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# Simulating crowding of urban green areas to manage access during lockdowns

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## HIGHLIGHTS

- The trade-off between green areas access and crowding is made explicit.
- Different policy scenarios have different impact on green areas access and crowding.
- Limiting maximum travel distance has small effects on the number of crowded parks.
- Hotspots where green areas are too far or at higher risk of crowding are identified.
- Off-the-shelf measures (e.g., opening schoolyards) work and can be adopted rapidly.

## ARTICLE INFO

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## ABSTRACT

During the COVID-19 emergency, cities around the world introduced measures to guarantee physical distancing that restricted access to urban parks and green areas, with potentially negative effects on citizens' health and wellbeing. This study aims at providing insights to manage access to urban green space in physical distancing times, when the risk of crowding should be avoided. Using the city of Trento (Italy) as a case study, the study simulates policy scenarios corresponding to different restrictions and assesses their effects on green space access and crowding. Policy scenarios are obtained by combining different distances that people are allowed to travel, different types of green areas available for public use (only urban parks or parks and schoolyards), and different target populations (all residents or only people with no private gardens). The results unveil the trade-off between access and crowding of green areas, and can be used to suggest policy interventions and regulations that can be adopted in an emergency. Particularly, the study shows that: i) The relationship between distance threshold and the percentage of people with access to green areas is non-linear, and this should be carefully considered when proposing travel restrictions; ii) Changing the maximum travel distance does not produce major effects on the number of crowded green areas, hence additional or alternative measures need to be adopted; iii) Off-the-shelf measures, such as opening schoolyards, are beneficial and can be implemented rapidly in an emergency. Finally, the study reveals "hotspots" of green space deprivation/overcrowding in the city that should be addressed by urban planning to ensure that green space continues to benefit citizens also during emergency conditions.

## 1. Introduction

During the COVID-19 pandemic, in many cities around the world, national and local administrations enforced measures to ensure physical distancing and minimize the risk of disease transmission. These included closing or restricting access to urban parks and green areas, in order to avoid overcrowding (Ugolini et al., 2020). Similar measures were enforced for example in Italy, where access to all urban parks was banned during the first lockdown. Other countries introduced travel restrictions in terms of time and distance (Musselwhite, Avineri, & Susilo, 2020): for example, in France people were allowed to walk only within 1 km of their homes and for a maximum duration of one hour. Such restrictions resulted in indirect limitations to the green areas that residents could visit.

These measures were highly controversial, given the paradox of their potential negative health effects. Physical and mental health benefits of

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green space in cities are well documented in the literature (Lee & Maheswaran, 2011; van den Berg et al., 2015); hence, denying or restricting access to them seemed like a way to exacerbate an already difficult situation (Slater, Christiana, & Gustat, 2020). This applies particularly to vulnerable groups of society that benefit the most from access to green space, e.g. people living in overcrowded dwellings with no terraces or gardens, children (Amoly et al., 2014; Dadvand et al., 2015; Markevych et al., 2014), elderly (Lee & Lee, 2019), and people affected by mental disorders or physical disabilities (Gascon et al., 2015; Lee & Maheswaran, 2011). Additionally, when green areas become inaccessible, people may end up spending time in potentially more crowded, hence riskier, locations, such as grocery shops, pedestrian areas, and sidewalks (Freeman & Eykelbosh, 2020).

The critical role of green space in supporting physical and mental wellbeing also during lockdown clearly emerged in those cities where access was allowed. In Oslo, for example, outdoor recreational activity increased by 291% during lockdown (Venter, Barton, Gundersen, Figari, & Nowell, 2020), while forest visitors around Bonn more than doubled since the start of the pandemic (Derks, Giessen, & Winkel, 2020). A survey conducted among people from 9 countries revealed that those who had restricted access to outdoor public spaces were more likely to show symptoms of mental health disorders than those who experienced partial or no restriction (Pouso et al., 2021).

Different types of green areas are associated to different uses, users, and distances that users are willing to travel to visit them (Stessens, Khan, Huysmans, & Canters, 2017). Green areas crowding is determined by several factors, including both intrinsic features of the green areas, such as size, canopy cover, and presence and quality of facilities; and characteristics of the surroundings, such as ease of access, population density, urban form and housing types (e.g., presence of gardens or communal open spaces), and proximity to alternative opportunities for nature-based recreation (e.g., forests) (Hamstead et al., 2018; Mears, Brindley, Maheswaran, & Jorgensen, 2019). The preferences and attitudes of the users, which depend, among others, on age, socio-economic status, and cultural background, determine the perception of these factors and their influence on individual choices. Policies that restrict mobility or access add up to these factors and modify their relevance, thus affecting green areas crowding. Particularly, travel restrictions reduce available alternatives for green space visitation, affecting the level of crowding of different areas. For example, in densely populated neighbourhoods, people might be forced to visit local and possibly overcrowded pocket parks, rather than large parks located further away. Therefore, when not carefully designed, such policies may produce ineffective results in terms of physical distancing, as well as exacerbate existing inequalities (McPhearson, Grabowski, Herreros-Cantis, Mustafa, Ortiz, Kennedy, & Vantu, 2020).

The objective of this study is to provide insights to manage access to urban green areas in physical distancing times. Particularly, we aim to simulate policy scenarios corresponding to different restrictions and to assess the effects on green areas access and crowding. By combining these two aspects, we can reveal potential trade-offs between the benefits produced by the recreational use of green areas and the increased risk of contagion due to reduced physical distance. Policy scenarios are obtained by combining different values of the maximum distance that people are allowed to travel from home, different types of green areas that are made available for recreation, and different target populations based on housing type. The city of Trento, in Italy, is used as a case study to illustrate the approach, and to discuss its results.

## 2. Methods

### 2.1. Study area

Trento is an alpine city of around 120,000 inhabitants located along the Adige River in the Eastern Alps. The largest part of the population lives in the valley floor, while around 30% lives in small villages on the hill- and mountainsides (Fig. 1). The urban landscape is representative of a mid-size European city characterized by a densely populated urban centre and a more diffuse urbanisation, with different housing types prevailing in different sectors. Urban parks cover 93.6 ha, which is equivalent to 3.1% of the urban area (and to 0.6% of the municipal area). This corresponds to an area of about 8 $m^2$ per inhabitant. We use the term urban parks to refer to all types of public green areas larger than 300 $m^2$ designed and managed for citizens' access and recreational use. Parks are distributed rather evenly within the urban fabric (Fig. 1), as a result of recent policies to enhance green areas in densely-populated neighbourhoods in the central and northern sectors of the city (Cortinovis, Zulian, & Geneletti, 2018). There are 98 urban parks in Trento, with different size and facilities, ranging from pocket parks to city-level parks and urban forests. Particularly, there are 61 small parks (<0.5 ha), 27 medium parks (0.5–2 ha) and 10 large parks (>2 ha). Among the latter group, there are five peri-urban parks larger than 5 ha, of which 3 are larger than 10 ha.

### 2.2. Designing access policies

We designed access policies based on three variables: i) types of accessible green areas; ii) maximum distance allowed; iii) access restrictions for specific target population based on housing type. Concerning the first variable, we included two possible states. The first one represents the status quo, where only urban parks are considered accessible. The second state simulates a situation where the local government opens up additional public green space, as an emergency response to the COVID-19 pandemic. We selected schoolyards as an example of available green space that can be rapidly made accessible to the general population. Schoolyards in Trento are public spaces, but the access and use is restricted to the students during school hours. Schoolyards, and especially primary schools', offer the advantages of being evenly distributed in the different parts of the city (Fig. 1), and of being administered by the local/regional government. Hence, their opening could be enacted rapidly, as a first response to the need of increasing the green space available to citizens.

Concerning the second variable, we formulated four possible states, corresponding to a maximum distance from home of 200 m, 300 m, 400 m, and 500 m. Considering an average conversion factor of 1.35 m/m from Euclidean to road network distance (Gonçalves, Gonçalves, de Assis, & da Silva, 2014) and an average walking speed of 4.7 km/h (Stessens et al., 2017), the thresholds correspond to walking times of 3.5 min, 5.2 min, 6.9 min and 8.6 min, respectively. These thresholds are suggested by common international standards and policy objectives for local green space planning (Stessens et al., 2017). In addition, some of them also represent the maximum distances allowed by the lockdown rules that were enforced by national and regional governments during the different phases of the pandemic. For example, the neighbouring region of Veneto restricted sport and recreation walking to 200 m from home.

Finally, access restrictions were introduced by considering two possible states: everyone living within the maximum distance can access the closest green area, or only people without a private garden are allowed to access the green areas. Limiting access to people living in housing types without a private garden is justified from an equity perspective. Assuming that -during an emergency- people who owns a private garden have the same need to access a public park as people who live in the dense central neighbourhoods would lead to actions that replicate or even reinforce existing inequalities. In addition, simulating a scenario where only people without a private garden are allowed to access public parks can help to identify priority areas for intervention. In an emergency, this measure could be introduced by public authorities as a recommendation, rather than a formal restriction, similarly to other recommendations formulated during the pandemic.

By combining all the possible states of the three variables, we generated 16 policy scenarios.

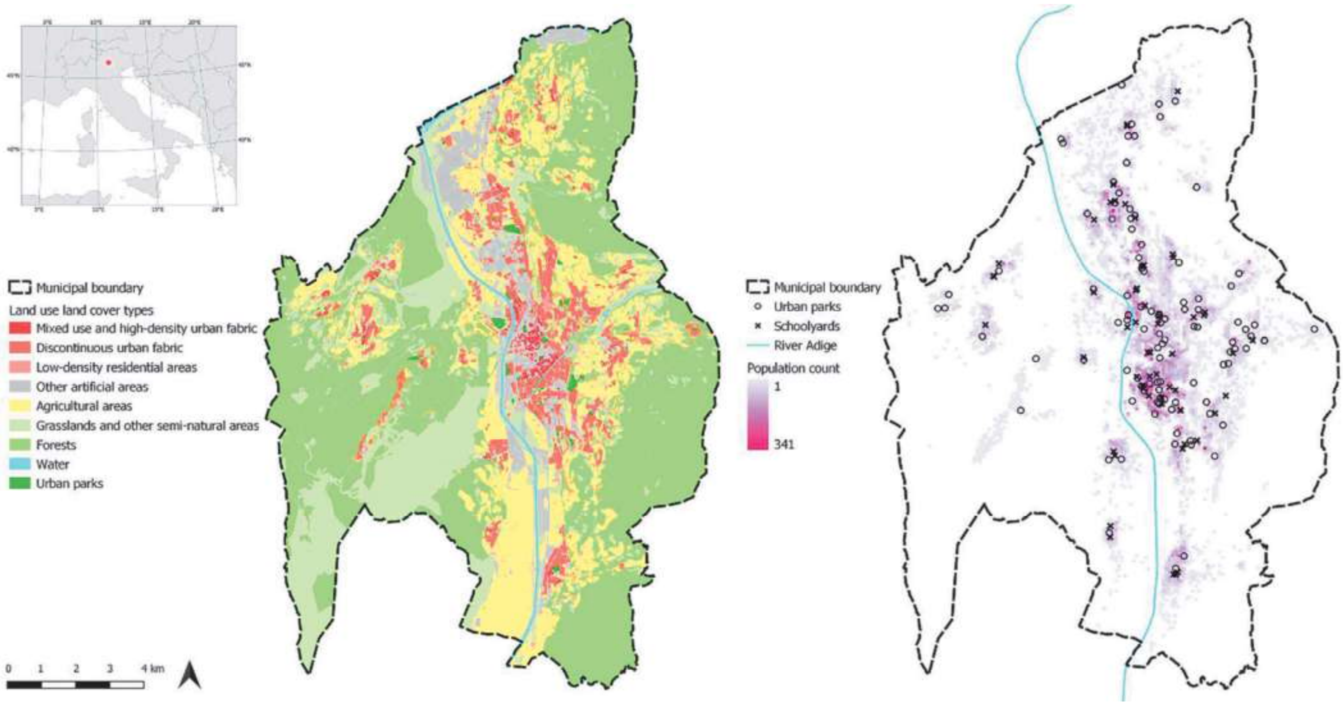


**Fig. 1.** Main land uses in Trento (left) and location of urban parks and schoolyards superimposed to a population density map (right).

### 2.3. *Assessing the effects on green area access and crowding*

To map the green areas for the analysis, we considered the urban parks (n = 98) and the schoolyards (n = 58) identified on the municipal map of green infrastructure (Fig. 1, left). Travel distances were measured considering the Euclidean distance from the boundary of the green areas. As a rule, we assumed that people visit only the closest green area. Besides being a common practice in studies assessing the accessibility to urban green spaces (e.g., Kimpton, 2017), the possibility of visiting only the closest park reflects a measure widely adopted during the emergency. In Italy, for example, following the first and strictest lockdown where park access was banned, several cities instructed citizens to visit only the closest green space to their residence. In the simulation, the only exception to this rule was for green areas next to the river. Since only few crossings exist, and railroad and highway run parallel to the river, neighbourhoods on the two sides are physically disconnected. Hence, the river was considered as a barrier and catchment areas were not allowed to cross it (Fig. 4 shows the effect of this rule on the shape of the catchments, and how they vary between the scenarios considering only urban parks and those including also schoolyards).

To identify the number of potential users of green areas, we generated a population distribution map based on census data and street numbers. Within each census tract (i.e., the smallest unit at which census data are available), we divided the total population by the number of street numbers classified as “residential”, assuming homogeneous residential housing types. In this way, we obtained the number of residents in each street number. To distinguish the population with no access to a private garden, we assigned each street number to a housing type based on the municipal land use map and assumed that:

- no household has access to a private garden in the areas classified as “mixed use” and “high-density urban fabric” (prevailing type: high rise buildings with commercial ground floor uses);
- one household per street number has access to a private garden in the areas classified as “discontinuous urban fabric” (prevailing type: single family or multi-family residential, with private gardens for ground-floor units);
- all households have access to a private garden in low density residential areas and in agricultural areas (prevailing type: villas or rural buildings).

We considered each household as composed of 2.16 people, i.e. the average household size in Trento, and subtracted from the total population in each street number the number of people with access to a private garden.

For each policy scenario, we estimated the number of people with access to a green area by selecting the portion of each catchment area within the maximum travel distance allowed, and summing the population associated to the street numbers inside it. Potentially-crowded green areas were identified using a threshold of 9 $m^2$/person, assuming all users visiting the green space simultaneously. This threshold was suggested by the minimum standard for green space per capita set by Italian urban planning regulations (Ministerial Order DM.1444/68). Although a situation where all possible users visit the green space at the same time is rather extreme, nothing prevents this from happening, so it was considered sensible to adopt a worst-case approach, as commonly done in the analysis of population pressure and green areas crowding (see e.g. Kimpton, 2017; Mears, Brindley, Maheswaran, & Jorgensen, 2019; Orta Ortiz & Geneletti, 2018; Shoari et al., 2020). Potential trade-off between accessibility and crowding were visualized using scatter plots and the results were mapped to reveal critical areas across the city.

## 3. Results

The share of population with access to a green area ranges from 58% to 95% of the total population (Fig. 2). In the worst-case scenario (only urban parks accessible within a distance of 200 m) about 42% of the population do not have access to a public green area, while the number is reduced to 5% in the best-case scenario (urban parks and schoolyards accessible within a distance of 500 m). According to the analysis, 37,690 people (about 32% of the population) have a private garden. When they are excluded from the target population, the share of population with access to a green area increases to a range between 64% (if a threshold distance of 200 m is considered) and 98% (threshold distance of 500 m),


**Fig. 2.** Share of population with and without access to a green area under the different policy scenarios. The top histograms present the scenarios that refer to the total population; the bottom histograms those that refer to the population without private garden only. No thr. indicates the results when no distance threshold is considered, i.e. all people can reach the closest urban park. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

corresponding to 44% and 66% of the total population, respectively.

The share of population with access to a green area obviously increases with increasing distance thresholds. However, the increase is not linear (Fig. 2). Particularly, the largest effect of increasing the distance is observed at lower values of the threshold. For example, changing from 200 m to 300 m guarantees access to an additional 17% of the total population when only urban parks are available, and to an additional 15% when also schoolyards can be used. The same 100 m increase from 400 m to 500 m provides access only to an additional 7% and 3% of the total population, respectively. Similarly, opening schoolyards to the public increases the amount of population with access to a green area for all distance thresholds, but the main increase is registered at shorter distances (Fig. 2). By making schoolyards available, more than 12,000 people gain access to a green area when the distance threshold is set at 200 m, but the difference amounts to only 3,000 people when the threshold is 500 m.

Out of 98 urban parks, 23 are uncrowded in all scenarios. This is equivalent to 68% of the total park surface, given that the largest parks are less crowded. Among people with access to a green area, those accessing a potentially uncrowded area are always, and by far, a minority (Fig. 2). Particularly, when a 500-m threshold is considered, only 20% of the people with access to an urban park has access to an uncrowded park. This percentage increases to 31% if a 200-m threshold is considered, with 37 uncrowded parks. In this situation, as expected, the crowding effect is minor due to the fact that less people live within the maximum allowed distance from the park, so the ratio between green surface and inhabitants is larger. The conditions improve slightly when the green areas available is expanded by adding schoolyards, or when the number of users is reduced by limiting access to people without private garden. In both cases, considering a distance threshold of 200 m, 33% of the users has access to an uncrowded green area.

The maps of accessibility and crowding (Fig. 3) show the effects of the uneven spatial distribution of the analysed variables across the city. These maps reveal districts where existing parks are enough to guarantee a safe recreational space and districts where none of the simulated scenarios can solve the risk of crowding. The former includes some of the suburbs detached from the main settlements, as well as neighbourhoods closer to the city centre but located in the proximity of large urban parks. The neighbourhoods most exposed to green area crowding include those immediately South of the city centre, as well as some more recent developments in the northern outskirts of the city. These neighbourhoods are characterised by relatively high population density and prevalence of multi-storey buildings.

A comparison of the maps for the different policy scenarios (see also the enlargement for a central sector of the city presented in Fig. 4) helps to visualize two overall trends: i) the number of potentially crowded green areas increases when increasing the distance thresholds (see, e.g., area A in Fig. 4), and ii) the number of potentially crowded green areas decreases when decreasing the potential users, either by limiting access only to people without a private garden, or by allocating part of the users to a different green area, e.g. a schoolyard. However, the effects are not homogeneous across the city. For example, reducing the number of potential users contributes to alleviate critical situations only in areas where the prevailing housing types include private gardens (see, e.g., area B in Fig. 4). On the other hand, opening schoolyards to public use alleviates the crowding of green areas in some dense neighbourhood (see, e.g., area C in Fig. 4), but the effect is limited to low distance thresholds due to the small surface of schoolyards (Fig. 3).

The analysis of the share of population without access to green areas (Fig. 5) complements the analysis of accessibility and crowding. When the total population is considered, the most critical areas are some of the most peripheral settlements (see Fig. 5, first and third row). However, this criticality is strongly reduced when focusing only on the population without private gardens, since housing types characterised by the presence of private gardens prevail in peripheral neighbourhoods (Fig. 5, second and fourth row). Combining this information with population density allows identifying hotspots of need across the city. Moreover, when read in combination with the risk of crowding in each catchment (Fig. 3), it can help to direct locally-specific strategies for intervention, as discussed in Section 4.2.

Plotting indicators of access and crowding in the same graph reveals more clearly the trade-off between the two variables, and the combined effects of policy scenarios (Fig. 6). For all set of scenarios, at increasing values of the distance threshold, the trend is a decreasing concave curve. This means that the risk of crowding increases when the population to which access is guaranteed increases. The only "local" exception to this

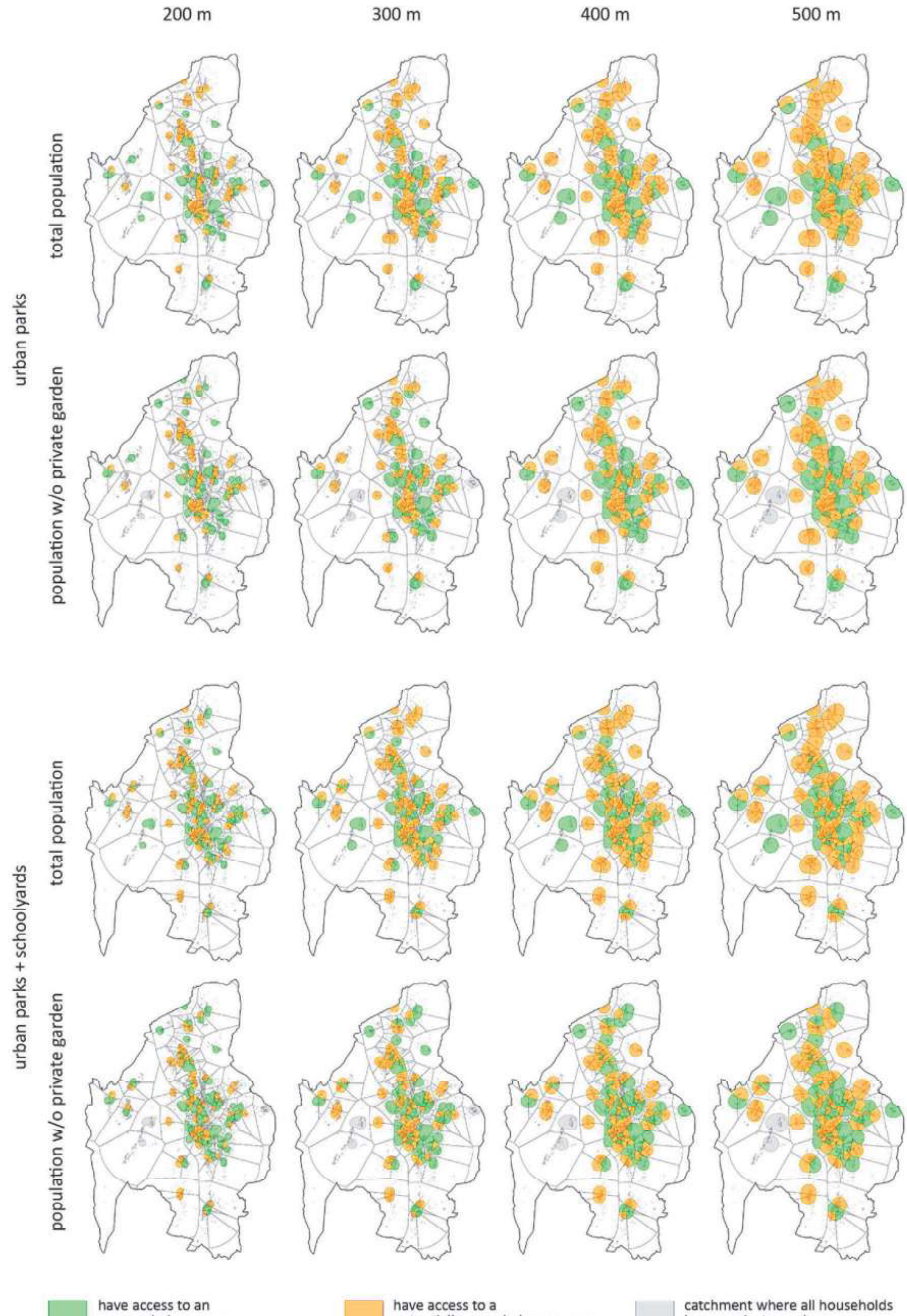


**Fig. 3.** Crowding levels of green areas in the different policy scenarios. Columns correspond to different distance thresholds, rows correspond to different green areas (maps in the top two rows include urban parks only, those in the bottom two rows include urban parks and schoolyards) and different users (maps in the first and third row include total population, those in the second and fourth row only population without a private garden). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

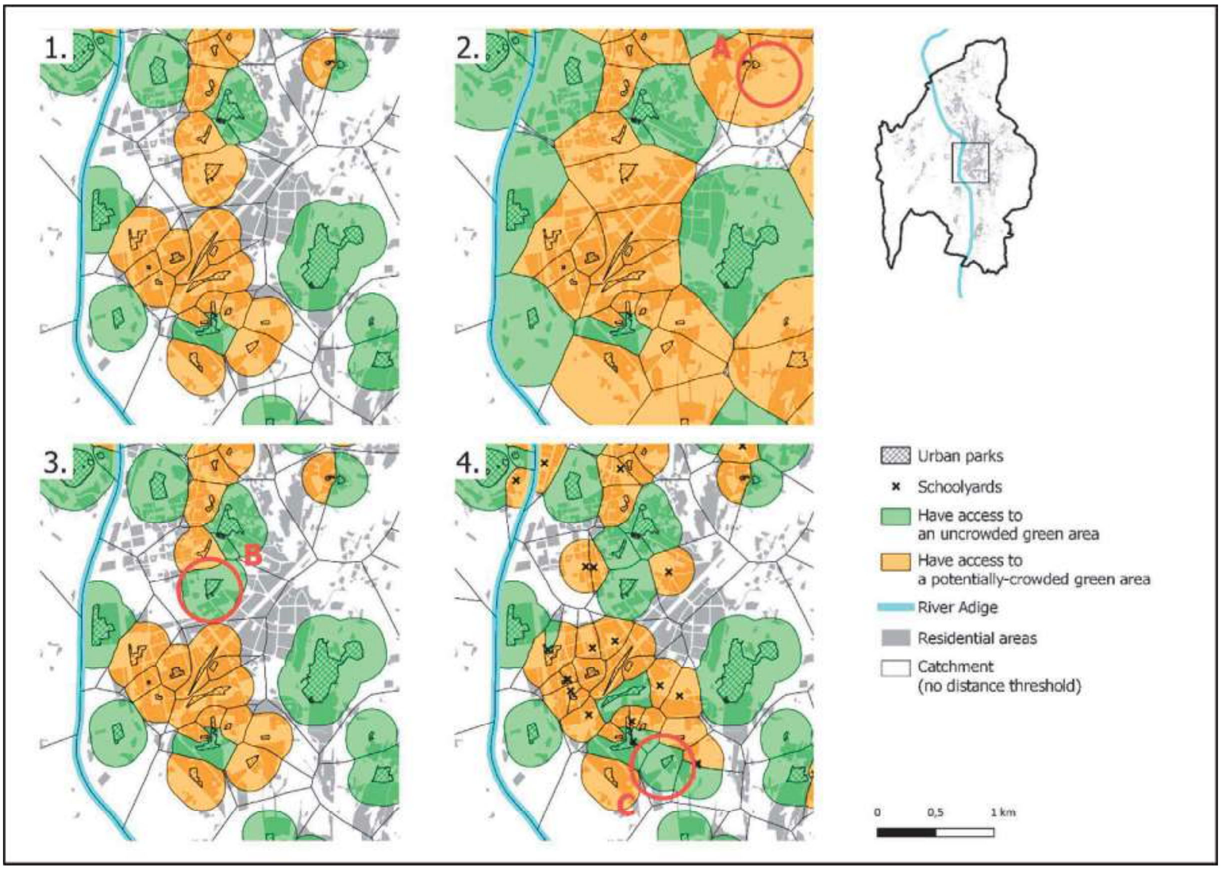


**Fig. 4.** Sub-window of the maps showing the crowding levels of green areas in different policy scenarios (Fig. 3). The four panels show how the crowding levels respond to changes in the different variables. Panel 1: Scenario considering urban parks, a distance threshold of 200 m, and the total population. Panel 2: Same as 1, but the distance threshold is increased to 500 m. Panel 3: Same as 1, but only people with no private garden have access to parks. Panel 4: Same as 1, but schoolyards are made available for public use. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

trade-off occurs when the distance threshold changes from 400 m to 500 m in the scenarios that consider only urban parks and population without private garden. This change produces an increase, albeit rather limited, in both the population with access to parks, and the population with access to an uncrowded park.

## 4. Discussion

### 4.1. On the case study

The results for our case study city show that Trento is in general well-equipped with, and has a rational distribution of, urban parks. This is confirmed particularly by the fact that more than 90% of the population live within 500 m from a park. This value is higher, for example, than the one for all cities in England and Wales analysed by Shoari et al. (2020) and for most of the 299 EU cities analysed by Kabisch, Strohbach, Haase, and Kronenberg (2016). In addition, by comparing the range of percentages of the total population with access to a green area with the percentages referred only to the population without private garden (see Fig. 2), it can be concluded that the neighbourhoods where private gardens are common are also relatively less supplied with public urban parks. Hence, people that have a private garden are on average further away from urban parks than people living in the denser neighbourhoods.

These results reflect the current distribution of urban parks in Trento, characterized by many small parks available in central sectors of the city and fewer but larger parks located in the surrounding areas. Indeed, the municipal administration has invested in recent years to improve particularly the availability of large green spaces in the peri-urban sectors (Cortinovis et al., 2018). While in normal times this planning strategy proved to be effective in serving a wide range of users, it reveals shortcomings when mobility restrictions are enforced. In these cases, small parks in densely populated areas are at risk of overcrowding, and larger parks can become inaccessible, hence underused. In the next paragraphs, we discuss more in detail the effects on access and crowding of the different policy measures.

Concerning maximum travel distance, the results show that the share of population with access to a green area obviously increases with increasing distance thresholds. However, the interesting finding here is that the increase is not linear (Fig. 2). Particularly, the largest effect of increasing the distance is observed at lower values of the threshold, despite the increase in the area covered by the catchment is generally smaller. For example, changing from 200 m to 300 m guarantees access to an additional 17% of the population when only urban parks are available, and to an additional 15% when also schoolyards can be accessed. The same 100-m increase from 400 m to 500 m provides access only to an additional 7% and 3% of the total population, respectively. Another remark is that the increase of the distance threshold produces a more homogeneous condition with respect to the share of population with access to green areas (Fig. 5). This means that, when a 500 m-threshold is considered, the spatial distribution of green areas is generally appropriate with respect to the distribution of residential areas.

Concerning the type of accessible green areas, our findings suggest that opening schoolyards to citizens for recreational use can be beneficial, particularly when the strictest mobility threshold (200 m) is enforced. In this case, the possibility to access schoolyards would benefit an additional 10% of Trento's population. This reflects the potential contribution of schoolyards as emergency playfields and pocket parks,

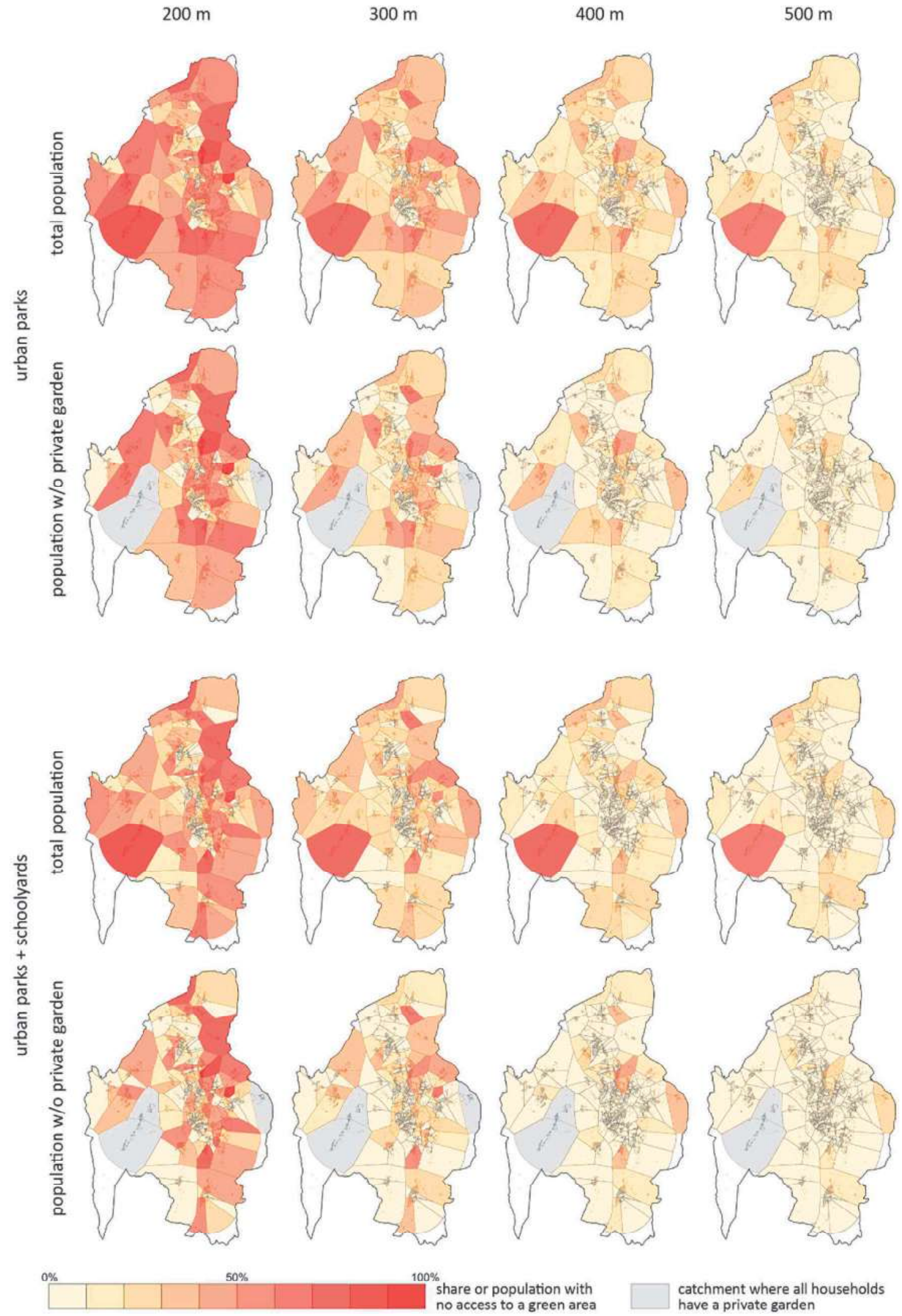


**Fig. 5.** Share of population with no access to a green area within each catchment in the different policy scenarios. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

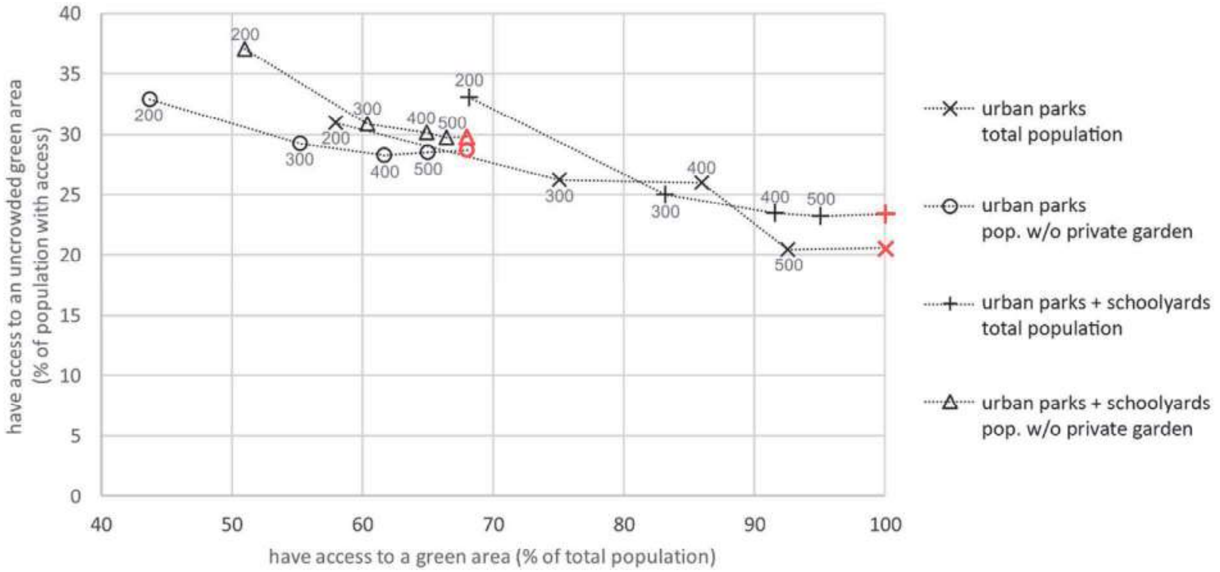


**Fig. 6.** Trade-offs between access and potential crowding. For each scenario, the graph shows, on the x-axis, the share of total population with access to a green area, and on the y-axis, the share of population with access that reaches an uncrowded area. In red, the results when considering no distance threshold (total population in the catchment areas).

despite their relatively small size, due to their strategic location in the most densely populated areas of the city.

In terms of crowding, our results demonstrate that changing travel distance does not produce major effects on the number of crowded green areas. Four out of five parks that are crowded when the distance threshold is set to 500 m are crowded already with a threshold of 200 m. At the same time, if the maximum travel distance is removed and people are allowed to visit the closest urban park, the number of crowded parks does not increase compared to the scenario with a 500-m threshold. The explanation for this is to be found in the spatial relation between uncrowded parks and population density. The less crowded parks tend to be larger, located in peri-urban areas and not directly adjacent to densely-populated neighbourhoods. By increasing the distance threshold, some of the inhabitants of these densely-populated areas gain access to the parks. However, in most cases, the increase in the potential users is not enough to make the larger parks crowded. This also explains the exception to the general trends of the trade-off curves shown in Fig. 6 and described earlier in the text. Hence, measures based on restricting the maximum travel distance are bound to be ineffective to reduce crowding, while causing a significant reduction in the number of people that have access to a green area. Policy interventions should therefore consider also measures related to the other two variables.

Finally, concerning target population, our results show that limiting access to people living in housing types without a private garden is an effective measure to increase the share of population with access to an uncrowded green area. This policy seems to be indirectly adopted anyway in Trento, given that urban sectors with more private gardens are less supplied with green areas. In real-life policy making, such a limitation could be probably formulated as a recommendation that the authorities could make in an emergency situation. Specifically, restricting access to public green areas to people that have a private garden is justified by the findings of studies conducted during the past year, which revealed the comparatively higher levels of wellbeing of garden owners due to their closer contact with nature (Corley et al., 2021; Lehberger, Kleih, & Sparke, 2021).

### *4.2. On general implications for future policy design*

During the COVID-19 pandemic, several studies focused on the perception and use of urban green areas and revealed an increase in parks visitation, and outdoor recreation in general (Derks, Giessen, & Winkel, 2020; Venter, Barton, Gundersen, Figari, & Nowell, 2020; Lopez, Kennedy, & McPhearson, 2020). The vital contribution of green space to urban dwellers' physical and mental wellbeing, also as a measure to mitigate urban inequalities, clearly emerged from this body of research. The studies highlighted the importance of preserving and enhancing green space (Geary et al., 2021; Kleinschroth & Kowarik, 2020), and of guaranteeing some form of access also during lockdown periods (Geng, Innes, Wu, & Wang, 2021; Slater et al., 2020). However, the potential risk of green area crowding, also due to the increased desire of spending time outdoor and the limited availability of alternative options, has emerged as a concern (Delen, Eryarsoy, & Davazdahemami, 2020). Our study addresses this concern, and although it is limited to a specific context, it can provide insights for the design of effective policies in similar mid-sized European cities, characterized by a densely populated urban centre surrounded by a more diffuse urbanisation.

Firstly, our study revealed that the trade-off between access and crowding of green areas is a complex challenge that cannot be addressed in a "one-solution-fits-all" way. Future studies similar to the one that we have undertaken can be used to point at specific situations where interventions are needed, and at specific variables that can be particularly effective. The non-linearity of the relationship between distance threshold and the percentage of people with access to green areas suggests city-specific values that should be considered in order to maximise the benefits of future policies. Future health guidelines related to safe social distancing in open space can help to identify appropriate thresholds for these variables, which could be tested through simulations of visitor behaviour in parks, as done for example by Yue, Burley, Cui, Lei, & Zhou, 2021 using agent-based modelling.

Secondly, the results suggest that there are off-the-shelf measures that work, and could be adopted rapidly in an emergency. In the study we tested the opening of schoolyards and the ban of public green to the owners of private gardens. Both proved to provide important benefits under all scenarios. Concerning schoolyards, our results are in line with the outcome of a recent study that analysed the extent to which opening schoolyards to the public during non-school hours could alleviate the problem of park access in cities across the United States of America (The Trust for Public Land, 2019). Granting public access to schoolyards and school playgrounds off-hours is becoming a common practice (e.g., in cities in Australia and the United States of America). For example, in New York hundreds of schoolyards have been renovated and opened to the public during non-school hours through the Schoolyards to Playgrounds program (https://www.nycgovparks.org/facilities/playgrounds/). Atlanta is implementing the Atlanta Community Schoolyards initiative, whose goal is to increase access to public land for kids, families, and communities by opening schoolyards in "park deserts" during non-school hours. (https://parkpride.org/what-we-do/atlanta-community-schoolyards/). In San Francisco, before COVID-19, there were over 50 schools enrolled in the Shared Schoolyard Program, with plans to expand as many yards as possible (https://www.sfusd.edu/sharedschoolyard).

Hence, opening schoolyards could be a viable strategy for cities, with some minimal security and logistic interventions. Besides the very limited costs, other advantages of this strategy are that schoolyards are publicly owned and managed and that their distribution across cities typically reflect population density. Other responses have been adopted around the world to increase the availability of green and open spaces. These include, among others, the installation of parklets in the public right of way (e.g., in San Francisco) and the adoption of "open streets" or "slow streets" initiatives (Slater et al., 2020). However, these additional open spaces probably cannot meet the diverse needs of users (e.g., play areas for families with young children). In addition, managing and controlling the risk of crowding in open streets might be more difficult than in a schoolyard. Another possible option is represented by community gardens, which are increasingly popular in Europe (Kirby et al., 2021). However, their access and use need to be regulated and they cannot be simply opened to the public in an emergency. Liu and Wang (2021) advocated turning vacant lots or abandoned lots to pocket parks as a strategy to increase accessibility to urban green space during COVID-19. Although this strategy is likely to be cost-effective, its implementation realistically requires more time.

Finally, the analysis of potential crowding revealed hotspots, i.e. areas in need of additional green space. Combining this information with the share of people in each catchment that do not have access to a green area (Fig. 5) can support decision-makers in identifying the best strategy to improve the current situation. In cases where the green area is at risk of crowding but the share of people without access is low, then potential solutions could involve enlarging the existing green area or, in an emergency, introducing locally-specific measures to control the number of users. The latter include management options not addressed in the simulated policy scenarios, such as modifications in scheduling and fees (Slater et al., 2020), shift rotations, dedicated park times for different age groups, and entry allocation systems combined with smartphone apps (Shoari et al., 2020). However, when the share of people without access within a catchment area is high, the response should rather be directed at increasing the availability of green areas, possibly close to people that live too far from the existing ones. In the medium-long term, this need can be addressed by urban planning. In the short term, and under an emergency, the information can support the selection of additional green or public areas to open to public use.

## 5. Conclusions

Quoting Honey-Rosés, Anguelovski, Chireh, Daher, Konijnendijk van den Bosch, Litt, and Sánchez (2020, p.8), "the pandemic has focused attention on healthy cities unlike anything seen in a generation". A key element for healthier cities is determined by the amount, quality and distribution of accessible green space, as demonstrated by a large body of research prior to the pandemic (see WHO Regional Office for Europe, 2021 for an overview), and confirmed by recent studies on the health effects of park visitation during lockdowns (e.g., Pouso et al., 2021). Cities around the world adopted a variety of responses to balance the need of ensuring physical distancing, while safeguarding the possibility to access green space. The wealth of experiences gained during the emergency that are being reported (e.g., in Geng et al., 2021) can help to target future interventions to the specific characteristics of the context. In order to achieve this purpose, case study-research like the one conducted in this study is needed to test the effectiveness of different measures, and support evidence-based policy making.

The pandemic forced a sudden change in the conditions under which we evaluate the effectiveness of public policies, including those affecting the distribution of green spaces. Green space in cities is planned and designed for "normal" times, when people are free to move, and to choose their own transportation mean. Hence, small parks with key facilities and easily accessible are typically much more common than larger parks (Salat, Bourdic, & Labbe, 2014; Wang, Zhou, Wang, & Yu, 2020), which offer more, and more diverse, facilities and infrastructures, closer contact with nature (e.g., forest tracts, water), as well as a broader range of recreation opportunities. This hierarchical structure works well in normal times, when people can travel longer to reach an area with specific facilities and opportunities. However, the lack of redundancy makes this structure vulnerable to crowding when access to some of the areas is -for any reason- restricted. Interventions such as those tested in the study can help to make the city more resilient in the face of sudden changes, ensuring that green space continues to benefit citizens also during unexpected and unforeseeable conditions.

## 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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