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Tree Planting Cost-Benefit Analysis:

A Case Study for Urban Forest Equity in Los Angeles

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Prepared by:
Antoine Kunsch, Doctoral Candidate,
UCLA Institute of the Environment and Sustainability
Ryan Parks, Undergraduate, UCLA and Intern, TreePeople

Edited by:
Yujuan Chen, Ph.D., TreePeople and USC School of Architecture
Manny Gonez, MPA, TreePeople

Designed by:
Bliss Parsons, TreePeople

Photography by:
Adam Corey Thomas, TreePeople
James Kellogg

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TreePeople
12601 Mulholland Drive | Beverly Hills, CA 90210
www.treepeople.org

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Executive Summary

Southern California is becoming more accustomed to increased heat wave frequency and other climate change consequences that can have a devastating effect on society, infrastructure and the environment, especially in urbanized areas. Urban forests are becoming increasingly important in these built landscapes with urban planners seeking to maximize the ecosystem services and other benefits provided by trees and other green infrastructure. Trees provide environmental benefits including oxygen production, air pollution removal, carbon sequestration, stormwater water runoff reduction, heat island effect mitigation, and support of wildlife habitat. They also generate a large number of socio-economic benefits by reducing energy demand for cooling, improving physical and mental public health, increasing economic activity in commercial areas, improving aesthetics of streetscapes and property values, reducing crime rate, and contributing to noise reduction. Urban forests are essential urban infrastructure for climate resilience and key components for building healthy and vibrant communities.

The primary objectives of this study is to identify the most common types of expenditures associated with privately-owned trees and publicly operated public tree programs in the Los Angeles region, and to quantify potential environmental benefits from a tree planting project in the Council District 8 of the City of Los Angeles as case study. Our goal is to provide recommendations supporting public policies and investment strategies aimed at addressing environmental inequity through the development of urban forestry. Specifically, this study seeks to:

- ***Determine the costs of planting and maintaining urban trees*** by analyzing four studies covering communities in Coastal Southern California, the Midwest, the Piedmont, and Northern California, and comparing them with testimonies from urban foresters in the City of Santa Monica and the Los Angeles County Department of Public Works (LACDPW).

- ***Quantify the environmental benefits of a tree planting scenario*** in a historically redlined district of the City of Los Angeles using a peer-reviewed software suite from the U.S. Forest Service (i-Tree Eco) to model the evolution of 24,003 trees over 40 years in Council District 8, one of the districts with the lowest canopy coverage at only 12.2%, well below the 21.6% average for the City of Los Angeles.

- ***Assess the role of modeling tools and their limitations*** in the decision-making process for locating future planting projects to increase climate resilience and environmental equity.

Key Findings

What is the annual cost of a public tree?

Although tree planting costs from published studies indicate an average annual cost for a medium-size public tree around $34, an analysis of local life cycle costs in Los Angeles County and the City of Santa Monica reveal an annual cost closer to $96. This steep difference can be explained by differences in accounting methods - especially regarding the integration of removal costs - and the variations in the definition of “public trees”. Trees located in public parks, that have much lower maintenance costs due to the absence of expensive infrastructure conflicts and repairs, are included in the scope of the published studies we analyzed whereas costs from LACDPW and the City of Santa Monica only include street trees.

How to reduce urban forest management costs?

Removal costs at the conclusion of a tree’s 40-year lifecycle can represent between 28% to 60% of a tree’s annual cost depending on maintenance practices, a clear incentive for long-term tree care to increase trees’ longevity and a higher return on investment from tree planting projects. The cost of no action - when it comes to tree management - can rapidly lead to a dramatic increase in maintenance and removal costs, limiting the ability of a municipality to reach its urban forest canopy goals and the ability of future generations of urban foresters to address local environmental and social challenges. Management costs can be reduced further by implementing *‘right tree, right place’* practices by selecting locations and tree species that can reduce the need for supplemental costs besides routine pruning, or allow for cost-saving maintenance practices such as block pruning. Climate-ready trees and block planting projects using tree species with similar growth rates can help support these strategies.

What is the annual value of trees’ environmental benefits?

A mature urban forest of 14,337 street trees in Council District 8 of the City of Los Angeles can provide environmental benefits quantified at $111,810 per year covering air pollution removal, energy savings, carbon sequestration and avoided runoff. Its structural value - the cost to replace a tree with one of similar value - is estimated at $50.6 million. Additional research is necessary to integrate a wider range of environmental and socio-economic benefits associated with street trees. Published studies reveal that the impact on aesthetic and property value can represent up to 72% of the total annual benefits of a public tree.

Study limitations for this project include limited availability of cost information related to local street tree management programs, as well as the technical limitations in environmental benefits calculations linked to the use of the i-Tree Eco.

Recommendations & Next Steps

Based on the findings, we highly recommend:

- Developing mechanisms to accurately capture comprehensive tree planting and management program costs.
- Completing city-wide tree inventories to support future cost-benefit analysis with tree-specific data and management history.
- Integrating socio-economic-health benefits of tree planting.
- Developing community programs to improve tree health monitoring and reduce costs.
- Using comprehensive and innovative urban forestry investment strategies to improve urban forest equity.

Introduction

The majority of the world's population resides in cities, and this trend is increasing. As cities grow, so do their impacts on the natural environment. Two hundred and twenty million vehicles race around Los Angeles' seemingly endless maze of streets, freeways, and boulevards each day, while over sixty-six billion kilowatt-hours of energy are exhausted in the City of Angeles annually [1] [2]. Los Angeles' insatiable consumption of resources has rendered many negative environmental effects, such as air pollution and extreme heat. Moreover, these environmental hazards are disproportionately manifested in low-income communities and communities of color that have been historically exposed to countless environmental hazards due to the inequitable distribution of ecosystems services, like trees, across Los Angeles [3] [4].

To respond to environmental risks and their unequal concertation in disadvantaged communities throughout Los Angeles, city-planners, academic researchers, and non-profit organizations are seeking to leverage urban forestry, not only as a tool to offset greenhouse gas emissions, filter air pollutants, decrease temperatures, and revitalize public health but also as an instrument to restore equity in communities where racially motivated discrimination has subjected vulnerable populations to environmental hazards for generations. While developing an urban forest equitably throughout Los Angeles is imperative to addressing environmental justice as well as public health disparities, investing in tree canopy is an economically effective way to regulate the city's rapid urbanization altogether. In California, *every dollar* invested in an urban tree yields *$5.82 in benefits*, given an average annual per tree management cost of $19.00 [5]. Furthermore, It is estimated that there are in excess of 5.5 billion urban forest trees comprising 21 million acres of urban forest in American cities, with an environmental asset value of $18.3 billion [6]. On top of this, trees are some of the only elements of city infrastructure that appreciate in value and utility as they age, providing increasing quantifiable environmental benefits.

This report explores the components of cost-benefit analysis in urban forestry and contextualizes its role in removing inequities inherited from redlining policies and unequal distribution of tree canopy. We begin by providing an overview of the main costs associated with public tree planting programs before providing a detailed analysis of local costs around Los Angeles. We end with an analysis of environmental benefits associated with a tree planting scenario in Council District 8 of the City of Los Angeles. We note that this report represents the first step in the development of new policies to support historically marginalized communities and neighborhoods by removing obstacles that contributed to environmental injustice and by offering a clear perspective on the limitation of traditional cost-benefit analysis tools.

The evolution of urban forestry and the race against rapid urbanization

During the latter segment of the twentieth century, tree planting in the urban setting spiked as a result of the observation that trees were effective in ameliorating the multi-faceted damages rendered by swift urbanization [7]. As tree planting expanded, the term urban forest was coined by city planners around the mid-1960s [8]. Subsequently, California implemented the California Urban Forestry Act of 1978, which acknowledged trees as cornerstones of the urban environment. The California Urban Forestry Act of 1978 also implored the Department of Forestry and Fire Prevention (CalFire) to protect urban trees, create lasting urban forestry jobs, and inspire community participation. In 2017, the California State Assembly Bill 1530 mandated tree canopy development targets in under-resourced communities while allocating funds to nonprofit environmental organizations serving disadvantaged communities [8].

This legislation paved the way for various urban forestry initiatives, such as TreePeople's campaign to plant a million trees in the City of Los Angeles prior to the 1984 Olympic Summer Games, mayoral commitment to plant one million trees through the Million Trees Los Angeles project, or the Green New Deal's pledge of planting 90,000 trees and expanding tree canopy cover in low-income net-impacted areas by fifty percent in Los Angeles [10].

Even with all of the disparate tree planting efforts, Los Angeles' tree canopy cover is being outpaced by urbanization. Although the gross amount of urban trees has grown from 5.9 million to 9.1 million over the past three decades, street tree density has shrunk by 30 percent [8]. The rate of planting a tree cannot seem to keep up with the frequency of city growth.

In order to overcome such obstacles, trees ought to serve as critical elements of green infrastructure plans that equip cities to resist a multitude of climate hazards while working to resolve the legacy of decades of redlining and environmental injustices. Urban forestry has the potential to be included within domestic and global programs and regulations that promote environmental vitality for everyone. For this potentiality to be actualized, the utility of trees in the immediate sense, as well as tree benefits over time, must be cataloged and quantified to deem whether or not their net impact implies admission into these programs, such as California's 30x30 goal of conserving 30 percent of the state's land and coastal waters by 2030 or the Paris Agreement. Los Angeles is currently rolling out a program called Forestry First Step, initiating the city's focus on a sustainable urban forest within its urban policy [15].

Redlining and tree canopy coverage

As cities like Los Angeles urbanize at an unprecedented rate, extreme heat in urban settings is a growing public health issue with Los Angeles County being the only place in the U.S. where heat-related deaths occur during the winter months [37]. According to the National Weather Service, heat is the highest weather-related cause of death in the United States [9]. Earlier this year, a team of interdisciplinary researchers from UCLA published a project titled *Heat Resilient L.A.* that maps the areas of Los Angeles that are most vulnerable to heat impacts and also determines the communities in the greatest need of cooling interventions. It was discovered that low-income regions and communities of color are up to ten degrees hotter than surrounding affluent areas. This temperature disproportion between affluent and low-income neighborhoods directly coincides with the percentage of tree canopy cover in particular neighborhoods. The average tree canopy cover in Los Angeles is around 19%. In wealthy communities, the tree canopy cover is significantly higher than Los Angeles' average. In low-income communities, the opposite is the case. The Pacific Palisades, one of the richest neighborhoods in the city, enjoys a tree canopy that covers 55% of its land. In Gramercy Park, a low-income neighborhood in the heart of Council District 8, the tree canopy covers 10% of its land (**Los Angeles County Tree Canopy Map Viewer**). According to the United States Environmental Protection Agency (EPA), trees reduce surface and air temperatures by 20-45°F. Strategically planting trees in disadvantaged areas in Los Angeles can substantially curb the disproportionate extreme heat experienced in these regions [11].

The unequal distribution of tree canopy and temperature variance among affluent communities and low-income neighborhoods of color signifies the overarching issue of environmental justice in Los Angeles and throughout the country. Low-income communities of color have significantly less access to green spaces than affluent, caucasian neighborhoods. On top of this, these low-income communities have minimal resources to preserve the green spaces that they due have access to. Severe lack in green space compounded with the historical social and economic disparities has led to disproportionately high levels of chronic health problems, such as hypertension and asthma, in low-income communities and communities of color [12].

However, trees and other green spaces are proven to catalyze social, economic, and physical wellbeing of communities[12].

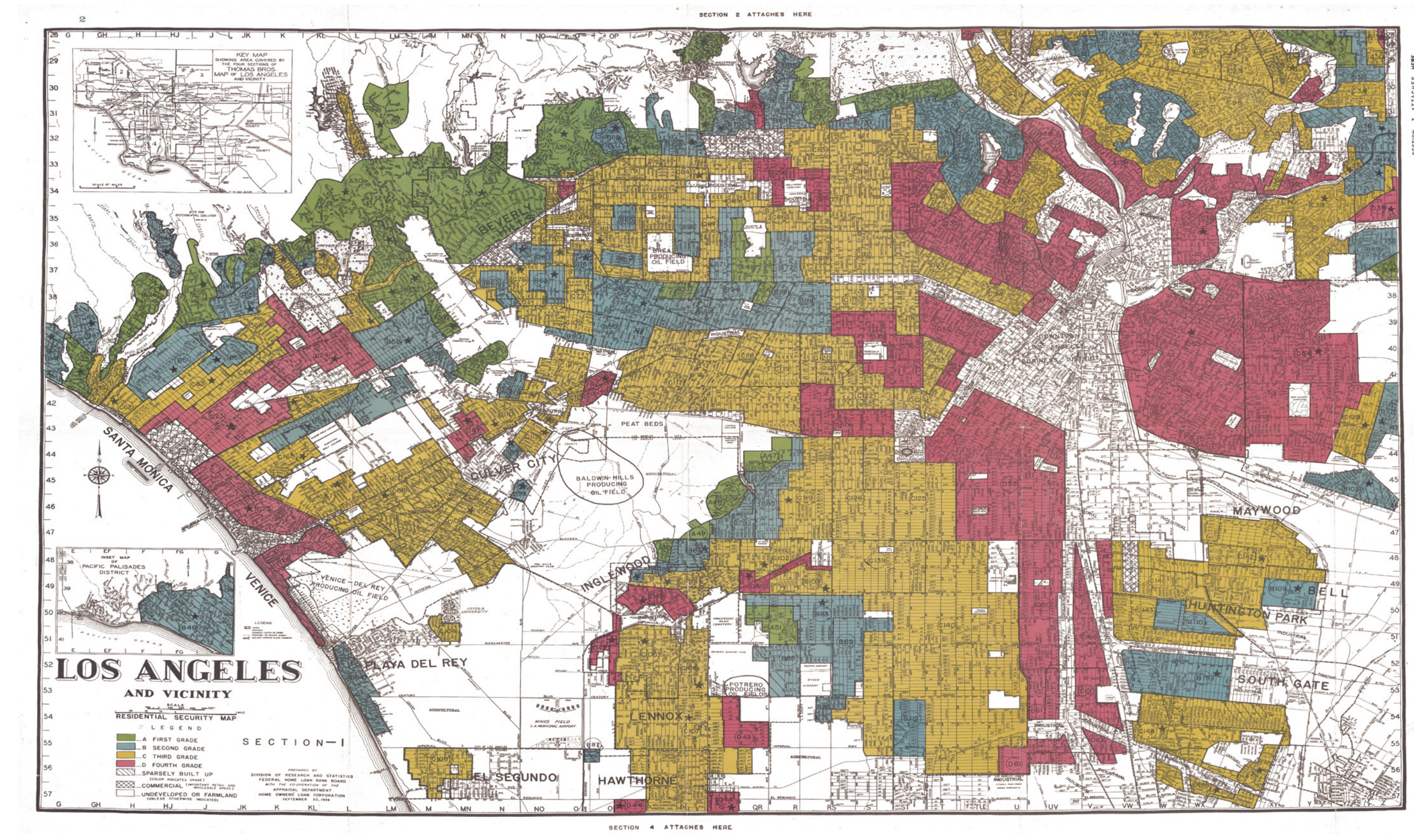


Figure 1. 1939 Home Owners' Loan Corporation (HOLC) historical redlining map of the City of Los Angeles (source: **Mapping Inequality**, University of Richmond)

Cost-benefit analysis and urban forest equity

Using traditional cost-benefit analysis as a planning tool, officials determined the areas that would be the least expensive to produce freeways and other infrastructure; areas that have been historically subjected to disinvestment. Thus, the interstate highway system separated neighborhoods and environments, severing the social tethers and physical spaces for emerging green spaces.

"In Los Angeles, low-income and minority areas have had a history of undesirable land uses, especially industrial installations with their attendant pollution of air, water, and soil. For example, the City of Los Angeles' 04 zoning code, the first in the nation, protected the affluent, predominantly Anglo Westside from such industrial uses. Higher density housing, commercial, and industrial activities were allowed to locate in the city's eastern and southern area in which lower income workers, including people of color, were concentrated. Public parks, as well as other urban services were, however, disproportionately targeted to other parts of town." [24]

Due to the developed cement buildout in disinvested communities, expansion of tree canopy is severely inhibited. This barrier makes tree canopy development cost-prohibitive. Moreover, these disinvested areas currently do not possess the capacity to rebuild and revamp infrastructure. Present cost-benefit analyses do not account for the injustice of this tree canopy constriction.

PART 1: How much does it really cost to plant a tree?

Trees contribute to the beautification of our cities and provide important ecosystem services including air quality improvement, energy conservation, stormwater interception and flood prevention, heat island mitigation, and atmospheric carbon dioxide reduction [5, 11, 13, 14]. These benefits must be weighed against the costs of planting, establishing, and maintaining these trees over their life-cycle to create management recommendations aimed at increasing urban tree canopy and associated ecosystem benefits in historically disinvested communities.

We identified tree planting cost categories based on key studies and reports published between 2000 and 2015, and through interviews with two urban forest managers in Los Angeles County to collect cost information related to tree planting, establishment care and long-term maintenance as well as non-programmatic costs including infrastructure repairs and administrative fees. The costs of urban tree management and maintenance is still not well understood as attempts to calculate the net value of urban trees frequently weigh the overall municipal budgets of urban forestry against the ecosystem services produced by public trees without the ability to itemize and track each cost category. Urban forestry funding at the municipal level are frequently considered non-essential city services [15] leading to budget cuts during challenging times. This has been confirmed during our interviews as city budgets had been reduced following the economic impact of the COVID-19 pandemic.

1.1. A review of the tree planting cost categories

We analyzed the findings of four studies by McPherson et al. [16-19] that used similar methodologies spanning over 10 years (2000-2010) to determine the cost of planting and maintaining a tree in an urban setting. We selected these studies from the literature because they have been performed in different regions of California including coastal Southern California. The most commonly reported cost categories include planting, pruning, irrigation, administration, pest control, liability, clean-up, and removal. Whether the study focuses on private or public trees can change the cost categories included in the analysis. For both public and private trees, we present the results of the literature as the total cost of tree planting ($/year/tree) and as a percentage of total cost represented by each category. All tree planting costs have been calculated on a 40-year average and adjusted for inflation to 2020.

We define small trees as trees under 20-ft tall, medium trees between 20-40-ft tall, and large trees above 40-ft tall at maturity. Small tree species include yew pine, crabapple, dogwood and camphor. Medium tree species include jacaranda, red oak, southern magnolia and cherry plum. Large tree species include camphor, hackberry, red maple, and velvet ash. Depending on the geographic location of the study, the same species can be considered large or small.

Table 1. List of common costs in tree planting projects [16-19, 21, 22, 31] .

PLANTING	Planting costs include the cost of the tree and the cost of planting, staking, and mulching. Planting costs depend on tree size at planting (i.e., 15 gallons vs. 24 in. box). Costs presented in this report are based on 15-gallon trees unless specified otherwise.
PRUNING	Pruning costs usually represent the most expensive cost category for publicly owned trees. Costs depend on tree size as larger trees may require additional pruning equipment, and on maintenance cycles followed by municipal services or their contractors. Most of the studies in this review consider a 3-year maintenance cycle for small trees, and a 6-year cycle for larger trees.
IRRIGATION	Newly planted trees in Southern California require irrigation for about three to five years [16]. Irrigation costs are historically not well captured in the literature as they either rely on pre-existing irrigation systems, or on naturally occurring rainfalls in the northern range of the state. When included, it captures the cost of water required during the establishment period based on municipal water price. It does not include the cost of watering crews in the case of absence of pre-existing watering systems.
PEST & DISEASE	Public trees receive treatments to control pests and disease on an as needed basis. Costs can vary greatly based on the location and are more substantial for private trees as they are usually treated more regularly than public trees.
REMOVAL	Include the costs of tree and stump removal by municipal crew or contractor. Removal costs depend on tree size ($ per inch of diameter at breast height or DBH).
INFRASTRUCTURE REPAIR	Many municipalities in California have a substantial number of large and old trees deteriorating sidewalks. As trees age, root systems can cause damage to sidewalks, curbs, paving and sewer lines. These costs are not easily captured as infrastructure repairs are usually managed by a different municipal department that does not automatically register the cause of the damage.
LIABILITY	Some municipalities started to track costs and legal fees incurred by trip-and-fall claims. This is still a rare occurrence and not well integrated with urban forestry expenditure.
ADMIN	Include administrative costs for salaries of supervisors and clerical staff, operating costs and overhead.
CLEANUP	Include the average annual per-tree cost for litter cleanup (i.e., street sweeping, storm damage cleanup).

We present itemized costs separately for public and private trees. The studies included in this analysis describe “yard” trees as trees privately managed and planted in residential sites, and “public” trees as trees planted on streets or in parks. It is important to note that mortality rate should be included in any subsequent cost-benefit analysis in order to obtain a realistic tree planting scenario. Mortality rates of the studies included here range from 22.5% to 45% over a 40-year life-cycle [16-19]. This assumption can be refined based on surveys of municipal and commercial arborists.

1.1.1. The planting costs of a private yard tree

Yard trees are planted and maintained on private commercial and residential properties. According to the **Bureau of Street Services**, there are over *10 million* trees growing in the City of Los Angeles and only *2 million* of them are publicly maintained. This shows the critical role played by privately owned and maintained trees in the overall ecosystem benefits produced by the urban forest, as well as the naturally chaparral vegetation along the famous hillsides of the city. Planting trees are typically higher for yard trees than for public trees since homeowners and residents usually plant larger than 15-gallon trees but the maintenance costs are much lower. Surveys indicate that 15-20% of households never prune their trees, and that only 20% of the households that do prune them regularly hire professional arborists -and usually only for large trees [16-19]. This results in yard trees having an annual cost of $18.87, $21.33 and $23.92 for small, medium, and large trees respectively.

Although all the studies we selected followed the same methodology, significant variations and assumptions need to be highlighted. For example, two studies considered the planting of a 15-gallon tree while two others respectively assumed the planting of a 2.5-in and 3-in DBH tree. A 15-gallon tree usually is around 1 to 1-½ inch in DBH. This resulted in planting costs ranging from $3-4 for the smaller trees up to $16 for the largest ones. Similarly, variations in maintenance and pruning cycles result in pruning costs ranging from $2.52 to $14.44 per year for a medium sized tree. For more information about each cost category, see *Appendix 1: Tree planting costs summary tables*.

As expected and shown in Figure 2, planting costs can represent up to 49% of the total annual cost of yard trees, followed by maintenance and pruning at about 25% to 30%. An easy way for cities to increase the number of trees planted is to develop free tree programs similar to CityPlants in Los Angeles. By eliminating one of the main cost categories, these programs contribute to the development of the urban forest while educating residents on the associated benefits. However, monitoring the mortality rate and drawing conclusions on the overall benefits generated by these trees is more challenging. Nevertheless, because yard trees are usually located closer to residential buildings than street trees, they provide additional benefits in energy savings, especially in warm climates like southern California [5, 20].

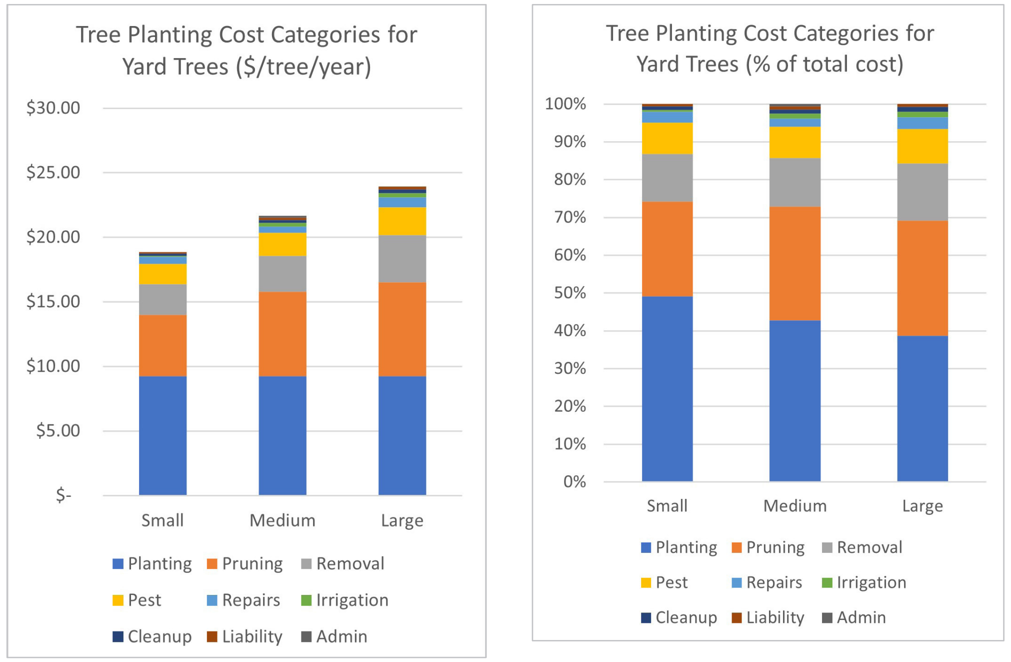


Figure 2. Tree Planting Cost Categories for Yard Trees (left = $/tree/year, right = % of total cost; based on a 40-year average).

1.1.2. The planting costs of a public tree

Public trees are defined here as trees planted on streets or in parks. As is to be expected, maintenance and pruning is the most expensive item for public trees ranging from 29% to 61% for a medium size tree depending on the study. This wide range can be explained by the differences in maintenance cycles used by municipalities. In a low cost scenario, small trees are inspected and pruned every 5 years, medium trees every 10 years, and large trees every 15 years. The most expensive maintenance cycle in our review had young trees being inspected and pruned every other year during the first 5 years, and every 4 years after this establishment period. Medium trees were inspected every 8 years, and large trees every 10 years. With comparable planting and removal costs, the difference in maintenance cycle resulted in an annual cost per tree increasing from $34.67 to $41.71.

Planting costs were fairly consistent across the studies -with 15-gallon trees- with minimal differences depending on staking and mulching costs being included. Irrigation costs were inconsistently reported as some municipalities in northern California relied on rainfalls and a couple others included irrigation during the first 3 to 5 years after planting in the planting costs. The only study that singled out irrigation costs by including the use of a crew and municipal water truck for young trees was focused on coastal southern California communities and should be considered by urban foresters in similar climates. Cleanup, administrative and liability costs are amongst the most difficult to capture. The value of cleanup costs is often based on poorly documented assumptions based on average street sweeping and storm-damage cleanup costs. More refined assumptions need to be developed taking into account the type of trees (i.e., deciduous or evergreen) as well as the frequency of street sweeping services needed for street tree maintenance. A commonly cited survey of western U.S. cities showed that an average of 8.8% of total tree-related expenditures was spent on tree-related liability [5]. Local data could help refine this assumption. Administrative costs are usually calculated by dividing the overall costs for salaries of supervisors and clerical staff, operating costs and overhead by the number of trees under management.

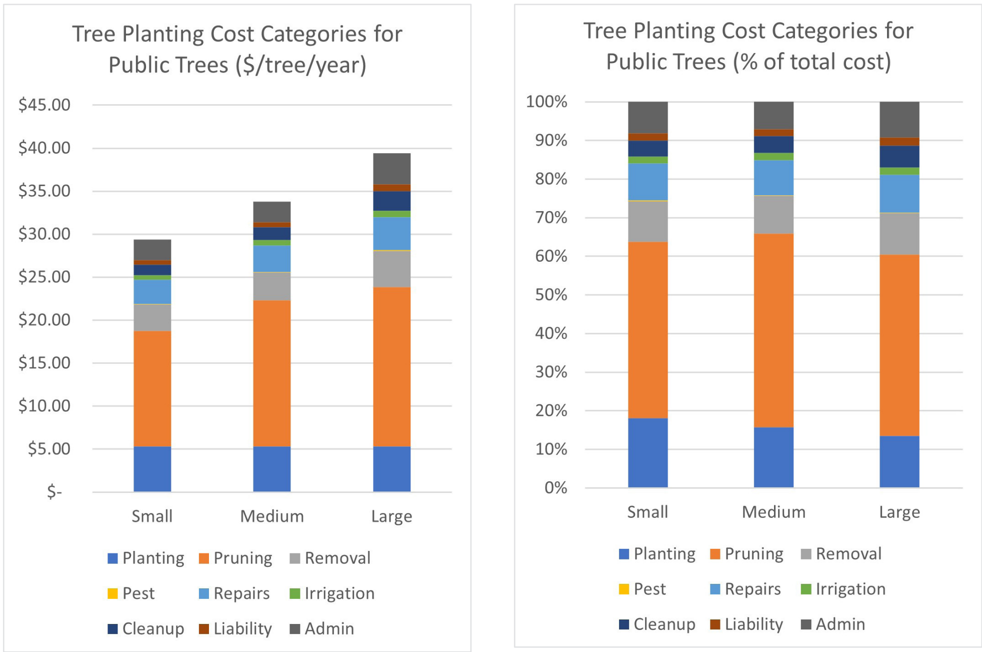


Figure 3. Tree Planting Cost Categories for Public Trees (left = $/tree/year, right = % of total cost; based on a 40-year average).

A critical factor to take into consideration when talking about public trees—especially street trees—is the potential cost associated with the planting sites. In an ideal world, all planting sites are readily usable without requiring any site modification such as concrete cutouts, raised medians, or creation of new tree wells. In this scenario, tree canopy goals are achieved by planting existing vacant locations. This is usually the assumption made in tree planting studies. The recognition of the complexity of every street, neighborhood and community in Los Angeles indicates that a realistic planting scenario would include planting sites requiring some level of modifications, thus driving up the planting costs. In the City of Los Angeles, a concrete cutout usually costs between $28 to $34 a square foot which includes cutting and breaking the concrete, disposing of the rubble, and backfilling the cut with soil. Assuming the creation of a 24 square foot tree-well, this would add up to an additional $816 to the planting costs we described earlier resulting in annual planting costs per tree increasing from $5.32 to $25.72. Due to this sharp difference in planting costs, municipalities may be tempted to prioritize readily plantable sites instead of focussing on environmental inequities and communities that have been heavily urbanized during the sprawling development of Los Angeles.

Table 2. Total Tree Planting Costs for Private and Public Trees from 4 selected studies ($/tree/year; based on a 40-year average).

	Yard trees	Public trees
Small tree (<20ft)	$19	$29
Medium tree (20-40ft)	$22	$34
Large tree (>40ft)	$24	$39

1.2 Local perspective from the Greater Los Angeles area

Estimating costs of street tree planting programs managed by municipalities and local governments is often a difficult task that relies on a combination of surveys with municipal foresters, arborists, and partial data from municipal forestry programs [5, 16-18]. We collected data from the Los Angeles County Department of Public Works and the City of Santa Monica Urban Forestry Program to compare tree planting costs identified earlier with local programs in southern California. This analysis focuses on public street trees only and excludes public park trees. Both street and park trees were included under the definition of "public trees" in previously cited studies [16-19] . Since costs for park trees tend to be lower than for street trees because there are fewer conflicts with infrastructure such as power lines and sidewalks, we can expect higher management costs when considering street trees exclusively.

1.2.1. Program and non-program expenditures

Table 3. Street Tree Planting Costs for Los Angeles County Public Works and the City of Santa Monica.

	Los Angeles County	City of Santa Monica
Service area	65% of Los Angeles County is Unincorporated - or 2,653 sq. miles	8.4 sq. miles
Tree planting (24-in box tree)	$550/tree	$290.80/tree
Establishment period	3 years to establish. Estimate of $1,080/tree. Requires resident support for irrigation.	Trees are under an 18-month guarantee after planting. Maintenance by contractors.
Post-establishment maintenance	3 or 6-year cycles depending on the growth rate of the tree. 2-year cycle for palm trees. Standard trim at $165/tree, accounts for cost increases over time as the tree matures.	2, 3, or 5-year prune cycle depending on species and location. Maintenance operations are usually outsourced. Safety prune costs $26.40/tree and full prune/crown reduction costs $52.80/tree.
Tree and stump removal	Cost is averaged over a 40-year lifecycle. No information on local mortality rate. $1,700/tree estimate.	Cost is averaged over a 40-year lifecycle. No information on local mortality rate. $1,692/tree (for a 40" DSH tree) **DSH = diameter at standard height*
Administrative costs	Factored into the tree planting costs. Estimated at about 10% of the total cost.	No available estimate for admin support. Assuming 10% of the total cost.
Infrastructure repairs	N/A - The cost of repairs has not yet been correlated with tree locations.	N/A - Sidewalk repair program does not identify the reason for repairs.
Liability costs	Claims managed by the County Chief Executive Office and not correlated with tree costs.	Unable to release data relating to risk management claims.

1.2.2. Data availability and limitations

Comparing data from a local municipal program (City of Santa Monica) and a county-wide program (Los Angeles County) will automatically result in significant cost differences as larger service areas will incur additional costs for setting up local forestry teams with the resources necessary to run street tree programs, especially when subdivided in several geographically separated districts. The City of Santa Monica also relies on contractors for a range of activities - including post-planting care - which may reduce program costs on the long run as observed in a 2012 analysis of San Francisco's urban forest where supplementing city staff with both private and nonprofit contractors was linked to a potential 30 percent reduction in program costs [21].

Infrastructure repairs or liability costs due to trip-and-fall claims - often referred to as non-program expenditures - can represent up to 20% to 30% of the total cost depending on the location [22]. Both the City of Santa Monica and the County of Los Angeles are not able to accurately monitor these cost categories as they are not directly managed by their forestry teams. Shared information systems between local government departments could help capture a more comprehensive cost for tree planting projects.

Common program expenditures - such as maintenance costs - can vary in structure as shown in our examples. Local governments in charge of street tree programs may rely on in-house crews, private contractors, nonprofit organizations, or a combination of these options. Maintenance cost post-establishment in Santa Monica is mostly rolled into staff salary for the younger trees as they can require an additional prune in between the 3 or 5-yr cycle managed by a private contractor. As a result, pruning costs may be underestimated as staff time or admin support is not correlated with tree program expenditures.

1.2.3. Results

We added to the results presented in Figures 4 and 5 data from a 2012 cost-benefit analysis of San Francisco's urban forest [21] to allow for a direct comparison with pre-existing similar research. The primary objective of this study was to evaluate the costs and benefits of a comprehensive, municipally operated street tree program in San Francisco managed by the Department of Public Works, a similar situation to Los Angeles County.

Maintenance costs - including pre-establishment care - range from 21% (City of Santa Monica, 5-year cycle) to 52% (LA County, 6-year cycle) of total cost depending on the location and maintenance practices. San Francisco reaches 61% of total cost which is consistent with the highest range identified in studies analyzed in Part 1. The City of Santa Monica manages to reach relatively low maintenance cost due to its unique 18-guarantee contract - a shorter establishment period than used by L.A. County - allowing the city to keep post-planting care below 10% of total cost. L.A. County's establishment costs are aligned with San Francisco's, representing about 20% of total cost.

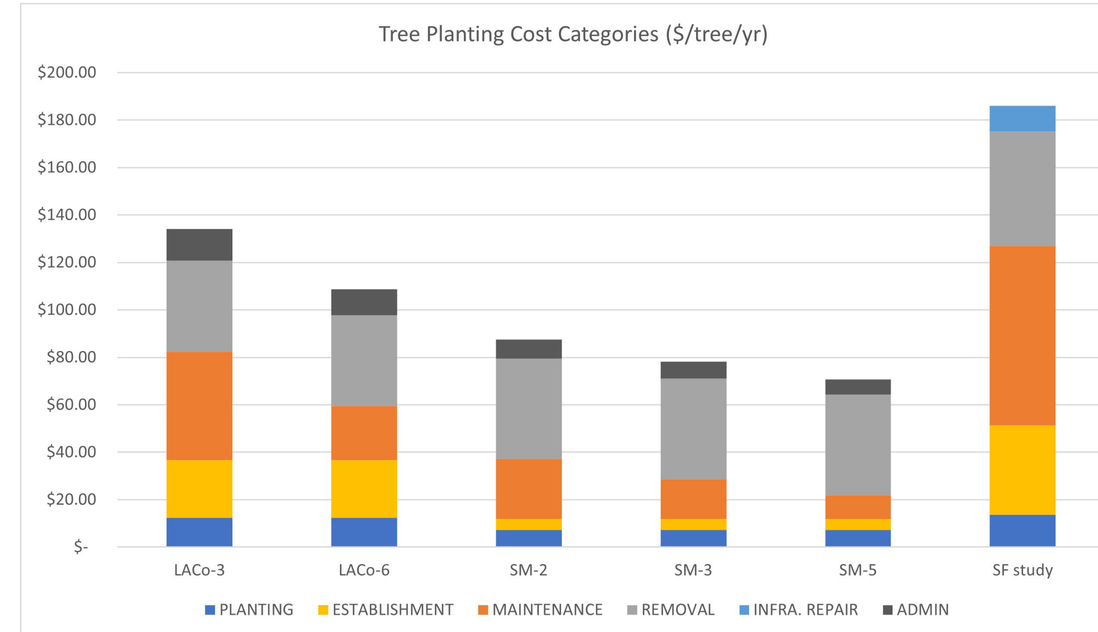


Figure 4. Tree Planting Cost Categories for Public Trees ($/tree/year, 40-year average; LACo-3 and LACo-5 refer to LA County data for 3 and 5-year maintenance cycles; SM-2, SM-3, and SM-5 refer to the City of Santa Monica 2, 3, and 5-year maintenance cycles; SF study refers to the 2012 San Francisco analysis).

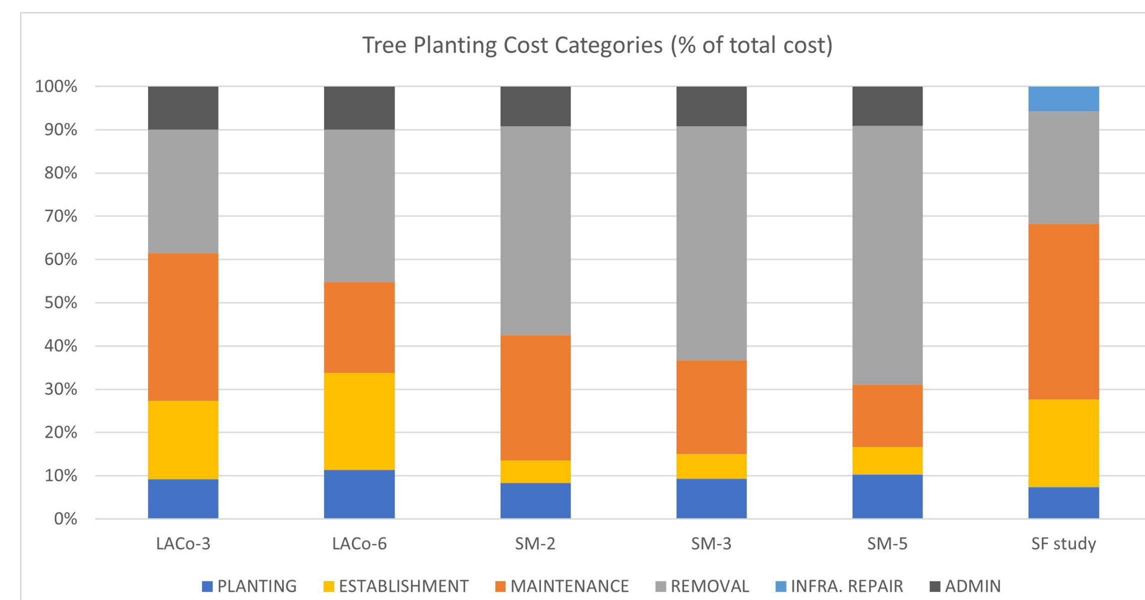


Figure 5. Tree Planting Cost Categories for Public Trees (% of total cost, 40-year average).

According to data collected, removal costs in L.A. County and Santa Monica can represent up to 59% of the total cost, a much higher proportion than previously identified in Part A. Regulatory restrictions, permit requirements, and accounting methods (discussed below) can drive up removal costs, especially in areas with sensitive and protected habitats like in L.A. County. Underestimating maintenance costs through a combined use of municipal crews, nonprofits and private contractors may result in an overestimation of program costs that can be measured more easily.

	LACo-3	LACo-6	SM-2	SM-3	SM-5	SF study
Planting	12	12	7	7	7	14
Establishment	24	24	5	5	5	38
Maintenance	46	23	25	17	10	76
Removal	38	38	42	42	42	48
Infrastructure Repairs*	-	-	-	-	-	11
Administrative*	13	11	8	7	6	-
TOTAL COST	134	109	88	78	71	186

Table 4. Average Annual Cost of Public Trees per Cost Category ($/tree/year, 40-year average)

Local street tree programs included in this analysis reveal annual costs up to four times the ones identified in Part A of this report, highlighting the need to tailor cost-benefit analysis to local conditions and regulations. Although tree planting cost categories can be easily identified, the complexity of the data collection process limits the ability of urban foresters to capture costs accurately and to provide a comprehensive answer regarding the annual cost of a tree over its lifecycle. The variation in maintenance costs can easily be attributed to pruning frequency -based on growth rate- and can increase significantly in the absence of a complete street tree inventory to support maintenance activity planning across a specific geographic area. Street tree inventories can provide valuable information about street tree maintenance needs, allowing for scheduled block pruning using private contractors and the reallocation of limited municipal staff to strategic resource management.

1.3. What causes tree planting costs to vary?

From our review of published studies and interviews with local urban foresters, public tree planting costs seem to vary greatly based on key program characteristics. This variability can be explained through the following components that need to be tailored to local conditions when performing an analysis of public tree planting programs.

Definition of "public tree"

We were able to restrict our analysis with the County of Los Angeles and the City of Santa Monica to street trees, excluding park trees that are included in the studies reviewed in the first part of this program. Management costs tend to be lower for park trees because of fewer conflicts with infrastructure such as power lines and sidewalks. Infrastructure conflicts for street trees may also result in early tree removal, increasing the relative share of these removal costs in the overall life-cycle of street trees compared to park trees.

Service area and accounting methods

We briefly mentioned how public entities with a large service area may incur additional costs in order to coordinate tree care and maintenance teams. Los Angeles County Departments provide municipal services for 120+ unincorporated areas located in 5 geographically separated districts. Studies included in our first review mostly focus on smaller municipalities similar to the City of Santa Monica. The tree planting cost data from these municipalities also often rely on general accounting and first-order approximations that need to be adapted and adjusted for local planting projects [16-19]. They provide an overview of the main expenditure categories that guided our interviews with local practitioners.

Mortality rates and removal costs

Long-term mortality data about the lifespan of urban trees is both rare and crucial to improve the accuracy of tree planting benefits over time. Based on a meta-analysis of survivorship data from 1 to 66 years after planting in different cities, the mean life expectancy of a street tree was estimated at 19-28 years, or an annual mortality rate between 3-5% [36]. Studies included in the first part of our report rely on annual mortality rates between 1-2% resulting in an underestimation of removal costs. In order to represent tree planting costs for L.A. County and the City of Santa Monica as a life cycle analysis, we averaged removal cost over the 40-year time period used subsequently in our environmental benefit estimations. Beyond the need for additional research on street tree longevity, the impact of removal costs on tree planting projects call attention to the importance of tree care and maintenance to reduce tree mortality rates in municipal programs.

Management costs can be reduced further by implementing *'right tree, right place'* practices by selecting locations and tree species that can reduce the need for supplemental costs besides routine pruning, or allow for cost-saving maintenance practices such as block pruning. Climate-ready trees and block planting projects using tree species with similar growth rates can help support these strategies.

Municipal crews, private contractors, and nonprofit organizations

The diversity of stakeholders in municipal and public tree programs increases the difficulty in accurately capturing management costs. For example, although the use of nonprofit organizations in growing urban forests and street tree programs is a preferred way to increase collaboration with local community organizers and educators, it lowers the overall costs of these programs reducing the accuracy of comparative studies and analysis.

PART 2 - Quantifying tree benefits for LA City - Council District 8 using i-Tree Eco

Los Angeles Council District 8 is one of the 15 districts of the City of Los Angeles representing much of Western South Los Angeles and home to more than 250,000 people, mostly Black and Latinx. The average life expectancy at birth - one of the most basic and important measures of the health of a community is 76.9 years, well below the county average of 82.3 years. It places low on the California Healthy Places Index (HPI) Clean Environment Score (32nd percentile), which is based on the average levels of four main sources of pollution: fine particles in the air (PM2.5), ground-level ozone (PM ozone), diesel particulate matter in the air (DPM), and groundwater contamination. PM2.5, PM ozone, and DPM are emitted from motor vehicles, industrial facilities, oil and gas wells, electric utilities, gasoline vapors, and chemical solvents. Groundwater can become contaminated by gasoline, oil, road salts, and other chemicals [23].

Based on the **Los Angeles County Tree Canopy Viewer**, tree canopy coverage for Council District 8 is very low at only 12.2%, well below the 21.6% average for the City of Los Angeles. The possible tree canopy coverage is estimated at 44.8%. Districts 9 (South L.A. and part of Downtown L.A.) and District 15 (L.A.'s southern area and the Port of Los Angeles) are the only two districts with lower canopy coverage at 11.7% and 10.0% respectively. Increasing urban canopy in those areas will deliver important health and environmental benefits by locally cleaning and cooling the air, reducing asthma and cardiovascular diseases as well as impact during increasingly common heatwaves. Given the long-term threat that increasing temperatures due to climate change poses to air quality, developing the urban forest in areas with high exposure to these pollutants should be a top priority for city planners and decision-makers.

The City of Los Angeles established the Green New Deal to increase tree canopy in areas of greatest need by at least 50% by 2028 to grow a more equitable urban forest that provides cooling, public health, habitat, biodiversity, energy savings, and other benefits [24, 25]. To reach that goal, a previous research group estimated that about 24,000 new trees needed to be planted in Council District 8 to reach 18.3 percent canopy cover [25]. We will use it as a baseline to quantify the potential environmental benefits of this scenario.

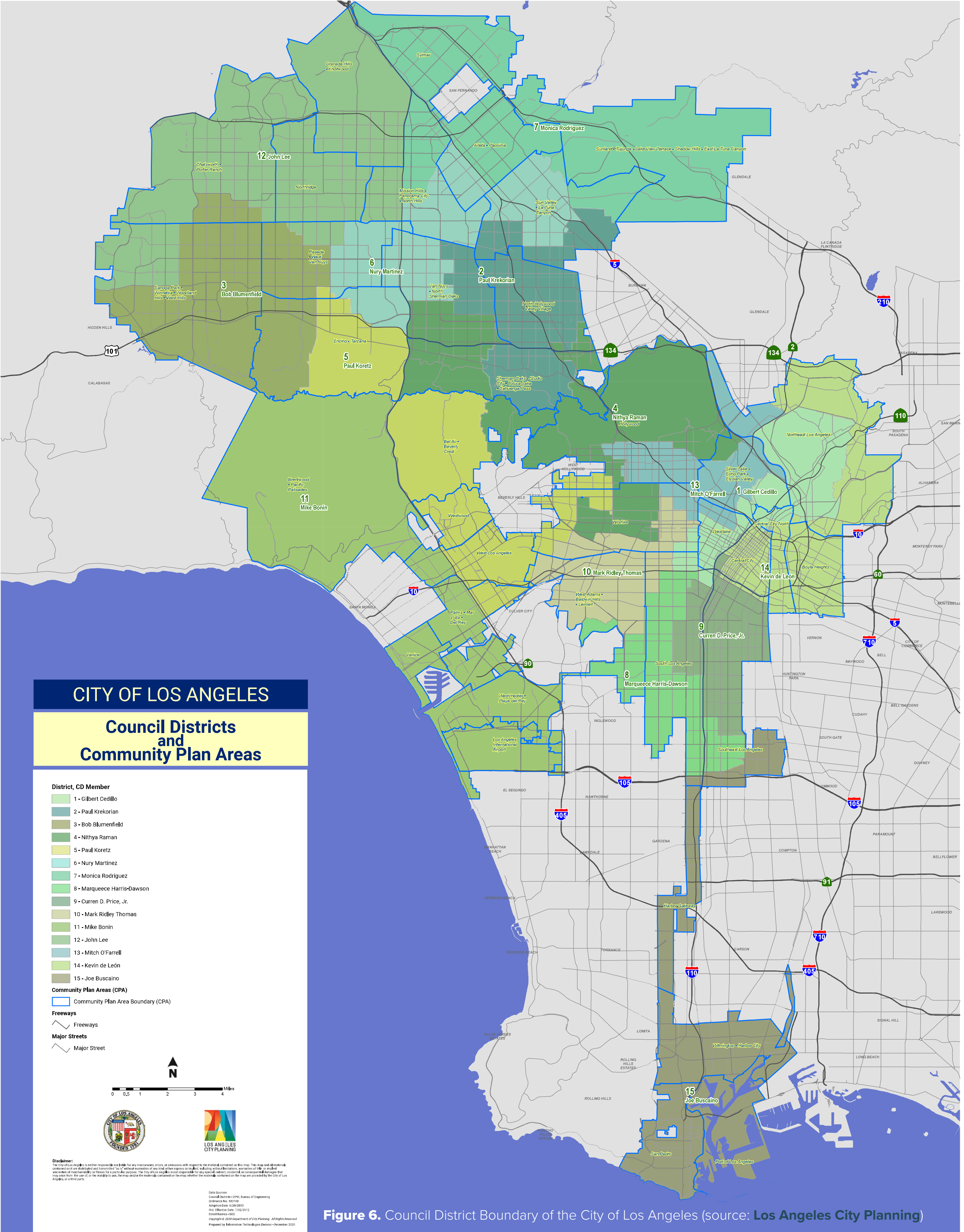


Figure 6. Council District Boundary of the City of Los Angeles (source: **Los Angeles City Planning**)

2.1 Methodology

To better understand the urban forest resource and its numerous values, the U.S. Forest Service, Northern Research Station, developed the Urban Forest Effects (UFORE) model, which is now known and distributed as i-Tree Eco at **www.itreetools.org**. i-Tree is a suite of computer software tools developed through a collaborative public-private partnership. These tools are designed to assess and value the urban forest resource, understand forest risk, and develop sustainable forest management plans to improve environmental quality and human health. The tools can assess individual trees and forests in both urban and rural areas. Over the past decade, the i-Tree suite's usage and capabilities have increased tremendously. As of the end of 2019, there have been more than 410,000 users of i-Tree tools in over 130 countries [26]. Based on the large number of trees (24,003) included in this planting scenario, we decided to use i-Tree Eco v6.0, one of the core programs, to calculate environmental benefits of this urban forest. We note that even though the environmental benefits of this scenario are significant, many environmental, economic, and social benefits still remain to be quantified.

The original dataset for this case study consisted of 24,003 trees. We assigned specific characteristics to each tree including species, DBH, land use, and placement around buildings. All trees were considered public street trees and the data was imported in i-Tree Eco as a complete inventory. More information about each parameter listed in Table 5 is available on the i-Tree Eco website.

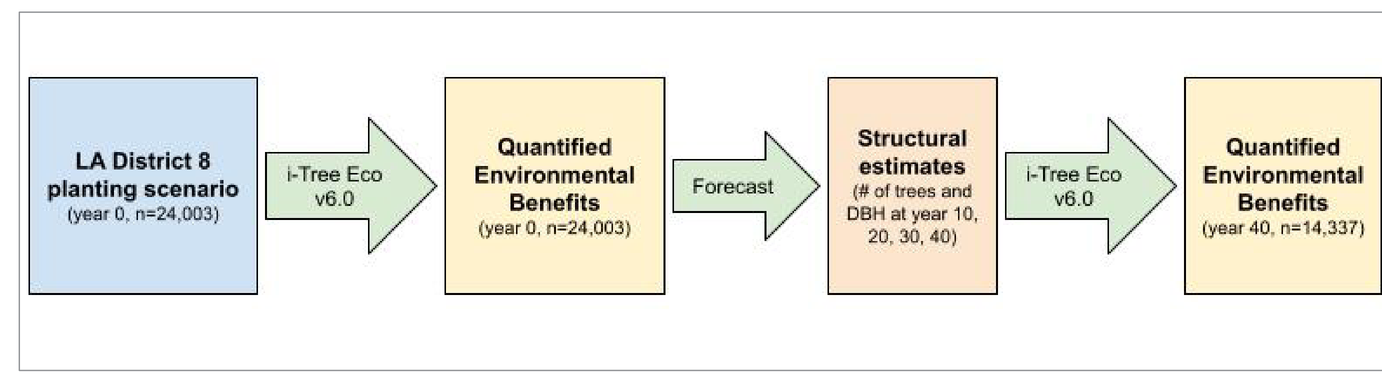


Figure 7. i-Tree Eco process for quantifying environmental benefits of L.A. Council District 8 planting scenario.

We used a separate component of i-Tree Eco v6.0, Forecast, to generate structural estimates including number of trees, and DBH. distribution of this tree planting scenario over time. We extracted data at year 10, 20, 30, and 40 after planting with an annual mortality rate of 1.6%. This annual mortality rate results in the death of about 40% of all trees after 40 years, a rate consistent with the average mortality scenario of the Los Angeles One Million Tree Canopy Assessment [27]. We ran i-Tree Eco v6.0 on the structural estimates to quantify environmental benefits including energy effect, carbon sequestration, pollution removal, avoided runoff, and structural values.

Table 5. Parameters of original dataset for tree planting scenario of 24,003 trees in L.A. Council District 8.

i-Tree Eco parameters	Description
Number of trees and diameter at breast height (DBH)	24,003 at year 0 with 100% in 0-3 in. DBH. category. See Table 6 for structural estimates at year 10, 20, 30, and 40.
Weather & Pollution	2015 weather and pollution data from weather station 722874-93134.
Species	African sumac *(Rhus lancea)*; Blue oak *(Quercus douglasii)*; Cajeput *(Melaleuca quinquenervia)*; Catalina Cherry *(Prunus ilicifolia)*; Cedar of Lebanon *(Cedrus libani)*; Chitalpa *(Chitalpa tashkentensis)*; Coast banksia *(Banksia integrifolia)*; Emory oak *(Quercus emoryi)*; Flaxleaf paperbark *(Melaleuca linariifolia)*; Honey mesquite *(Prosopis glandulosa)*; Indian rosewood *(Dalbergia sissoo)*; Island oak *(Quercus tomentella)*; Italian stone pine *(Pinus pinea)*; Lemon bottlebrush *(Callistemon citrinus)*; Netleaf hackberry *(Celtis reticulata)*; Osage orange *(Maclura pomifera)*; Peppermint tree *(Agonis flexuosa)*; Prickly-leaved paperbark *(Melaleuca styphelioides)*; Rose gum *(Angophora costata)*; Silverleaf oak *(Quercus hypoleucoides)*; Soapbark tree *(Quillaja saponaria)*; Strawberry tree *(Arbutus unedo)*; Sweet bay *(Laurus nobilis)*; Willard acacia *(Mariosousa willardiana)*; Texas ebony *(Ebenopsis ebano)*; Weeping bottlebrush *(Callistemon viminalis)*; White bottlebrush *(Callistemon salignus)*.
Crown health	Default value of 13% dieback.
Land use	Based on the South L.A. Community Plan (2017). See Table 7.
Direction to building	Based on the ground-truthing results of the Los Angeles One Million Tree Canopy Assessment [27]. See Table 8.
Distance to building	
Street tree (Y/N)	Yes
Public tree (Y/N)	Yes

Species selection

The selection of these species was based on data availability and is not intended to endorse their use in large numbers. The species selection is based on analysis of locally approved street trees, and a list of **climate ready trees** developed by University of California Davis to identify trees that perform well under stressors associated with climate change in the Southern California Coast climate zone. We are using the same distribution between small, medium, and large trees as in the 2007 Los Angeles Million Tree Canopy Assessment (small = 49%, medium = 42%, and large = 9%).

Diameter at breast height (DBH)

All trees are considered newly planted 24-in box trees at year 0. This is the smallest common box-size and is usually preferred by municipal tree planting programs to prevent vandalism and start with a more mature tree for the community. At the time of planting, DBH is assumed to be between 1 to 2.5-in depending on the species. The first category in i-Tree Eco covers DBH from 1 to 3-in without differentiating. Table 6 summarizes the DBH distribution as estimated by i-Tree Eco Forecast every decade up to 40 years after planting. The total number of trees decreases every year at a rate of 1.6%.

Table 6. Yearly distribution of DBH at year 10, 20, 30, and 40 as estimated by i-Tree Eco Forecast.

DBH (in.)	number of trees				
	year 0 (n=24,003)	**year 10** (n=20,868)	**year 20** (n=18,518)	**year 30** (n=16,396)	**year 40** (n=14,337)
0-3	24,003	-	-	-	-
3-6	-	17,413	-	-	-
6-12	-	3,455	18,518	7,542	3,896
12-18	-	-	-	8,854	8,912
18-24	-	-	-	-	1,529

Land Use

Land use types are based on data from the **South Los Angeles Community Plan** that was updated in 2017. Land use types were randomly assigned.

Table 7. Existing Land Use Distribution in the South Los Angeles Community Plan.

Land Use (Type)	Land Use (%)	i-Tree Eco Code	# of Trees
Single-family	29	R	6,961
Multi-family	42	M	10,080
Commercial	15	C	3,601
Industrial	2		480
Open Space	2	P	480
Public Utilities	10	U	2,401

Direction and Distance to Building

A combination of the direction from a tree to the closest part of the nearest building, and of the shortest distance from a tree to the closest part of the nearest building. We are using the distribution of potential tree planting sites developed for the Los Angeles Million Tree Canopy Assessment.

Table 8. Distribution (%) of potential tree planting sites around homes based on ground-truthing [27]

Distance class	N	NE	E	SE	S	SW	W	NW
Adjacent <20 ft	10.8	1.5	10.0	2.3	10.0	3.8	6.2	2.3
Near 21-40 ft	7.7	2.3	12.3	4.6	6.2	3.8	3.8	1.5
Far 41-60 ft	1.5	0.0	3.8	1.5	1.5	0.8	0.8	0.8

2.2 Quantified benefits

Though urban forests provide wide ranging environmental, social and economic benefits, only a few of these attributes can be assessed and quantified through standard data analyses. i-Tree Eco is designed to use data collected as complete inventories (or randomly located plots) with local hourly air pollution and meteorological data to quantify forest structure, environmental effects, and value to communities. This report summarizes results and values of forest structure, air pollution removal, carbon storage, annual carbon removal (sequestration), and building energy savings for a mature urban forest composed of 14,337 trees in L.A. Council District 8.

2.2.1. Air pollution removal

The American Lung Association recently released its 2021 "**State of the Air**" annual national quality report. It uses the most recent air pollution data, compiled by the U.S. Environmental Protection Agency, for the two most widespread types of pollution: ozone (O3) and particle pollution (PM2.5). One of the main findings indicates that 4 in 10 Americans - more than 135 million people - live in areas with unhealthy levels of ozone or PM2.5. Los Angeles remains the city with the *worst ozone pollution* in the nation.

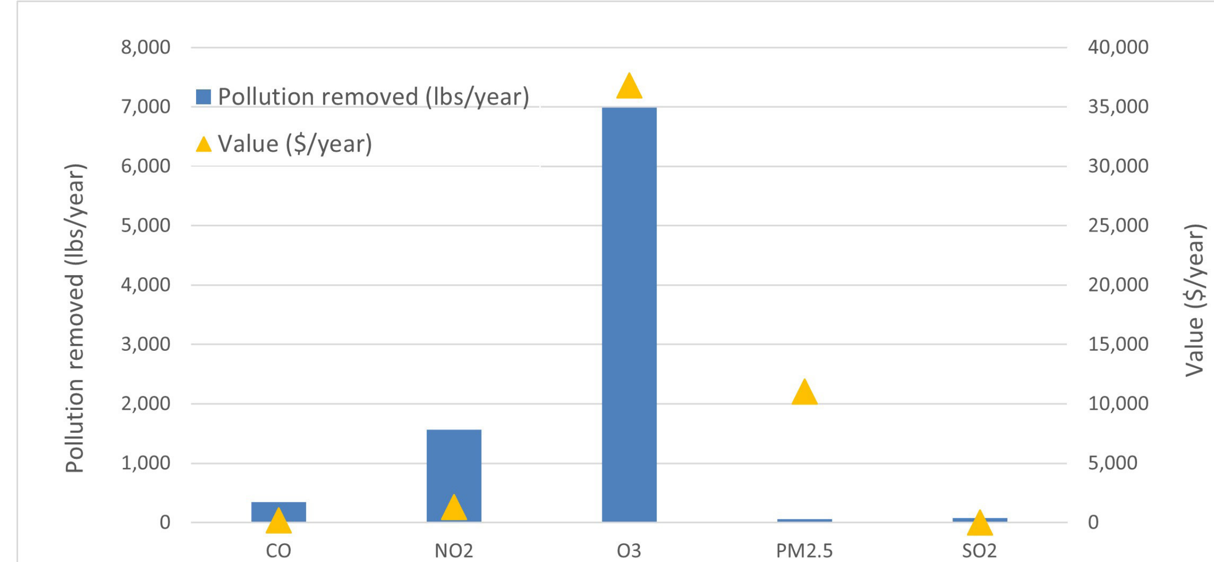


Figure 8. Annual pollution removal (bars) and values (points) by urban trees.

Pollution removal by trees was estimated using the i-Tree Eco model in conjunction with hourly pollution and weather data for the year 2015. Pollution removal was greatest for ozone, one of the main air pollutants in Los Angeles. It is estimated that trees remove 4.515 tons of air pollution (ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter less than 2.5 microns (PM2.5), and sulfur dioxide (SO_2) per year with an associated value of $49,486.09.

For this analysis, pollution removal value is calculated based on the prices of $1,380 per ton (carbon monoxide), $10,533 per ton (ozone), $1,693 per ton (nitrogen dioxide), $646 per ton (sulfur dioxide), $377,774 per ton (PM2.5). Default air pollution removal values are calculated based on local incidence of adverse health effects and national median externality costs. The number of adverse health effects and associated economic value is calculated for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter less than 2.5 microns using data from the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (**BenMAP**).

2.2.2. Carbon storage and sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power sources [28]. Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of trees in this scenario is about 214.5 tons of carbon per year with an associated value of $36,600.

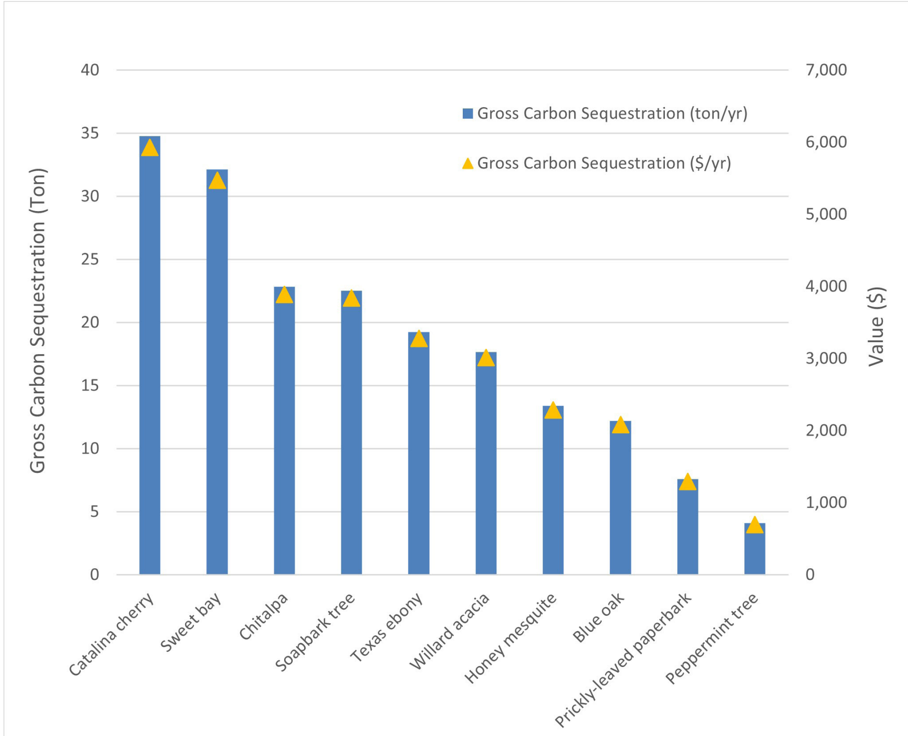


Figure 9. Estimated annual gross carbon sequestration (bars) and values (points) for urban tree species with the greatest carbon sequestration.

Carbon storage is another way trees can influence global climate change. As a tree grows, it stores more carbon by holding it in its accumulated tissue. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions [29]. When a tree dies, using the wood in long-term wood products, to heat buildings, or to produce energy will help reduce carbon emissions from wood decomposition or from fossil fuel or wood-based power plants.

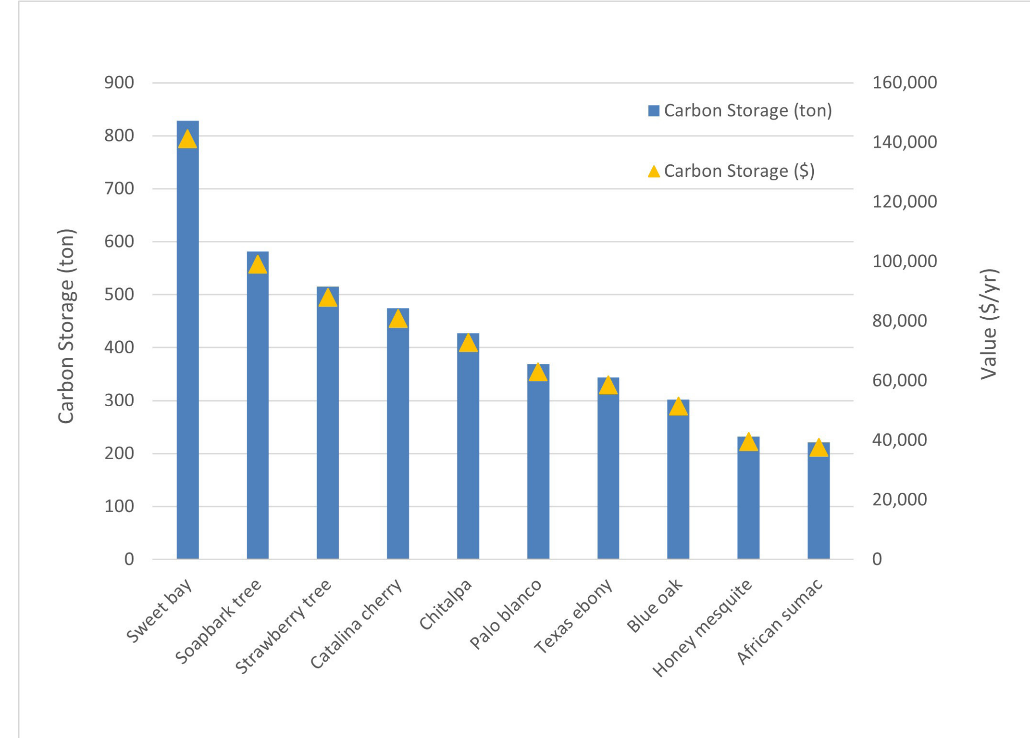


Figure 10. Estimated carbon storage (bars) and values (points) for urban tree species with the greatest carbon storage.

Trees in this scenario are estimated to store 5,620 tons of carbon valued at $958,000. Of the species sampled, Sweet bay (*Laurus nobilis*) stores the most carbon (approximately 14.7% of the total carbon stored) and Catalina cherry (*Prunus ilicifolia spp. lyonii*) sequesters the most with approximately 16.2% of all sequestered carbon.

2.2.3. Building energy use

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space conditioned residential buildings [30].

Table 9. Annual energy savings due to trees near residential buildings.

	Heating	Cooling	Total
MBTU[a]	-1,996	n/a	-1,996
MWH[b]	-92	315	223
Carbon avoided (t)	-39	26	-13

[a]Million British Thermal Units
[b]Megawatt-hour

Table 10. Annual savingsc (U.S. $) in residential energy expenditures during heating and cooling seasons.

	Heating	Cooling	Total
MBTU[a]	-25,825	n/a	-25,825
MWH[b]	-18,801	64,466	45,665
Carbon avoided (t)	-6,626	4,472	-2,154

[a]Million British Thermal Units
[b]Megawatt-hour
[c]Based on on the prices of $204.7 per MWH and $12.93 per MBTU

Trees in this scenario are estimated to reduce energy-related costs from residential buildings by $19,800 *annually*. We note that negative numbers in Tables 9 and 10 indicate that there was not a reduction in carbon emissions and/or value, rather carbon emissions and values increased by the amount shown as a negative value. In the energy model used by i-Tree Eco, in the climate zone of Los Angeles, only about a third of the 60' area out and around a structure will provide positive heating benefits. This area is roughly between 0' and 20' oriented North-northwest to North-northeast (340 to 19), and between 20' and 40' and oriented West-northwest to East-northeast (300 to 63). A significant number of trees for this project are located outside this optimal area and have a negative impact on heating.

2.2.4. Summary and study limitations

Urban forests have a structural value based on the trees themselves (e.g., the cost of having to replace a tree with a similar tree). In this scenario, 40 years after planting 24,003 trees in L.A. Council District 8, the structural value of this newly created forest is about $50.6 million, with annual functional values of $111,810 per year. We note that these estimations are only based on a limited number of environmental benefits available through i-Tree Eco and do not capture the full range of socio-economic benefits. We also assumed all trees were planted simultaneously in order to estimate the environmental benefits at maturity. Distributing tree planting over several years would provide a more realistic growth scenario and ensure better age diversity throughout the tree population.

The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees [31]. Annual functional values also tend to increase with increased number and size of healthy trees, and can easily reach several million dollars per year for a city like Los Angeles.

Total structural values:

- Structural value: $50.6 million
- Carbon storage: $958,000

Annual functional values:

- Pollution removal: $49,500
- Carbon sequestration: $36,600
- Reduced energy costs: $19,800
- Avoided runoff: $5,910

We note that many other functional values or benefits are not quantified in this report such as reduction in air temperatures and UV radiation, aesthetics and property value, wildlife habitat, and biodiversity. In cost-benefit analysis [16-19], aesthetics and other benefits are estimated by capturing differences in sales prices of properties that are associated with trees. This benefit can end up representing up to 72% of the total annual benefits of a public tree [19].

Social and economic benefits are also missing from currently available tools. Los Angeles is home to the most vivacious retail landscape in the United States. In 2016, the Los Angeles retail industry employed upwards of 400,000 people and doled a payroll of $13.3 billion. These numbers are twice the numbers in Chicago, the city with the second-largest retail presence in the United States. (U.S. Census Bureau). The impact of green infrastructure and urban forests on the economic activity of an area should be included as "shoppers are willing to spend 9%-12% more on goods, more time shopping, and will travel greater distances to shop in districts with high-quality trees" [32].

Next Steps

This analysis and associated case study reveals important areas of improvement needing to be addressed by sustaining coalitions of community groups and local governments for the development of a more equitable urban forest in Los Angeles.

Developing mechanisms to accurately capture comprehensive tree planting and management program costs

Collecting tree planting cost information is still a complex exercise of broad assumptions and budget patchworking across multiple local government entities that rarely have in place the necessary structure to capture each cost category described in this report, especially in situations where street tree management is carried out by in-house municipal crew, nonprofit organizations, and private contractors simultaneously. Multiple factors - including size of the service area and degree of urbanization - can impact local tree planting costs making comparisons with existing studies a complicated exercise. Most municipalities and local government entities are able to accurately capture direct programmatic costs such as planting, pruning and removal costs. Infrastructure repairs, lability and other administrative costs are however rarely correlated with urban forest programs, and often rely instead on broad assumptions in the few cases where they are included in cost-benefit analysis. It is critical for city managers and policymakers to invest in the infrastructure that will help identify the *true* local costs of tree planting programs to allocate the necessary funds to support the development and long-term health of urban forests. Delaying tree planting—or replacement—as well as necessary care and maintenance due to budget limitations can incur additional costs later in a tree's life cycle that were not anticipated, reducing the ability of future generations of urban foresters to address local environmental and social challenges [15].

Completing city-wide tree inventories to support future cost-benefit analysis with tree-specific data and management history

The City of Los Angeles is in the process of completing its first inventory of the more than 700,000 street trees under management by the Bureau of Street Services, with final reports by Council Districts due upon completion. Complete inventories are essential datasets with information relative to a tree's location, species, height and canopy size, and distance from nearest buildings. All these parameters are essential to perform true cost-benefit analysis and most of them are necessary for using modeling tools such as i-Tree Eco without relying on general assumptions. For example, the distance to the nearest building and the position of a tree relative to this building will provide more accurate energy savings quantification. The ability to track work history by linking each individual tree with maintenance actions will also provide granular data and insights for urban foresters to better control costs and respond to the needs of the urban forest at the local level.

Integrating socio-economic-health benefits of tree planting

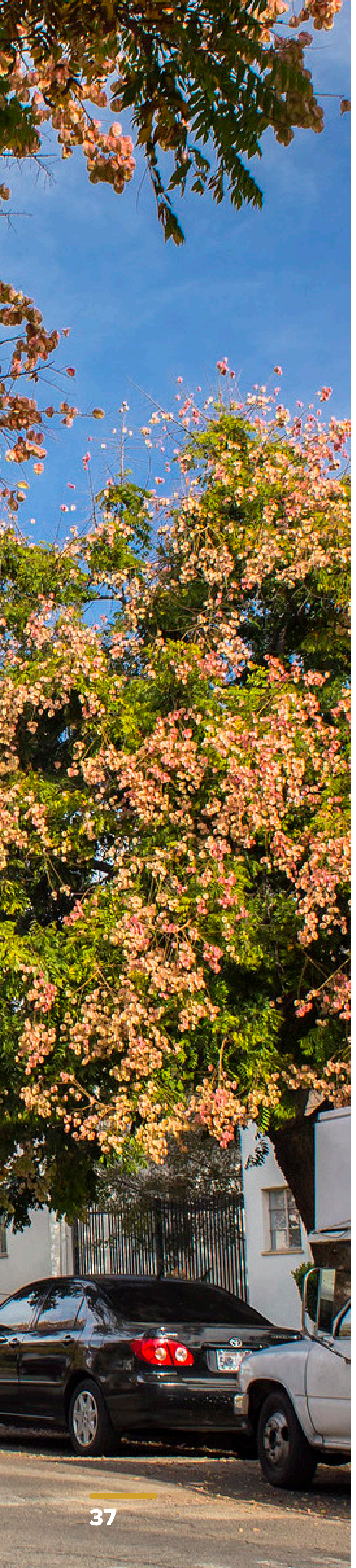
In a way similar to the lack of integration of indirect planting costs in municipal urban forestry budgets, the impact of trees on economic growth, social well-being, and physical and mental public health are rarely quantified [34]. The structural value and some environmental benefits can now be estimated using tools like i-Tree Eco—including for large planting projects—and their associated economic values can be simulated over the life cycle of the project. Urban trees are increasingly managed to maximize the few benefits we are able to quantify, posing the risk to see their capital value in urban planning restricted to a few ecosystem services. Urban trees are a central component of urban economies and human social interactions and need to be fully integrated to urban development strategies, not limited to functional environmental values.

Developing community programs to improve tree health monitoring and reduce costs

Maintenance and pruning represent some of the most important and best recorded costs over a tree's life cycle. Both Los Angeles County and the City of Santa Monica have implemented maintenance routines to ensure each tree is visited at least once every 5 or 6 years. As cities across the United States are growing their urban forest and increasing the number of trees under public management, tree health monitoring is becoming a critical area of research to ensure planting projects can yield the optimal return-on-investment (ROI) of time and resources [35]. Community tree stewardship programs can provide critical information on urban trees' health status—such as stress level and pest detection—and even increase tree care capacity by watering, mulching, and weeding trees planted in a community more frequently than planned in municipal maintenance routines. The City of Los Angeles should invest in a volunteer training program to maximize its urban forestry ROI. A stewardship program with trained local volunteers will provide urban foresters with reliable data to prioritize tree care, allowing for a more responsive management response, increase the urban forest health, and build local hubs of community scientists able to support the future of urban forestry in Los Angeles.

Using comprehensive and innovative urban forestry investment strategies to improve urban forest equity

Conventional cost-benefit analysis and the use of net benefit ratio as a decision-making tool has only reinforced environmental inequity by not prioritizing green investments in communities with built-up landscapes - such as freeways and other infrastructure. Tree planting costs can increase considerably when infrastructure modifications are required. We mentioned the example of concrete cutouts—a common requirement in built-up neighborhoods—that can multiply by 5 the annual planting costs per tree over its lifecycle. Historically disinvested neighborhoods are rendered less attractive for new planting projects by only considering the net cost-benefit ratio in its current state, unable to capture the complete range of environmental and socio-economic benefits. City planners and urban foresters should not select tree planting sites only by assessing their readily available potential - that tends to favor existing vacant locations - but also consider investments in green infrastructure alternatives like rain gardens, green walls/roofs, and bioswales to provide equivalent local environmental, social, and psychological benefits to frontline communities impacted the most by the consequences of climate change and the lack of urban nature.



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City Plants

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Los Angeles County Department of Public Works

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Appendix A: Tree planting costs summary tables

Table A1. Average Annual Cost of Yard Trees per Cost Category ($/tree/year, 40-year average)

	Small tree (<20ft)	Medium tree (20-40ft)	Large tree (>40ft)
Planting	9.26	9.26	9.26
Pruning	4.75	6.54	7.28
Removal	2.38	2.78	3.64
Pest & Disease	1.55	1.78	2.17
Infrastructure Repairs	0.54	0.48	0.76
Irrigation*	0.11	0.29	0.33
Cleanup	0.17	0.22	0.31
Liability	0.12	0.19	0.19
Administrative	-	-	-
TOTAL COST	18.87	21.66	23.92

Table A2. Average Annual Cost of Public Trees per Cost Category ($/tree/year, 40-year average)

	Small tree (<20ft)	Medium tree (20-40ft)	Large tree (>40ft)
Planting	5.32	5.32	5.32
Pruning	13.43	16.97	18.51
Removal	3.09	3.28	4.23
Pest & Disease*	0.04	0.06	0.08
Infrastructure Repairs	2.83	3.09	3.85
Irrigation*	0.52	0.61	0.74
Cleanup	1.22	1.46	2.26
Liability	0.54	0.62	0.80
Administrative	2.40	2.38	3.64
TOTAL COST	29.39	33.80	39.44

Table A3. Average Annual Cost of Public Trees per Cost Category ($/tree/year, 40-year average)

	LACo-3	LACo-6	SM-2	SM-3	SM-5	SF study
Planting	12.38	12.38	7.27	7.27	7.27	13.68
Establishment	24.30	24.30	4.51	4.51	4.51	37.63
Maintenance	45.79	22.89	25.41	16.94	10.16	75.60
Removal	38.25	38.25	42.30	42.30	42.30	48.33
Infrastructure Repairs*	-	-	-	-	-	10.72
Administrative*	13.41	10.87	8.05	7.17	6.46	-
TOTAL COST	134.13	108.69	87.54	78.19	70.71	185.96

Appendix B: Species composition, functional and structural values at year 40 after planting.

Species	#	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Structural Value
		(ton)	($)	(ton/yr)	($/yr)	(ft³/yr)	($/yr)	(ton/yr)	($/yr)	($)
African sumac *(Rhus lancea)*	780	220.72	37,643.60	0.26	44.08	2,296.59	153.52	0.12	1,284.86	2,730,289.52
Blue oak *(Quercus douglasii)*	660	301.88	51,485.41	12.21	2,081.69	7,293.73	487.56	0.37	4,080.57	2,583,190.64
Cajeput *(Melaleuca quinquenervia*	765	73.28	12,498.04	0.11	18.05	4,407.71	294.64	0.22	2,465.95	2,662,595.12
Catalina Cherry *(Prunus ilicifolia)*	694	474.32	80,896.22	34.77	5,929.79	5,006.70	334.68	0.26	2,801.06	2,383,863.18
Cedar of Lebanon *(Cedrus libani)*	145	150.79	25,717.41	0.14	24.2	1,376.53	92.02	0.07	770.12	648,021.87
Chitalpa *(Chitalpa tashkentensis)*	785	426.65	72,765.24	22.82	3,891.61	3,755.87	251.06	0.19	2,101.27	2,732,558.17
Coast banksia *(Banksia integrifolia)*	142	52.5	8,954.57	0.8	136.21	1,100.79	73.58	0.06	615.85	479,207.15
Emory oak *(Quercus emoryi)*	139	85.81	14,634.33	3.85	657.18	1,402.43	93.75	0.07	784.61	658,133.07
Flaxleaf paperbark *(Melaleuca linariifolia)*	677	56.17	9,579.75	2.44	416.81	4,539.17	303.42	0.23	2,539.50	2,346,971.69
Honey mesquite *(Prosopis glandulosa)*	673	231.93	39,556.19	13.4	2,284.84	3,422.98	228.81	0.17	1,915.03	2,301,510.04

Species	#	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Structural Value
		(ton)	($)	(ton/yr)	($/yr)	(ft³/yr)	($/yr)	(ton/yr)	($/yr)	($)
Indian rosewood *(Dalbergia sissoo)*	147	43.91	7,489.62	2.23	379.81	1,220.12	81.56	0.06	682.61	549,780.71
Island oak *(Quercus tomentella)*	140	82.67	14,098.98	3.77	642.64	1,589.20	106.23	0.08	889.1	632,832.16
Italian stone pine *(Pinus pinea)*	150	45.97	7,840.62	1.7	289.98	1,231.41	82.31	0.06	688.93	581,290.10
Lemon bottlebrush *(Callistemon citrinus)*	794	82.64	14,094.73	3.66	623.89	3,304.92	220.92	0.17	1,848.98	2,770,059.41
Netleaf hackberry *(Celtis reticulata)*	660	108.53	18,509.22	0.34	58.06	6,120.12	409.1	0.31	3,423.97	2,355,640.68
Osage orange *(Maclura pomifera)*	144	62.85	10,718.87	0.08	12.97	1,442.62	96.43	0.07	807.09	521,222.93
Peppermint tree *(Agonis flexuosa)*	628	96.45	16,450.39	4.1	698.78	4,493.34	300.36	0.23	2,513.86	2,274,159.15
Prickly-leaved paperbark *(Melaleuca styphelioides)*	807	114.36	19,503.80	7.59	1,294.68	4,676.07	312.58	0.24	2,616.09	2,803,708.73
Rose gum *(Angophora costata)*	142	17.59	3,000.55	0.74	126.99	1,760.59	117.69	0.09	984.98	479,908.51
Silverleaf oak *(Quercus hypoleucoides)*	145	88.51	15,096.24	4	682.83	1,512.10	101.08	0.08	845.96	677,022.73

Species	#	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Structural Value
		(ton)	($)	(ton/yr)	($/yr)	(ft³/yr)	($/yr)	(ton/yr)	($/yr)	($)
Soapbark tree *(Quillaja saponaria)*	662	581.46	99,168.84	22.52	3,841.52	4,439.17	296.74	0.23	2,483.55	2,312,967.11
Strawberry tree *(Arbutus unedo)*	792	515.49	87,917.61	0	0	4,388.14	293.33	0.22	2,455.00	2,418,433.71
Sweet bay *(Laurus nobilis)*	679	828.29	141,265.68	32.14	5,482.07	5,549.88	370.99	0.28	3,104.95	2,356,720.58
Texas ebony *(Ebenopsis ebano)*	680	343.21	58,534.16	19.24	3,280.92	4,208.30	281.31	0.21	2,354.38	2,343,960.63
Weeping bottlebrush *(Callistemon viminalis)*	760	72.98	12,447.09	3.85	656.88	2,164.37	144.68	0.11	1,210.88	2,688,009.41
White bottlebrush *(Callistemon salignus)*	791	91.92	15,676.51	0.1	17.83	3,272.25	218.74	0.17	1,830.70	2,749,317.08
Willard acacia *(Mariosousa willardiana)*	756	369.02	62,937.10	17.67	3,014.23	2,477.87	165.64	0.13	1,386.28	2,577,827.60
TOTAL	**14,337**	**5,619.90**	**958,480.77**	**214.53**	**36,588.54**	**88,452.97**	**5,912.73**	**4.50**	**49,486.13**	**50,619,201.68**

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12601 Mulholland Drive | Beverly Hills, CA 90210
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