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Urbanization, Energy-Use Intensity and Emissions: A Sectoral Approach

Abstract

This paper investigates the relationship between urban population and CO_2 emissions from various sectors with a view towards understanding *energy-use intensity* as the link between urbanization and CO_2 emissions, considered a key driver of climate change. In contrast to extant literature, we analyse this link from two distinct perspectives, involving disaggregation according to sectors or by level of development. Further, using econometric mediation analysis, we provide a deeper exploration of the mechanisms through which climate change manifests exploring the technological inefficiencies that lead to carbon emissions at the sectoral as well as developmental level. Our results indicate that *energy-use intensity*, an indicator of technological inefficiency in controlling emissions, is particularly of importance in the manufacturing sector, playing a vital role in the process through which urbanization affects CO_2 emissions. We also show that the overall link between urbanization/development and emissions is a conditional one, requiring a deeper analysis that separately explores groups of countries classified by income levels as well as various sub-sectors of those economies. Furthermore, the mechanism through which these effects manifest is robust in residential and manufacturing sectors; technological inefficiencies, leading to high levels of energy use intensity are the key contributors to carbon emissions. The findings suggest a sector-based targeted approach that takes into account levels of development is more appropriate relative to a one-size-fits-all approach to global policy.

Keywords: Urbanization; Development; CO_2 emissions; Energy-use intensity; Mediation analysis; Inverted N-shaped relationship

1. Introduction

The world has urbanized rapidly since the twentieth century (Chadchan and Shankar, 2009). While cities only cover 3 percent of the world's land area, they account for at least 60 percent of energy consumption and 70 percent of carbon emissions (United Nations, 2015).[1] Meanwhile, the need to study environmental consequences of urbanization has intensified recently, given the increase in urban relative to rural population, and the emphasis on planning urbanization in a way that mitigates its impact on the environment. Such planning has implications for urban policy. Without policies that incentivize such planning, along with coordination at the global level it will be difficult to achieve desired levels of mitigation. See, for example the United Nations Environment Program (UNEP) Annual Report 2018, which emphasizes the need for planning "climate-smart" cities and setting up the right legal and institutional framework that achieves this end. Likewise, studies in the urban economics/planning literature emphasize policies that lead to green cities (e.g. Fang et al., 2015; Silver, 2017; Glaeser and Kahn 2010).

A gap in this literature, however, is the lack of a perspective that formally and rigorously considers the impacts of urbanization on CO_2 emissions from *different sectors* in an economy and for economies at *different levels of development*. These perspectives are important given that limited resources often constrain policymakers to take a targeted approach to environmental policies, by focusing on areas that need the most attention. However, it is hard to identify these areas without a rigorous examination at a sectoral as well as cross-country level. The former identifies the sectors of the economy that need to be focused on, while the latter suggests a closer look at how the process of development contributes to emissions, so that international policy

[1] Facts from Goal 11: Sustainable cities and communities of the Sustainable Development Goals (SDGs) set up by the United Nations in 2015. Source: https://sdgs.un.org/goals/goal11.

coordination takes into account constraints relevant for countries at different stages of development.

We focus on emissions from the residential sector, public electricity and heating, transportation and manufacturing and construction. These four sectors are closely connected to the urban development, and the main sectors in which emission reductions that could achieve the sustainable cities and communities of the Sustainable Development Goals (SDGs) set up by the United Nations. As urbanization takes place, economies typically show growth in these sectors. However, the patterns of growth and what type of technologies are used in these sectors show a different pattern at different levels of development, due to the use of different types of technologies across countries at different income levels.

The perspectives we provide constitute an important contribution to the literature, which tends to emphasize single-country or regional approaches. While single-country or regional approaches are important, they are more likely to inform regional policies at a given point of time. However, as we have noted above, it is reasonable to hypothesize that emissions vary depending on the nature of processes leading to those emissions. Different sectors of economies employ alternative technologies and we would also expect varying levels of carbon emissions from their use. For example, many recent green technologies such as alternative energy-efficient fuels, zinc-hybrid-cathode-batteries and electric-vehicles are mainly involved in the transportation sector. Likewise, countries at lower levels of development use alternative technologies in the same sectors, relative to their developed counterparts. The sectoral perspective provides an overview of the broader technological forces that contribute to emissions, while the developmental perspective provides insights into the dynamic nature of the problem and how it evolves over time. The aim of this study is to examine these issues, which are critical to understanding the urbanization-emissions link, and thereby inform the urban policies that underpin the development of sustainable cities.

Using a data set of 99 countries spanning more than four decades (1971-2012), we first examine the factors that may lead to CO_2 emissions from different sectors by using a panel data model; our key independent variables are per capita income level, urbanization, and intensity of energy use. Subsequently, we further explore, using mediation analysis, the sectoral and technological mechanisms through which economic growth and urbanization affect CO_2 emissions. These mechanisms are explored using mediation analysis, where we consider the impact of exogenous variables having direct effects as well as indirect effects on emissions via variables that can be considered as "mediators". In the context of this paper, the key mediator variable is energy-use intensity, particularly relevant given that an economy exhibits different levels of energy-use intensity that changes over time as the economy develops and undergoes structural and technological change. This variable represents an indirect proxy of technological inefficiencies that contribute to carbon emissions, and we hypothesize that it is the critical variable determining carbon emissions. To explore the idea that these sectoral and technological aspects also interact with development, we further conduct an analysis that explores the relationship between urbanization and emissions for low-income, middle-income, and high-income countries.

Our results suggest that *energy-use intensity*, an indicator of technological inefficiency, is particularly of importance in the manufacturing sector, playing a vital role in the process through which urbanization affects CO_2 emissions. When we look at analyses of sub-samples of high, middle and low-income countries, manufacturing remains the largest contributor in the urbanization-emissions link in middle- and low-income countries. This result changes in the high-income case, where public electricity use is more important. The mediation analysis shows that in residential and manufacturing sectors, the *mechanism* through which urbanization contributes to emissions relates to energy-use intensity. These insights underline the importance of a sectoral and disaggregated approach to climate policy, while highlighting a need for international policy coordination, and the planning of urbanization in a way that takes account of the above factors.

The remainder of the paper is organized as follows. Section 2 further discusses the motivation and background of this paper. Section 3 discusses the methodology and data. Section 4 presents the empirical analysis and discusses the empirical results. Section 5 concludes.

2. Background and Motivation

2.1 Non-linearities in the emissions-development and emissions-urbanization links

The Environmental Kuznets Curve (EKC) inspired by Simon Kuznets' inequality and development link (see Kuznets, 1955) suggests an inverted U-shaped relationship between economic development, measured by income per capita, and pollution indicators (Grossman and Krueger, 1991). The theory is that at low level of development, as economic growth speeds up the intensification of various forms of resource extraction, the rate of resource regeneration begins to fall behind the rate of resource depletion. At high levels of development, structural change towards advanced technology, the growth of information-intensive industries and services, and higher environmental expenditures and environmentally focused planning of cities, result in a levelling-off and decrease in environmental degradation (Panayotou, 1993).

Many researchers have found empirical evidence supporting an EKC; see, for example, Duarte et al. (2013), Kasman and Duman (2015), and Fujii et al. (2018). Also, Sengupta (1996) finds an N-shaped pattern and emphasises that finding the true structural relationship is important from a policy perspective, in terms of setting appropriate emissions standards at various levels of development. Particularly, in the case of CO_2, empirical findings, in common with the broader literature, show mixed evidence. Most of the studies do not find conclusive evidence to support this hypothesis (Holtz-Eakin and Selden, 1995; Ekins, 1997). However, the EKC hypothesis between GDP and CO_2 is supported for 18 Latin America and Caribbean countries (Al-mulali et al., 2015).

Regarding the significance of levels of development, one can apply two alternative approaches. One approach is to explore the short-run aspect by considering non-linear relationships in the data, reflected, for example in the literature on the EKC, or studies that postulate N-shaped relationships with respect to environment and development. This approach is also applicable to other aggregates given that the concept of development has several correlates, such as urbanization, a key variable of focus in this paper. Another alternative is to explore the long-run aspect by considering countries at different levels of development separately and explore how various aggregates impact on CO_2 emissions in low-income, middle-income, or high-income economies. Studies have indeed found that the impact of urbanization depends on the level of development using these alternative approaches; Martínez-Zarzoso and Maruotti (2011) look for an Environmental Kuznets Curve relating to urbanization, while Sharma (2011) looks at urbanization and emissions using a linear model estimated for groups of economies classified as low-income, middle-income, and high-income. We choose to take a refined version of both approaches and, in a later section, highlight how our approach could yield insights relative to the literature.[2]

[2] Neither of these studies looks at the sectoral dimension, so our analysis differs not only from the point of view of the empirical models used, but also from the perspective of sectoral as opposed to aggregate emissions.

In the context of urbanization, studies often focus on a *linear* relationship between urbanization and air pollution (e.g. Parikh and Shukla, 1995; Sadorsky, 2014). More recently, however, there are trends in this literature that recognize non-linearities in this link. Single country analyses unearth some non-linearity in the form of a significant squared term for their proxy of urbanization (Wang et al., 2017, Shahbaz et al., 2016, Makido et al., 2012, in the case of China, Malaysia and Japan, respectively). Furthermore, in the context of regional analyses, Xu and Lin (2015) find that urbanization follows an inverted U-shaped pattern with CO_2 emissions in the eastern region of China, and a U-shaped pattern in the central region. There is also an inverted U-shaped pattern for the relationship between urbanization and carbon emissions in the context of Malaysia (for e.g. Bekhet and Othman, 2017), and in cross-country samples (as in Zhang et al., 2017). According to some studies, such a relationship varies depending on different levels of development (Li and Lin, 2015). In addition, there are variations based on cross-country samples of low, middle and high-income countries; Wang and Wang (2021) find that the relationship between urbanization and carbon emissions in the high-income countries is an inverted U-shaped, while the relationship in middle- and low-income countries is nonlinear. With respect to the studies focusing on CO_2 emissions from specific sector, Huo et al. (2021) find a nonlinear influence of urbanization on carbon emissions relating to urban buildings.

Recognizing that urbanization is a more complex process with diverse effects on emissions, this paper specifically introduces non-linearity in the models used to examine the urbanization and CO_2 emissions link. In particular, we consider a second turning point of the urbanization process (including cubic term of urbanization in the estimated equation), which suggests that there could be a non-monotonic pattern in the way urbanization impacts on CO_2 emissions with several turning points over time. For example, in the context of another environment-related aggregate, labelled "eco-efficiency", Bai et al. (2018) find the impact of urbanization reflected in an N-shaped form. However, a priori, we do not hypothesise an N-shaped relationship – we simply include a cubic term which allows estimation of an N-shape or inverted N-shape pattern depending on the data set. Given the lack of theoretical research, one can only provide economic intuition for either case.

To investigate the long-run aspect, as mentioned earlier, we use three sub-samples of economies with high, middle, and low income. The inverted N-shaped pattern between urbanization and emissions is dominant across different sub-samples though there are some variations. However, as we will discuss later, the magnitude of the urbanization-emissions link varies in different sub-samples, further highlighting the relevance of a disaggregated approach in informing policy.

2.2 Sectoral Variations

Regarding the non-linear impact of increases in urban population size, there can be sectoral dimensions to consider. As urbanization occurs, cities grow, which impacts emissions in diverse ways according to the changes in technology that take place across sectors and over time. For example, as city develops, the urban population increases due to changes in settlement patterns, leading to CO_2 emissions from the residential sector (Ali et al., 2019). Additionally, urbanization may also cause localized concentration of manufacturing, resulting in changes in CO_2 emissions from the manufacturing industry (Lehmann, 2012). At the cross-country level, however, this idea of sectoral and regional variations interacting with urbanization remains a relatively under-explored aspect of the literature on carbon emissions.

Our results illustrate another layer of complexity in the relationship between urban population increase and sectoral CO_2 emissions. Specifically, a key aspect of the results pertains to the manufacturing sector. In this case, we find that energy-use intensity has the greatest impact overall, in addition to being an important mechanism through which urbanization and development impact on emissions. Even so, when one looks at the sub-samples of high-, middle- and low-income countries, the pattern is not clear-cut.

The above analysis highlights the need for considering the impact of various factors influencing emissions from a broader, more holistic perspective. Levels of development matter, as do technological changes across sectors and over time. Most previous studies ignore these effects and their interaction. This paper attempts to do so by exploring the urbanization-emissions relationship at an aggregate as well as disaggregated level, in addition to exploring mechanisms through which urbanization and development can impact CO_2 emissions. Such an analysis is important, given that policies have been largely informed by the regional level analyses (see, e.g. Makin, 2002; Xu and Lin, 2015; Bekhet and Othman, 2017); however, global cooperation on environmental issues can dramatically reduce the total cost and enhance the effectiveness of climate change mitigation (Siriwardana and Nong, 2021). Such coordination needs to be informed not only by regional analyses, but cross-country analyses of the type conducted in this paper.

3. Methodology and Data

As discussed above, we anticipate a non-linear relationship between CO_2 emissions from various sectors with respect to urbanization and development. As such, we estimate equations as below:

$$cre_{it} = \alpha_0 + \alpha_{11} y_{it} + \alpha_{12} y_{it}^2 + \alpha_{21} urban_{it} + \alpha_{22} urban_{it}^2$$

$$+\alpha_{23} urban_{it}^3 + \alpha_3 enre_{it} + \alpha_i + u_{it}^{re} \quad (1)$$

$$cele_{it} = \beta_0 + \beta_{11} y_{it} + \beta_{12} y_{it}^2 + \beta_{21} urban_{it} + \beta_{22} urban_{it}^2$$

$$+\beta_{23}urban_{it}^3 + \beta_3 enele_{it} + \beta_i + u_{it}^{ele} \quad (2)$$

$$ctran_{it} = \gamma_0 + \gamma_{11}y_{it} + \gamma_{12}y_{it}^2 + \gamma_{21}urban_{it} + \gamma_{22}urban_{it}^2$$

$$+\gamma_{23}urban_{it}^3 + \gamma_3 entran_{it} + \gamma_i + u_{it}^{tran} \quad (3)$$

$$cmanu_{it} = \delta_0 + \delta_{11}y_{it} + \delta_{12}y_{it}^2 + \delta_{21}urban_{it} + \delta_{22}urban_{it}^2$$

$$+\delta_{23}urban_{it}^3 + \delta_3 enmanu_{it} + \delta_i + u_{it}^{manu} \quad (4)$$

where cre_{it}, $cele_{it}$, $ctran_{it}$ and $cmanu_{it}$ are the natural logarithm of CO_2 emissions (unit: Gg) from residential sector, public electricity and heating, road transport and manufacturing industries and construction, respectively in year *t*, for country *i.* [3] Data are obtained from the Emissions Database for Global Atmospheric Research (EDGAR). The variable *y* is the natural logarithm of GDP per capita (Real GDP per capita in 2011US$), obtained from Maddison Project Database 2018 and is a proxy for the level of development. The variable *urban* is the natural logarithm of urban population obtained from World Bank Development Indicators. Variables $enre_{it}$, $enele_{it}$, $entran_{it}$, $enmanu_{it}$ are the natural logarithm of energy use per capita (kg of oil equivalent per capita) in residential, public electricity and heating, road transport and manufacturing industries, respectively. These sectoral variables can be interpreted as indicators which represent the intensity of energy use in the four different sectors. As mentioned previously, these variables are an indirect proxy for differences in technology across sectors. Data are obtained from Burke and Csereklyei

[3] In the context of this paper, we employ carbon emission rather than the carbon emissions per capita to measure climate change. This is because that dividing by population number scales the variable down (Soytas et al., 2007). Friedl and Getzner (2003) suggest the use of total rather than per capita emissions since the Kyoto Protocol calls for a reduction in the percentage of emissions. In addition, total emission is used in many studies; see, for example, Zhang and Cheng (2009) and Apergis and Payne (2014). Once we use the total data for carbon emissions, we use total data rather than per capita data for urban population; see, for example Saidi and Hammami, (2015). We use energy use per capita measures the technical progress since per capita data instead of the total energy consumption can better measure the technology level.

(2016).[4] Annual data for 99 countries are collected over the period 1971 to 2012 and the descriptive statistics of the complete sample is presented in Table 1.

Insert Table 1 here

To investigate the mechanism underlying how various factors in this paper affect the CO_2 emissions, we use structural equation modelling which builds on standard mediation analysis proposed by Baron and Kenny (1986). We first describe this approach and then use it as a benchmark to explain the structural equation modelling (SEM) approach used in this paper.

A standard mediation model suggests that the independent variable influences the dependent variable through the mediator variable instead of a direct causal relationship. Mediation analysis is adopted to explore the underlying mechanism through which the independent variable affects dependent variable (Cohen et al., 2014). Therefore, the mediator variable clarifies the nature of the known relationship between the dependent variable and the independent variable (MacKinnon, 2012). Fig. 1 shows a visual representation of a simple mediation model. The arrow in the figure below represents the causal relationship.

Insert Figure 1 here

The direct effect, denoted by the coefficient "C" in Fig. 1, measures the degree to which the dependent variable alters in response to a one-unit increase in the independent variable when the mediator variable remains unchanged; this is measured by running a regression of the dependent variable on the key independent variable without including the mediator as a regressor. On the contrary, the indirect effect, denoted by the product of coefficients "A" and "B", with "A" measured by regressing the mediator variable on the independent variable and "B" measured by

[4] Data for energy use per capita in commercial and public services in Burke and Csereklyei (2016) is used as a proxy for the energy use intensity in the public electricity and heating sector in this paper.

regressing the dependent variable on the mediator variable (Robins and Greenland, 1992). In a linear context, the total effect is the sum of the direct and indirect effects (C + AB). In a nonlinear context, the total effect is a modified combination of the direct and indirect effects, but not simply the sum of two effects (Pearl, 2001).

The traditional approach proposed by Baron and Kenny (1986) requires two regression models presented in Eq. (5) and Eq. (6); one regression with the independent variable predicting the mediator, and one with both the mediator and the independent variable predicting the dependent variable.

$$E[M|X] = ƙ_0 + ƙ_1 X + ƙ_2 C + \nu_1 \quad (5)$$

$$E[Y|X, M] = ƶ_0 + ƶ_1 X + ƶ_2 M + ƶ_3 C + \nu_3 \quad (6)$$

where M denotes the mediator, X is the dependent variable and C denotes the vector of control variables. The indirect effect is calculated by taking the product of the effect of the independent variable on the mediators and the effect of the mediator on the dependent variable, $ƙ_1 ƶ_2$. The direct effect is $ƶ_1$, total effect is measured by the sum of the direct and indirect effect $ƙ_1 ƶ_2 + ƶ_1$.

However, from the point of view of our approach, we are interested in several rather than a single variable impacting emissions through a mediator variable. In equations (1)-(4) above, both output (*y*) and urbanization (*urban*) could affect emissions via the sectoral energy-use intensity (*enre, enele, entran, enmanu*). Output could also impact on urbanization, and therefore influence emissions through another indirect channel. The simple mediator model is however somewhat cumbersome to apply when several mediator variables are involved.

In this paper, we therefore use structural equation modelling (SEM), which is more efficient in dealing with a multiple-step and multiple-mediator models compared to the standard model

(Hayes, 2009). This modern method of mediation analysis does not, a priori assign "mediator" or "independent variable" status to specific regressors but explores causality more comprehensively to determine how the hypothesized mediation model fits the data (Imai et al., 2010).

To elaborate on the mediation analysis specifically relevant to our model, we are interested in whether (i) the level of development indirectly influences emissions through urbanization; (ii) urbanization indirectly influences emissions through intensity of energy-use; (iii) the level of development influences emissions indirectly through intensity of energy-use. A generic representation of the estimated relationships is presented in Figure 2, where c represents sectoral emissions (as stand in for cre, cele, ctran or cmanu), while en stands for setoral energy-use intensity (representing respectively enre, enele, entran or enmanu).[5] Other variables in the system appear with similar notation as they do in the equations (1)-(4) with the subscripts 'it' suppressed for presentational convenience.

Insert Figure 2 here

Estimating these relationships would require multiple steps. For example, when we estimate the equation for CO_2 emission from the residential sector we estimate

$$cre_{it} = \theta_0 + \theta_1 y_{it} + \theta_2 y_{it}^2 + \theta_3 urban_{it} + \theta_4 urban_{it}^2 + \theta_5 urban_{it}^3 + \theta_6 enre_{it} + \varepsilon_1 \quad (8)$$

$$enre_{it} = \zeta_0 + \zeta_1 y_{it} + \zeta_3 urban_{it} + \zeta_4 urban_{it}^2 + \zeta_5 urban_{it}^3 + \varepsilon_2 \quad (9)$$

$$urban_{it} = \lambda_0 + \lambda_1 y_{it} + \varepsilon_3 \quad (10)$$

[5] We consider different mediation specifications and specification tests suggest that the model presented here is a better fit for the data. In the interest of a succinct and focused presentation, we do not report these results. They are, however, available upon request.

where the direct effect of $urban_{it}$ on *cre* is θ_3, the indirect effect of $urban_{it}$ on *cre* is the product of θ_6 and ζ_3. The total effect is the sum of the direct effect and indirect effect, $\theta_3+\theta_6\zeta_3$. For the squared term of urbanization, the direct effect of $urban_{it}^2$ on *cre* is θ_4, the indirect effect of $urban_{it}^2$ on *cre* is the product of θ_6 and ζ_4. The total effect is the sum of the direct effect and indirect effect, $\theta_4+\theta_6\zeta_4$. For the cubic term, the direct effect on *cre* is θ_5, the indirect effect of $urban_{it}^3$ on *cre* is the product of θ_6 and ζ_5. The total effect is the sum of the direct effect and indirect effect, $\theta_5+\theta_6\zeta_5$. For economic growth, the direct effect of y_{it} on *cre* is θ_1, the indirect effect of y_{it} on *cre* is $\lambda_1\theta_3+\zeta_1\theta_6+\lambda_1\zeta_3\theta_6$. The total effect is the sum of the direct and indirect effect, $\theta_1+\lambda_1\theta_3+\zeta_1\theta_6+\lambda_1\zeta_3\theta_6$. In Section 4.3 below we estimate analogous relationships for all sectors.

4. Results and Analysis

4.1 Regression Results for All Countries

Equation (1), Equation (2), Equation (3) and Equation (4) are first estimated for 99 countries.[6] Table 2 shows the results of regressions. According to the Hausman Test, all models are fixed-effects models. However, we also present pooled-OLS results in parallel to the fixed-effects regressions.[7] As shown in Table 2, for the four models, both the coefficients for the linear term and the quadratic term of economic development are significant. The coefficients of output for the linear term are positive and those for quadratic term are negative in the residential, public, and

[6] Before estimating the specifications, we employ the Fisher panel-based unit root tests to test (Maddala and Wu, 1999; Choi, 2001) whether the datasets are stationary. The results of the unit root test indicate the rejection of the null hypothesis. Thus, all the variables are stationary in levels.

[7] We present the pooled-OLS results here as a frame of reference for the mediation analysis in Section 4.3. To our knowledge, mediation analysis has only been explored in the context of pooled-OLS models and the statistical package we use for mediation analysis (STATA version 14) also applies it in the context of pooled-OLS.

manufacturing sectors, reflecting an inverted U-shaped link between economic development and CO_2 emissions.[8] Therefore, in the context of this data set, there is evidence to support the EKC hypothesis in terms of CO_2 emissions from these three sectors. The economic intuition underlying these relationships has been discussed at length in the EKC literature and we do not further elaborate on it in the context of our regressions.

Insert Table 2 here

However, the output-CO_2 emissions link in the transport sector is U-shaped, reflecting that CO_2 emissions increase after a decrease as output level increases. One possible explanation might be that many economies under study are middle-income economies. Developing countries might ignore the application of eco-friendly technologies as they set economic development as their priority in the process of transition. This hypothesis is confirmed from results in Section 4.2. The relationship between economic development and CO_2 emissions from transport is inverted U-shaped in high-income economies, while the corresponding relationship in middle-income economies is U-shaped. To elaborate further on the intuition underlying this result, at a low level of economic development, CO_2 emissions associated with road transportation might be lower when middle-income countries develop extensive public transport systems which decrease the CO_2 emissions from the transport sector. Thus, economic growth has a negative impact on transport CO_2 emissions when a country is at this stage. As countries continue to grow, accompanied by the take-off of industrialization, a larger number of people use their own vehicles. CO_2 emissions in

[8] As a robustness check we considered the inclusion of a cubic term for output; however, in most cases, the term was not significant and specification tests suggested that the models presented here are a better fit for the data. In the interest of a succinct and focused presentation, we do not report these results. They are, however, available upon request.

countries at this level are therefore expected to increase significantly as they achieve economic growth (ADB, 2006).

Furthermore, we note that this relationship has further implications regarding emissions through *indirect channels* not considered in previous literature. One of these channels is urbanization, as discussed in the introductory section of this paper. Our focus in the next sub-section is therefore to explore the link between urbanization, sectoral energy-use intensity, and sectoral emissions. Following these discussions, we explore the mechanisms through which urbanization and other variables impact on emissions; our approach to this end involves the use of mediation analysis as discussed in Section 4.3.

4.1.1 CO_2 emissions from residential sector

Revisiting Table 2, we find that the coefficients for the linear term and cubic term of urbanization are negative and that for quadratic term is positive, suggesting an inverted N-shaped relationship between urban population and CO_2 emissions. [9] The coefficients for urbanization (including the level, quadratic and cubic term) are significant for CO_2 emissions from the residential sector. We briefly offer some economic intuition underpinning this relationship. At an early stage of city formation, there is a low level of urbanization. At this stage, a denser settlement may lead to lower CO_2emission from the residential sector. This is because denser settlement patterns can be more efficient to heat or cool than detached suburban houses (Kelbaugh, 2013). In addition, the process of urbanization not only involves the concentration of houses, but also encourages the development

[9] As mentioned in Section 3.2.1, we do not make an assumption that there is an N-shaped relationship – we simply include a cubic term which allows estimation of an N-shape or inverted N-shape pattern depending on the data set. Given the lack of theoretical research, one can only provide economic intuition for either case. As discussed in Section 3.1, our research unearths an inverted N-shape in two sectors when examining the data for all countries in our sample, but there are variations in estimated relationships across different sectors when we consider different sub-samples of countries classified by income.

of apartment buildings in the cities. Thus, urban population size has a negative impact on residential CO_2emissions when a country is at an early stage of urbanization.

In the second stage, as urban population grows, which might be because of economic development, CO_2emissions are particularly severe because of the dramatic increase in heating or cooling and cooking needs.[10] Furthermore, continuing urbanization will cause population density in cities increase and an over-exploitation of urban resources. Urbanization, therefore, leads to an increase in residential CO_2emissions at this stage.

As countries continue to grow, accompanied by advances in technology, fossil fuel combustion for cooking needs, management of waste as well as the use of electricity become more efficient. Urbanization and the development of cities may also encourage economies of scale in the sanitation facilities provision to facilitate environmental improvements (Martínez-Zarzoso and Maruotti, 2011).[11] Moreover, a high level of urbanization also couples with the enforcement of stricter environmental regulations and increased environmental awareness. Therefore, at a high level of urbanization, urbanization might mitigate the CO_2 emissions. Our results are consistent with the qualitative findings of Nejat et al. (2015) who suggest that developed economies have shown a promising trend of reduction in CO_2 emissions. However, developing countries still encounter with considerable increases in greenhouse gas emissions, which are most likely to be related to the absence of strict, efficient policy aimed at mitigation of greenhouse gas emissions.

[10] The fact that economic growth leads to an increase in urban population is confirmed by our mediation analysis in Section 4.3.

[11] In contrast to our study, Martinez-Zarzoso and Maaruotti consider a simpler model of the urbanization-emissions link which does not take into account indirect effects of urbanization and economic development, which is explored in Section 4.3 below. Furthermore, the countries in their data set are different and they do not consider a sectoral breakdown of emissions.

4.1.2 CO_2 emissions from public electricity and heat production

There is no significant relationship between urbanization and CO_2 emissions from the public sector. This might be attributed to the fact that in low-middle income economies, increase in urban population does not affect CO_2 emissions from the public sector due to the limited funding for public facilities in these countries. In other words, even as people shift from rural areas to the cities, the government cannot afford to build significantly more public facilities. We provide additional evidence to support this result in our disaggregated analysis in Section 4.2. In addition, energy-use intensity in the public sector has the smallest impact on CO_2 emissions across sectors, indicating technological inefficiency is of least significance in the public sector among all sectors under study. This finding remains consistent in disaggregated results with different development levels in Section 4.2.

4.1.3 CO_2 emissions from manufacturing industries and construction

Urbanization also follows an inverted N-shaped pattern with CO_2 emissions from manufacturing industries and construction. To provide an economic intuition for this result, the initial development in urbanization might be accompanied with the adjustment of industrial structure. Industrial structural upgrading effectively reduces the emissions (Zhou et al., 2013). Moreover, greenhouse gas emission might decrease since an increase in the number of people who live in cities encourages the concentration of manufacturing, thus achieving economies of scale. Therefore, urban population size has a negative impact on CO_2 emissions at the early stage of urbanization. As the economy develops, the emission increases because of the increase in production volume. As countries continue to urbanize and cities continue to expand, governments tend to adopt strict regulations on emissions of greenhouse gases relating to the manufacturing sector (Zhang et al., 2015). Furthermore, production processes also improve through technical progress, thus reducing the emissions. For example, the adoption of environmentally friendly machines helps manufacturers to lower CO_2 emission when producing a certain volume of products.

It is important to point out that magnitudes of the impact of energy-use intensity and the urbanization-emissions link are greater relative to other sectors. This is of further significance considering our subsequent finding based on mediation analysis in Section 4.3 below which suggest that energy-use intensity is the key mechanism via which urbanization and development impact on emissions.

4.1.4 CO_2 emissions from road transport

However, based on the panel data analysis presented in Table 2, we do not find a significant relationship between urbanization and CO_2 emissions from road transport. This might be because urbanization impacts emissions from road transport through the change of *mode* of transport. However, modes of transport are associated with the spatial distribution of population in the city instead of urban population. For example, dense concentrations of population encourage the use of public transport, and therefore, decrease transport emissions. A caveat that applies here is that national-level urbanization population, which is the variable used in our study, is not a very accurate measure of spatial distribution. For example, Melbourne in Australia, a highly urbanized city, has a relatively high reliance on personal transport (Liddle and Lung, 2010). Therefore, merely focusing on urban population cannot yield insightful results. The impact of urbanization on emissions from transport needs to be investigated in future research using a more specific indicator of urbanization.

4.2 Regression Results for Groups of Countries with Different Income levels

Next, to further address our hypothesis that the level of development matters for the urbanization-emissions link we repeat the same exercise for three sub-samples of high-, middle- and low-income countries as per the World Bank classification of countries. The high-income group contains 35 countries, the middle-income group contains 54 and the low-income group contains 10 countries. The list of countries in each group is presented in Appendix A. The estimation results for different groups are shown in Table 3, Table 4, and Table 5.

Insert Table 3, Table 4, and Table 5 here

The EKC hypothesis is confirmed in high-income countries for CO_2 emissions from all four sectors we study. However, we fail to find robust evidence to support an EKC with respect to CO_2 emissions from road transport sector in middle-income countries. This might be because in middle-income economies, increasing use of vehicles is expected to create a higher level of CO_2 emissions (Hu et al., 2010). One potential factor which might drive CO_2 emission from road transportation could be shifting choices regarding the type of vehicle, from those that are less emission-intensive to those that are more emission-intensive. Furthermore, an increase in private vehicles leads to an increase in the frequency of traffic congestion which is a common phenomenon in many middle-income countries such as China and India. Therefore, for those middle-income countries, promoting public transport facilities and improving the car-sharing platform might be an effective way to reduce carbon emissions in the short-run. As countries continue to grow and reach the high-income level, accompanied by advances in technology, the process of production becomes more advanced, and vehicles become more efficient because of technological changes such as engine modifications and exhaust gas recirculation.

Disaggregated results show that the inverted N-shaped link between urbanization and emissions in residential and manufacturing sectors in the complete sample is driven by middle- and low-income economies. While there is no significant relationship between urbanization and CO_2 emissions in public electricity and heating sector in the complete sample, an inverted N-shaped link exists in high- and middle-income economies. To elaborate the economic intuition underlying this result, at a low level of urbanization, higher residential density leads to a conglomeration of public amenities as well, given that people live closer together in smaller urbanized locations. This concentration alleviates emissions to some extent. As urbanization increases, accompanied by the further and more widespread development of public facilities such as public schools, shopping malls and libraries, as well as the development of air conditioning systems in these facilities, CO_2emissions from public electricity and heating increase. Finally, when urbanization reaches a high level, efficiency of public electricity and heating increases due to investment in technologies targeted at reducing emissions. Moreover, a high level of urbanization, as mentioned earlier, also couples with the enforcement of stricter environmental regulations and increased environmental awareness. Therefore, at a high level of urbanization, urbanization might mitigate CO_2 emissions. For low-and middle-income countries with a lower level of urbanization, policy makers should focus on improving public infrastructure in a climate-smart way while putting in place regulations and reform that incentivize investment emissions-reducing technologies.

Overall, the evidence for the relationship between urban population and CO_2 emission is mixed in countries at different income levels. For instance, in high-income economies, the urbanization-emissions link seems to be strongest in public electricity and heating sector, followed by manufacturing. This might be because the transport, residential facilities and manufacturers are already well-developed in high-income economies. The largest change that urbanization could bring is the development of public facilities. For middle-and low-income countries the contribution of the manufacturing sector in the urbanization emissions link seems to be the greatest, followed by public electricity and heating sector. Unlike the circumstance in high-income countries, the largest change that urbanization could bring in middle- and low-income countries lies in the manufacturing sector, followed by the public utility sector. This suggests that the greatest gains in the mitigation of CO_2 emissions may manifest through the development of green technologies in manufacturing.

In general, regardless of sectors and income groups, the coefficients for energy-use intensity are positive and significant, which means the energy-use intensity has a noticeable and positive impact on CO_2 emissions. However, there are some interesting differences to note when we compare the aggregate results with estimations for sub-samples of countries. In the larger sample, for instance, we find that the magnitude of energy-use intensity in manufacturing sector is the largest relative to other sectors. Such a pattern is not, however, uniformly observable in all the sub-sample results. Particularly, for low-income countries, the coefficient for the intensity of energy use in residential sector is the largest, followed by that in manufacturing sector. One explanation for this could be that the other three sectors are at a relatively low developmental level in terms of technology, and the progress of technology has decreased the technological inefficiency for urban housing. Therefore, the largest change that technology brings is within the residential sector. However, in the context of high- and middle-income countries, energy-use intensity remains the greatest contributor in manufacturing relative to other sectors. It is also interesting to note that, regardless of development level, technological inefficiency in public electricity and heating sector, as indirectly proxied by the energy-use-intensity variable, is of the smallest magnitude across all sectors.

The key point to highlight in the above results is that relationships based on aggregate data do not necessarily manifest when disaggregation based on the level of development is applied. This is only natural to expect, given that structural changes that occur in the process of transition are bound to shift the contribution of sectors in growing economies. As such, aggregate relationships may be misleading from the point of view of informing policy. International coordination on environmental policy should likewise consider relationships that are regionally and sectorally relevant.

4.3 Mediation Analysis

In this section, we perform the mediation analysis discussed in Section 3, as illustrated using equations (8)-(10) and the graphical representation in Fig. 2 in the context of the residential sector for all the four sectors. In what follows, we present the results in Table 6 below, where Panels A, B and C respectively present the direct, indirect, and total effects. As a frame of reference, we note that the direct effect is essentially captured by the pooled-OLS results presented earlier in Section 4.1. [12]

Insert Table 6 here

Panel C shows the total effects which present the estimation results considering the mediation mechanism, while Panel B is indirect effects which are the decomposition result by subtracting the

[12] Several limitation may apply to SEM. First, in the absence of a fixed-effect SEM estimation in Stata (the statistical software used), we can only perform the mediation analysis using pooled-OLS estimation. Second, the estimator used in SEM, i.e. maximum likelihood, allows the effects of a misspecified parameter to be propagated (Kaplan 1988, 1989). Thus, an omitted path could potentially bias estimates of other structural or measurement parameters that would appear to be far downstream from the misspecified parameter (Tomarken & Waller, 2005).

direct effect from the total effects. For example, the third column in Table 6 shows the total; indirect and direct effects for the manufacturing sector, the indirect effect of *urban* on *cre* -4.627 equals to the total effect of *urban* on *cre* -13.519 less the corresponding direct effect -8.892. For the non-linear term, the indirect effect of *urban2* on *cmanu* 0.272 equals to the total effect of the squared urbanization term, *urban2* on *cmanu* 0.852 less the corresponding direct effect 0.580. Likewise, the indirect effect of *urban3* on *cmanu* -0.005 equals to the total effect of urban3 on *cmanu* -0.016 less the corresponding direct effect -0.011.

Panel B shows that the linear term, the quadratic term as well as the cubic term of urbanization have an indirect and significant impact on CO_2 emissions from residential and manufacturing sectors, suggesting that energy-use intensity is an effective mediator in the process through which urbanization affects CO_2 emissions. Furthermore, as shown in Panel C, which is looking at the total effects (direct plus indirect effects), we find that when considering the mechanism as shown in Fig. 2, the coefficients for the linear term, the quadratic term, as well as the cubic term of urbanization are significant for CO_2 emissions from residential and manufacturing sectors. Particularly, the largest contributor in the urbanization-emissions link, inconsistent with the results in Section 4.1, remains the manufacturing sector. The signs of the coefficients for the linear term and the cubic term of urbanization are negative, while the coefficient for the quadratic term is positive. Thus, in parallel with previous results for the "direct effects" in Section 4.1, our mediation analysis confirms that economic growth and urbanization have a non-linear relationship with CO_2 emission in residential and manufacturing sectors, when indirect effects are considered. In contrast, indirect effects in public and transport sectors are not significant. This proves that aggregated analysis might lead to misleading results. This is because as the urbanization-emissions link varies across sectors. Similarly, the role of energy-use intensity as the mediator via which urbanization and economic development impact emissions is also not robustly observed across all sectors.

Furthermore, the total effects in Panel C, show that the magnitude of sectoral energy-use intensity, an indicator of sectoral technological inefficiency, is the largest in the manufacturing sector, which is consistent with our analysis in Section 4.1. Energy-use intensity is not significant in the public electricity and heating sector, again consistent with the findings in Section 4.1, indicating that technological inefficiencies are of little significance in this sector.

Overall, the mediation analysis confirms the inverted N-shaped relationship between urbanization and CO_2 emissions from residential and manufacturing sectors. Based on the mediation analysis, energy-use intensity is the key mechanism via which urbanization and development impact on emissions in residential and manufacturing sectors. This suggests good returns to policies aimed at green technologies in the residential and manufacturing sectors. However, as emphasized earlier, the nature of the impact at the disaggregated level is different in comparison with the analysis of the complete sample.

Another striking aspect of these results relates to our sector-wise comparisons of CO_2 emissions. Although the impact of energy-use intensity is of the greatest magnitude in the manufacturing sector for the complete sample, the results show heterogeneity across sub-samples at different income levels as presented in Appendix B. From the perspective of policymaking, countries at different development level can focus on technological advances in different sectors to achieve a reduction in CO_2 emissions.

4.4 Summary of Key Results and Contributions Relative to Literature

To summarize, the key results and contributions that emerge from our analysis are as follows:

(i) *The sectoral dimension*: An insight that emerges is that the largest contributor in the urbanization-emissions link, viewed from a cross-country level is the manufacturing sector. This outcome, along with studies that highlight the importance of manufacturing in leading to international income convergence, such as that of Rodrick (2014), suggest a trade-off between growth and environmental sustainability. There is then obvious implication for global policy here; given such a trade-off bringing about global cooperation on climate related policies may be difficult.[13] In order to bring about consensus, the approach could focus on finding ways to address the trade-off, for example, by investing in research and development in cost-effective transitional solutions that address sustainability issues in countries where adoption of green technology is prohibitive due to implementation costs.

(ii) *The technological dimension and its interaction with the sectoral dimension*: We use mediation analysis for the full sample of countries to highlight that, in the residential and manufacturing sectors, the *mechanism* through which urbanization contributes to emissions relates to energy-use intensity, suggesting that sector-specific technological inefficiencies in controlling emissions are important. The policy implication, in light of the fact that highest emissions come from the manufacturing sector, is that investments in green technologies are likely to have the highest returns in the manufacturing sector.

[13] Such conflict over climate policies is reflected in the lack of consensus witnessed in international congregations over policies such "net-zero by 2050" at the Glasgow COP26 summit, e.g. the United States, European Union as well as Australia set the target to become net-zero by 2050, while China, Russia and Saudi Arabia set a 2060 target, and India set a 2070 target. Plans regarding the achievement of these standards also differ across countries. For example, Australia and Austria are the two leading countries to engage in the Net Zero Industries Mission that aims for net-zero in the industrial sectors.

(iii) *The level of development* is another aspect which we need to consider in the urbanization and emissions link. When we look at analyses of sub-samples of high, middle and low-income countries, the picture is slightly different. In middle- and low-income countries, manufacturing remains the largest contributor in the urbanization-emissions link. This result changes in the high-income case, where public electricity use is more important. The policy implication here is that a one-size-fits-all policy for countries at different levels of development may not work. Instead, our results suggest targeting of public electricity use in high-income countries, while focusing on the manufacturing sector in middle and low-income countries.

(iv) *The dynamic aspect* which can only be unearthed using the disaggregated panel-data analysis is important. We find that in residential and manufacturing sectors, the relationship between urbanization and emissions is best reflected in an inverted N-shaped specification; urbanization in its initial and later stages impacts negatively on emissions but there is an in-between stage where the impact is positive. There is however some variation in the estimated relationships across levels of development. Again, this reinforces the need for a closer examination of the process of development in conjunction with its level while designing policies for climate mitigation.

In contrast to the extant literature, we explore the role of energy-use intensity in the urbanization-CO_2 emissions link using mediation analysis which, to our knowledge, has not been used in this context. Additionally, this paper differs from the literature in that it considers a sectoral as well as level-of-development perspective to these issues. Existing studies investigate the urbanization-carbon emission link for a specific sector, for example, see Ali et al. (2019) for the residential sector, and Lehmann (2012) for manufacturing industry. However, to date, research on the relationship between urbanization and carbon emissions has been explored to a limited degree in cross-sectoral as well as longitudinal comparisons. Our paper also contributes to the literature by extending the non-linear perspective of urbanization-carbon emissions link from a one-inflection-point to two-inflection-points view. Previous findings on the non-linear urbanization-carbon emissions link indicate that urbanization follows an inverted U-shaped pattern with carbon emissions (e.g. Xu and Lin, 2015; Bekhet and Othman, 2017; Zhang et al., 2017). Our study suggests that when viewed at the sectoral level, there is an inverted-N shaped relationship between urbanization and carbon emissions in residential and manufacturing sectors.

5. Policy Implications and Concluding Remarks

The recent rapid increases of world temperature have led to increasing concerns among policymakers and other citizens of the global economy. In light of this phenomenon, the possible impact of urban population growth on CO_2 emissions has also come into focus as a major driver of global warming; this has occurred as a result of the dramatic growth in cities and the consequent increase in urban population size experienced in recent times. The findings of this paper show that urban expansion is the important driving force behind the change in CO_2 emissions from residential and manufacturing sectors at a global level. However, the nature and magnitude of the urbanization-emissions link vary across sectors and different levels of aggregation leading to further insights of relevance to any approaches aimed at mitigating emissions.

Furthermore, our results identify energy-use intensity as a key variable influencing emissions. Our mediation analysis suggests that it acts as a mechanism in the process through which urbanization affects CO_2 emissions in the residential and manufacturing sectors, suggesting technological inefficiencies in these sectors. This is an important finding, showing that both the direct and indirect impact of this aggregate is of concern. Specifically, although the qualitative nature of this impact generally remains homogenous across countries at different income levels, the quantitative nature varies in different sub-samples. The results suggest that the largest magnitude of energy-use intensity occurs in the residential sector in low-income countries, and in the manufacturing sector in middle- and high- income countries.

This paper extends the extant research in several ways. First, we identify the mechanism through which urbanization affects carbon emissions using SEM and find that technological inefficiency, measured by energy-use intensity, plays an important role in the residential and manufacturing sectors. The approach we employ is very powerful in exploring the underlying mechanism and to our knowledge, has not been used in studies regarding climate change. Second, we find the inverted-N shaped relationship between urbanization and carbon emissions. In contrast to existing studies which only use the squared term to investigate the non-linearity (e.g., Martínez-Zarzoso and Maruotti, 2011; Wang and Wang, 2021), we explore the potential for additional non-linearities in the urbanization-emissions link. Third, we analyse the urbanization-CO_2 emissions link across different sectors as well as different levels of development. The heterogeneity in the sectoral and developmental dimensions levels suggest the need to formulate climate policies that are sector and development specific.

To elaborate, policies aimed at mitigating emissions should look at the sectoral contributions as they shed light on avenues for technological development and regulation. Given that all sectors contribute to emissions, there is a need for a broad-based policy in addition to sector-specific policies. Secondly, the non-linearity of the relationship is of relevance, as is the fact that disaggregated data can show diversity in the nature of the urbanization-CO_2 emissions link, pointing towards the need for policy coordination at an international level. Thirdly, the relationship may have different patterns at different development levels. For low-and middle-income countries with a lower level of urbanization, policymakers should encourage urbanization in a controlled, sustainable way to take the advantage of agglomeration effects and scale economies. In addition, urban planning should be prioritized with governments investing in the design of a well-organized city network and public transportation system to avoid traffic congestion.

If urban population concentrates in a few metropolitan cities inefficiently, the total carbon footprint in the transport sector may increase while emissions in the other public electricity, residential and manufacturing sectors decrease. As such policies aimed at more even development across regions may be more beneficial and sustainable. Lastly, the comprehensive investigation of sectoral carbon emissions can also assist policymakers in the efficient allocation of resources aimed at mitigating carbon emissions. In high- and middle-income countries, one of the most essential policies is improving energy efficiency in the manufacturing sector. In contrast, in low-income countries, an environmentally friendly energy consumption pattern could be promoted. Furthermore, in these countries, investments in the use of energy efficient technologies in the residential sector could yield returns in terms of reduced residential carbon emissions.

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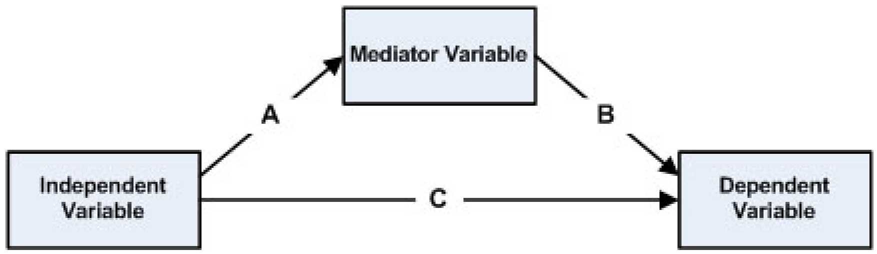

Figure 1 A Simple Mediation Model

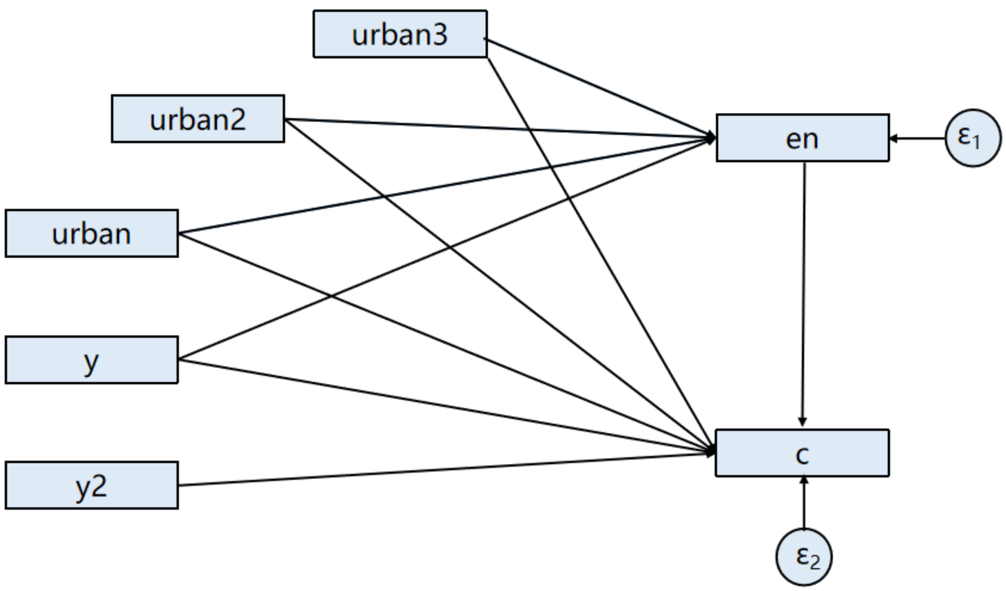

Figure 2: Visual Representation of the Mediation Analysis for Residential Sector

Note: urban, urban2, urban3 denote the linear term, quadratic term, and the cubic term of urbanization (*urban* in Equations 1-4), respectively. The symbols y, y2 denote the linear term, quadratic term of economic development (*y* in Equations 1-4). The notation for energy use intensity is 'en' a generic stand-in for sectoral energy (respectively enre, enele, entran or enmanu in equations 1-4) while 'c' stands for sectoral carbon emissions (respectively cre, cele, ctran and cmanu in equations 1-4).

Table 1: Variable Description and Summary Statistics

Variable	Description	Observation	Mean	Std.dev	Min.	Max.
cre	Logarithm of CO2 emissions from residential sector (unit: Gg)	4158	8.017	2.244	2.157	13.719
cele	Logarithm of CO2 emissions from public electricity and heating (unit: Gg)	4132	8.369	2.722	1.076	15.308
ctran	Logarithm of CO2 emissions from road transport (unit: Gg)	4158	8.658	1.813	3.619	14.250
cmanu	Logarithm of CO2 emissions from manufacturing industries and construction (unit: Gg)	4113	8.343	2.191	1.051	14.697
enre	Logarithm of energy use per capita (kg of oil equivalent per capita) in residential sector	3920	5.482	0.833	-0.448	7.840
enele	Logarithm of energy use per capita (kg of oil equivalent per capita) in public electricity and heating sector	3593	3.452	1.864	-4.128	6.915
entran	Logarithm of energy use per capita (kg of oil equivalent per capita) in road transport sector	3918	5.069	1.386	0.056	8.527
enmanu	Logarithm of energy use per capita (kg of oil equivalent per capita) in manufacturing industries	3914	5.145	1.554	-2.236	8.700
urban	Logarithm of urban population	4158	15.723	1.503	11.555	20.368
y	Logarithm of GDP per capita (Real GDP per capita in 2011US$)	4158	8.865	1.104	5.922	11.314

Table 2: Regression Results for the Complete Sample

Dependent variable	*Fixed-effects*				*Pooled OLS*			
	cre	*cele*	*ctran*	*cmanu*	*cre*	*cele*	*ctran*	*cmanu*
y	3.125***	1.662***	-0.372***	2.694***	2.202***	5.655***	-1.135***	1.258***
	(0.172)	(0.327)	(0.057)	(0.167)	(0.221)	(0.309)	(0.084)	(0.159)
y^2	-0.172***	-0.060***	0.026***	-0.150***	-0.090***	-0.257***	0.058***	-0.072***
	(0.009)	(0.018)	(0.003)	(0.009)	(0.013)	(0.018)	(0.005)	(0.009)
$urban$	-4.952***	-2.726	0.111	-8.214***	-11.313***	-6.553***	-8.524***	-8.892***
	(1.632)	(2.917)	(0.542)	(1.599)	(1.401)	(2.091)	(0.533)	(1.086)
$urban^2$	0.396***	0.131	0.025	0.559***	0.763***	0.449***	0.582***	0.580***
	(0.103)	(0.183)	(0.034)	(0.101)	(0.090)	(0.134)	(0.034)	(0.069)
$urban^3$	-0.009***	-0.001	-0.0003	-0.012***	-0.015***	-0. 008***	-0.012***	-0.011***
	(0.002)	(0.004)	(0.001)	(0.002)	(0.002)	(0.003)	(0.001)	(0.001)
$enre$	0.444***				0.524***			
	(0.022)				(0.022)			
$enele$		0.141***				0.005		
		(0.017)				(0.020)		
$entran$			0.977***				0.770***	
			(0.008)				(0.011)	
$enmanu$				1.123***				0.786***
				(0.016)				(0.014)
Constant	6.510	10.853	-1.800	28.450***	41.995***	3.677	46.179***	38.302***
	(8.537)	(15.415)	(2.841)	(8.370)	(7.374)	(11.018)	(2.810)	(5.710)
Observations	3920	3572	3918	3875	3920	3572	3918	3875
R-squared	0.5087	0.4079	0.9544	0.6793	0.8371	0.7660	0.9640	0.8993

Note: Standard errors are given in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 3: High-income Countries

Dependent variable	cre	$cele$	$ctran$	$cmanu$
y	3.385*** (0.420)	3.779*** (0.744)	1.691*** (0.150)	2.436*** (0.366)
y^2	-0.179 (0.021)	-0.191*** (0.037)	-0.081*** (0.007)	-0.136*** (0.018)
$urban$	6.763** (2.713)	-32.014*** (5.202)	0.112 (0.950)	9.272*** (2.360)
$urban^2$	-0.425** (0.181)	2.224*** (0.343)	-0.016 (0.063)	-0.598*** (0.157)
$urban^3$	0.009** (0.004)	-0.048*** (0.007)	0.002 (0.001)	0.013*** (0.003)
enre	0.473*** (0.026)			
$enele$		0.097*** (0.027)		
$entran$			1.013*** (0.013)	
enmanu				1.174*** (0.017)
Constant	-46.955*** (13.739)	130.150*** (26.745)	-9.768** (4.847)	-57.232*** (11.983)
Observations	1400	1371	1400	1400
R-squared	0.5082	0.5441	0.9729	0.8709

Note: Standard errors are given in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 4: Middle-income Countries

Dependent variable	cre	$cele$	$ctran$	$cmanu$
y	2.151*** (0.423)	2.780*** (0.751)	-0.655*** (0.150)	3.959*** (0.468)
y^2	-0.115*** (0.025)	-0.115*** (0.044)	0.039*** (0.009)	-0.219*** (0.027)
$urban$	-5.023** (2.140)	-14.166*** (4.049)	5.441*** (0.778)	-14.581*** (2.390)
$urban^2$	0.403*** (0.133)	0.883*** (0.248)	-0.288*** (0.048)	0.960*** (0.148)
$urban^3$	-0.009*** (0.003)	-0.017*** (0.005)	0.006*** (0.001)	-0.020*** (0.003)
enre	0.575*** (0.037)			
$enele$		0.093*** (0.020)		
$entran$			1.000*** (0.011)	
enmanu				1.027*** (0.027)
Constant	9.460 (11.408)	61.801*** (21.765)	-30.315*** (4.126)	56.540*** (12.749)
Observations	2120	1849	2118	2095
R-squared	0.5727	0.5544	0.9519	0.6099

Note: Standard errors are given in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 5: Low-income Countries

Dependent variable	*cre*	*cele*	*ctran*	*cmanu*
y	-5.955***	2.829	1.010**	0.254
	(1.932)	(3.182)	(0.427)	(1.169)
y^2	0.436***	-0.214	-0.073**	-0.049
	(0.135)	(0.222)	(0.030)	(0.082)
$urban$	-144.682***	-80.135	5.581	-185.583***
	(22.899)	(51.191)	(5.020)	(16.173)
$urban^2$	10.011***	5.649	-0.374	12.508***
	(1.538)	(3.468)	(0.337)	(1.080)
$urban^3$	-0.229***	-0.132*	0.009	-0.280***
	(0.034)	(0.078)	(0.008)	(0.024)
enre	2.080***			
	(0.227)			
$enele$		-0.571***		
		(0.139)		
$entran$			0.936***	
			(0.019)	
enmanu				1.882***
				(0.059)
Constant	704.814***	373.984	-30.287	916.114***
	(116.156)	(253.964)	(25.506)	(82.144)
Observations	400	352	400	280
R-squared	0.5137	0.0930	0.9663	0.7857

Note: Standard errors are given in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 6: Mediation Analysis Results

Panel A: Direct Effect					
Dependent Variable		cre	cele	ctran	cmanu
	urban	-11.313***	-6.553***	-8.524***	-8.892***
		(1.401)	(2.091)	(0.533)	(1.086)
	urban2	0.763***	0.449***	0.582***	0.580***
		(0.090)	(0.134)	(0.034)	(0.069)
	urban3	-0.015***	-0. 008***	-0.012***	-0.011***
		(0.002)	(0.003)	(0.001)	(0.001)
	y	2.202***	5.655***	-1.135***	1.258***
		(0.221)	(0.309)	(0.084)	(0.159)
	y2	-0.090***	-0.257***	0.058***	-0.072***
		(0.013)	(0.018)	(0.005)	(0.009)
	enre	0.524***			
		(0.022)			
	enele		0.005		
			(0.020)		
	entran			0.770***	
				(0.011)	
	enmanu				0.786***
					(0.014)
Dependent Variable	urban				
	y	0.120***	0.116***	0.120***	0.099***
		(0.022)	(0.023)	(0.022)	(0.022)
Dependent Variable		enre	enele	entran	enmanu

	urban	2.440^{**} (1.126)	10.318^{***} (1.742)	-0.493 (0.820)	-5.885^{***} (1.274)
	urban2	-0.154^{**} (0.072)	-0.632^{***} (0.111)	0.030 (0.052)	0.346^{***} (0.081)
	urban3	0.004^{**} (0.002)	0.013^{***} (0.002)	-0.001 (0.001)	-0.007^{***} (0.002)
	y	0.367^{***} (0.011)	1.371^{***} (0.007)	1.174^{***} (0.008)	1.078^{***} (0.013)
Panel B: Indirect Effect					
Dependent Variable		cre	cele	ctran	cmanu
	urban	1.279^{**} (0.592)	0.053 (0.211)	-0.380 (0.632)	-4.627^{***} (1.005)
	urban2	-0.080^{**} (0.038)	-0.003 (0.013)	0.023 (0.040)	0.272^{***} (0.064)
	urban3	0.002^{**} (0.001)	0.0001 (0.0003)	-0.0005 (0.0008)	-0.005^{***} (0.001)
	y	-1.010^{***} (0.287)	-0.748^{***} (0.287)	-0.163 (0.220)	-0.496 (0.335)
Panel C: Total Effects					
Dependent Variable		cre	cele	ctran	cmanu
	urban	-10.034^{***} (1.519)	-6.501^{***} (2.082)	-8.903^{***} (0.826)	-13.519^{***} (1.475)
	urban2	0.682^{***} (0.097)	0.446^{***} (0.133)	0.605^{***} (0.053)	0.852^{***} (0.094)
	urban3	-0.014^{***} (0.002)	-0.008^{***} (0.003)	-0.012^{***} (0.001)	-0.016^{***} (0.002)
	y	1.192^{***} (0.370)	4.907^{***} (0.437)	-1.298^{***} (0.236)	0.762^{**} (0.372)
	y2	-0.090^{***} (0.013)	-0.257^{***} (0.018)	0.058^{***} (0.005)	-0.072^{***} (0.009)
	enre	0.524^{***} (0.022)			
	enele		0.005 (0.020)		
	entran			0.770^{***} (0.011)	
	enmanu				0.786^{***} (0.014)
	R-squared	0.9985	0.9990	0.9999	0.9993

Note: urban, urban2, urban3 denote the linear term, quadratic term, and the cubic term of urbanization (*urban* in Equation (1), (2), (3), (4)), respectively. y, y2 denote the linear term, quadratic term of economic development (*y* in Equation (1), (2), (3), (4)). Standard errors are given in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Appendix A: Lists of Countries Classified by Income Group

Source: World Development Indicators

High-income Countries

Australia, Austria, Belgium, Canada, Chile, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Rep., Luxembourg, Netherlands, New Zealand, Norway, Oman, Poland, Portugal, Saudi Arabia, Singapore, Spain, Sweden, Switzerland, Trinidad and Tobago, United Kingdom, United States, Uruguay.

Middle-income Countries

Albania, Algeria, Argentina, Bangladesh, Bolivia, Brazil, Bulgaria, Cameroon, China, Colombia, Congo, Rep., Costa Rica, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Gabon, Ghana, Guatemala, Honduras, India, Indonesia, Iran, Islamic Rep., Iraq, Jamaica, Jordan, Kenya, Lebanon, Libya, Malaysia, Mauritius, Mexico, Morocco, Myanmar, Nicaragua, Nigeria, Pakistan, Panama, Paraguay, Peru, Philippines, Romania, South Africa, Sri Lanka, Sudan, Syrian Arab Republic, Thailand, Tunisia, Turkey, Venezuela, RB, Vietnam, Yemen, Rep., Zambia.

Low-income Countries

Benin, Congo, Dem. Rep., Ethiopia, Haiti, Mozambique, Nepal, Senegal, Tanzania, Togo, Zimbabwe.

Appendix B: Mediation Analysis Results for Sub-samples

Table B1: Mediation Analysis Results for the Group of High-income Countries (continued)

Panel A: Direct Effect					
Dependent Variable		cre	cele	ctran	cmanu
	urban	-4.333*	-13.754***	-6.123***	-8.280***
		(2.303)	(3.257)	(1.079)	(1.631)
	urban2	0.326**	0.950***	0.404***	0.577***
		(0.151)	(0.213)	(0.071)	(0.107)
	urban3	-0.006**	-0. 020***	-0.008***	-0.012***
		(0.003)	(0.005)	(0.002)	(0.002)
	y	3.354***	7.151***	3.953***	2.702***
		(1.207)	(1.707)	(0.565)	(0.855)
	y2	-0.181***	-0.386***	-0.171***	-0.169***
		(0.061)	(0.086)	(0.029)	(0.043)
	en	0.742***	0.668***	0.327***	1.177***
		(0.053)	(0.074)	(0.025)	(0.037)
Dependent Variable	urban				
	y	0.443***	0.443***	0.443***	0.443***
		(0.080)	(0.080)	(0.080)	(0.080)
Dependent Variable	en				
	urban	-10.755***	-10.755***	-10.755***	-10.755***
		(1.121)	(1.121)	(1.121)	(1.121)
	urban2	0.668***	0.668***	0.668***	0.668***
		(0.074)	(0.074)	(0.074)	(0.074)
	urban3	-0.014***	-0.014***	-0.014***	-0.014***
		(0.002)	(0.002)	(0.002)	(0.002)
	y	0.825***	0.825***	0.825***	0.825***
		(0.022)	(0.022)	(0.022)	(0.022)
Panel B: Indirect Effect					
Dependent Variable		cre	cele	ctran	cmanu
	urban	-7.978***	-7.183***	-3.517***	-12.661***
		(1.006)	(1.095)	(0.452)	(1.379)
	urban2	0.496***	0.446***	0.219***	0.787***
		(0.065)	(0.070)	(0.029)	(0.090)
	urban3	-0.010***	-0.009***	-0.004***	-0.016***
		(0.001)	(0.001)	(0.001)	(0.002)
	y	-4.836***	-8.715***	-3.996***	-8.297***
		(1.448)	(2.215)	(0.917)	(1.913)
Panel C: Total Effects					
Dependent Variable		cre	cele	ctran	cmanu
	urban	-12.311***	-20.938***	-9.639***	-20.941***
		(2.391)	(3.257)	(1.112)	(2.065)
	urban2	0.822***	1.396***	0.623***	1.364***
		(0.157)	(0.214)	(0.073)	(0.136)
	urban3	-0.017***	-0.029***	-0.012***	-0.028***
		(0.003)	(0.005)	(0.002)	(0.003)
	y	1.482	-1.564	-0.043	-5.595***
		(1.938)	(2.867)	(1.098)	(2.119)
	y2	-0.181***	-0.386***	-0.171***	-0.169***
		(0.061)	(0.086)	(0.09)	(0.043)

en	0.742*** (0.053)	0.668*** (0.074)	0.327*** (0.025)	1.177*** (0.037)
R-squared	0.9995	0.9997	0.9996	0.9997

Note: urban, urban2, urban3 denote the linear term, quadratic term and the cubic term of urbanization (*urban* in Equation (1), (2), (3), (4)), respectively. y, y2 denote the linear term, quadratic term of economic development (*y* in Equation (1), (2), (3), (4)). Standard errors are given in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. The direct effect is estimated using the pooled OLS estimation.

Table B2: Mediation Analysis Results for the Group of Middle-income Countries (continued)

		cre	cele	ctran	cmanu
Panel A: Direct Effect					
Dependent Variable		cre	cele	ctran	cmanu
	urban	15.036***	7.224**	11.372***	-8.328***
		(2.495)	(3.372)	(1.356)	(2.484)
	urban2	-0.829***	-0.376*	-0.609***	0.538***
		(0.154)	(0.208)	(0.083)	(0.153)
	urban3	0.016***	0. 008*	0.012***	-0.010***
		(0.003)	(0.004)	(0.002)	(0.003)
	y	3.597***	1.524**	3.408***	2.397***
		(0.468)	(0.632)	(0.254)	(0.466)
	y2	-0.207***	-0.058	-0.175***	-0.144***
		(0.028)	(0.037)	(0.015)	(0.027)
	en	0.667***	0.859***	0.375***	1.037***
		(0.042)	(0.057)	(0.023)	(0.043)
Dependent Variable	urban				
	y	0.010	0.007	0.010	-0.011
		(0.041)	(0.042)	(0.041)	(0.042)
Dependent Variable	en				
	urban	3.041**	3.104**	3.041**	3.091**
		(1.250)	(1.257)	(1.250)	(1.225)
	urban2	-0.194**	-0.197**	-0.194**	-0.199***
		(0.077)	(0.077)	(0.077)	(0.075)
	urban3	0.004***	0.004***	0.004***	0.004***
		(0.002)	(0.002)	(0.002)	(0.002)
	y	0.721***	0.721***	0.721***	0.709***
		(0.013)	(0.013)	(0.013)	(0.012)
Panel B: Indirect Effect					
Dependent Variable		cre	cele	ctran	cmanu
	urban	2.030**	2.666**	1.142**	3.206**
		(0.844)	(1.094)	(0.474)	(1.278)
	urban2	-0.129**	-0.170**	-0.073**	-0.207***
		(0.052)	(0.067)	(0.029)	(0.079)
	urban3	0.003**	0.004***	0.002***	0.004***
		(0.001)	(0.001)	(0.001)	(0.002)
	y	0.653	0.693*	0.397	0.791***
		(0.707)	(0.415)	(0. 518)	(0.217)
Panel C: Total Effects					
Dependent Variable		cre	cele	ctran	cmanu
	urban	17.066***	9.890***	12.514***	-5.122*
		(2.628)	(3.537)	(1.433)	(2.787)
	urban2	-0.959***	-0.545**	-0.681***	0.332*
		(0.162)	(0.218)	(0.088)	(0.172)
	urban3	0.019***	0.011***	0.013***	-0.006
		(0.003)	(0.004)	(0.002)	(0.004)
	y	4.250***	2.217***	3.805***	3.188***
		(0.847)	(0.756)	(0.577)	(0.513)
	y2	-0.207***	-0.058	-0.175***	-0.144***
		(0.028)	(0.037)	(0.015)	(0.027)
	en	0.667***	0.859***	0.375***	1.037***
		(0.042)	(0.057)	(0.023)	(0.043)

R-squared	0.9992	0.9948	0.9995	0.9986

Note: urban, urban2, urban3 denote the linear term, quadratic term and the cubic term of urbanization (*urban* in Equation (1), (2), (3), (4)), respectively. y, y2 denote the linear term, quadratic term of economic development (*y* in Equation (1), (2), (3), (4)). Standard errors are given in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. The direct effect is estimated using the pooled OLS estimation.

Table B3: Mediation Analysis Results for the Group of Low-income Countries (continued)

		cre	cele	ctran	cmanu
Panel A: Direct Effect					
Dependent Variable		cre	cele	ctran	cmanu
	urban	-116.939***	-57.635	-6.252	-101.361***
		(23.038)	(48.408)	(17.274)	(35.675)
	urban2	8.043***	4.381	0.482	6.981***
		(1.537)	(3.226)	(1.152)	(2.367)
	urban3	-0.182***	-0.109	-0.011	-0.159***
		(0.034)	(0.071)	(0.026)	(0.052)
	y	-6.770***	-7.828**	7.652***	-11.232***
		(1.907)	(3.450)	(1.253)	(2.094)
	y2	0.490***	0.632***	-0.502***	0.838***
		(0.134)	(0.242)	(0.088)	(0.147)
	en	1.506***	1.419***	1.041***	1.224***
		(0.128)	(0.230)	(0.084)	(0.138)
Dependent Variable	urban				
	y	-0.495***	-0.491***	-0.495***	-0.454***
		(0.078)	(0.078)	(0.078)	(0.075)
Dependent Variable	en				
	urban	-3.763	-2.935	-3.763	-13.720
		(13.019)	(11.463)	(11.178)	(13.458)
	urban2	0.274	0.220	0.274	0.916
		(0.867)	(0.763)	(0.745)	(0.892)
	urban3	-0.007	-0.005	-0.007	-0.020
		(0.019)	(0.017)	(0.016)	(0.020)
	y	0.079**	0.078**	0.079**	0.086**
		(0.035)	(0.035)	(0.035)	(0.036)
Panel B: Indirect Effect					
Dependent Variable		cre	cele	ctran	cmanu
	urban	-5.667	-4.164	-3.919	-16.793
		(19.618)	(16.276)	(11.646)	(16.549)
	urban2	0.413	0.312	0.286	1.122
		(1.307)	(1.084)	(0.776)	(1.197)
	urban3	-0.010	-0.008	-0.007	-0.025
		(0.029)	(0.024)	(0.017)	(0.024)
	y	60.829***	30.466	5.118	53.759***
		(17.367)	(25.495)	(10.324)	(20.475)
Panel C: Total Effects					
Dependent Variable		cre	cele	ctran	cmanu
	urban	-122.607***	-61.780	-10.170	-118.154***
		(29.526)	(50.970)	(20.788)	(40.733)
	urban2	8.457***	4.693	0.768	8.103***
		(1.968)	(3.395)	(1.386)	(2.701)
	urban3	-0.192***	-0.116	-0.018	-0.183***
		(0.044)	(0.075)	(0.031)	(0.060)
	y	54.059***	22.639	12.771	42.527**
		(17.156)	(24.757)	(10.086)	(20.098)
	y2	0.490***	0.632***	-0.502***	0.838***
		(0.134)	(0.242)	(0.088)	(0.147)
	en	1.506***	1.419***	1.041***	1.224***
		(0.128)	(0.230)	(0.084)	(0.138)

R-squared	0.9999	0.9993	0.9964	0.9999

Note: urban, urban2, urban3 denote the linear term, quadratic term and the cubic term of urbanization (*urban* in Equation (1), (2), (3), (4)), respectively. y, y2 denote the linear term, quadratic term of economic development (*y* in Equation (1), (2), (3), (4)). Standard errors are given in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. The direct effect is estimated using the pooled OLS estimation.