Identification and mapping of areas and buildings with high roof greening potential

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***Abstract*— Climate change impacts are threatening the sustainability and livability of cities, which are asked to respond from an integral perspective that combines mitigation and adaptation through an evidence-based decision making. Nature-based solutions have been recognized as key in addressing environmental, social and economic challenges and their benefits and effectiveness have been demonstrated in several studies. Specifically, green roofs have shown potential in urban areas, where space for new green infrastructure is often limited.**

The methodology described in this paper aims at providing results supporting decision-makers in sustainable development by estimating the potential for green coverage at rooftop level identifying the most suitable locations. By the development of a Digital Surface Model based on LiDAR data and the combination parameters related to land surface temperature, imperviousness, normalized difference vegetation index and cadaster information, the method proposed generates two main results: the maximum green roof potential and the prioritization of green roofs. The application of the method to the city of Donosti-San Sebastian is presented.

Keywords— green roofs, NBS, climate change adaptation, urban planning, Copernicus

I. Introduction

Climate change is a complex problem which requires an integral perspective that combines measures to mitigate greenhouse gas emissions with policies to adapt to its impacts, along with sustainable development principles. As stated in the IPCC Sixth Assessment Report, there is high confidence that climate risks are appearing faster and will get more severe sooner. Furthermore, even if climate action has increased in all levels of governance, there is evidence that opportunities for adaptation will have less effectiveness if the 1.5ºC global warming is exceeded [1]. According to UN Habitat, cities play a crucial role in the fight against climate change, as more than 70% of emissions are produced at urban level. Within cities, nature-based solutions are recognized to help societies in addressing diverse environmental, social and economic challenges in a sustainable way. Examples of these solutions are green roofs, green walls, urban farms, street trees and other urban vegetation, which all contribute to reduce heat and especially extreme heats events [2], [3] ad help manage stormwater and floods [4]. Specifically, green roofs have demonstrated multiple benefits such as collecting rainwater, contributing to well-being and air quality and are an effective adaptation option in heat resistant and energy efficiency building design. At the building level, green roofs significantly lower energy demand during peak periods as they reduce the use of cooling systems such as air conditioning [4] and lower surface temperatures, contributing to reduce the overall heat profile of cities at the urban scale, of widely employed [5]. Knowing the capacity of a city to host these types of nature-based solutions allows defining which areas have the highest potential to accommodate these solutions and provide decision-makers with different scenarios on green roof potential deployment.

In urban areas, where space for new green infrastructure is often limited, rooftops are considered as suitable places to increase green areas. This approach has been included in planning tools and local governments are supporting the wider implementation of green roofs by different forms of incentives, tax reduction policies and land use regulations [6], [7]. Information on suitable locations is therefore essential for urban planning and decision-making processes. Based on the available information provided by the Copernicus Core Services, as well as data provided by contributing missions and local information it is possible to derive this information with the necessary spatial resolution to produce map-based results to make informed decisions.

The methodology presented in this paper aims to estimate the potential for green coverage at rooftop level by identifying suitable locations for green roof deployment and supporting decision-making towards broader sustainable urban development and has been applied to the case study of Donosti-San Sebastián.

II. Methodology

A. Description of the case study

The city of Donosti-San Sebastián has a long trajectory in planning and carrying out actions aimed at reducing greenhouse gases emission and adapting to the main impacts derived from climate change, especially in relation to storm waves, sea level rise, heat waves and floods. In this context, the Municipality developed a local climate change strategy that allows citizens to connect with this challenge and face it collectively, taking advantage of the opportunity to solve other urban environmental and social conflicts. The first local plan to fight against climate change was adopted in 2008 and the city has recently launched the Klima 2050 plan, which emphasize the importance of renaturing water bodies and promoting green infrastructure as adaptation actions. Specifically, the objective set by the municipality is to increase the green and permeable surface in buildings and public space by 15% by 2030, prioritizing neighborhoods that present a lower green surface per capita. Based on this assumption, the methodology described in this paper, aims at supporting the initial steps of the decision-making process in urban planning, by providing evidence on the maximum green roof potential and an objective prioritization of buildings with highest greening potential, to maximize their impact.

B. Methodological sequence

The methodology proposed aims to estimate the potential for green coverage at rooftop level by identifying suitable locations for green roof deployment and supporting decision-making towards broader sustainable urban development by selecting high priority buildings. Two main outputs are generated: (i) Maximum green roof potential and (ii) prioritization of green roofs.

The starting point is a Digital Surface Model created based on LiDAR data, which allows for the roof slope calculation for each cell inside each building included in the area. Publicly available LiDAR data with a resolution of 2.2 pts/m2 were downloaded from Basque government portal [8]. Then, from LiDAR data a DSM in raster format was generated using LASTools plugin for QGIS. The generated DSM has a resolution of 1 meter. Afterwards, building footprints were used to delineate the roofs by intersecting the polygons of the buildings with the DSM raster file. From here, the cells of the slope raster that exceed a certain threshold are filtered out. Subsequently, the area of each roof that does not exceed this threshold is calculated and this area is assigned to each vector building, obtaining the maximum green roof potential. To prioritize the green roofs, the priority of each building is combined with the priority of the area where it is located. The building priority is based on the year of construction and the maximum green roof potential, while the area priority is based on the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST) and imperviousness values. The process for obtaining the outputs is described in more detail below.

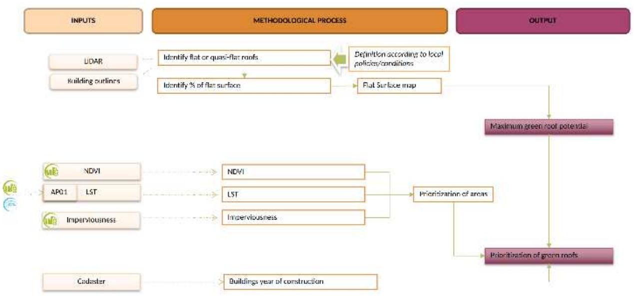

Fig. 1 Methodological sequence of the proposed method

The algorithm has been developed in python and packaged in a Docker container. This container has been deployed on a DIAS (Data and Information Access Services). By using a cloud-based platform, it has been possible to optimize access to large volumes of data from Copernicus.

The selected DIAS was WEkEO due its capabilities to respond to the applications requirements specifications developed in the context of CURE project. WEkEO is the EU's Copernicus DIAS reference service for environmental data, virtual environments for data processing and skilled user support. Additionally, it offers a large range of pre-processed Sentinel satellite fleet data, data from Copernicus Services, and additional in-situ data. In total 235 open datasets are available ranging over many thematic and geographic areas.

C. Data sources

The data source of NDVI, LST and Imperviousness is the European Union's Earth observation program Copernicus. Specifically, NDVI and Imperviousness come from the Land service, while LST comes from CURE application 1 which uses data from the Land and Atmosphere Copernicus services (e.g., Urban Atlas, Imperviousness, High Resolution Vegetation Phenology and Productivity, UERRA regional reanalysis for Europe on single levels from 1961 to 2019 and ERA5 hourly data on single levels from 1979 to present).

In addition to the data from Copernicus, case study specific data has been used including a LIDAR of the study area, outlines of the buildings and the year of construction of the buildings. The former provided by the local government and the latter from the cadaster.

D. Identification of the maximum green roof potential

As flat or quasi flat roofs are the ones more suitable to host a green cover, slope computation is performed at the building level, by measuring the actual slope at each pixel of the roof. The estimation of the real slope of each building is calculated using a statistical algorithm and the threshold for the slope is adjusted to 10%, notwithstanding the value can be adjusted on a case by case, considering local regulations and policies. Furthermore, the year of construction of the buildings is used to discard structures built prior to 1900, as most of them have cultural values which limit the installation of green roofs and are mainly characterized by pitched roofs. The necessary semantic information is collected from the local cadaster and included in the model. This lets to identify the maximum green roof potential, which means the maximum surface that can be ideally covered by vegetation. The map-based result shows the buildings which can be ideally covered by vegetation and provides information on the total square meters that can be greened.

E. Prioritization of areas and buildings with highest benefit

The identification of areas with highest greening potential is performed considering several parameters aiming at maximizing the impact of the solutions. Benefits of green roofs are larger if these solutions are installed in areas characterized by low NDVI, impervious surface and high LST, contributing also to reduce the Urban Heat Island effect. All these characteristics determine the priority of the area where the buildings are located. The area priority is a raster layer which is the result obtained after aggregating the previously normalized NDVI, Imperviousness and LST layers.

Finally, to prioritize the buildings for implementing green roofs, the area priority and the building priority is combined. Even if almost all buildings can host green roofs, some of their characteristics make the design and installation complex and expensive. Again, the year of construction is used to prioritize buildings in which roof greening would not require extensive structural rehabilitation. Based on the case study and estimating the loading capacity according to the construction regulations, we can assume that buildings built before 1900 should be discarded, the ones built between 1901 and 1961 would require a detailed analysis and thus have a low priority, while buildings constructed after 1962, year in which the Spanish construction code was introduced, have the highest priority. Therefore, the building priority is vector layer which results from combining the area priority where the building is located, the year of construction and the maximum green roof potential of the building.

These prioritizations are calculated through a weighted combination that can be specified by the user depending on the city characteristics and the user profile. Less experienced users can use default values, while others can change variables values or weights according to their specific location or objectives. The map-based result, in this case, shows the normalized prioritization index for each building, represented by a 0-1 scale.

III. RESULTS

The results obtained for the city of Donosti-San Sebastian are shown below. The following figure (Fig. 2) shows the maximum green roof potential, which expresses the amount of square meters that can accommodate a green roof, where dark green colors are the buildings with higher maximum green roof potential. It can be seen that the buildings with the highest green roof potential are located in the more peripheral areas of the city as they are newer buildings with larger roof areas. Furthermore, out of the total number of roofs on buildings in Donosti-San Sebastian, around 20 percent are suitable for green roofs, compared to the 80 percent that are not, due to their age, roof slope or small area.

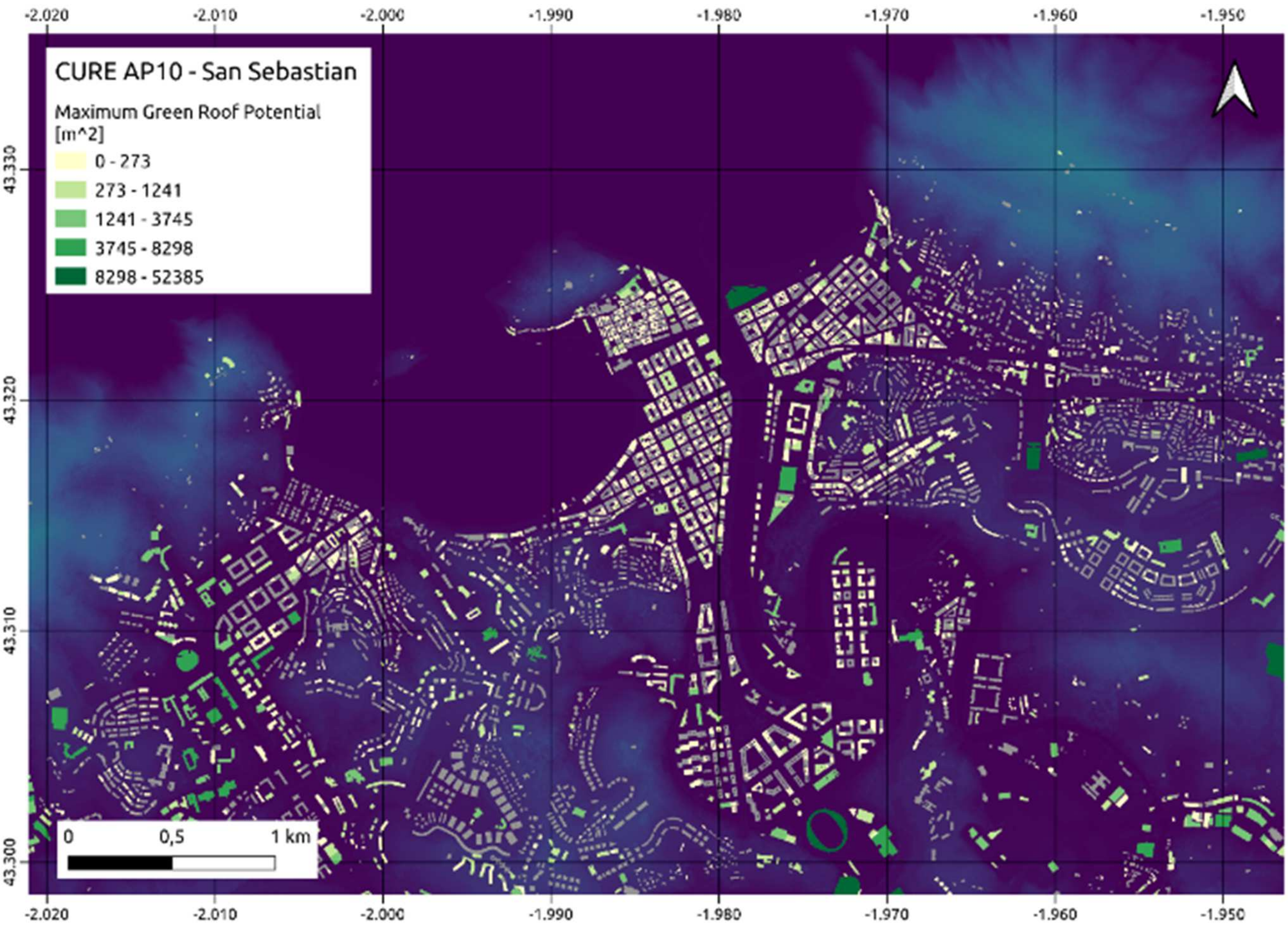

Fig. 2 Maximum green roof potential expressed in square meters ranges for the city of Donosti- San Sebastian

Finally, the roofs of the highest priority buildings have been identified taking into account the maximum green roof potential of the building, as well as the LST, Imperviousness and NDVI. The application allows establishing, by means of a series of parameters, the weights of the criteria used to obtain the prioritization index according to the most critical issues for the city, such as thermal stress or flooding.

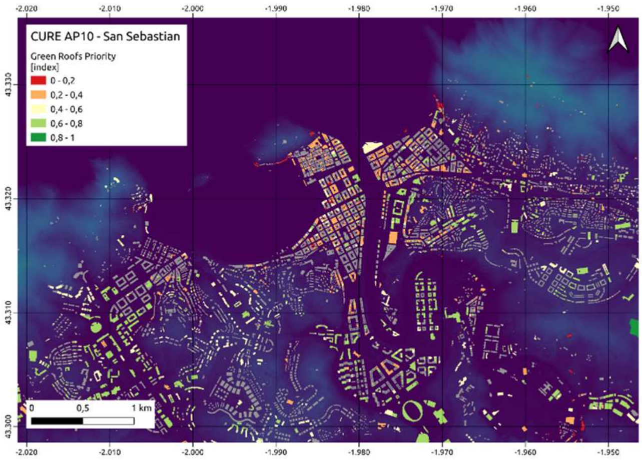

Fig. 3 Green roof prioritization map of the city of Donosti- San Sebastian

Fig. 3 shows the green roof prioritization map, where greenish colors are buildings with high ranking (high prioritization) and reddish colors buildings with low ranking (low prioritization). It can be seen that in the city of Donosti-San Sebastian the areas that obtain a higher priority level are located in the west, as well as in the center and south of the city.

According to the methodology proposed the maximum green roof potential is estimated in 118 ha, with 3554 green rooftops. By implementing the prioritization method, 1204 roofs resulted in a high priority, 1091 in medium priority and 959 in low priority, being the district of Ibaeta the most suitable to host this type of solution.

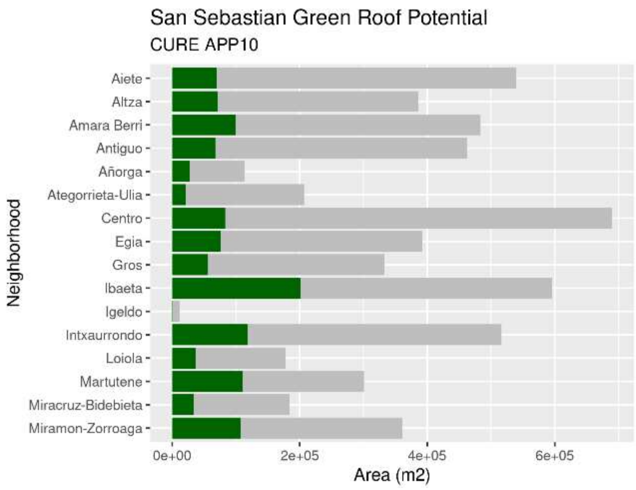

Fig. 4 Representation of the maximum roof area that can potentially be vegetated (in green) compared to the total roof area (in grey) by neighborhoods of the city of San Sebastián

IV. CONCLUSIONS

The approach presented in this paper supports policy initiatives at local level in the promotion of green infrastructure and the related European Union priority objectives [9]. The method allows municipalities to have information on greening potential and capabilities to host green roofs in their cities according to a prioritization based on reliable parameters. The information needed for the calculation is simple and available in almost all European cities and results contribute to a sustainable and comprehensive urban planning and decision-making process by providing an accurate and realistic assessment of green roofs installation. The study shows important insights to inform decision makers and urban planners on improving green roofs policies and strategies in the city of San Sebastian. The methodology developed is applicable to other locations, as users can set different threshold parameters and modify weighting criteria according to their priorities and relative importance criteria. Next step of the research will be to combine greening capabilities with solar panels and other solutions to increase impacts and benefits.

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