Co_2 Emissions in the Domestic Energy Sector, Bangalore

Dr. T.V. Ramachandra
Energy & Wetlands Research Group, Center for Ecological Sciences [CES TE 15]
Centre for Sustainable Technologies (astra)
Centre for infrastructure, Sustainable Transportation and Urban Planning [CiSTUP], Indian Institute of Science, Bangalore

T V Ramachandra is a faculty at Centre for Ecological Sciences (CES) and Associate Faculty at Centre for Sustainable Technologies (astra) and Centre for infrastructure, Sustainable Transportation and Urban Planning (CiSTUP), Indian Institute of Science. His areas of research include energy systems, energy planning, renewable energy, aquatic ecosystems, ecological modelling, environmental management, regional planning, spatial decision support systems, GIS and remote sensing. He teaches principles of remote sensing, digital image processing, environmental and natural resources management. He has published over 306 research papers, 61 book chapters as well as fourteen books. He is a fellow of the Institution of Engineers (India) and Institution of Electrical Engineers (UK), Senior member, IEEE (USA) and AEE (USA), and many similar institutions. Details of his research and copies of publications are available at http://ces.iisc.ernet.in/energy https://www.researchgate.net/profile/T_V_Ramachandra/publications

Abstract

Greenhouse gas emissions due to the electricity production constitute about 28% and approximately 79.8 percent electricity generated in India is from burning fossil fuels and mostly coal. This paper analyses greenhouse gas (GHG) emissions due to energy consumption in the domestic sector considering household activities and also socioeconomic parameters. A stratified random survey of about 2050 households in Bangalore pertaining to the energy consumption reveals that annual per capita electricity consumption ranges from 9.64 to 2337 kWh/year with an average of 336 ±267 kWh/year. Emission from most of the wards (66 wards) is about 10 to 15 Gg/year, while wards in peri-urban areas emit less than 10 Gg/year. Extrapolation of these, show that total carbon dioxide from all wards of Greater Bangalore accounts to 3350 Gg/Year. This analyses reveal a proportional increase in the per capita energy consumption with the family income suggesting that economic levels in respective wards is an important parameter in the domestic energy consumption and also GHG emissions. Also, the study reveals that the annual per capita electricity consumption among the dwellers of high rise buildings is about ten times higher than those in the buildings (without glass facades). High-rise buildings with glass facades are suitable for temperate climate (wherein one needs to conserve heat in the cold environment). Adoption of such architecture in the tropical climate region (such as Bangalore, etc.) has increased the consumption of electricity in Bengaluru, evident from higher electricity consumption of 13000-15000 units/person/year in zones dominated by high-rise buildings (with glass facades) compared to the normal buildings (750-1796 units/person/year). This highlights the need to regulate glass facades buildings in the tropical climate region as adoption of wrong building architecture has contributed to higher electricity consumption and hence higher GHG emission in the domestic sector

Introduction

Energy constitutes a fundamental and strategic tool to attain the minimum quality of life and energy consumption patterns are closely linked to the agro-climatic conditions and socio-economic factors (Ramachandra et al., 2000). Exploitation and conversion of natural resources through various energy conversion devices for heating, lighting to energy intensive commercial steel production have made significant improvement in lifestyles. However, over exploitation of natural resources especially perishing fossil fuels for meeting the ever increasing energy demands has affected the environment and health. Consumption of fossil fuels is the prime reasons for enhanced greenhouse gases (GHG) in the atmosphere trapping heat and light in the earth's atmosphere, resulting in the global warming. The problem of energy use and GHG emission is particularly acute in cities, as urban areas support 50% of the world population (WBG, 2010) and are responsible for 67% of the world's energy demand. By 2030, 73% of the world energy use will be in cities (WEO, 2008). In terms of the global total anthropogenic GHG emission, cities contribute roughly 75– 80%. Within cities, the domestic sector is the major energy consumer (Pachauri, 2004). Urban households in India, for example, are responsible for about 45% of total primary energy use nationwide, and a large share of which is through non-commercial fuels such as fuel wood, dung, etc. The residential energy consumption is shooting up with the changes in lifestyle consequent to the rapid urbanization in many towns and cities in India (Ramachandra et al., 2017). This has necessitated studies on carbon emissions due to energy consumption in the residential sector, Bangalore, India.

The household sector is one of the largest users of energy with about 30% of final energy consumption (excluding energy used for transport) in India (CMIE, 2006). The annual electricity sale to domestic sector is 6.20 billion kWh which accounts to 16.5% of the total electricity in Karnataka (BEE). Energy consumption due to different household activities plays a major role in determining the pattern and magnitude of domestic energy use, which also depends on family size, climate, appliance ownership, lifestyle, physical characteristics of a house and also human's energy behaviour. In order to devise strategies to reduce the energy consumption, sustainable lifestyles in an equitable and efficient fashion, requires an understanding of the empirical links between lifestyles and the associated energy consumption and carbon emissions or carbon footprint. This helps to minimise the GHG emissions and the resultant destabilisation of the Earth's biosphere.

Bangalore has been experiencing rapid unplanned urbanisation since 1990 resulting in the clumped growth with intense economic activities at some pockets and dispersed (sprawl) growth at outskirts. Data analyses reveal that some wards have higher energy consumption and CO_2 emission than others, but an understanding of the spatial patterns is yet to be acquired. Thus, the objective of the current research is to assess the effect of socioeconomic factors such as household size, income level on the energy consumption and emission. The study has been carried out for a rapidly urbanizing region in India. Greater Bangalore is the administrative,

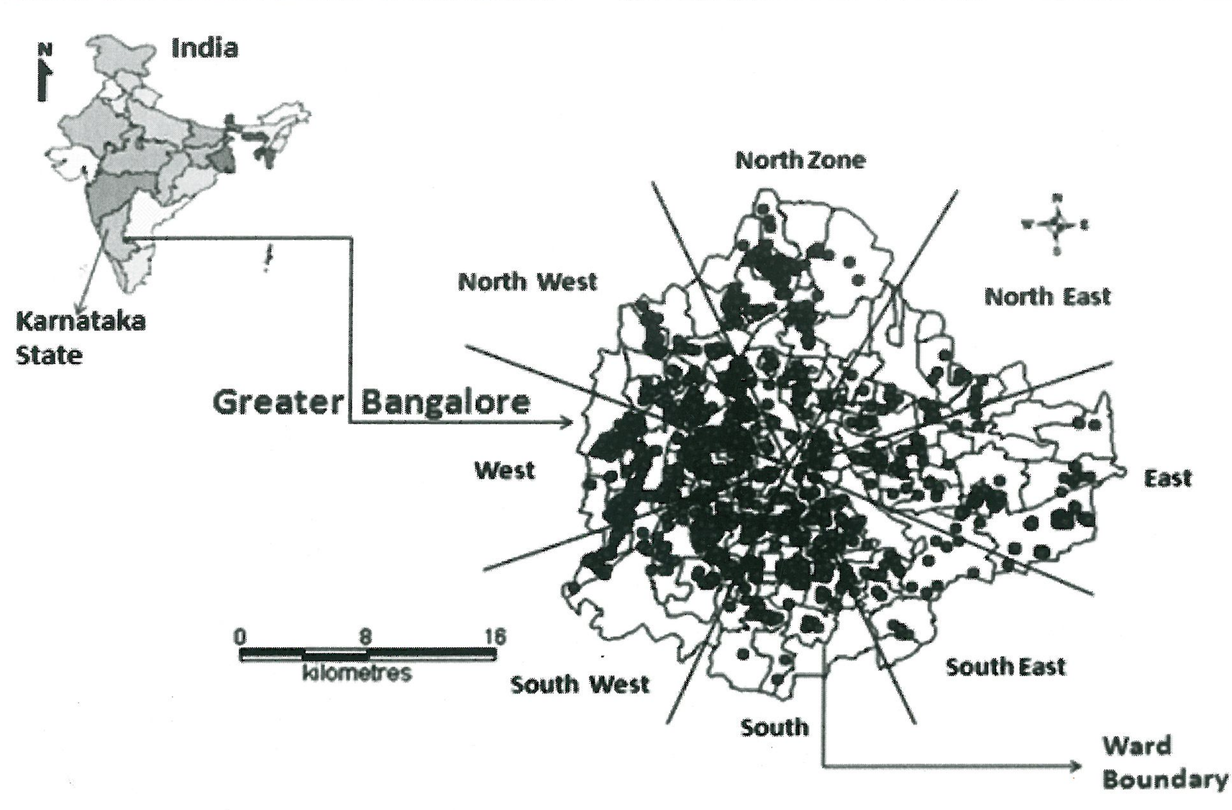

Figure 1 : Study Area – Bangalore city, Karnataka, India

Table 1: Emission factors and net calorific values (NCV)

Source	Emission Factor	Net calorific value (NCV)	References
LPG	63t/Tj	47.3 Tj/Gg	Ramachandra and Shwetmala, 2012
Electricity	0.81t/MWh		CEA, 2011

cultural, commercial, industrial, and knowledge capital of the state of Karnataka, India with an area of 741 sq. km. and lies between 12°39'00" to 13°13'00" N and 77°22'00" to 77°52'00" E (Figure 1). Bangalore city administrative jurisdiction was redefined in the year 2006 by merging the existing area of Bangalore city spatial limits with 8 neighboring Urban Local Bodies (ULBs) and 111 Villages of Bangalore Urban District. Bangalore has grown spatially more than ten times since 1949 (~69 square kilometers to 741 square kilometers) and is the fifth largest metropolis in India currently with a population of about 8.5 million (Sudhira et al., 2007; Ramachandra and Kumar 2008). Bangalore city population has increased enormously from 65,37,124 (in 2001) to 95,88,910 (in 2011), accounting for 46.68 % growth in a decade. Population density has increased from 10,732 (in 2001) to 13392 (in 2011) persons per sq. km (Ramachandra et al., 2011a; Ramachandra et al., 2012). The per capita GDP of Bangalore is about $2066, which is considerably low with limited expansion to balance both environmental and economic needs

Assessment of the spatial patterns in GHG emissions due to domestic energy consumption involved i) primary survey of sample household through the pretested and validated structured questionnaire and ii) compilation of ward wise electricity consumption data from the government agencies. Bangalore with a spatial extent of 741 sq.km has 198 administrative wards. Wards were prioritized for sampling based on type, economic activities and social aspects. The survey was carried out during 2011-12 in select households chosen based on stratified (economic status) random selection and validation of sampled data was done during 2012-13. Survey covered 1967 households representing heterogeneous population belonging to different income, education, and social aspects. The spatial distribution of sampled household is depicted in Figure 1. The questionnaire included parameters such as satisfaction with overall environment, residential status, building type, kind of facilities near home, energy consumption behavior of households. Energy consumption in a household is an outcome of various household behavior such as type of water heating systems (solar, electricity, LPG, etc.), type of fuel used for cooking (electricity, LPG, fuel wood), etc.

Spatial patterns in energy consumption and GHG emission is assessed considering various growth poles based on the extent of urbanization. The study area was divided into 8 zones based on directions –North, Northeast (NE), East (E), Southeast (SE), South, Southwest (SW), West (W), Northwest(NW), respectively (Figure 1) based on the Central pixel (Central Business district, CBD). The electricity and LPG consumptions were computed for each zones based on the compiled data through sample surveys in each zones.

Emission due to electricity use in the domestic sector is quantified using equation 1 considering quantity of electricity consumption and emission factor. The emission factors and net calorific values (NCV) for different sectors are listed in Table 1.

$$C = \beta E \qquad \ldots 1$$

Where, C is carbon dioxide emission β is emission factor (Table 1) and E is consumption of electricity.

Emissions due to LPG consumption: LPG is the principal fuel used for cooking. Emission due to LPG consumption is computed using equation 2.

$$E = Fuel * NCV * EFGHG \qquad \ldots 2$$

Where E is the emission; Fuel quantity consumed; NCV is net calorific value; EFGHG is the emission factor of LPG (given in Table 1)

Population census of 2011 (http://censusindia.gov.in) shows that majority (56%) of urban households have four or less members. The analysis of 1967 households reveals a similar trend of 4.5 persons per household. The distribution of household family size in urban areas - 4 persons per family dominates the sample (45.9%) followed by 19.2% family having 5 persons, 14.5% family with 3 persons. A larger family of greater than 6 constitutes 6.5% of the total sample. Spatial distribution of size of the households in study area i.e. different wards of Greater Bangalore illustrate that majority of the households (902) have household size of 4, while 128 households have more than 6 persons indicating the prevalence of joint family in Bangalore. Earlier studies have revealed the linkage of family income with the level of energy consumption, evident from 3 times higher consumption of electricity in high income category compared to low income homes (Ramachandra et al., 2000). Middle income (Rs. 1-5 lakh per year) with 64.6% (1278 samples) constitutes the major category among the surveyed households. The spatial distribution of various income categories is

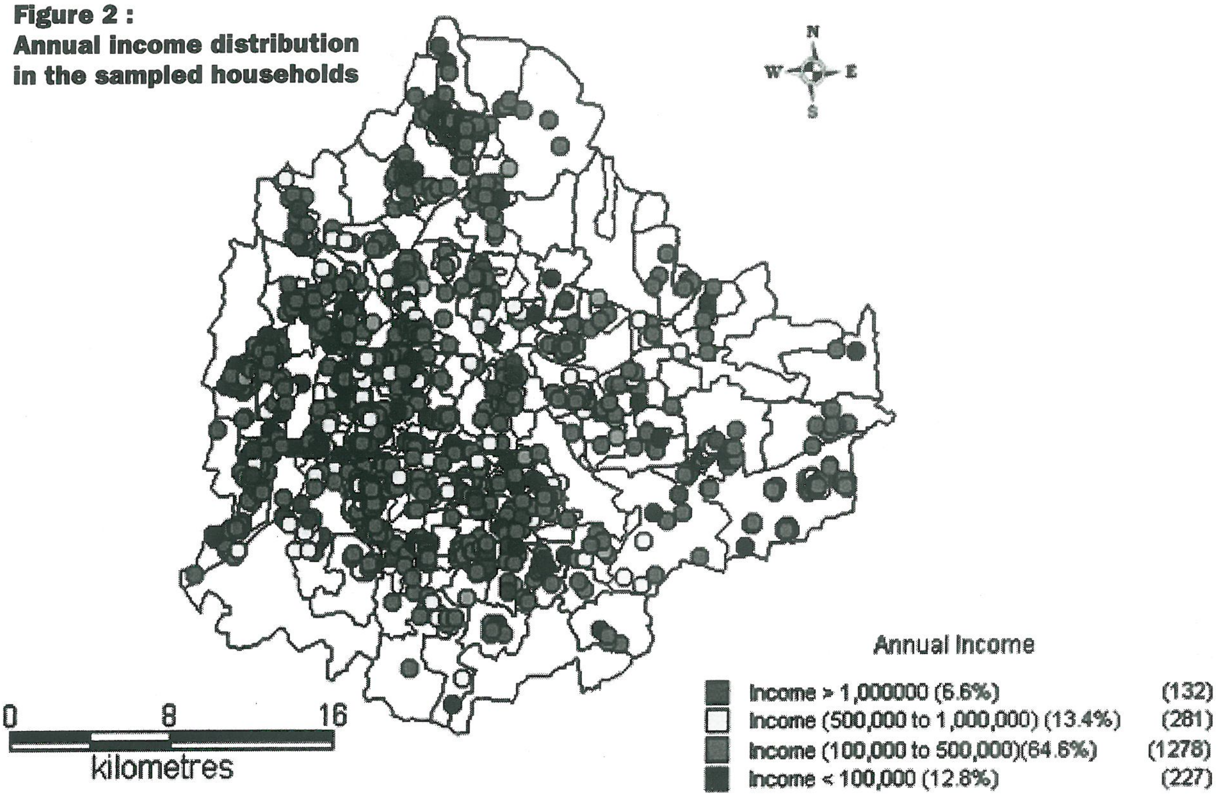

Figure 2 : Annual income distribution in the sampled households

given in Figure 2, indicating 132 households have the annual income > 1 million Rs. in Doddanekundi, Raja Rajeshwari Nagar, Ullal, Chowdeswari ward, etc.

Bangalore grew rapidly subsequent to the globalization and consequent opening up of markets leading to unplanned urbanization. This is evident from intense urbanization at city centre and dispersed growth at outskirts. Most of the buildings are either low raise apartment (41.99%, 826 units) or single storey row houses (40.72%, 801),15% were detached houses mainly in SE zone and only 2% are high-rise apartment which are concentrated in the center of the city. Zone wise distribution of different types of buildings (Figure 3) indicate that single storey row houses are concentrated in the NE (59%) followed by W(47.2%), SE (45.1%), N (43.0%), S (39.0%), NW (33.8%), and E (31.0%) zones. Similarly, 57% low-raise apartments are in NW and 21.1% in NE. E zone has large proportion of detached houses or town houses (35.9%). High raise apartment constitutes 1.1% in E to 3.4% in NE zones.

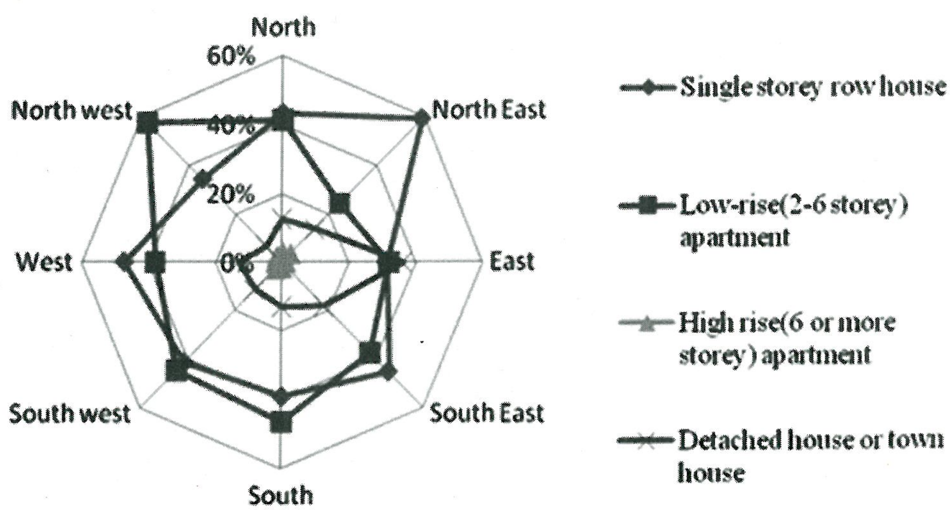

Figure 3 : Type of building

Solar energy is the most abundant permanent energy resource on earth and it is available for use in its direct (solar radiation) and indirect (wind, biomass, hydro, ocean, etc.) forms (Ramachandra et al., 2011b). Solar energy is clean, safe, easy to maintain and sustainable method of generating power. Solar energy is widely accessible and it is free from greenhouse gases emission and does not contribute to global climate change. Assessment of solar potential in India reveals nearly 58% of the geographical area potentially represents the solar hotspots in India with more than 5 $kWh/m^2/day$ of annual average Global insolation (Ramachandra, 2011c). A techno-economic analysis of the solar power technologies and a prospective minimal utilization of the land available within these solar hotspots demonstrate their immense power generation as well as emission reduction potential. Renewable energy sources and technologies have potential to provide solutions to the longstanding energy problems being faced by the developing countries like India (Sharma et al., 2012).

The National Action Plan on Climate Change (NAPCC) under Jawaharlal Nehru National Solar Mission (JNNSM) identified the development and deployment of solar energy technologies in the country to achieve parity with grid power tariff by 2022 (http://mnre.gov.in/file-manager/UserFiles/draft-jnnsmpd-2.pdf). Energy is used for heating, lighting and motive power (pump water) in the domestic sector. Water heating for bathing purposes constitutes one of the energy intensive activity in most households. Using clean energy such as electricity for low-end energy inefficient activities such as water heating necessitates the policy interventions towards energy efficient devices. Heating systems used for water heating (bathing purpose) includes fuel wood stove, solar water heater, electrical heaters and others. Majority samples (39.76%) use electric heaters, followed by solar water heaters (24.76 %), others (which include LPG, etc.) constituting 20.1%. Higher penetration of solar water heaters in Bangalore could be attributed to the energy policy of the federal government. The Government has mandated compulsory installation of Solar water heaters in the residential and commercial buildings having plinth area of more than 600 sq. ft. in Karnataka (http://www.gokenergy.gov.in/energy_c.html). About 8.1% of the population still use traditional fuel wood stove for water heating purpose.

About 53.4% of samples have adopted solar devices for water heating and these households have adopted solar devices for water heating as the option is environment friendly (17.49%, 344 samples), saving energy (16.73%, 329 samples) or due to subsidy from the government (3.30%, 65 samples). The spatial distribution of use of electric heater, solar heaters, etc. for water heating highlights the success of alternate technologies for water heating especially in some locations such as K.R.Puram, Hosakerehalli, Kengeri and Dasarahalli etc. Expenditure on heating bill with subsidy indicates majority households (497, 25.97%) spend monthly about Rs. 200-500 whereas 250 households (13.62%) spend less than 200 rupee per month. Energy used for cooking purposes in domestic sector includes electricity, fuel wood, LPG, etc. In India, about 33.6 million households uses the LPG as cooking fuel (Ramachandra and Shwetmala, 2012).Use of fuel wood, LPG, etc. contribute emissions of greenhouse gases. LPG is used for cooking in the majority (78.75%, 1549) households. LPG and electric heaters are used in 11.54% or 227 households. Most of the households have major rooms towards east (39.76%, 782 samples) and north (22.01%, 433 samples) from better ventilation perspective.

Majority of households (62.89%, 1237 samples) are keen to conserve energy to reduce the carbon emission while 398 samples for economic reasons and 7.47% want to conserve to save energy as well as money. Analysis shows the deployment of solar appliances in 584 samples. Among these, 430 households have availed the facility of government subsidy. About 55.47% (1091 samples) wants to switch over to solar appliances as they are environment friendly. 14.79% (291) wanted to adopt solar appliances to save money as well as for environment friendliness. About 22.42% of household (441) have plan to install solar appliances. However, large proportions of the sample (997, 50.69%) are not sure of installing solar appliances.

Spatial Variations in Household Energy Consumption:

The domestic sector plays a dominate role in energy consumption. In India, about 30% of total residential electricity is consumed for lighting followed by the refrigerators, fans, electric water heaters, televisions, mobile charging, etc. (http://siteressources.worldbank.org/INTURBAND EVELOPMENT/ .../Gupta.pdf). Electricity consumption in the domestic sector has been increasing rapidly in Bangalore. Usage of air conditioners and high energy gadgets has enhanced the energy consumption in high income households. The annual per capita electricity consumption variation spatially reveals that about 700 samples use annual per capita electricity in the range 100 -400 kWh. About 226 households use annual per capita electricity in the range 400-600 kWh. An energy guzzler (1000 units per year per person) happens in 140 households. 36 households are highly energy intensive consuming

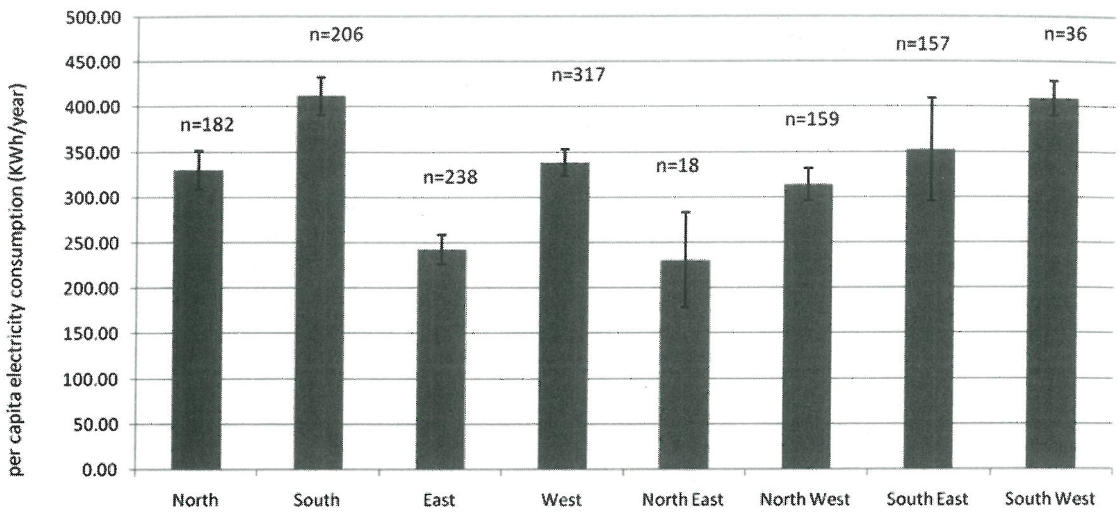

Figure 4 : Per capita annual electricity consumption in different zones

more than 1000 units (kWh)/Year.

Zone wise analysis of annual electricity consumption, shows the variation from 917.21± 754.05 (NE) to 1764.03±1362.29 (S) zone. Similar trends are observed in per capita annual electricity consumption (Figure 4), which varies 230.91±210.84 (NE) to 412.30±297.75 (S). Zone wise variation of per capita electricity consumption shows the variation of 30 kWh/year to a max of 1796 kWh/year (SW) followed by the North East with 9.64 to 750 kWh/Year. East Zone is with minimum per capita electricity consumption 18.57 to 2337 kWh/year.

Ward-wise electricity consumption details were compiled for 2011-12 from the respective zonal offices of BESCOM (Bangalore Electricity Supply Company) were synthesized to understand variations across wards considering all sectors. Figure 5 reveals that about 40 wards have annual per capita electricity consumption of 500 kWh, 23 wards have consumption of 500-1000 kWh. Majority of wards (84) are in the range of 1000-2000 kWh/person/year, 31 wards have the consumption of 2000-4000 kWh/person/year. A very high consumption of more than 4000 kWh/person/year is in 24 wards of SE Bangalore, mainly due to large scale high raise buildings with glass facdes. Per capita annual electricity

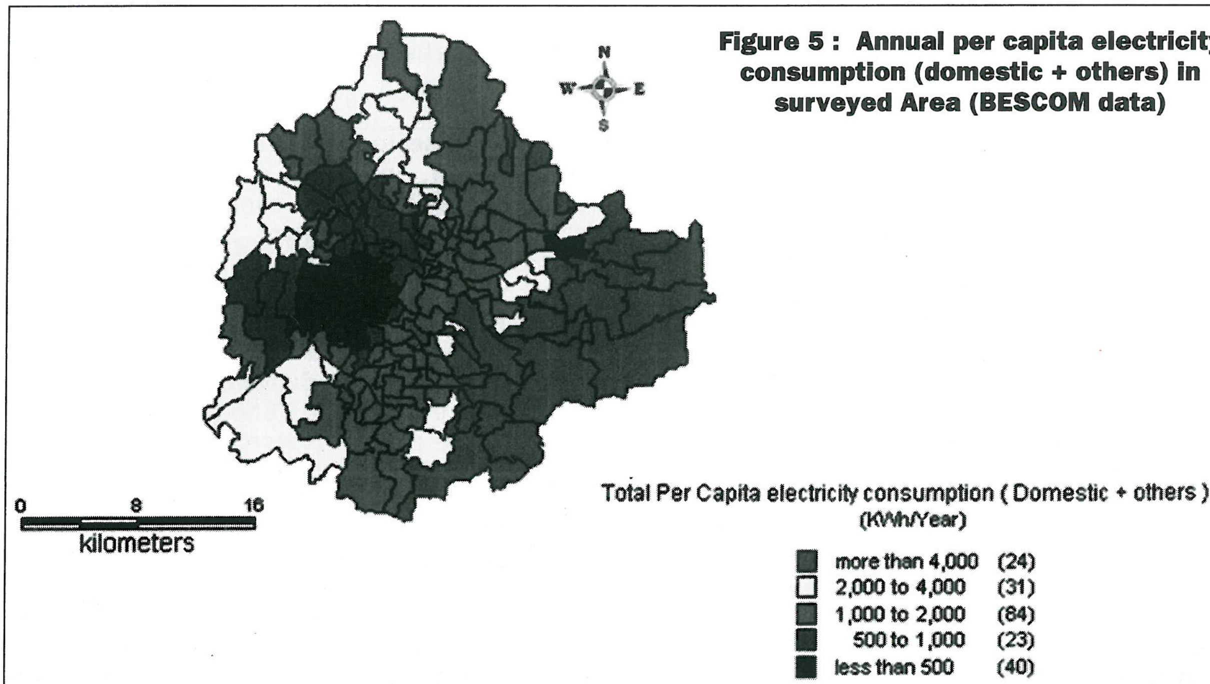

Figure 5 : Annual per capita electricity consumption (domestic + others) in surveyed Area (BESCOM data)

consumption ranges from 112.16 kWh (Devsandara ward) to 7668.48 kWh (Ejipura ward).

High-rise buildings with glass facades are suitable for temperate climate (wherein one needs to conserve heat in the cold environment). Adoption of such architecture in the tropical climate region (such as Bangalore, etc.) has increased the consumption of electricity in Bengaluru, evident from higher electricity consumption of 13000-15000 units/person/year in zones dominated by high-rise buildings (with glass facades) compared to the zones with lower glass façade buildings (750-1796 units/person/year). This highlights the need to regulate glass facades buildings in the tropical climate region as adoption of wrong building architecture has contributed to higher electricity consumption and hence higher GHG emission in the domestic sector.

LPG is a dominant fuel used in the domestic sectors. The spatial distribution of monthly LPG consumption reveals that majority (1499, 76.2%) consumes one cylinder (of 14 kg LPG) per month while 219 samples require 2 cylinders. The average per capita LPG consumption is 15.5 kg/month. Wards like K.R.Puram, Kengeri, Hoskerehalli, JnanaBharathi consumes 2 cylinders of LPG. The LPG consumption varies from 181.46±57.94 (W) to 208.75± 97.50 (SE). Per capita annual LPG consumption varies 42.33±20.02 (E) to 54.02±34.76 (SE). The annual electricity and LPG consumed in each household were aggregated with common energy unit (GJ) and was divided by the respective household family size to get the per capita energy consumption. Analysis shows that 767 households consume < 2 GJ/year while 888 households consuming 2-4 GJ/year. The energy consumption ranges from 0.129 GJ/year to 12.39 GJ/year with the average of 2.9±1.4 GJ/year and this is comparable to earlier reports (Government of India. Annual Report 2009-10).

Table 2 : Per capita electricity consumption in zones

Zones	Electricity consumption (kWh/person/year)
North	1796
South	1902
East	2337
West	13796
North East	750
North West	3252
South West	5718
South East	14849

Spatial Pattern of Domestic CO_2 Emission in Bangalore: An emission due to electricity consumption in the domestic sector is computed as explained earlier in Methods section.CO2 emissions from electricity consumption in 419 households range between 1 to 2 tons/year followed by 379 households with 0.5 to 1 ton/year. 29 households with higher consumption of electricity emit more than 4 tons/year. Similarly, emissions due to LPG consumption is computed and results shows that most of the households (1501 households) have emission ranging between 0.4 to 0.6 tons/year followed by 230 households with 0.6 ton/year. Figure 6 provides the CO2 emission from total energy (LPG and electricity), which illustrates that 40% households (751samples) emits between 0.5 to 1tons/year, followed by 37% households (695) emitting 1 to 2 tons/year. 44 households emit more than 4 tons/year.

Based on the survey data, considering the population of the wards, CO2 emission from electricity and LPG are extrapolated for different wards of Greater Bangalore. CO2 emissions from electricity consumption show that majority of the wards (71 wards) emits in the range of 10 to 15 Gg/year while 9 wards in the city centre emits more than 20 Gg/year. Wards such as Atturu, Kadugodi located at outskirts of the city emits between 15 to 20 Gg/Year and 16 wards emits less than 4 Gg/Year.The emissions due to electricity consumption in Bangalore is about 11,112 Gg/Year and emission from electricity consumption in domestic sector from the sample of 1907 households is 2246 Gg/Year, which is about 20% of total emission.

CO_2 emission due to LPG consumption shows that 48 wards mostly located in the outer zone of the city emits CO_2 in the range of 4 to 5 Gg/year. 28 wards emits less 4 Gg/year and 26 wards in the city center like Chickpet, Shanti nagar, Vijay Nagar emits CO_2 more than 7 Gg/year. Wards such as Nandini layout, Benniganahalli, Shettihalli emits 6 –7 Gg/year. Emission from most of the wards (66 wards) ranges between 10 to 15 Gg/year, wards located at city center such as Kacharkanahalli, Vijnanapura, Sarvagana Nagra, Malleswaram have emissions more than 25 Gg/year. Maximum carbon dioxide emission is 46.56 Gg/Year in Sarvagna nagar ward and minimum emission is 3.66 Gg/Year in Konena Agrahara ward. Total carbon dioxide emission from all wards of Greater Bangalore is 3350 Gg/Year.

Role of socioeconomic factors in residential energy consumption and CO_2 emission: Household energy demand and associated carbon emissions depend on many factors, like household size, income levels, attitude towards energy savings which is related to the education level, government policies, etc. Earlier studies have focused on the role of

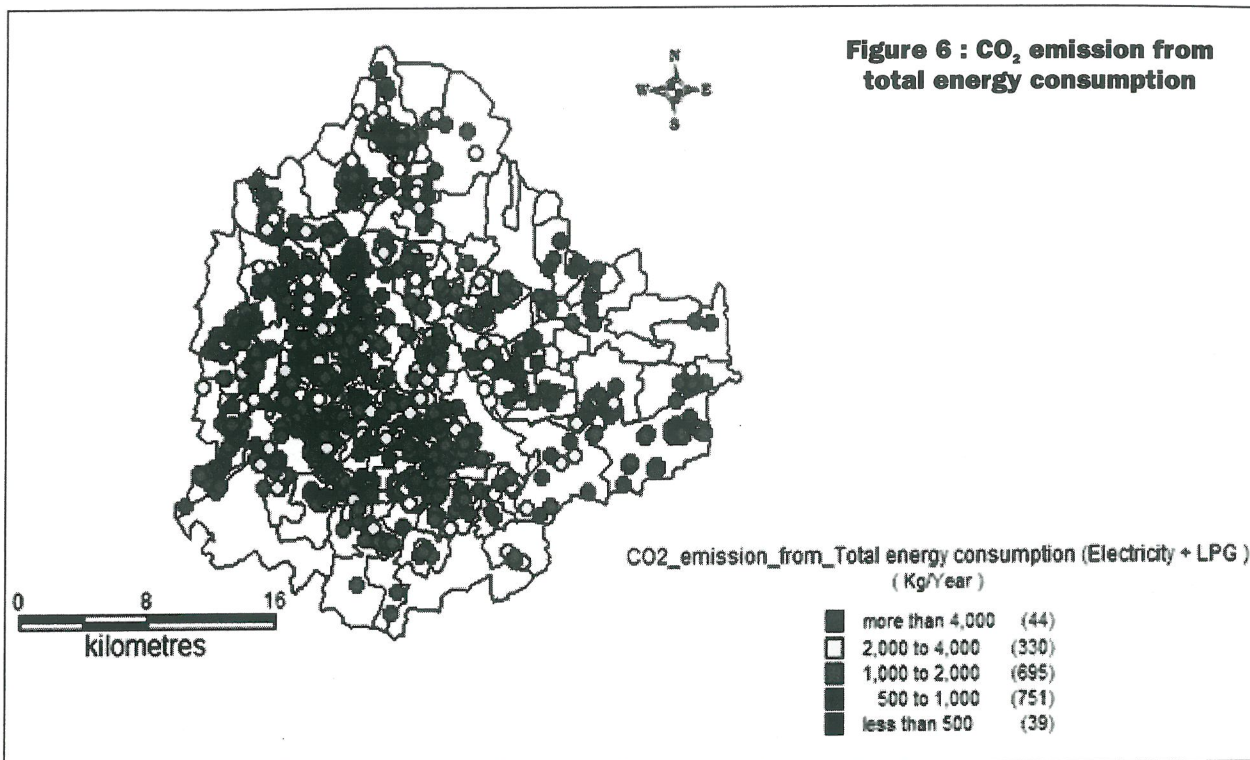

Figure 6 : CO_2 emission from total energy consumption

education, family size, climatic parameters on the level of energy consumption in rural area (Ramachandra et al., 2000). Results reveal per capita LPG as well as electricity consumption with the increase in the number of persons per household and the probable relationship is Y = 9.4007 e-0.266x (r=0.973, p<0.05) comparable to the earlier study (Yu et al., 2011). Family income is a key variable in the household energy consumption intensity (Pauchauri, 2004), evident from Table 3, which illustrate the increase of per capita electricity consumption with the income and the probable relationship is y= -.0002x2+29.287x+2E+06(r= 0.983, p<0.05). A proportional increase in the per capita energy consumption with the family income, suggests that economic level, is an important parameter in the domestic energy consumption and GHG emissions.

Conclusion:

Domestic sector is the major consumer of energy and contribute large extent to the total energy use in a city. Understanding the spatial pattern of domestic energy consumption is necessary for an appropriate policy measures towards low carbon city. The current analysis includes understanding of neighborhood and community of household, energy consumption pattern and corresponding carbon dioxide emission due to different inside household activities. Present study provides understanding of the trends in CO2 emission in the urban household sector of different wards of Greater Bangalore. This study illustrates that different segments of population have very different energy consumption depending their socio-economic characteristics. The survey reveals a typical household family size, family income and the extent of adoption of renewable energy devices (Solar water heaters, etc.) play an important role in the energy consumption at households.

Energy used for cooking purposes in domestic sector includes electricity, fuel wood, LPG, etc. LPG is being used for cooking in the majority (78.75%, 1549) households. The spatial analysis of annual per capita electricity consumption reveals that about 700 samples use annual per capita

Table 3 : Consumption pattern of electricity in the surveyed area of Greater Bangalore

Income category	Quantity of Electricity used (KWh/month)	No of households	Percent	Per capita consumption (KWh/month)
Income < 100000	3482.50	156	9.0	22.32
Income (100000 to 500000)	22617.11	816	58.6	27.72
Income (500000 to 10,00000)	8230.42	193	21.3	42.64
Income > 10,00000	4284.99	92	11.1	46.58

electricity in the range 100-400 kWh and about 226 households use annual per capita electricity in the range 400-600 kWh. Zone wise analysis of annual electricity consumption shows the variation from 917.21± 754.05 (N E) to 1764.03±1362.29 (S). Similar trends are observed in per capita annual electricity consumption, which varies 230.91±210.84 (NE) to 412.30 ±297.75 (S). Ward-wise total electricity (domestic and other sectors) consumption synthesis reveals that about 40 wards have annual per capita electricity consumption of 500 kWh, 23 wards have consumption of 500-1000 kWh. Majority of wards (84) are in the range of 1000-2000 kWh/person/year, 31 wards have the consumption of 2000-4000 kWh/person/year. A very high consumption of more than 4000 kWh/person/year is in 24 wards of South East Bangalore, mainly due to IT and BT industries and large scale high raise apartments.LPG is a dominant fuel used in the domestic sectors. Majority of households (1499, 76.2%) consumes one cylinder (of 14kg LPG) per month while 219 samples require 2 cylinders.LPG consumption varies from 181.46±57.94 (W) to 208.75± 97.50 (SE). Per capita annual LPG consumption varies 42.33±20.02 (E) to 54.02±34.76 (SE). Pertaining to the link between energy consumption with the social factors, negative correlation between household size and energy consumption per capita is observed in the sample analysis. A proportional increase of the per capita energy consumption with income (r= 0.983), suggests that economic level of a household is an important factor in domestic energy consumption. The spatial distribution of annual per capita energy consumption shows that 767 households consume < 2 GJ/year while 888 households consuming 2-4 GJ/year. The energy consumption ranges from 0.129 GJ/year to 12.39 GJ/year with the average of 2.9±1.4 GJ/year and this is comparable to earlier reports. Emission from most of the wards (66 wards) is 10 to 15 Gg/year, while wards in peri-urban areas emit less than 10 Gg/year. Wards located at city center emit more than 25 Gg/year with maximum of 46.56 Gg/Year (Sarvagna Nagar) and minimum of 3.66 Gg/Year (Konena Agrahara ward). Extrapolation of these, show that total carbon dioxide from all wards of Greater Bangalore accounts to 3350 Gg/Year. The study illustrate that domestic sector contributes significantly to GHG emissions in the city. The findings emphasise the need to improve the end use energy efficiency to conserve household energy to mitigate emissions and focus on renewable sources of energy while formulating the sustainable energy policies.

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