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PAPER

Predicting willingness to pay and implement different rooftop strategies to characterize social perception of climate change mitigation and adaptation

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Supplementary material for this article is available online

Abstract

With the latest IPCC report, dramatic global climate action must be taken immediately to limit global warming to 1.5 °C, or face more frequent and extreme weather events with catastrophic implications. Cities must invest in climate resilience development; however, government policies are only effective if they are supported by the society in which they serve. As such, this study aims to characterize the social perception of climate resilience development, in particular the implementation of sustainable urban rooftop strategies, to support policy makers and enable individual action. This was accomplished through the analysis of 1,100 answered surveys in Cerdanyola del Vallès (Spain), to assess one's willingness to pay (WTP) and willingness to implement (WTI) rooftop strategies according to: 1. socio-demographical characteristics; 2. social perceptions and beliefs; and 3. surrounding land use and land cover, and vulnerabilities identified through temperature and normalized difference vegetation index (NDVI) maps. The results of this study found age played a significant role in predictability, with 18–39-year-olds being the most willing to pay and implement the various rooftop scenarios. However, our results uncovered societal inequality as those 85+ were the second group most interested in rooftop agriculture but the most financially restricted. Belief in the viability of rooftop strategies increased respondents WTP and WTI while having access to ones' rooftop increased willingness to partake in rooftop food cultivation and enhance rooftop greenery. A new finding presented by this study is the quantifiable impact that urban greenery plays on increasing survey respondents WTP and WTI.

1. Introduction

Cities are home to over half the worlds population and are significant contributors to climate change. For example, cities account for 80% of global gross domestic production (GDP) (UN-Habitat 2016) and consume up to 70% of global food supplies (FAO 2017) and 75% of global energy (80% of green house gas emissions (GHG) emissions) (Ash *et al* 2008). At the same time, cities are also highly vulnerable to the shocks and stresses of climate change that have direct and indirect compounding effects on a city's greenery, resilience, and inclusivity (World Bank Group 2022).

By adopting climate resilient development, cities can play a transformative role in limiting global warming to 1.5 °C (and improving inclusivity), with the greatest points of leverage being: the food sector, electricity, buildings and land-use (IPCC Press Office 2023). However, due to existing urban developments and real estate competition (el-Baghdadi and Desha 2017), cities lack the space required for urban green infrastructure (UGI) to improve city resilience and greenery, and must consider how UGI can be incorporated into existing infrastructure (Tsantopoulos *et al* 2018, Langemeyer *et al* 2020, Zambrano-Prado *et al* 2021). Cities leading this initiative include Paris (Mairie de Paris 2016), Barcelona (Barcelona City Council 2018) and Rotterdam (Gemeente Rotterdam 2023), which have all recognized green roofs and mixed rooftop use (rainwater harvesting, and photovoltaic (PV) panel energy production) as a key strategy for climate resilience and are implementing policies and incentives for their installation on rooftops.

Effective policies against climate change are ones that are not only accepted by the public, but influence the public to quickly implement it (Zhang *et al* 2019). Considering current economic models do not provide monetary value of the benefits of public environment products, the measurement of the publics willingness to pay (WTP) provides a valuable method for measuring public financial support and public participation (Wang *et al* 2017, Zhang *et al* 2019).

2. Literature review and objectives

2.1. Literature review

One component of climate resilient development involves the restoration of ecosystem services which contributes to stormwater management, thermal regulation and subsequent decreasing of the urban heat island effect, increased albedo, production of food, noise reduction, and improved human mental and physical wellbeing (Mitchell and Popham 2007, Maas *et al* 2009, Li *et al* 2014, Li and Sullivan 2016, Tsantopoulos *et al* 2018, Langemeyer *et al* 2020, Toboso-Chavero *et al* 2021).

Rooftop agriculture (RA) in particular can enhance a buildings' environmental efficiency through thermal insulation, integration of rainwater harvesting, and utilizing building by-products such as biomass residues, greywater, heat, and CO_2 (Manríquez-Altamirano *et al* 2020, Muñoz-Liesa *et al* 2022); while also tackling food deserts, sequestering CO_2, increasing city biodiversity, and enhancing air quality (Lepp 2008). RA is an alternative to present-day food supply chains that can contribute to a circular urban food production system (Sanyé-Mengual *et al* 2016, Nadal *et al* 2018) and to climate resilience development. This compounding effect of improved building efficiency and food systems should not be taken lightly as food production and real estate are responsible for 26% (Ritchie *et al* 2022) and 40% (70% of which is operational emissions) (Carlin 2022) of global carbon emissions respectively.

Despite the previously mentioned environmental benefits offered by green roofs, social action continues to be lagging due to lack of understanding on how to take action and the belief that individual action is not impactful (Semenza *et al* 2008). This is attributed to a limited understanding of how to change one's behavior, misunderstandings regarding the benefits of individual action, and low-income earners hindered by time and financial constraints (Semenza *et al* 2008). Considering demographical characteristics are normally considered in ones WTP (Sanesi and Chiarello 2006, Specht *et al* 2016, Wang *et al* 2017, Zhang *et al* 2019, He *et al* 2021, Toboso-Chavero *et al* 2021), it is important to also consider the complexity and diversity of people who make up a society and how land use with respect to urban planning can influence the societal acceptance of policies. For example, high-quality green space is known to contribute to a residents' positive attitude towards urban nature (Sanesi *et al* 2006). Could there be a link between urban planning and land-use, and ones WTP?

2.2. Research questions and objectives

This case study considers six rooftop scenarios involving rooftop agriculture, PV solar panels, and rainwater harvesting to analyze:

Research Q1: How can the characterization of social perception related to UGI aid policy makers.

Research Q2: How can government policy in urban planning support social acceptance of the development of climate resilience strategies.

This was accomplished by considering ones willingness to pay (WTP) and willingness to implement (WTI) the various uses according to:

Objective 1: Socio-demographical characteristics.

Objective 2: Social perceptions of rooftop strategies in European cities and perceived challenges facing the EU within the next 20 years.

Objective 3: Identifying other variables such land use and climate change vulnerabilities (heat and vegetative cover) that could potentially influence one's WTP or WTI.

In this study, perception refers to how one collects and interprets information; belief is an acceptance of truth or falsehood and is influenced by personal experience, values, social background, etc; and preference is a subjective evaluation through individual reasoning (SEP 2023). This study further contributes to scientific literature by focusing on small cities whose nuances are largely neglected by the scientific community. Current literature focuses primarily on mega-cities (12% of the global population), and very few studies consider small cities (less than 300,000 inhabitants) despite accounting for 42% of the world's population (Lamb *et al* 2019). This study aims to represent this underrepresented population (Bell and Jayne 2009, Musterd and Kovacs 2013, Grossmann and Mallach 2021) by applying innovative methods to the small European city (50,000–100,000) (Dijkstra and Poelman 2012) of Cerdanyola de Vallès, Spain (population 57,217) (IDESCAT 2022) by analyzing 1,100 answered surveys regarding respondents' social perception and beliefs of rooftop strategies, and their WTP and WTI in Cerdanyola del Vallès (now referred to as Cerdanyola). The study area is described below, along with methods of analysis in the methodology, a detailed analysis in the results, the discussion which includes limitations and recommendations for future research, followed by the conclusion.

3. Methodology

Throughout this section, the study area is described in more detailed, followed by the survey design, analysis and data used from various maps.

3.1. Study area

As of November 2021, Barcelona became the first Resilience Hub in Europe following proactive action against climate risks and vulnerabilities that considered infrastructure vulnerabilities, natural hazards, and socio-economic risks (UNDRR 2022). This study expands on previous studies analyzing Barcelona's vulnerabilities and resilience mitigation strategies (Baró *et al* 2019, Langemeyer *et al* 2020, Toboso-Chavero *et al* 2021) by focusing on the small municipality of Cerdanyola located 12 km north of Barcelona, Catalunya.

Cerdanyola's urban composition is well varied and comparable to typical European cities; comprised of a historic center, a distributed mix of single and multi-family housing, well delimited housing estates in various areas, and isolated industrial parks (PDU 2017). As a Mediterranean city, Cerdanyola has hot summers (36 °C) with an annual average rainfall of 610 l m^{-2}, and one-third of the area includes the Collserola mountain range (Ajuntament de Cerdanyola del Vallès 2022). Climate risks that threaten Cerdanyola include heat stress, drought, and forest fires (Barcelona City Council 2018).

In 2021, the 30.6 km^2 municipality of Cerdanyola was home to 57,217 inhabitants (1,872.3 inh/km^2), which in 2011, consisted of 32,499 economically active (24,959 employed and 7,540 unemployed) and 24,365 inactive inhabitants with a 2020 GDP of 34.3 thousand euros (annual household disposable income of 1,123.5 thousand euros, or 19,500 euros per capita) (IDESCAT 2022). Of the 25,300 registered homes in 2011, 83.8% are owned and over half of these (57.07%) were between 61–90 m^2, while 19.05% and 11.06% are between 91–121 m^2 and over 121 m^2 respectively (IDESCAT 2022)

A detailed land use and land cover map of Cerdanyola in figure 1 demonstrates that 78% of homes had at least 0.5 ha of green space located within a 300 m radius from their home, and 69% had 1 ha or more. Additionally, 52% had at least 0.5 ha of naturalized landscapes, and 34% had at least 0.5 ha of roads and infrastructural development.

The normalized difference vegetation index (NDVI) values ranged from 0.04 (0 being urban area or water) to 0.35 (1 being greener) with the average person having 0.16 within 300 m of their home, indicating that greenness is relatively limited within the city, and temperatures tend to be highest within the urban centre (figure 2).

3.2. Survey design

In April 2021, over one year into the COVID-19 pandemic, a survey was conducted regarding the alimentary consumption habits of residents with relation to the types of buildings, family size, and demographical characteristics. The protocol for the survey was approved by the Ethics Committee on Animal and Human Experimentation of the Autonomous University of Barcelona (reference number: CEEAH 5539) and with the explicit consent of all anonymous participants. The aim was to inform policy plans regarding the need for RA, photovoltaic (PV) solar panels, and rainwater harvesting in a way that benefited the municipality and residents socially, environmentally, and economically. Therefore, residents were asked to provide their preferences for WTP for general rooftop installations features and WTI specific rooftop scenarios (open-air farming, rooftop green houses, green roofs, rainwater harvesting, PV panels, or mixed use), specify their perception of the use of these strategies in other European cities, and to rank key challenges facing the EU within the next twenty years. This survey was answered by 1,100 residents by phone and is a stratified random sample that encompasses various forms of urban typology (housing estates, and originary fabrics, which include the historic center,

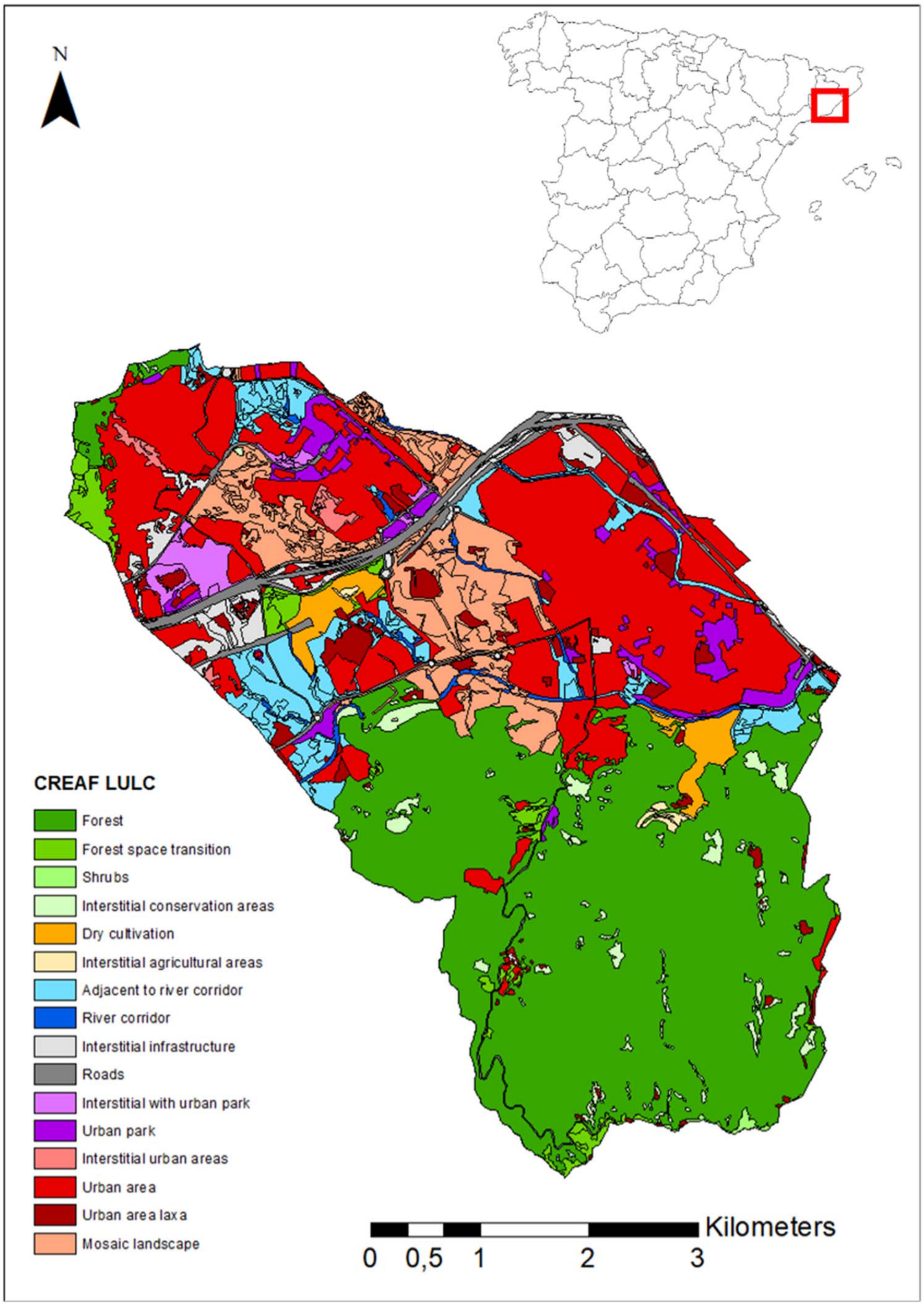

Figure 1. Cerdanyola municipality land use land cover (CREAF) map.

suburban extensions, and single-family housing areas). The dataset is available in open access: https://doi.org/10.5565/ddd.uab.cat/267206 and here (Toboso-Chavero *et al* 2023) Subsequently, these results were validated by average values obtained by official statistics.

Bearing in mind the wealth of data provided in this survey, it was decided to focus solely on measuring respondents' WTP and WTI according to their demographical characteristics, different types of urban fabrics (building blocks, single family homes, or historic centre), their perception and beliefs regarding the various rooftop strategies, and their top three challenges facing the EU in the next twenty years. The survey questions, and results are provided in the supplementary material.

3.3. Statistical analysis

Categorical variables were summarized as frequencies and proportions. The variables of interest (WTI and WTP) were binary variables and therefore a logistic regression was performed. The logistic regression was run

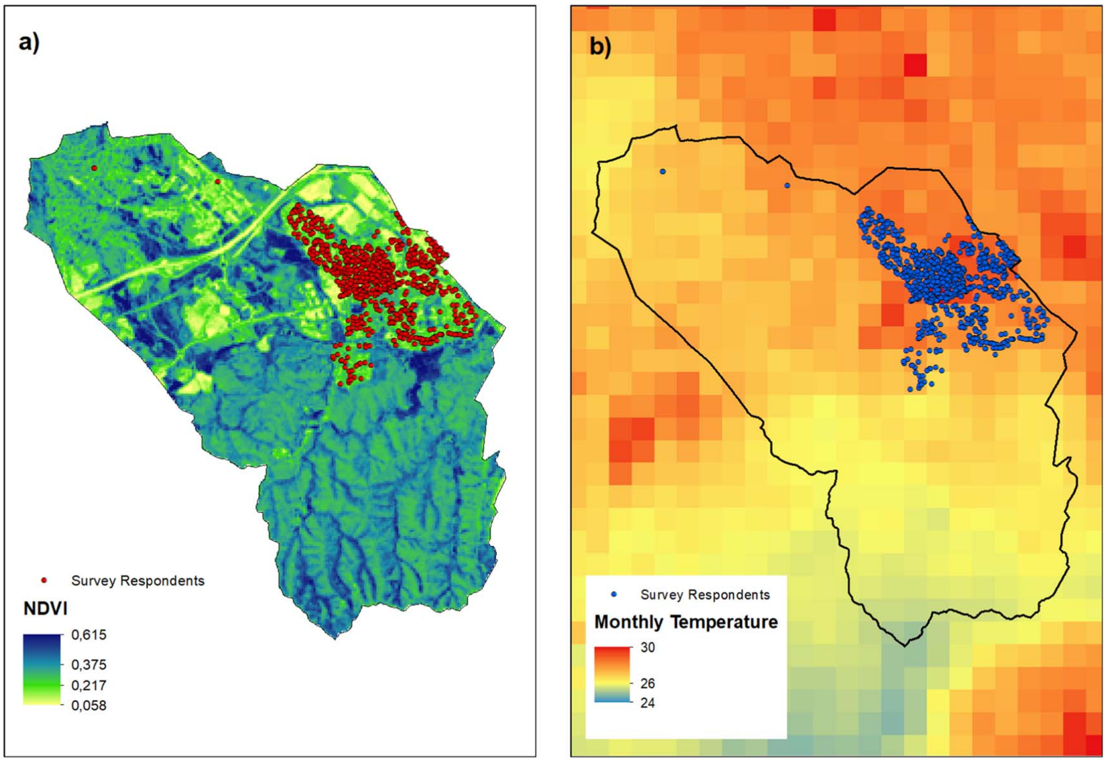

Figure 2. Cerdanyola survey respondents in relation to (a) NDVI values, (b) average monthly temperature (25 June—25 July 2015).

independently for WTP and the six WTI rooftop scenarios: open-air farming, rooftop greenhouses, green roofs, PV panels, rainwater harvesting, and a mixture of the scenarios.

The factors considered for demographics and living characteristics which influence ones' WTP and WTI included: gender, age, salary, urban morphology, inhabitants per household, size of the home (m^2), access to outdoor space (i.e., balcony, garden, terrace, etc) and if they have access to and use their rooftop.

With respect to survey respondents perceptions and beliefs, the factors considered consisted of respondents' perception of various strategies occurring in European cities (energy production through solar panels, food production through urban agriculture, and rainwater harvesting), if they believe these strategies to be viable solutions, and their perceived greatest challenge facing the EU in the next 20 years (i.e., pandemics, lack of housing, the economy and jobs, pandemics, climate change, national security, immigration, lack of basic resources, and mobility). To understand the impact of surrounding land use and WTP and WTI, the logistic regression was completed in two stages: 1. with the various land use groups; and 2. the NDVI and temperature values.

The results of the logistic model are presented in terms of odds ratio (OR) and their standard error (SE). The significance level was set at 0.05 for all tests. The results were analysed using the software R-Gui v4.0.4, The R Foundation, Vienna, Austria.

3.4. Land use and temperature maps

This study aims to identify environmental factors (surrounding land use, vegetative cover, and temperature vulnerabilities) which may influence a respondents' WTP or WTI. As such, four maps were created for this analysis.

Two temperature maps were produced with data obtained from the Weather Research and Forecasting using simulations with 333 m resolution centered within the Metropolitan Area of Barcelona, which included 8 LT to 20 LT (Segura *et al* 2022). Temperature was for 2 m of every hour between 25 June 2015 to 25 July 2015. One temperature map consisted of the average 24 h temperature during this time frame, while the second map focused on the average daytime temperature between 4 July 2015 to 7 July 2015, which was a particularly hot and dry heatwave. A normalized difference vegetative index (NDVI) map was obtained from Landsat 8 OLI/TIRS images and provided by Gilabert *et al* (2021). The NDVI and monthly temperature data can be seen in figure 2.

The land use and land cover map (figure 1) was provided by the Integrated System Analysis of Urban Vegetation and Agriculture (URBAG) project (Mendoza Beltran *et al* 2022) which combined a DUN-SIGPAC

Table 1. Groups and categorization of various land use and land cover types obtained from URBAG.

Land use and land cover category	Land use and land cover types
Green Space	Intersecting Urban park, Urban park, Adjacent to river
Naturalized	River corridor, Adjacent to river, Dry cultivation, Forest, Forest area transition, Intersecting conservation areas, Intersecting agricultural areas
Roads and Infrastructure	Intersecting infrastructure, Roads

map from the Department of Agriculture, Livestock, Fisheries and Food from the Generalitat de Catalunya (DARPA 2015) and an MCSC map (CREAF 2015).

The survey respondents were mapped in ArcGIS and given a 300 m buffer zone to determine surrounding land use, temperature, and vegetative cover as recommended by the WHO Regional Office for Europe (2017) which states that residents should have at least 0.5–1 ha of green space within 300 m of their home. The area for each land use was grouped into three categories, specified in table 1. These categories were then subdivided into two groups: 1. survey respondents with 0.5 ha or more of the land use group within 300 m; and 2. survey respondents with 1 ha or more of the specified land use group.

4. Results

4.1. Survey socio-demographics and surrounding characteristics

The survey results were compared to official statistics to ensure a representative survey sample, and a summary of the demographics of the survey respondents can be seen in table 2. The male to female ratio of Cerdanyola is 49–50 (IDESCAT 2022), and therefore our results are overrepresented by women by 9%. The household size is comparable to IDESCAT (2022), except for two or more people without a nucleus being over represented in our study by 15%. When comparing the national average of 15–64-year-olds to the survey sample group of 18–64-year-olds, this study underrepresents this age group by 13%, but overrepresents 65–84-year-olds by 13.4% (IDESCAT 2022).

Regarding perception of rooftop use in the EU, majority of respondents (56%) thought energy production was used throughout European cities, while the majority did not perceive the occurrence of rooftop agriculture or rainwater harvesting (42% and 49% respectively). Over half of respondents believed rooftop energy production, open-air farming, and rainwater harvesting (87%, 55%, and 68% respectively) were viable solutions. Unfortunately, 64% believed rooftop use for producing local resources in cities was very unlikely to make cities more resilient. Overall, 21.6% of respondents were not WTP, while 23.1% were WTP € 1–30, 18.7% WTP € 31–60, 7.8% WTP € 61–90, and 1% WTP over € 91. Of those 53.9% of respondents WTP for at least one of the rooftop mitigation measures, 76.7% were WTI PV panels, 42.6% were WTI rainwater harvesting, and an average of 72.3% said they were not WTI open-air farming, rooftop greenhouses, nor green roofs. Additional data is provided in the supplementary information.

4.2. Unpacking complexities of WTP

To characterize ones WTP, a logistic regression was performed as outlined in the methodology and a summary of significant values is provided in table 3. Interestingly, the perception of mobility being the greatest challenge facing the EU in the next 20 years led respondents to be more WTP than those who perceived the economy and jobs to be a more pressing issue. While those who had access to at least 0.5 ha of city green space within 300 m of their home were also more WTP than those who did not have the minimum amount of green space suggested by WHO Regional Office for Europe (2017).

With regards to the one's socio demographic characteristics (objective 1), no significant results were found for gender. A quick glance shows younger generations (18–64 years of age) were more WTP than those between 65–85-year-olds, while mid to high income earners (1,660–3,500 €/month) where more WTP than low-income earners (0–1,659 €/month). However, a closer inspection of figure 3 demonstrates that those 65 and older (82.6% of survey retirees) are grouped in the lower-income groups.

According to figure 4, ones WTP may have been influenced by PV panels. The belief in PV panels to produce energy production for cities increased survey respondents WTP, and over 90% of respondents in each age group believe PV panels to be a viable solution (95.5% for 18–39-year-olds, and steadily decreasing to 91.7% for those with 85+ years), with over 90% of each salary group following this same trend with the highest monthly income earners (earning € 5,500+) having the lowest percent at 90.5%.

Table 2. A detailed breakdown of the survey sample demographics, household specifications, and accessibility to outdoor space shows the number of survey respondents who identified with each category and the percentage in relation to the sample size.

Variable	Category	Count	%
Gender	Male	424	38.5%
	Female	676	61.5%
Age	18–39	90	8.2%
	40–64	607	55.2%
	65–84	384	34.9%
	85+	19	1.7%
Work Status	Working with a contract	451	41.0%
	Working without a contract	20	1.8%
	Currently on ERTO due to the pandemic	9	0.8%
	Unemployed	117	10.6%
	Student	25	2.3%
	Retired	461	41.9%
Salary (€/month)	0–1,659	316	28.7%
	1,660–3,500	365	33.2%
	3,501–5,500	71	6.5%
	5,500+	23	2.1%
Household Size	Partner with children	435	39.5%
	Two People	207	18.8%
	Partner Without children	185	16.8%
	One Person	127	11.5%
	Father or mother with children	104	9.5%
	Other nuclear family members	17	1.5%
	Two or more nuclear family members	24	2.2%
Urban Morphology	Originary fabrics	400	36.4%
	Housing estates	350	31.8%
	Single-family housing	350	31.8%
House Size (m^2)	<40	2	0.2%
	40–59	33	3.0%
	60–79	236	21.5%
	80–99	340	30.9%
	100–120	219	19.9%
	120+	199	18.1%
Available Outdoor Space	Rooftop	66	6.0%
	Balcony/Terrace	712	64.7%
	Patio	134	12.2%
	Garden	182	16.5%
Rooftop Access and Use	It's not accessible	585	53.2%
	Accessible but not used	178	16.2%
	Accessible and used	331	30.1%

4.3. Unravelling WTP with WTI

To further understand WTP, survey respondents were asked if they would be willing to implement (WTI) six different rooftop strategies which include: open-air farming, rooftop greenhouses, green roofs, PV panels, rainwater harvesting, and a mixed combination of strategies. Following the methods outlined in the methodology, age was found to be a significant variable (figure 5). However, it is important to remember the previously discussed impacts regarding the distribution of salary and age (figure 3). Each rooftop strategy will be discussed independently in the following subsections. However, no significant results involving gender, or the temperature maps were found in any rooftop strategy analysis.

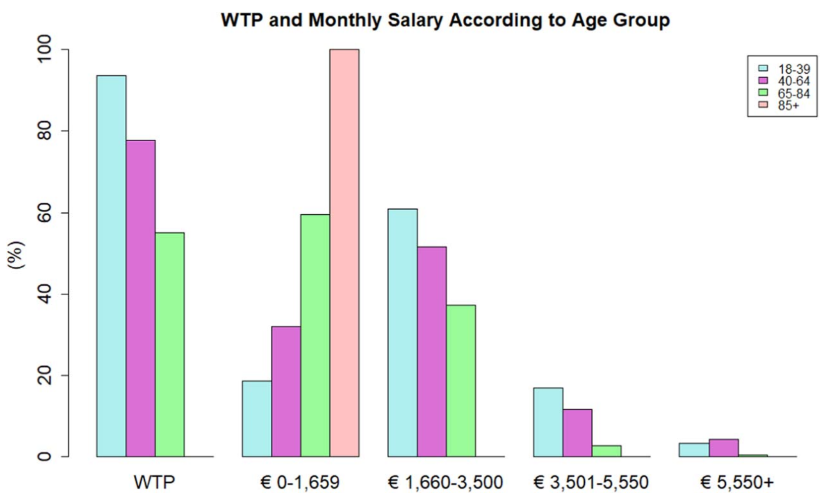

Figure 3. Stratified analysis of WTP (willingness to pay) and monthly salary income according to age groups, demonstrating how low pensions impact WTP.

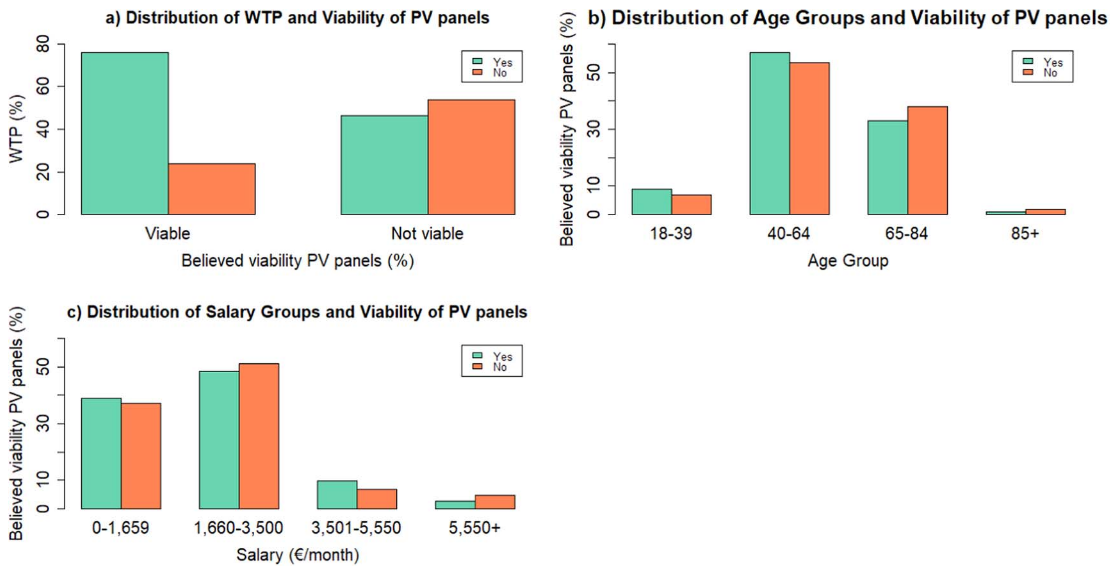

Figure 4. A breakdown of the believed viability of PV panels to produce energy in cities according to WTP, age groups, and salary.

Table 3. Odds ratio (OR), standard error (SE), and p-value of logistic regressions regarding willing to pay (WTP) for all three objectives.

Objective	Category	Contrast	OR	SE	p-value
1. Socio demographic characteristics	Age	18–39 years / 65–84 years	8.00	2.00	0.0032
	Age	40–64 years / 65–84 years	2.00	1.00	0.0002
	Salary	€ 1,660–3,500 / € 0–1,659	2.05	0.10	0.0036
	Salary	€ 3,501–5,500 / € 0–1,659	5.15	0.11	0.0142
2. Perceptions	Believes PV panels are a viable solution	Yes / No	3.34	1.00	0.0001
	Biggest challenge for Europe in next 20 years	Mobility / The economy and jobs	6.80	3.80	0.0079
3. Land use and climatic vulnerabilities	0.5 ha of green space within 300 m	Has / Does not have	1.44	0.12	0.0414

4.3.1. WTI open-air farming

Concerning WTI open-air farming, 18–39-year-olds were 3.06 ± 0.8 (p-value 0.0001) and 2.29 ± 1 (p-value 0.0039) times more WTI than 65–84-year-olds and 40–64-year-olds respectively. This is likely attributed to

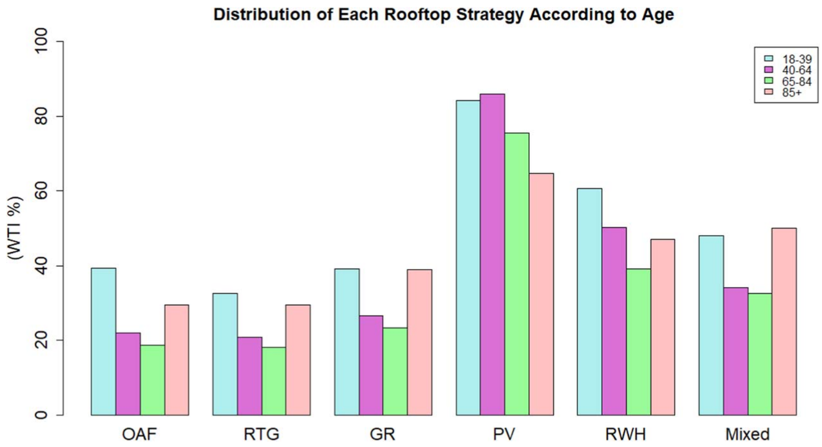

Figure 5. Percentage of willing to implement (WTI): open-air farming (OAF), rooftop greenhouses (RTG), green roofs (GR), PV panels (PV), rainwater harvesting (RWH), and a combination of mixed strategies.

18–39-year-olds being the strongest believers (74%) in the viability of UA for food production as the belief that food production through UA was a viable solution resulted in respondents being 1.71 ± 0.34 (p-value 0.0071) times more WTI open-air farming. Furthermore, the perception of UA taking place in European cities meant respondents were 1.62 ± 0.29 (p-value 0.0074) times more WTI open-air farming than those who did not. However, the previously mentioned impacts do not apply to those 85 years and older, as they were the groups least likely to believe UA was a viable solution (43%) and least likely to perceive UA was taking part in EU cities (44%) despite being the second age group most WTI open-air farming.

Having access to and using ones rooftop resulted in respondents being 2.38 ± 0.07 (p-value < 0.0001) times more WTI open-air farming compared to those who did not have access to their rooftop. Whereas ones surrounding land use and climate change vulnerabilities (heat and vegetative cover maps) did not yield significant results.

4.3.2. WTI rooftop greenhouses

Those between 18–34 years of age were 2.19 ± 0.58 (p-value 0.0158) times more WTI rooftop greenhouses than 64–84-year-olds, with the belief in the viability of UA leading respondents to be 2.73 ± 0.53 (p-value < 0.0001) times more WTI rooftop greenhouses than those who did not concur. Similar to the reasons explain in open-air farming, this does not apply to those 85+ as they were the second age group most WTI rooftop greenhouses.

Surrounding land use had the most influence on respondents WTI rooftop greenhouse than any other rooftop strategy with those having over 1 ha of roads and infrastructure within 300 m of their home being 1.53 ± 0.11 (p-value 0.008) times more WTI rooftop greenhouses than those who did not have the same land use characteristics. Having 0.5 ha of city green space within 300 m of their home being 2.12 ± 0.14 (p-value 0.0101) times more WTI rooftop greenhouses. While not having 1 ha of city green space within 300 m of their home, made respondents 1.69 ± 0.42 (p-value 0.0346) times more WTI rooftop greenhouses than those who did have 1 ha of green space.

4.3.3. WTI green roofs

This rooftop strategy was most influenced by having access to resources. For example, those who had access to and used their rooftop were 2.04 ± 0.08 (p-value <0.0001) more WTI green roofs than those who did not have access to their rooftop. And those who had a garden were 2.88 ± 0.14 (p-value 0.0489) times more willing than those who did not have a garden.

4.3.4. WTI PV panels

Easily the most WTI rooftop strategy, with 40–65-year-olds being 2.03 ± 0.35 (p-value 0.0003) times more WTI than 65–84-year-olds, and receiving the least interest from those 85-yeas and older. In relation to urban morphology, single family dwellings were 1.7 ± 0.12 (p-value 0.0219) times more WTI PV panels on their rooftops compared to those living in originary fabrics (historic center and suburban extension).

4.3.5. WTI RWH

Another rooftop strategy heavily influenced by age, with 18–39-year-olds being the most willing age group according to table 4.

Table 4. Odds ratio (OR), standard error (SE), and p-value of logistic regressions regarding Age and WTI rainwater harvesting.

Contrast	OR	SE	p-value
18–39 years / 40–64 years	2.26	0.69	0.0367
18–39 years / 65–84 years	3.90	1.30	0.0002
18–39 years / 85+ years	9.89	8.69	0.0452
40–64 years / 65–84 years	1.72	0.32	0.0154

Those who believed rainwater harvesting was a viable solution for the sustainability and resilience of cities were 2.24 ± 0.40 (p-value <0.0001) times more WTI rainwater harvesting than those who did not consider it a viable solution. In the sample analysis, 86% of those aged between 18–39 and 82% of those between 40–64 believed rainwater harvesting was a viable solution compared to their counterparts whose belief steadily declined with age.

The NDVI maps did result in a significant logistic regression for WTI rainwater harvesting with those having lower levels of vegetative cover (and higher levels of urbanization) being 55.11 (p-value 0,0012) times more WTI rainwater harvesting.

4.3.6. WTI a combination of strategies

Considering the high interest in PV panels for energy generation, it is unsurprising that those who believed PV panels were a viable solution were also 4.46 ± 2.15 (p-value 0.0019) times more WTI a combination of rooftop strategies.

5. Discussion

This paper sought to measure the various factors among residents of a small city that influence their WTP and WTI various rooftop strategies through statistical analysis of survey results and land use, NDVI, and temperature maps.

5.1. The complexity of demographics

In previous studies, females demonstrated more concern for climate change (Semenza *et al* 2008, Crona *et al* 2013) and were more WTI RA (Sanesi and Chiarello 2006, Baptiste *et al* 2015, Toboso-Chavero *et al* 2021). However, this study found no significant difference between genders, but age proved to be a valuable indicator with the younger generations being more willing. Younger generations have been found to have a high concern for climate change (Semenza *et al* 2008), a greater appreciation for the aesthetics of green roofs (Tsantopoulos *et al* 2018), and value green spaces for socializing and gathering (Sanesi and Chiarello 2006). Thus, explaining why 18–64-year-olds were more WTP and WTI.

Similar to other studies (Zhang *et al* 2019, He *et al* 2021), economic factors did have an impact on ones WTP an WTI, most notably high income earns exhibiting less interest which is likely due to the ability to insulate ones self from the climate risks. Moreover, low-income earners (0–1,659 €/month) were less WTP than those of medium to high income earners (1,660–5,500 €/month). However, 100% of those over 85 and 59.5% of those between 65–84-years-old identified as low-income earners; 82.6% of those 65 years and older were retired. In 2019, the average retirement pension in Catalunya was 1,174.65 €/month (IDESCAT 2022), leaving little room for investing in new projects. Thus indicating, that UGI is a privilege and that government subsidies (or a more general pursuit of economic equality) could support low-income residents in implementing these rooftop strategies.

Interestingly, those over 85 were the second group most willing to partake in food cultivation and rainwater harvesting. While this may be attributed to lower income groups desiring a need for higher self-sufficiency, empowerment, and resource and financial savings (Toboso-Chavero *et al* 2021); or they may simply want to partake in easily accessible activities (on their rooftop). The desire for 85+ year olds to partake in activities is especially apparent as they were the least likely to perceive UA partaking in EU cities, which increased respondents WTI open-air farming, but they were the second age group most WTI open-air farming. Suggesting future research could be assessing perception and willingness to use already installed rooftop strategies as opposed to investing.

It is noteworthy that less than half of survey respondents had access to and used their rooftop. Those who did have access, were more WTI open-air farming and WTI green roofs compared to those who did not have access.

Indicating that access to a resource increases ones' interest in utilizing it, and therefore policy-makers and building designers should implement policies that make rooftops accessible to all residents.

5.2. Perceptions and beliefs, a case for educational campaigns

It was evident that residents who believed the mitigation strategy was a viable solution resulted in a higher WTI, and is in line with Semenza *et al* (2008), who noted that voluntary adoption of mitigation strategies can only be achieved if the stakeholders and general public perceive the benefits. Whereas Liu *et al* 2023, found heat adaptation awareness and knowledge also increased ones WTP. Moreover, the perception that urban agriculture was taking place in European cities increased ones' WTI open-air farming and may be attributed to the influence of social norms (Schade and Schlag 2003) and the need for social integration.

A limitation of this study is that the environmental education and awareness of climate vulnerabilities of a respondent was not considered. Our results indicate that this could be a factor to consider in policy making, and therefore further research regarding effective educational and awareness campaigns is recommended to improve public acceptance of policies. Increased awareness of UGI and RA benefits (as described in the literature review of this paper) enhances residents understanding of how challenges facing the EU within the next 20 years could be solved through these rooftop installations. A hindrance to the installation of green roofs is the lack of knowledge regarding the benefits and incentives (Tsantopoulos *et al* 2018). For example, a 'save the rain' campaign in Syracuse, NY involving public education and awareness of stormwater problems improved residents' awareness of the stormwater issues (Barnhill and Smardon 2012) which may have resulted in their WTI UGI in a following study that considered UGI implementation (Baptiste *et al* 2015).

As this study focused solely on WTP and WTI to characterise social perception and does not consider preferences for the various rooftop scenarios, there is scientific literature that helps explain reasons for different rooftop preferences. For example, previous studies found resident concerns over the distribution of responsibility and lack of maintenance of such structures (Sanesi and Chiarello 2006), and were perceived to require significant time and financial investment (Toboso-Chavero *et al* 2019). Additionally, Sanyé-Mengual *et al* (2016) and Specht and Sanyé-Mengual (2017) found public perception of soilless growing systems were considered 'artificial, unnatural, and not real', that agricultural production should take place on plots of land, and food produced in hydroponic systems had a lower nutritional value. Whereas in Greece, residents opposing the installation of green roofs believed the installations only offered social benefits (Tsantopoulos *et al* 2018). Furthermore, RA is viewed as a competitor against other rooftop initiatives such as PV panels and rainwater harvesting, while other residents perceived economic risks in RA, believing a 200 m2 rooftop would be too small to make a living (Specht and Sanyé-Mengual 2017). Thus explaining the lack of respondent interest in the mixed rooftop scenario.

Information can influence attitudes (Broussard *et al* 2001) and plays a critical role in overcoming the aforementioned barriers regarding rooftop strategies. A strong public awareness campaign would need to be strategic and cohesive in its messaging regarding climate change and related issues because of its strong influence on public perception (Budescu *et al* 2009). This is emphasized by Crona *et al* (2013) that found residents in countries with non-homogenized scientific or government news reporting, developed personalized and idiosyncratic views. While citizens want to be included in decisioning making processes, different demographics also have preferences for receiving information, which can play a critical role in educational campaigns with older residents preferring public meetings, large family units relying on the press, and younger generations preferring multimedia (Sanesi and Chiarello 2006).

5.3. Capitalizing on urban planning

Semenza *et al* (2008) found residents were more concerned about climate change when city infrastructure was more conducive to a low-carbon lifestyle; providing adequate access to public transport and locally grown food, and had dense mixed-use neighborhoods. Thus, this study aimed to see if Cerdanyola residents were aware of these benefits (subconsciously or consciously) and if living within close proximity to urban parks and green spaces influenced ones' WTP or WTI. Alternatively, this study also considered the impacts of other land use types to quantify if residents felt a need for additional ecosystem services, however it did not consider respondents preference to different land use types.

Those with at least 1 ha of roads and intersecting infrastructure were more WTI rooftop greenhouses, indicating a need for increased ecosystem services or associated physical and psychological benefits offered by increased access to nature. It is possible that those with access to adequate green space observed the benefits and would like to increase local green space. However, there appears to be a balance between how much green space is necessary to increase ones' WTP or WTI. Those with at least 0.5 ha of green space were more WTI rooftop greenhouses than those with over 1 ha of green space. This is similar to salary: those earning between 1,660–5,550 €/month were more WTP whereas those earning over 5,500 €/month. It is interesting that land use only influenced WTI rooftop greenhouses, and further investigation as to respondents' perception of RA may indicate their preference for rooftop greenhouses over open-air farming in urban areas. This may be related to residents perceiving higher rates of contamination through air, soil and water in urban agricultural products (Mendoza Beltran *et al* 2022), and therefore they may perceive rooftop greenhouses to be safer as it creates a closed system that is isolated from urban pollution.

The NDVI map provides an alternative to land use, as land use describes municipality zoning and does not reflect the amount of green vegetation. Thus, higher NDVI values resulted in a stronger WTI rainwater harvesting, unlike the land use and land cover analysis, indicating the recognition that rainwater is a valuable and passive resource for watering surrounding vegetation which increases the permeability of urban surfaces. However, extreme weather did not yield significant results and is likely explained by Semenza *et al* (2008) who found extreme weather events did not encourage public behavioral changes to mitigate climate change. Reasons as to why those with different surroundings may be more WTP or WTI vary as scientific literature regarding this topic is limited. As such, we refer to the physical and psychological benefits of UGI and how urban planning has been found to influence resident attitudes.

In addition to the ecosystem services, we have described so far, academic literature highlights the physical and psychological health benefits associated with being surrounded by naturalized environments in urban centres (Mitchell and Popham 2007). These include health benefits from living within proximity to green space (Maas *et al* 2009), stress reduction, reduced morbidity (Mitchell and Popham 2007, Maas *et al* 2009), and attention restoration (Li and Sullivan 2016). This was observed in Bari, where 25–44-year-olds with higher academic qualifications and working class with limited green space being more likely to visit green spaces for fresh air and relaxation than those living in the city outskirts (Sanesi and Chiarello 2006). Our results confirm these findings, given that 18–64-year-olds (and largely working-class) were more WTP and WTI, suggesting a desire to break from city and working life and seek the physical and psychological benefits found through nature.

Interestingly, horticulture was found to have significantly more benefits for physical and mental health compared to green spaces (Dennis and James 2017). Explaining why those with access to urban green space, and likely seeking mental and physical refuge in these centers, were WTI rooftop greenhouses and enhance their connection with nature by partaking in food cultivation. This is very similar to our other results demonstrating that those who have access to and use their rooftops or garden are more WTP and WTI.

Studies indicate residents want to contribute to climate change solutions and suggest leveraging legislative and regulatory measures that encourage both structural and behavioural changes (Reiner *et al* 2006). Current EU legislation focuses on new building and construction projects, and old buildings are not given significant incentives for renovations that enhance building performance (Tsantopoulos *et al* 2018). While these legislations contribute to adapting towards an extreme climate, it would be wise to focus on strategies that also mitigate climate change. There is enormous potential in legislation and regulation in implementing mitigation strategies (in new and old buildings) such as RA, PV panels, and rainwater harvesting to increase carbon dioxide sinks, provide opportunities for low carbon activities, and decrease supply chain distances while mitigating urban heat island effect and effectively managing city resources. Policy-makers interested in implementing these rooftop strategies must re-evaluate regulations and legislation, ensuring they incentivize all residents and building owners. Considering 75% of EU buildings are energy inefficient, European building stock must be renovated (Directorate-General for Energy 2019) and is identified as a key action within the European Green Deal (Directorate-General for Energy 2020), there is a wealth of opportunity to incentivize the implementation of rooftop mitigation strategies.

6. Conclusion

The findings of this paper offer particular value to policy makers and scientific community by quantifying the influence of urban landscapes on one's willingness to take specific climate actions. Through the successful characterization of ones WTP and WTI, it was found that 18–39-year-olds were the most WTP and WTI generation followed by those between 40 and 64 years of age. Majority of respondents were most WTI PV panels, followed by rainwater harvesting, is likely attributed to the perceived direct return of investment that would be seen on energy and water bills. Our findings demonstrated that the belief in the viability of each rooftop scenario and perception of the implementation of each scenario in the EU (most notably in younger generations) resulted in and enhanced WTI, especially with regards to open-air farming and rooftop greenhouse. Moreover, it is important to highlight the complexity of social situations by acknowledging all those 85 and older, receiving low pensions, were considered low-income earners which likely affected their concern over the required financial investment. Furthermore, data regarding those 85+ suggests that this age group is less motivated by social conformity and climate adaption, but by the opportunity to partake in the social activities attributed to rooftop agriculture.

The most novel aspect of this study, was the finding that a minimum amount of greenspace within 300 m of a respondent's home, increases ones WTP and WTI. This is an important finding for policy makers who should ensure a minimum 0.5 ha of quality greenspace within 300 m of a resident's home to encourage acceptance of policies addressing rooftop uses. Furthermore, considering 53% of respondents did not have access to a rooftop or balcony which had a negative impact on ones WTI, policy makers should not only consider improving one's access to useable rooftops, but should ensure that building codes of new buildings or major renovations allow residents to have access to a rooftop or balcony in order to increase ones WTI open-air farming and green roofs.

By quantifying ones WTP and WTI the various scenarios, this case study provides valuable insight into determining the economic value of environmental benefits and guidance into future policies of climate change adaptation according to a persons socio-demographic characteristics, belief of the effectiveness of each rooftop scenario and perceived challenges facing in the EU in the next 20 years, and more subtle influences of ones surroundings and vulnerabilities to climate change such as heat stress. Furthermore, this study highlights the need for researchers to consider the underrepresentation of small cities (which represent 42% of the global population) in scientific literature in order to address climate change more holistically and on a global level.

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Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.5565/ddd.uab.cat/267206.

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