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# Public green Shadow price In Verona: a willingness to pay

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MANAGEMENT OF BUILT ENVIRONMENT

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# Abstract

The aim of this work is to explore and delve into one of the key solutions for adapting our cities to the challenges they will face in the near future. The urban tree heritage represents a good without a reference market, making it essential to identify the most effective methodology to estimate its economic value. Too often, tree-lined avenues, parks, gardens, and public green spaces are considered mere decorative elements or, even worse, expenses for the community.

Attention tends to focus on the inconveniences these silent allies may cause: such as pollen, fallen leaves, or broken branches; while overlooking the crucial role that trees play in urban ecosystems.

The inspiration for this study comes from a simple question: if trees did not exist, what kind of device would we need to invent to replicate their functions? And how much would it cost to power them?

Fortunately for us, trees do exist. They perform multiple essential functions for us and the ecosystem—for free. What needs to change is our perception of them: from mere decorative elements to vital green infrastructure that must be managed, maintained, and renewed over time to ensure their full value and benefit for future generations.

**Key-words:** Shadow price, Contingent Valcity health, public green, trees.

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# 1. Introduction

## 1.1 Cities, future scenarios.

Future scenarios for those living in cities, faced with the continuous increase in temperatures and pollution, present several critical challenges. The combination of climate change and urbanization could exacerbate a series of problems related to health, quality of life and the sustainability of cities themselves. Let's briefly analyze the main risks and future scenarios:

First, heat waves are becoming more intense and frequent, causing serious health risks. Cities are showing vulnerability to heat waves due to the “urban heat island” effect, where urban areas retain heat due to high paved or built surfaces and a lack of public green spaces. High temperatures contribute to increasing the risk of heat-related diseases and worsening chronic conditions such as cardiovascular and respiratory diseases, especially in the most vulnerable population groups such as the elderly and children<sup>1</sup>.

The impact of heat stress not only affects people but also infrastructures, subjecting them to overload resulting in losses of efficiency, blackouts or interruptions of essential services<sup>2</sup>.

The continuous use of fossil fuels does not contribute to improving air quality, on the contrary it worsens it, increasing the incidence of respiratory problems and diseases. Fine particles (PM2.5) and nitrogen oxides, present in all cities, aggravate respiratory diseases such as asthma, chronic bronchitis and increase the risks of lung cancer and other serious diseases<sup>3</sup>.

The challenges related to the urbanized environment do not end here. The same more intense and frequent meteorological phenomena that damage crops in the urban context generate floods that cause discomfort and damage to the population. And if some areas are submerged, other areas suffer prolonged droughts, which reduce the availability of drinking water and increase conflicts for access to water resources.

If current trends are not reversed or stopped, there will be a reduction in urban livability: the combination of high temperatures, air pollution and scarcity of resources could make life in cities less pleasant. Reduced access to green spaces and healthy environments could worsen the quality of life, leading to greater social alienation and reduced social cohesion.

It is therefore necessary to undertake every possible solution to mitigate the impact of these phenomena. Green spaces and green infrastructure must be improved or

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<sup>1</sup> Khomenko et al., «Premature Mortality Due to Air Pollution in European Cities».

<sup>2</sup> European Environment Agency., *Urban Adaptation to Climate Change in Europe*.

<sup>3</sup> European Environment Agency., *Europe's Urban Air Quality*.

expanded to reduce local temperatures, improve air quality and provide climate refuges for residents.

The design focus of cities must foresee and study new systems to make our cities more resilient, energy efficient, equipped with sustainable transport, to reduce environmental impact.

The future of cities in a context of rising temperatures and pollution presents significant challenges for human health, quality of life and the sustainability of urban infrastructure. However, with the right planning, management and technological innovation policies, cities can prepare to become more resilient and liveable even in a difficult climate context.

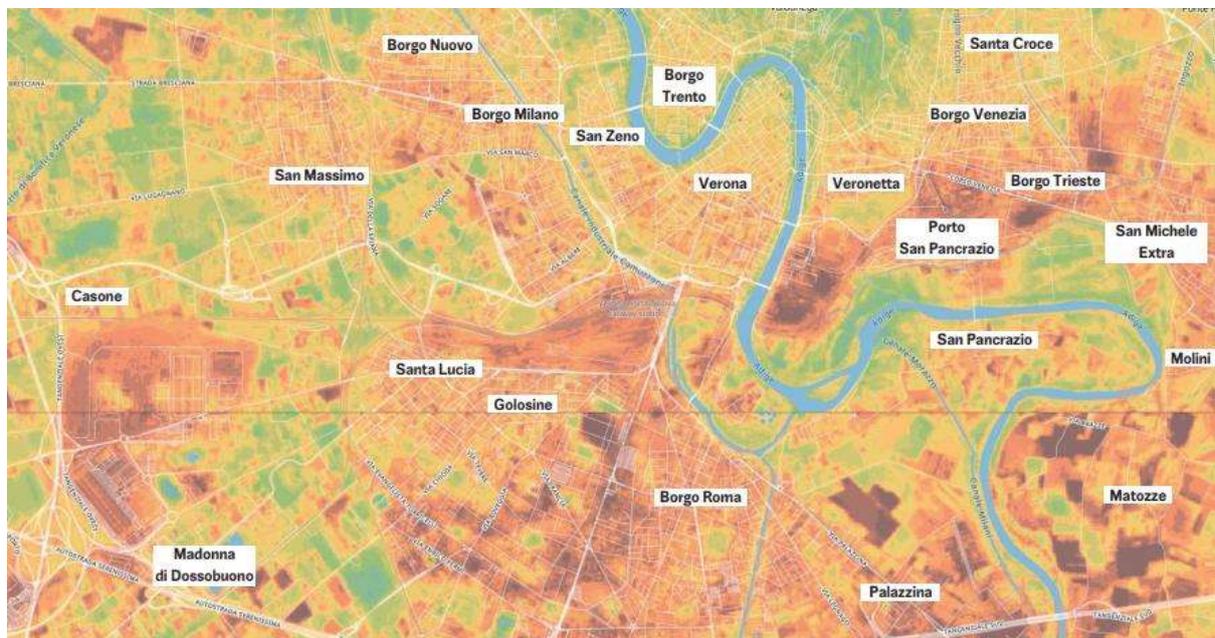


Figure 1: heatmap survey of the city of Verona summer 2024, Meteoblu.com

## 1.2 Climate Change Mitigation: Possible Solutions

Climate change represents one of the most urgent and complex challenges for humanity in the coming years. To mitigate its impact, it is necessary to adopt an integrated set of solutions, which can vary in terms of effectiveness, implementation times and costs. Some strategies allow immediate and low-cost results, while others require significant investments and a longer time horizon.

All solutions converge on a single objective: reducing greenhouse gas emissions and increasing the capacity to remove CO<sub>2</sub> from the atmosphere. However, there is no single decisive action: it is essential to combine different strategies to achieve an effective rebalancing of the atmospheric composition and limit the increase in global temperatures.

The main solutions for climate change mitigation can be divided into five macro-areas:

1. Decarbonization of the energy system
  - Transition to renewable sources (solar, wind, hydroelectric, geothermal).
  - Increased energy efficiency in buildings, industries and infrastructures.
  - Development of smart grids and energy storage systems.
  - Carbon Capture and Storage (CCS) technologies.
2. Sustainable mobility
  - Electrification of transport and development of charging infrastructure.
  - Strengthening public transport and shared mobility.
  - Reduction of the use of private vehicles through sustainable urban planning.
3. Sustainable management of resources and the economy
  - Implementation of Circular Economy models to reduce waste and refuse.
  - Adoption of Zero Waste policies for recycling and reusing materials.
  - Optimization of water management and reduction of water waste.
4. Nature-based solutions
  - Urban greening and increase of green areas in cities.
  - Protection and reforestation of natural ecosystems for carbon sequestration.
  - Sustainable agriculture and reduction of the environmental impact of the food chain.
5. Digitalization and Innovation for Smart Cities
  - Use of advanced technologies for resource optimization (Internet of Things, AI, big data).
  - Smart urban planning to reduce the environmental impact of cities.
  - Development of buildings and infrastructure with high energy standards.

All these strategies, when implemented jointly and systematically, can ensure an effective transition to a more sustainable future by reducing greenhouse gas emissions and improving the quality of life in cities.

With this thesis, I have chosen to focus on the primary nature-based solution: urban greening.

Urban greening is one of the most balanced solutions in terms of costs and benefits, with positive effects distributed across the short and medium term, and an increasing impact in the long term as trees mature. Compared to other climate mitigation solutions, urban greening is generally more affordable and accessible for many cities. Moreover, it provides immediate collateral benefits for the quality of life.

Benefits in the short-medium term (5-10 years):

- Improvement of air quality: trees start to capture fine dust and air pollutants already in the first years.
- Regulation of urban temperature: the creation of shade and evapotranspiration reduce the "heat island" effect, with visible benefits within a few years.
- Improvement of psychophysical well-being: green spaces promote sociality and mental well-being right from the start.

Long-term benefits (over 10-20 years):

- Carbon sequestration: when trees reach maturity, their carbon storage capacity peaks.
- Urban resilience: trees and green infrastructure strengthen the city's ability to absorb extreme weather events.

Urban greening is a scalable solution, with visible effects already in the short term and an increasing impact over time, which is why it is considered one of the most cost-effective strategies.

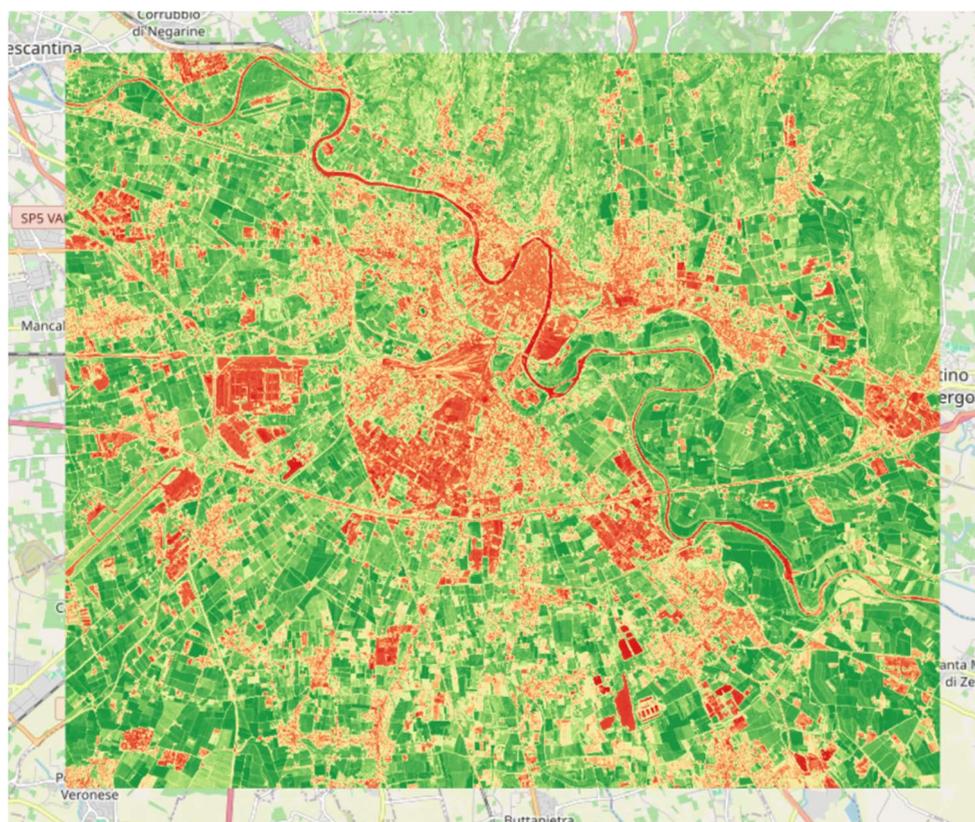


Figure 2 Land cover distribution in the Verona area, elaborated within the èVRgreen project of the University of Padua (UNIPD). The image shows the distinction between urban areas (in red), transition areas (in yellow) and vegetation cover (in green), with a spatial resolution of 10x10 meters.

## 1.3 Existing methodologies for estimating the value of trees.

It is therefore necessary to analyze the main existing methodologies for estimating the economic value of trees. By doing so, we can establish a baseline economic value to compare against the benefits provided by parks, gardens, tree-lined avenues, in other words, green infrastructure and urban trees. This valuation is crucial for attracting greater investments by demonstrating the profitability and advantages of these initiatives.

The primary methodologies include:

- Direct Market-Based Methods
- Indirect Market-Based Methods
- Non-Market Valuation Methods
- Ecosystem Service Valuation Method

### 1.3.1 Direct Market-Based Methods

These methodologies estimate the value of trees based on observable commercial transactions and market data. They primarily focus on the material value rather than the intrinsic worth of the living organism.

#### 1. Replacement Cost Method

This approach determines the cost of replacing a tree with another of the same size and species, including planting and maintenance expenses. It is generally applied to small-sized trees commonly used for urban decoration. The primary use cases include tree removal due to urban development, storms, or vandalism. However, a major limitation of this method is that it does not account for non-market benefits such as carbon sequestration or biodiversity.

#### 2. Hedonic Pricing Method

This method analyzes real estate data to estimate how trees influence property values. It is widely applied in urban areas, where trees enhance the aesthetic appeal and overall livability of neighborhoods. A key limitation is that it captures only indirect economic value, overlooking broader ecological and social benefits.

The Hedonic Pricing Model is generally represented as:

$$P = f(S, N, E)$$

Where:

$P$  = Property price

$S$  = Structural characteristics of the property (e.g., size, number of rooms)

$N$  = Neighborhood characteristics (e.g., crime rate, schools, infrastructure)

$E$  = Environmental attributes (e.g., presence of trees, parks, air quality)

A more detailed regression equation commonly used in hedonic pricing is:

$$P_i = \beta_0 + \beta_1 S_i + \beta_2 N_i + \beta_3 E_i + \varepsilon_i$$

Where:

$P_i$  = Price of property  $i$

$S_i, N_i, E_i$  = The respective characteristics of property  $i$

$\beta_0, \beta_1, \beta_2, \beta_3$  = Coefficients estimated from regression analysis

$\varepsilon_i$  = Error term

This method helps isolate the contribution of trees to property values by analyzing differences in house prices.

### 3. Timber Valuation

This methodology assesses the market price of timber, primarily for construction or furniture production. It is mainly used in forested areas where trees are harvested for wood products. However, this method does not consider ecological functions, conservation value, or non-commercial benefits of trees.

The Timber Valuation Formula is:

$$V = \sum \left( \frac{P_t \times V_t}{(1+r)^t} \right)$$

Where:

$V$  = Present value of the timber

$P_t$  = Price per unit of volume of timber at time  $t$

$V_t$  = Volume of timber available at time  $t$

$r$  = Discount rate

$t$  = time period

This formula is commonly used in forestry economics to determine the economic value of standing timber by considering future harvesting revenues discounted to present value.

## 1.3.2 Indirect market based methods

These methodologies assess the value of trees by estimating the costs they help to avoid. The logic behind them is to calculate and convert all ecological benefits into economic ones by estimating the costs that would be incurred to develop artificial systems capable of performing the same functions as trees.

### 1. Avoided Cost Method

This technique measures how much money is saved thanks to trees reducing:

- Energy consumption: A tall tree casts a shadow on buildings, cooling them naturally and reducing air conditioning costs.
- Stormwater management: Tree roots absorb large amounts of water due to their extensive surface area, reducing the need for artificial drainage systems.
- Air pollution control: Trees absorb carbon dioxide and other pollutants, improving air quality and reducing healthcare and environmental remediation costs.

The formula for Avoided Costs:

$$V_{\text{avoided cost}} = C_{\text{alternative system}} - C_{\text{tree management}}$$

Where:

$V_{\text{avoided cost}}$  = Economic value of the avoided cost

$C_{\text{alternative system}}$  = Cost of an artificial system providing the same ecosystem service

$C_{\text{tree management}}$  = Cost of planting and maintaining tree

### 2. Carbon Sequestration Valuation

This method assigns value to the amount of carbon dioxide (CO<sub>2</sub>) absorbed by trees, based on either:

- The social cost of carbon (SCC): Estimated damages caused by CO<sub>2</sub> emissions, such as climate change impacts.
- Carbon credit market prices: The price of carbon offsets in voluntary or regulated markets.

The formula for Carbon Sequestration Value

$$V_{\text{carbon}} = C_{\text{sequestered}} \times P_{\text{carbon}}$$

Where:

$V_{\text{carbon}}$  = Economic value of carbon sequestration

$C_{\text{sequestered}}$  = Amount of CO<sub>2</sub> absorbed by the tree (tons)

$P_{\text{carbon}}$  = Market price of CO<sub>2</sub> per ton (\$/ton)

### 1.3.3 Non Market Valuation methods

These methodologies have been developed more recently because non-market impacts were traditionally ignored in economic assessments. Non-market valuation assumes that even if a good is not bought or sold in a conventional market, it can still be assigned an economic value as if it were traded in a competitive market.

The price obtained in these methods is called the shadow price. There are two main ways to estimate the shadow price of a non-market good:

- **Revealed Preferences:** The value is indirectly reflected in the price of related market goods.
- **Stated Preferences:** The value is derived from surveys that ask individuals their hypothetical willingness to pay for a given good.

#### 1. Revealed Preferences

Revealed preference methods use market behavior to infer the value of non-market goods. **Hedonic pricing** can be included in both direct market-based and non-market-based methodologies because revealed preferences are included as a variable among the variables. In fact, they estimate the value of a given attribute in the case in which it is incorporated into the value of a market good.

$$P = f(\text{size, location, tree cover, neighborhood, other factors})$$

A purely non-market valuation that uses revealed preferences is the **Travel cost** methodology. Travel cost is used primarily for recreational projects and assumes that the cost of traveling to access an asset is a good approximation of its underlying value. Travel costs estimate value based on how much people spend traveling to visit green spaces, national parks, or other natural attractions.

The Travel Cost Formula is:

$$V = f(\text{Travel Cost, Visitor Count, Trip Frequency})$$

## 2. Stated Preferences

Among the non-market valuation methodologies we will only consider **Contingent Valuation**, a statistically representative sample is administered a question aiming at uncovering its willingness to pay Wtp for a non market good characterized by different levels of market characteristics.

Contingent valuation analyzes are based on the following stages:

- Identification of a sample to be interviewed
- Individuals are then interviewed about their WTP for a given good
- Results are statistically analyzed and this yields an estimate of the shadow price of the non-market good
- The estimate of the shadow price for the whole population is then obtained by extrapolation on the results of the interviewed sample

The formula for the Contingent Valuation is:

$$V = \frac{\sum(\text{Willingness to Pay Responses})}{n}$$

### 1.3.4 Ecosystem Service Valuation Method

These methodologies assess the full range of environmental benefits provided by trees, including improved air quality, carbon sequestration, energy savings, water regulation, and support for biodiversity. Unlike traditional market-based methods, these approaches aim to quantify the economic value of ecosystem services to better support decision-making in urban planning, conservation projects, and policy making.

#### 1. Cost-Benefit Analysis

Cost-Benefit Analysis is a fundamental economic method used to compare the costs associated with tree planting and maintenance against the monetary benefits trees provide over time. These benefits can include energy savings, health improvements, and flood prevention. Cost-Benefit Analysis is widely used by governments, municipalities, and urban planners to justify and motivate investment in green infrastructure.

The formula for the Cost benefit Analysis is :

$$\text{NetBenefit} = \sum \frac{B_t - C_t}{(1 + r)^t}$$

Where:

$B_t$  = Benefits generated by trees in year

$C_t$  = Costs associated with tree planting and maintenance in year  $t$

$r$  = Discount rate

$t$  = Time period over which costs and benefits are evaluated

## 2. Tree Appraisal Methods

Tree valuation methods are used to assign a monetary value to individual trees based on multiple factors, including species, size, health, and location. These methods are essential for legal cases involving trees of monumental or special significance, urban planning, and insurance claims. The most widely used method is the Council of Tree & Landscape Appraisers Guide for Plant Appraisal.

The Three appraisal method formula is:

$$V = (\text{Base Value} \times \text{Condition Rating} \times \text{Location Rating})$$

Where:

*Base Value* = a standardized value per unit of tree size

*Condition Rating* = a percentage value based on the tree health

*Location Rating* = adjusted value based on visibility, ecological importance, and impact on property value.

## 3. Ecosystem Service Modeling Tools

Ecosystem services modeling tools are scientific tools that quantify the environmental and economic benefits of trees, supporting data-driven decision making for urban planning and green space management. There are several tools, such as **InVEST** (Integrated Valuation of Ecosystem Services and Tradeoffs), which evaluates various ecosystem services, such as climate regulation and water protection. Another tool is **ARIES** (Artificial Intelligence for Ecosystem Services), which uses artificial intelligence models to analyze interactions between ecosystems and human activities.

However, the most relevant tool for urban tree valuation is **I-Tree**, developed by the U.S. Forest Service. This suite of tools is widely used to measure the ecological and economic benefits of urban forests.

The i-Tree project provides a set of tools that quantify the economic and environmental value of trees in cities, assessing parameters such as:

- Removal of air pollution (PM2.5, NO<sub>2</sub>, O<sub>3</sub>, CO<sub>2</sub>). • Carbon sequestration and storage (reduction of greenhouse gas emissions).
- Reduction of stormwater runoff (mitigation of flood risks).
- Energy savings due to shading effects.

The two main tools are:

- i-Tree Eco: a detailed urban forest analysis tool that requires specific tree data.
- i-Tree Canopy: a rapid tool to estimate tree cover and related benefits using satellite imagery.

i-Tree Eco is for more detailed urban forest analysis and requires extensive field data collection to produce reliable results. To properly perform an analysis with I-Tree Eco, you would need a detailed tree inventory, including species, diameter at 1.5 meters above ground, and overall tree height; Tree health to assess disease and pest risks; local climate data, including temperature, precipitation, and air quality; Carbon sequestration and air quality models to assess environmental impact.

Using this data, i-Tree Eco can calculate:

- The amount of carbon sequestered and stored by trees.
- The impact of trees on reducing urban temperatures and saving energy.
- The ability of trees to mitigate stormwater runoff, reducing the risk of urban flooding.

I-Tree Canopy does not require detailed tree inventories, but instead relies on satellite imagery and random sampling to estimate percent tree cover, unlike urban areas. This makes it an ideal tool for monitoring vegetation changes over time and identifying areas without tree cover.

## I-Tree Canopy Analysis in Verona

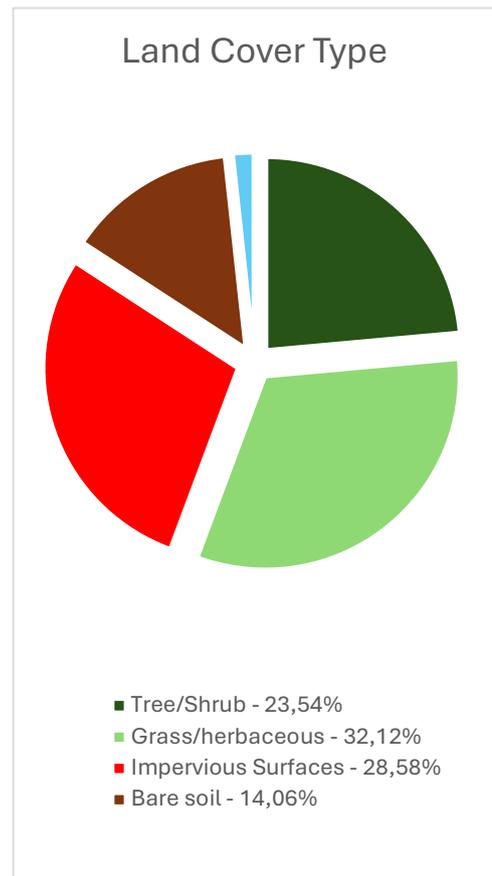
i-Tree Canopy v7.0

Rapporto sulla valutazione della copertura e sui benefici dell'albero  
Stimato utilizzando statistiche di campionamento casuali il 5/7/2020



Figure 3: I-tree canopy plot

Here is an example of an i-Tree Canopy analysis conducted in the city of Verona, using a random sampling of 10,000 points. By analyzing the results, we can quantify the economic and ecological benefits of the Verona urban forest.



## Carbon sequestration and storage

Carbon Benefit	Amount	Economic Value (€)
Annual Carbon Sequestration	14.32 kt (52.51 kt CO <sub>2</sub> )	€2,480,556 per year
Total Carbon Stored in Trees	359.66 kt (1,318.75 kt CO <sub>2</sub> )	€62,296,081

Table 1: Carbon sequestration and storage

Verona's trees sequester 14.32 kilotons of carbon per year, equivalent to 52.51 kilotons of CO<sub>2</sub>, with an economic value of €2.48 million annually.

The total amount of carbon stored in Verona's urban forest is 359.66 kilotons, preventing 1.3 million tons of CO<sub>2</sub> from being released into the atmosphere. The economic value of this stored carbon is estimated at €62.3 million.

## Air Pollution Removal

Pollutant	Amount Removed (t/year)	Economic Value (€)
Ozone (O <sub>3</sub> )	256.88	€36,644
PM2.5 (Particulate Matter <2.5 μm)	12.48	€75,751
Nitrogen Dioxide (NO <sub>2</sub> )	25.79	€704
Carbon Monoxide (CO)	4.73	€409
Sulfur Dioxide (SO <sub>2</sub> )	16.25	€123

Table 2: Air Pollution removal

Verona's trees remove 402.18 tons of air pollutants annually, providing a total economic benefit of €140,233 per year.

The most significant contribution comes from PM2.5 removal, accounting for over 50% of the total economic value (€75,751 out of €140,233). Ozone (O<sub>3</sub>) removal is the largest in quantity at 256.88 tons per year, with an economic benefit of €36,644. Although NO<sub>2</sub>, CO, and SO<sub>2</sub> contribute smaller monetary values, they are still essential for improving urban air quality.

## Stormwater Management

Table 3

Stormwater Benefit	Amount	Economic Value (€)
Avoided Runoff	22.64 kl	€49 per year
Evaporation & Interception	Over 1,800kl	Not monetized

Table 4: Stormwater Management

Trees help prevent 22.64 kiloliters of stormwater runoff annually, saving €49 per year. While evaporation and interception exceed 1,800 kiloliters, the economic value for these services is not estimated in this report.

By reducing runoff and enhancing natural water filtration, urban trees mitigate urban flooding risks, lowering stormwater infrastructure costs.

## 2. Purpose of the study

The aim of this study is to quantify the economic value of public green spaces as essential infrastructure for the well-being of cities and urban resilience, focusing on the city of Verona.

Green spaces are often considered decorative elements or costs for the community; however, they perform fundamental functions in terms of climate mitigation, air quality improvement, social and health benefits and positive effects on the local economy.

This study aims to provide an economic evaluation of public green spaces through the analysis of the Willingness to Pay (WTP) of the population of Verona City, using contingent valuation methodologies and economic analysis tools to estimate the value that citizens attribute to urban green areas.

### 2.1 Choice of methodology to adopt

The methodology adopted is based on an economic valuation approach of natural capital, in particular through non-market valuation methods, which allow to estimate the value of urban greenery considering the indirect benefits it generates.

The main method used is the analysis of willingness to pay (WTP), which, through a sample survey, provides an estimate of the economic value that the population attributes to public greenery. This approach was chosen for its ability to capture the subjective value that citizens assign to these spaces and for the possibility of extrapolating the data collected to the overall population of Verona.

Furthermore, the shadow price method is considered, which allows to quantify the environmental benefits provided by green infrastructures through comparison with avoided costs, such as the reduction of health costs, the mitigation of heat islands and the improvement of air quality.

To analyze the data collected, linear regression and multivariable logistic regression models will be used, in order to relate variables such as age, gender, income and education of the participants.

## 2.2 Public Green is a public infrastructure

Urban greenery is not simply an aesthetic element, but a real public infrastructure with essential functions for the sustainability of cities. Parks, gardens and street trees play a role comparable to that of transport networks or energy infrastructures, offering tangible and quantifiable benefits for the community.

Public administrations should therefore adopt strategies for the management and enhancement of urban greenery on a par with other strategic infrastructures, providing adequate investments for the maintenance and expansion of green areas, with a view to a sustainable and resilient city.

### Ecosystem Services

Urban green spaces provide numerous ecosystem services, which can be classified into four main categories:

- Provisioning services: provision of natural resources such as oxygen, biodiversity and shade areas.
- Regulating services: mitigation of air pollution, regulation of microclimate and management of storm water.
- Cultural services: improvement of quality of life, spaces for leisure and aesthetic and identity value.
- Support services: maintenance of biodiversity, nutrient cycling and support of urban habitats.

The economic valorization of public green spaces is essential to incentivize investments and management strategies based on concrete evidence.

### Economic Benefits

Green spaces generate both direct and indirect positive economic impacts:

- Increase in real estate value: proximity to parks and green areas can increase the value of homes by up to 20%. Studies such as Crompton(2001)<sup>4</sup> have highlighted how proximity to green spaces positively influences real estate values.
- Reduction of health costs: thanks to the beneficial effects on the physical and mental health of the population. For example, Donovan(2017)<sup>5</sup> discussed the economic benefits related to health resulting from the presence of urban trees.

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<sup>4</sup> Crompton, «The Impact of Parks on Property Values».

<sup>5</sup> Donovan, Landry, e Winter, «Urban Trees, House Price, and Redevelopment Pressure in Tampa, Florida».

- Tourism and urban attractiveness: greener cities attract more visitors and investors. Chiesura(2004)<sup>6</sup> analyzed the recreational value of urban parks and their impact on the attractiveness of cities.
- Savings on infrastructure costs: the presence of trees and green areas reduces the need for artificial systems for stormwater management and urban cooling. Gill et al.(2007)<sup>7</sup> examined how urban greenery can contribute to sustainable stormwater management.

## Social and Health Benefits

Numerous studies show that urban greenery has a positive impact on health and social well-being, contributing to:

- Reducing stress and improving mental health: Ulrich et al.(1991)<sup>8</sup> highlighted how the view of natural environments can accelerate recovery from stress.
- Encouraging physical activity and socialization: Kaczynski and Henderson(2007)<sup>9</sup> found a positive correlation between the presence of green spaces and the physical activity of the population.
- Mitigating social isolation, particularly among the elderly and vulnerable groups: Maas et al.(2009)<sup>10</sup> showed that living near green areas is associated with improved social cohesion and quality of life.
- Improving urban safety: the presence of well-maintained green spaces can reduce crime rates. According to Kuo and Sullivan(2001)<sup>11</sup>, green areas can improve the perception of safety and reduce crime in urban neighborhoods.

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<sup>6</sup> Chiesura, «The Role of Urban Parks for the Sustainable City».

<sup>7</sup> Gill et al., «Adapting Cities for Climate Change».

<sup>8</sup> «Roger S. Ulrich: View through a window May influence recovery from surgery».

<sup>9</sup> Kaczynski e Henderson, «Environmental Correlates of Physical Activity».

<sup>10</sup> Maas et al., «Morbidity Is Related to a Green Living Environment».

<sup>11</sup> Kuo e Sullivan, «Environment and Crime in the Inner City».

## Resilience and Sustainability

In the context of climate change, urban greenery represents one of the most effective strategies to improve the resilience of cities, contributing to:

- Mitigate the urban heat island effect: Bowler et al.(2010)<sup>12</sup> analyzed the effect of green areas on reducing urban temperatures.
- Absorb and retain rainwater: urban greenery reduces the risk of flooding and relieves drainage systems. Konijnendijk et al.(2005)<sup>13</sup> documented the role of urban greenery in the sustainable management of stormwater.
- Increase carbon sequestration capacity: According to Nowak et al.(2013)<sup>14</sup>, urban forests contribute significantly to CO<sub>2</sub> absorption.
- Promote urban biodiversity: urban greenery creates favorable habitats for flora and fauna. Aronson et al.(2014)<sup>15</sup> studied the role of cities in biodiversity conservation through green infrastructure.

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<sup>12</sup> Bowler et al., «A Systematic Review of Evidence for the Added Benefits to Health of Exposure to Natural Environments».

<sup>13</sup> Konijnendijk et al., *Urban Forests and Trees*.

<sup>14</sup> Nowak et al., «Carbon Storage and Sequestration by Trees in Urban and Community Areas of the United States».

<sup>15</sup> Aronson et al., «A Global Analysis of the Impacts of Urbanization on Bird and Plant Diversity Reveals Key Anthropogenic Drivers».

## 3. Survey Design

The aim of the survey is to collect data and opinions on the perception and importance of public green spaces in Verona, in relation to community health and well-being, air pollution reduction, climate change, biodiversity, safety, economic value, social cohesion and cultural heritage. Furthermore, the survey aims to understand the willingness of the population to support the increase of public green spaces through financial contributions and the definition of the priorities of the interventions that the municipality of Verona could undertake to promote public green spaces. Finally, demographic data are collected to analyse variations in responses based on age, gender, education level, occupation, household income and area of residence.

### 3.1 Questionnaire structure

The questionnaire was structured in different sections to obtain data on various dimensions related to public green spaces in Verona. Public green spaces, being an economic resource without a conventional market, require a contingency analysis to assess their importance and the level of community support.

The questionnaire was categorized to obtain data on different dimensions linked to the public green areas of Verona. Public greenery, being an economic asset that does not have a market requires a contingency analysis to evaluate its importance and community support.

This is how the questionnaire was categorized to investigate different dimensions.

1. Current situation: this section provides context and information relevant on the current state of air pollution in Verona and about the potential impacts on public health and the environment. This introduction is important to give more information for understanding of the importance of public green spaces and the need for actions to address the environmental challenges.
2. Personal information: collects demographic data such as age, gender, and time of residence in Verona. This information can be used to analyze whether there are differences in people's response based on these variables.
3. Benefits of public green spaces: explore participants' perceptions of benefits of public green spaces for health, the environment and climate change, biodiversity, security, economy, social cohesion and cultural heritage.
4. Willingness to support the increase in public green areas: investigate the willingness of participants to contribute financially to the increase of public green spaces and their annual financial availability.

5. General options: gives the respondents the chance to share their opinions on what Verona should do to promote public greenery and to provide any additional observations or comments.
6. Final demographics datas: collects additional demographic information such as the level of education, work, and area of residence in Verona.

Below is the questionnaire's structured layout with its specific questions:

<b>Questionnaire Section</b>	<b>Question</b>
<b>Current Situation</b>	What do you consider the main environmental problems in Verona? (Multiple choice: pollution, heat islands, etc.)
	Are you aware of any municipal policies aimed at improving public green spaces in Verona? (Yes/No)
<b>Personal Information</b>	What is your age? (Under 18, 18-30, 31-45, 46-60, Over 60)
	What is your gender? (Male/Female)
	How many years have you lived in Verona? (Less than 1 year, 1-5 years, 6-10 years, Over 10 years)
<b>Benefits of Public Green Spaces</b>	How important do you consider public green spaces for community health and well-being? (Very important, Fairly important, Slightly important, Not important)
	Do you believe that increasing public green spaces could help reduce air pollution in Verona? (Yes/No/Don't know)
	How important do you consider managing stormwater through public green spaces? (Very important, Fairly important, Slightly important, Not important)
	Do you think public green spaces can help mitigate climate change and create microclimates? (Yes/No/Don't know)
	Have you noticed an increase in summer heatwaves in Verona in recent years? (Yes/No/Don't know)

Questionnaire Section	Question
	Do you think public green spaces are important for biodiversity conservation? (Very important, Fairly important, Slightly important, Not important)
	Do you believe public green spaces can help reduce violent, sexual, and property crimes? (Yes/No/Don't know)
	Do you think there are economic benefits from increasing public green spaces (such as new jobs and increased property values)? (Yes/No/Don't know)
	How important is public green space in promoting social cohesion? (Very important, Fairly important, Slightly important, Not important)
	Do you think public green spaces contribute to enhancing Verona's cultural heritage? (Yes/No/Don't know)
<b>Willingness to Support Public Green Projects</b>	Would you be willing to contribute financially to the expansion of public green spaces in Verona? (Yes/No)
	What is your annual financial availability to support public green spaces? (Less than €50, €50-100, €101-200, Over €200)
<b>General Options and Suggestions</b>	Which of the following actions should the Municipality of Verona prioritize? (Multiple choice: increase maintenance, raise awareness, provide plants to residents, plant more trees, create more urban gardens)
<b>Final Demographic Data</b>	What is your education level? (Elementary school, Middle school, High school diploma, University degree, Master's/PhD)
	What is your occupation? (Student, Employee, Self-employed, Unemployed, Retired)
	What is your total household income? (€0-9,999, €10,000-19,999, ..., Over €100,000)

Questionnaire Section	Question
	In which district of Verona do you live? (Choice among the 8 city districts)

Table 5: Questionnaire structure

## 3.2 The academic literature underlying the questionnaire questions

The questionnaire was designed for the entire population of Verona, covering different social classes and educational backgrounds. Therefore, it was structured to be clear and accessible. One of the main objectives was to assess public perception of key topics, even when scientific research had already demonstrated the validity of certain questions. Below are the academic studies supporting the survey questions.

### Health and Well-being (Q3)

- Ulrich, R.S.(1984)<sup>16</sup>. A study showing that patients in hospital rooms with natural views recover faster than those with views of brick walls.
- Kellert & Wilson(1993)<sup>17</sup>. The Biophilia Hypothesis states that humans have an innate connection with nature, benefiting mental and physical health.
- Bringslimark et al.(2009)<sup>18</sup>. Research demonstrating that exposure to plants reduces stress and improves emotional well-being.

### Air Pollution Reduction (Q4)

- Nowak et al.(2014)<sup>19</sup>. Research analyzing how trees improve air quality by filtering pollutants and benefiting human health.

### Stormwater Management (Q5)

- Cadenasso et al.(2007)<sup>20</sup>. Study on how urban greenery reduces stormwater runoff, mitigating urban flooding.
- Hatt et al. (2009)<sup>21</sup>. Research showing the effectiveness of biofiltration systems in public green spaces for improving water quality.

### Climate Change Mitigation and Microclimates (Q6)

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<sup>16</sup> «Roger S. Ulrich: View through a window May influence recovery from surgery».

<sup>17</sup> «The Biophilia Hypothesis, Stephen R. Kellert and Edward O. Wilson. 1993. Island Press, Washington, DC. 484 Pages. ISBN».

<sup>18</sup> Bringslimark, Hartig, e Patil, «The Psychological Benefits of Indoor Plants».

<sup>19</sup> Nowak et al., «Carbon Storage and Sequestration by Trees in Urban and Community Areas of the United States».

<sup>20</sup> Cadenasso, Pickett, e Schwarz, «Spatial Heterogeneity in Urban Ecosystems».

<sup>21</sup> Hatt, Fletcher, e Deletic, «Hydrologic and Pollutant Removal Performance of Stormwater Biofiltration Systems at the Field Scale».

- Konijnendijk et al(2013)<sup>22</sup>. A systematic review on how urban parks help reduce temperatures and regulate local climates.

#### Crime Reduction (Q9)

- Troy & Grove (2008)<sup>23</sup>. Research indicating that well-maintained urban parks contribute to lower crime rates.
- Wheeler (2019).<sup>24</sup> An analysis of how green infrastructure can help prevent crime and improve urban security.

#### Economic Benefits (Q10)

- Lutzenhiser et al. (2001). A study confirming that homes near green spaces have higher property values.

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<sup>22</sup> Konijnendijk et al., *Urban Forests and Trees*.

<sup>23</sup> Troy e Grove, «Property Values, Parks, and Crime».

<sup>24</sup> Hunter et al., «Environmental, Health, Wellbeing, Social and Equity Effects of Urban Green Space Interventions».

### 3.3 Definition of the sample number to have statistical significance

Defined the structure, categories and reference literature supporting the questionnaire have been defined, the last necessary step before starting data collection is the definition of the sample number of responses necessary to be able to be compared to the entire population of Verona. To determine the sample size for the contingent analysis on public green spaces in the city of Verona, having 255.298 inhabitants and to calculate the confidence interval, various factors must be taken into consideration, such as the desired confidence level and the acceptable margin of error.

$$n = \frac{Z^2 \times p \times (1-p)}{e^2}$$

Where:

- $Z$  is the  $z$  value corresponding to the confidence level (1.96 for 95%)
- $p$  is the estimated population proportion (we use 0.5 to maximize the sample size)
- $e$  is the margin of error (0.05)

proceeding with the calculations:

$$n = \frac{1,96^2 \times 0,5 \times 0,5}{0,0025}$$

$$n = \frac{0,9604}{0,0025} \approx 384,16$$

So, for a population of 257,353 people, with a 5% margin of error and a 95% confidence level, the necessary sample size is approximately 385 responses.

## 4.Data Analysis

Once the data had been collected and organized, it was possible to calculate the shadow price basing its processing on the willingness to pay for the questionnaire sample. The starting point was to divide the different answer options to calculate the average of the average willingness to pay average WTP:

Category 1	< €50		619
Category 2	€ 50	€ 100	319
Category 3	€ 101	€ 200	49
Category 4		> € 200	24

Table 6: WTP categories

To estimate the average WTP of each category, we take the midpoint of the range. For the "over €200" category, we can choose an arbitrary value, for example €250.

- Category 1: Average WTP = €25 (midpoint of €0-50).
- Category 2: Average WTP = €75 (midpoint of €50-100).
- Category 3: Average WTP = €150 (midpoint of €101-200).
- Category 4: average WTP = €250 (chosen arbitrarily).

Once the different average WTPs for the four categories have been obtained, it is possible to proceed and compare them to the corresponding number of choices indicated per category.

However, it is necessary to make a consideration; although the questionnaire has totaled a total of 1082 answers, to calculate the Willingness to Pay in the most realistic way possible we must exclude a total of 470 answers that have provided contradictory answers to two important questions.

The first question that motivates the exclusion of this subsample is having answered negatively to question no. 13 of the questionnaire: "Would you be willing to contribute financially to the increase of public greenery in Verona?". Since the next question is: "What is your annual financial availability to support public greenery?" we must exclude the answers of people who have previously refused to financially support public greenery projects because their answer cannot be considered reliable and informed.

If we were to calculate the WTP with the entire sample, the results would be as follows:**Calculation of total WTP for each category (entire sample):**

- Category 1: € 25 \* 619 = €15,475
- Category 2: € 75 \* 319 = €23,925
- Category 3: € 150 \* 49 = €7,350
- Category 4: € 250 \* 24 = €6,000

Proceeding to add the results obtained, **Sum of total WTP to obtain the total WTP of the sample:**

$$\text{Total WTP} = 15,475 \text{ €} + 23,925 \text{ €} + 7,350 \text{ €} + 6,000 \text{ €} = 52.750 \text{ €}$$

Obtaining, **Calculation of the average WTP of the sample:**

$$\text{Average WTP of the sample} = \frac{52.750}{1082} \approx 48,75$$

And extending this average WTP value, **Projection of WTP on the entire population of Verona:**

$$\text{Total WTP for Verona} = \text{average WTP of the sample} \times \text{Population of Verona}$$

$$\underline{\underline{\text{Total WTP for Verona} = 48,75 \text{ €} \times 255298 \approx 12.445.777,5 \text{ €}}}$$

Excluding instead the subsample that answered negatively to question number 13, **Calculation of total WTP for each category:**

- Category 1: € 25 \* 253 = € 6325
- Category 2: € 75 \* 287 = € 21525
- Category 3: € 150 \* 45 = € 6750
- Category 4: € 250 \* 22 = € 5500

Proceeding to add the results obtained, **Sum of total WTP to obtain the total WTP of the sample:**

$$\text{Total WTP} = 6325 \text{ €} + 21525 \text{ €} + 6750 \text{ €} + 5500 \text{ €} = 40100 \text{ €}$$

**Calculation of the average WTP of the sample:**

$$\text{Average WTP of the sample} = \frac{40100}{612} \approx 65,52$$

## **Projection of WTP on the entire population of Verona:**

Total WTP for Verona = average WTP of the sample × Population of Verona

$$\underline{\text{Total WTP for Verona} = 65,52 \text{ €} \times 255298 \approx 16.727.124,96 \text{ €}}$$

The first difference we can notice is how the average WTP has risen from a value of 48.75 to 65.52. Now, however, we must make some considerations based on the different age groups of the population of the city of Verona.

The average WTP obtained on a theoretical level could be applied to the total number of the population, but it would not be an accurate representation of reality. This is why it is necessary to make some weightings.

Once the problem has been defined, we proceed to extend the results obtained from the valid answers to the total population of Verona, divided by age groups and gender.

Data available:

- Population of Verona : 255.298

Population distribution by age group :

- **Under 18 (15-18 years):** 11.647 (5.911 girls, 5.736 boys)
- **18-30 years:** 26.260 (13.495 men, 12.765 women)
- **31-45 years:** 45.161 (22.608 men, 22.553 women)
- **46-60 years:** 58.370 (28.432 men, 29.938 women)
- **60+ years:** 84.432 (36.425 men, 48.007 women)

Collected and valid answers:

- **Under 18 (15-18 years):** 30 (22 girls, 8 boys)
- **18-30 years:** 90 (56 women, 34 men)
- **31-45 years:** 119 (64 women, 55 men)
- **46-60 years:** 197 (126 women, 70 men)
- **60+ years:** 178 (98 women, 80 men)

## 2. Calculation of expansion factors

the expansion factor is calculated with :  $F \text{ expansion} = \frac{\text{Population target}}{\text{Valid respondents}}$

Let's calculate the factors for each age group and gender:

Age Group	Male Population	Male Respondents	Male Factor	Female Population	Female Respondents	Female Factor
15-18	5.911	8	738.88	5.736	22	260.73
18-30	13.495	34	397.0	12.765	56	227.9
31-45	22.608	55	411.1	22.553	64	352.4
46-60	28.432	70	406.2	29.938	126	237.7
60+	36.425	80	455.3	48.007	98	489.9

Table 7: expansion factors for male and female population

## 3. application of expansion factors

You can now multiply the number of respondents by the respective expansion factor to get an estimate of the total number of people in the population who would have responded similarly.

Estimate of responses for the total population, For the male population:

$$\text{Estimate} = \text{Respondents} * \text{Expansion factor}$$

Age group	Male Esteem
15-18	8×738.88=5.911
18-30	34×397.0=13.495
31-45	55×411.1=22.608
46-60	70×406.2=28.432
60+	80×455.3=36.425

Table 8: male population – expansion factor

For the female population:

Age group	Female Esteem
15-18	22×260.73=5.736
18-30	56×227.9=12.765
31-45	64×352.4=22.553
46-60	126×237.7=29.938
60+	98×489.9=48.007

Table 9: female population – expansion factor

#### 4. Results interpretation

After applying the expansion factors, we can verify that the weighted responses faithfully reproduce the population of Verona.

The sum of the estimated population obtained with the expansion factors is:

Estimated male population: 106,878

Estimated female population: 119,012

Total estimated population: 225,890

Now it's finally possible to apply the average wtp obtained previously to the population of Verona. The number of people to which to apply the average wtp was obtained by excluding children under 15, subsequently reporting, proportioning and expanding for each age group of the population.

#### Projection of WTP on the estimated population of Verona:

Total WTP for Verona = average WTP of the sample × Population of Verona

**Total WTP for Verona = 65,52 € × 225890 ≈ 14.800.313 €**

	Age population	Male WTP (€)	Female WTP (€)
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0	15-18	387291.3408	375826.6512
1	18-30	884388.96	836192.448
2	31-45	1481439.96	1477711.872
3	46-60	1862995.68	1962337.104
4	60+	2386500.48	3145628.304
Total		7002616.421	7797696.379
Sum Total (€)	14.800.313		

*Table 10: Synthesis table for the whole population of Verona*

Therefore, the estimated shadow price for the overall value of green assets Veronese including parks, squares and tree-lined avenues, based on the population's willingness to pay, is approximately 14.8 million euros. This number represents the overall economic value that the Veronese population would attribute to the public good in question, according to the contingent valuation method.

## 4.1 Multi-variable Logistic Regression Analysis

The statistical analysis conducted in this study required the choice of an appropriate model for the outcome variable. Since the outcome was not a continuous variable but only assumed some discrete values, the use of a linear regression was not the most appropriate. To solve this problem, logistic regression was adopted, which allows to model the probability of belonging to one of the two categories defined for the outcome variable.

Two cutoffs were chosen to transform the outcome into a dichotomous variable:

- Cutoff  $\geq 75$ : those willing to pay at least 75 monetary units compared to those who are not.
- Cutoff  $\geq 150$ : those willing to pay at least 150 monetary units compared to those who are not.

This transformation allowed to apply a multivariable logistic regression model, including the independent variables of interest.

## 4.2 Choice of Independent Variables:

- Gender (sex): categorical (male/female).
- Age (age): divided into groups (18-30, 31-45, 46-60, over 60).
- Education level (school): categorical (lower secondary school, high school, college degree or more).
- Income (income): continuous variable.
- Score (score): continuous variable that represents an individual evaluation score.

## 4.3 Analysis of the results

### Model with Cutoff 75

	Estimate	Std, Error	z value	Pr(> z )
(Intercept)	-0,8478	0,4774	-1,776	0,0757
sex	-0,2993	0,1825	-1,64	0,101
age18-30	-0,686	0,5886	-1,166	0,2438
age31-45	-0,2022	0,5882	-0,344	0,731
age46-60	-0,1188	0,5693	-0,209	0,8347
ageOltre 60	-0,1232	0,5658	-0,218	0,8277
School:superiori	0,968	0,4516	2,144	0,0321
School:laurea o più	0,9671	0,4514	2,142	0,0322
reddito	0,1416	0,036	3,933	0,000084

Table 11: Data logistic regression cutoff 75

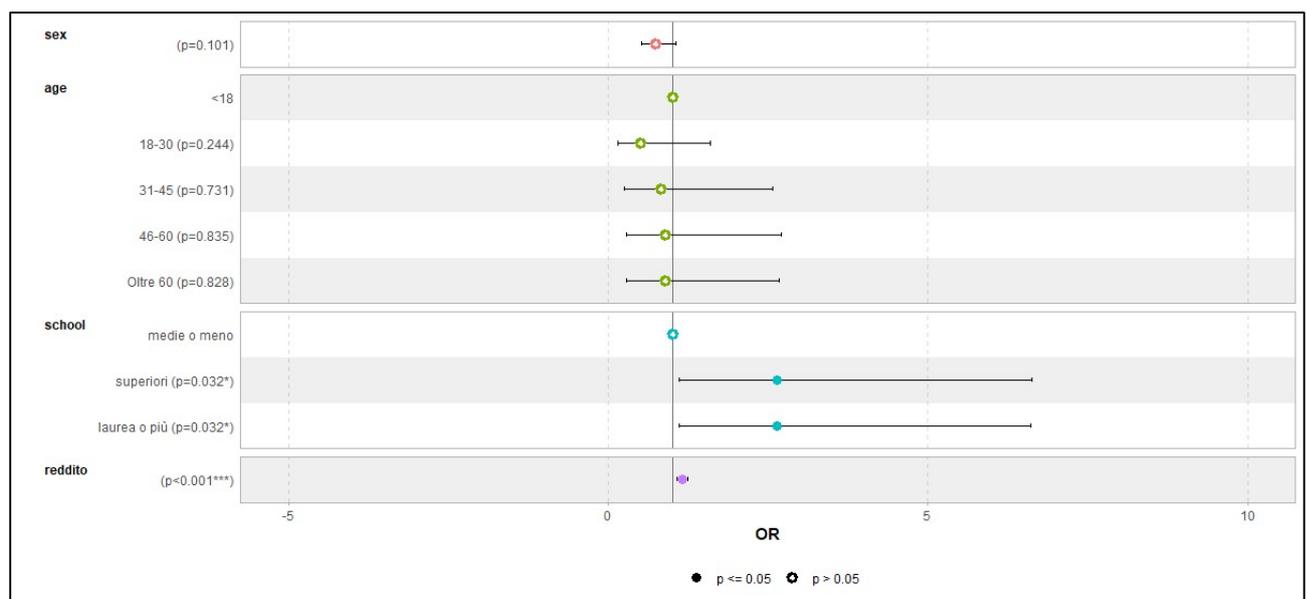


Figure 4: Graph logistic regression cutoff 75

From the results obtained, it is observed that:

- Income is significantly associated with willingness to pay  $\geq 75$  ( $p < 0.001$ , OR = 1.15 95%CI 1.08-10.24), indicating that as income increases, the probability of exceeding this threshold increases.
- The level of higher education or degree is statistically significant ( $p < 0.05$ , high school: OR = 2.62 95%CI 1.10-6.59; degree or more: OR = 2.61 95%CI 1.09-6.55), suggesting that those with a higher education are more likely to pay over 75.

- No age category and gender are significant.

## Model with Cutoff 150

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	-4,08574	0,890407	-4,589	0,00000446
sex	0,000146	0,285892	0,001	0,988
age18-30	-0,55311	1,097437	-0,504	0,614
age31-45	0,438536	1,065395	0,412	0,681
age46-60	0,047516	1,038544	0,046	0,964
ageOltre 60	0,524235	1,018985	0,514	0,607
School:superiori	0,436658	0,83938	0,52	0,603
School:laurea o più	0,300867	0,840588	0,358	0,72
reddito	0,240472	0,049552	4,853	0,00000122

Table 122: Data logistic regression cutoff 150

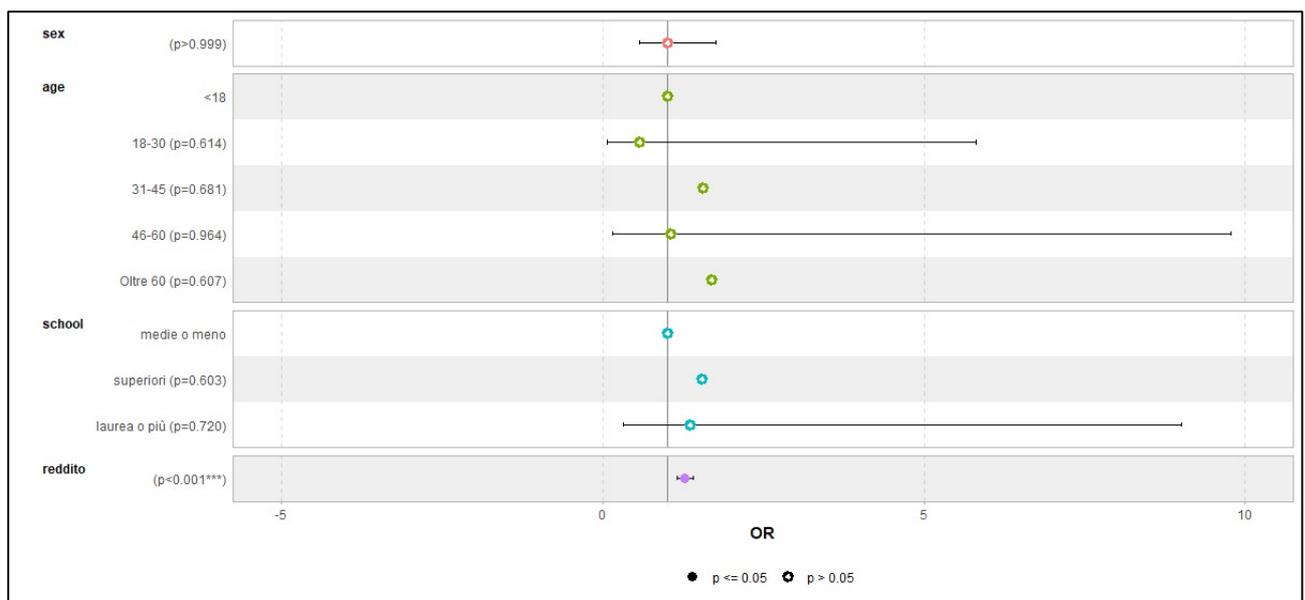


Figure 5: Graph logistic regression cutoff 150

For the 150 cutoff:

- Income remains a highly significant variable ( $p < 0.001$ , OR = 1.27 95%CI 1.16-1.41), with an even stronger effect than in the previous model.
- Education is no longer significant, indicating that for higher payment thresholds, income becomes the main determinant.
- Gender and age do not significantly influence the probability of exceeding this threshold.

## 4.4 Conclusions

The analysis showed that:

- Income is the most relevant factor for both payment thresholds.
- Age over 60 has a significant effect only for payments above €150.
- Gender and education level do not have a statistically significant impact.

Income is the most important factor in determining the willingness to pay, with a positive and highly significant effect in both models. Education has an impact only for the lower cutoff (75), while age and gender do not seem to significantly influence the probability of payment. These results suggest that income plays a crucial role in the propensity to spend, and that for higher amounts, education level loses relevance.

## 5.Challenges and considerations

The study confirmed that public greenery is an essential component of the urban environment of Verona, not only from an ecological point of view, but also from an economic and social one. Through the analysis of the Willingness to Pay (WTP) and the shadow price, it was possible to estimate the economic value that citizens attribute to public greenery. The main results obtained include:

- An average WTP of €65.52 per inhabitant, leading to an overall estimate of approximately €14.8 million for the economic value of public greenery in Verona.
- A strong correlation between income and willingness to pay, highlighting how those with greater economic capacity are more inclined to support investments in projects related to public greenery.
- The widespread perception of the importance of urban greenery for the quality of life, with over 90% of interviewees considering public greenery essential for health and well-being.
- A positive impact on the reduction of pollution, mitigation of climate change and improvement of social cohesion, key aspects for sustainable urban planning.

The results obtained highlight the need to consider public green spaces not as a simple aesthetic element, but as a strategic urban infrastructure, with measurable benefits in environmental, social and economic terms. Therefore, it is crucial that local administrations adopt targeted policies to:

- Expand and maintain public green areas: Invest in new parks, tree-lined avenues and equipped green areas, based on economic evidence such as the estimated shadow price.
- Involve citizens: The WTP analysis suggests that a part of the population would be willing to contribute economically for the improvement of urban green areas. This opens the way to participatory financing strategies, such as civic crowdfunding or incentives for urban planting.
- Integrate green areas into the city's climate management: Public green areas can be a key tool in the fight against urban heat islands, in the management of storm water and in the reduction of CO<sub>2</sub> emissions.

The aim of this study can be considered achieved by providing clear evidence of the value of public green areas not only for the improvement of quality of life, but also as an economic and social investment. The data collected support the idea that urban green areas are not a cost, but a strategic asset for the city of Verona. Future planning should therefore integrate this evidence to promote more sustainable, resilient and community-oriented urban growth.

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