ESTIMATION OF CARBON FOOTPRINT OF INDIAN HOUSEHOLDS IN KALYANI SUBDIVISION OF DISTRICT NADIA, WEST BENGAL, INDIA

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ABSTRACT

The present study aims to assess the contribution of Indian households to the increase in carbon footprint. Hence, this cross-sectional study was conducted in the Kalyani subdivision of Nadia district, West Bengal, India. Data were collected from 610 households, comprising 299 rural and 311 urban households, to analyse energy consumption patterns for various purposes. To summarize the dependent and continuous data, descriptive statistics were employed, while for inferences, independent sample t-test, Pearson correlation and regression were used. A significant difference was observed in total annual household carbon footprint between the urban and rural households due to varied energy consumption ($t = 15.60$, $p < 0.05$). The urban households were emitting twice (2325.20 kgCO_2e) as much as the rural ones (1125.77 kgCO_2e). It can also be inferred that emission was determined by the increase in household size, income, and improvement in the standard of living. Thus, in addition to several determinants, a complex cultural system, social practices, and awareness of green consumerism should also be incorporated and studied through an interdisciplinary approach to reduce the overall household carbon footprint.

Keywords: *rural, household, consumption, fuel, urban*

INTRODUCTION

Over the last two decades, global warming and its impact have come to the forefront of global awareness [1 - 3]. The rising emissions of greenhouse gases (GHG) are a result of the rampant increase in anthropogenic activities, leading to climate change. Despite continuous efforts, the goal of reducing emissions has not been achieved. According to the United Nations, a global total of 55.3 Gt CO_2e was recorded in 2018 [4]. Over the past 1000 years, profound changes in socio-economic systems, both globally and locally, have resulted in significant changes in the composition of our atmosphere. Hence, there is an increasing emphasis on the idea of creating a low-carbon future and adopting green energy.

Researchers are interested in quantifying carbon emissions at both local and global levels [1] by investigating the micro and macro-level causes of global warming [5 - 7]. Recently, the term "carbon footprint" (CF) has gained widespread usage for quantifying carbon emissions and predicting the contributing factors [1, 8]. It has been defined as the measure of the total emissions of CO_2 and other greenhouse gases (GHGs), such as methane, nitrous oxide, or chlorofluorocarbons, which are expressed in terms of mass of CO_2 equivalent [8 - 12]. It can occur either directly or indirectly through products, organizations, services, events, and the activities of individuals or populations, as well as throughout the product life cycle [8]. Many organizations are actively working on monitoring and reducing their carbon footprint and have developed several standardized measures and methods to control the rising greenhouse gas emissions [9, 10]. Carbon emissions can be attributed to various sectors, including production and manufacturing. Nowadays, household emissions have also become a focus of concern as people increasingly adopt materialistic and luxurious lifestyles. Even a poor household may have some luxurious items like refrigerators and motorbikes, which can contribute significantly to GHG emissions. Increasing income and rising standards of living directly influence consumption patterns, often seen as symbols of pride and class, ultimately resulting in high carbon-intensive lifestyles and environmental degradation.

Household consumption of varied goods and services is also accountable for global warming as in the case of the manufacturing and travel sectors. The estimation of the carbon footprint at the household level relied entirely on consumption pattern which is influenced by the socio-demographic structure of each household [5], geographical/spatial distribution and climatic conditions [13, 14]. Several studies have found a proportionate increase in household emissions from different countries or regions. During 1997, the carbon emission percentage was recorded at around 41 % in the USA [15], while in China an increase in emissions of 30 - 40 % was reported [16]. On the other hand, direct emissions from households in Japan contributed 38.81 % of the emission of greenhouse gases [17]. Therefore, work on climate change mitigation and devising policies to reduce emissions without including the consumption behaviour of households is unrealistic, because due to economic development and urbanization, carbon footprint of the household shows a significant contribution that makes up 27 - 56 % of emissions due to different consumption [18 - 21]. Therefore, this study aims to measure and compare the magnitude of energy sources and their related annual household carbon footprint in urban and rural India. The objectives of this study are: to calculate the size of household carbon footprint (HCF) and to study the impact of income, household size and standard of living on the emission of carbon footprint.

METHODOLOGY

Study area

This cross-sectional study was performed in the rural and urban areas of the Kalyani subdivision which falls under the district of Nadia in West Bengal state in eastern India. In Kalyani subdivision, Kalyani Township was selected for this study. The town was established in such a way that the sustainability and harmony between nature and man can be maintained. Kalyani had a history of establishment and development. The foundation stone of this township was laid in 1949, after recognizing the influx of population and the great disruption that Kolkata faced due to the partition in 1947 and the immigration of a large number of refugees from the newly formed nation known as Pakistan [22].

Selection process

The selection of municipalities and community development blocks was carried out using the method of stratified sampling. The two municipalities, Kalyani and Gayeshpur, and one community development block, Haringhata, were selected. Villages and wards were selected based on probability proportional to size (PPS) after being ranked in ascending order based on the total number of households according to the 2011 census. Later, the households were randomly selected in both urban and rural areas. A total of 650 households were selected for this study. Out of 650 households, only 610 households (urban = 311 and rural = 299) with completely collected data were selected for further study.

Extensive fieldwork was conducted between December 2021 and May 2022. Before the fieldwork, the tools were validated and standardized. In addition, permission was obtained from the government authorities. Since the respondents speak Bengali, under the guidance and supervision of experts, the interview schedule was designed in both Roman English and Bengali script which helped the researchers to elaborate the purpose of the study to the respondents properly. For data validation and analysis, the English language was taken into account. Before the interview, prior written and verbal consent was obtained from all the respondents and data collection was completed following the ethical guideline of the Helsinki declaration. Each respondent was interviewed for about 45 - 50 minutes. Due to the long duration of the interview, the research participants were interviewed mainly in their free time, which prevented the occurrence of any risk during the study.

Data analysis process and carbon footprint calculation

Data analysis for this study was conducted step-by-step in 2 different phases:

- The first phase was carried out to perform data validation in MS Excel by extracting data from 610 interview schedules.
- In the second phase, all the validated data were imported into the SPSS (statistical package for the social science) software for statistical analysis to calculate the size of carbon footprint emitted from various energy sources.

After reviewing country-specific and universal carbon footprint calculation models and calculators, the emission accounting method developed by the Intergovernmental Panel on Climate Change (IPCC) was used [23 - 25].

During the household survey, all the 610 households were asked about the following: i) the average monthly consumption of electricity as recorded on their electricity bill in kWh, ii) the types and quantities of fuel (litres) used monthly for cooking and other purposes, and iii) the types and quantities of fuel (litres) used monthly for a personal vehicle. All the recorded energy consumption was primarily used to calculate the annual consumption and then multiplied by appropriate carbon equivalent emission factors to obtain the annual carbon footprint for each household from different energy sources. Furthermore, when all the data were correctly entered and computed, at the final stage, a summation of all the emissions from different sectors was made showing the overall carbon footprint at the household level per year.

Statistical analysis

First, descriptive statistics were used to summarize the dependent and continuous data through mean and standard deviation. Independent sample t-test, Pearson correlation and regression analysis were used for conclusions.

RESULTS AND DISCUSSION

It is evident from Table 1 that urban and rural households used different types of energy. The difference in their consumption pattern is evident. In the case of urban households, an average of 177.01 kg (34.2 %) of fuel was used annually for cooking and other purposes, while rural household consumed 340.46 kg (65.8 %) of fuel annually and the difference is significant ($t = -14.52$, $p < 0.05$). However, consumption of liquified petroleum gas (LPG) and electricity is higher in urban households. The mean of LPG consumption in urban households was 154.71 ± 34.81 kg compared to 130.92 ± 44.73 kg in rural households. The t-test was found to be significant ($t = 6.49$, $p < 0.05$). In the case of electricity, the mean annual consumption was 1179.50 ± 870.14 kWh in urban households and is significantly higher than in rural households where the annual average consumption was only 280.45 ± 155.98 kWh due to lesser use of electrical devices. Therefore, the mean difference was found to be significant ($t = 17.92$, $p < 0.05$). In contrast, the annual consumption of wood for the cooking was 360.89 ± 87.92 kg in rural households since it is freely available in the surrounding area; and if it is purchased, even in that case it is cheaper than LPG. The annual consumption of kerosene was 23.40 ± 11.65 litres, which means that wood and kerosene were consumed in larger quantities in rural households than in urban households. On average, the urban households consumed 290 ± 87.92 kg of wood and 21.24 ± 10.02 litres of kerosene per year, which turned out to be significant ($t_{wood} = -2.91$, $t_{kerosene} = -1.29$, $p < 0.05$). The difference is insignificant in the case of annual fuel consumption for transportation ($t = 1.03$, $p < 0.05$), since the annual consumption in urban households was 171.08 ± 91.84 litres, while in rural areas, the annual consumption of fuel $_{(personal\ vehicle)}$ was 158.25 ± 94.84 litres (Table 1).

In the case of the global rural population, a ~ 10 % drop in emission levels was observed over the past decade. In 2010, it was 71 %, while in 2020 it fell to 61 % [26]. In the present study, it was found that the rural dwellers relied on natural resources like wood and cow dung cakes as they are all easily available at minimal cost. Rural dwellers use a variety of cooking fuels including LPG, kerosene, wood, and cow dung cakes, although dependence on wood was high. On average, ~ 360.89 ± 87.92 kg of wood was consumed annually, followed by LPG (130.92 ± 44.73 kg), cow dung cakes (25.63 ± 16.98 kg) and kerosene (23.40 ± 11.65 litres). On the other hand, compared to rural households, urban dwellers mostly depend on LPG for cooking and other purposes. Out of 311 households, 98.39 % used LPG as the main fuel for cooking with an average of 154.71 kg per year because it takes less time to cook. Only 5.78 % of households depended solely on wood for cooking and consumed an average of 290 kg per year due to low income and non-affordability of purchasing LPG cylinders at the price of nine hundred and twenty-six rupees, which is too expensive for the low-income group. In addition, 117 households used kerosene with LPG or wood. On average, ~ 21.24 litres of kerosene were consumed annually. The same trend was observed in Pakistan [27] and rural Haryana [28] where rural households used fuelwood, dung, and crop residues for cooking, while natural gas or LPG were rarely preferred. A complete transition to cleaner fuel has not yet taken place [28]. Similarly, 63.86 % preferred to use kerosene because it was cost effective and easily available in Zaria metropolis, Nigeria [29]. On a global scale, the population still relied on traditional fuels, but over the past three decades, the use of such fuels has been in steady decline from 53 % in 1990 to 36 % in 2020 [26]. Several studies observed that cultural preferences, cooking practices, and taste of food played a crucial role in fuel choice [29].

Table 1. Mean and standard deviation of the annual consumption of energy at the household level

Annual fuel consumption	Urban			Rural			t-value
	Number (N)	Mean	Standard deviation (SD)	Number (N)	Mean	Standard deviation (SD)	
LPG, kg	306	154.71	34.81	197	130.92	44.73	6.49*
Kerosene, l	117	21.24	10.02	88	23.40	11.65	- 1.29*
Wood, kg	18	290.00	87.92	201	360.89	87.92	- 2.91*
Cow dung cakes, kg	-	-	-	55	25.63	16.98	
Sum of all cooking fuels	311	177.01	72.37	299	340.46	191.43	- 14.52*
Electricity consumption, kWh	311	1179.50	870.14	299	280.45	155.98	17.92*
Fuel used for the personal vehicle, l	175	171.08	91.84	85	158.25	94.84	1.03

* p - value < 0,05

Consequently, the consumption of different energy sources caused large emissions. Therefore, in order to know the average emission in the studied area, descriptive statistics and independent t-test were used. The results revealed significant differences ($t = 15.60$, $p < 0.05$) in the total annual HCF, as the mean value for urban households ($\bar{X} = 2325.20$, SD = 1254.98) was higher than for rural households ($\bar{X} = 1125.77$, SD = 478.09) (Table 2). It can be concluded that the urban area emitted twice as much as the rural area. This is mainly due to the consumption of electricity and cooking fuels in households (1658.23 $kgCO_2e$ and 491.53 $kgCO_2e$ respectively), while the lowest emission was observed from vehicle fuel (294.26 $kgCO_2e$) due to the availability of e-rickshaw and restrictions imposed by the COVID-19 pandemic. In the case of rural areas, among all the emission sources, cooking fuels emitted 662.77 $kgCO_2e$ and had the highest contribution to HCF, followed by electricity consumption and fuels used for personal vehicles (398.24 $kgCO_2e$ and 272.20 $kgCO_2e$). The emissions were lower in rural areas due to the low incomes that limited their ability to purchase any products responsible for emissions. The differences in emission levels between urban and rural areas were significant in the case of annual carbon footprint (CF) of cooking fuels ($t = -9.28$, $p < 0.05$) and electricity ($t = 18.65$, $p < 0.05$) (Table 2). In contrast, in the case of Chinese urban households, 40 % of CF is contributed by electricity and it is a main contributor [30] and the same was observed in some parts of India [13, 31 - 34], while some studies differed greatly as they found housing and transportation to be major contributors (53 - 66 %) in American households [35]. On the other hand, the effect of urbanization on Malaysian lifestyle and CF was shown, and as a result ~ 59.78 % of the total annual household CF was caused by personal travel. A similar pattern was observed in EU (European Union) regions where the major contributor (13 - 44 %) was transport fuel [36]. In contrast, heating and cooling were largest contributor in Japan for a specific season [37].

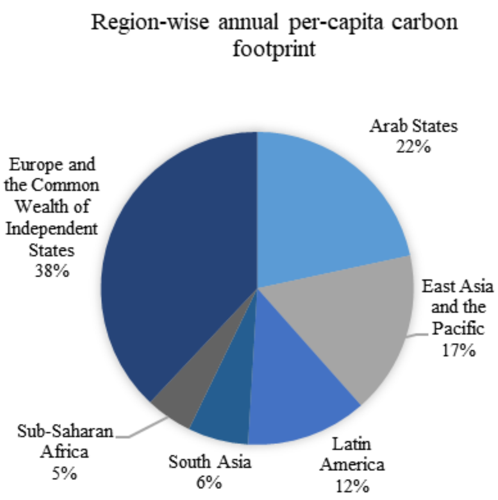
Figures 1a - 1c clearly show and compare the degree of distribution of carbon footprint per capita in different regions, countries, and major Indian cities. According to comparative carbon footprint analysis, the global annual per capita carbon footprint is 6.71 tCO_2e. Compared to the global emission, the regional carbon footprint varies significantly. The share of Europe and the commonwealth independent states in emissions is 38 %, which is higher than other regions: Arab States (22 %), East Asia and the Pacific (17 %), Latin America (12 %), South Asia (6 %) and Sub-Saharan Africa (5 %). On the other hand, among all the countries, the USA has the largest per capita carbon footprint (19.27 tCO_2e). For comparison, values for several other countries are shown below: 12.99 tCO_2e in the Netherlands, 12.18 tCO_2e in Singapore, 10.62 tCO_2e in Germany, 10.12 tCO_2e in Malaysia, 9.99 tCO_2e in Japan, 9.71 tCO_2e in China, 6.97 tCO_2e in UK, 6.63 tCO_2e in Hong Kong, and 2.67 tCO_2e in India. It can also be noted that the share of major Indian cities in the annual per-capita emission in India vary from 11.87 % for Kolkata to 12.76 % for Ahmedabad, 13.83 % for Bangalore, Chennai, Hyderabad, and Mumbai, and 15.95 % for Delhi. However, the studied area in this research recorded only 4.1 %. Therefore, it can be concluded that, compared to other major Indian cities, the studied area consumes less energy per capita than other cities in India. The rapidly changing lifestyles of other major Indian cities somehow affect their purchasing behaviour and personal choices that indirectly contribute to emissions, while the studied area is still in the process of fully absorbing modernism [34, 38, 39].

Correlation and regression analysis was performed in SPSS to find the correlates and determinants of GHG emissions. It is evident from Table 3 that annual income and household size have a significant and strong relationship with higher GHG emissions. In the case of urban households, the correlations between carbon footprint and household size ($r = 0.266$), annual household income ($r = 0.693$) and standard of living ($r = 0.157$) were low, but have positive Pearson correlations coefficient. These correlations were statistically significant ($p < 0.05$).

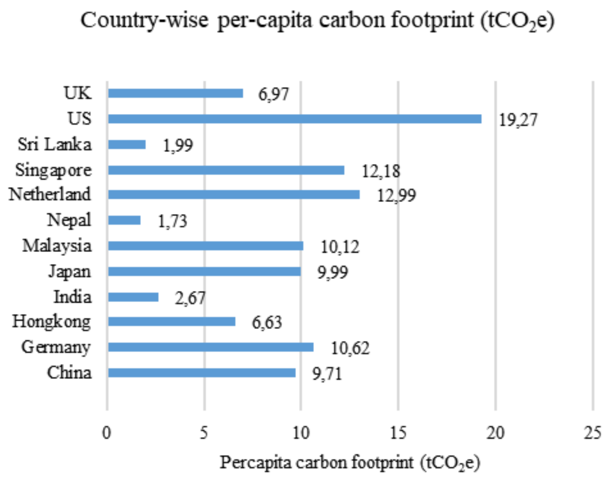
Table 2. Mean and standard deviation of annual HCF in urban and rural areas

Annual carbon footprint of different energy types ($kgCO_2e$)	Urban			Rural			t-value
	Number (N)	Mean	Standard deviation (SD)	Number (N)	Mean	Standard deviation (SD)	
Cooking fuels	311	491.53	115.47	299	662.77	298.35	- 9.28*
Electricity consumption	311	1658.23	1169.65	299	398.24	221.50	18.65*
Vehicle fuel	175	294.26	157.97	85	272.20	163.13	1.03
Total annual household carbon footprint (HCF)	311	2325.20	1254.98	299	1125.77	478.09	15.60*

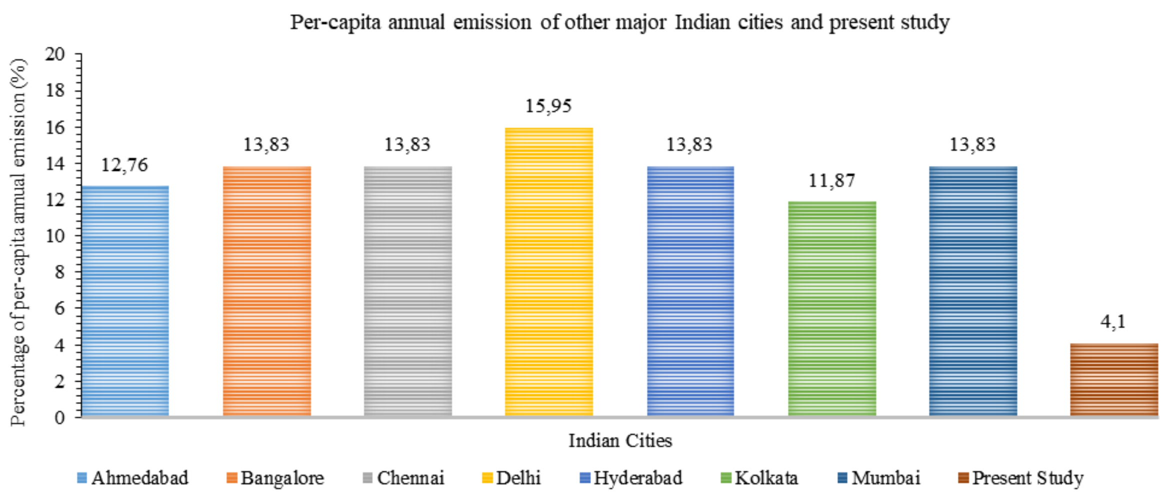
*p - value < 0.05



a)



b)



c)

Figure 1. a) percentage of emission per capita by regions, b) percentage of emission per capita by countries, c) annual per capita emission of other major Indian cities and the present study (studied area)

The correlation matrix of rural areas also shows a positive correlation between carbon footprint and household size ($r = 0.594$), annual household income ($r = 0.658$) and standard of living ($r = 0.485$). These correlations were also statistically significant ($p < 0.05$) (Table 3).

Table 3. Correlation matrix of total annual household carbon footprint (THCF) (cooking fuel + electricity consumption + fuel used for personal vehicles) in urban and rural areas with different predictor variables in the studied area

Urban area (311 households)				
Variables	(1)	(2)	(3)	(4)
(1) $THCF_{(urban)}$	1	.266**	.693**	.157**
(2) Household $size_{(urban)}$		1	.077	.107
(3) Annual $income_{(urban)}$			1	.202**
(4) Standard of $living_{(urban)}$				1
Rural households (299)				
Variables	(1)	(2)	(3)	(4)
(1) $THCF_{(rural)}$	1	.594**	.658**	.485**
(2) Household $size_{(rural)}$		1	.349**	.296**
(3) Annual $income_{(rural)}$			1	.640**
(4) Standard of $living_{(rural)}$				1

** correlation is significant at $p < 0.05$ level

The rising income and standard of living bring improvement in lifestyle and social status. However, this had a negative effect on the environment as people are less aware of green consumption and unknowingly spend more on unsustainable products. Several studies have shown that income played a major role in all emissions. Marked differences in CF have been observed moving from the poorest to the richest quintile [3, 13, 40 - 44]. Hence, using demographic characteristics as the independent variable (IV) and total household carbon footprint as the dependent variable (DV), regression analysis was performed separately for urban, rural, and pooled data. Table 4 separately elaborates the standard error (SE), degrees of freedom (df), ratio of two variances (F-value) and regression coefficient (R^2) to understand the amount by which change in IV affects the DV.

Rural area

The results show that household size has a significant positive effect on total annual household carbon footprint (THCF) ($\beta = 221.675$, $F = 253.717$, $t = 15.928$, $p < 0.05$), i.e. THCF increases with the household size. Annual household income and standard of living also affect the total annual HCF in the rural area ($\beta = 0.003$, $F = 149.453$, $t = 12.225$, $p < 0.05$; $\beta = 35.481$, $F = 87.397$, $t = 9.349$, $p < 0.05$). Regression coefficient (R^2) for household size is 0.353, 0.433 for annual household income and 0.236 for standard of living. Therefore, these predictors of THCF determine its variability as 35.3 %, 43.3 % and 23.6 %.

Table 4. Linear regression analysis using demographic characteristics as the independent variable and total household carbon footprint as the dependent variable

IV	DV	R^2	β ± SE	df	F - value	t -value	p - value
Rural							
Household size	THCF	0.353	221.675 ± 17.95	297	253.717	15.928	.001*
Annual income		0.433	0.003 ± 0.00	297	149.453	12.225	.001*
Standard of living		0.236	35.481 ± 3.78	297	87.397	9.349	.001*
Urban							
Household size	THCF	0.080	302.436 ± 17.95	309	23.563	5.192	.001*
Standard of living		0.421	95.891 ± 6.42	309	223.18	14.939	.001*
Annual income		0.180	0.001 ± 0.00	309	284.220	8.206	.001*
Pooled							
Household size	THCF	0.227	221.783 ± 29.75	477	251.19	5.510	.001*
Standard of living			30.271 ± 4.30			5.330	.001*
Annual income			0.001 ± 0.00			8.393	.001*

* linear regression is significant at $p < 0.05$ level

Urban area

In the urban area, household size has a significant and positive effect on the total annual household carbon footprint (β = 302.436, $t = 5.192$, $p < 0.001$). Standard of living and the annual household income significantly influenced the total annual household carbon footprint in the urban area (β = 95.891, $t = 14.939$, $p < 0.001$; $\beta = 0.001$, $t = 8.206$, $p < 0.001$). Regression coefficient (R^2) for household size is 0.080, 0.421 for standard of living and 0.180 for annual income of a household indicating that THCF was determined with 8 %, 42.1 % and 18 % of the variability, respectively. Among them, the standard of living has a higher variability and showed a strong influence on total HCF compared to other predictor variables.

Therefore, it can be concluded that both in rural and urban areas household size, annual household income and standard of living significantly contributed to the household carbon footprint, although in the case of rural areas the impact is greater than in urban households. Furthermore, in the case of pooled data, a positive and significant impact of the same predictors on THCF in the studied region was found. The results show that household size has a significant positive impact on total annual household carbon footprint (THCF) (β = 221.783, $t = 5.510$, $p < 0.05$). Annual household income and standard of living also affect THCF ($\beta = 0.001$, $t = 8.393$, $p < 0.05$; β = 30.271, $t = 5.330$, $p < 0.05$). The regression coefficient (R^2) for all three predictors was 0.227, determining the variability of 22.7 % (Table 4).

A similar pattern has been observed in other states of India where household income directly affects the purchasing power and total household expenditure, and it was concluded that a shift from medium to high expenditure households was responsible for the increase of total CF from 674.7Mt CO_2 to 744.6 Mt CO_2 [13]. This study also agrees with [45] in which household income and expenditure are the best predictors of total CO_2 emission. Additionally, in a comparative study conducted in Indonesia and its cities Jambi and Sulawesi, it was observed that Jambi with a lower per capita income than the national average (Indonesia) had a higher household carbon footprint (HCF) due to a distinctly carbon-intensive lifestyle, while, compared to Indonesia, the average emission of Sulawesi is lower [46]. Similarly, in Germany, income is a major factor in household carbon footprint, with the highest income group emitting 4.25 times more CO_2e from indirect consumption of energy including housing (34 %), food (18 %), goods (15 %) and transport (34 %), than the lowest income group [42]. A recent study also observed a similar trend and noted that the average household carbon footprint is much higher (11.50 tCO_2e) among affluent people than those with the low incomes (1.65 tCO_2e) [34]. In addition to income and standard of living, earlier research also found that household or family size played a significant role in the carbon footprint [11, 42, 47, 48]. Similarly, in the present investigation, it is found that with each additional person, the total consumption increases, which directly contributes to the increase of THCF in both the urban (R^2 = 0.266) and rural (R^2 = 0.594) households, although in the case of urban households, the effect of family size is much smaller. The usage pattern and consumer choices can also be the reason for lower impact of family size in urban areas. A similar trend was also observed in Kolkata [34] and Islanders of Malaysia [49].

Therefore, reducing greenhouse gases (GHG) emissions is one of the main goals of climate change mitigation policies at the global, national, and regional levels. Researchers and decision-makers have now turned their focus to the individuals, groups or households that were previously overlooked as emitters or contributors to global warming [18, 32, 50]. The differences between prevailing lifestyles today and the targets for 2030 and 2050 in each area highlight the need for significant adjustments in household consumption patterns and carbon intensity levels [51].

Globally, mega-emitting industrial sectors and carbon-intensive lifestyles at the individual or family level have been observed to act as noteworthy sources of emissions when measured at the population level. The influence of modernity and westernization has motivated people to buy carbon-intensive goods and services [13, 14, 44, 46, 52]. Because of this, during the last few decades, GHG emissions have increased many times over. Therefore, a lot of research has been carried out to estimate the emission of carbon dioxide emitted from industries, construction sites, cars, the agriculture sector, livestock or due to deforestation, crop burning, etc. In addition to all of the above, carbon emissions are also measured at the household level, as they contribute about 24 % of total GHG emissions [49]. Although the contribution of household emissions to global warming is low, the adoption of unsustainable lifestyles over time is likely to lead to human consumption and it will become a serious explanation for global warming in the coming years [13].

CONCLUSION

It can be concluded that the emission level in the studied area is much lower than in other parts of the country, as well as in countries around the world. The correlation and regression analysis show that the emission at the household level was determined by income, household size and improvement of the standard of living. Moreover, there is variation in energy consumption in urban and rural areas. Rural households are still heavily dependent on conventional types of energy sources for cooking, such as wood and cow dung cakes, hence their cooking fuel emission are higher. On the other hand, urban households are shifted to commercial energy sources, e.g. LPG, electricity, and petrol. At the same time, due to the excessive consumption of electricity, the total emission of urban households was twice as high as that of rural households. The use of green energy, i.e. solar, wind etc., which can reduce the dependence on conventional energy sources as well as the emission of GHG, is still miles away from Indian households.

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