

Determining residential energy consumption-based CO₂ emissions and examining the factors affecting the variation in Ankara, Turkey

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Abstract. Energy demand of Turkey has been showing a remarkable increase in the last two decades due to rapid increase in population and changes in consumption trends. In parallel to the increase in energy demand, the CO₂ emissions in Turkey are also increasing dramatically due to high usage of fossil fuels. CO₂ emissions from the residential sector covers almost one fourth of the total sectoral emissions. In this study, CO₂ emissions from the residential sector are estimated, and the factors affecting the emission levels are determined for the residential sector in Ankara, Turkey. In this study, detailed surveys are conducted to more than 400 households in Ankara. Using the information gathered from the surveys, the CO₂ emissions associated with energy consumption of the households are calculated using the methodology outlined at IPCC. The statistical analyses are carried out using household income, dwelling characteristics, and household economic and demographic data to determine the factors causing the variation in emission levels among the households. The results of the study present that the main factors impacting the amount of total energy consumption and associated CO₂ emissions are household income, dwelling construction year, age, education level of the household, and net footage of the dwelling.

1 Introduction

Since the industrial revolution, the rapid increase in the use of fossil fuel, rapid population growth and the destruction of forests have led to an increase in greenhouse gas (GHG) concentrations in the atmosphere. Climate change stemming from this increase has become an agenda item on a global scale especially in the last two decades. It is now widely accepted that increasing average temperatures with a rapid acceleration are a consequence of GHG emissions from human activities. This increase in temperature causes the climate

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characteristics to change in different parts of the world [1]. The main gases that cause climate change are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), which account for 99% of total GHG emissions. Owing to fossil fuel burning and deforestation, concentration of atmospheric CO₂ has increased from 280 ppm at preindustrial revolution era to 406 ppm in February 2017 [2, 3]. Carbon dioxide emission mainly results from the use of fossil fuels and also the sector with the largest share in the formation of carbon dioxide emission is energy production [4]. Historically, there is a link between development and energy consumption, and access to appropriate energy sources is considered as an important sustainable development indicator [5]. Population and income growth are the main factors leading to an increase in energy consumption. Projections show that the world population will rise 8.3 billion in 2030 year. This situation indicates that 1.3 billion more people should be provided with energy supply [6].

Turkey's economy is an energy-intensive economy when compared to similar economies. Looking at the development of energy consumption in Turkey, it is seen that annual demand increase is 8% [7]. While total energy consumption in the country is 87 million tonnes of oil equivalent (Mtoe) in 2011, this value reached 99 Mtoe in 2015 [6]. As a result, Turkey's GHG emissions have increased significantly since 1990. GHG emissions of 187 million tonnes of CO₂ equivalent in 1990 increased to 468 million tonnes of CO₂ equivalent in 2014. As a CO₂ equivalent, total GHG emissions increased in the range of 125% in 2014 compared to 2009 levels. The amount of CO₂ emissions in the residential sector in 2007 was 34 Mtonnes [8]. While the equivalent CO₂ emission per capita in 1990 was calculated as 3.7 tonnes/person, this value was calculated as 6.1 tonnes/person in 2014 [9]. As of 2011 year, total GHG emissions were estimated at 422.4 million tonnes of CO₂ equivalent. Table 1 presents total GHG emissions as million tonnes of CO₂ equivalent for each sector from 1990 to 2011. While the largest share of CO₂ emissions in 2011 is energy-related emissions with 71%, followed by industrial operations with 13%, waste with 9% and agricultural activities with 7% [10].

Table 1. Sectoral GHG emissions, millions tonnes [9].

	1990	1995	2000	2005	2010	2011
Energy	133	162	213	242	285	301
Industrial Processes	15	24	24	29	54	56
Agricultural Operations	30	29	28	26	27	29
Waste	10	24	33	33	36	36
Percent Increase based on 1990	-	27%	58%	77%	113%	124%

The highest CO₂ emissions among the sectors stem from electricity generation. The main reason for this high share resulting from the electricity production is that the majority of electricity in Turkey is generated at fossil fuelled power plants as can be seen from Table 2 [8].

Table 2. Share of fuel type for electricity generation in Turkey from 2011 to 2015 [6].

Primary Energy Source	2011	2012	2013	2014	2015
Thermal	75%	73%	72%	80%	69%
Hydraulic	23%	24%	25%	16%	26%
Geothermal	0.3%	0.4%	0.6%	0.9%	1.3%
Wind	1.7%	2.6%	2.4%	3.1%	3.7%

Energy consumption in Turkey has been showing a dramatic increase in parallel to the increase in population and industrial development. Energy consumption in 2015 (98,811 ttoe) is 14 % higher than 2011 (86,952 ttoe) [6]. According to 2011 data, the residential sector has a significant share of 24% in total electricity consumption (Table 3).

Table 3. Distribution of net electricity consumption by sectors in Turkey from 2011 to 2015 [11].

Primary Energy Source	2011	2012	2013	2014	2015
Residential	24%	23	23%	22%	22%
Commercial	16%	16%	19%	19%	19%
Government Offices	4%	5%	4%	4%	4%
Industrial	47%	47%	47%	47%	48%
Street Lighting	2%	2%	2%	2%	2%
Others	7%	7%	5%	6%	5%

In order to better understand the environmental impacts of energy consumption, the factors that affect consumption activities need to be identified and better assessed. Households are an important target in this respect, because consumers have been playing an important role in the increase of production structures resulting in the consumption of intensive energy and resource. However, the residential sector is a difficult sector to examine due to various reasons such as the sector consists of units with various sizes, geometries and thermal properties and household behaviour varies greatly. This situation affects energy consumption widely. In addition, the collection of residential energy consumption data is more difficult due to the confidentially issues as well as conducting detailed energy consumption measurements at homes brings an extra cost to the studies.

Households are responsible for a significant portion of the CO₂ emissions due to use of fossil fuels for space and hot water heating, transportation, and electricity [12–14]. Households consume energy in two ways: direct (space heating, lighting, vehicle fuel, etc.) and indirect (consumed energy for production, transport and disposal of consumer goods) [15–17]. Investigations have shown that the household energy consumption is influenced by such factors as income level [18–23], that the location of the residence is the urban or rural area [15] and dwelling type, size and age [24–27], as well as geographical conditions [15, 16, 19], household size and properties [27], and age and education level of the household head. The most influential factor is estimated as the income level of the household in some studies [19, 21, 23]. Increased income levels can lead to the increase in the use and number of electrical appliances, and thus the household electricity consumption and the energy consumption for heating/cooling and hot water increase [28]. Some of the literature findings related to the studies performed to investigate the factors affecting energy consumption in the households are presented below. Aydinalp et al. (2003) found that factors affecting the electricity consumption owing to electrical household appliances, lighting and cooling are income, type of building, housing ownership, and population of living place as well as number of adults and children living in the residence [29]. Druckman and Jackson (2008) stated that energy consumption and carbon dioxide emissions in residential areas have a strong relationship with income level [19]. According to Rosas et al. (2010), in Mexico, inequality in income distribution reflected to the electrical household appliances ownership, household energy consumption and CO₂ emissions [23]. The aim of the study is to assess households on the basis of the factors that cause increased energy consumption and CO₂ emissions in Turkey and to shed light on the complex relationship between household energy consumption, lifestyles, and development.

2 Methodology

The methodology of this study includes multiple steps which can be divided into three main stages; determination of study area and data gathering and survey development as well as data analysis. The following sections describe these three stages in detail.

2.1 Study area

The study was conducted in Ankara, the capital city of Turkey. Ankara is the second biggest city and has a significant proportion in energy consumption in the country. The study was conducted in 2011 when the population of the city was approximately four million eight hundred ninety-one thousand.

2.2 Survey development and administration

This study aimed at calculating the CO₂ emissions from direct energy consumption and determine the factors affecting the level of direct energy consumption. A survey inquiring about the condition of the building, socio-economic condition of the household and aspects determining the energy consumption level was administered by publishing on a webpage designed for the survey and by distributing as printed questionnaires. The printed materials were distributed in primary schools located in the neighbourhoods with different socioeconomic characteristics. Prior to distribution of the surveys, the students were informed about climate change and the role of energy consumption in global warming with a presentation and their questions were answered in order to increase the intergenerational influence in the survey. A total of 451 surveys were obtained, and 396 surveys with electricity consumption data was used in the analysis.

2.3 Data analysis

In order to develop a more systematic approach, the research participant households were clustered according to their structural features. Clustering is a method used in market researches for a long time. Categories such as social class, income level, geographical location, number of adults and children in the household, age and education level of the household head have been used in clustering method [30, 31]. In similar researches on household energy consumption, it is determined that income is the dominant determinant [19, 23, 26]. Thus, the questionnaires are clustered into three income levels (low income, middle income and high income). In the study, CO₂ emissions are calculated by using energy sector guideline of the Intergovernmental Panel on Climate Change (IPCC), published to assist national GHG inventory preparations. Tier 1 method, which is based on calorific value and CO₂ emission factor assumptions for different fuel types, is used as there are no country specific values for these factors. In Tier 1 method, CO₂ emissions are calculated by transforming fuel consumption amount given in mass or volume into Tera joule using the lower calorific value and multiplying the result with the related CO₂ factor [32]:

$$\text{Emission}_{\text{CO}_2} = \text{Fuel Consumption (FC)}_{\text{fuel}} \times \text{CO}_2 \text{ Emission Factor (EF)}_{\text{fuel}} \quad (1)$$

where; Emission_{CO₂} is the amount of CO₂ emitted from fuel usage (kg), Fuel Consumption (FC)_{fuel} is the amount of fuel consumed (TJ), CO₂ Emission Factor (EF)_{fuel} is the CO₂ emission factor for the specific fuel consumed (kg CO₂/ TJ).

Emissions are calculated by multiplying the amount of fuel used for heating the house and water by the household with the lower calorific value published by Turkish Statistical Institute for the specific type of the fuel used. Electricity consumption is either provided with the exact value of the latest monthly consumption in kWh, or the price of the consumption. The price of consumption is transformed into kWh by estimating via regression analysis with the existing kWh data. In the survey, main fuel used for cooking is asked. If the main fuel is electricity or natural gas, emissions from this consumption are not calculated as they are covered under electricity and natural gas consumptions. If it is bottled gas, it is assumed that a 4-people family consumes a 12 liter bottle of gas per month, and the emissions are calculated estimating the amount of bottle gas consumed in line with the household size. The fuel consumption is asked in terms of the type of the fuel and monthly fuel cost and transformed into liters using the average price of the related fuel.

3 Results and discussion

This section summarizes the obtained results from the stages of the study. In this section, annual energy consumption amounts according to the sources, annual residential CO₂ emission amounts according to the sources, correlation between income and energy consumption from different sources and factors affecting total energy consumption examined.

3.1 Average energy consumption

Results of the study showed that the highest energy consumption in the households in Ankara is 73 GJ per home which is the total main space and water heating energy consumption. Second highest consumption is for secondary heating, which means additional heating sources are used to back up main heating. Electricity consumption and private vehicle energy consumption has an insignificant share in the total energy consumption as seen in Table 4.

Table 4. Annual energy consumption amounts according to the sources.

End-use Energy Consumption	Average Consumption (GJ)	Standard Deviation (GJ)	Lowest Consumption (GJ)	Highest Consumption (GJ)
Main space and water heating	72.724	32.056	16.744	200.000
Secondary heating	1.725	6.793	0	54.428
Electricity	850	402	52	2.578
Private car	652	856	0	6.975
Total	76.015	31.777	18.198	203.148

3.2 CO₂ emissions

When energy consumption based CO₂ emissions are examined, heating and hot water energy consumption has the highest emission amount (4.34 tonnes) per household. Electricity consumption related CO₂ emissions ranks second (1.69 tonnes), followed by private car usage and auxiliary heating energy consumption emissions as seen in Table 5.

Table 5. Annual residential CO₂ emission according to the sources.

End-use Energy Consumption	Average Emission (tonnes)	Standard Deviation (tonnes)	Lowest Emission (tonnes)	Highest Emission (tonnes)
Main space and water heating	4.24	1.81	0.94	11.25
Secondary heating	0.15	0.68	0.0	5.43
Electricity	1.69	0.85	0.11	5.43
Private car	0.60	0.78	0.0	6.21
Total	6.68	2.28	1.97	15.56

3.3 Correlations between energy consumption and income

Income has the highest impact on energy consumption [16, 18–20, 23, 26]. In order to analyse the correlation between the income and energy consumption related CO₂ emissions, Spearman’s Rank Correlation Test is used. As the significance probability (*p*) in the correlation test gets lower than 0.05, the correlation between the factors increases [21]. Results of Spearman Rank Correlation Test showed that there is statistically meaningful correlation between income and energy consumption (for all sources of consumption) and CO₂ emissions as seen in Tables 6 and 7. Main space and water heating energy consumption, electricity consumption and energy consumption from private vehicle usage is positively correlated with the income, while auxiliary heating energy consumption is negatively correlated.

Table 6. Correlation between income and energy consumption from different sources.

Energy Consumption Source	Correlation	Statistical Significance (<i>p</i>)
Main space and water heating	0.4159	0.0000
Secondary heating	-0.2333	0.0000
Electricity	0.2628	0.0000
Private car	0.3848	0.0000
Total	0.3584	0.0000

(*p* < 0.05)

Table 7. Correlation between income and CO₂ emissions from different sources.

Energy Consumption Source	Correlation	Statistical Significance (<i>p</i>)
Main space and water heating	0.2411	0.0000
Secondary heating	-0.2380	0.0000
Electricity	0.2641	0.0000
Private car	0.4176	0.0000
Total	0.2894	0.0000

(*p* < 0.05)

Total energy consumption and CO₂ emissions decline as the income level increases. The lowest income group has a total of 5.7 tonnes CO₂ emission, while the mid-income group has 6.58 tonnes and the high income group has 7.69 tonnes of CO₂ emissions per year.

3.4 Factor affecting residential energy consumption and related CO₂ emissions

Spearman’s rank correlation test is used to determine the factors affecting energy consumption and CO₂ emissions. The results of the analysis showed that the age of the building, the floor the resident is located [19, 26], household size [29], age and education

level of the household head [19] and net usage area of the residence [28] are the factors affecting the energy consumption for space and water heating as seen in Table 8. The total energy consumption is affected from the age of the building, age and education of the household head and net usage area of the residence [21]. A significant proportion of the total energy consumption is done for heating the house and water, thus the factors affecting them are similar.

Table 8. Factors affecting total energy consumption.

Factor	Correlation	Statistical Significance (p)
Age of the building	0.1299	0.0098
Age of household head	0.1459	0.0037
Education of household head	0.2153	0.0000
Net area of the residence	0.1696	0.0007

(p < 0.05)

Similar to the study conducted by Chen et al. [26], the analysis showed that energy consumption increases as the age of the building increases as seen in Table 9. Furthermore, energy usage increases as the net usage area of the residence increases [21, 33] as well as the age of the household head increases. In general, there is a positive correlation between the education level of the household and total energy consumption; however, energy consumption reaches to the highest level in its income cluster in the households with illiterate household heads.

Table 9. Factors affecting CO₂ emissions from total energy consumption.

Factor	Correlation	Statistical Significance (p)
Age of the building	0.1304	0.0098
Age of household head	0.1420	0.0049
Education of household head	0.1344	0.0077
Age of the building	0.1895	0.0002

(p < 0.05)

It is determined that CO₂ emissions from total energy consumption is affected from the type and the age of the building, age and education level of the household head and net usage area of the residence.

4 Conclusion

In this study, it was aimed to determine the amount of CO₂ emissions due to the energy consumption in the residential sector in Ankara and the factors that affect the energy consumption at homes. According to the results of this study, there is a significant relationship between energy consumption, as well as CO₂ emissions, and income. This relationship is positive with respect to energy consumption and emissions from main space and water heating, electricity consumption, and private vehicle use, while it is negatively correlated with energy consumption and emissions from secondary heating. It has been determined that factors influencing the total energy consumption and CO₂ emissions at the homes are the building construction year, the age and education of the household head, and the floor and net usage area of the dwellings.

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