IDEC DP² Series Vol. 2 No. 5

Developmnet Discussion Policy Paper

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January, 2012

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Impacts of urbanization on national residential energy use and CO_2 emissions: Evidence from low-, middle- and high-income countries

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ABSTRACT

Despite several previous studies, the potential differential impact of urbanization on energy consumption and CO_2 emissions across stages of development has rarely been investigated. This paper attempts to fill this knowledge gap by examining the influence of urbanization on national residential energy use and emissions in low-, middle- and high-income countries. Using the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model and a sample of 88 countries for the period 1975–2005, interestingly, the results suggest that urbanization decreases residential energy use in the low-income countries, while it increases residential energy use in the high-income countries. In the middle-income countries, household energy consumption first falls and then rises with urbanization with a turning point at about 70%. Conversely, based on a sample of 80 countries over the same period, this study shows that urbanization increases residential emissions in the low- and middle-income countries, whereas the residential emissions of the high-income countries rise initially and decline subsequently with urbanization with a turning point at around 66%. These findings imply that urbanization brings with it both costs and benefits. These tradeoffs should be considered in future discussions of global energy and climate change policies.

Keywords: Urbanization; Residential energy use; Residential CO_2 emissions; Development stages; STIRPAT Model

JEL Classification: R22; Q41; Q56

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1. Introduction

It is widely accepted in the scientific community that global climate change results primarily from human activities, especially the combustion of fossil fuels (coal, oil and natural gas) which increases the concentration of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere (IPCC, 2007). Many studies found that population and economic growth is the main driver behind the increase in fossil fuel use and CO_2 emissions (hereafter emissions) (Cole and Neumayer, 2004; Dietz and Rosa, 1997; IPCC, 2007; Kebede et al., 2010; Martínez Zarzoso et al., 2007; Shi, 2003; York et al., 2003a; York, 2007a, 2007b). In addition to these factors, urbanization is another important factor influencing energy use and emissions (Jones, 1989, 1991, 2004; Liddle and Lung 2010; Parikh and Shukla, 1995; Poumanyvong and Kaneko, 2010; York, 2007a, 2007b).

Urbanization has been observed as a phenomenon of socioeconomic modernization that involves social, economic and ecological transformations. Socially and economically, it is a process of concentrating population and economic activity in relatively compact settlement areas, defined as urban areas by each country. Through this process, the world has experienced rapid urbanization and economic modernization in recent decades. The world's urban population rose from 1.51 billion in 1975 to 3.42 billion in 2009 (UN, 2010). It was estimated that cities contributed to about 80% of the global gross domestic product (GDP) in 2007 (MGI, 2011). Ecologically, it alters land use and land cover, thus influencing the functioning of local and global ecosystems (Huang et al., 2010). Although urban areas were estimated to occupy only approximately 3% of the Earth's land area (UN-HABITAT, 2006), their average annual growth between 1990 and 2000 was remarkably fast, 3.2% per annum (Angel et al., 2005). Higher concentrations of population and economic activity in cities are often associated with higher levels of energy use, which are a major driver of CO_2 emissions (Kamal-Chaoui and Robert, 2009). One such estimate shows that cities consumed around 67% of global primary energy and were responsible for roughly 71% of global energy-related emissions in 2006, even though only around half of the world population lived there (IEA, 2008). As global urbanization continues to rise, the share of cities in global energy use and emissions is projected to increase to 73% and 76% in 2030, respectively (IEA, 2008). This will pose great challenges to long-term sustainability, but also means that the urban areas can play a significant role in ascertaining sustainability.

Despite its importance, the influence of urbanization on energy consumption has been relatively understudied (O′Neill and Chen, 2002). Over the past two decades, most research efforts have been devoted to examining the impact of economic and population growth on energy use and emissions. Only few studies have investigated rigorously and quantitatively the relationship between urbanization, energy use and emissions (Jones, 1989, 1991, 2004; Parikh and Shukla, 1995; Poumanyvong and Kaneko, 2010; York, 2007a, 2007b). Most of these studies focused on the national level with little attention to the potential differential impact of urbanization across development stages, which are characterized by gross national income (GNI) per capita. To the best of our knowledge, only one study has attempted to examine quantitatively the influence of urbanization on aggregate energy use and emissions in low-, middle-, and high-income countries (Poumanyvong and Kaneko, 2010). They found that the impact of urbanization varies across the three income groups. It influences aggregate energy use in the low-income countries negatively, while it affects aggregate energy use in the middle- and high-income countries positively. In the same study, they suggested that the impact of urbanization on aggregate emissions is positive in all the three income groups, but the magnitude of the impact in the high-income countries is lower than in the other groups.

The existing literature implies that the influence of urbanization on national residential and emissions may vary across the low-, middle- and high-income countries. Different stages of development imply different levels of affordability, different rates of electrification (see Table 1), different structure of residential energy use (see Fig.1), and different levels of energy efficiency. These differences are likely to mediate the impact of urbanization on residential energy use, thus causing it to vary across the low-, middle- and high-income countries. In fact, some studies suggested that urbanization contributes to a reduction in residential energy use in developing countries by facilitating fuel switching from inefficient traditional fuels (biomass) to modern fuels (kerosene, liquefied petroleum gas and electricity), which are more efficient (Pachauri, 2004; Pachauri and Jiang, 2008). Others found that urbanization increases residential energy consumption in developed countries through changes in lifestyles, standards of living, access to electricity and stocks of electrical appliances (Holtedahl and Joutz, 2004; Liddle and Lung, 2010). However, the former findings are derived from qualitative analysis of household energy use per capita in China and India only, while the latter ones are based on time-series analysis of residential electricity use per capita in Taiwan, and on panel analysis of national residential energy use in 17 OECD countries. It remains unclear what the impact of urbanization on national residential energy use and emissions in the low-, middle- and high-income countries is. In order to advance the existing literature, and to provide policy makers with insightful information, further investigation is imperative.

Table 1
Total, urban and rural electrification rates by region in 2002.

Country	Total (%)	Urban (%)	Rural (%)
Developing Africa	35.5	62.4	19.0
Developing Asia	68.7	86.7	59.3
All developing countries	65.5	85	52.4
OECD and transition economies	99.5	100	98.2
World	73.7	90.7	28.2

Source: IEA, 2004.

This paper investigates empirically the influence of urbanization on national residential energy consumption and emissions in the low-, middle- and high-income countries over the period 1975–2005. Specifically, it estimates percentage changes in national residential energy use and emissions as a result of a 1% change in the percentage share of the urban population in the total population (a measure of urbanization).[1] It examines the urbanization–residential energy use relationship using a sample of 88 countries, while it uses a sample of 80 countries to analyze the urbanization–residential emission relationship. This study differs from the existing studies in four ways. First, it divides the sample into low-, middle- and high-income groups, and then estimates urbanization's impact for each group separately. Second, it investigates not only the impact on national residential energy use but also national residential CO_2 emissions, which has rarely been studied empirically. Third, it explores the potential existence of a nonlinear relationship among urbanization, income per capita, residential energy use and emissions. Fourth, it checks the robustness of results using four different estimation techniques.

The paper is organized in following sections. Section 2 presents the literature review. Section 3 details the empirical model, data and method. Section 4 describes and discusses the descriptive and empirical results. Section 5 concludes the study.

2. Literature review

The body of literature on the relationship urbanization and household energy use has been growing in recent years. However, most of the existing studies are descriptive in nature or simply treat urbanization as a control variable. For the sake of brevity, only a highly relevant literature is discussed in this section. To begin with descriptive analysis, Sathaye and Meyers (1985) analyzed household energy consumption surveys conducted in several cities of China, Liberia, Guatemala, the Philippines, Malaysia, Thailand and Taiwan, and noted that urbanization brings with it changes in the ways that energy resources are allocated, distributed and consumed. Urbanization facilitates household income growth and lifestyle changes that not only encourage a shift from traditional to modern energy sources, but also spur demand for new services such as refrigeration, air-conditioning, water heating and other electric appliances. Such a shift leads to greater efficiency of energy use and has a negative influence on overall

[1] In the absence of better alternative measures, we use the conventional measure of urbanization, the percentage share of the urban population in the total population, which is used widely in the existing literature.

residential energy consumption, while the increase in appliance holdings has an opposite effect on it. Likewise, Pachauri and Jiang (2008) conducted a comparative study of household energy transitions in China and India using both aggregate statistics and nationally representative household surveys in various years, and suggested that per capita household energy use is lower in urban areas than in rural areas because of a shift from inefficient solid fuels (biomass and coal) to cleaner and efficient modern energy such as kerosene, liquefied petroleum gas (LPG) and electricity.

In the context of cross-sectional analysis, Pachauri (2004) also found that when controlling for household expenditure, household size and dwelling attributes, urban residents of India have lower total household energy requirements (direct and indirect energy use) per capita than their rural counterparts because of increased use of commercial fuels in urban areas. The urban household energy transition from non-commercial to commercial energy sources can be influenced by various factors. In addition to income, urbanization plays a considerable role in the household energy transition process (DeFries and Pandey, 2010; Heltberg, 2004; Pachauri and Jiang, 2008; Sathaye and Meyers, 1985). It gradually limits the space to collect and store low density fuels, including fuelwood and animal dung through population densification. Meanwhile, it facilitates the substitution of higher density fuels for the low density fuels through greater access to kerosene, LPG and electricity. These modern fuels are not only more efficient, but also produce less indoor air pollution compared with traditional fuels.

However, based on time-series data analysis in Taiwan over the period 1955–1995, Holtedahl and Joutz (2004) found a positive correlation relationship between urbanization and residential electricity consumption per capita for two reasons. First, urbanization implies greater access to the electricity grid, which is likely to encourage more household electricity consumption. Second, rural households that already had access to electricity before migrating to urban areas are likely to increase their consumption by using their existing electric appliances and purchasing new items (increased stock of electric appliances). Applying a similar approach to Turkish data for the period 1968–2005, Halicioglu (2007) also concluded that urbanization influences residential electricity per capita positively.

Table 2
Summary of the relevant literature.

Authors	Method	Sample	Period	Results
Sathaye and Meyers (1985)	Descriptive analysis	Household surveys from 7 developing countries	Various years	Urbanization → Modern fuels (↑) → Appliance stock (↑)
Pachauri (2004)	Input–Output analysis, Multiple regression model	Household surveys	1993–1994	Household energy requirements (direct and indirect) per capita in urban areas < in rural areas
Pachauri and Jiang (2008)	Descriptive study	Household surveys and national statistics from China and India	1985–2002; 1983–2005	Urbanization → Modern fuels (↑) Residential energy use per capita in urban areas < in rural areas
Parikh and Shukla (1995)	Multiple regression analysis	43 developing countries	1965–1987	Urbanization → residential electricity use per capita (↑)
Holtedah and Joutz (2004)	Cointegration testing, Error correction model	Taiwan	1955–1995	Urbanization → residential electricity use per capita (↑)
Halicioglu (2007)	Autoregressive distributed lag, Error correction model	Turkey	1968–2005	Urbanization → residential electricity use per capita (↑)
Liddle and Lung (2010)	STIRPAT model, Multiple regression analysis	17 developed countries (5-year interval data)	1960–2005	Urbanization → national residential energy and electricity use (↑)

Using a panel data set of 43 countries over the period 1965–1987, Parikh and Shukla (1995) found that holding income per capita, the share of agriculture in gross national product (GNP) and population density constant, urbanization contributes to an increase in electricity use per capita because of increased access to urban amenities, particularly electricity supplies. A similar conclusion was drawn by Liddle and Lung (2010), who examined quantitatively a sample of 17 developed countries for the period 1960–2005, and suggested that urbanization has a positive impact on both national residential energy and electricity use.

In short, despite mixed results in the existing literature, the negative correlation between urbanization and household energy consumption is found only in developing countries, where non-commercial fuels are the main household energy source. In developed countries, where household energy is predominated by modern fuels, urbanization appears to influence residential energy use positively. Most previous studies also suggest that urbanization has a positive impact on residential electricity consumption in both the developed and developing countries. Table 2 presents a brief summary of the relevant literature.

3. Empirical model, data and method

3.1. Empirical model

This study applies the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model (Dietz and Rosa, 1994; York et al., 2003a), which is increasingly used to investigate the interaction between socioeconomic changes and the environment. This model treats population as one of its explanatory variables, and uses aggregate environmental impact as its dependent variable. Hence, it addresses the weakness of the environmental Kuznets curve (EKC) model, which uses environmental impact per capita as its dependent variable by assuming implicitly that the population elasticity of environmental impact is unitary (Cole and Neumayer, 2004; Martínez-Zarzoso et al., 2007; Shi, 2003; York et al., 2003a). The EKC assumption may not be correct because several studies have found that the population elasticity of energy use and emissions varies noticeably between developed and developing countries (Martínez-Zarzoso et al., 2007; Poumanyvong and Kaneko, 2010; Shi, 2003). The initial specification of the STIRPAT model is as follows:

$$I_i = aP_i^b A_i^c T_i^d u_i \tag{1}$$

where I represents total environmental impact, including energy use, which is determined by a multiplicative combination of three factors: population size (P), GDP per capita (A) and technology or the impact per unit of economic activity (T), which can be disaggregated into multiple variables other than A and P that influence I (York et al., 2003a), depending on types of environment impact being investigated. For instance, Shi (2003) analyzed aggregate emissions and used the share of industry and services in GDP to express T, while York (2007a) studied national energy consumption, and used urbanization to express T. Economic structure and urbanization were used to represent T (Poumanyvong and Kaneko, 2010). The subscript i denotes the unit of analysis, namely the country, a is the constant term, b, c and d are parameters are to be estimated, and u is the error term.

The STIRPAT model is widely used to examine the influence of social, demographic and economic changes on the environment has been growing recently. Several researchers applied the model to identify factors influencing CO_2 emissions (Cole and Neumayer, 2004; Martínez-Zarzoso et al., 2007; Shi, 2003; York et al., 2003a), while Squalli (2009) used it for air pollution analysis. It was also employed to analyze the effects of socioeconomic changes on national energy use and the ecological footprint (Jorgenson et al., 2010; Poumanyvong and Kaneko, 2010; York, 2007a, 2007b; York et al., 2003b). Its recent application was used to examine the influence of urbanization and other socioeconomic factors on national transport emissions, residential energy and electricity consumption (Liddle and Lung, 2010).

3.2. Data and Method

Based on Eq. (1) and the recent study by Liddle and Lung (2010), we derive the basic empirical model for the panel data of aggregate residential energy use and emissions and rearrange it as follows:

$$\ln I^*_{it} = a_0 + a_1 \ln (P_{it}) + a_2 \ln (A_{it}) + a_3 \ln (URB_{it}) + C_i + Y_t + u_{it} \quad (2)$$

where subscript i refers to countries, t refers to years and I^* denotes aggregate residential energy use and emissions. A is GDP per capita, the main determinant of residential energy and electricity consumption (Block, 2004; Holtedahl and Joutz, 2004; Pachauri, 2004). P is population size, which influences aggregate energy use positively (Poumanyvong and Kaneko, 2010; York, 2007a). URB denotes urbanization, the percentage of the urban population in the total population. Since both the dependent and independent variables are in logarithmic form, coefficients a_1, a_2 and a_3, should be interpreted as elasticities.

C is a country dummy used to capture unobserved country-specific effects that are constant over time but yet to be included in the model. These possibly include geographical locations, climatic characteristics and cultural preferences as they could possibly influence energy consumption and emissions (Burke, 2010; Cole and Neumayer, 2004; Shi, 2003). *Y* is a year dummy used to account for effects that are common to all countries but vary over time, other than *P*, *A* and *URB*. These possibly capture fluctuations in global energy prices, technical progress and other common shocks that might affect energy use and emissions (Burke, 2010; Liddle and Lung, 2010; Shi, 2003). The inclusion of the country and year dummies could not only mitigate the omitted control variable bias (Green, 2000), but it also helps remove possible cross-sectional dependence and the spurious regression problem (Petersen, 2009; Wooldridge, 2007). Despite these benefits, we need to test whether the country and year dummies are jointly statistically significant. If they are not, they are dropped from the model because including irrelevant variables can lead to less efficient estimates.

Based on Eq. (2), we further explore the potential existence of an inverted U-shaped relationship between residential energy use, emissions, income and urbanization by including their quadratic terms. Yoo and Lee (2010) found an inverted U-shaped relationship between electricity consumption per capita and income per capita in developed and OECD countries, while Tamazian and Rao (2010) suggested that there is an EKC for emissions per capita in transition economies. In addition, some studies suggested that some environmental indicators may follow an EKC relative to urbanization rather to income per capita (Ehrhardt-Martinez, 1998; Ehrhardt-Martinez et al., 2002). Nonetheless, the quadratic terms of income and urbanization are dropped from the models if they are statically insignificant.

The paper analyzes residential energy use and emissions using two balanced panel datasets of 88 and 80 countries for the period 1975–2005, respectively (see Tables A.1 and A.2 in Appendix A). The sample selection is based mainly on the data availability for the dependent and independent variables.[2] In order to examine the potential differential influence of urbanization on residential energy use and emissions across the three stages of development, the sample is divided into three groups: low-, middle- and high-income groups, based on the World Bank's country classifications (World Bank, 2009), and then each group is analyzed separately.[3] In the sample of the residential energy use analysis, the low-income group consists of 21 countries, while the middle- and high-income countries groups comprise 39 and 28 countries, respectively. In the sample of the residential emissions analysis, the low-income group comprises 17 countries, whereas the middle- and high-income groups consist of 37 and 26 countries, respectively. For comparative purposes, the results of the whole sample analysis is also reported, however, it is not pivotal interest of this paper.

Table 3
Description of the variables used in the analysis for the period 1975–2005.

Variable	Definition	Unit	Data source
Population *(P)*	Mid year population	Number	World Bank (2007)
GDP per capita *(A)*	Gross domestic product divided by mid year population	US$ in PPP (2000 prices)	World Bank (2007)
Urbanization *(URB)*	The percentage of the urban population in the total population	Percent	World Bank (2007)
Total residential energy use	All fuels consumed by households, excluding fuels used for transport	kilotonne of oil equivalent (ktoe)	IEA (2009a,b)
Total residential carbon dioxide (CO_2) emissions	CO_2 emissions from the residential sector, excluding emissions from biomass fuel consumption	kilotonne	IEA (2009c)
Residential CO_2 emissions intensity	Total residential emissions divided by total residential energy use	kilotonne per ktoe	Calculated using data from IEA (2009a,b,c)

The data on population, urbanization and GDP per capita are mainly from the World Bank

[2] The sample for the residential emissions analysis is smaller than that for the residential energy use analysis because of the exclusion of the countries with data missing.

[3] Low-income countries are those with GNP per capita ≤ US$765 in 2004; middle-income countries are those with GNP per capita between US$766 and US$9,385; high-income countries are those GNP per capita > US$9,385.

(2007). GDP per capita data were missing for some countries; therefore we use data from the International Energy Agency (IEA, 2009a, 2009b) for these countries. The data on national residential energy use and emissions are obtained from IEA (2009a, 2009b, 2009c). Table 3 provides a detailed description of the variables and the data sources used in the analysis.

Traditionally, the fixed and random effects estimates are often used for panel data analysis. Both estimators are efficient and consistent if their residuals are homoskedastic and serially uncorrelated. Violating these assumptions could possibly lead to biased estimates. To check whether serial correlation is present, the Wooldridge test for autocorrelation in panel data (Wooldridge, 2002) is used. The test results indicate that serial correlation is present in our panel data models. Moreover, the presence of heteroscedasticity is detected in these models after applying the modified Wald test for group-wise heteroscedasticity developed by Greene (2000). We further check for the potential existence of cross-sectional dependence using two different tests proposed by Frees (1995) and Pesaran (2004), respectively. The test results are inconclusive.[4] To address autocorrelation, hetorescedasticity as well as the potential presence of cross-sectional dependence, the fixed effects estimates with Driscoll–Kraay starndard errors (Driscoll and Kraay, 1998) and with Newey–West standard errors (Newey and West, 1987) are applied.[5] Hoechle (2007) claimed that when the residuals are cross-sectionally correlated, the Newey–West standard errors are underestimated, while the Driscoll–Kraay starndard errors are well calibrated. However, in this study, we found opposite evidence, which suggests that the fixed effects estimation with the Newey–West standard errors is more appropriate. To check the robustness of results, the Prais–Winsten estimation (Prais–Winsten) proposed by Beck and Katz (1995) and feasible generalized least squares (FGLS) developed by Parks (1967) are also used. To accommodate autocorrelation, these two estimators calculate autoregressive parameters and

[4] For the sake of brevity, the test results for autocorrelation, heteroscedasticity and cross-sectional dependence are not shown in this paper. However, they are available from the authors on request.

[5] The Hausman test suggests that the fixed effects model is appropriate.

use them to transform the data. Consequently, their estimates sometimes can be sensitive to the selection of autoregressive parameters. For instance, the estimates based on common parameters may differ from those based on heterogeneous parameters. Henisz (2002) suggested that the estimation with Newey–West standard error correction has more advantages than Prais–Winsten and FGLS because it not only easily addresses autocorrelation that is of higher order than one, but also simplifies the estimation of models that have nonlinear parameters. Hence, the models using the Newey–West standard error adjustment with three lags determined by the selection technique proposed by Newey and West (1994) are preferred.

4. Results and discussion

4.1. Descriptive analysis of the main variables

Fig. 1 illustrates the structure of household energy consumption by income group in 1975, 1985, 1995 and 2005. It not only varies substantially among the low-, middle- and high-income groups, but also changes over time. In the low- and middle-income groups, biomass fuels (including wastes, solid and liquid biofuels) accounted for a very large proportion of their total household energy use for the year 1975, whereas oil and gas predominated in the high-income group. The percentage share of biomass of the low-income group declined gradually and was replaced with a gradual increase in the percentage share of oil, natural gas and electricity. A similar trend was evident in the middle-income group, but its pace was faster and more noticeable. Between 1975 and 2005, the high-income group experienced a sharp decline in the percentage share of coal and oil. Such a decline was replaced with a significant increase in the share of natural gas and electricity. The share of coal use also decreased slightly in the low- and middle-income groups. The share of oil use increased steadily in the low-income group, whereas it first rose and then fell in the middle-income group. Despite significant changes in the structure of residential energy use in the low- and middle-income groups, biomass fuels are still their main source of household energy. Note that ‘other’ in Fig.1 refers to other fuels, including geothermal, solar, wind and heat.

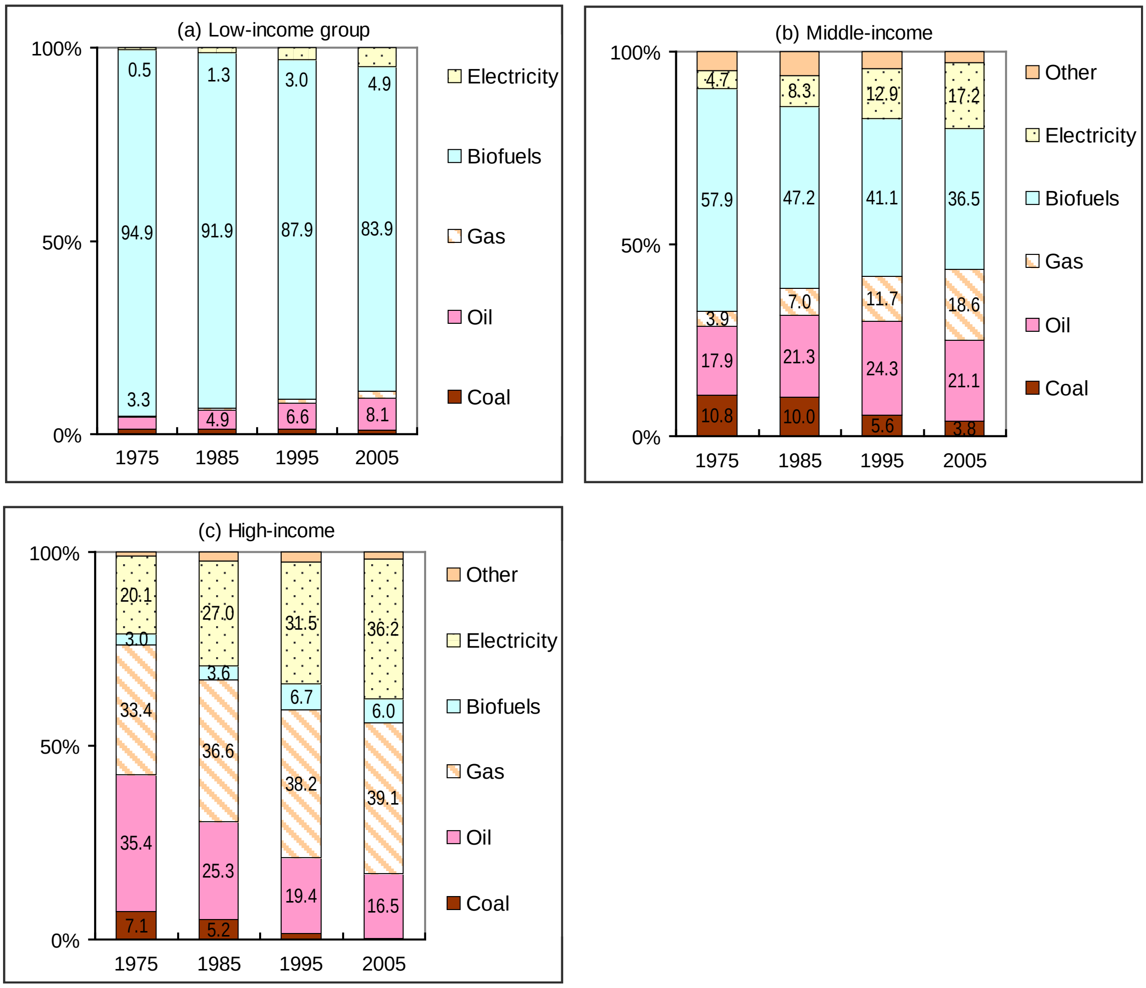

Fig. 1. Structure of residential energy use by income group.

Fig. 2 shows urbanization levels, residential energy use and emissions per capita in 1975 and 2005 by income group. They vary noticeably among the low-, middle- and high-income groups. The higher the per capita income of a country, the higher its level of urbanization and residential emissions per capita. Surprisingly, in 1975 and 2005, the household energy consumption per capita of the low-income group was slightly higher than that of the middle-income group. Between 1975 and 2005, residential energy use per capita in the low-income group declined slightly, whereas it rose in the other groups. On the other hand, while residential emissions per capita rose noticeably in the low- and middle-income groups, it fell significantly in the high-income group. The figure also indicates that the average annual rate of urbanization in the low-income group was around 1.5%, which is noticeably higher than in the other groups.

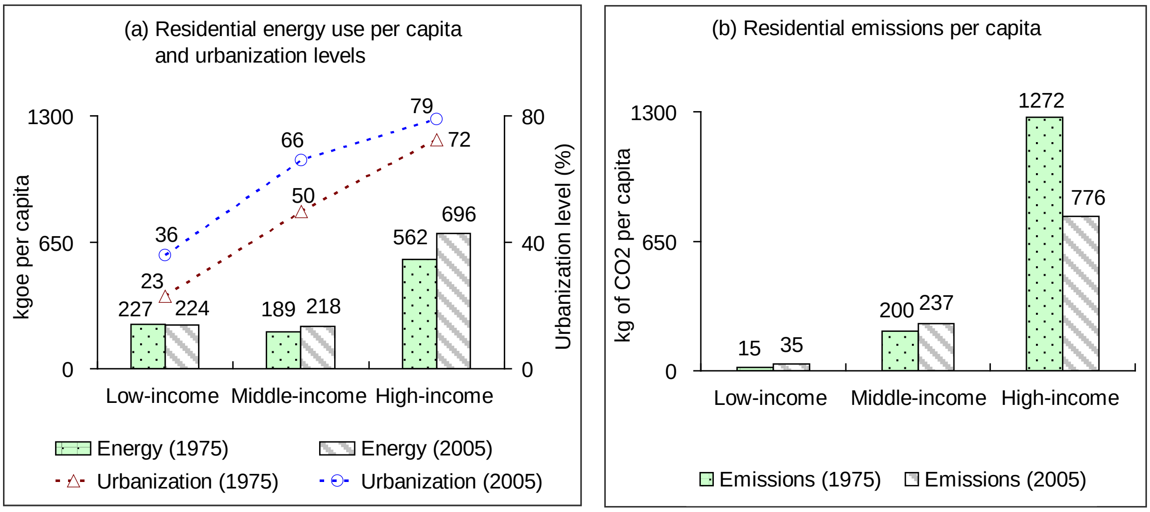

Fig. 2. Urbanization levels, residential energy use and emissions per capita by income group.

Fig. 3 describes relative percentage changes in the aggregate residential energy consumption, emissions and carbon intensity of the low-, middle- and high-income groups compared with the base year (1975 = 0). They differ noticeably among the three income group. When compared with the base year, all the three groups experienced an increase in their residential energy consumption. However, the percentage increase of the low- and middle-income groups was more pronounced than that of the high-income group. While the low- and middle-income groups experienced a significant increase in their residential emissions, the high-income group witnessed a noticeable reduction in their residential emissions, 50% down compared with the base year. This reduction may relate to a steady decline in their carbon intensity as illustrated in Fig. 3 (b). The middle-income group also experienced a decrease in their carbon intensity, whereas the low-income group saw a sharp rise in their carbon intensity, 138% up compared with the year 1975 level.

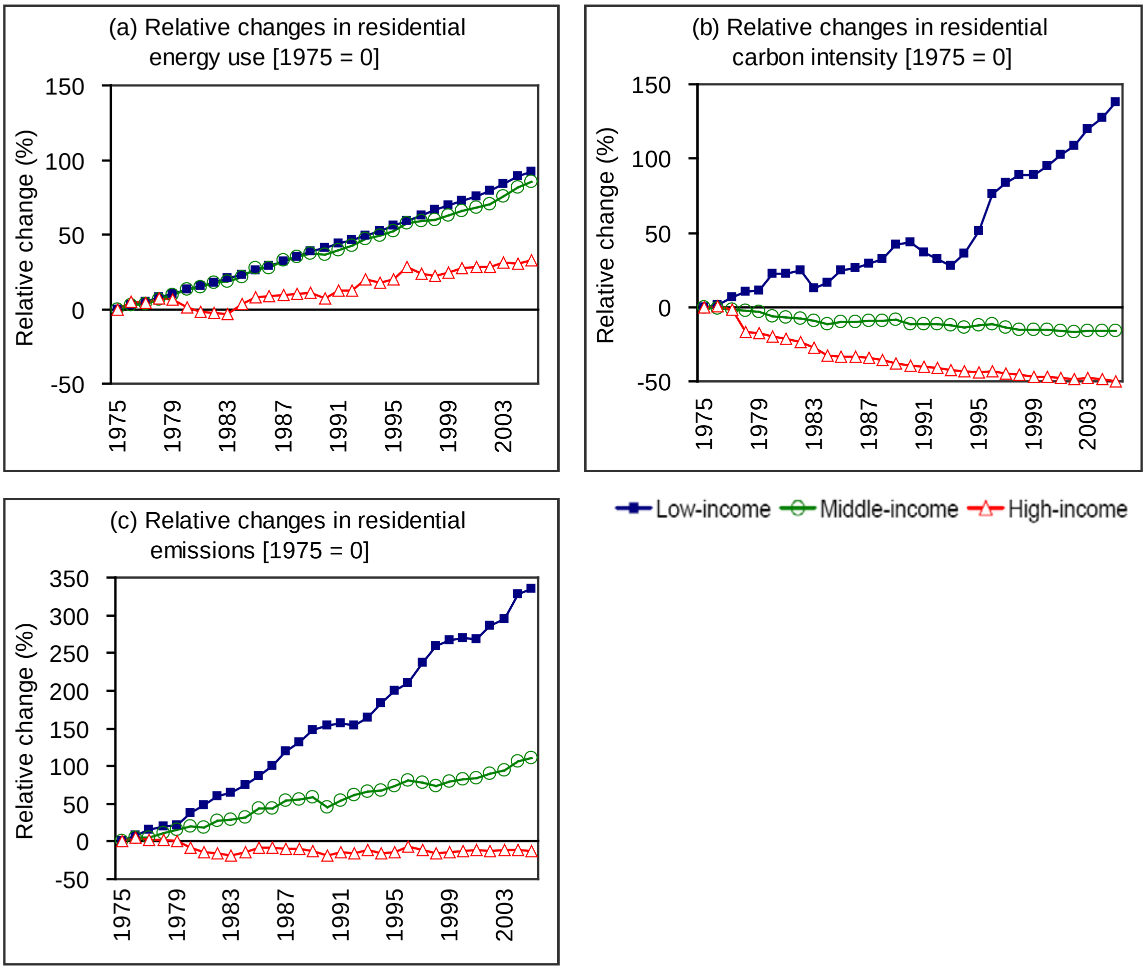

Fig. 3. Relative changes in total residential energy use, emissions and carbon intensity by income group compared with the year 1975 level.

4.2. Empirical results and discussion

Table 4 presents the results of the residential energy use analysis for the whole sample, whereas Tables 5, 6 and 7 report the results for the low-, middle- and high-income groups. As Models 1, 5, 9 and 13 are preferred, our main interpretations focus only on them. Model 1 suggests that without consideration of the stages of development, population size and income per capita influence household energy use positively, while urbanization affects it negatively. A 1% increase in population size and income per capita raises residential energy use by about 1.6% and 0.27%, respectively, whereas a 1% rise in urbanization reduces it by almost 0.7%.

However, the results from Models 5, 9 and 13 suggest that the influence of population, income and urbanization varies noticeably among the three income groups.

The elasticity of household energy consumption with respect to changes in population size is about 2 in the high-income group, which is substantially higher than that of the low- (1.661) and middle- (1.233) income groups. The elasticity with respect to changes in GDP per capita is also positive linear in the low- and middle-income groups, while it exhibits an inverted U-shape in the high-income group. In the low- and middle-income groups, a 1% increase in income per capita raises residential energy use by 0.118% and 0.217%, respectively. In the high-income group, household energy use first rises and then falls with income. The turning point occurs at a level of income per capita around US$20,398 [calculated by taking the antilogarithm of (–7.621/2(–0.384))], within the range of observations (see Table B.1 in Appendix B). The findings support the previous research by Yoo and Lee (2010), who found an inverted U-shape relationship between income per capita and electricity consumption per capita in developed countries. They can also be new supporting evidence for the energy–EKC at the sectoral level.

Interestingly, the influence of urbanization on residential energy use in the low-income group is negative, while it is positive in the high-income group. A 1% increase in urbanization decreases household energy consumption in the low-income by 0.223%, whereas in the high-income group, it raises household energy consumption by 1.645%. In the middle-income group, residential energy use first declines and then rises with urbanization with a turning point at around 70% [calculated by taking the antilogarithm of (2.872/2(0.338))]. This nonlinear relationship implies that the urbanization elasticity of residential energy use varies over the level of urbanization, but it can be calculated by taking the first partial derivative with respect to '*lnURB*' in the model (York et al., 2003a). In doing so, the elasticity function can be written as (–2.872 + 0.676 ln*URB*). It varies from –0.871 when urbanization is 19.3% (the lowest level of the middle-income group) to 0.195 when urbanization is 93.4% (the highest level of the middle-income group). Nonetheless, the middle-income group comprises 39 countries with diverse levels of urbanization, calculating the elasticity with respect to changes in the mean urbanization of the group is more rational. After inserting the mean urbanization (58.74%), the elasticity is –0.122. This implies that a 1% increase in urbanization reduces the residential energy use of the middle-income group by 0.122%.

To a large extent, the results from the residential energy use analysis are consistent with the findings by Poumanyvong and Kaneko (2010) that the impact of urbanization on aggregate energy use varies among the low-, middle- and high-income groups. The negative correlation between urbanization and household energy use in the low- and middle-income groups appears to support the argument that urbanization encourages fuel switching from inefficient traditional fuels to modern fuels, which are more efficient, thereby reducing residential energy use (Pachauri, 2004; Pachauri and Jiang, 2008). It is consistent with the argument that low levels of urbanization improve energy efficiency (York, 2007b). The negative urbanization elasticity of household energy use may also relate to limited access to electricity in urban areas of the developing world, which could restraint their urban household energy usage (see Table 1). In 2005, globally, there were nearly one billion people living in urban slums, lacking access to basic urban services (UN-HABITAT, 2006). The vast majority of these people resided in the developing world. Jorgenson et al. (2010) found a negative link between national energy use and the percentage of a population living in urban slums.

The positive relationship between urbanization and household energy consumption in the high-income group is consistent with the argument that urbanization implies lifestyle changes higher standards of living, greater access to electricity supplies and increased stocks of energy-using appliances, which are likely to contribute to an increase in residential energy use (Halicioglu, 2007; Holtedahl and Joutz, 2004; Liddle and Lung, 2010). It can also be attributed to fact that as urbanization and income levels rise, the high-income countries experience a decline in average household size (Carpenter, 1966; Lenzen et al., 2006), and an increase in their average living space (UN-HABITAT, 2008). These changes are likely to require greater amounts of residential energy used for lighting, heating and cooling, thus increasing in aggregate residential energy consumption.

Table 4
Estimation results for residential energy use models (all income groups).

Variable	Newey–West (1)	Driscoll–Kraay (2)	Prais–Winsten (3)	FGLS (4)
ln*P*	1.599*** (18.94)	1.599*** (34.81)	1.550*** (25.77)	1.529*** (59.62)
ln*A*	0.271*** (7.65)	0.271*** (12.53)	0.231*** (7.07)	0.229*** (16.35)
$(\ln A)^2$	–	–	–	–
ln*URB*	–0.699*** (–6.88)	–0.699*** (–14.40)	–0.569*** (–6.97)	–0.516*** (–5.11)
$(\ln URB)^2$	–	–	–	–
Observations	2,728	2,728	2,728	2,728
R^2	0.982	0.610	0.979	–
Country dummies	Yes	Yes	Yes	Yes
Year dummies	–	–	–	–
Turning point (*A*)	–	–	–	–
Turing point (*URB*)	–	–	–	–
URB elasticity	–0.699	–0.699	–0.569	–0.516

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita and *URB* denotes urbanization. Coefficients of the fixed effects (country and year dummies) and constant are not reported. *t*-values are shown in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 5
Estimation results for residential energy use models (low-income group).

Variable	Newey–West (5)	Driscoll–Kraay (6)	Prais–Winsten (7)	FGLS (8)
ln*P*	1.661*** (9.00)	1.661*** (13.88)	1.311*** (6.99)	1.229*** (44.37)
ln*A*	0.118*** (3.81)	0.118*** (4.13)	0.038* (1.66)	0.031*** (8.30)
$(\ln A)^2$	–	–	–	–
ln*URB*	–0.223*** (–4.36)	–0.223*** (–11.46)	–0.205*** (–6.16)	–0.202*** (–28.40)
$(\ln URB)^2$	–	–	–	–
Observations	651	651	651	651
R^2	0.997	0.916	0.996	–
Country dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Turning point (*A*)	–	–	–	–
Turing point (*URB*)	–	–	–	–
URB elasticity	–0.223	–0.223	–0.205	–0.202

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita and *URB* denotes urbanization. Coefficients of the fixed effects (country and year dummies) and constant are not reported. *t*-values are shown in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 6
Estimation results for residential energy use models (middle-income group).

Variable	Newey–West (9)	Driscoll–Kraay (10)	Prais–Winsten (11)	FGLS (12)
ln*P*	1.233***	1.233***	1.239***	1.243***
	(10.83)	(39.82)	(10.73)	(31.33)
ln*A*	0.217***	0.217***	0.214***	0.201***
	(3.19)	(6.47)	(4.42)	(18.20)
$(\ln A)^2$	–	–	–	–
ln*URB*	–2.872**	–2.872***	–2.878**	–2.810***
	(–2.15)	(–4.76)	(–2.17)	(–5.12)
$(\ln URB)^2$	0.338*	0.338***	0.347*	0.339***
	(1.83)	(3.68)	(1.82)	(4.79)
Observations	1,209	1,209	1,209	1,209
R^2	0.915	0.543	0.977	–
Country dummies	Yes	Yes	Yes	Yes
Year dummies	–	–	–	–
Turning point (*A*)	–	–	–	–
Turing point (*URB*)	70%	70%	63.24%	63.09%
URB elasticity	–0.122	–0.122	–0.054	–0.051

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita and *URB* denotes urbanization. Coefficients of the fixed effects (country and year dummies) and constant are not reported. *t*-values are shown in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 7
Estimation results for residential energy use models (high-income group).

Variable	Newey–West (13)	Driscoll–Kraay (14)	Prais–Winsten (15)	FGLS (16)
ln*P*	2.029***	2.029***	1.912***	1.925***
	(12.56)	(15.95)	(17.40)	(84.01)
ln*A*	7.621***	7.621**	5.475***	5.346***
	(3.16)	(2.29)	(2.78)	(15.29)
$(\ln A)^2$	–0.384***	–0.384**	–0.272***	–0.266***
	(–3.18)	(–2.35)	(–2.77)	(–15.07)
ln*URB*	1.645**	1.645***	1.541***	1.531***
	(2.55)	(3.09)	(2.85)	(23.39)
$(\ln URB)^2$	–	–	–	–
Observations	868	868	868	868
R^2	0.989	0.728	0.978	–
Country dummies	Yes	Yes	Yes	Yes
Year dummies	–	–	–	–
Turning point (*A*)	20,398 (US$)	20,398 (US$)	23,490 (US$)	23,130 (US$)
Turing point (*URB*)	–	–	–	–
URB elasticity	1.645	1.645	1.54	1.531

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita and *URB* denotes urbanization. Coefficients of the fixed effects (country and year dummies) and constant are not reported. *t*-values are shown in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 8 reports the results of the residential emissions analysis of the whole sample, whereas Tables 9, 10 and 11 present the results for the low-, middle- and high-income groups. Since Models 17, 21, 25 and 29 are preferred, our main interpretations focus only these models. The results from Model 17 show that without considering the stages of development, the impact of population size on aggregate residential emissions is positive linear, while aggregate residential emissions rise initially and fall subsequently with income per capita. The turning point occurs at a level of income per capita US$18,249. There also exists a U-shaped relationship between urbanization and household emissions with a turning point at 20.48%. This implies that household emissions first decline and then rise with urbanization. However, the elasticity of residential emissions to the mean urbanization of the whole sample is 0.948.

While considering the stages of development, the results from Models 21, 25 and 29 suggest that the influence of population, income per capita and urbanization is differential significantly among the low-, middle- and high-income groups. A 1% rise in population size raises residential emissions in the low-, middle- and high-income groups by 1.463%, 1.799% and 2.97%, respectively. The income elasticities of residential emissions in the low- and middle-income groups are positive linear, 0.921 and 0.538, respectively. In the high-income group, household emissions first rise and then fall with income. The turning point occurs at a level of income per capita around US$16, 621, within the range of observations (see Table B.2 in Appendix B). This can be fresh evidence at the sectoral level to support the findings by Tamazian and Rao (2010) that there exists an inverted U-shaped relationship between income and emissions per capita.

In contrast to the urbanization–energy use relationship, the impact of urbanization on residential emissions is positive linear in the middle-income group. A 1% increase in urbanization raises residential emissions in the middle-income group by 0.636%. In the low-income group, residential emissions decrease initially and increase subsequently with a turning point at 23.02%. In the high-income group, emissions first rise and then fall with urbanization with a turning point at 65.53%. This supports the argument that some types of environmental impact may follow an EKC relative to urbanization (Ehrhardt-Martinez, 1998; Ehrhardt-Martinez et al., 2002). For comparative purposes, the elasticities of residential emissions with respect to changes in the mean urbanization of the low- and high-income groups are calculated using a similar procedure as stated in the residential energy use analysis. They are 0.59 and –1.535, respectively. These figures imply that urbanization contributes to an increase in residential emissions in the low-income group, while it contributes to a reduction in residential emissions in the high-income group. These findings are different noticeably from those derived from the aggregate level analysis by Poumanyvong and Kaneko (2010), who found that urbanization has a positive impact on aggregate emissions in all the three income groups, but the magnitude of the impact is lower in the high-income group than in the other income groups. However, the impact trend of urbanization from this study largely conforms to that from the aggregate level analysis.

The varying impact of urbanization on residential emissions among the three income groups can possibly be attributable to their differences in the structure of household energy use and energy efficiency, and to their differential changes in these two factors. The positive correlation between urbanization and residential emissions in the low- income group may relate to the fact that this group has shifted from carbon neutral fuels (biomass) towards carbon intensive fuels (fossil fuels) as illustrated in Fig. 1 (a). This shift is also evident in Fig. 3 (b) that the carbon intensity of this group increased sharply between 1975 and 2005. For similar reasons, urbanization influences residential emissions in the middle-income group positively. Conversely, the negative association between urbanization and residential emissions in the high-income group can be attributed largely to their fuel switching towards low carbon intensive fuels and technological progress. As illustrated in Fig. 1 (c), the percentage share of coal and oil use in their total household energy use declined significantly between 1975 and 2005. This decline was replaced with a significant increase in the share of natural gas and electricity use. Unlike the low- and middle-income groups, the electricity mix of the high-income group has shifted towards low carbon intensive sources such as nuclear and modern renewables (Burke, 2010).

Hence, over the period 1975–2005, the high-income group experienced a noticeable reduction in both residential carbon intensity and emissions as shown in Fig. 3 (b) and (c).

Table 8
Estimation results for residential emissions models (all income groups).

Variable	Newey–West (17)	Driscoll–Kraay (18)	Prais–Winsten (19)	FGLS (20)
ln*P*	2.090***	2.090***	2.026***	2.102***
	(11.19)	(19.37)	(12.15)	(18.36)
ln*A*	3.807***	3.807***	3.032***	2.252***
	(5.04)	(5.25)	(3.67)	(4.90)
$(\ln A)^2$	–0.194***	–0.194***	–0.157***	–0.112***
	(–4.44)	(–4.48)	(–3.30)	(–4.10)
ln*URB*	–2.778***	–2.778***	–1.963*	–1.588***
	(–3.30)	(–5.35)	(–1.67)	(–2.68)
$(\ln URB)^2$	0.460***	0.460***	0.356**	0.304***
	(3.63)	(7.05)	(2.31)	(3.31)
Observations	2,480	2,480	2,480	2,480
R^2	0.979	0.457	0.947	–
Country dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Turning point (*A*)	18,249 (US$)	18,249 (US$)	15,616 (US$)	23,239 (US$)
Turing point (*URB*)	20.48%	20.48%	15.75%	13.62%
URB elasticity	0.948	0.948	0.920	0.874

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita and *URB* denotes urbanization. Coefficients of the fixed effects (country and year dummies) and constant are not reported. *t*-values are shown in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 9

Estimation results for residential emissions models (low-income groups).

Variable	Newey–West (21)	Driscoll–Kraay (22)	Prais–Winsten (23)	FGLS (24)
ln*P*	1.463***	1.463***	1.507***	1.585***
	(5.37)	(18.84)	(7.32)	(14.62)
ln*A*	0.921***	0.921***	0.794***	0.697***
	(5.40)	(6.62)	(4.74)	(15.28)
$(\ln A)^2$	–	–	–	–
ln*URB*	–6.812***	–6.812***	–4.663***	–3.174***
	(–4.14)	(–4.80)	(–2.73)	(–4.62)
$(\ln URB)^2$	1.086***	1.086***	0.757***	0.532***
	(3.74)	(4.84)	(2.84)	(4.38)
Observations	527	527	527	527
R^2	0.953	0.537	0.844	–
Country dummies	Yes	Yes	Yes	Yes
Year dummies	–	–	–	–
Turning point (*A*)	–	–	–	–
Turing point (*URB*)	23.02%	23.02%	21.76%	19.75%
URB elasticity	0.590	0.590	0.496	0.452

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita and *URB* denotes urbanization. Coefficients of the fixed effects (country and year dummies) and constant are not reported. *t*-values are shown in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 10

Estimation results for residential emissions models (middle-income groups).

Variable	Newey–West (25)	Driscoll–Kraay (26)	Prais–Winsten (27)	FGLS (28)
ln*P*	1.799***	1.799***	1.755***	1.660***
	(8.48)	(14.15)	(7.05)	(23.64)
ln*A*	0.538***	0.538***	0.350***	0.326***
	(4.87)	(8.80)	(4.40)	(15.32)
$(\ln A)^2$	–	–	–	–
ln*URB*	0.636***	0.636***	0.664***	0.713***
	(2.75)	(6.91)	(3.24)	(11.93)
$(\ln URB)^2$	–	–	–	–
Observations	1,147	1,147	1,147	1,147
R^2	0.977	0.545	0.954	–
Country dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Turning point (*A*)	–	–	–	–
Turing point (*URB*)	–	–	–	–
URB elasticity	0.636	0.636	0.664	0.713

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita and *URB* denotes urbanization. Coefficients of the fixed effects (country and year dummies) and constant are not reported. *t*-values are shown in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 11
Estimation results for residential emissions models (high-income groups).

Variable	Newey–West (29)	Driscoll–Kraay (30)	Prais–Winsten (31)	FGLS (32)
ln*P*	2.970***	2.970***	2.768***	2.687***
	(7.95)	(20.83)	(8.65)	(27.82)
ln*A*	11.079***	11.079***	6.556**	6.714***
	(3.07)	(3.50)	(2.07)	(9.60)
$(\ln A)^2$	–0.570***	–0.570***	–0.341**	–0.349***
	(–3.01)	(–3.55)	(–2.05)	(–9.66)
ln*URB*	47.012***	47.012***	41.043***	38.458***
	(4.30)	(14.42)	(6.55)	(16.25)
$(\ln URB)^2$	–5.620***	–5.620***	–4.853***	–4.534***
	(–4.17)	(–13.50)	(–6.37)	(–15.75)
Observations	806	806	806	806
R^2	0.981	0.331	0.976	–
Country dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Turning point (*A*)	16,621 (US$)	16,621 (US$)	14,957 (US$)	15,047 (US$)
Turing point (*URB*)	65.53%	65.53%	68.62%	69.48%
URB elasticity	–1.535	–1.535	–0.878	–0.707

Notes: ln denotes natural logarithms, *P* denotes total population, *A* denotes GDP per capita and *URB* denotes urbanization. Coefficients of the fixed effects (country and year dummies) and constant are not reported. *t*-values are shown in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

5. Conclusion

This paper examines the potential differential influence of urbanization on aggregate residential energy use and related CO_2 emissions among the low-, middle- and high-income countries for the period 1975–2005. Using the STIRPAT model and controlling for population size and GDP per capita, the results suggest that the impact of urbanization on national residential energy use and emissions varies among the three income groups. Urbanization contributes to a reduction in household energy consumption in the low-income group, while it contributes to the growth of household energy consumption in the high-income group. In the middle-income group, residential energy consumption falls initially and rises subsequently with urbanization with a turning point at 70%. However, the elasticity of residential energy consumption with respect to the mean urbanization of this group is negative.

The varying influence of urbanization among the three income groups can possibly be attributed mainly to their differences in the structure of residential energy use, energy efficiency and lifestyles, and to their differential changes in these factors. As a result of urbanization, household energy use in the low-income group shifts gradually from inefficient traditional fuels such as fuelwood, charcoal and animal dung to modern fuels such as kerosene, LPG and electricity. Such a fuel shift coupled with technological progress could result in efficiency gains, thus dragging their national residential energy consumption down. However, as countries develop further, access to electricity and stocks of electrical appliances in urban areas tend to rise. This coupled with other lifestyle changes is likely to increase residential energy consumption, thus gradually canceling out the efficiency gains from the fuel switching and technological progress at the early stage of development. Hence, the urbanization elasticity of residential energy use changes from –0.223 in the low-income group to –0.122 in the middle-income group. Unlike these two groups, the high-income group urbanizes with virtually universal access to electricity, greater stocks of electrical appliances, smaller household size and increased living space. These attributes may require greater amounts of energy used for lighting, heating and cooling. Consequently, urbanization influences aggregate residential energy consumption in this group positively.

The impact of urbanization on national residential CO_2 emissions is conditional on the structure of household energy consumption and technological progress. It also differs among the three income groups. However, the impact trend is opposite to that of the urbanization–energy use relationship. In the low-income group, residential CO_2 emissions first fall and then rise with urbanization with a turning point at about 23%, while they increase monotonically with urbanization in the middle-income group. In the high-income group, household CO_2 emissions increase initially and decrease subsequently with urbanization with a turning point at around 66%. Nonetheless, the elasticities of residential CO_2 emissions with respect to changes in the mean urbanization of the low- and high-income groups are 0.419, –0.878, respectively. Collectively synthesizing, the impact of urbanization on residential CO_2 emissions shifts from a positive sign in the low- and middle-income groups to a negative sign in the high-income group. This could also be attributed mainly to fuel switching and technological progress. The structure of household energy use shifts from biomass dominance (carbon neutral fuels) in the low-income group to high carbon intensive fuel mix in the middle-income group and then to low carbon intensive fuel mix in the high-income group. Fig. 4 summarizes the impact of urbanization on national residential energy use and emissions.

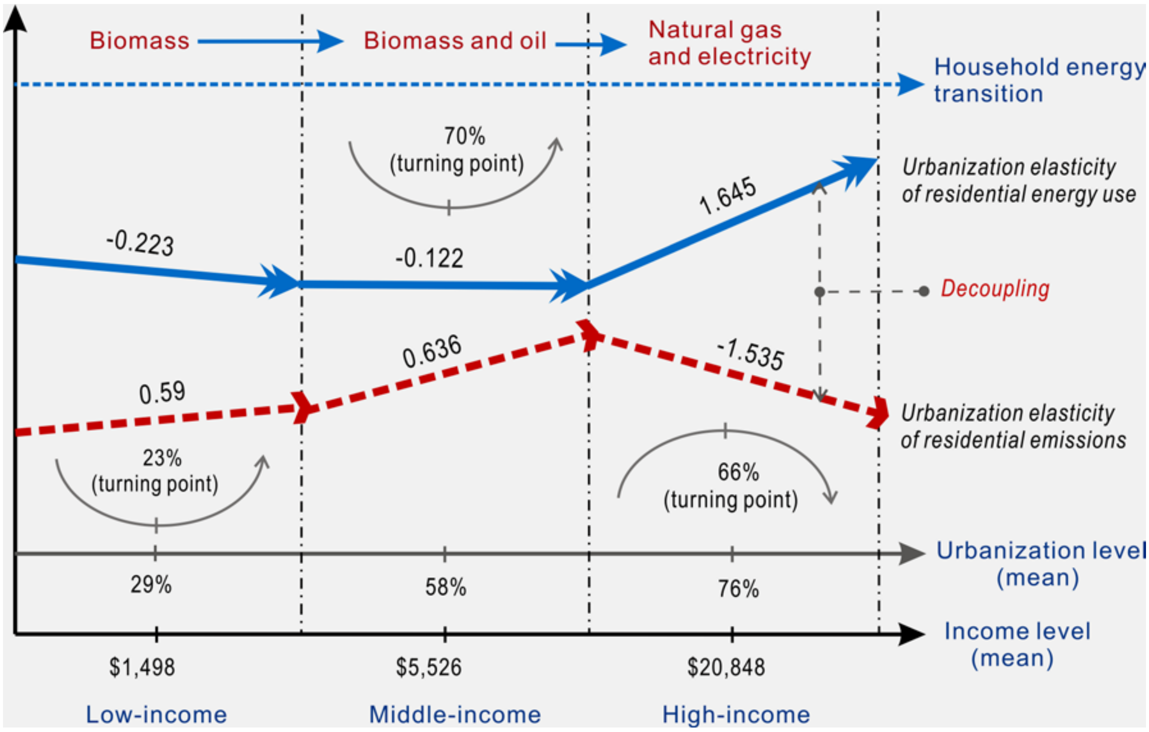

Fig. 4. Summary of the impact of urbanization on national residential energy use and emissions.

This study not only sheds further light on the existing literature, but also presents policy makers with insightful information on the effect of urbanization on national residential energy use and emissions. The findings imply that urbanization brings with it both benefits and costs in different ways for countries of different income levels. Policy makers should be informed and be aware of these tradeoffs. The results also suggest that fuel switching and technological progress brought about by socioeconomic modernization could decouple urbanization’s impact on household emissions from its impact on household energy consumption. Nonetheless, given the importance of biomass to the developing countries and the urgent need to address global climate change, special attention should be devoted to formulating strategies and policies to improve the efficient use of biomass and to accelerate household energy transitions toward low-carbon intensive fuels.

It should be noted that the results of this analysis are based on a national level analysis using a relatively imperfect measure of urbanization. However, in the absence of better alternative measures, and consistent historical data on residential energy use and emissions at the city level, we think our paper makes an important step in deepening our understanding of the impact of urbanization on national residential energy consumption and emissions. Hopefully this paper will encourage further investigation into this regard.

Acknowledgements

We thank the staff of the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), particularly Masakazu Ichimura and Kohji Iwakami for their assistance with data collection. This research is financially supported by the Global Environment Research Fund “Establishing of Methodology to Evaluate Middle to Long Term Environmental Policy Options toward Asian Low-Carbon Society (S-6)” from the Ministry of Environment, Japan. All remaining errors are ours.

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Appendix A

Table A.1
List of 88 countries used for the residential energy use analysis.

1. Low income group (21 countries with per capita GNP ≤ US$765 in 2004)

Bangladesh, Benin, Cameroon, Congo, Dem. Rep., Cote d'Ivoire, Ghana, Haiti, India, Kenya, Mozambique, Myanmar, Nepal, Nicaragua, Pakistan, Senegal, Sudan, Tanzania, Togo, Vietnam, Zambia, Zimbabwe

2. Middle income group (39 countries with per capita GNP between US$766 and US$9,385 in 2004)

Albania, Algeria, Argentina, Bolivia, Brazil, Bulgaria, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Egypt, El Salvador, Guatemala, Honduras, Hungary, Indonesia, Iran, Jamaica, Jordan, Lebanon, Libya, Malaysia, Mexico, Morocco, Panama, Paraguay, Peru, Philippines, Poland, Romania, South Africa, Syria, Thailand, Tunisia, Turkey, Uruguay, Venezuela

3. High income group (28 countries with per capita GNP > US$9,385 in 2004)

Australia, Austria, Bahrain, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Kuwait, Malta, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Arab Emirates, United Kingdom, United States

Table A.2

List of 80 countries used for the residential emission analysis.

1. Low income group (17 countries with per capita GNP ≤ US$765 in 2004)

Bangladesh, Benin, Cameroon, Cote d'Ivoire, Haiti, India, Kenya, Mozambique, Nicaragua, Pakistan, Senegal, Sudan, Tanzania, Togo, Vietnam, Zambia, Zimbabwe

2. Middle income group (37 countries with per capita GNP between US$766 and US$9,385 in 2004)

Albania, Algeria, Argentina, Bolivia, Brazil, Bulgaria, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Egypt, El Salvador, Guatemala, Honduras, Hungary, Indonesia, Iran, Jamaica, Jordan, Malaysia, Mexico, Morocco, Panama, Paraguay, Peru, Philippines, Poland, Romania, South Africa, Syria, Thailand, Tunisia, Turkey, Uruguay, Venezuela

3. High income group (26 countries with per capita GNP > US$9,385 in 2004)

Australia, Austria, Bahrain, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Malta, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States

Appendix B

Table B.1
Descriptive statistics of GDP per capita and urbanization for energy use models (1975–2005).

Variable	Observation	Mean	Std.dev	Minimum	Maximum
All groups					
A (US$)	2,728	9,440	8,851	477	44,843
URB (%)	2,728	57.10	22.14	4.8	98.3
Low-income					
A (US$)	651	1,498	775	447	6,394
URB (%)	651	29.29	10.64	4.80	59.00
Middle-income					
A (US$)	1,209	5,526	2,662	1,101	20,341
URB (%)	1,209	58.47	15.78	19.30	93.40
High-income					
A (US$)	868	20,848	6,088	5,089	4,4843
URB (%)	868	76.05	12.93	40.80	98.30

Table B.2
Descriptive statistics of GDP per capita and urbanization for emissions models (1975–2005).

Variable	Observation	Mean	Std.dev	Minimum	Maximum
All groups					
A (US$)	2,480	9,489	8,625	447	37,267
URB (%)	2,480	57.38	21.09	8.7	97.2
Low-income					
A (US$)	527	1,557	820	447	6,394
URB (%)	527	30.20	10.42	8.70	59.00
Middle-income					
A (US$)	1,147	5,383	2,396	1,101	15,961
URB (%)	1,147	57.40	15.41	19.30	93.40
High-income					
A (US$)	806	2,0518	5,789	5,089	3,7111
URB (%)	806	75.12	12.72	40.80	97.20