# ARE COMPACT CITIES MORE CARBON-EFFICIENT? AN INTEGRATED ANALYSIS OF SUSTAINABILITY AND ECONOMIC GEOGRAPHY BASED ON LATIN AMERICAN URBAN SETTINGS

# ¿SON LAS CIUDADES COMPACTAS MAS EFICIENTES EN RELACIÓN CON LAS EMISIONES DE CARBONO? UN ANÁLISIS INTEGRADO DESDE LAS OPTICAS DE LA SOSTENIBILIDAD Y LA GEOGRAFÍA ECONÓMICA BASADO EN LOCALIZACIONES URBANAS EN LATINOAMÉRICA


Rafael, Van der Borght[1]

Montserrat, Pallarès-Barberà[2]

[1] Universitat Autònoma de Barcelona, Departament de Geografia, 08193 Bellaterra (Cerdanyola del V.), Spain. E-mail: vdb.rafael@gmail.com

[2] Universitat Autònoma de Barcelona, Departament de Geografia, 08193 Bellaterra (Cerdanyola del V.), Spain. E-mail: Montserrat.Pallares@uab.cat



## ABSTRACT

Cities are of central importance for both economic growth and sustainable development. While urbanization has enhanced agglomeration economies, urban sprawling has simultaneously increased land-use and energy consumption, making the transition to a low-carbon development pathway particularly complicated. In this context, compact cities (i.e. densely populated) have been increasingly mentioned as a key option to limit the global increase in temperature. However, in urban settings of Latin America, higher density might exacerbate negative congestion effects already affecting urban areas and produce uncertain impacts on CO2 emissions. To better understand the CO2 emissions impact of higher density in Latin-American cities, a new methodological approach is developed to systematically assess city-level CO2 emissions for a set of 570 cities distributed across 7 countries. Based on this new dataset, a spatial panel model is built with the purpose to find robust evidence that higher density reduces CO2 emissions at the city-level. Results also shed lights on the crucial role that spatial planning can play to help curbing CO2 emissions in Latin-American.



**Keywords:** urban emissions; low-carbon cities; population-based clusters; economic geography; spatial patterns

**RESUMEN**

Las ciudades son, en la actualidad, de central importancia tanto en relación con los aspectos de crecimiento económico como con el desarrollo sostenible. En este sentido mientas que los procesos de urbanización han favorecido las economías de aglomeración, los de expansión urbana han incrementado el consumo de suelo y de energía, haciendo de la tan deseada “transición hacia economías bajas en carbono” una meta todavía lejana. En este contexto, las ciudades compactas (por ejemplo aquellas con altas densidades de población) están siendo cada vez más valoradas como opciones clave para limitar el calentamiento global. Pese a ello, en las ciudades de Latinoamérica las altas densidades pueden incrementar los efectos negativos de la congestión, lo que afecta sin duda a muchas de ellas, produciendo impactos inciertos.

Con objeto de entender de manera acertada las repercusiones de las emisiones de $CO_2$ en ciudades de alta densidad, se ha desarrollado una aproximación metodológica que evalúa el nivel de emisiones de un conjunto de 570 ciudades en 7 países de la región. Empleando la base de datos confeccionada, se ha elaborado un modelo espacial que pretende hallar evidencias robustas que demuestren que las altas densidades reducen las emisiones de $CO_2$ en la escala urbana. Los resultados también ofrecen pruebas sobre el papel esencial que puede jugar la Ordenación del Territorio a la hora de reducir las emisiones de carbono en América Latina.

**Palabras claves:** emisiones urbanas; ciudades con bajas emisiones de carbono; conglomerados demográficos; geografía económica; patrones espaciales.

## 1 CONTEXT AND THEORETICAL FRAMEWORK

Cities are of central importance for economic growth. However, urban processes can make sustainable transition particularly complicated if urban development occurs in sprawl, implying high land use and energy consumption. Compact cities, more densely populated, have nonetheless been increasingly mentioned as a key option to limit the global increase in temperature.

For more than a century, it has been recognised that as people, firms and resources concentrate in close geographic space, multiple benefits arise (Marshall, 1890). Well-documented “agglomeration economies” enhance productivity through various channels ranging from labour pooling, to spreading of costs and sharing of suppliers or innovation. However, cities also bring about negative congestion effects such as increasing prices of living and doing business or overcrowded public infrastructure and roads (see Giuliano et al. 2019 for a recent discussion on role of agglomeration economies in the evolution of urban form). While every city is affected by both effects, there is strong evidence that in the USA and Europe higher productivity occurs in places with greater economic density (Ahlfeldt and Pietrostefani, 2017; Glaeser, 2011). However, the benefits of agglomeration differ across countries: in Mexico, for example, urban compactness can be negatively associated with economic productivity (Monkkonen et al., 2019). In general, cities in Latin-America fail to fully leverage the benefits of agglomeration, depicting a more nuanced relationship between cities and economic growth (Ferreira et al., 2018).

Simultaneously, urbanization is one of the most irreversible land-use change and a major driver of environmental changes. Across the world, cities are responsible for about 75% of global primary energy consumption (UN Habitat, 2016) and they are increasingly viewed as critical actors to transition to a low-carbon development pathway. As an analogy to agglomeration economies, a large body of literature has highlighted how density delivers climate benefits: denser cities streamline energy consumption, rationalize transport, they reduce commuting and, everything else being equal, diminish CO2 emissions. In the USA, there is consistent evidence that high density metropolitan areas emit less than highly disperse ones (Brown et al. 2009; ULI 2010). Further research estimated that doubling the density of the biggest US metropolitan areas was conducive to a reduction of 35 to 48 percent in CO2 emissions (Lee and Lee, 2014); or that urban form is the main driver of the ecological footprint variations among the municipalities of the Barcelona Metropolitan Area (Muñiz and Galindo, 2005). However, more contrasted results have been found in different contexts. In China, for example, the benefits of higher density in terms of CO2 emissions depend on city's development level (Ou et al. 2019) and factors such as transport organization (Zhang et al. 2019).

Better understanding the relationship between cities' spatial structures and CO2 emissions in different socio-economic and geographical contexts is key to inform low-carbon development. In Latin-American urban settings for example, weak urban governance and suboptimal provision of public infrastructure might lead to a situation where higher density exacerbates congestion effects, resulting in uncertain impacts on CO2 emissions. As part of a broader investigation, this communication is thus exploring the following question: in urban settings of Latin America, what is the CO2 emissions impact of higher density?

## 2 CITIES EMISSIONS TRENDS IN SEVEN LATIN AMERICAN COUNTRIES

Following Djikstra et al. (2020) and the methodology endorsed by the United Nations Statistical Commission in March 2020, we build a comprehensive dataset on cities' emissions.[1] Cities are defined using a population-based approach that seeks to capture the socio-economic reality of urban structures -as opposed to the administrative boundaries. Leveraging on the work of Oda et al. (2018), which provides spatially disaggregated CO2 emissions at a 1km2 resolution, we estimate CO2 emissions at the city-level as the emissions that are product of fossil-fuelled activities occurring within the boundaries of cities. As a result, our dataset provides systematic information for 570 cities distributed across 7 Latin-American countries (México, Brazil, Argentina, Chile, Perú, Ecuador and Colombia[2]) for the years 2000 and 2015.

[1] UN resolution available here. The methodology was applied to the GHSL population grid provided by the European Union at a resolution of 30 arcsec.
[2] Collectively these countries account for 76% of GHG emissions of the region.

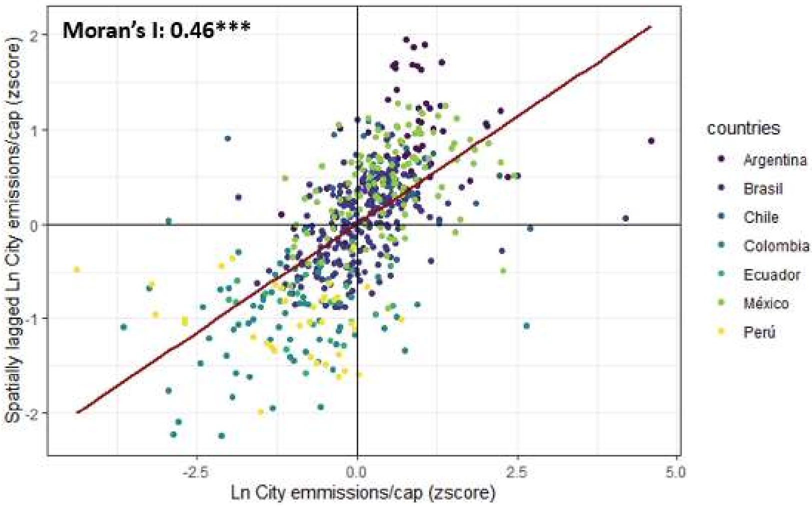


**Figure 1.** Moran's I scatter plot of CO2 emissions per capita at the city-level in 2015.
Note: emissions per capita and their spatial lag have been standardized and are plotted as z-scores.
Source: Authors

Emissions per capita at the city-level display significant spatial correlation with a global Moran's I estimated at 0.46 in 2015 and significant at the 1% confidence level (figure 1). This confirms that cities with similar emissions per capita are located closer to each other.[3] In addition, we conduct a Local Indicator of Spatial Association (LISA) analysis that reveals a double pattern of local spatial autocorrelation: the clustering of cities with higher-than-average emissions per capita was mainly distributed along the valleys and grasslands of south Brazil, Argentina and the Mexican plateau. On the other side, cities with lower-than-average levels of emissions per capita cluster in the Andean region and along the Pacific coast. These findings are a reminder of Tobler's first law of Geography, which states that "*everything is related to everything else, but near things are more related than distant things*". Properly accounting for this spatial dependence is crucial to disentangle the causal impacts of density on CO2 emissions and ensure unbiased estimations (Anselin, 1988).

## 3 THE EMISSIONS IMPACT OF DENSITY: EMPIRICAL FRAMEWORK AND ESTIMATION RESULTS

To assess emissions impact of density, we developed a spatial panel model that builds upon the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model. This model has been widely used and is inspired by the Kaya equation (see Kaya, 1990, for the original IPAT and York et al., 2003, for STIRPAT). Here, we seek to explain city-level CO2 emissions through population, affluence and

[3] The neighbour's matrix used for this communication defines neighbours as the 5 closest cities based on geographic distance. The Global Moran's I of cities emissions -i.e., not controlling for population- is also significant and estimated at 0.17.

population density (i.e. the ratio of city habitants/ city area). Our model has the following form:

$$ln\,Y_{i,t} = \lambda \sum_{j \neq i} W_{ij}\,Y_{j,t} + \beta_1 ln\,population_{i,t} + \beta_2 GDPPC_{c,t} + \beta_3\,ln\,Density_{i,t} + \omega_i + \varepsilon_{i,t} \quad (1)$$

With $ln\,Y_{i,t}$ denoting the natural logarithm of CO2 emissions of city i in year t, $W_{ij}$ the row-standardized neighbours matrix used to compute the spatial lag of cities' emissions and $\lambda$ the spatial lag parameter, which reflects the strength and direction of spatial autocorrelation between one city and its geographical neighbours. $ln\,population_{i,\,t}$ is the log-transformed population of city i in year t, while $GDPPC_{c,\,t}$ accounts for Gross Domestic Product (GDP) per capita of country c in year t. Finally, $\omega_i$ are city fixed effect that allow to control for time invariant unobserved heterogeneity such as city geographic characteristics.

Column 1 of table 1 presents estimation results for a static panel. Column 2 and 3 are the results of estimating equation 1 first with density and then with the log-transformed value of density.[4] Across all specifications, the coefficient on density is negative and significant, indicating that, on average, higher density reduces C02 emissions at the city-level. The coefficients for population and GDP/capita have the expected positive impacts and are significant at the 1 percent confidence level, indicating that richer or more populated cities emit more CO2.

The coefficient of the spatial lag factor was found to be positive and significant, implying that the level of CO2 emissions of a city has a positive impact on the level of emissions of neighbouring cities. This confirms that city-level CO2 emissions are affected by a spatial diffusion process, which underscores that cities do not operate alone and their carbon performance is also the result of interactions within a broader "system of cities". Considering this spatial diffusion process, our results further indicate that a 1 percent increase in city population has a total impact on city CO2 emissions of +3.12 percent, while a 1 percent increase in city density is conducive to a total decrease of -2.13 percent, significant at the 1 percent and 5 percent confidence level respectively.

[4] For the sake of brevity, we do not discuss the test that led us to opt for this specification form but include them at the bottom of table 1 for reference. We also tested whether the impact of density follows a U-inverted shape by introducing density in its quadratic form but found no evidence of such an impact.

| | Static Panel Model | Spatial Panel Model (1) | Spatial Panel Model (2) |
|---|---|---|---|
| | | Ln City CO2 emissions | |
| Spatial Factor $\lambda$ | | 0.509 *** | 0.511 *** |
| | | (0.027) | (0.027) |
| Density | -0.065 ** | -0.050 ** | |
| | (0.024) | (0.015) | |
| Ln Density | | | -1.045 ** |
| | | | (0.39) |
| Ln Population | 1.038 *** | 0.692 *** | 1.526 *** |
| | | | (0.39) |
| GDPPC | 0.135 *** | 0.060 *** | 0.059 *** |
| | (0.006) | (0.005) | (0.005) |
| City Dummy | YES | YES | YES |
| Observations | 1,140 | 1,140 | 1,140 |
| Individuals | 570 | 570 | 570 |
| Adj. R-Squared | 0.50 | | |
| AIC | | -265.7316 | -262.1618 |
| Hausmann Test | 36.938*** | 43.051*** | 35.693*** |
| Robust LM panel test for spatial lag dep. | | 112.41*** | 136.35*** |
| Robust LM panel test for spatial error dep. | | 0.061924 | 2.43 |
| Note | | * p<0.1; ** p<0.05; ***p<0.01 | |

**Table 1.** STIRPAT model estimation results
Source: Authors

## 4 CONCLUSION

This communication provides preliminary evidence that for 570 cities distributed across 7 countries in Latin America, density has a significant and negative impact on CO2 emissions at the city-level. These findings are in line with previous studies and suggest that compact cities are more carbon-efficient. Further research will be needed to identify the specific channels of transmission of such an impact and assess whether these impacts differ in function of development levels or other local factors. Looking forward, these results shed lights on the role that spatial planning can play to curb CO2 emissions: as urban population is expected to keep rising in Latin-America (UNDESA 2018), sthrengntened urban planning can constrain urban land expansion and help fully leveraging the climate and socio-economic benefits of higher density through complementary reforms in transport and energy sectors.

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