International Conference on Applied Energy 2020
Nov. 29 - Dec. 2, 2020, Bangkok, Thailand
Paper ID: 89

Spatial Analysis of Building-related Urban CO2 Emissions Based on the Local Climate Zones Classification System

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ABSTRACT

The carbon dioxide (CO_2) emission patterns of urban areas are likely to be closely associated with urban form. Using geographical information of Los Angeles County, this study examines potential linkages between urban form and CO_2 emission patterns. For this purpose, we rely on the Local Climate Zones (LCZ) classification system, which is a universal framework for classifying urban areas into different categories according to their urban form characteristics. Our purpose is to see if there are any associations between types of LCZ and emission patterns. First, we developed the LCZ map for the county. Next, we obtained information related to residential and commercial building CO_2 emissions across different neighborhoods from the official database of county. Next, we linked the emission data to the LCZ map to estimate per hectare and per capita emissions of each LCZ type. Results show that, in most cases, different LCZ types feature similar per capita emission patterns. This is, particularly, the case for commercial emissions. In terms of residential buildings, however, LCZ NO. 9 that refers to sparsely built development type exhibits significantly higher per capita emissions. This support common arguments regarding the environmental footprints of urban sprawl. Overall, results of this study indicate that the LCZ-based urban carbon mapping can provide useful insights into emission patterns of different urban forms. However, further research is needed to gain a more comprehensive understanding.

Keywords: CO_2 emissions, urban form, local climate zones, Los Angeles county, commercial buildings, residential buildings

1. INTRODUCTION

Over the past few decades, global warming has emerged as one of the greatest environmental challenges confronted by humans. Rising greenhouse gas (GHG) emissions, especially CO_2 are assumed to be the key drivers of global warming [1],[2]. Moreover, fast-growing urban areas worldwide have contributed to the rapid growth in CO_2 emissions [3]. According to the International Energy Agency urban areas account for more than 70% of global CO_2 emissions and more than two-thirds of global energy consumption [4]. This proportion would rise dramatically because it is projected that nearly 66% of the world's population will live in urban areas by 2050 [5]. This rapid urbanization is increasingly transforming land use patterns and causing detrimental environmental impacts. In fact, evidence shows that land-use change is the second primary source of CO_2 emissions[6]. This illustrates explicitly how important, regulating urban growth and land-use changes is for minimizing global CO_2 emissions [7].

Several studies examined the impacts of spatial structure and urban form on CO_2 emission patterns [6], [8], [9]. However, there is still no absolute knowledge about emission patterns of different urban form patterns. Additionally, emission patterns are highly context specific and may vary from one city to another due to the effects of other intervening socio-economic and environmental factors.

Among various methods for classification of urban land use and urban form, the Local Climate Zones (LCZ) system has received significant attention in the recent years. LCZ is a universal approach to divide cities into 17

Selection and peer-review under responsibility of the scientific committee of the 12th Int. Conf. on Applied Energy (ICAE2020).

land use/urban form classes. Of those, 10 are related to buildings and, the others are associated with land cover/vegetation type [10]. In this study, we specifically focus on the 10 classes related to buildings to examine the CO_2 emission behaviors of different urban forms. This way, we intend to examine if certain urban form types are associated with higher levels of CO_2 emissions.

2. MATERIAL AND METHODS

2.1 Study area and data

This study is focused on the Los Angeles county. Los Angeles County, with a population of about 10 million in 2016, was ranked the 15th among the world's cities and 5th among the cities of the United States for emitting nearly 29 million metric tons of CO_2 annually [11]. The rate of CO_2 emission in the neighborhoods of the city in 2016 was extracted from the Energy Atlas database, which is an information bank of cumulative spatial energy consumption for the county (Fig 1) [12].

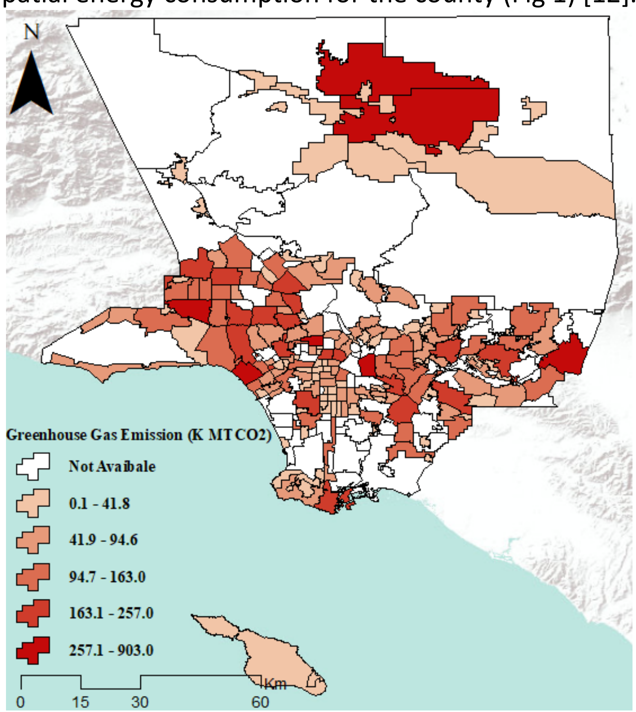

Fig 1 Rate of CO2 emission in Los Angeles quarters

2.2 Urban area classification

This study employs the LCZ framework to classify urban areas. The local climate zone classification is a universal method for the categorization of urban zones (urban land-use) and separately divides urban areas into 10 urban and 7 natural classes. In this method, these classes are identifiable by the satellite images of Landsat 8 (this study exploits 4 Landsat 8 images prepared in summer 2016.). The 10 urban classes include diverse building and land use types, with different heights and densities. In addition, the natural classes feature different types of natural vegetation, and arable lands. To obtain the LCZ map of the Los Angeles county with a resolution of 100m *100m (1 hectare), this study employs the SAGA GIS, Google Earth, Envi, and ArcMap software tools. Fig 2 illustrates the LCZ map of the Los Angeles county (for 17 separate classes).

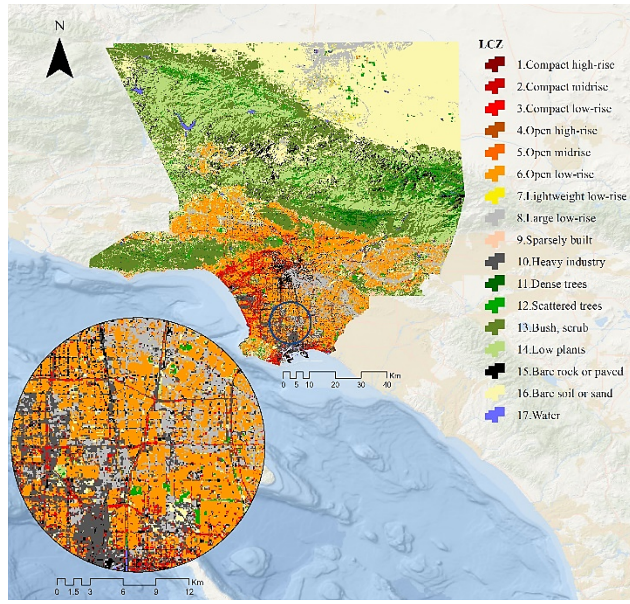

Fig 2 LCZ map of Los Angeles (Cell size 100 m)

2.3 Methods to calculate CO_2 emissions and per capita emission in each LCZ class

To investigate the average CO_2 emission in each hectare of the zones classified according to the LCZ method as well as the per capita CO_2 emissions, the study first prepares the LCZ map and divides it into 1-hecare cells (the LCZ map was calculated by the cell size of 100m *100m). Likewise, by having the CO_2 emission rate of every neighborhood at hand and dividing it by the number of the 1-hectare cells of the neighborhoods, we can estimate the average CO_2 emission. Then, the average CO_2 emission in every LCZ is computed by overlapping CO_2 emission and LCZ maps. On the other hand, by dividing the CO_2 emission rate in every neighborhood by the population of that neighborhood, we could obtain the average CO_2 emission per individual in every neighborhood. Next, the population density in each hectare is separately calculated for the neighborhoods and multiplied by the CO_2 emission rate of every individual so that the consumption rate of each person per hectare is estimated for the neighborhoods. Ultimately, the average emission of every individual in every class of urban areas is calculated (Fig 3).

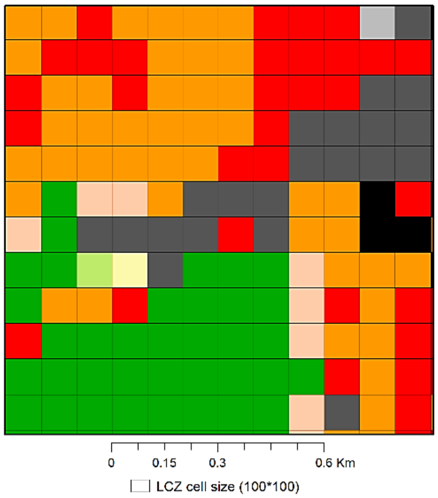

Fig 3 Sample LCZ map based on 1-hectare cells

3. RESULTS AND DISCUSSION

As mentioned earlier, the LCZ method has been used in this study as a framework to map land use/land cover to estimate CO_2 emission throughout the whole city. It's been assumed that identical LCZs show similar emission patterns. We have accounted for residential, as well as, commercial CO_2 emissions. Table 1 shows the occupied area and the population density for different classes of LCZ. Almost 50% of Los Angeles County's area is formed by open arrangement urban form with an abundance of pervious land cover and few and scattered trees. Therefore, among Los Angeles County's neighborhoods, the LCZ class 6 has the largest area (126531 Hectares) and the LCZ class 2 has the smallest area (807 Hectares). Also, the highest population densities in the Los Angeles County could be seen in LCZ 3, LCZ 2, and LCZ 3, and the lowest in LCZ 9.

Table 1. Characteristics of each LCZ classifications in the Los Angeles County

classifications	Area (Ha)	Population density (person per Ha)
LCZ 1: Compact high-rise	1441	39.24
LCZ 2: Compact midrise	807	37.45
LCZ 3: Compact low-rise	19807	40.63
LCZ 4: Open high-rise	2236	32.03
LCZ 5: Open midrise	10589	34.16
LCZ 6: Open low-rise	126531	30.03
LCZ 7: Lightweight low-rise	7900	20.06
LCZ 8: Large low-rise	62100	21.79
LCZ 9: Sparsely built	26454	12.49
LCZ 10: Heavy industry	21129	31.03

The results showed that, in terms of total emissions per hectare, dense urban areas with few or no trees have higher CO_2 emissions compared to the less compact areas (Figure 4).In fact, areas like LCZ1, LCZ2, and LCZ3 that have the highest amounts of density and feature limited green space have the highest levels of CO_2 emission. In contrast, LCZ 4 and LCZ 6 that are less dense and have more green space emit less CO_2 in the atmosphere. This may indicate the importance of green space for mitigating building related CO_2 emissions. However, as we have not considered transport-related emissions, it should not be used as a basis to conclude that high-density areas are less desirable for climate change mitigation.

Figure 4 shows that heavy industries (almost 8% of the Los Angeles County's area) account for a significant amount of CO_2 emission. On the other hand, it is shown in the present study that residential buildings have a bigger share of CO_2 emissions than commercial buildings which is not surprising considering the amount of energy needed for heating, cooling, and ventilation of residential buildings. In addition, comparing the total CO_2 emissions to the residential and commercial buildings in LCZ1 to LCZ5 areas demonstrates the significance of studying other building types to gain a better understanding of emission patterns.

Table 1 shows that population density of the first lCZ classes is comparatively higher than the others. This may be one reason behind their higher levels of CO_2 emissions. Therefore, it is essential to also examine the per capita emissions across different LCZs. Results show that the average annual per capita CO_2 emissions value is equal to 2.5 metric tons, and the values are equal to 1.34 and 0.57 metric tons for residential and commercial sectors, respectively.

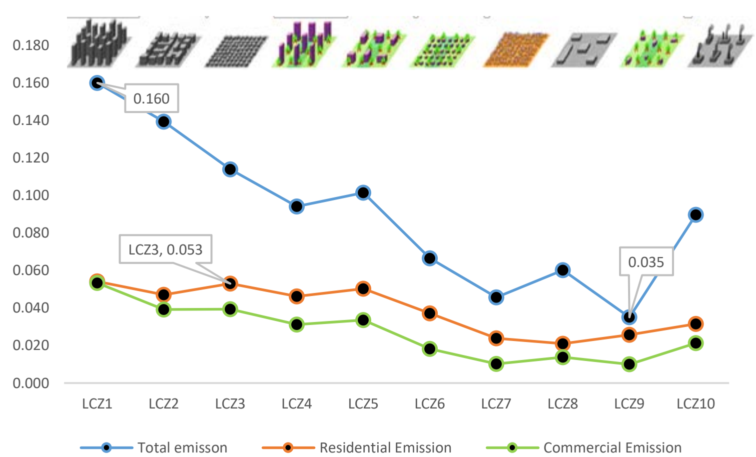

Fig 4 Per area (1ha) emissions for each LCZ (K MTCO2)

Figure 5 shows consumption per person in each of the Local Climate Zone classifications. It shows that, higher levels of density in some of the LCZs (e.g., 1,2, and 3) has contributed to reducing emissions. The highest level of CO_2 emission per capita could be seen in class 9 and the lowest emission per capita could be seen in class 7. LCZ 9 represents the sprawling development pattern, confirming that urban sprawl is energy intensive.

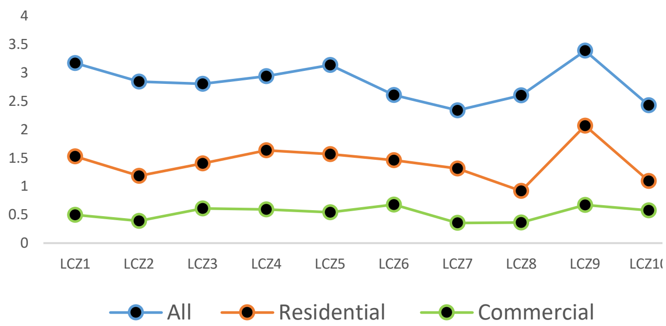

Fig 5 Per capita emissions for each LCZ (MTCO2)

4. CONCLUSIONS

In this study, the goal was to estimate the CO_2 emission levels of different urban forms using the LCZ framework that provides a universal platform for classifying cities into 10 urban and 7 natural classes. The findings of this study showed that dense areas with few or no vegetations emit more CO_2 when total emissions per hectare are considered. These findings are similar to the findings of a study in Shanghai [8] , which show that LCZ1 has the highest carbon emission levels. Results also show that emission levels of residential buildings are higher than commercial buildings. The only exception was per hectare emissions in LCZ1 that indicates the high density of commercial activities in compact high-rise areas.

Estimating the per capita emission results across different LCZs showed that increasing density can provide some efficiency improvements. Indeed, it was found that the high-density LCZs were no longer among the highest emitting areas of the city. Instead, LCZ 9 that is characterized by urban sprawl had significantly higher levels of emission.

Even though this study showed that a better understanding of the effect of urban form on CO_2 emission and per capita throughout the cities could be reached by utilizing the LCZ method, but it has some limitations. In fact, the buildings' energy consumption in different LCZs is not only affected by urban form, but it also depends on other parameters like economic and social factors, the building's different components including the materials used in the buildings and also the building's operation mode. In addition, this stud does not account for transportation CO_2 emissions. Therefore, including transport-related emissions and using mechanisms to take account of socio-economic and environmental factors are necessary for better understanding of emission dynamics using the LCZ framework. The results of this study could help urban planners and policymakers to better understand emission patterns of different urban patterns. In particular, the fact that density can provide efficiency improvements could be used as a basis to further promote compact urban development and avoid sprawling patterns that not only emit more CO_2, but also cause other detrimental impacts on the environment.

ACKNOWLEDGEMENT

This work was supported by JSPS KAKENHI Grant Number 19K20497.

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