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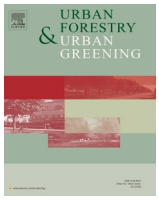
Urban Forestry & Urban Greening 112 (2025) 128928

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug



Original article

Citizens' perception and willingness to pay for green roofs and nature-based solutions in three Italian metropolitan cities

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ARTICLE INFO

Keywords:
Urban green infrastructures
Climate change
Citizens' perspective
Smart cities
Urban sustainability
Environmental awareness

ABSTRACT

Nature-Based Solutions have been largely investigated and technically improved in the last decades. Thanks to their multiple benefits, these solutions can largely contribute to the sustainable urban development, especially if diffusely installed over large areas. A key point to support their implementation is to actively involve citizens, increasing interest and willingness to pay for installation and maintenance. Through an anonymous online survey distributed in three Italian metropolitan cities (i.e., Cagliari, Palermo and Torino), this study investigates citizens' awareness of potential benefits provided by urban Nature-Based Solutions and their willingness to invest in different infrastructures, with a specific focus on green roofs. The aim of the study is to understand how different climatic and socio-demographic conditions could influence citizens' interest in these tools, also exploring the potential impeding elements perceived by citizens. Results highlighted a higher interest for green roofs on public buildings than on private ones; most of the citizens are willing to financially contribute for green roofs and nature-based solutions in public spaces, with an average of 71€/year. Understanding citizens' perception of environmental issues and willingness to pay for green solutions is essential for decision makers to properly define investments and incentivization policies, fostering the development of sustainable cities.

1. Introduction

Nature-based solutions (NBSs) have widely shown to efficiently contribute to climate adaptation strategies (Frantzeskaki, 2019; Voskamp et al., 2021) and to a sustainable urban development. Green Roofs (GRs) are climate adaptive NBSs particularly appreciated by the society, since they allow to exploit otherwise unutilized spaces, offering several environmental, social and economic advantages (Mihalakakou et al., 2023). The large-scale implementation of GRs provides multiple benefits for the environment, addressing recurrent urban challenges (Cristiano et al., 2021; Teotónio et al., 2021). Beside the widely recognized capacity to improve buildings' acoustic and thermal insulation, reducing their energy needs for air conditioning indoor environments (Berardi et al., 2014; Pastore et al., 2017; Polo-Labarrios et al., 2020; Pumo et al., 2023a), GRs ensure a mitigation of the urban heat island (Muhammad and Reeho, 2017; Solcerova et al., 2017), an improvement of the air quality (Abhijith et al., 2017; Li et al., 2010) and an increase of biodiversity (Coffman, 2007; Gonsalves et al., 2022; Williams et al., 2014). GRs are also particularly effective at reducing runoff generation during rainfall events, mitigating the risk of urban pluvial floods (Cristiano et al., 2023b; Hellies et al., 2018; Pumo et al., 2023b; Pumo et al., 2025). Moreover, they can increase the aesthetic value of the city (Frantzeskaki, 2019; Loder, 2014; Williams et al., 2019), contributing to the creation of a beneficial environment for physical and mental human health (van den Bosch and Ode Sang, 2017).

Although, from a technical perspective, it is clear that GR implementation offers multiple benefits for the urban environment, social interest and willingness to pay (WTP) for these solutions are crucial factors for their actual success (Untereiner et al., 2024; Viti et al., 2023). To ensure the maximum efficiency of GRs, and more in general of urban NBSs, it is, in fact, necessary to involve various stakeholders (Mitincu et al., 2023), including local communities and citizens, and investigate to what extent they are interested in investing in these solutions. Different factors, such as socio-demographic and economic status of the participants, as well as climatic and geographical characteristics, could influence significantly the interest and WTP for these solutions (Chui

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https://doi.org/10.1016/j.ufug.2025.128928
Received 16 January 2025; Received in revised form 16 June 2025; Accepted 17 June 2025
Available online 18 June 2025

and Ngai, 2016; O'Donnell et al., 2021; Tian et al., 2020; Venkataramanan et al., 2020; Zhang et al., 2023).

In the last decade, the use of online questionnaire and/or face-to-face interviews is becoming popular to investigate different aspects of the urban sustainable development (Anthony, 2024; Brůhová Foltýnová et al., 2020; Ji et al., 2021; Kuang and Lin, 2021; Van Schoubroeck et al., 2023). Although face-to-face interviews are generally considered more reliable, online surveys are less expensive and easier to organize and enable to reach different geographical locations and potentially more respondents (Guest et al., 2020; Oates et al., 2022). Recent studies relied either on in-person or on online surveys to investigate citizens' perception and interest in NBSs and urban greening, highlighting the importance of these analyses for urban planners and policy makers (Macháč et al., 2022; Ramírez-Agudelo et al., 2022; Schneider et al., 2024; Sturiale et al., 2023). High interest in green infrastructures is, however, not always followed by a proper awareness of the potential benefits of these solutions nor by an adequate WTP for installation and maintenance (Salm et al., 2023; Sturiale et al., 2023; Zhang et al., 2023; Zhang et al., 2020).

Although literature offers many examples of analyses on the citizens' perception and WTP for NBSs, only few studies investigated specific solutions; in particular, GRs were scarcely investigated in the past, and results were often contrasting in identifying influencing factors. The earliest studies addressing GRs specifically, analyzed citizen's perception and interest in these tools as potential solution for specific environmental issues (Fernandez-Cañero et al., 2013; Sarwar and Alsaggaf, 2020; Vanstockem et al., 2018). Zhang et al. (2019), for example, addressed citizens' interest in GRs in Beijing (China), focusing only on the urban heat island mitigation properties. Fernandez-Cañero et al. (2013) and Vanstockem et al. (2018), investigate the interest in GRs in relation to the lack of green spaces and the potential increase of aesthetic value, in Spain and Belgium, respectively. Subsequent studies also included the analysis of the WTP for GRs installation on public buildings, as part of long-term projects supported by a tax increase (Ji et al., 2022; Meyer and Trandafir, 2023; Netusil et al., 2022; Zhang et al., 2019; Zhang et al., 2020). Estimated WTP varies depending on geographic location and presented project, from 3.1 € per household per year in South Korea (Ji et al., 2022) to 18 € in China (Zhang et al., 2020), and up to a maximum of 397 € in Portland, USA (Netusil et al., 2022). The WTP for private investments was investigated in Portugal (Teotónio et al., 2020) in terms of percent increase of rent/mortgage, observing an average WTP of 3 % of the house rent. Differences between interest and WTP of Sardinian citizens (Italy) for GRs on public and private buildings were investigated by an online survey in Cristiano et al. (2023a). The results revealed a high interest for GRs installation on public buildings, and, for private installations, a clear citizens' preference in investing in solar panels rather than in GRs.

The majority of the studies available in the literature, however, focuses only on a single specific location, without analyzing the influence of different climatic conditions, environmental issues and socio-economic aspects. Factors such as a different mean annual precipitation, average temperature, population density, level of education, average salary and percentage of green areas can influence the perception of common environmental issues, i.e., pluvial floods, heat waves, high electricity costs for cooling/heating systems, air and acoustic pollution, lack of green spaces and water scarcity, and the trust in NBSs. In this context, the aim of this work is to investigate how climatic conditions, socio-economic aspects and perceived environmental issues could influence interest and WTP for GRs and for other urban NSBs. To achieve this goal, citizens living in three different Italian metropolitan cities (i.e., Torino, Palermo and Cagliari) characterized by different climatic and sociodemographic aspects, have been involved in this survey analysis.

In addition to outlining the study's objectives, we aim to explore the suitability of some common research hypotheses, such as the expectation that higher levels of environmental awareness are associated with a greater willingness to pay for green roofs, and/or that younger, more educated, or higher-income respondents are more likely to financially support green infrastructures, and/or that residents of central metropolitan cities may demonstrate a higher willingness to pay compared to those in surrounding municipalities.

The paper is structured as follows. Section 2 introduced the methodology adopted, with a special focus on the three case studies and on the survey structures. Results are illustrated in Section 3, where perception of the most common environmental issues, interest and WTP for GRs and NBSs are analyzed. Finally, Section 4, discuss the results and their potential implications, providing useful guidance and suggestions for policy makers and urban planners.

2. Methodology

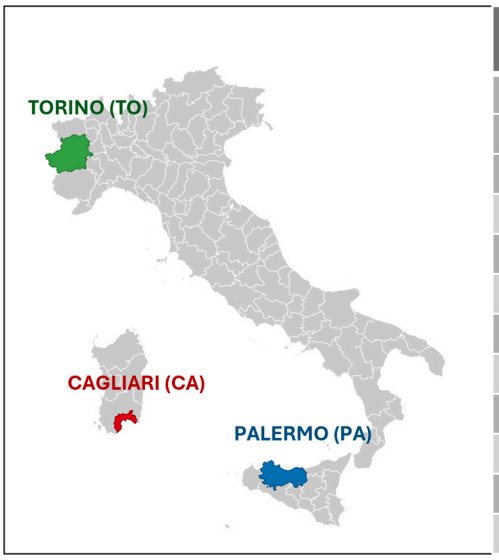
2.1. Case study

The survey developed in this study was submitted to the citizens of Turin (TO, Piedmont), Cagliari (CA, Sardinia), Palermo (PA, Sicily) and their Metropolitan cities, which in Italy are defined as the entire administrative units that include both the main city and the surrounding municipalities and countryside. The three case studies, located in three different regions of Italy, can be considered as representative of different climatologic conditions and socio-economic backgrounds. As shown in Fig. 1, the metropolitan cities of TO (316 towns, including Turin) and PA are highly populated (4th and 5th most populated metropolitan cities in Italy, respectively), while CA is representative of a moderately populated metropolitan area (it is ranked 32nd out of 110 Italian metropolitan cities). The three metropolitan cities together include almost the 7 % of the entire Italian population. TO and CA are respectively the 18th and the 19th Italian metropolitan cities for population density, while the number of inhabitants for km^2 in the metropolitan area of PA is significantly lower (it is ranked 39th).

The metropolitan area of TO is located in northwestern Italy, and it is composed of a mountainous part to the west and north along the Alpine border and a flat and hilly part in the south and east. Climate in TO is significantly colder and rainier than in the metropolitan cities of CA and PA. These are coastal metropolitan cities lying in the two major Italian islands, with climate highly influenced by the Mediterranean Sea. Both are characterized by dry and hot spring-summer seasons, while autumn and winter are significantly rainier and colder. The metropolitan area of CA counts a total of 71 towns, including Cagliari, prevalently located in flat areas, while the metropolitan area of PA counts a total of 82 towns, including Palermo, located at highly variable elevations

The three metropolitan cities are characterized by different economic conditions; according to the national report of 2022 (ISTAT, 2023), the GDP (Gross Domestic Product) per capita in Piedmont is slightly higher than the national average, while the GDP in Sicily and Sardinia is almost the 65 % of Piedmont GDP and among the lowest across the various regions of Italy. This difference is also related to a different level of industrialization, which is higher in the TO metropolitan area than in the other two metropolitan cities (Vanolo, 2015). The combination of this aspect with the different geomorphological location is reflected in a different level of air quality: the metropolitan area of TO, and in particular the city of Turin, are characterized by the worst air quality compared to CA and PA, both in term of PM10 and ozone concentrations (Trentin, 2023).

Different indicators highlight marked social differences between the three case studies. For instance, from 2019 to 2023, Sicily and Sardinia were the regions of Italy with the highest NEET (Neither in Employment nor in Education and Training) for young (between 15- and 29-year-old) people (i.e. 26 %), while the NEET in northwestern Italy was around 11 % (https://www.istat.it/it/files//2024/04/2.pdf). In 2023, people between 25 and 35 years old with at least one academic degree (BCs, MSc, PhD, etc.) are 29.5 % of the overall population in Piedmont, 27 % in Sardinia and 21.8 % in Sicily, while people between 25 and 64 years



	Cagliari CA	Palermo PA	Torino TO
Inhabitants [inh]	418'761	1'198'594	2'203'353
Inhabitants living in the main city [inh]	149'092	630'427	853'477
% of inhabitants living in the main city [%]	36%	53%	39%
Density [inh/km^2]	336	240	323
Area [km^2]	1248	5005	6828
Number of towns in the Province	71	82	316
Elevation variability [m a.s.l.]	0 to 1113	14 to 1697	142 to 4026
Mean Annual Rainfall [mm/year]	428	600	981
Average Min and Max Temperature [°C]	12,4 – 22,6	15,5 – 22,2	8 – 18,4
Mean daily PM10 [μg/m^3]	23,4	28	34,8
Ozone [days above threshold]	0	0	94
Average Annual Net Salary [€/year]	17'568	17'728	24'581

Fig. 1. Geographical location of the three surveyed metropolitan cities and summary of the most significant characteristics.

with at least a high-school diploma are 66 % in Piedmont and 55 % in both Sicily and Sardinia (https://www.istat.it/it/files//2024/04/2.pdf).

2.2. Survey structure and dissemination method

The investigation on the interest and WTP for GRs has been conducted with the support of anonymous online surveys, with structure similar to that used in Cristiano et al. (2023a). The survey, realized using Google Forms, is structured into six sections composed of a total of 22 multiple-choice questions, focusing on:

- socio-demographic and financial aspects;
- household and neighbourhood;
- environmental issue perception;
- GR awareness;
- interest and WTP for GRs;
- interest and WTP for NBSs.

Three informative sections are also implemented, with the aim to increase citizens' awareness and knowledge about GRs and NBSs and the benefits that they can provide. Following the approach proposed by Netusil et al. (2023) when investigating the WTP to support a new GR program in Portland (USA), figures have been included in the survey, with the aim to facilitate the citizens' understanding of some technical aspects of the various solutions. The complete survey is here provided as supplementary material.

For the metropolitan area of CA, answers have been derived as subset of the dataset collected at regional level during summer 2021 and already presented in Cristiano et al. (2023a). For the other two case studies, besides the five environmental issues investigated in Cristiano et al. (2023a) (i.e., pluvial flood, temperature rise, high energy consumption for cooling/heating the building, air pollution and lack of green spaces), the present analysis extended the survey also to noise pollution and water scarcity problems, which are strongly affecting the metropolitan cities of TO and PA, respectively. Moreover, based on the results of the previous survey in Sardinia (Cristiano et al., 2023a), which highlighted a strong preference of citizens for solar panels compared to green roofs, in the surveys for TO and PA a third option of an integrated system that combines this two solutions has been added as possible answer to the question "If you could invest, which of the following options would you prefer to install?". The integrated solar panel and green roof system is a solution already available in the market, that combines the production of clean energy with the multiple benefits of the NBSs (Maurer et al., 2023). However, the high potential still needs to be validated on a large scale and in long-term applications (Shafique et al., 2020).

The survey for TO and PA metropolitan cities has been shared through the mailing list of the Polytechnic of Turin and the University of Palermo (which includes both students and employees), institutional social media, private contacts and mailing lists. The survey for PA was also shared with 11 non-profit citizens associations, the Palermo Municipality and some online newspapers, which supported its dissemination through their official communication channels (i.e., mailing list).

For the metropolitan cities of TO and PA, the survey has been shared for more than two months, from January 15th, 2024, to March 23rd, 2024. An estimation of the minimum sample size of respondents, representative of the population per metropolitan area, can be obtained using the Slovin's formula, which is based on the total number of inhabitants and a given marginal error. The latter, for similar past works, was assumed around 5 % (Chui and Ngai, 2016; Cristiano et al., 2023a; Sarwar and Alsaggaf, 2020). For the metropolitan area of TO a total of 599 questionaries were collected, which considering the total population (i.e., 2'200'000 inhabitants) corresponds to the minimum sample size threshold with a marginal error of 4 %. For the metropolitan area of PA (1'200'000 inhabitants), a total of 1'089 questionaries were collected, corresponding to the minimum threshold for a marginal error of 3 %. For both cases, the sample size is thus higher than the suggested minimum threshold that corresponds to a marginal error of 5 %, which would lead to a minimum of 400 questionaries for both metropolitan cities. For the metropolitan area of CA the sample size was slightly lower; in this case, we retrieve a total of 244 answers from the previous regional survey (Cristiano et al. (2023a) that, considering the population (419'000 inhabitants), is corresponding to the minimum sample size threshold associated with a marginal error of 6.5 % according to the Slovin's formula. While the sample sizes can be considered adequately representative of the population within each metropolitan area, it is worth noting that they may be slightly skewed due to the non-perfectly random selection of respondents. The survey dissemination methods employed have resulted in a high relative fraction of academic students and respondents with medium to high level of education and/or a medium-high average annual household income; these proportions may not accurately reflect the broader population's distributions. However, these distortions, which will be discussed in the following, are consistent across the three samples, and probably align more closely with the profiles of potential stakeholders for GRs and NBSs (Chui and Ngai,

2016), thereby facilitating the analysis of the results and their comparison at the metropolitan area level.

3. Results

3.1. Socio-economic and demographic analysis

The first section of the survey is aimed to the identification of the socio-economic and demographic characteristics of the respondents. Results are summarized in Fig. 2 and Fig. 3, analysing personal information (Fig. 2) and information related to the household and living conditions (Fig. 3), for each metropolitan area and for the aggregated sample, which can be considered as representative of national results. Collected data have been compared to the most recent statistics reported by the Italian National Institute of Statistics (ISTAT), to evaluate the representativeness of the sample.

Due to the fact that the survey was shared online, there is a bias in the age of the citizens that have been involved in the questionnaire: the small percentage of people over 60 that has been reached, which varies between 9 % and 12 % depending on the metropolitan area, does not represent the high presence of this category in the reality (between 36 % and 38 %). If we consider the aggregated dataset compared to the National statistics, about 35 % of the Italian citizens are older than 60, while only 10 % of the respondent are in this category. This could be also attributed to the fact that in an online survey, segments of the population with limited or no internet access might be underrepresented compared to younger individuals, who are generally more inclined to participate in online surveys. The gender representativeness of the samples, on the other hand, has been ensured in all the three metropolitan cities and at the national level, with almost 50 % of male respondents and 50 % of female ones. A negligible percentage indicated to be non-binary or preferred to not answer this question.

The most evident distortion in the sample with respect to ISTAT data in terms of personal information emerges for the distribution of data concerning the education level and the working status (Fig. 2), with retired, freelancer and NEET categories significantly underrepresented and the category of people holding at least a Ph.D. degree markedly overrepresented, especially for the metropolitan cities of TO and CA.

The educational level of the respondents from the metropolitan area of TO and CA is quite similar, with almost half of them holding a PhD and only a small fraction (9 % and 15 % respectively) having a high school education degree. In PA, the educational level of the participants is slightly lower than in the other two metropolitan cities, with less than 30 % of citizens holding a PhD. The values recorded by ISTAT are however quite different, underling a lower educational level across the Italian population. More than 17 % of the citizens holds at maximum the Elementary degree and only 17 % hold at least a Bachelor's degree. This parameter is strongly biased by the fact that the survey was mostly distributed through the Universities channels, reaching mostly people with high educational level. In PA, the influence of addressing people involved with the University is particularly evident, especially looking also at the working status: almost half of the respondents (43 %) are students. Most of the respondents have a full-time job, and the percentage of part-time employees, that ranges between 3 % (PA) and 6 % (CA), is well representative of the trend recorded by ISTAT. Retired and unemployed people are however underestimated in this survey compared to the National conditions reported in the ISTAT databases.

Regarding the household dimension, the 2022 ISTAT report provided values only at national level, declaring that 35 % of the Italian citizens live by themselves, 28 % of families are composed by 2 people, 18 % by 3 people, 14 % by 4 and 5 % by more than 4 people. These characteristics are well aligned with what observed on average from the surveys in the three metropolitan cities, as reported in Fig. 3. The income results collected from the survey are representative of the national values,

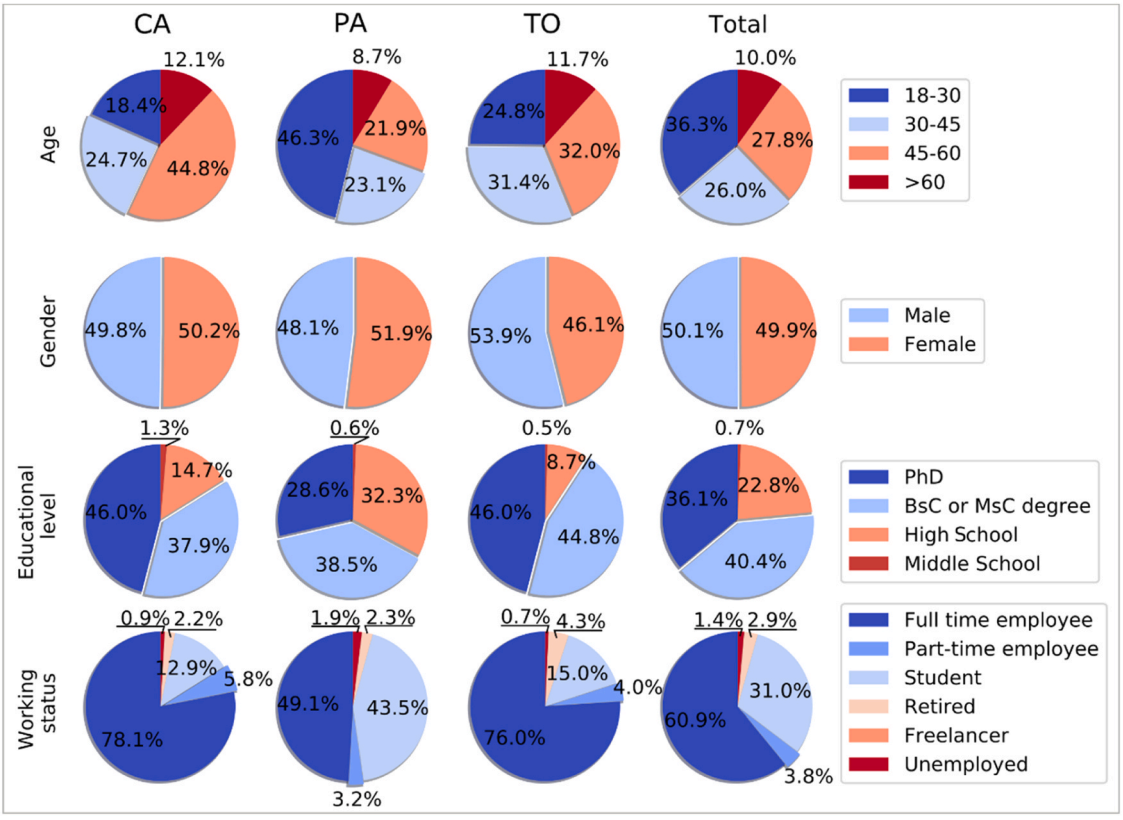


Fig. 2. Personal information regarding age, gender, educational level and working status of the survey respondents for the three case studies (CA, PA and TO) and the aggregated sample (Total).

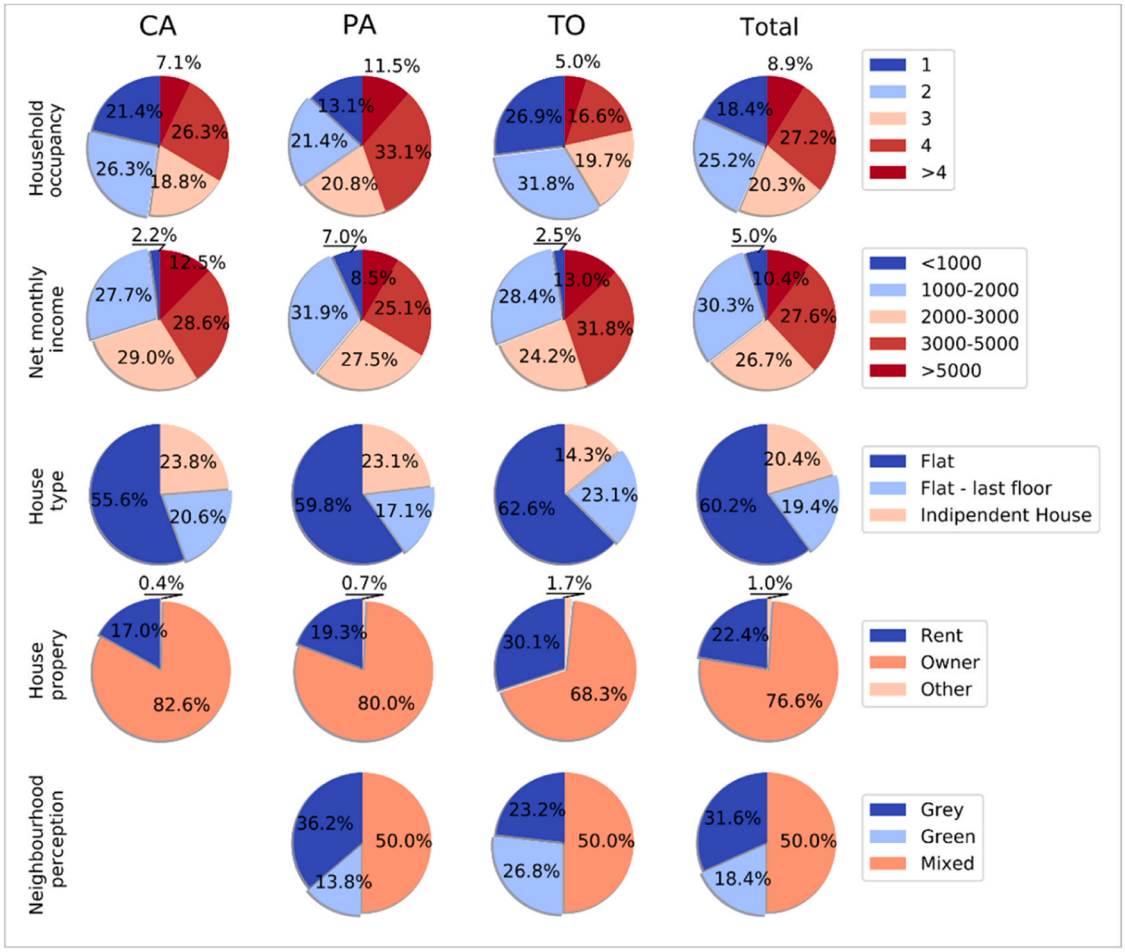


Fig. 3. Information regarding the living conditions, such as number of people in the household, net monthly income, house type and property and perception of the neighbourhood, of the survey respondents for the three case studies (CA, PA and TO) and the aggregated sample (Total).

highlighting the highest median monthly net income in TO and the lowest in PA. However, it should be noted that potential distortions in the samples may be mitigated or obscured by the significant fraction of students who responded to the questionnaire, which could affect the overall income distribution within the survey data.

The fact that most of the respondents (around 80 %) live in apartments, is aligned with the ISTAT data, which estimates that slightly more than 30 % of the citizens live in an independent house. Similarly, the distribution of the respondents' house ownership is well represented by the collected sample. Most of the respondents own their house, and only a smaller percentage is renting the accommodation: specifically, 17 % of the respondents in the metropolitan area of CA, 19 % in PA and 30 % in TO. This approximately reflects ISTAT data, which report 14 %, 20 % and 23 % respectively.

In the new questionnaires for the metropolitan cities of TO and PA, it was also asked how green the respondents perceive their neighborhoods; the results for the two metropolitan cities were consistent with each other, with significant differences in the response between respondents living in large, urbanized cities (e.g. Turin, Palermo) and those living in small cities. Overall, half of respondents perceive the neighborhoods as "mixed", while the responses for the remaining part are almost equally divided between "green" and "grey" in the metropolitan area of TO and more "grey" (36 %) than "green" (14 %) for the metropolitan area of PA. The results, limited to only the major cities per metropolitan area, highlight how Palermo, excluding Palermo city, is prevalently perceived as mixed-grey (50 % and 43 %), while only 7 % of the respondents from the main city consider their neighborhood green. On the other hand, the perception of the metropolitan area of TO, excluding Turin city, is more "green" (63 %) than "grey" (10 %). It is worth noticing that according to the ISTAT data, in 2022 the percentages of green areas for the city of Turin and Palermo were 18 % (the 6th greenest large city in Italy) and 4 %, respectively, highlighting significant differences between the two cities. The percentage of green areas for the city in Cagliari in the same year was intermediate (9 %).

The predominant profile of respondents, when considering the aggregated sample for the three metropolitan cities, is characterized by individuals under the age of 60 years, possessing a high level of education (at least a BSc degree), primarily employed full-time, with a monthly net household income exceeding 2'000 €/month. They mainly reside in their own flat, which they share with one to three other individuals. This demographic profile highlights an economically stable segment of the population with a high educational level, which may influence the overall findings of the survey.

3.2. *Environmental issues*

The second section of the survey explores perceptions and awareness of green roofs as possible solution of environmental issues. About 20 % of the participants indicated that they are unfamiliar with green roofs (15 % CA, 22 % PA, 22 % TO), and an equal percentage reported only a vague understanding of these systems (25 % CA, 15 % PA, 18 % TO). Conversely, around a quarter of respondents in CA and PA (24 % and 29 %, respectively) and nearly 40 % in TO, declared to be knowledgeable about green roofs and to have encountered these solutions at least once. These findings underscore the need for enhanced public education on key climate adaptive solutions for urban areas, such as green roofs.

The survey then explored the citizens' perception of some of the most common urban environmental issues, defined in Section 2.2, evaluating the perceived frequency of each by the respondents. After an informative session explaining the typical components of green roofs and their main functions, it was asked to which extent respondents think GRs could be a solution for the aforementioned environmental issues. It is important to underline that the informative section does not provide information regarding the potential of GRs to address environmental issues, with the aim of not affecting respondents' opinions.

Fig. 4 illustrates with the support of a nested pie chart the frequency perception of specific environmental issues and the trust in GRs as a potential solution for the selected three metropolitan cities, which are identified with different hatches. The inner pie represents the respondents from CA, the middle one from PA and the external from TO. The first line shows the frequency perception of the selected environmental issues, highlighted with colours from dark blue ("Never") to dark red ("Often"). The second line, instead, reports the trust in GRs as solution for the addressed issues, with a colour range from dark green ("A little") to magenta ("Solve completely"). Results highlight a high variability in frequency perception of the environmental issues depending on the considered metropolitan area. Pluvial floods, lack of green spaces and water scarcity issues in the metropolitan area of PA are perceived much more frequently than in the other two areas. A similar perception of scarce air quality and noise issue characterizes the responses for the metropolitan cities of TO and PA. Despite the significantly different climate conditions, the results highlight a similar perception of frequent occurrences of issues related to high temperature and high costs for energy consumption for air conditioning systems in all the metropolitan cities. These seem to be the most perceived environmental issues for the metropolitan area of CA. This outcome could be partially influenced by contingent situations, as the survey was shared during the summer (when temperature-related issues are more pressing) in the metropolitan area of CA, and during the winter in PA and TO.

GRs are perceived principally as an effective measure of high temperature mitigation and building energy efficiency. The effect of air pollution remotion is highly recognized, especially from the responses relative to the metropolitan cities of CA and PA. In metropolitan cities with a low fraction of green areas, such as CA and PA, GR is perceived as an extremely effective measure to face the lack of green spaces. On the other hand, the respondents trust slightly less in GRs as possible solution for water related issues, such as pluvial floods and water scarcity, as well as measure of noise attenuation. Although the frequency perception of environmental issues shows high variability across the three metropolitan cities, the trust in GRs is less influenced by geographical location. This analysis can serve to drive efforts in the improvement of dissemination activities for enhancing citizens' awareness of specific co-benefits offered by green roofs that are scarcely known by the population.

An informative section, placed immediately after the questions related to perception of GRs' benefits, was included in the questionnaire with the aim of explaining in detail the main functions and potential benefits of GRs.

3.3. Interest and willingness to pay for GRs

The interest and WTP for potential implementations of GRs in private and public buildings have been evaluated separately in the fourth section of the survey. The citizens' interest in having a GR installation is measured on a scale from 1 (not interested) to 5 (very interested), considering five possible classes. The WTP for GRs installation on public buildings is meant as willingness to accept an annual tax increase to cover both installation and maintenance costs in public buildings of the city (e.g., hospitals, offices, schools, prisons, etc.). Four WTP classes are considered, ranging from an investment of less than 20 €/year (less than 0.1 % of the average annual net salary) to over 200 €/year (more than 1 % of the average annual net salary). This information could be used by policymakers and urban planners in developing sustainable long-term projects, assessing their economic feasibility also based on citizens' willingness to contribute. The WTP for GR installation on private buildings is measured as willingness of respondents to cover the costs for individual private installations on their own homes. In this case, for the

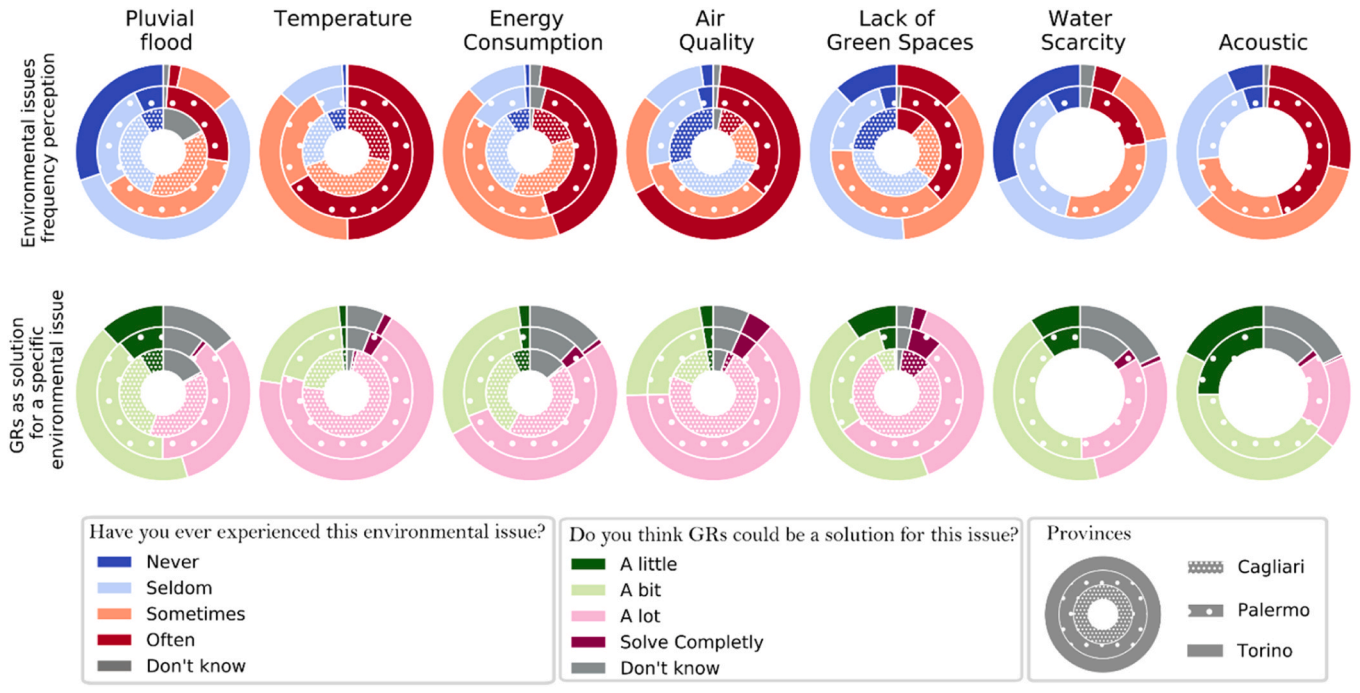


Fig. 4. Citizen's perception of common environmental issues and of GR as potential solution. Each column characterizes an environmental issue. The frequency perception of the issues (first line) is described with a colour scale from dark blue ("Never") to dark red ("Often"), while the potential of GRs as solution (second line) is illustrated with a colour scale from dark green ("A little") to magenta ("Solve completely"). The three metropolitan cities, identified also with different hatches, are allocated in different positions of the nested pie: CA corresponds to the inner pie, PA to the middle one and TO to the external one.

PA and TO metropolitan cities, five different WTP classes are considered, varying between less than 500 € to 10'000–20'000 €, investment that would enable to install and maintain a large private GR. To facilitate the comparison with the results previously obtained for the CA metropolitan area, these classes have been subsequentially aggregated in the same ranges considered (Cristiano et al., 2023a), varying from less than 1000 € to 10'000–20'000 €.

Outcomes from the survey in the three metropolitan cities regarding interest and WTP have been crossed and depicted using Sankey plots in Fig. 5, which enable us to understand if respondents with higher interest are willing to invest more than non-interested citizens. Specifically, Fig. 4(a) refers to potential installations in public buildings, while Fig. 5b focuses on installations in private buildings. Overall, high interest in having green roofs on public buildings can be observed, with, on average across the three metropolitan cities, a percentage of 83 % respondents being interested (25 % rating class 4) or very interested (58 % rating class 5), and only 7 % being scarcely interested (i.e., rating class 1 or 2). The distribution of rates among the five interest classes for the metropolitan area of CA is very similar to that obtained for the metropolitan area of PA, while results for the metropolitan area of TO show an overall slight lower interest in investing for public installations of GRs. This straightens the idea of the scarce perception of available green spaces in the metropolitan cities of CA and PA compared to the metropolitan area of TO, and the overall perception of potential installation of GRs on public buildings as a possible solution. On average, half of the respondents are willing to pay between 20 and 100 € per year, while only 5 % would be willing to accept an annual tax increase exceeding 200 €/year. Considering only the interested respondents (i.e. rating interest classes 4 and 5), on average the 78 % are willing to accept an annual tax increase for public GRs installation and maintenance below 100 €/year while around the 22 % would accept a higher (up to 200 €/year or above 200 €/year) tax increase, almost equally partitioned between the two WTP classes.

Considering the lower bound for each WTP class (e.g., 20 €/year for the class 20–100 €/year, and 100 €/year for the class 100–200 €/year, etc.), and making a weighted average based on the number of answers obtained for each class, we can derive that Italian citizens are willing to spend at least 32.3 €/year for installation and maintenance of GRs on public buildings (32.6 €/year CA, 30.8 €/year PA, 33.3 €/year TO). If we base the same analysis on the central value of each WTP class (e.g., 10 €/year for the <20 €/year class, and 60 €/year for the 20–100 €/year class), the average Italian WTP can be estimated equal to 66 €/year (66 €/year CA, 64 €/year PA, 68 €/year TO). The WTP for GRs on public building is quite similar among the three selected metropolitan cities, with slightly lower values observed in the PA metropolitan area and higher in the TO one. The declared WTP would enable to define long term plans for a large-scale installation of green roofs on public buildings in medium-large Italian cities.

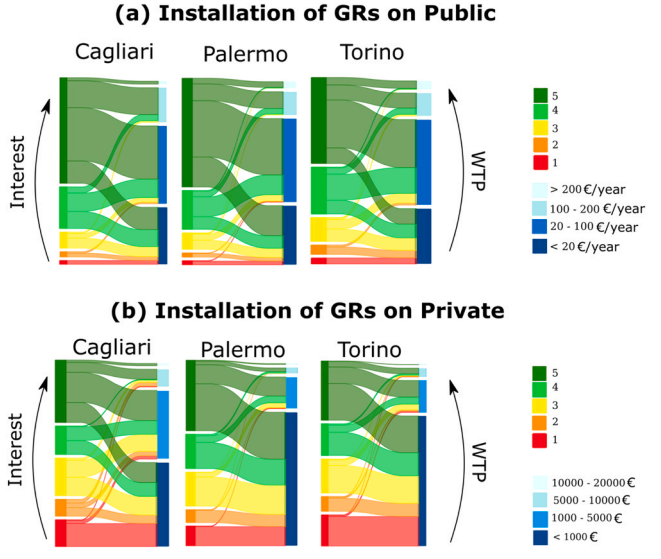


Fig. 5. Interest to have GRs vs willingness to pay for their installation (a) on public buildings, (b) on private buildings. The interest is rated with a scale from 1 (not interested, red) to 5 (very interested, dark green). WTP is illustrated with a blue scale of colours.

As shown in Fig. 5b, the interest in installing GRs on their own private building is quite lower than that for public installation, with almost half of respondents (44 %) rating interest classes 1–3 (39 % PA and 47 % CA and TO). Coherently, also the WTP is relatively low, with a significant percentage (on average the 67 %, 49 % CA, 78 % PA, 76 % TO) of the respondents from all the metropolitan cities willing to invest less than 1'000 €. Assuming an average cost of 150 €/m^2, this potential investment in the context of an individual contribution for a condominium installation would allow for the implementation of small extensive GRs, with surfaces on the order of a few dozen of m^2, whose advantages could be limited in terms of both benefits for the owner and for the environment. However, around half of respondents (i.e., on average, 56 %) declared to be highly interested in private installations (rating interest classes 4 or 5) and a very relevant percentage of them (on average, 42 %) would be willing for investments over 1'000 €. Interest and WTP for GRs on both private and public buildings seems to not be influenced by educational level nor household income.

3.4. Concerns about GR installation

Relevant factors contributing to the manifested lower interest in green roofs on private properties compared to public installation were also investigated in this section of the survey. Respondents were asked to identify the primary concerns associated with installing GRs on their own buildings. This question was structured as a multi-choice question, allowing respondents to select up to three responses and to include additional concerns. The range of options provided by the survey included: high installation costs; high maintenance costs; the presence of animals and insects; humidity and potential leaks from the roof; the presence of pollen allergens. Among the reasons potentially deterring interest in green roofs on private buildings (Fig. 6), the most shared ones are the high maintenance (71 % Average, 59 % CA, 72 % PA, 77 % TO) and installation costs (57 % Average, 50 % CA, 61 % PA, 52 % TO). Another common concern is the fear of humidity and potential water infiltrations from the roof (63 % Average, 46 % CA, 70 % PA, 60 % TO), while the presence of insects and small animals might be an issue for around 32 % of the interviewed citizens in the three metropolitan cities.

While for the metropolitan area of CA, and more in general for the Sardinia region (Cristiano et al., 2023a), the actual or potential presence of photovoltaic panels was among the most frequent alternative added by the participants as reason to not install green roofs, for the metropolitan cities of TO and PA other factors were highlighted in the survey, such as the structural feasibility and challenges in reaching consensus among residents of the same building. An interesting response, added exclusively by respondents from the metropolitan area of PA, was the concern about potential fires from green roofs. This reflects its particular relevance for residents in Sicily, a region that has experienced several fires in recent years, including a significant event near the city of Palermo in July 2023.

The last question of this section examines the preferences of citizen among GRs, photovoltaic panels, and hybrid GRs with photovoltaic. As explained in Section 2.2, in the Sardinian survey (Cristiano et al., 2023a) participants could chose only between GRs (28 % of the CA respondent) and solar panels (72 %). The increase of popularity in the last year of hybrid GRs-photovoltaic systems, with different solutions commercially available, suggested the need to include this option in the survey. The outcomes reveal a general preference of respondents from the metropolitan area of TO (59 %) and PA (64 %) for investing on the hybrid

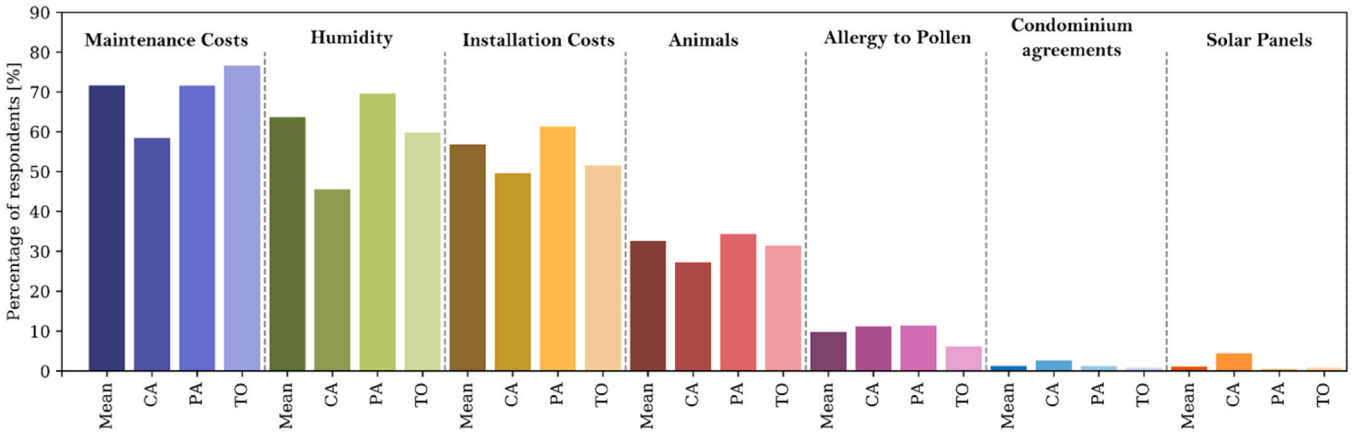


Fig. 6. Reasons to not install GRs on their own buildings. Participants were allowed to select more than one preference.

solution. However, the survey in all metropolitan cities show a citizen preference on photovoltaic panels rather than on GRs: less than 10 % (7 % PA, 8.5 % TO) would opt for a traditional GR, and the remaining 30 % would decide on solar panels (28 % PA, 32 % TO); this is probably due to a higher perception of the direct economic benefits that these measures can provide, especially in terms of reduction of the costs for energy consumption (which actually was one of the most perceived issues from the respondents, Fig. 4), and the shorter payback times.

3.5. *Interest and willingness to pay for other NBSs*

The last section of the survey switches the focus from GRs to NBSs in general, with an informative part describing functional aspect and benefits of four typical NBSs in urban areas, such as: green walls, rain gardens, permeable pavements and rainfall harvesting systems. Finally, respondents were asked to identify the preferred green measures for large scale implementation in their own city among the four described in the previous informative part, also allowing for multiple selections and with the possibility to include additional ones. This section was not available in the Sardinian survey; hence the outcomes are presented only for the metropolitan cities of PA and TO.

As shown in Fig. 7a, all the proposed NBSs aroused the interest of most of the respondents and each one was supported by more than 55 % of the participants. The preferred solutions that citizens would like to be installed in their town are rainwater harvesting systems in the Metropolitan area of PA (selected by 65 % of the participants), while in the Metropolitan area of TO are permeable pavements (70 %). The different preference manifested in the two metropolitan cities could be influenced by the different perception of environmental issues and their frequency in the two areas, as presented and discussed in Section 3.2; this, in fact, highlighted how water scarcity in PA is seen as a stronger issue than in TO. In both metropolitan cities, respondents highlight the need of maintaining the already installed solutions and suggested the creation of parks and urban gardens for agriculture, underling perception of green space lacking.

The WTP for the installation of NBSs across the city is also explored in terms of willingness to accept an annual tax increase. Four WTP classes, equal to the ones used for exploring WTP for public installation of GRs, were considered, ranging from an investment of less than 20 €/year to over 200 €/year. Fig. 7b compares the WTP for NBSs with the one declared for GRs, in the metropolitan cities of PA and TO. As expected, results show a WTP for NBSs slightly higher than that specifically expressed for GRs. In both metropolitan cities, while the percentage of respondents willing to spend for NBSs more than 200 €/year (on average around 5 %) is similar to the one willing to invest for GRs, the number of participants willing to pay more than 20 € for NBSs is higher than in the case of only GRs.

As presented for the WTP for GRs (Section 3.3), if we consider the central value of each WTP class, we can estimate from the aggregated sample, weighted on the number of participants, that Italian

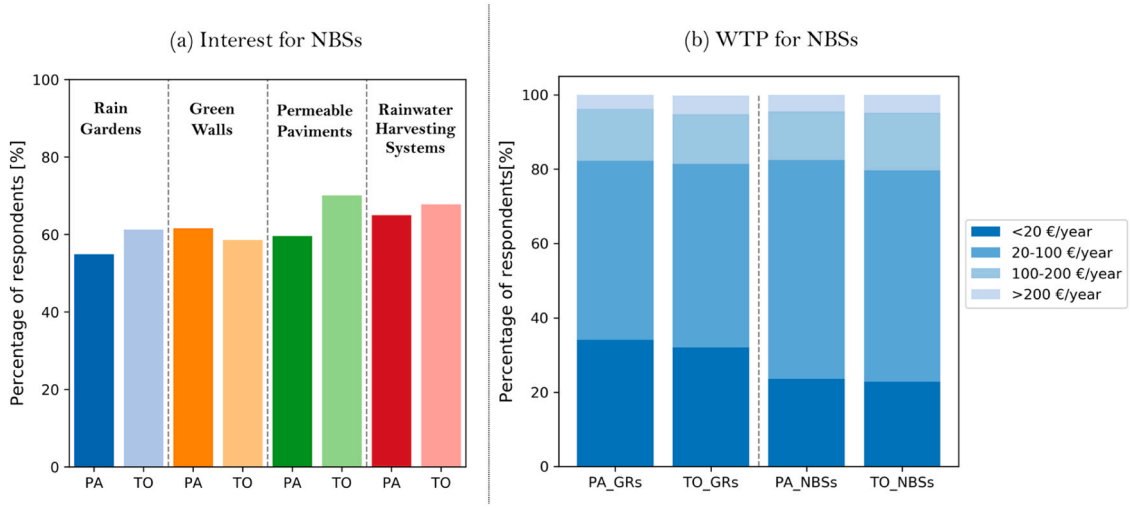


Fig. 7. Interest and WTP for NBSs in PA and TO. (a) Interest in different NBSs, such as rain gardens, green walls, permeable paviments and harvesting systems. (b) Comparison between.

respondents are willing to spend 71.4 €/year for implementing NBSs in their cities, with scarce variability between the two metropolitan cities (i.e., 70 €/year in PA and 74 €/year in TO). On average, higher WTP for both GRs and NBSs is observed in the TO metropolitan area compared to what observed in the PA metropolitan area: this can be probably related to the higher average salary as described in Section 2.1.

4. Policy implications

The outcomes of the survey underline the high interest of people in implementing GRs and NBSs in public spaces. On average, the WTP for GRs was estimated equal to an increase of yearly taxes of 66 €, while the WTP for NBSs can be estimated equal to 71 €. These values are aligned with the few results available in the literature for other countries, which varies from 3.1 € in Asia (Ji et al., 2022; Zhang et al., 2020) to 397 € in the USA (Netusil et al., 2022). WTP provides fundamental support for decision makers and urban planners. Through the knowledge of an average WTP value it is possible to design and assess the financial feasibility of long-term (20–30 years) projects for large-scale installation and maintenance of GRs and NBSs. For instance, under the hypothesis of a 25-year project for GRs installation in the major cities of the three investigated metropolitan cities (Cagliari, Palermo and Turin) and assuming installation and maintenance costs around 150 €/m^2 and 10 €/year/m^2, respectively, it would be possible to estimate the total area of rooftop that can be potentially covered by green infrastructures. Based on the WTP expressed in our survey, in a small city like Cagliari (about 150'000 inhabitants), it would be possible to transform 0.6 km^2 of roofs into GRs. Increasing the population involved, as for the cases of Palermo (670'000 inhabitants) and Turin (890'000), the large-scale GR design could cover a total area up to 2.7 km^2 and 3.8 km^2, respectively.

Another important aspect for policy makers is the potential conflict between GRs and solar panels. Our results highlight how citizens prefer solar panels to green roofs, probably because they see direct benefits in the photovoltaic energy production and, at the same time, they are not fully aware of the high potential of NBSs. This would confirm results observed in Sardinia (Cristiano et al., 2023a), in Spain (Untereiner et al., 2024), and in the USA (Meyer and Trandafir, 2023), where the preference for solar panels or integrated solutions was clearly stated. In Italy, this strong preference can be partially explained since the government provided the opportunity to obtain a partial/total reimbursement of the investment costs up to 110 %, in the form of a tax deduction over 5 years, for the realization of new photovoltaic system starting from 2012 (Bragolusi and D'Alpaos, 2021; Colasante et al., 2021; D'Adamo et al., 2020). Thanks to this policy, in Italy there are almost 1.6 million of photovoltaic system for a total production of 30.28 GW, of which 30 % are on private houses and 50 % on industries (GSE, 2023). Government financial support was actually one of the most relevant factors driving the interest and spread of solar panels (Mundaca and Samahita, 2020; O'Shaughnessy, 2022); similar strategies applied to support the installation of GRs (or other private NBSs, such as rainwater harvesting or green walls), could inevitably lead to a rapidly increase in the presence of these solutions in the cities. The main issue for the public administration is hidden behind the fact that, while it is easy to estimate the energy produced by a solar panel system and to convert this in saved money, the benefits provided by GRs are not immediately quantifiable in monetary terms. The pluvial flood mitigation capacity, for example, it is difficult to economically translate in a lower expected damage. In the same way, the reduction of the urban heat island and the increase of biodiversity achievable with large scale GRs installation are intangible benefits, hard to quantify and to translate in monetary investment.

Financial support from the government is, however, not the only impacting factor: the WTP for private GRs (on average 1624 €) is quite low compared to the WTP observed in the literature for solar panels (e.g., 6000 € in New York (Badole et al., 2024). In order to increase the WTP for GRs, and more in general for NBSs, it is necessary that decision makers promote the importance of these solutions, highlighting the multiple benefits for the sustainable development and potential financial savings.

The analysis of the responses revealed a significant interest in both public and private GR installations, although WTP does not always align with the expressed interest. Addressing this disparity could be pivotal towards the implementation of effective incentivization policies. Such policies could bridge the gap between citizens' WTP, and the costs associated with the realization and maintenance of a functional network of GRs, and more broadly NBSs, within a city, encompassing both private and public spaces. Furthermore, it is evident that there is a need to enhance public understanding of green roofs and to address concerns that are often perceived but not grounded in technical rationale.

5. Conclusions and future development

This work investigates awareness, interest and willingness to pay (WTP) for green roofs (GRs) and Nature-based solutions (NBSs) in three Italian metropolitan cities (Cagliari, Palermo and Torino), with the aim to identify how different socio-demographic and climatic conditions influence the perception of these innovative solutions. Specifically, we analysed how instruction level, net income, and urbanization degree affect the perception of environmental issues in different climatic areas and the trust and WTP of people for GRs as possible solution. An anonymous online survey has been distributed via Universities' mailing lists and social media, collecting samples representative in size for each metropolitan area.

Different climatic conditions strongly affect the presence and perception of environmental issues. Results highlight that environmental issues are perceived differently in the various metropolitan cities, correctly reflecting the different frequency of each issue in the three areas: while high temperatures, frequent pluvial flood and lack of green spaces are highly perceived in the metropolitan area of Palermo, respondents from the metropolitan area of Torino often include air pollution among the prominent environmental issues. On the other hand, answers collected in the metropolitan area of Cagliari show a low perception of pluvial floods and air quality issues. Although the perception of the investigated problems is quite different, the manifested trust in GRs is similar among the three selected metropolitan cities, highlighting as this solution is seen as an efficacious option to face high temperatures and reduce energy consumption for cooling/heating the buildings, as well as it is well recognized the possible benefit of improving air quality.

Italian citizens seem to be very interested in GRs and other NBSs, such as green walls, rainwater harvesting systems, raingardens and permeable pavements, especially in public spaces, where the average WPT is 71.4 € per year. In cities with a medium-high population density, this amount would enable policymakers to design sustainable programs for the implementation of an integrated network of different NBSs. The similar results collected in the three investigated metropolitan cities with regard to interest in GRs and NBSs, demonstrate that this is scarcely related to socio-demographical factors, and results could be used for the entire country. It is important to underline that, although our samples present a significant bias in the representativeness of the educational degree, presenting in the sample a higher number of respondents holding a PhD compared to reality, the interest and WTP for GRs and NBSs is not correlated to it. Moreover, the fact that citizens strongly prefer the installation of GRs on public spaces, independently from personal income, suggests how NBSs are primary seen as a collective and shared solution for climate change adaptation and sustainable development.

A lower interest is, instead, manifested for private installations, where citizen would rather prefer to install hybrid structures with solar panels. The WTP for GRs on private buildings is generally quite low (under 1000 €/year) making their installation and maintenance feasible primarily for large buildings with multiple housing units, when considered as a condominium-level investment. The reasons for such a

low manifested interest in private GRs could be addressed by analyzing respondents' concerns, which includes the high maintenance and construction costs, potential issues of humidity and presence of insects and small animals.

Our findings also suggest the key role of governmental policies in supporting a sustainable urban development. On top of an effective campaign to inform residents about the potential benefits of GRs and NBSs in multiple sectors, the government and the municipalities should also foresee financial support for private implementation of different sustainable solutions to ensure a large-scale development of NBSs.

CRediT authorship contribution statement

Elena Cristiano: Writing – original draft, Visualization, Methodology, Investigation, Data curation, Conceptualization. **Fulvio Boano:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Dario Pumo:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Francesco Viola:** Writing – review & editing, Supervision, Investigation, Conceptualization. **Matteo Ippolito:** Writing – review & editing, Investigation, Data curation.

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.

Acknowledgments

This study was carried out within the «CLEVER» project – funded by European Union – Next Generation EU within the PRIN 2022 program (D.D. 104–02/02/2022 Ministero dell'Università e della Ricerca). CUP: F53D23002240006. This manuscript reflects only the authors' views and opinions and the Ministry cannot be considered responsible for them. This manuscript reflects only the authors' views and opinions, and the Ministry cannot be considered responsible for them. This project has received funding from the European Union's Horizon H2020 innovation action programme under grant agreement 101037424 (ARSINOE).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2025.128928.

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