Estimation of Greenhouse Gas Emissions by Household Energy Consumption: A Case Study of Lahore, Pakistan

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Abstract

The quest of urban lifestyle and higher living standards have created race like situation among the nations, which has resulted as unplanned and uncontrolled development due to fast growing urbanization. The present research aims to perform household survey-based estimation of greenhouse gas (GHG) emissions in CO_2 equivalent (CO_2e) from urban residential consumption of electricity, transportation (automobile combustion) and use of cooking/heating fuel in Lahore city of Pakistan in 2016. Total 300 households, 100 from Walled City, 100 from Awan Town and 100 from Model Town were surveyed using a semi structured questionnaire. Total 0.78 Gg CO_2e per month were estimated, from which fuel consumption of domestic vehicles contribute 0.53 Gg CO_2e (69 %), electricity consumption contribute 0.15 Gg CO_2e (19 %) and cooking/heating fuel consumption contribute 0.098 Gg CO_2e (12 %) per month. Furthermore, the results indicate that the socio economic factors are main influential reason of GHG emissions. Household area is widely recognized as a major influencing factor of urban residential GHG emissions. Larger households tend to be more efficient in terms of per capita energy use. However, per capita residential GHG emissions decrease with increasing household size (number of persons). The domestic vehicles solely contributed approximately 2/3 of the total GHG emissions, which indicate the scarcity of standard and potential urban transportation system in the city of Lahore that shunt its inhabitants towards personal vehicles and make the alarming situation of future scenario of GHG emissions. The survey based estimation approach of GHG emissions from urban consumption categories presents a simple technique and tool to estimate GHG emissions at municipal level. In addition, it can be used to indicate the sector of significant emissions of GHG and for devising better tailored mitigation strategies and polices of the future in the context of sustainable development.

Key Words: Energy consumption, GHG emissions, Global warming, household, Lahore

Introduction

Rapid urbanization and increasing population growth are changing the global climate at the unprecedented rate. Pakistan ranks amongst the top of those nations where vulnerability index due to climate changes is very high. At present the country's GHG emissions are increasing at an annual rate of 6 % or 18.5 million tons of carbon dioxide (CO_2) equivalent. In 2008 the emissions were 147.8 million tons of CO_2e equivalent in 2008 (Shaikh and Tunio, 2015). "Pakistan's carbon emissions will reach 400 million tons of CO_2e per year by 2030 if the situation remains intact," said Qamar-uz-Zaman Chaudhry, author of Pakistan's climate change policy (Mustafa, 2015). Uncurbed emissions would speed up the melting process of glaciers in the north of Pakistan, actuate severe floods and damage the country's economic growth (Chaudhry, 2012).

The issue of GHG by households, since long, has significant status worldwide but in Pakistan, it has gained importance in recent years. Among the less developed countries, Pakistan is a country where ever growing urban centers are greatly contributing to the increase of GHG emissions. Increasing size of the urban centers and improvement of living standards, both are collectively responsible in the increase of GHG emission rate from the household sector. Urban life style improvement has changed the consumption patterns of energy and fuel. Population growth and urban sprawl are the major reason of increase in vehicle's need for domestic purpose, which also caused increase of traffic volume. GHG emissions vary from household to household and from one locality to another, according to people living standard and life styles which is directly related to consumption patterns of electricity, fuels and domestic transportation. Household categories are further characterized by demographic patterns of the locality i.e. size of family, literacy rate,

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while sizes of house and income groups play key role in emission levels at household scale. Numbers of electricity appliances and domestic usage of vehicles also increase by the change of life styles and behaviors. It might be considered as improving urban living standard but this unplanned development ultimately results in drastic threat to global climate. Industrial activities and transport vehicles are also playing key role in GHG emissions. Number of studies has been conducted on the GHG emissions and its impact on climate change around the world. However, research on household sectors GHG emissions is neglected so far in Pakistan. There is an imperious need to carry out research to address in development perspective to mitigate the GHG emissions at household level.

United Nations Organization (UNO) established separate department named Intergovernmental Panel on Climate Change (IPCC) for standardized recording of emissions at state level. Numerous international organizations e.g. International Energy Agency (IAE), Environmental Protection Agency (EPA) of United States of America made projection of future emissions, effects and draw their mitigations. Therefore, we intended to perform an exact estimation of GHG emissions from households in Lahore, Pakistan, considering it as a severe threat to regional as well as global environment. Lahore, the 2nd largest city, singly contributed 12.7 % to the total urban population of Pakistan. Increasing urban energy consumption and transportation are the largest sources, together making up 50 % of the national GHG inventory total. Many researches are done on different GHG emission sectors e.g. industry, agriculture, transportation, etc. (Ramachandra et al., 2015; Zahabi et al., 2012; Sheng, 2012) but research on the estimation of GHG emissions by households sector has not been yet done in Lahore City. As anthropogenic activities are major sources of GHG emissions therefore in Lahore, due to high rate of population growth increasing GHG emissions have significant importance. Per capita income and better literacy rate has boosted the living standard of inhabitants of the city. High income class of the city lives in large size houses, consumes more energy and fuel for running electrical appliances, cooling and heating of their houses and transportation. Most of the new planned localities located in fringe areas of Lahore City caused urban sprawl, which ultimately resulted in increase of vehicles and fuel demands.

This research aims at the better understanding of GHG emissions estimation by examining the urban consumption patterns of different localities of Lahore. The inhabitants of Lahore are unaware of present situation of GHG emissions and its harmful impacts at regional as well as worldwide scale. Although the unawareness of GHG emission rate from the household sector of Lahore is a silent feature of environmental degradation but it can become a drastic situation in future. Domestic consumers of urban centers are the largest electricity consuming sectors among the other sectors like industry. Therefore, indirectly they are involved in high GHG emissions due to electricity generation as well to fulfill their high electricity demand.

GHG emissions are estimated through three different consumption categories i.e. electricity, cooking-heating fuel and transport fuel consumptions in three selected localities of Lahore based on their economic status and living standard (low, middle and high). The main objectives of the research are to demonstrate with the facilitation of data that cities play a significant role in tackling climate change. For a low carbon city, the proposed research can contribute to device better policies to reduce household GHG emissions in urban residential communities of Lahore, Pakistan. The results and findings of this research can be generalized for other mega cities of Pakistan, and it can be used as a reference research document for further investigations in this field.

Greenhouse Gases (GHG)

The major greenhouse gases (GHGs) are (Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Tropospheric Ozone (O_3), CFC-12 (CCL_2F_2), HCFC-22 (CCl_2F_2), Sulfur Hexaflouride (SF_6). Among all GHGs, three major gases, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) that are also known as Kyoto gases, have the key role in global warming and climate change (Solarin, 2014a). These three greenhouse gases (CO_2, CH_4 and N_2O) are mainly responsible for holding heat near to the Earth surface for a long period that caused serious threat to global climate.

Carbon dioxide (CO_2)

Carbon dioxide (CO_2) is most significant among GHGs as it contributes more than 70 % of atmospheric concentrations (Shahbaz, 2014; Sheng et al., 2012; Zahabi et al., 2012). CO_2 emissions have rapidly increased in last few decades. The main source of CO_2 emissions is combustion of fossil fuels and land-use conversion and it sustain in atmosphere for between 50-200 years. Motor vehicles, generators, cooking heating fuels, etc. are some of the household level sources which emit CO_2 in urban residential centers at large scale.

Methane (CH_4)

Wide range of anthropogenic activities like, livestock manure management, rice cultivations, waste management, biomass burning and fossil fuel production, etc. produce the methane. Wet land, permafrost, oceans, fresh water bodies and wild life are natural sources of methane release to atmosphere. Also human related activities contribute more than 50 % of global methane emissions. Fossil fuel (natural-gas, Liquid Petroleum Gas (LPG)) consumption and household waste (organic and inorganic) emit CH_4 at household levels.

Nitrous oxide (N_2O)

Both natural resources and human related activities, produces the Nitrous Oxide (N_2O). Naturally, nitrous oxide is produced from various biological processes in water and soil. Human activities such as, mobile and stationary combustion of fossil fuels, agricultural soil management and sewage treatment are major emission sources of N_2O.

Study Area

Lahore is a second largest populated urban center of Pakistan, and ranked 40th most populated urban area in the world, according to the City District Government the population size of Lahore in 2011 was estimated at 9,226,092. The average annual population growth rate according to 1998 census was 3.5 %.

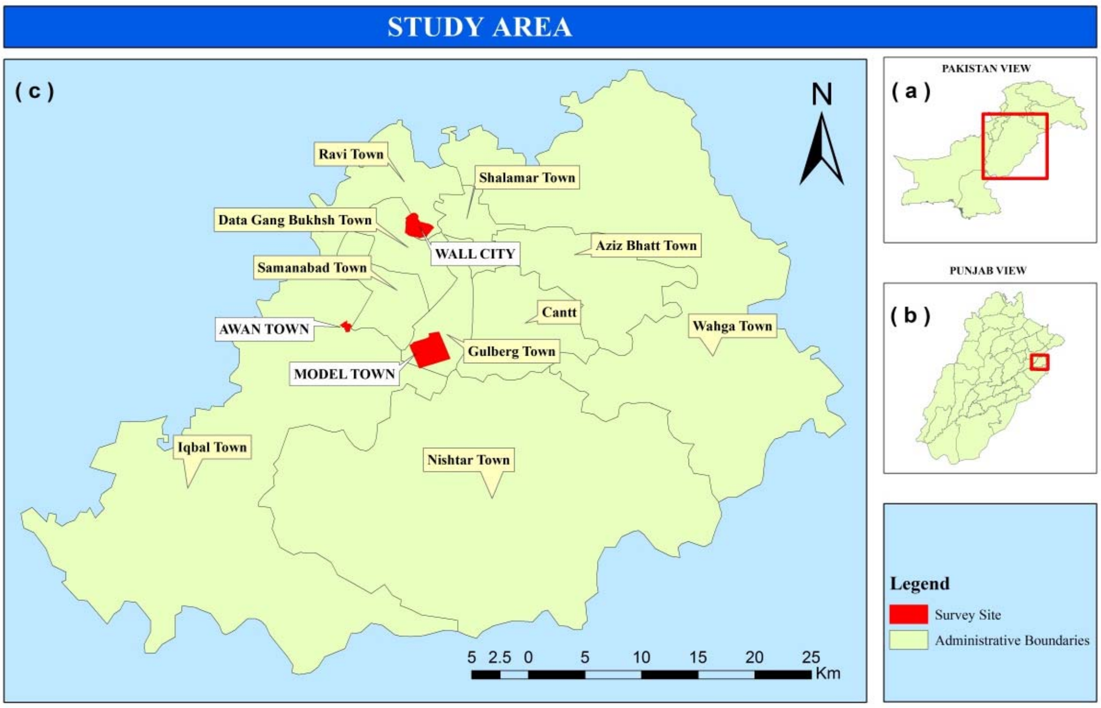

Figure 1: Map of study area **(a)** showing location of Punjab Province in Pakistan **(b)** showing location of Lahore in Punjab **(c)** District map of Lahore showing location of selected sites in red colour.

Estimated population density of Lahore is 5,207 people per km^2 as against 3,566 people observed in 1998 which indicate the fast population growth rate. The Lahore District comprises of nine administrative towns and one Cantonment i.e. Lahore Cantt (Figure 1). District Lahore is situated on the banks of the river Ravi covering total area of 1,772 km^2 while Lahore city covers an area of 404 km^2 which is still growing. It is lying between 31°15′-31°45′ N and 74°01′-74°39′ E. Lahore is bounded on the north and west by the Sheikhupura District, on the east by the Amritsar of India, and the south by the District Kasur. The river Ravi flows on the northern and north western side of Lahore. The climate of Lahore is subtropical steppe/low-latitude semi-arid hot climate (Köppen-Geiger classification: BSh), with cool winters and hot dry summers (in January mean minimum temperature decline to 6°C and in July mean maximum temperature rises to 40˚C). The average annual precipitation is around 24.8 inches (628.6 mm).

Materials and Methods

Data Collection

<u>Primary Data</u>

Primary data plays vital role to examine the urban residential consumption patterns and its effects on the GHG emissions from households. Therefore, major information about the households was collected through a properly self-structured questionnaire (Annex-1). It was filled up by using interview method. The household survey was conducted from 15th April to 15th August 2016 from three different localities i.e. Walled City, Awan Town and Model Town of Lahore by assuming low, middle and high life style areas respectively. Total 300 Questionnaires from randomly selected 300 households (100 from each locality) were filled by means of interview technique (Figure 2). The selected localities are situated in different administrative towns of Lahore, which all have different patterns of demography, residential patterns; both congested and open localities, belong to different income groups. Respondents were both males and females of different ages, literacy levels and income groups.

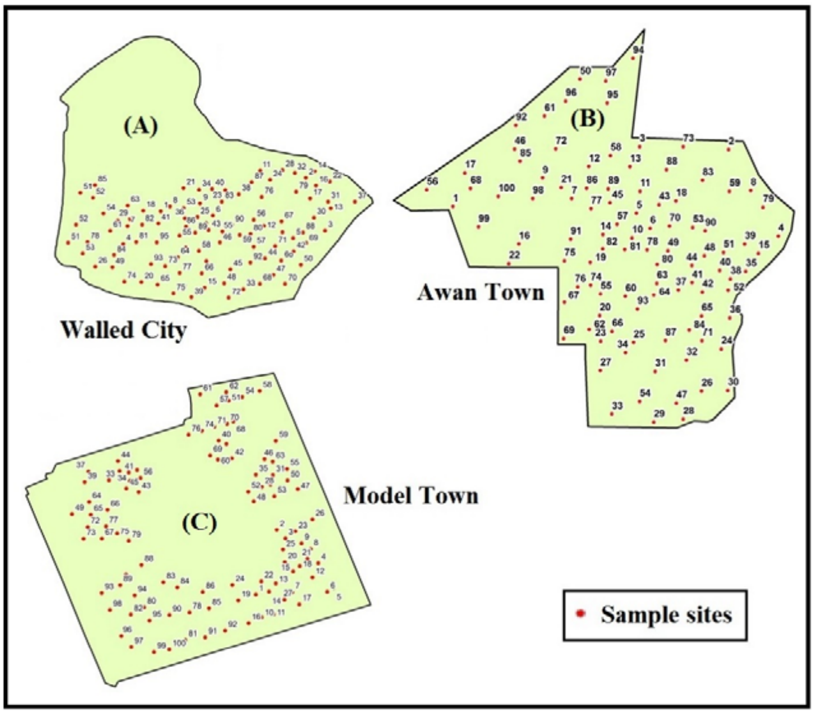

Figure 2: Map showing spatial distribution of sample sites in (A) Walled City, (B) Awan Town and (C) Model Town, Lahore.

Secondary Data

Secondary data of GHG emission factors for different energy sources (e.g. electricity, petrol, natural-gas, LPG, Diesel) were obtained from various national and international organizations e.g. United Nations Framework Convention on Climate Change (UNFCCC), Intergovernmental Panel on Climate Change (IPCC), International Energy Agency (IEA), Environmental Protection Agency (EPA) of the United States, World Resource Institute (WRI), Environmental Protection Agency (EPA) Pakistan, Lahore Development Authority (LDA), Water and Sanitation Authority (WASA), Water and Power Development Authority (WAPDA), Lahore Electric Supply Company (LESCO), Population Census Organization, Punjab Development Statistics, Urban Unit Lahore and other research reports.

Procedure of GHG Emissions Estimation

The IPCC (2006) guidelines provided a methodology to calculate the inventories of GHG emissions, and have been widely used worldwide. Emission of each GHG factor is estimated by multiplying activity data (consumption of electricity, cooking heating fuel and transportation fuel) with the corresponding emission factor. The default GHG emission factors provided by IPCC have been used in the study. Total emissions of gas from all its source categories are summed as given below (Eq. 1).

$$\mathbf{Ei} = \sum A \times EF \qquad \text{(Eq. 1)}$$

Where Ei is the emissions of given gas from all its source categories; A is the activity data (obtained from field survey) which generates emissions of the gas under consideration; EF is the emissions factor of a given gas type by its source category. Different emission factors for stationary combustion (indoor usage) and mobile combustion (transportation) emissions factors were used for different activity data (Tables 2 and 3). GHG emissions are reported in units of carbon dioxide equivalent (CO_2e). Gases are converted to CO_2e by multiplying with their global warming potential (GWP) as shown in Table 1.

Table 1: Global warming potential values relative to CO_2.

Greenhouse Gas	Chemical formula	Global warming potential value
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298

(Source: IPCC, 2007)

Estimation of GHG Emissions from Electricity Consumption

Combustion of fuels for electricity generation contributes to major GHG emissions total. The huge number of fossil fuels are used for electricity generation at global level. Electricity consumption in different sectors i.e. industry, agriculture, commercial and domestic (households) are considered as indirect emission or scope 1 emission (IPCC). Improved living standard has rapidly increased the usage of electricity appliances (e.g. refrigerators, air conditioners, washing and drier machines, etc.), that have raised the proportion of residential/domestic consumption of electricity, among all other sectors (industrial, agriculture and transport) in Pakistan.

Following equation (Eq. 2) is used to estimate GHG from electricity.

$$\mathbf{E}_{\mathrm{E}} = E_c \times EF_e \qquad \text{(Eq. 2)}$$

Where

$\mathbf{E}_{\mathrm{E}}$ is GHG emissions from residential electricity consumption per month; E_c is residential electricity consumption per month; EF_e is country specific or default GHG emission factor for electricity

Electricity Emission Factors for Pakistan

Emission factors for electricity generation and its consumption are prepared according to the energy mix (oil, coal, natural-gas, hydro, nuclear, solar, etc.) of specific country, electricity transmission and distribution losses (Brander et al., 2011). Electricity generation is the amount of electricity produced over a specific period of time from a generator while electricity consumption is defined as a resource which receives electrical energy for its own use. Each country generates electricity by different sources however thermal fuels and coal based electricity generation contribute high rate of GHG emissions. Country specific emission for Pakistan (Table 2) is lower as it mostly depends upon oil, natural-gas and hydro power generation. Emissions from electricity are considered as indirect emissions, it means when we consume electricity than we indirectly involve in emissions which were made at the time of electricity generation. Pakistan faced 20 % to 25 % electricity loses during transmission and distribution (T&D) which cause the emission rate of electricity consumed.

Table 2: Electricity emission factors for Pakistan.

Consumption Category	kgCO_2/kWh	kg CH_4/kWh	kgN_2O/kWh
Electricity (generated)	0.473378547	0.00001383671	0.00000243096
Electricity (consumed)	0.615374995	0.00001798722	0.00000316016

(Source: Brander et al., 2011; IEA, 2010a; IEA, 2011a, 2011b; IPCC, 2006)

Estimation of GHG Emissions from Fuel Consumption

Household activities such as indoor cooking and heating (stationary combustion factors) and usage of transport vehicles (mobile combustion factors) i.e. motor cycle and cars are responsible for direct emissions or scope (1) type emissions. GHG emissions of these two consumption categories are calculated by multiplying the actually consumed amount of fuel by the corresponding stationary and mobile emission factors (Table 3) using following equation (Eq. 3).

$$\mathbf{E}_F = (EF_{ng} \times W_{ng} + EF_{lpg} \times W_{lpg}) \times F_c \qquad \text{(Eq. 3)}$$

Where

$\mathbf{E}_F$ is GHG emissions from residential gas consumption per month.

EF_{ng} is GHG emission factor for natural-gas.

W_{ng} consumption of natural-gas per month.

EF_{lpg} is GHG emission factor for LPG.

W_{lpg} is consumption of LPG per month.

F_c consumption of residential gas per month.

Stationary and Mobile Combustion Emission Factors of Fuels

Emissions factors of fossil fuels are classified according to combustion activity for better reporting of emission inventories. Stationary combustion includes household stoves, residential boilers, power plants and industrial combustion plants. The inventory of mobile combustion sources comprises the emissions from the transport sectors or machinery types.

Table 3: Stationary and mobile combustion emissions factors of fuels.

Fuel type	CO_2 kg	CH_4 g	N_2O g
Stationary combustion emissions factors			
Natural-Gas (per standard cubic foot SCF)	0.05444	0.0013	0.00010
LPG (per gallon)	5.68	0.28	0.06
Kerosene (per gallon)	10.15	0.41	0.08
Coal (per short ton)	2016	235	34
Wood and wood residual (per short ton)	1640	126	63

Mobile Combustion Emission Factors			
Petrol (per gallon)	8.78	0.3516667	0.0318667
Diesel (per gallon)	10.21	0.57	0.26
LPG (per gallon)	5.68	-	-
C.N.G. (per scf)	0.0545	-	-

(Source: DEFERA, 2011b; EPA, 2010; IPCC, 2006)

Data Analysis Techniques

The collected data was computed and analyzed using Microsoft Excel and SPSS (Statistical Package for the Social Sciences). First, primary data was tabulated using MS Excel 2010, then the data were put into already designed equations for different emission sources along with their relative emission factors, to calculate total CO_2e for each household and each locality. For statistical analysis data was entered in SPSS to perform the cross tabulation and Chi-square test for the purpose to find out the association between different household characteristics and GHG emissions.

Chi-square

In the present study chi-square test, was applied to check the association between the demographic factors and GHG emissions; association between the socio-economic factors and GHG emissions; association between the impact of household consumption and GHG emissions. The chi-square (χ2) consists of the square of modification between the observed and the predictable occurrences of two variables. P-value provides the indication for their probability. Higher evidence provides the lower measures against the hypothesis. But the lower evidence gives the strong measures against the hypothesis. Mostly the level of significance is equal or less than 0.05 in each test of Chi-square.

$$\chi 2 = \sum \frac{(oi-ei)2}{ei} \qquad \text{(Eq. 4)}$$

The formula of chi-square obtained= (observed value-expected value)^2 / expected value.

Results and Discussions

Respondent Socio-demographics

Among 300 respondents, 218 were male and 82 were female. Most of the respondents (133) were between 31-45 year age groups, while 96 were between 16-30 years ages and 71 were above 45 years. 167 were married, 120 were unmarried and a very minute number (11) were widows and divorced (2). Respondent's education and occupations were focused to examine the socio-economic patterns of surveyed localities. Large numbers of respondents were literate e.g. 108 were intermediate, 69 were graduate, 58 were postgraduates or above while 44 were matric or below and 21 were illiterate. The analyses of respondent's occupation indicate that 38 were doing Government job, 26 were private job holders, 50 were self-employed, 52 were doing their own work, 31 were engage in small business, 18 were working in industry and only 12 were landlords. However, 73 respondents were unemployed. As the reliable data depend on capability of respondents thus, all the respondents were capable. Income group depicts the living standard of people. The highest number (102) of respondents belong to the 40-80 thousand income group, while 34 were earning < 40,000. 50 persons belong to 80,000-100,000, 60 persons belong to 100-200, and 54 persons belong to > 200 income group respectively (Figure 3).

Household Physical Characteristics

75 houses comprise less than 3 Marla, while 91 were 20 Marla houses. 58 were 10 Marla, 17 were 3 Marla, 12 were 5 Marla, 36 were 40 Marla and only 3 were greater than 80 Marla houses. The maximum number of households (135) were nuclear, while 105 were extended, 57 were composite and only 3 were one person household. 93 households consist between 1-7 residents, 144 consists between 8-14

persons, 53 consists between 15-21 persons and only 10 houses comprised greater than 22 persons (Figure 4).

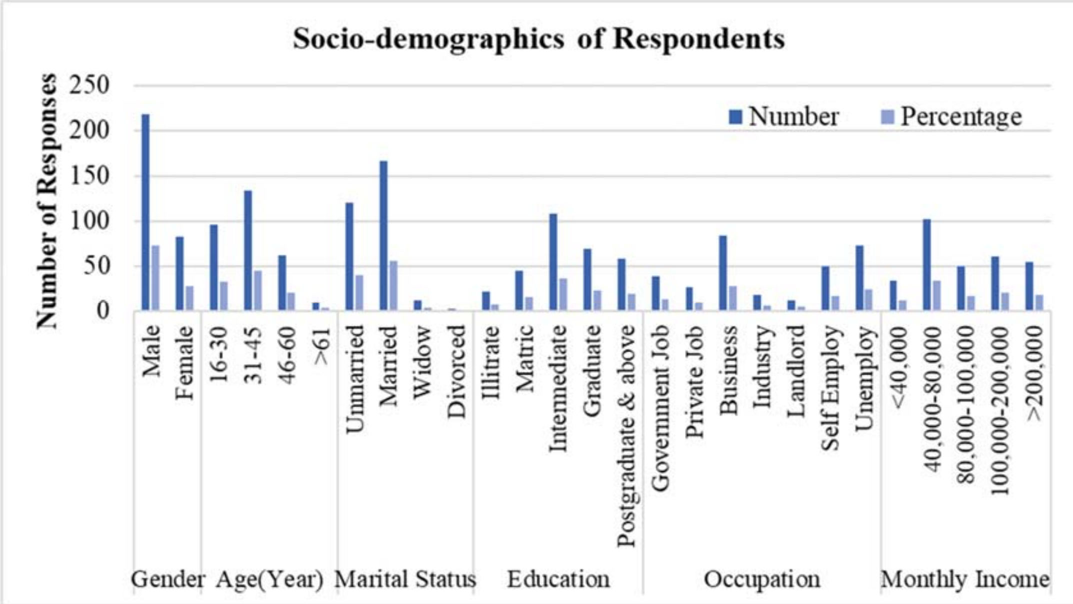

Figure 3: Graph showing frequency distribution of socio-demographic characteristics of respondents.

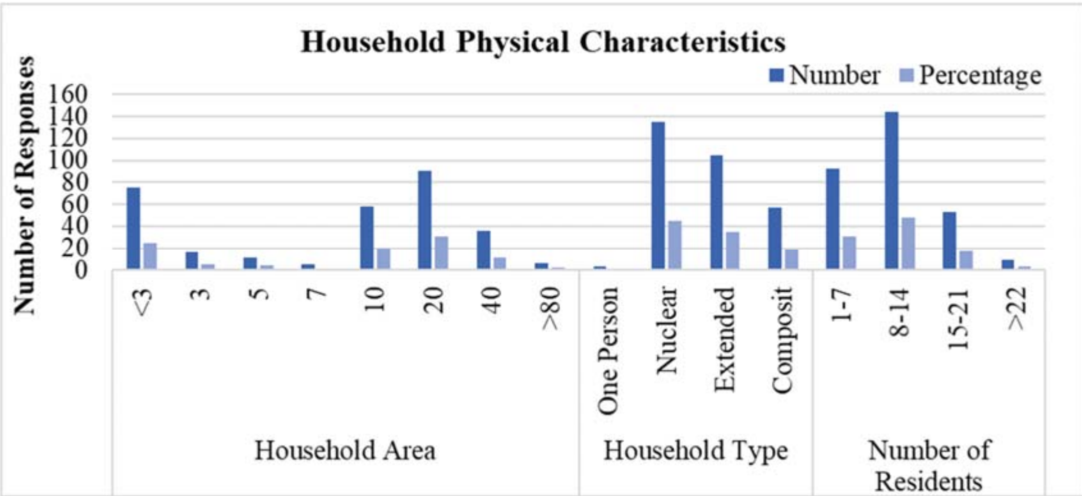

Figure 4: Graph showing frequency distribution of households' physical characteristics in studied localities.

Household Electrical Appliances and Vehicle Pattern

129 households have one refrigerator, 112 have two refrigerators, while 49 have 3 refrigerators. 80 households have 5 or more air conditioners that shows the increased trend of using cooling appliances. All studied households use washing machines, 168 of households have one washing machine and 114 have two washing machines. Frequency distribution of household vehicles shows that most of the households (130) have 2 motor bikes and 83 have one motor bike. While 55 households have 3 motor bikes that show the significant increase of domestic vehicle usage. Similarly, 67 households have 1 car, but 127 households have no car. The remaining households have 2 or more cars in their use (Figure 5).

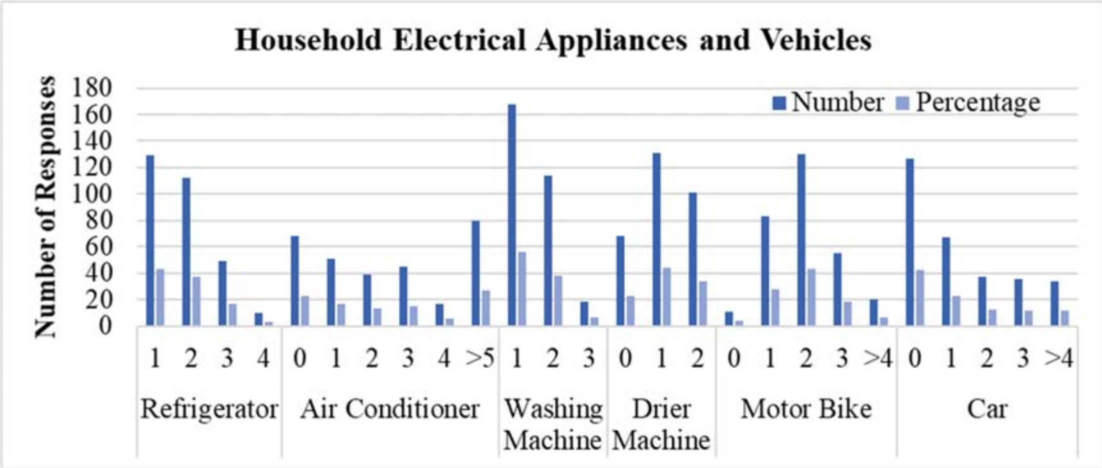

Figure 5: Graph showing number of electrical appliances and vehicles in surveyed households.

Household Energy Consumption by Electricity and Fuel

Table 4 indicates that 31 % of the household consume 200 to 400 units of electricity. 24 % of the households consume 401 to 600, 11 % consume the 601 to 800 units, 7 % consume 801 to 1000 units, 15 % consume 1001 to 1200 units and 13 % of the households consume more than 1200 units of electricity. Households of study areas (Walled City, Awan Town and Model Town) kept a large number of vehicles i.e. motor bikes and car for domestic purpose. These domestically used vehicles consumed fuel (petrol). Analysis of household consumption pattern of transport fuel indicate that 127 household used 100 to 200 liters of gasoline fuel, 93 used 201 to 400 liters of gasoline fuel, 38 used 401 to 600 liters of gasoline fuel and 42 of the households used more than 600 liters of gasoline fuel. Households of Model Town consumed highest amount of fuel in comparison of other two localities, Walled City consumed fuel in very less quantity.

Table 4: Household energy consumption by electricity and fuel.

Sources of Energy	Units of Consumption	Number of Households	Percentage
Electricity Units (kWh)	200-400	94	31
	401-600	72	24
	601-800	32	11
	801-1000	20	7
	1001-1200	44	15
	>1200	38	13
Fuel (Liters)	100-200	127	42
	201-400	93	31
	401-600	38	13
	>600	42	14

Total Emissions from Different Energy Consumption Categories

300 households of selected surveyed localities emitted total 0.78 Gg CO_2e per month. Domestic vehicle fuel (petrol) emitted 0.53 Gg CO_2e emissions per month and singly shared for 69 % of the total GHG emissions. Emission from electricity were estimated 0.15 Gg CO_2e per month, and shared 19% of the total GHG emissions. The consumption category of fuel (Natural-Gas and LPG) for cooking-heating

has contributed 0.098 Gg CO_2e per month and shared 12 % of total GHG emissions. Table 5 is showing a summary of emission results by sectors, fuel, gases (CO_2, CH_4, N_2O) and their CO_2eq.

Table 5: Summary of emission results by sectors.

Urban Consumption Category	CO_2 (kg)	CH_4 (g)	N_2O (g)	CO_2e (kg)	CO_2e (Gg)
Electricity	146,051.5014	4.269039	0.7500213	146,056.5205	0.15
Petrol	527,309.0562	2,112.039216	1,913.849676	531,334.9451	0.53
Natural-Gas	80,020.1043	7.13126625	0.14263174	80,027.3782	0.08
LPG	17,829.62606	0.1412805	0.00282504	17,829.7702	0.02
Diesel	291.151407	0.039291	0.00023542	291.1909	0.0003

Locality Wise GHG Emission by Different Category Sources

GHG Emissions from Transportation Fuel (Petrol) Consumption

Fuel (petrol) consumption by domestic vehicles has emitted GHG at large scale. Walled City shows low emission (78,941.19 kg CO_2e) of GHG and Model Town shows high emission (305,644.1 kg CO_2e) of GHG per month. Awan Town shows medium emission (146,749.65 kg CO_2e) of GHG per month (Figure 6).

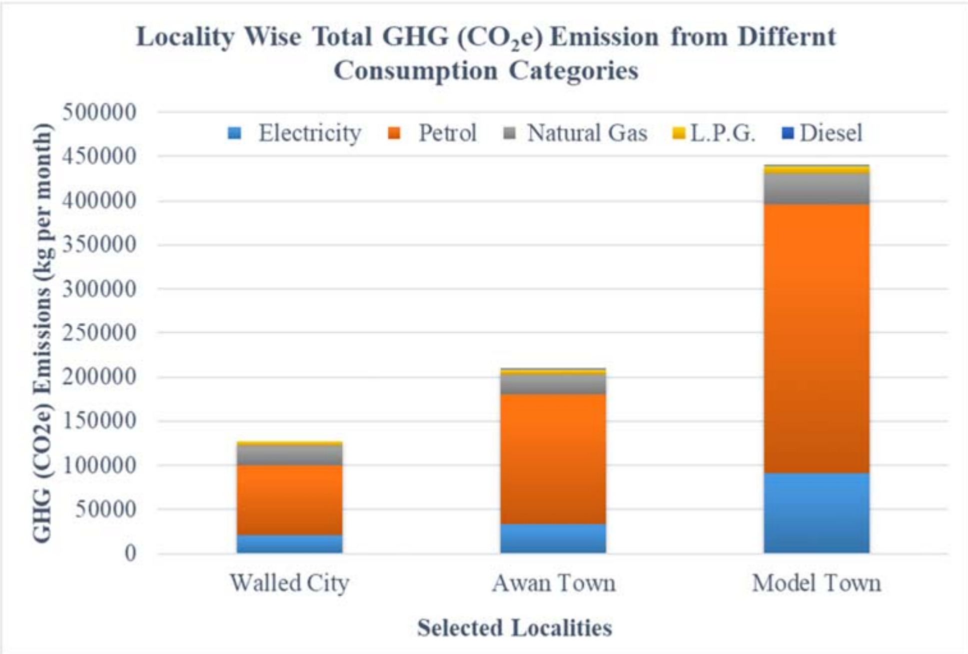

Figure 6: Graph showing locality wise GHG emissions from residential consumption of electricity, petrol, natural-gas, LPG and diesel.

GHG Emissions from Electricity Consumption

Analysis of collected data indicates that Model Town was at the highest level in comparison to Walled City and Awan Town for electricity consumption and related GHG emissions. Model Town shows high (90,785.13 kg CO_2e) GHG emission per month from electricity consumption. Awan Town shows medium (33,638.02 kg CO2e) GHG emission per month while Walled City represented least (21,508.32 kg CO_2e) GHG emissions per month from consumption of electricity (Figure 6).

GHG Emission from Natural-Gas Consumption

Natural-gas is recognized as cleaner fuel therefore it emits GHG at the lowest rate. It is consumed widely for cooking and heating purpose in households of study area. A wide difference of consumption quantity was found between selected localities. Walled City and Awan Town shows less GHG emission i.e. 22,210.42 kg CO_2e and 23,043.96 kg CO_2e per month respectively, in comparison to Model Town that emit 34,765.65 kg CO_2e emissions per month from natural-gas consumption (Figure 6).

GHG Emissions from LPG Consumption

GHG emission from LPG (liquefied petroleum gas) found to be a lowest emission source category. However, GHG emissions from LPG in Model Town ranked high (7,653.3 kg CO_2e) among all three localities. Walled City emitted 4,831.14 kg CO_2e, while Awan Town emitted 5,345.35 kg CO_2e per month from LPG consumption (Figure 6).

GHG Emissions by Diesel Consumption

Generators are used for alternative arrangement of electricity at domestic level. Diesel is used as a fuel for functioning of generators. Very few houses in Model Town and Awan Town use generators. GHG emissions from diesel in Model Town were high (255.81 kg CO_2e) as compared to Awan Town that emit only 35.37 kg CO_2e emissions per month (Figure 6).

Spatial Analysis of GHG Emissions by Selected Localities

The comparison of GHG emissions from different source categories in selected localities is shown in Figure 7. Petrol is highest GHG emission source category in all localities followed by electricity and natural-gas respectively. Model Town is the highest CO_2e emitting locality that is emitting 439,103.94 kg CO_2e (57 %) per month. Model Town is emitting 69 % GHG from the petrol (transport fuel) consumption, 21 % from electricity consumption and only 8 % from natural-gas (cooking heating fuel) consumption. While Awan Town is moderate emission locality that is emitting 208,812.35 kg CO_2e (27 %) per month. Awan Town is emitting 70 % GHG from the petrol consumption, 16 % from electricity consumption and 11% from natural-gas consumption. Walled City ranked the lowest emitter among the surveyed localities by emitting 127,491.08 kg CO_2e (16 %) per month. Walled city is emitting 62 % GHG from the petrol consumption, 17 % from electricity consumption and 17 % from natural-gas consumption (Figure 7).

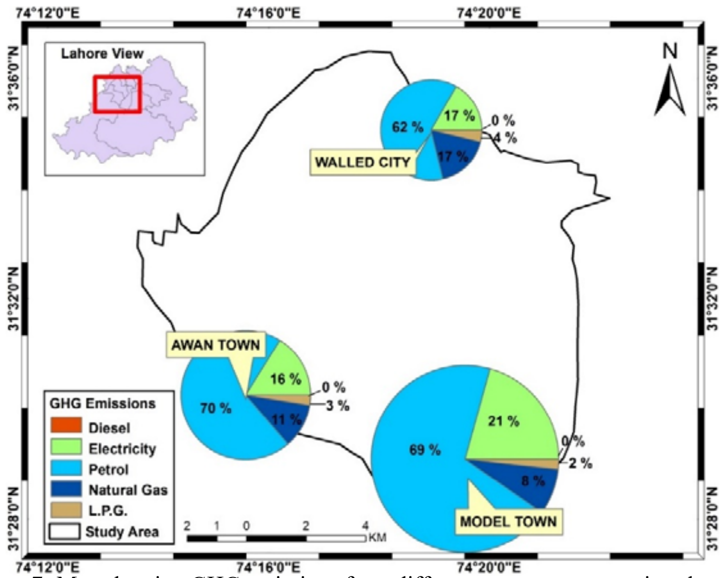

Figure 7: Map showing GHG emissions from different category sources in selected localities.

Per Capita GHG Emissions from Selected Localities

The average GHG emissions per household for Walled City was 425.38 kg CO_2e per month, for Awan Town was 696.04 kg CO_2e, and for Model Town was 1,463.61 kg CO_2e per month. At the household scale in each locality, the per capita average of GHG emissions from household consumption activities; Walled City was ranked as the lowest emitter, i.e. 141.48 kg CO_2e per month per capita (person) emissions. Awan Town represent moderate emitter of GHG as it emitted 178.01 kg CO_2e per month per capita, while Model Town was considered as the highest emitter that accounted for 406.57 kg CO_2e per month per capita emissions.

Chi-square Analysis

Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) which is capable to test whether data from various groups have a common mean, ANOVA was applied to test which factors would cause a significant difference ($P<0.05$) GHG emissions from urban residential consumption.

H1: All localities do not emit equal GHG.

Ho: All localities emit equal GHG.

The present research conducted in three localities of Lahore, Walled City, nucleus of the city, the most congested locality; Awan Town present the middle-class locality and Model Town as a locality, large size houses with high income group. Table 6 shows that P value (.000) is significant; it means H1 is true/accepted and Ho is rejected. Significant result means all localities emitted different GHG which leads us to the conclusion that difference among the locality effects on the GHG. ANOVA test accepted H1 that means the all three localities emit GHG at different scale.

Table 6: Analysis of variance (ANOVA).

	Mean Square	F	Sig.
Between Groups	261086259.47	165.40	.000
Within Groups	1578499.75		

Least Square Difference

Six pair wise comparison established to know the difference of emissions. The p-value against each pair indicates that there is a significant difference between these localities (Table 7). None of the three localities are equal and there is no common factor among them. The positive value of mean difference for Model Town shows its higher contribution of GHG emission by all factors then the other two localities and the locality of Walled City emitted the lowest GHG.

Table 7: Least square difference (L.S.D) of selected localities.

Locality (I)	Locality (J)	Std. Error	Sig.	95 % Confidence Interval	
				Lower Bound	Upper Bound
Walled City	Awan Town	177.67947	.000	-1161.6326	-462.2920
	Model Town	177.67947	.000	-3464.5489	-2765.2084
Awan Town	wall city	177.67947	.000	462.2920	1161.6326
	Model Town	177.67947	.000	-2652.5866	-1953.2461
Model Town	wall city	177.67947	.000	2765.2084	3464.5489
	Awan Town	177.67947	.000	1953.2461	2652.5866

Pearson's Correlation Analysis

Pearson's correlation analysis was preformed to check the intensity of the relationship which exists between two variables by using statistical software SPSS. The value of Pearson's correlation coefficient (r) ranges from +1 to -1. If the outcome value is +1, it means there exists a positive relationship among variables and -1 value refer that there is no relationship between variables and if coefficient value is 0 then it denotes the null relationship among variables. For the better understanding of data collected through field survey and to find out the association between different variables following hypothesis were built.

H_1: there is a relationship between household consumption patterns and GHG emissions ($P<0.05$).

$H_{0:}$ there is no relationship between household consumption patterns and GHG emissions ($P>0.05$).

With the help of results, hypotheses are accepted or rejected, based on calculated p-value. The hypotheses of the present study i.e. 'there is strong relation between urban residential consumption and GHG emissions is tested by bivariate analysis technique of Pearson's correlation by applying the mean and standard deviation statistics. The results indicate that there is a positive relation between household consumption and GHG emissions by showing highly significant (r =0.12**) value at level of **p<0.5 (Table 8). Thus the main hypothesis H_1 accepted and proved that there is a significant positive relation between household consumption and GHG emissions.

Table 8: Pearson's correlation analysis of household consumptions and GHG emissions.

Variables	r	M	SD
Household	-	46.17	6.27
Emissions	0.12**	-13.65	2.84

Note: Household consumption and GHG Emissions; **P<.05; N=300

The collected data of present study is tested by applying Pearson's correlation analysis, between the different urban residential consumption categories and their respective GHG emissions. This test was applied to find out those household factors consumption which are probably effecting in emitting GHG. Finally, only those factors are presented that have shown significant degree of correlation among different variables showing p-value = P<0.05 (Table 9)

The P-value is not greater than alpha value 0.05. So according to the H1: there is a relationship between household consumption patterns and GHG emissions (P<0.05) different income group and GHG emissions as the calculated P-value is less than the significance level alpha 0.05, so the null hypothesis H0 is rejected and alternative hypothesis H1 is accepted.

Household Demographic Factors Association with GHG Emissions

Table 9 show that there is a significant association between the household demography and GHG emissions. The p-value of certain demographic characteristics of surveyed households (e,g. number of residents, income groups, type of houses and occupation type) proved that GHG emissions was significantly influenced and have association with demographic factors. The increase of number of residents, income level and household area caused the increased GHG emissions.

Household consumptions association with GHG emissions

The three consumption categories of households; electricity (electricity units and electricity appliances), cooking-heating fuel (natural-gas and LPG) and domestic vehicles fuel consumption (petrol) mainly examined. The p-value of correlation declared significant association between household consumption categories and GHG emissions. The results of correlation analysis proved that increase consumption of electricity (units) and petrol (liter) is related to increased GHG emissions.

Table 9: Final model of Pearson's correlation test showing significant p-value.

Estimated Relationship of Two Different Frequencies		Pearson Correlation (r)	P-value
Factors of Household Demography Affecting Emissions of GHG			
1	Number of residents effect GHG emissions.	.250**	.000
3	One person types household effect GHG emissions.	.399	.000
4	Nuclear type households effect GHG emissions.	.601	.000
5	Extended type households effect GHG emissions.	.740	.000
6	Composite type households effect GHG emissions.	.592	.000
7	Number of married persons effect GHG emissions.	.192**	.001
Types of Occupations and GHG Emissions			
1	Government employs effect GHG emissions.	.182**	.002
2	The private employs effect GHG emissions.	.136**	.018
3	Businessmen's effects GHG emissions.	.093	.010
4	Industrialists effect GHG emissions.	.262**	.000
5	Landlords effect GHG emissions.	.136**	.019
Household Income Levels and Emissions of GHG			
1	80,000-100,000 income effect GHG emissions.	.267**	.000
2	100,000-200,000 income effect GHG emissions.	.901**	.000
3	200,000-400,000 income effect GHG emissions.	.228	.000
4	> 400,000 income effect GHG emissions.	.368	.000
Electricity Consumption/Number of Appliances and Emissions of GHG			
1	Number of refrigerators effect GHG emissions.	.598*	.000
2	Number of air conditioners effect GHG emissions.	.752**	.000
3	Number of washing machines effect GHG emissions.	.625	.000
4	Number of drier machines effect GHG emissions.	.563	.000
Household Consumption of Cocking and Heating Fuel and GHG emissions			
1	Natural-gas consumption effect GHG emissions.	.057**	.000
2	LPG consumption effects GHG emissions.	.079	.001
Household Consumption of Vehicles Fuel and Emissions of GHG			
1	1-200 liter petrol consumption effect GHG emissions.	.024	.000
2	201-400 liter petrol consumption effect GHG emissions.	.482**	.000
3	401-600 liter petrol consumption effect GHG emissions.	.530*	.012
4	> 600 liter petrol consumption effect GHG emissions.	.319	.028
5	Number of cars effects GHG emissions.	.576**	.000
6	Number of motor cycles effect GHG emissions.	.870**	.000

*Correlation is significant at the **P<0.05

Conclusion

The survey based estimation approach of GHG emissions from urban consumption categories, presents a simple technique and tool to estimate GHG emissions at city level. In addition, it can be used to indicate the sector of significant emissions of GHG, and it can be used for devising better tailored mitigation strategies and polices of the future. In Lahore the main emissive urban consumption activities e.g. use of electricity, cooking-heating fuel and transportation fuel consumption mostly contribute the GHG emissions. The Domestic vehicles fuel consumption singly contributed 2/3 of the total GHG emissions, which also indicate the scarcity of potential urban transportation system in the city of Lahore that shunt city inhabitant towards personal vehicles and make the alarming situation of future scenario of GHG emission. According to the emissions classification, the most of the GHG emissions from urban residential consumption in Lahore City are from scope 1 type (direct emissions), including transportation fuel combustion and cooking-heating fuel consumption. The direct household GHG emissions accounted for 81 % of the total GHG emissions. While the scope 2 (indirect emissions) including emissions from electricity accounted for 19 % of the total emissions.

The present study demonstrated the large inequality in emission profile between different localities, high emitting households emit about seven times more GHG as compared to low GHG emitting households. High CO_2e emitting localities emit about three times higher GHG as compared to low CO_2e emitting localities. Household consumptions which resulted in the major source of GHG emissions and which would likely to increase significantly in the near future, should be the main focus area for policy making of low emitting urban residential consumption in Pakistan. The present method of GHG emissions estimation from households and different localities within the municipal boundary can be readily applied to other cities.

The present study enabled to identify main emissive sources and household activities that mostly contribute to the GHG emissions that can be helpful to design targeted mitigations. The variation of urban demographic patterns and socio-economic factors widely influenced the urban residential consumption categories and GHG emissions (Büchs and Schnepf, 2013). The analyses indicate that the socio economic factors are main influential factors of GHG emissions. Household area is widely recognized as a major influencing factor of urban residential GHG emissions, larger households tend to be more efficient in terms of per capita energy use. Another main advantage of the survey based accounting methodology is that, it reveals future prospect of influential factors. The present study found that residential GHG emissions per capita tend to decrease with increasing household size. Various household characteristics are significantly associated with urban residential emissions. Therefore, household types (one person, nuclear, composite and extended) were the key factors in determining further future emissions tendencies of Pakistan (Lin et al., 2013). Socio economic indicators indicate that increase in income levels play vital role in future patterns of urban lifestyle. Therefore, demand for larger houses, more vehicles and increasing energy consumption may grow significantly with the increasing income levels that also change level of GHG emissions, that likely to increase rapidly.

Recommendations

There are numerous recommendations that could be used to reduce GHG emissions from household level. These are as under:

- Advanced Energy efficient electrical appliances should be used in everyday life; due to that GHG emissions can be decreased.
- Used or old electrical equipment should be banned that can also help to reduce urban emissions.
- Hybrid and energy efficient domestic vehicles should be used and regular certification of the vehicle should be examine through regulatory authority.
- Environment friendly (renewable) and more efficient fuel should be promoted.
- Potential public transport and transit system should be planned to reduce dependency on personal vehicles like cars and motor cycles, which become helpful to reduce the GHG emissions in city areas.

- Behavioral preparation of community can play vital role as many of social and economic factors of emission are derived by specific approach.
- Traffic discipline need to be maintained and there can be some governmental checks on the traffic regulating authorities. Traffic of the city can be managed properly by chalking out suitable plans.
- Carbon/emission tax may help the reduction strategies in higher emitting sectors.
- Standards of urban life style should be planned according to sustainable parameters as set by national, regional and international agenda.
- Environment friendly goods should be promoted.
- Chapters of sustainable development and its goals should include at each level of compulsory studies.
- Awareness programs of causes and effects of climate change should be lunched widely for future mitigation of GHG emissions.

Limitations of the research

No previous study was conducted on households of Lahore about the GHG emissions due to urban residential consumption of electricity and fuels; therefore, no previous material was available. Many problems were faced during the field survey of data collection, i.e. some household owners were not cooperative and refused to provide the information. Some of the respondents were illiterate and did not know about the significance of research, therefore show carelessness about responding the questionnaire. Some household owners were afraid about the consequences of the survey and felt hesitate to provide personal data.

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ANNEX-1

Estimation of Greenhouse Gas Emissions by Household Energy Consumption: A Case Study of Lahore, Pakistan

Questionnaire

Serial Number______________ Date_________________

Name of Locality ___________ House No.____________ Street No.__________ Block ______

Respondent name____________ Age_____________ Gender ☐ Male ☐ Female

Education_______________ Occupation________ Number Residents in Household _____________

1. Household information

Household type: ☐ one person ☐ nuclear ☐ Extended ☐ Composite ☐ Other

Marital status: ☐ Unmarried ☐ Married ☐ Divorced ☐ widow

Age (years): ☐11-20 ☐21-30 ☐31-40 ☐41-50 ☐51-60 ☐>60

Education: ☐Primary ☐Middle ☐Secondary ☐Intermediate ☐Graduate ☐Postgraduate ☐ other

Occupation: ☐ Education ☐ Govt. Employee ☐ Private Employee ☐Business ☐ Unemployed

Household income: ☐<20000 ☐20000-40000 ☐40000-60000 ☐60000-80000 ☐80000-100000 ☐>100000

Housing area in Marla: ☐< 3 ☐3 m ☐5m ☐7m ☐10m ☐15m ☐20m ☐30m ☐40m ☐Other …

2. Household Energy Consumption

Electricity units consumed per month ________________________

Type of Appliances	No. of Appliances	Model	Age	Duration of use
Refrigerator				
Air conditioner				
Washing machine				
Drier machine				
Kitchen appliances				
Vacuum cleaner				
Others				

Fuel Consumption for Cooking-heating

Fuel Type	Units / month
Natural-Gas	
LPG	
Wood	
Kerosene oil	
Other	

Use of Transportation

(Private/ Self Transport

Vehicle Type	No. of Vehicles	Fuel type	Fuel use in L/month	Model	Age
Motor cycle					
Car					
Other					

Public Transport

Mode of transport	**No of trips**	**Destination mileage**	**Travel time**	**Fuel type**
Raksha type 1				
Raksha type 2				
Van				
Taxi				
Bus				
Metro Bus				
Other				