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Contribution of green urban areas to the achievement of SDGs. Case study in Valencia (Spain)

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ABSTRACT

The Agenda for Sustainable Development 2030 of United Nations is made up of the 17 Sustainable Development Goals (SDGs) that humanity will have to meet by 2030. In achieving the SDGs, green urban areas (GUA) play a fundamental role at the local level as they provide recreational and bioclimatic regulatory functions and act as a carbon sink, as well. Specifically, the GUAs contribute directly to three SDGs: SDG 11 Sustainable cities and communities, SDG 13 Climate Action and SDG 15 Life on land.

This paper evaluates direct contribution of GUA to this SDGs with high spatial resolution in the case study of the city of Valencia (Spain). The evaluation carried out has made it possible to make a diagnosis of the quantity and accessibility of GUA at sub-neighbourhood level. The results for SDG 11 show that only 9.23% of the population do not have desirable access to GUA and 2.73% live in areas without easy walking distance access to GUA. On the other hand, the evaluation of SDG 15 shows that each inhabitant has at their disposal 10 m^2 of GUA, below the average of cities of more than 250,000 inhabitants in Spain. The high spatial resolution of the evaluation has also made it possible to identify the city areas with the worst access to GUA and the least amount of GUA per inhabitant. In consequence, the results allow determining zones with high potential to improve. Additionally, the quantification of the CO_2 fixed by the GUA carried out for the evaluation of SDG 13, shows that the fixed carbon is equivalent to 0.04% of total gross GHG emissions of the city and is 36% higher than the total GHG emissions of the annual fuel consumption of the total fleet in the city. Finally, the monitoring of the indicators applied allows evaluating the evolution of the GUA to improve the sustainable development of the city.

1. Introduction

Sustainable Development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nations 2021). This idea, concept or goal has been treated and debated in depth in the most important international policy forums since its introduction in the Brundtland report by the World Commission on Environment and Development (WCED) (United Nations 1987). Since then there have been great approaches towards the assumption of international commitments in relation to sustainable development, the definition of concrete goals and ways of evaluating their achievement such as the Rio Declaration on Environment and Development (1992), the Millennium Declaration, the World Summit on Sustainable Development (2002) or the United Nations Conference on Sustainable Development (Rio + 20) in 2012. It was finally in 2015, when 193 member states of the United Nations unanimously agreed on the Agenda for Sustainable Development 2030 (United Nations 2015). This agenda is made up of the 17 Sustainable Development Goals (SDGs) (inspired by the millennium goals) that humanity will have to meet by 2030.

However, the progress made to date on the SDGs has demonstrated the need to address them at the local level, specifically at urban level. Most of the population in the world will live in cities (Ritchie and Roser 2018). In Europe, 83.7% of the population will live in cities in 2050, in comparison with 74% in 2018 (United Nations, 2018). Furthermore, Adelphi and Urban Catalyst (2015) indicate that 65% of the SDG agenda may not be fully achieved without the involvement of urban and local actors. Moreover, about one third of the 232 SDG indicators can be measured at the local level, making it an important unit for action and tracking of progress towards sustainable development (Unated Nations-Habitat, 2018).

Cities are the places where the positive interlinkages amongst the SDGs are boosted (Siragusa et al. 2020). Therefore, involving local authorities in the implementation of the 2030 Agenda is crucial (Benz,

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2020). For this reason, the Joint Research Centre of the European Commission (JRC) published a European Handbook for Local SDGs with quantifiable and comparable indicators to configure voluntary local reviews in order to monitor progress and maintain the transformative action of local actors towards the achievement of the SDGs (Siragusa et al., 2020). Nevertheless, a global assessment at the city level allows to check the level of achievement but not to improve it efficiently, since it does not allow to identify and locate potential areas for improvement. Thus, an evaluation of the SDGs achievement at the sub-city scale or even sub-neighbourhood scale would not only make it possible to evaluate the SDGs level of achievement, but would also allow to identify areas with potential improvement. In addition, a granularity greater than city scale also allows to ensure equitable sustainable development in order to all citizens can be benefited from sustainable development. Green Urban Areas (GUA) have great relevance and are a key element in the achievement of the SDGs in cities (Elgizawy, 2014). They provide a great ecological, aesthetic and recreational value to cities and also act as bioclimatic regulators on humidity and temperature that makes them a key urban infrastructure in promoting quality of life and public health for the citizenship (Siragusa et al., 2020). In addition, lignocellulosic material of urban green areas acts as a carbon sink by storing atmospheric CO_2 during photosynthesis (Strohbach et al., 2012). Therefore, it is necessary to appropriately manage and protect these spaces and ensure the access of the population to these islands of tranquillity within the urban hustle and bustle of cities (Watts et al. 2013). However, according to United Nations (2019), most cities have difficulty ensuring that their populations have easy access to GUA. In this survey, from 220 cities of 77 countries, only 21% of the population has easy access to GUA in 2018. This could be due to two reasons: the lack of GUA or their unequal distribution.

Following the European Handbook for Local SDGs (Siragusa et al. 2020), GUA contribute directly to three SDGs at urban level:

a) ODS 11 “Sustainable cities and communities”: also known as the “Urban Goal”, calls for making cities and human settlements inclusive, safe, resilient and sustainable.
b) ODS 13 “Climate action”: take urgent action to combat climate change and its impacts, and without a doubt, protecting and promoting carbon sinks such as GUA is a mitigation and adaptation action against climate change.
c) ODS 15 “Life on land”: aims to protect, restore and promote the conservation and sustainable use of terrestrial, inland-water and mountain ecosystems. From a planning point of view, the public character of GUA is significant, since it is considered to contribute to the quality of life. On the other hand, the preservation of GUA represents a value to preserve of biodiversity, reduce of the heat island effect, increase the permeability of the soil, and reduce the flood risk (Siragusa et al. 2020).

The evaluation of these three SDGs from the point of view of GUA has been carried out at different scales by many authors in recent years using different indicators. Joint Research Centre (JRC) (2020) propose an indicator to evaluate the contribution of GUA to SDG 11 “Sustainable cities and communities” based on the methodology presented by Poelman (2018), which considers the spatial distribution of both population and GUA throughout the cities’ territory, and produces also indicators about the proximity of the GUA to the citizenship. In addition, United Nations (2019) proposes an indicator that considers that a citizen has easy walking access to a GUA when the distance that separates them is less than 400 m from home. On the other hand, Casado (2015) presents an indicator that considers both conditions of distance to the GUA and the GUA size to determine the level of desirable access to it. Moreover, another proposal for evaluating this SDG is through an indicator that measures the GUA area and sports facilities per inhabitant (Sánchez et al. 2018). Finally, Fox and Macleod (2019) defined another approach for the city of Bristol (United Kingdom), which assesses social behaviour and the use made of GUA through indicators such as trips to parks or walking areas, use of outdoor spaces for sporting purposes or healthy or even percentage of people who visit a park at least once a week.

The evaluation of SDG 13 “Climate Action” with regard to greenhouse gases (GHG), affects all sectors and sources of GHG emissions, not only the fixation caused by GUA. Several authors propose methodologies for evaluating the positive impacts of urban vegetation on climate change that could be used as an indicator for evaluating this SDG (McPherson et al. 1998; Nowak and Crane 2002; Yang et al. 2005; Nowak et al. 2006; Zhao et al. 2010; Escobedo et al. 2011; Weissert et al. 2014). Following these authors, GUA influence climate change through two impacts:

Carbon fixation by urban carbon sinks: the amount of fixed carbon depends mainly on growth rates (fast-growing trees initially capture more CO_2 than slow-growing ones), (Chaparro and Terradas 2009), age (young individuals retain carbon at higher rates than mature trees) and life expectancy because when the tree decays, carbon is released into the atmosphere, either by burning of the residual biomass or by biodegradation (Stoffberg et al. 2010). There are different methodologies to calculate the carbon capture and storage carried out by vegetation in GUA (Mijangos Hernández, 2015), even at a local scale (Garrido et al. 2009; Guarín-Villamizar et al. 2014).
Indirect reduction of GHG emissions caused by the influence of GUA due to three factors related to energy consumption in buildings: a) due to the reduction of heat absorbed and stored in buildings by the shade provided by urban trees (Akbari et al. 1997, (Romero-Lankao and Gratz, 2008; Nowak et al., 2010); b) due to the decrease in air temperature caused by the evapotranspiration of the foliage humidity (Huang et al. 1990; Kurn et al. 1994, Romero-Lankao and Gratz, 2008; Nowak et al., 2010); c) due to the decrease in the frequency and intensity of the winds that causes a decrease in heat losses caused (Huang et al. 1990; Nowak et al., 2013).

Finally, to evaluate the contribution of GUA to SDG 15 “Life and land”, Siragusa et al. (2020) proposes as indicator the total amount of green area in square meters as approximated by the Normalized Difference Vegetation Index (NDVI) based on satellite imagery. Another method is described by the Cabot Institute for the Environment of the University of Bristol (CIE 2019) that assesses social behaviour using an indicator that measures the proportion of respondents who visit GUA at least once a week. Valenciana (2018) proposes indicators such as number of urban or periurban Protected Natural Areas, percentage of managed urban forest area, ownership of urban forestland, and forest area affected by fires or pests. However, most of these indicators are difficult to adapt to the urban scale. Finally, Sánchez et al. (2018) and Ajuntament de Barcelona (2019) propose two similar indicators, but with a slight nuance between them. These authors propose as indicator the natural area per capita and the area of GUA per capita.

After analyse the state of the art, we can conclude that none of the described studies carried out by other authors analyse the specific and direct contribution of GUA to the SDGs of a city at sub-neighbourhood level. This would allow to have a quantified global vision of its importance in society, as well as to identify opportunities for improve it efficiently based on observed weaknesses in order to ensure an equity sustainable development in the different areas of the city. Therefore, our research analyses the direct and specific contribution of GUA to the achievement of three SDGs at sub-neighbourhood level. To do this, the indicators that have been considered most appropriate have been selected, adapted and applied to evaluate the contribution of GUA to SDG 11 “Sustainable Cities and Communities”, SDG 13 “Climate Action” and SDG 15 “Life and Land” in the study case of the city of Valencia (Spain). The results allow to identify potential areas of the city to improve the sustainable development regarding to GUA, and to analyse the level of equity in the sustainable development between different parts of the city to promote the environmental justice of the city.

2. Methods

2.1. Pilot city for the case study

Valencia city council and Joint Research Centre have a Collaboration Agreement signed to use Valencia as a City Lab under the framework of the Community of Practice on CITIES (JRC, 2020), to identify new approaches in the areas of urban indicators and Sustainable development goals. Thus, the city of Valencia (Spain) has been selected as a case study to carry out the evaluation of the contribution of GUA to the achievement of the SDGs. The city of Valencia is located in the Valencian Community in the Eastern part of Spain. Currently, Valencia city has 764,000 inhabitants and is the third biggest city of Spain. The metropolitan area, which includes other municipalities adjacent to the city, reaches more than 1,500,000 inhabitants. The city of Valencia is administratively divided into 19 districts, subdivided into 88 neighbourhoods, which are subdivided into 606 census sections, as shown in Fig. 1. Census sections of the centre of the city have less population density due to the age, size and type of building, as buildings of the centre of the city is generally buildings with lower heights where less population lives. This directly affects population density. However, as you go away from the centre, some census sections have greater separation between buildings or higher buildings where the population density may differ between adjoining census sections (Fig. 1).

A Geographic Information System (GIS) has been used for the calculation of the indicators and the graphic representation of the results to obtain the maximum spatial resolution in the evaluation and analysis of the results, thanks to zoning the city into 606 different polygons. The GUA of the municipality of Valencia are georeferenced and represented by a polygon with attributes of the area of the polygon, the number of trees and the species. Additionally, a census population layer is also used for each census section downloaded from the Valencia City Council Smart City Platform (de València, 2019).

2.2. Evaluation of GUA to achieve SDG 11 "Sustainable cities and Communities"

The contribution of GUA to the achievement of the Sustainable Development Goal 11 "Sustainable Cities and Communities" has been evaluated using two indicators, which assess the percentage of the citizenship that has access to GUA from two different approaches.

2.2.1. Population without desirable access

The definition of "desirable access to GUA" is an adaptation obtained from the different degrees of compliance that Casado (2015) uses to evaluate access to GUA at the city scale. Casado (2015) classifies as "desirable" when 100% of the population meets the four conditions described below, "acceptable" when 100% of the population meets three conditions and "unacceptable" when less than three conditions or less than 100% of the population meets three conditions. However, these evaluation parameters have been adapted at the sub-neighbourhood level, evaluating only how much population has "desirable access".

Thus, the condition proposed by Casado (2015) to have desirable access to a GUA occurs when the following conditions are met simultaneously:

- It is located at less distance than 200 m (walking distance) from a GUA larger than 1,000 m^2.
- It is located at less distance than 750 m (walking distance) from a GUA larger than 5,000 m^2.
- It is located at less distance than 2 km (commuting by bicycle) from a GUA larger than 1 ha (10,000 m^2).
- It is located at less distance than 4 km (travel by public transport) from a GUA larger than 10 ha (100,000 m^2).

Therefore, the polygons of GUA are divided into 4 different categories according to the mentioned intervals of their area and those under

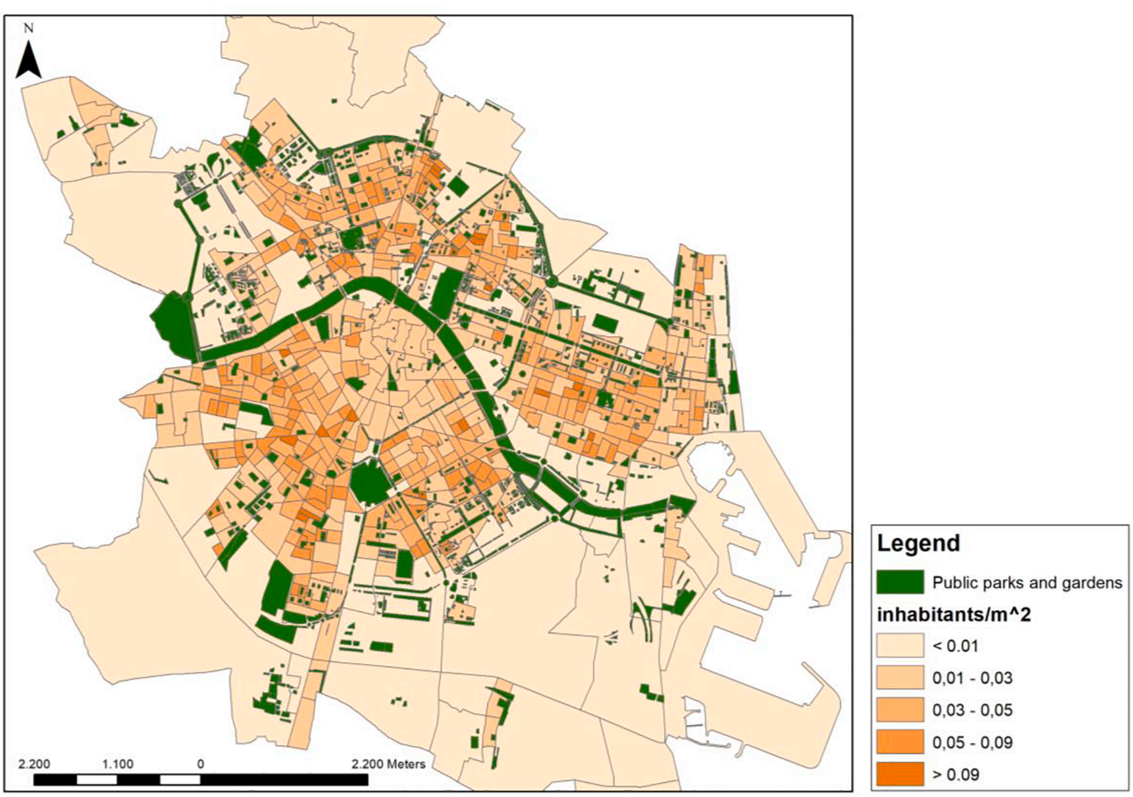

Fig. 1. Geographical distribution of the Green Urban Areas in the city of Valencia and population density of the city of Valencia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

1,000 m^2 are excluded from the calculation for this indicator. After that, a buffer is made with the aforementioned distance from the centre of each polygon depending on the category to which each polygon belongs. After that, the following equation is applied:

$$\%PWDA = \frac{\sum_{CS} CS_i population \times \frac{CS_{iPWDA} area}{CS_i area}}{\sum_{CS} CS_i population} \times 100 \quad (1)$$

where:

PWDA: Population without desirable access
CS_ipopulation: Population of the census section i
CS_iarea: Area of the census section i
PWDAarea: Area not covered by buffer of influence of GUA (area without desirable access).
CS_{iPWDA}area: Area of the census section i without desirable access to GUA.
CS_i: Census section i

2.2.2. Population without easy walking distance access

For the evaluation of easy walking distance access, the indicator proposed by Siragusa et al. (2020) has been used. This indicator is calculated considering an area of easy walking distance approximately of 10 min of walking time. In order not to give the same weight to very small GUA as to the rest, areas smaller than 1,000 m^2 have also been excluded. In addition, the same but more restrictive indicator has also been applied using an area that is easier walking distance access, considering 5 min of walking time.

Thus, influence buffers are calculated to represent the distance that can be reached from parks in a specified period of time using the Network Analyst extension of the ArcGIS software. Assuming that a citizen walks at 3.5 km/h (considering that the speed of an older person or child is less than an adult), the areas of influence of 5 and 10 min have been achieved. Next, a network of the streets of Valencia is configured from *pgrouting* in *Postgis*. From this network, the time of each street is calculated in a new field. Finally, the necessary layers are added to the network to achieve the polygons of areas of influence at the speed set to obtain the areas of influence according to the architecture of the streets.

After that, Eq. (2) is applied to the new buffer generated to calculate the Population without easy walking distance access.

$$\%PWEW = \frac{\sum_{CS} CS_i population \times \frac{CS_{iPWEW} area}{CS_i area}}{\sum_{CS} CS_i population} \times 100 \quad (2)$$

where:

PWEW: Population without easy walking distance access.
PWEWarea: Area not covered by buffer of influence of GUA that represent 10 or 5 min trip by foot.
CS_{iPWEW}area: Area of the census section i without easy and easier walking distance access of GUA.

2.3. Evaluation of GUA to achieve SDG 13 "Climate Action"

The evaluation of the contribution of GUA to SDG 13 "Climate Action" has been done by quantifying carbon fixation (expressed as CO_2 equivalent) by the vegetation (mainly trees and palm trees) of the GUA through the photosynthesis activity. For the calculation, the values of annual growth described by Montero et al. (2005) have been used. After that, a value of carbon fraction of dry weight biomass of 0.5 (weight carbon / weight dry biomass) has been applied as mean value of different authors consulted (IPCC, 2006, Montero et al. 2005, McGroddy et al. 2004, Hughes et al., 2000, Feldpausch et al. 2004, Andreae and Merlet 2001, Gayoso et al. 2002, Lamlom and Savidge 2003). Finally, the stoichiometric relationship between carbon and CO_2 is applied to obtain the total CO_2 eq. fixed annually. Thus, the calculation of CO_2 eq. fixed is calculated by the following equation:

$$FixedCO_2eq. = \sum_i n_{ij} \times AG_j \times CF_j \times \frac{44}{12} \quad (3)$$

where:

Fixed CO_2 eq.: Total amount of CO_2 eq. fixed by photosynthesis of trees and palm trees. (in kg CO_2 eq.)
n_{ij}: Number of trees of the species j in the polygon i
AG: Annual growth of dry weight in kg per year.
CF: Carbon fraction of dry weight biomass (0.5 kg C/kg dry biomass)
i: polygon
j: species
44/12: Stoichiometric relationship CO_2-C.

GUA of the pilot study of Valencia are composed by 322 different species. The bibliography consulted does not have data for all these species. Therefore, a simplification has been made by cataloguing all the species without exact referenced data for the species in three types: coniferous, broadleaves and palm trees. Thus, an average value for each type has been calculated based on the species that we do have data in the bibliography. Thus, the annual growth values (in kg dry biomass/year) used for the species without referenced data are: coniferous 3.07; broadleaves 5.08 and palm tree 2.71. These values were calculated in TRUST 2030 strategic cooperation project of The Valencian Innovation Agency (AVI TRUST 2019). Thus, annual growth values were calculated based on statistics of Valencia city (number and spices of the trees) (de València 2019; Ajuntament de València, 2019) with coefficients used by Montero et al. (2005).

2.4. Evaluation of GUA to achieve SDG 15 "Life and Land"

Finally, the evaluation of the contribution of GUA to the SDG 15 "Life and Land" has been carried out using the indicator used by Sánchez et al. (2018) and Ajuntament de Barcelona (2019) that calculates the GUA per capita. Thus, the indicator used is calculated using the following equation:

$$GUAperinhabitant = \frac{\sum_{CS} CS_i GUA}{\sum_{CS} CS_i population} \quad (4)$$

where:

GUA: Green Urban Area
CS_ipopulation: Population of the census section i
CS_iGUA: Green Urban Area (in m^2) of the census section i

In addition, the calculation of this indicator has been carried out in every census section individualized to achieve more spatial resolution in the analysis and to be able to identify which census sections of the city have the worst results or the most opportunity for improvement.

3. Results and discussion

3.1. Contribution of GUA to achieve SDG 11 "Sustainable cities and Communities"

3.1.1. Population without desirable access

The combination of the four influence buffers of the GUA categories allows to identify the area of population without desirable access to GUA (blue area of Fig. 2). Fig. 2 shows which parts of the city meet the criteria described of desirable access or do not meet them. It can be seen that the peripheral areas of the city have a large area considered as "without desirable access to GUA". However, these areas are outside the urban nucleus where there is almost no GUA because little or no population lives here. These results show that the distribution of GUA in the city is

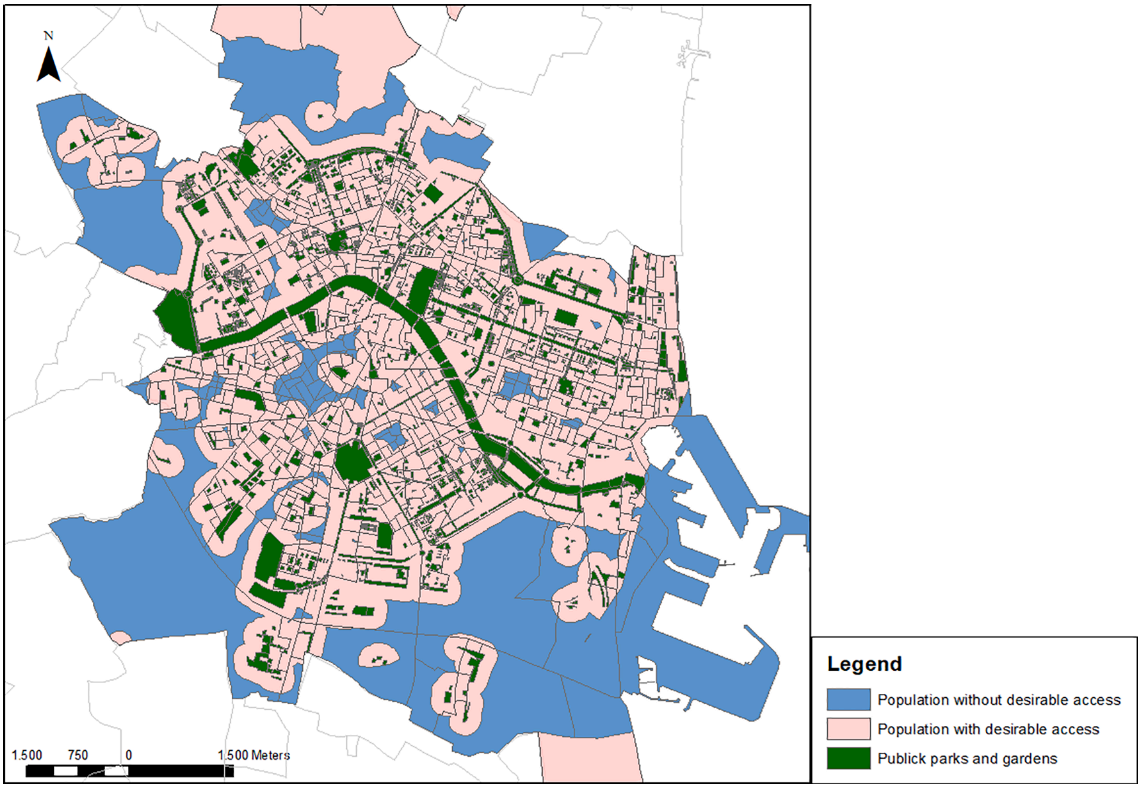

Fig. 2. Population without desirable access to GUA in the city of Valencia.

generally equitable. Only the blue area of the city centre has worse results. This is because it is the oldest area of the city and has fewer GUA spaces. Thus, the results of the applied indicator show 70,497 inhabitants without desirable access to GUA because they are living in areas that do not comply with the distances described in the four categories of access to GUA, simultaneously. This means 9.23% of city inhabitants do not have desirable access to GUA. The specific analysis of the central area of the city where more space is identified as "without desirable access" is analysed more in detail in Fig. 3.

Fig. 3 shows the part of the city with the highest population without desirable access to GUA. This is the southwest area of the city, where the neighbourhoods of the districts of Patraix, Ciutat Vella and Extramurs are located. This zone lacks GUA less than 200 m away and therefore does not meet the first condition of accessibility (see Section 2.1.1).

3.1.2. Population without easy walking distance access

The application of second indicator to evaluate the contribution of GUA to the achievement of SDG 11 can be observed in Fig. 4. In Fig. 4, the purple area represents the area with easy walking distance access to a GUA and the pink area represents the area without easy walking distance access to GUA. Thus, the analysis of these results shows a total of 20,885 citizens without easy walking distance (PWEW). This supposes 2.73% of the total population of Valencia city. Most of the population without easy walking distance access to GUA is located in the south of the city. Nevertheless, compared with other municipalities of Spain, the city of Valencia has less population without easy walking distance access to GUA than e.g. Madrid (14.41% PWEW), Barcelona (17.6% PWEW) or Bilbao (10.26% PWEW) according to the results of Sánchez et al. (2018). However, these results are very sensitive to assumptions made to apply the methodology. For example, the speed of walking or even the layout of the streets have a significant influence on the results. Thus, Sánchez et al. (2018) obtained a result of 26.69% without easy walking distance access in the municipality of Valencia instead of the 2.73% that we have obtained. One of the reasons is also due to the fact that we have applied the indicator to the city of Valencia, excluding the outside neighbourhoods of the North and South of districts "Poblats del Nord" and "Poblats del Sur" respectively for being far away of the urban area and close to natural areas (beaches or forests). Nevertheless, the districts excluded represent less than 3% of Valencia municipality population. Thus, in our case, the differences observed regarding Sánchez et al. (2018) results are due to the assumption made in terms of speed of walking and the specific application of the methodology (for example the road streets characteristics or the location of entrances to the park that determine the length of the journey by foot).

Fig. 5 shows the result of the application of the same indicator, but more restrictive as people without easier walking distance access. This indicator calculates the easier walking distance access considering 5 min of walking time. In Fig. 5, purple area shows the area with easier walking distance access calculated by criteria described in Section 2.2.2 and pink area represent the zones of the city where people do not have easier walking distance access. The result shows a total of 154,062 citizens without easier walking distance access that suppose the 20.17% of the population of Valencia city. The zone with worst results is again the southwest area of the city where the neighbourhoods of the districts of Patraix, Ciutat Vella and Extramurs are located. In this area of the city, two factors occur at the same time that justify this poor result, it is an area with few nearby GUA and also has a high population density. Some of the city centre neighbourhoods apparently close to GUA appear as "without easier walking distance access". This is because the influence buffer depends as much on road streets characteristics as the location of the entrances to the specific GUA polygons. Therefore, some large GUA polygons with the entrance located in a part of the polygon, just going around the polygon or following the route described by the road streets layer to the entrance can suppose more than 5 min of walking time. This means that some areas of the centre near large GUA have been considered as "Without easier walking distance access".

3.2. Contribution of GUA to achieve SDG 13 "Climate action"

The 901 GUA with available data in Valencia fix 812,230 t CO_2 eq.

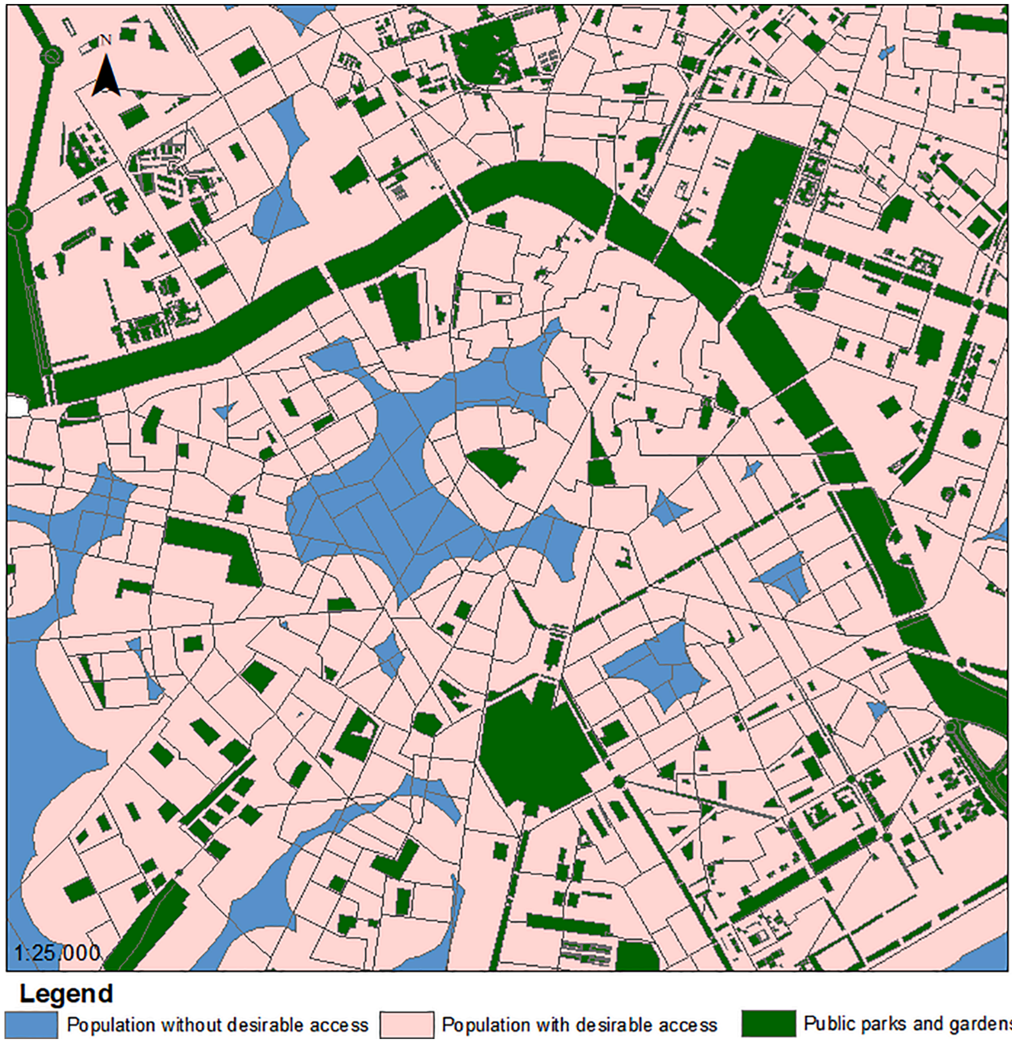

Fig. 3. Population without desirable access to GUA in the city of Valencia. Zoom detail of southwest area of the city.

annually. The results are shown in Fig. 6, which represent the carbon fixation of each GUA. The maximum amount of CO_2 eq. fixed is 49,505 kg CO_2 eq. and correspond to the park "Jardines del Real Viveros". There are also polygons with low carbon fixation due to contain very little vegetation or the presence of non-arboreal or shrub vegetation, which is not quantified in this study (such as meadows).

The geolocation of public parks and gardens and its importance as carbon sinks, can be observed in Fig. 7. As can be seen, the biggest carbon sinks green urban areas are in a linear green infrastructure that crosses the city from east to west through the centre. This linear green infrastructure offers a strategic location that allows most areas of the city to have good access to GUA.

We have to consider that the results obtained correspond to the quantification of CO_2 eq. fixed only by public parks and gardens. Thus, the CO_2 eq. fixation of the vegetation of the individual trees in pits on sidewalks of some streets as well as private parks and gardens are outside this quantification. However, the monitoring of this indicator allows evaluating it annually to check and monitor its evolution. Despite this, we have compared this result with the city of Torrent (Spain), which is smaller city in the same region (Torrent has 69.32 km2, and Valencia has 134.6 km2). Thus, de Torrente (2015) quantified a CO_2 sequestration of 590 tCO_2/year by GUA. The carbon fixation of the GUA of Torrent is equivalent to 0.18% of its gross emissions according to its Sustainable Energy Action Plan (de Torrent 2015). In Valencia, however, the total CO_2 fixation quantified is equivalent to 0.04% of total gross GHG emissions according to the Sustainable Energy and Climate Action Plan (de València 2019). Sustainable Energy Action Plan has a common methodology that allows us to compare objectively two cities of very different sizes. Thus, the Valencia's assessment of the GUA's contribution to SDG 13 "Climate Action" is worse than Torrente's.

3.3. Contribution of GUA to achieve SDG 15 "Life and Land"

The contribution of GUA to the achievement of SDG 15 "Life and Land" has been evaluated calculating the green urban area per capita. Thus, the overall result shows 10.03 m^2/inhabitant to the city of Valencia (Fig. 8). This result shows that Valencia is slightly above the minimum amount of 9 m^2 of green open space per person recommended by World Health Organization (2009).

Valencia surface area of green urban area per capita is above than other Spanish cities such as Sevilla (8.57 m^2 GUA/inhabitant), Barcelona (7.00 m^2 GUA/inhabitant) or Bilbao (9.30 m^2 GUA/inhabitant) evaluated by Sánchez et al. (2018). However, the result of Valencia is far below others such as Madrid (20.9 m^2 GUA/inhabitant), Córdoba (34.01 m^2 GUA/inhabitant), Cartagena (24.42 m^2 GUA/inhabitant) or San Sebastián (39.72 m^2 GUA/inhabitant) according to the same author.

In comparison to other cities in Europe, European Green Capital Award (2013) reports 57 m^2 GUA/inhabitant for Nantes and 18.85 m^2 GUA/inhabitant for Amsterdam, 22.73 m^2 GUA/inhabitant for Berlin, 19.23 m^2 GUA/inhabitant for London, 13.61 m^2 GUA/inhabitant for

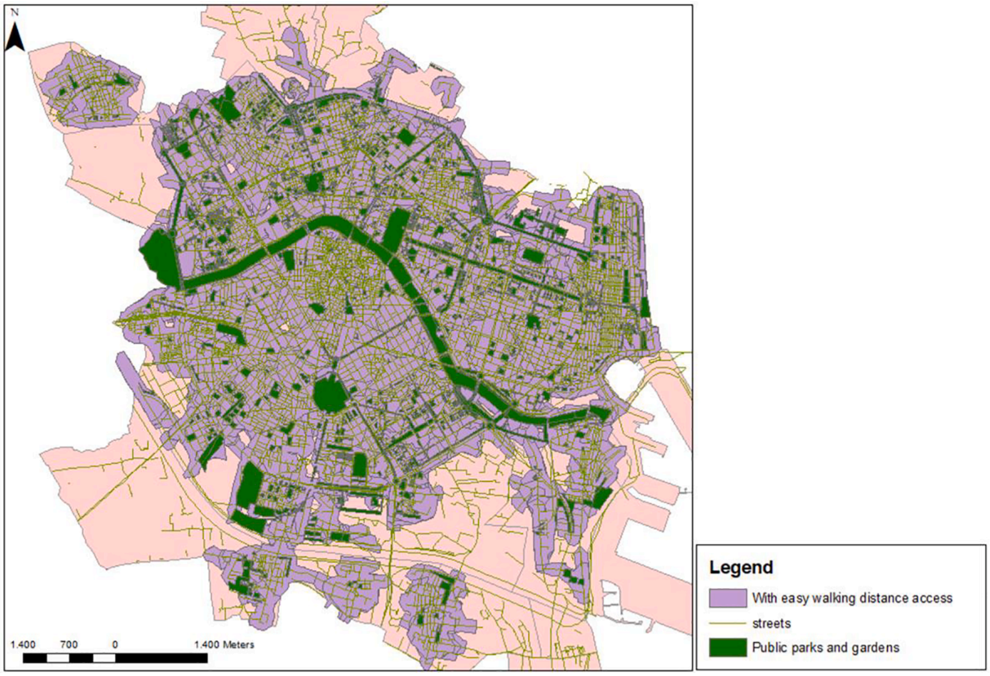

Fig. 4. Population with easy walking distance access to GUA in the city of Valencia.

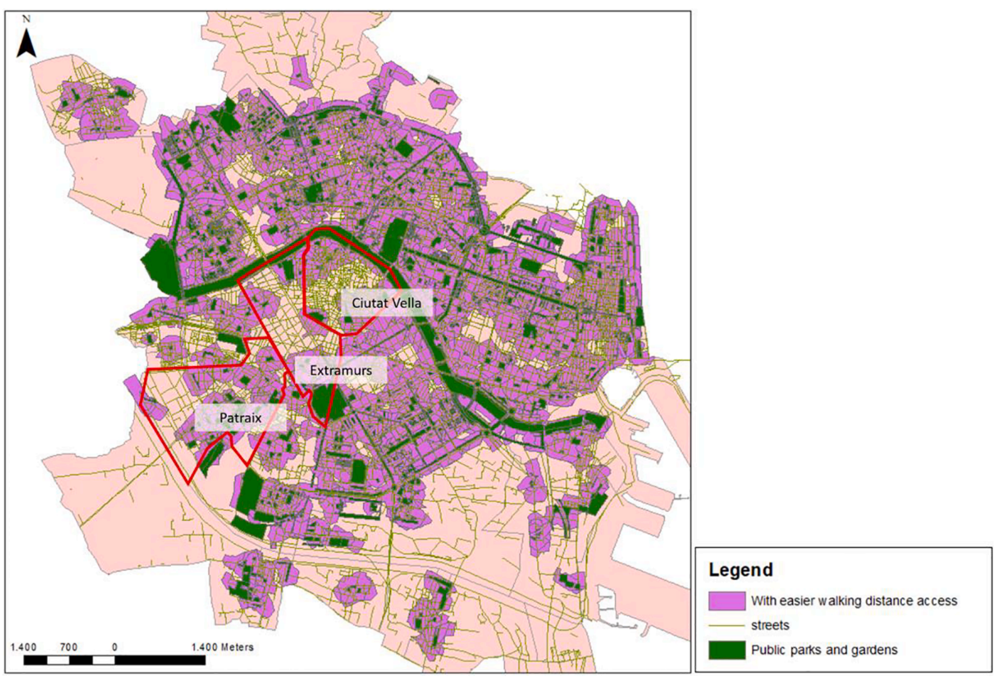

Fig. 5. Population with easier walking distance access to GUA in the city of Valencia.

Roma and 7.6 m^2 GUA/inhabitant for Athens according to Maes et al. (2019). Valencia is above the average value obtained for European Southern countries of 4.84 m^2 GUA/inhabitant according to Kabisch et al. (2016) but below the European average value of 18.2 m^2 of publicly accessible green space per inhabitant (Maes et al. 2019). On a worldwide level, Geotab (2019) reports 13.14 m^2 GUA/inhabitant for New York, 21.52 m^2 GUA/inhabitant for New Dehli (Ramaiah and Avtar, 2019) and 1.13 m^2 GUA/inhabitant for Marrakech (Bounoua et al. 2020). So, we can consider that the results obtained for Valencia are in medium range in comparison with other large cities.

In addition, the green urban area per capita has been calculated in each census section (Fig. 8) to evaluate the sustainable development equity, regarding GUA per inhabitant, between the different zones of the city. Thus, the worst results correspond to the neighbourhoods of the districts of Patraix, Ciutat Vella and Extramurs, like the results of the evaluation of SDG 11 obtained in the section 3.1.1. Nevertheless, in this indicator the neighbourhoods of the district of Eixample present also very bad results, as can be observed in a detailed view in Fig. 9.

Finally, the results of the GUAs' contribution to the achievement of SDG11, SDG15 and SDG13 at the sub-neighbourhood level show that equitable sustainable development must simultaneously ensure that the GUA have adequate location, size, quantity and quality (quantity and

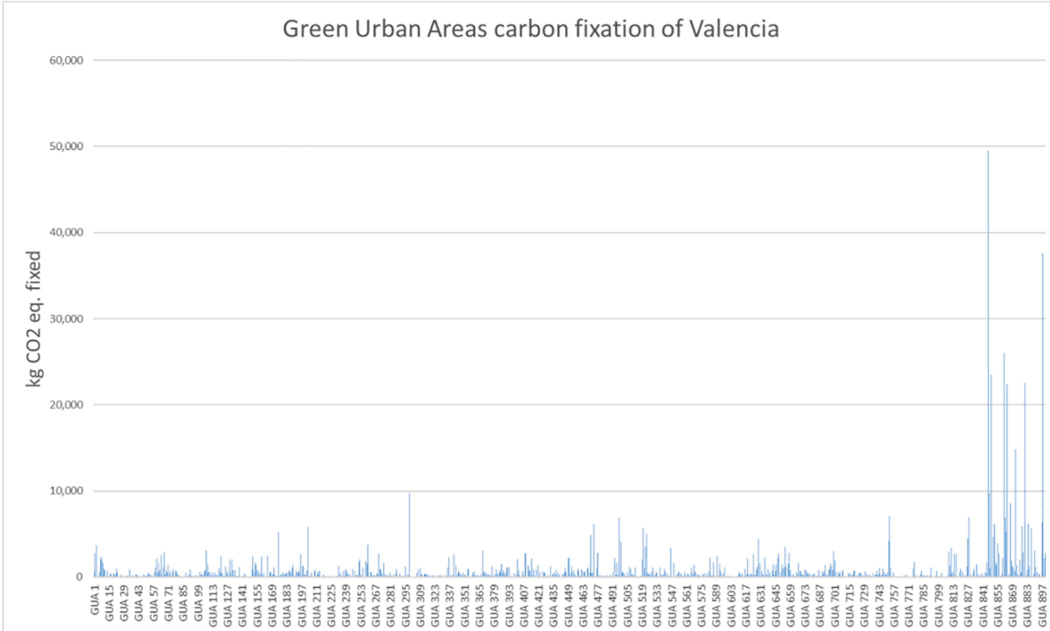

Fig. 6. Carbon fixation per GUA of the city of Valencia.

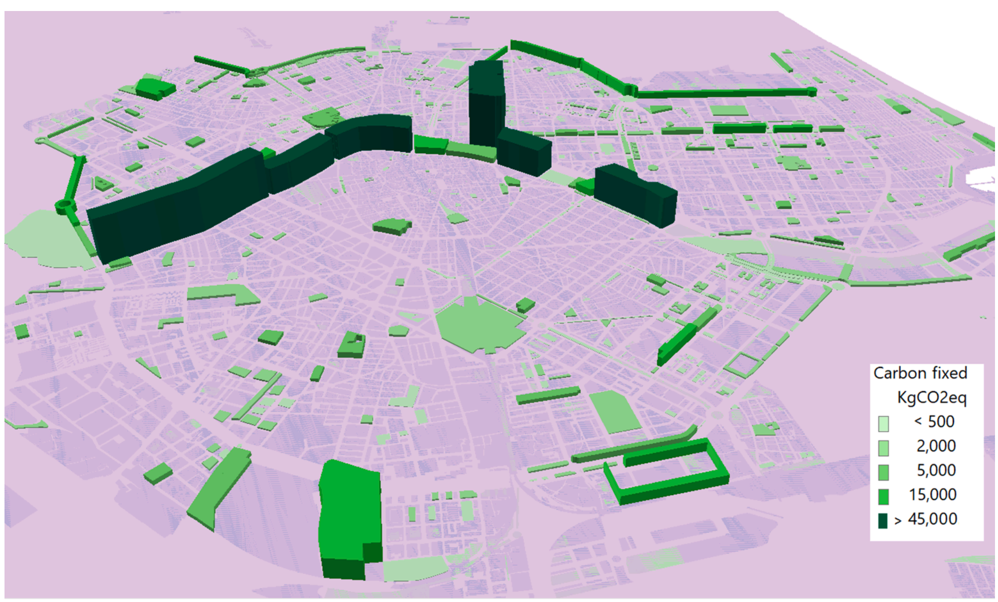

Fig. 7. Location of GUA with extrusion proportional to their fixed carbon value of the city of Valencia.

type of vegetation). Therefore, proper planning of GUAs in cities must take into account all these factors in order to have equitable sustainable development among all areas of the city.

4. Conclusions

The contribution of public green urban areas (GUA) to the achievement of three Sustainable Development Goals (SDGs) and the sustainable development equity between 606 different zones have been evaluated in a case study in the city of Valencia (Spain). Specifically, the SDG 11 “Sustainable Cities and Communities”, SDG 13 “Climate Action” and SDG 15 “Life on Land” have been analysed and evaluate with a Geographic Information System (GIS). For this, four different indicators have been applied in the 606 areas into which the city has been divided. The evaluation of SDG 11 “Sustainable Cities and Communities” offers a result of 9.23% of the citizens with difficult access to GUA and 2.73% without easy walking distance access. However, applying a more restrictive criterion to the indicator described as population without easy walking distance access, which quantifies the distance based on 5 min walking time instead of 10 min, the result worsens to a total of 20.17% of the population without easier walking distance access. The GIS analysis has allowed to identify the least equitable zone of the city with the worst results. Thus, the southwest zone of the city has obtained the worst results due to two causes overlapped, on the one hand the low number of GUA and on the other hand the high population density. Consequently, the methodology designed and applied and the results obtained show that future green infrastructure expansion programs should focus on these less favoured areas of the city, in order to comply with this SDG ensuring equity between the different areas of the city, specifically in the application of the Urban 2030 Agenda for a

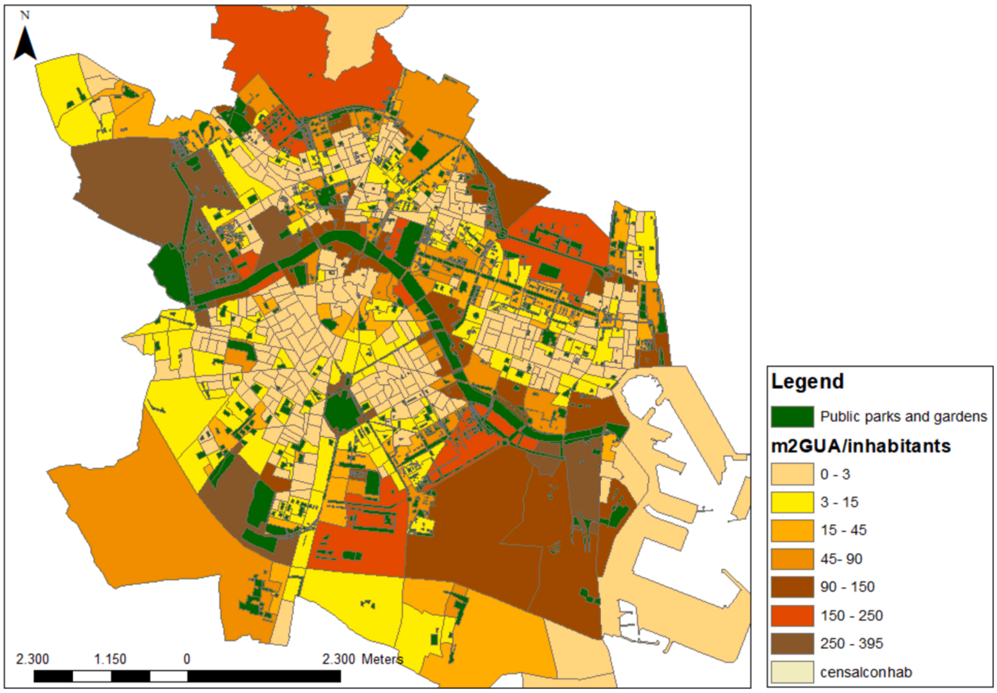

Fig. 8. Green urban area per capita in each census section of the city of Valencia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

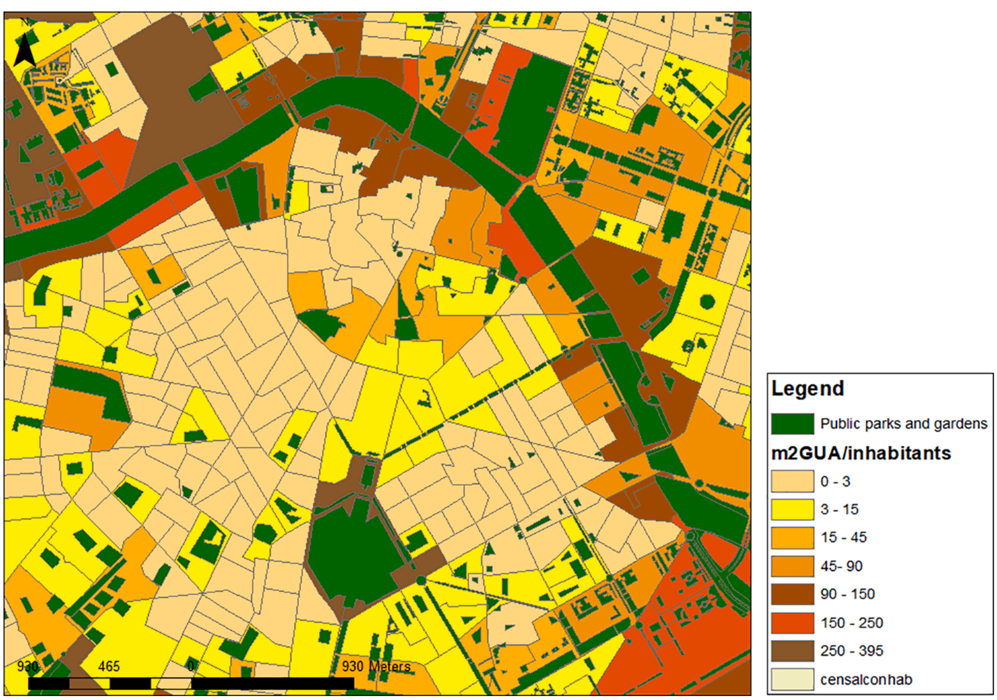

Fig. 9. Green urban area (GUA in m^2) per capita (inhabitants) in each zone (divided by census section) of the city of Valencia. Zoom detail of southwest and south centre area of the city. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

sustainable city. Moreover, the calculation methodology for the two indicators that have been defined and applied to assess the influence of GUA on SDG 11 can be considered as very appropriate and easy to apply for their follow-up and monitoring in a Smart City platform. However, these indicators need to be improved, for example by fine-tuning the age groups (elderly people and children) as well as disabled people. Currently, our research group is working on the integration of these data to refine the indicators, in order to obtain models and practical solutions for the better access of these groups to the GUA, as well as to facilitate decision-making by local administrations in urban, environmental and social planning of the GUA in cities.

The contribution of GUA to SDG 13 “Climate Action” has been evaluated calculating the carbon fixed by public GUA. The result shows that carbon fixed by GUA is equivalent to 0.04% of total gross GHG emissions of the city. The spatial resolution of the calculation allows identify the parks and gardens that most contribute to mitigate climate change. Thus, in the case of the city of Valencia, the main urban carbon sink is located in a large linear green infrastructure that crosses the city from east to west through the centre. The location of this large green infrastructure has proven to be strategic, not only for the achievement of this SDG but also of the other SDGs evaluated. However, it is important to note that the structure of each type of park or garden significantly influences the carbon fixation capacity of the vegetation that composes it. Thus, young trees and shrubs are capable of absorbing more carbon due to their rapid growth, while mature trees are already declining in their growth and, consequently, in their fixing capacity. It must also be taken into account that meadows or grasslands do not have a significant capacity for carbon fixation. Therefore, we consider that this is another factor to take into account when planning the green infrastructure of cities. With all this, after this research we can affirm that the methodology designed and applied allows us to obtain an indicator of the contribution of GUA to the mitigation of Climate Change through carbon fixation that is easy to record, evaluate and monitor, also for inclusion in a Smart City platform. However, in order to improve the accuracy of this indicator, our research group is refining this indicator by including both the linear trees in the sidewalk pits and also by introducing the emissions derived from the cultural treatments of the GUA (fuel consumption for tillage machinery and soil improvement, nutrient contributions through fertilization, pruning, final felling, irrigation facilities, etc.) in the calculation of net carbon fixation.

The evaluation of SDG 15 “Life and Land” by applying the indicator of green urban area per inhabitant offers a result of 10 m^2 GUA per inhabitant. This result places Valencia in a medium/low level in comparison with other large cities in Spain, and in a medium range level in comparison with other large cities in Europe or even worldwide. After the investigation, it can be concluded that the methodology designed and applied allows evaluate the sustainable development equity of the different zones of the city thanks to obtaining results with high spatial resolution. Thus, the results of this indicator make it possible to identify with very high precision the areas, neighbourhoods and districts where GUA are clearly insufficient for the well-being and health of citizens. Therefore, this indicator is key for planning future green infrastructures in cities.

In the case study of the city of Valencia, after the evaluation carried out, we can conclude that the GUA that exist today sufficiently fulfil their environmental and social functions in terms of accessibility and quantity and quality of green urban areas close to citizens. Regarding the applicability of the methodology, we can conclude that the four indicators defined and applied are very appropriate for evaluating the contribution of GUA to the three SDGs analysed. They are therefore quantitative indicators, easy to understand and interpret by citizens and their public decision-makers, with a clear methodology, with sufficient spatial and temporal resolution, and easy to monitor and include in a Smart City platform. They are, therefore, key indicators for planning a sustainable city and for the fulfilment of a Sustainable Urban Agenda 2030 in an equitable way between all areas of the city. Finally, the inclusion of additional parameters related e.g. to the age structure of citizenship, typology of accessibility difficulties due to disabilities, more accurate information on structure and composition of parks and gardens and their cultural treatments, will allow us to further refine the calculation, measurement, evaluation and monitoring of these indicators and their degree of compliance with the SDGs in cities.

CRediT authorship contribution statement

Edgar Lorenzo-Sáez: Conceptualization, Formal analysis, Methodology, Investigation, Writing – original draft. **Victoria Lerma-Arce:** Supervision, Validation, Writing - review & editing. **Eloina Coll-Aliaga:** Supervision, Data curation, Writing - review & editing. **Jose-Vicente Oliver-Villanueva:** Conceptualization, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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