Environmental Science & Technology

Policy Analysis

pubs.acs.org/est

Relationship between Urbanization and CO_2 Emissions Depends on Income Level and Policy

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Supporting Information

ABSTRACT: We investigate empirically how national-level CO_2 emissions are affected by urbanization and environmental policy. We use statistical modeling to explore panel data on annual CO_2 emissions from 80 countries for the period 1983–2005. Random- and fixed-effects models indicate that, on the global average, the urbanization–emission elasticity value is 0.95 (i.e., a 1% increase in urbanization correlates with a 0.95% increase in emissions). Several regions display a statistically significant, positive elasticity for fixed- and random-effects models: lower-income Europe, India and the Sub-Continent, Latin America, and Africa. Using two proxies for environmental policy/outcomes (ratification status for the Kyoto Protocol; the Yale Environmental Performance Index), we find that in countries with stronger environmental policy/outcomes, urbanization has a more beneficial (or, a less negative) impact on emissions. Specifically, elasticity values are −1.1 (0.21) for higher-income (lower-income) countries with strong environmental policy, versus 0.65 (1.3) for higher-income (lower-income) countries with weak environmental policies. Our finding that the urbanization–emissions elasticity may depend on the strength of a country's environmental policy, not just marginal increases in income, is in contrast to the idea of universal urban scaling laws that can ignore local context. Most global population growth in the coming decades is expected to occur in urban areas of lower-income countries, which underscores the importance of these findings.

INTRODUCTION

This article evaluates environmental implications of global urbanization. Urbanization has increased dramatically, from ∼30% in 1950 to more than 50% today, with ∼60% projected by 2030.[1,2] The urban developing-country population grew by ∼3 million people per week during 1990–2010, equivalent to one new developing-country megacity per month, and is projected to more than double from 2.3 billion in 2005 to 5.3 billion in 2050. By 2050, Asia and Africa are expected to be home to about two-thirds of the world's urban population (3.3 and 1.2 billion people, respectively). UN-HABITAT predicts that the developing world will be home to 95% of the world's urban population growth during the next four decades.[2]

Urbanization is a complex phenomenon, with myriad impacts.[2,3] Under favorable conditions, urbanization increases productivity, provides economic opportunities, generates wealth, and leads to a flourishing of new ideas in the arts, sciences, politics, and other fields.[4−6] Under other conditions, urbanization quickens the spread of disease and exacerbates ills such as crime, poverty, exclusion, and environmental degradation.[4] The United Nations estimates that more than 1 billion people lived in areas classified as slums in 2005.[7] On the global average, within a country, health is generally better in urban than in rural areas, owing to improved sanitation and nutrition, and easier access to contraception and health care.[8,9]

To evaluate environmental impacts of urbanization, we explore here the following hypotheses related to per capita CO_2 emissions. Our unit of analysis is nations, because available global CO_2 estimates and international regulations styled on the Kyoto Protocol generally track and report emissions by country. Empirical evidence from North America and Europe emphasizes the possible energy efficiencies of urban areas, especially of denser urban areas,[8,9] suggesting the following hypothesis:

Hypothesis 1a: in higher-income countries, the urbanization–emission elasticity is negative (urbanization reduces emissions).

Investigations of urbanization and CO_2 emissions in lower-income countries are limited. Potential differences between higher- and lower-income countries include how cities generate, spend, and distribute income. Higher-income service economies in the West have comparatively low levels of urban-scale income inequality and have resources to invest in urban form and infrastructure.[2,10−12] In contrast, cities in lower-income

Received: April 11, 2013
Accepted: January 14, 2014

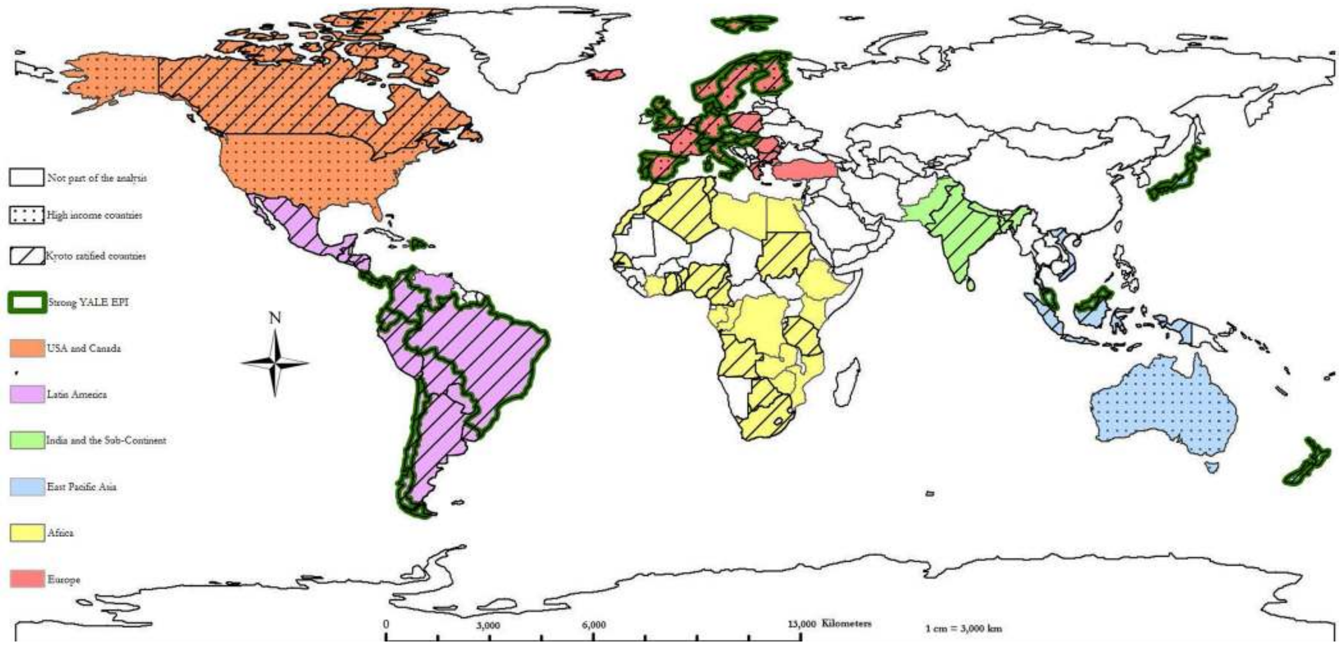

Figure 1. Countries and subgroups included in the analysis.

countries are experiencing rising incomes, but also rising pollution and income inequality.[2,10−12] Our expectation for lower-income countries is that urbanization increases wealth (a socially beneficial outcome) and that in lower-income countries (unlike in higher-income countries), wealth effects outweigh urban energy efficiency.

Hypothesis 1b: in lower-income countries, the urbanization−emission elasticity is positive (urbanization increases emissions).

Recent analyses of urban areas emphasize universal urban scaling laws,[13,14] and imply little or no impact of local context (e.g., culture, politics) on aspects of cities such as the provision of material infrastructure (e.g., road surface, gasoline stations, length of electrical cables), patterns of social activity (e.g., crime rates, patent creation, private R&D employment), and individual human needs (e.g., household electrical and water consumption).[13] Thus, we anticipate that energy consumption and CO_2 emissions depend on income and urbanization rates, not local context (e.g., environmental regulations).

Hypothesis 2a: in higher-income countries, presence or absence of strong pro-environment policy does not change the urbanization−emission elasticity.

Hypothesis 2b: in lower-income countries, presence or absence of strong pro-environment policy does not change the urbanization−emission elasticity.

A novel aspect of our work is exploring the importance of national environmental policies. We employ panel rather than cross-sectional data, and present results for fixed- and random-effects models.

■ METHODS

We tested the hypotheses using panel data on 80 countries for the period 1983−2005. From the original (109-country) data set, we dropped 9 countries because of the paucity of data. We additionally omitted five countries (China, Singapore, Ireland, Trinidad and Tobago, and Thailand) as statistical outliers, and 15 Middle Eastern countries because of colinearity and paucity of data (see the Supporting Information).[15,16] We stratified the data by region (Africa, Latin America, North America, Europe, India and the Sub-Continent, East Asia), higher- versus lower-income (annual Gross National Income per person is more/less than US$11,456, based on the World Bank's year-2009 income classifications),[17] and environmental policy. Income group is binary (higher; lower) because analyses using four income groups (low, lower-middle, upper-middle, and high) yielded similar results for the first three bins. "Higher-income" here equates to the "high income" label by the World Bank; "lower-income" here would equate to "low, lower-middle, and upper-middle income" using World Bank labels.[17] Income groups are created based on final-year income. For example, Cyprus (considered here to be higher income) changed from upper-middle to high income between 1983 and 2005. Variables were added via forward stepwise regression, controlling for variables described in the literature as the most robust determinants for emissions. Age structure has been used in the literature as an estimator; we do not include it here, as its validation and correct specification have so far remained inconclusive.[18,19]

We separately employed two indicators of the strength of national environmental policy: (1) ratification status for the Kyoto Protocol (ratified/nonratified), and (2) the Yale Environmental Performance Index (EPI), a country-specific comprehensive evaluation of environmental quality.[20] The EPI ranks countries on 25 performance measures, including ecosystem vitality, environmental health, agricultural water intensity, and air pollution and its effect on ecosystems and human health. Strictly, EPI is a measure of national environmental outcomes and performance. However, we argue here that it provides a reasonable gauge at the national scale of how close countries are to established environmental policy goals; with few globally available alternative metrics to choose from, we use EPI here as an (imperfect) proxy for the strength of national environmental policies.[20] Based on EPI, we grouped countries into two bins (stronger/weaker environmental policy), with the top-ranked 22 countries with available data regarded as having stronger environmental policy (Figure 1). Our models interact

Table 1. Descriptive Statistics

group[a]	income (US\$ GDP person^{-1} year^{-1})	urbanization (% of population living in urban settlements)	CO_2 emissions (tCO_2 person^{-1} year^{-1})
	mean (std)	mean (std)	mean (std)
all countries	\$7,000 (\$9,400)	55% (22%)	2.3 (3.2)
EPI countries	\$14,000 (\$11,000)	69% (11%)	3.6 (1.8)
non-EPI countries	\$4,400 (\$1,200)	50% (23%)	1.8 (2.5)
Kyoto countries	\$7,800 (\$9,700)	57% (21%)	2.5 (2.5)
non-Kyoto countries	\$4,100 (\$7,600)	47% (25%)	1.6 (2.4)

[a] Group comparisons were performed via analysis of variance (ANOVA). All entries in the bottom four rows are statistically significantly different than the first row ($p < 0.01$). "EPI" refers to the 22 high-EPI countries (EPI = environmental performance indicator).

urbanization with income and environmental policy to evaluate these connections.

We used the following analyses and tests to investigate our hypotheses. Group comparisons were evaluated using one-way analysis of variance (ANOVA). We tested for heteroskedasticity (White's test) and autocorrelation (Wooldrige's test) and corrected for autocorrelated errors (1st term autoregressive: AR1) and heteroskedasticity using generalized least-squares (GLS) regressions with both fixed and random effects. We employed the Hausman test to evaluate how parameter estimates differ between both approaches: the null of the test is that the coefficients estimated by the random effects estimator (more efficient) are the same as the ones estimated by the fixed effects estimator (more consistent). If the difference is statistically significant ($p < 0.05$), then analyses should use fixed effects estimators. Here we provide both fixed and random effects results, as we do not find sufficient evidence to fully reject the null of random effects (see the Supporting Information, Tables S1 and S2). The random effects model assumes that the time and individual components are not fixed over time, and that all countries in the panel have time-variant effects. Stated differently, the random effects model allows for estimating the urbanization coefficient taking into account heterogeneity across nations, with the time and individual error components being estimated individually from each other. An important drawback of the random effects approach, however, is the bias that partial pooling introduces in coefficient estimates, especially in situations where omitted variable bias may occur, which is likely to be the case here. The fixed effects estimation, in contrast, avoids that bias, because confounding from an omitted variable is removed via the separate unit effects.[21] Fixed effects models respect the orthogonality assumption and are better suited as an estimator for a nonrandomly selected sample of countries. Our fixed effects estimator also allows us to correct for endogeneity between emissions and energy variables. We do not consider the endogeneity to be evidence of true causality because emissions and energy-use could be driven by a common third process with different lags. Our fixed effects specification corrects for endogeneity albeit with a large standard error. From a theoretical standpoint, we also expect high energy-consumption (in a fossil fuel based economy) to lead to more CO_2 emissions and not the other way round; therefore, we do not find issues with reverse causality and misspecification in the model.

The net outcome of our models is estimates of the impact of urbanization on national CO_2 emissions per capita, controlling for variables such as per capita income,[22] percentage of land dedicated to agriculture,[22] and energy use.[22] In our analyses, CO_2 per capita refers to the natural log of metric tons of petroleum consumption per capita (dependent variable). Agriculture intensity is the natural log of the proportion of land dedicated to agriculture adjusted for population. Total energy use is log-transformed (units: natural log of kg of oil-equivalent per capita). Income is the natural log of GDP per capita (2005 dollars).[23] The natural logarithm allows us to correct for some of the skewness of the distribution, making the data sets closer to a normal distribution, and allows for the coefficients to be interpreted as elasticities.

Urbanization is defined here as the percentage of the total population that lives in urban areas, as defined by the United Nations (UN) Section on Population Division, Estimates, and Projects.[24] This definition follows country-by-country definitions of "urban"; it thus avoids using uniform criteria to distinguish between urban and rural areas because of the variety of situations in which urbanization arises around the world, instead relying on national statistical offices to establish and characterize the most appropriate criteria for their urban areas.[24] Establishing a rigid criterion that would define an urban area as one where, for example, population exceeds a certain amount could be inappropriate for countries like India, where rural areas with none of the characteristics of urban areas frequently can have a large number of inhabitants.[24] The data on urban areas and urban populations employed here are based on definitions by national statistical offices, and are reported by the UN.[24] Those definitions could include administrative boundaries, population size and density, economic, and other criteria related to the functional nature of urban areas (e.g., availability of water-supply, sewerage, or electric lighting).

As a sensitivity analysis, we separately developed models allowing for nonlinearities, including interactions between income, urbanization, and strength of environmental policy; results are in the Supporting Information. Results below are statistically significant for one and two-sided tests unless stated otherwise.

RESULTS AND DISCUSSION

Descriptive statistics are in Tables 1 and S1 (Supporting Information). Correlations among the variables are in Table 2. For the period 1983–2005, economic growth rates were slightly higher for high-EPI than for low-EPI countries

Table 2. Correlations Among Variables

	CO_2	agricultural intensity	energy use	GDP/capita	urbanization
CO_2	1				
agricultural intensity	0.12	1			
energy use	0.88	0.053	1		
GDP/capita	0.93	0.081	0.89	1	
urbanization	0.76	0.051	0.68	0.79	1

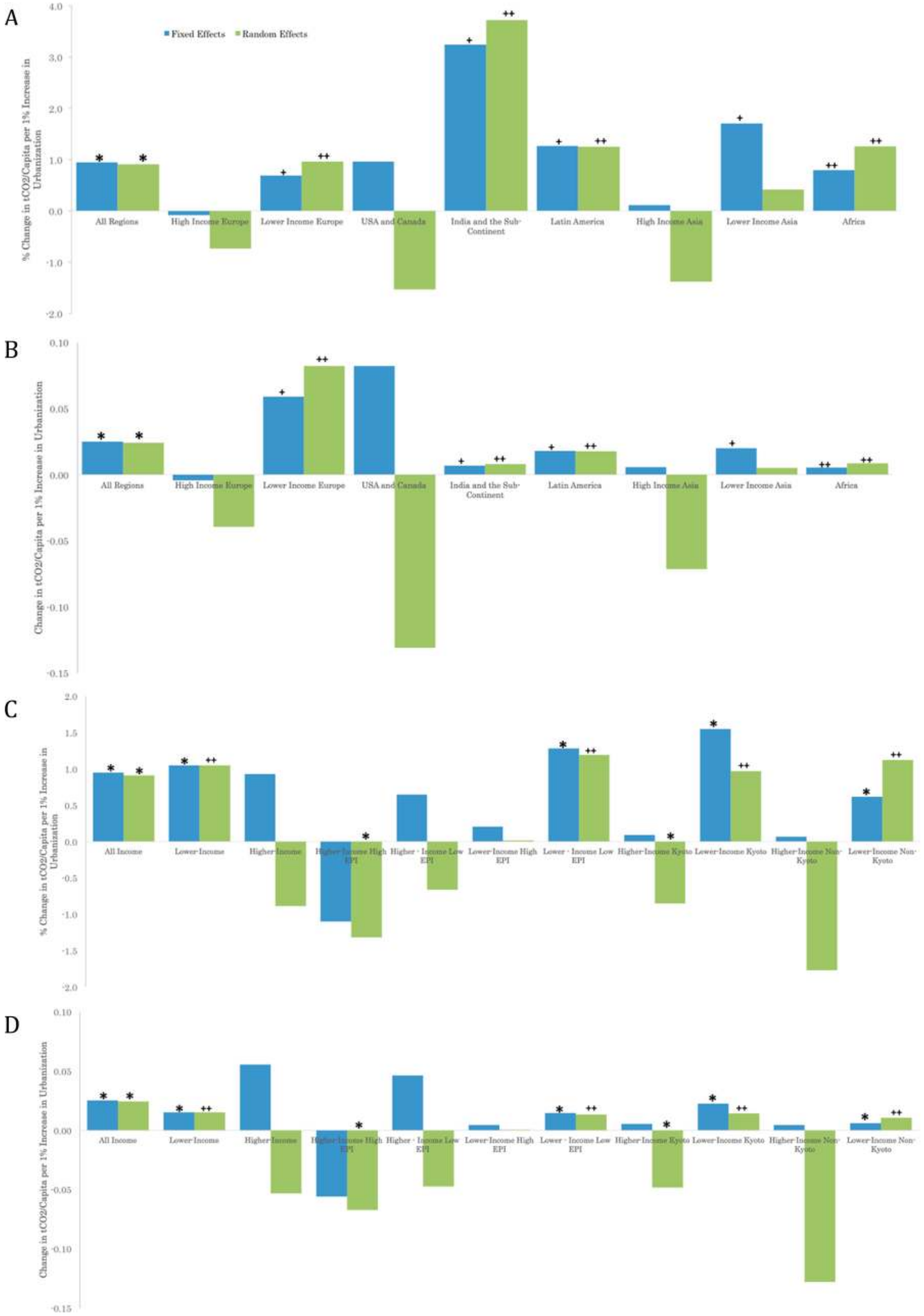

Figure 2. Elasticity values by geographic region (subplots A and B) and by policy framework (C, D), based on percent changes (A, C) and absolute-value changes (B, D). For example, for all regions, a 1% increase in urbanization is associated with a 0.95% (0.021 tCO_2) increase in emissions per person per year. "Higher-income" versus "lower-income" categorization is based on the year-2009 GPD per capita being above or below US$11,456. ++ Statistically significant at the 1% level for *one and two-sided* significance tests. + Statistically significant at the 10% level for *one and two-sided* significance tests. * Statistically significant at the 10% level for *one-sided* significance tests (H_0 for higher-income countries: coef ≥ 0; H_0 for lower-income countries: coef ≤ 0).

(average annual GDP growth: 2.6% versus 2.3%, respectively, $p < 0.05$). Among higher-income countries, per capita GDP is similar between high versus low EPI countries (means: \$23,500 vs \$22,300; $p < 0.06$). In contrast, for lower-income countries, mean income differs between high-EPI (\$4,400) versus low-EPI (\$2,100) nations ($p < 0.01$). Average annual growth in per capita CO_2 is greater in higher-income than in lower-income countries if one considers absolute emission-increases (annual change in emission rate, units: [$kgCO_2$ person^{-1} y^{-1}] y^{-1}: 66 vs 17, $p < 0.01$), but the reverse holds if one considers relative emission-increases (0.63% y^{-1} [higher-income] vs 0.88% y^{-1} [lower-income], $p < 0.01$). Between 1983 and 2005, average annual growth in urbanization rates was six times higher for lower-income countries than for higher-income countries (0.89% y^{-1} vs 0.15% y^{-1}).

Our regression models estimate CO_2 emissions (dependent variable) as a function of urbanization, percentage of land dedicated to agriculture, income, and energy use. We find little evidence to support a nonlinear relationship between environmental impacts and urbanization. (We also do not find evidence in the data to support an environmental Kuznets curve for CO_2 emissions.) Here we highlight results from our monotonic (log−linear) model (Supporting Information, Tables S2 and S3 model A), which is parsimonious, yet it explains 82% of the variance in CO_2 emissions.[25,26] In general, regression models isolate the impact of each independent variable on the dependent variable, accounting for variations in other independent variables. Some countries in the panel have a significant proportion of nonfossil energy, including the Scandinavian countries (~45% large renewables), France (~80% nuclear), Belgium (~54% nuclear), Switzerland (~40% nuclear), Brazil (~90% hydro), and Germany (25% renewables). Other countries have an energy mix that is diverse and changing. On average, increases in income, energy use, and the percentage of land dedicated to agriculture each lead to higher emissions levels. Agriculture is energy-intensive and may play an important role in national CO_2 emissions.[27]

The all-country emissions elasticity for urbanization is statistically significant, with a value of 0.95 (95% CI: 0.27−1.7); i.e., a 10% increase in urbanization is on average associated with a 9.5% increase in emissions per capita, all else being equal. An elasticity between 0 and 1 ("inelastic") indicates that the percentage change in emissions is smaller than the percentage change in urbanization. An elasticity greater than 1 ("elastic") means that a percentage change in urbanization leads to a more than proportionate change in CO_2 emissions. A negative elasticity means that urbanization reduces per capita emissions. Elasticity values from random and fixed effects models are statistically significant for lower-income Europe (0.96; 95% CI: 0.33−1.6), India and the Sub-Continent (3.2, 95% CI: 0.18−6.3), Latin America (1.3; 95% CI: 0.64−1.9), and Africa (1.3; 95% CI: 0.72−1.8). Elasticity values for lower-income Asia are statistically significant for fixed effects models but not random effects models.

Figure 2 presents relative and absolute changes in emissions per change in urbanization. Coefficient estimates and confidence intervals are presented in Tables S3−S6 (Supporting Information). The lower-income group shows a positive and statistically significant elasticity with random and fixed effects estimators (1.1; 95% CI: 0.35−1.7); overall, elasticity values for the higher-income group are not statistically significant.

Elasticity values for countries with strong environmental outcomes and policy (high scoring EPI) suggest that, all else equal, strong environmental policy reduces the urbanization emission elasticity (makes it less positive or more negative). That is, urbanization has a more beneficial impact (or, a less negative impact) in countries with strong environmental policy than in other countries. Elasticity values are statistically significant for both random and fixed effects models for lower-income countries with low EPI, Kyoto ratified, or Kyoto nonratified. In addition, for random effects models, elasticity values are statistically significant for higher-income countries with strong environmental outcomes and policy (high EPA and Kyoto ratified). Urbanization is correlated with reduced CO_2 emissions in lower-income countries with strong environmental performance (0.21; 95% CI: −1.1 − +1.6) than in lower-income countries with weaker environmental policies (1.3; 95% CI: 0.51−2.1).

A negative elasticity (coefficient < 0) suggests that urbanization reduces average per capita emissions. A negative "elastic" elasticity (coefficient < −1; see higher-income, high-EPI, random effects model) implies not only that urbanization reduces emissions, but also a multiplier effect whereby an individual moving from a rural to an urban area impacts his/her own emissions plus emissions from other people in a community.[28] (The rationale that elasticity < −1 necessarily uncovers a "multiplier" effect follows from the observation that any individual, including one moving to an urban area, can at most reduce her own emissions by 100% [i.e., to zero emissions]; therefore elasticity < −1 means that each person moving to an urban area impacts [reduces] others' emissions too.) Potential mechanisms for a multiplier effect are as follows. As urban demand for goods, services, employment, and schools increases, governments and markets may respond with improved public transportation services, roads, and other infrastructure that could reduce total emissions,[29] all potential aspects of energy-efficient urban form.[10] Under the right circumstances, urbanization can also trigger two other important greenhouse gas (GHG) offsetting forces: it can slow national population growth through changing fertility patterns (as women have more employment opportunities, they might marry later and delay having their first child), and it can provide incentives for smaller household sizes (urban land is more expensive than rural land; health care is more readily available in urban areas, which reduces child mortality and thereby makes smaller family size more likely), which potentially reduces a household's energy demand.[29,30]

Most (~95%) of the global population growth in coming decades is expected to occur in urban areas of lower-income countries.[31] Our results suggest that for lower-income countries, the elasticity is positive, elastic, and statistically significant (i.e., growth in urban population increases per capita emissions). Urbanization correlates with increasing economic activity, which can increase energy consumption and CO_2 emissions.[29,31,32]

We generated several alternative models to explore the robustness of our findings; see the Supporting Information. The additional models generally yielded consistent results. For example, if we allow an urbanization−income^2 interaction term in the model, the urbanization−emissions elasticity remains positive and small for lower levels of income with strong environmental policy (0.37; 95% CI: −0.96 − +1.7) and remains negative but not statistically significant for higher-income countries with strong environmental policy (−0.95; 95% CI: −4.3 − +2.4). Our policy−income^2−urbanization^2 interaction terms were equally consistent with the results described above (Supporting Information, Tables S4−S7).

Table 3. Urbanization and CO_2 Emissions in the Literature

author(s)	stratification	methodology[a,b,c]	control variables	data	urbanization elasticity
Martinez-Zarzozo and Maroutti, 2011	income	STIRPAT (LC)	population, GDP/capita, urbanization (%), age structure,energy efficiency, industry (%) GDP	88 developing countries: low, lower-middle, and upper-middle income, 1975–2003, yearly data	all countries (0.51–1.3) low/low-middle income (0.80) low-middle/upper-middle income (0.45)
Poumanyvong and Kaneko, 2011	income	IPAT (FD)	population, GDP/capita, energy intensity, industry (%) GDP, services (%) GDP, urbanization, total energy use	99 countries: low, middle, and high income countries, 1975–2005, yearly data	all countries (0.45) low income (0.43) middle-income (0.51) high-income (0.36)
Shi, 2003	income	STIRPAT (GLS)	population, GDP/capita, manufacturing (%) GDP, services (%) GDP, nontradable(%) GDP, working population stratified by age(%)	93 countries: low, lower-middle, upper-middle, high income countries, 1975–1996, yearly data	population not urbanization. all countries (1.42) low-income (1.58) lower-middle (1.97) upper-middle (1.42) high income (0.83)
Liddle and Lung, 2010	age structure	STIRPAT (OLS)	population, GDP/capita, population structure, urbanization (%), non fossil fuels (%), residential electricity consumption (%) total, rail (%) total road network, industrial energy consumption (%) total	17 developed countries: 1960–2005 and include observations at 5-year intervals	developed countries (0.48)
Fan et al., 2010	income	STIRPAT (PLS)	population, GDP/capita, urbanization, population structure, energy intensity	208 countries: low, lower-middle, upper-middle, and high income countries 1970–2005, yearly data	all countries (0.24) low-income (0.33) lower-middle (0.23) lower-middle (0.23) high (0.57)
Cole and Neumayer, 2004	no stratification	STIRPAT (FD)	population, urbanization rate, age structure, GDP/capita, energy intensity, manufacturing (%) GDP	86 countries, 1975–1998, yearly data	all countries (0.70)
York et al., 2003	no stratification	STIRPAT (RLS)	population, GDP/capita, industrial (%) GDP, urbanization (%)	146 countries, 1996	all countries (0.62)
Present article	income, region, and environmental policy	population adjusted (GLS)	GDP/capita, urbanization (%), agricultural land (%), energy use (kg oil equivalent per capita)—all variables include population adjustments	80 countries, 1983–2005; income (low, lower-middle, upper-middle, and high income countries); region (Europe, Latin America, North America, Africa, Sub-Continent, Pacific East Asia); policy (Kyoto Ratification, Yale University's Environmental Performance Index)	all countries (0.91) low income–high EPI (0.02) low income–low EPI (1.19) high income–high EPI (−1.32) high income–low EPI (−0.67)

[a] All dependent variables are country level CO_2 emissions. [b] STIRPAT is the stochastic environmental impacts by regression on population, affluence, and technology model. IPAT refers to impact = population × affluence × technology. [c] Statistical methods listed here include latent class (LC) models, first differences (FD), generalized least-squares (GLS), partial least-squares (PLS), and restricted least-squares (RLS).

As income increases, environmental impacts may shift from immediate and localized issues, to more delayed issues such as air and chemical pollutants and later to sustainability.[12,44−46] With increasing urbanization and wealth, developing nations have been shown to pollute faster, and at lower income levels, than did developed countries.[48] Although recent research has reported a negative urbanization−emissions elasticity for higher-income countries, and some work has investigated regional impacts, no prior research has investigated the income, regional and policy interactions of this relationship.[48−51] Importantly, our investigation did not find evidence that urbanization reduces emissions similarly across all incomes and environmental policy groups; instead, we found evidence of a negative elasticity only in some cases (higher-income countries with high EPI or with Kyoto ratification).

Our results corroborate earlier findings that urbanization is an increasingly important determinant of GHG emissions in the developed and developing world.[57−64] We bridge a gap in the literature by considering the urbanization−emissions relationship by region, national income, and strength of environmental policy (Table 3). STIRPAT (stochastic environmental impacts by regression on population, affluence, and technology)-based approaches have reported that urbanization's impact on CO_2 emissions is smaller in higher-income countries than in other countries but with a positive elasticity for all income levels.[49−51] In contrast, we find the urbanization−emissions elasticity to be negative and statistically significant only in specific cases (countries with higher-income and strong environmental policy). Our findings indicate that the relationship between urbanization and higher-income is not in itself sufficient to foster a negative elasticity with carbon emissions; rather, strong environmental policy and its implementation are essential to reduce the environmental footprint of urbanization. That finding, highlighting the importance of environmental policy, is a core contribution of this article to the literature.

A strength of the analyses presented here is that they employ panel data, thereby allowing us to explore changes over time in many locations. A limitation of our analyses is that we are unable to identify specific policies that might impact the elasticity in different regions and levels of urbanization and development. That type of research is an important next step. Variables not explicitly examined here include urban density, the proportion of specific energy end points (e.g., transportation, heating, electricity-generation) met using nonfossil sources, and weather. We leave those evaluations for future research. Our data rely on self-reported values from participant countries; we were unable to verify raw-data estimates. In addition, our data cover direct emissions only, not life cycle emissions; others have found that life cycle approaches shed important and useful light on understanding the environmental impacts of urbanization.[53−56]

As with many empirical analyses, causation is unclear: policy differences may cause the observed differences in elasticity values, may be caused by the differences in elasticity, or may merely correlate with other unobserved differences. Although not explored here, as different regions and countries develop and populations grow, they face vastly different challenges related to urbanization (and, potentially, different urbanization−emission elasticity values); policy solutions may differ by region, country, or within-country area. Our statistical analyses in some cases grouped low, lower-middle, and upper-middle income categories, because certain models given here yielded similar results for the three groups; however, the policy challenges and potential solutions they face may differ. Evaluating how population density and how national and inter-regional urban area characteristics shape the urbanization−emissions elasticity − within national and regional scenarios − is a natural next step in future work.

Overall, our results support hypothesis 1b but do not support hypotheses 2a and 2b. We find only partial support for hypothesis 1a, specifically only for higher-income nations with strong environmental policy. Our findings highlight the potential role of policy as a contributor to the elasticity magnitude; the results do not reveal location-invariant universal urban scaling laws. Our research suggests that in both developed and developing countries alike, the CO_2 impacts of urbanization are better (lower) if they come accompanied by the successful development and implementation of strong environmental policies.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Additional details about our statistical methods, results with complete tables and figures for all of our models (linear, nonlinear and interactions), and further statistical analyses. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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