	1761	1810	1858	1919	2028	2046
Rajasthan	982	1011	1123	1164	1166	1282
Uttar Pradesh	450	472	502	524	585	606
Uttarakhand	1297	1285	1358	1431	1454	1467
Chhattisgarh	1495	1601	1719	2022	2016	1961
Gujarat	1796	1973	2105	2248	2279	2378
Madhya Pradesh	753	764	813	929	989	1084
Maharashtra	1239	1183	1257	1318	1307	1424
Daman & Diu	7927	8003	6960	7836	7965	7758
D. & N. Haveli	14341	14515	13769	15137	15783	15179
Goa	2045	2198	1803	2738	2466	2274
Andhra Pradesh	1135	1196	1040	1230	1319	1480
Telangana	-	-	1356	1439	1551	1896
Karnataka	1129	1179	1211	1242	1367	1396
Kerala	630	645	672	704	763	757
Tamil Nadu	1226	1544	1616	1688	1847	1866
Puducherry	2136	1692	1655	1672	1784	1745
Lakshadweep	592	665	657	649	633	554
Bihar	145	160	203	258	272	311
Jharkhand	847	810	835	884	915	938

Odisha	1209	1349	1419	1564	1622	1628
West Bengal	594	609	647	660	665	703
Sikkim	862	700	685	687	806	873
A.& N. Islands	559	368	361	355	370	597
Arunachal Pradesh	719	503	525	600	648	703
Assam	240	280	314	322	339	341
Manipur	353	266	295	360	326	371
Meghalaya	690	684	704	835	832	881
Mizoram	469	445	449	503	523	617
Nagaland	268	259	311	346	345	356
Tripura	296	331	303	329	470	514
Total All India	**914**	**957**	**1010**	**1075**	**1122**	1181

Source: Government Of India, Ministry Of Power, **Rajya Sabha, Starred Question No.164,** Answered On 31.07.2017; Government Of India, Ministry Of Power, Lok Sabha, Starred Question No.73, To Be Answered On 21.11.2019

Household Schedule

Economic Development and CO_2 Emissions: A Household Level Study of Lucknow District in Uttar Pradesh

Research Study

By

Ekta Srivastava

BABASAHEB BHIMRAO AMBEDKAR UNIVERSITY
(A CENTRAL UNIVERSITY)