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Review

Configurations for Four Urban Tree Species in the Santiago Metropolitan Region and Their Impact on the Environment According to CO_2, PM2.5, Biogenic Volatile Organic Compounds and Water Resource Criteria

Marco Antonio Díaz [1,*], David Blanco [2,*], María Belén Almendro-Candel [1], Ignacio Herrera [2], Ignacio Allende [2], Pablo Pulgar Rubilar [1], Marcela Lizana [3], Francisco Pardo [4], Luis Perillán [5] and Carolina Tapia [2]

[1] Department of Agrochemistry and Environment, Miguel Hernández University of Elche, Av. Universidad s/n, 03202 Elche, Spain; mb.almendro@umh.es (M.B.A.-C.); pablo.pulgar@goumh.umh.es (P.P.R.)
[2] Department of Construction Sciences, Universidad Tecnológica Metropolitana, Dieciocho 161, Santiago 833-0689, Chile; ignacioahr@gmail.com (I.H.); i.allendel@utem.cl (I.A.); ctapia@utem.cl (C.T.)
[3] Doctoral Program in Local Development and International Cooperation, Universitat Jaume I, Av. Vicent Sos Baynat s/n, 12071 Castellón de la Plana, Spain; al420032@uji.es
[4] Department of Education, Universidad CEU Cardenal Herrera, C/Grecia 31, 12006 Castellón de la Plana, Spain; francisco.pardo@uchceu.es
[5] Faculty of Social Sciences, Universidad de Chile, Av. Libertador Bernardo O'Higgins 1058, Santiago 833-0689, Chile; luis.perillan@gmail.com
* Correspondence: marco.diaz@goumh.umh.es (M.A.D.); dblanco@utem.cl (D.B.); Tel.: +56-22-787-7375 (M.A.D.); +56-965-16-10-57 (D.B.)

Abstract: The rapid and disproportionate growth of many cities in South America, such as Santiago de Chile, has not included a design that considers the impact caused. Furthermore, industrial and housing growth has been based mainly on unsustainable economic criteria, attributing less importance to environmental criteria. This has caused problems related to global warming, pollution, water scarcity and health, especially harming populations with fewer resources. This study estimates and compares the impact of four tree species commonly used at the urbanization level, according to variables such as carbon dioxide (CO_2), fine particulate matter (PM2.5), water resources, and biogenic volatile organic compounds (BVOCs). Then, we will use the variable PM2.5 to assess the trees' impact on the population and their economic resources using these tree species as a method of capturing this pollutant. The results obtained will be used to determine which one of the four species is the most suitable in each type of space within the Metropolitan Region of Chile (small spaces, uncultivated areas, large spaces near industrial areas, areas with patients with breathing problems, etc.) according to three criteria: a comparison between species using the number of trees in the investigated territory; contrasting the species with the amount of social housing; and a comparison between the species according to the total number of dwellings.

Keywords: environment; global warming; carbon dioxide

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1. Introduction

Urban development has experienced constant problems over time due to the large number of variables that come into play within cities. The most important ones, according to a state-of-the-art study carried out, are the effect that the increase in population has had on the demand for land use [1], connectivity and proximity between territories [2,3], the detriment to the environment [4], accessibility to goods and services [5], and harmful effects on the health of the population [6], among others. Factors like these lead to urban landscaping, which is the result of the effects produced by the interrelation between population growth and city expansion [7]. However, from the start, this process was

developed as a system where ornamental aspects prevailed [8] and with a lack of planning, among other characteristics [9,10].

Today, the situation is different, since many professions are adapting their vision into a more sustainable one with a serious commitment to national and international treaties, laws and regulations. This is how, for example, the choice of trees for a project went from covering a simple need to impacting other economic, environmental and social aspects [11–13]. Therefore, this selection should be more rigorous when distinguishing between the best options for a project based on their environmental, economic, social and public health advantages. However, this situation does not conform to reality because developing countries present many difficulties in developing design and management systems [14].

Chile currently has a legislative proposal that aims to regulate the planting of trees in the city, which would grant certain responsibilities in this matter to municipalities [15]. However, the country also neglects aspects that are essential to achieve positive changes. An example is the large gap between green areas within the Metropolitan Region of Santiago de Chile, where communities with greater financial power have access to larger green areas and better management plans [16,17]. At the same time, pollution follows the same distribution pattern, where communities of a medium or low social stratum register higher pollution levels [18–21]. This is also affected by geographical factors that worsen the air quality during winter [22,23].

Meanwhile, the projected housing demand in Chile in 2022, according to estimates from the Ministry of Housing and Urban Development (MINVU) based on data from the 2017 census, rose to 643,534 homes and is projected to reach 1,300,000 in 2035. This deficit is due to factors such as population growth, the high cost of housing, overcrowding, precariousness and the lack of effective public policies on environmental matters.

On 3 July 2022, the Republic of Chile presented the Emergency Housing Plan (PEH, in Spanish) 2022–2025 (Emergency Housing Plan—Ministry of Housing and Urban Development (Plan de Emergencia Habitacional: Las claves de la estrategia y las metas por región—Gob.cl (www.gob.cl) accessed on 5 October 2023), a strategy developed by the MINVU to urgently address Chile's housing deficit, and this is part of the new Law of Social and Urban Integration. Its main objectives include recovering the state's central role in housing planning and management, along with delivering 260,000 homes during the government's current term. Thanks to the PEH, it will be possible to cover at least 40% of the current housing requirements, which are concentrated, mainly, in the Metropolitan Regions (accounting for an estimated 40% of the deficit at the national level), followed by Valparaíso and Biobío.

This context has produced a historic opportunity for the present proposal to use native tree species to capture CO_2 and improve the environmental indicators, mainly in the Metropolitan Region of Chile, which has a population of 7,112,808 inhabitants according to the last census carried out in 2017.

These reasons create the need to learn about the economic, environmental and health impacts that the choice of tree can have in an urban environment such as the Metropolitan Region of Santiago. The results could help obtain a viewpoint for the medium term and provide the bases for future regulations.

2. State of the Art

Over the years, environmental problems such as urban heat islands, soil erosion, water stress or the generation of various types of waste and pollution [24–26] (all products of urbanization) have been worsening as cities grow, representing a constant concern for authorities. This is how various international groups and countries sought strategies to reduce or control these phenomena. During the development of these measures, it became clear that one of the most controversial issues is the relationship between the uneven development of green and urban areas depending on the wealth and social context of the city area concerned, leaving out aspects such as the link between green areas and economic

growth, the insertion of trees in cities, the inequality between socioeconomic groups and the proportion of wooded areas. This led the European Union (EU) to investigate new alternatives and to propose three policies on the management and promotion of green areas and urban trees. These three policies are building green infrastructure for Europe [27], the European Green Deal [28] and the European Union Strategy on Biodiversity for 2030 [29].

The 'Building a Green Infrastructure for Europe' project [30] set out to promote and facilitate green infrastructure projects using existing financial, political and legal instruments. On the other hand, it managed to obtain financing through the Cohesion Fund, intended for states that present a gross national income per inhabitant lower than 90% of the EU average [31], and the European Regional Development Fund, which strengthens economic and social partnerships in the EU by correcting regional imbalances [32]. The EU also supports research and innovation in the environmental field [33].

The 'European Green Deal' [28] developed a program focused on biodiversity through proposals that seek to establish greener cities and that promote urban spaces, allowing the protection of biodiversity and control over its deterioration. This agreement also contains detailed information on green infrastructure, the percentage of green areas in cities and their distribution, and the percentage of representativeness of artificial and natural elements, in addition to the number of green areas per person [34].

In Europe, there is quite a unique development at the country level, since each one autonomously generates its own laws, norms or standards for designs that fit their cultural, economic, political and urban realities. Some European countries have policies similar to the Chilean regulations on urban planning, like Great Britain, where there are national technical documents that establish voluntary protocols [35]. On the other hand, in Spain, each city decrees its own system to guarantee its well-being under a mixed legal framework, with voluntary manuals [36] or mandatory provisions through communal ordinances [37,38]. Meanwhile, Germany stands out because it has legal information at the governmental [39] and local levels [40–42], and all its documentation is mandatory.

At the Chilean national level, there is a legal body governed by the General Urban Planning and Building Ordinance (OGUC) [43], which is not rigorous or specific in terms of the implementation of tree species. In its articles, it defines green area projects as 'plantations and ornamental works'. Meanwhile, the Organic Constitutional Law of Municipalities [44] establishes that it is the municipalities' task to uphold 'communal cleanliness and orateness' and that they must have a municipal unit to do so. Therefore, each city has different parameters for planning, using and caring for urban tree species.

In the absence of specific normative or legislative figures, the available options clearly tend to be voluntary or informative. These categories include technical manuals [45,46], studies on the link between the number of green areas and the people's socioeconomic level [47], magazines on the situation of urban trees [48], studies on quality of life in relation to tree species [49] and private initiatives [50]. However, in 2018, the Ministry of Agriculture set out to produce a law on urban trees [51] and created a legislative proposal in April 2021 [15].

Regarding financing these projects, Chile does not have a clear public policy that promotes, supports or subsidizes sustainable urban development proposals, ignoring aspects such as the maintenance of species (pruning, root care and growth control), soil conservation (nutrients, composition and water) and the relationship between the tree and its environment (interactions between signs, poles, electrical wiring and diseases). It is up to each municipality to ensure the creation and conservation of green areas and trees, creating a gap between municipalities with a high purchasing power [52,53] versus others with fewer resources [54,55]. This could be one of the reasons behind a possible link between socioeconomic level and environmental pollution [47,56,57].

In light of the above, it is highly important to analyze the environmental behavior of urban tree species (in this case, one introduced and three native trees) frequently used in the Metropolitan Region of Santiago de Chile (represented in Figure 1) with respect to four variables: carbon dioxide (CO_2) emissions and capture, PM2.5 particulate matter

emissions and deposition, biogenic volatile organic compound (BVOC) emissions, and the water requirement and amount of rainwater.

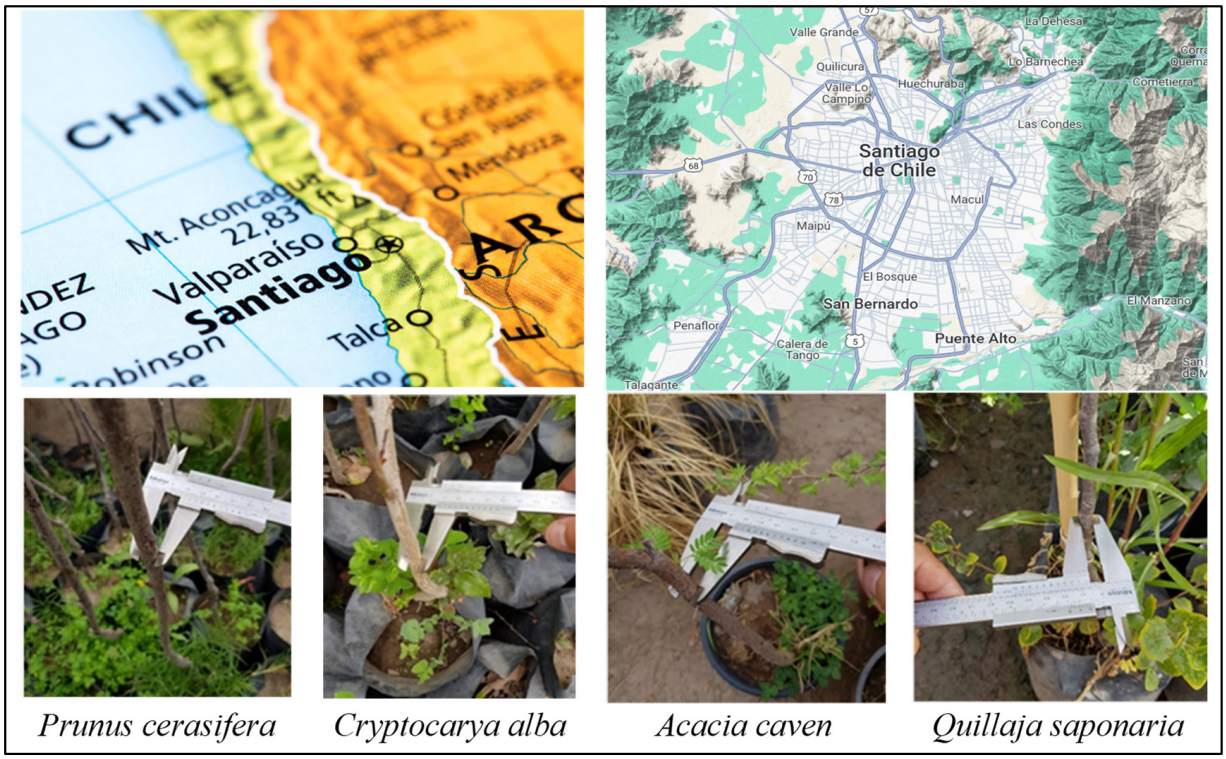


Figure 1. Graphic references of the area and species being studied.

On the other hand, the comparison between using tree species only in social housing or using them in all existing housing will allow us to reveal the potential significant differences in the environmental, economic and health aspects using the same parameters mentioned in the previous paragraph.

3. Materials and Methods

Since this applied methodology is our own, it has not been published and is not referenced in the literature, and it is summarized so that it can be replicated in other research.

The first step is determining, according to the statistical criteria laid out in the Chilean National Census of 2017, the population size, available social houses and the total number of homes that exist in the area. This will make it possible to learn about the number of inhabitants that are environmentally affected in the region.

Then, the measurement of the tree trunk is used to analyze two variables. The first is related to the maturity of the species in question, since it is closely linked to the trunk's diameter. However, the growth in diameter is statistically insignificant for the first 10 years, which is why it is more important during this period to calculate the second variable, which is the maintenance cost of each species.

Next, the following parameters, the criteria of maintenance, permanence over time and relationship with its environment for each tree, are studied. Subsequently, with the results obtained for each of the species, comparative analysis is conducted. To do so, the variables chosen are the following:

(a) Maintenance: investigating the data related to tree management over time and how they should be cared for according to sustainable parameters.
(b) Soil conservation: providing the necessary elements to the land that maintains the tree so that its nutritional contribution is sustainable over time.

(c) Tree–environment relationship: characteristics of the interrelation of the species with elements of the city and the environment.

This would make it possible to obtain information to project a city toward greater constructive, urban and architectural integration, since the city's environmental neighborhoods would improve, and the buildings' conditions would improve.

4. Application of the Methodology

4.1. Research Location

This research focused on the Santiago Metropolitan Region in the central area of the country, which is surrounded by mountain ranges. In the summer, there is a thermal inversion layer that enables the evacuation of certain pollutants. In the winter, the opposite occurs as the layer descends [58–60].

4.2. Population

The Santiago Metropolitan Region has the highest population index in the country and the largest urban area [61,62]. This research was backed by data from the National Institute of Statistics (INE) and a methodological report on urban growth from the Ministry of Housing and Urban Planning (MINVU), which showed the highest rate of population growth in the region.

4.3. Tree Species

We analyzed a set of autochthonous tree species and an introduced species planted in the city, comparing their characteristics and behaviors in an urban environment using urban tree recognition guides and studies related to BVOC emissions [63–67].

4.4. Dwellings

In this study, we also looked at social interest housing, with the aim of promoting community integration and the sustainable development of people in vulnerable socioeconomic situations. Social housing was defined according to the DS49 housing subsidy granted by the state to families in a situation of social vulnerability and in need of housing. We used data from the MINVU Urban Observatory and the decree law that transfers the 'social housing' programs and the law on real estate co-ownership to the Ministry of Housing and Urbanism [68–71]. In addition, the types of houses in the area, which includes social housing, were analyzed to compare the results [72,73].

The total number of homes, whether they are social or non-social, addressed in this study corresponds to official statistics from the corresponding government entity [68,69] and is presented in Table 1.

Table 1. Number of existing homes in the Santiago Metropolitan Region. Source: [1] Urban Observatory, Ministry of Housing and Urbanism [68]; [2] National Institute of Statistics (INE) [61].

Social Dwellings [1]	Total Dwellings [2]
1,219,311	6,486,533

The introduced species with deciduous leaves and edible fruits and which is currently the most used species in the city is Ciruelo Flor (*Prunus cerasifera Ehrh*) [74]. The others are native: Peumo (*Cryptocarya alba*) and Quillay (*Quillaja saponaria*), with perennial leaves, and Espino (*Acacia caven*), with deciduous leaves and less foliage [74]. Although they cannot compete in regard to quantity with the first species, they are readily available on the market.

The number of individuals or trees that each species has, shown in Table 2, was calculated based on the percentage of real prevalence in a study of tree diversity [74].

Table 2. Total number of trees that exist for each tree species and percentage of representativeness within the Santiago Metropolitan Region. Source: twelve-year change in tree diversity and spatial segregation in the Mediterranean city of Santiago, Chile [74].

Tree Species	Individuals	Percentage of Representativeness (%)
Ciruelo de Flor (*Prunus cerasifera Ehrh*)	465,608	7.4
Peumo (*Cryptocarya alba*)	51,594	0.82
Espino (*Acacia caven*)	232,175	3.69
Quillay (*Quillaja saponaria*)	218,962	3.48
Total	968,339	15.39

4.5. Capture and Emission of CO_2

CO_2 is currently the gas that contributes the most to global warming [75]. This is why most countries worldwide have made commitments to reduce these emissions. In Chile, there is a National Plan [76] that sets out to reduce it by 30% by the year 2030.

To help balance these levels out, we learned about the CO_2 capture capacities of each species by using the following procedure, In the case of the introduced species (Ciruelo de Flor), we conducted an analysis in Ecuador Park in the city of Concepción [77] using its surface area, the number of individual Ciruelo de Flor trees and CO_2 absorption capacity to establish proportional relationships and the absorption capacity of this gas that the city of Santiago could have; for the other species, we analyzed a native forest [78].

Finally, to estimate the individual absorption capacity of each tree (kg/m^2), we determined the characteristic diameters and crown surfaces [63,79–81] of each species, using the result to calculate the absorption capacity. An individual tree's maximum capacity to capture CO_2 during a given period is shown in Table 3.

Table 3. Capture capacity of CO_2 on an individual level and for each species measured over a year (source: own).

Arboreal Species (Individual)	Capture of CO_2 (kg/Year)
Ciruelo de Flor (*Prunus cerasifera Ehrh*)	0.00478
Peumo (*Cryptocarya alba*)	2.00000
Espino (*Acacia caven*)	0.78995
Quillay (*Quillaja saponaria*)	3.60000

The information was extracted from the website of the National System of Greenhouse Gas Inventories (SNI) of the Ministry of the Environment (MMA) for the years 2017 and 2018 [82]. For 2016, there was information at the regional level [83,84], which was used to project values at the Metropolitan Region level for 2017 and 2018. There was no information for 2019, so the results of Table 4 were obtained using a geometric method and trend line, thus obtaining a relationship between emissions and the surface of the study area.

Table 4. Emissions of CO_2 in the years 2017, 2018 and 2019 (source: own).

Item	2017	2018	2019
Emissions of Carbon Dioxide, CO_2 (kg)	22,243,120,000	22,462,520,000	23,288,888,888

4.6. PM2.5 Particulate Emissions

Particulate matter is currently a problem in urban areas of the world, raising the number of respiratory diseases in the winter and causing an increase in said diseases and the collapse of health systems [85,86]. This creates the need to assess trees' capacity to deposit or capture particulate matter.

We obtained the deposition capacity of Ciruelo de Flor from the analysis carried out in Ecuador Park [77] and of the other species from a report carried out in the research region [87]. The information collected is shown in Table 5.

Table 5. Estimated deposition capacity of PM2.5 on an individual level and according to each species, measured over a year (source: own).

Arboreal Species (Individual)	PM2.5 Deposition (kg/Year)
Ciruelo de Flor (*Prunus cerasifera Ehrh*)	0.001
Peumo (*Cryptocarya alba*)	2.054
Espino (*Acacia caven*)	0.736
Quillay (*Quillaja saponaria*)	2.563

4.7. Water Requirement and Rainfall

There have been droughts in Chile since 2007 [88]. To combat them, the government has implemented measures for the management of water resources [88–90]. The deficient management of water use [91] has increased the water stress in many areas of the country, requiring extensive technological management to reduce the costs of the resource in the long term [92]. An example of relevant management could be the use of ozone for treating gray water, which yields recovered water of a high quality for reuse [93–96]. This research used the parameter 'Water requirement' ($m^3/m^2/year$) to analyze the necessary amount of this resource according to each tree species and their consumption to reach maturity [80,97–100]. These data were contrasted with the amount of annual rainfall in the Metropolitan Region ($m^3/m^2/year$), which was obtained from the website of the Chilean Meteorological Directorate [101].

This allowed us to obtain a balance of demand and availability of the resource, laying the foundations for an eventual reform of the design and planning of the urban landscape. This reform could include, for example, the option of irrigation with gray water in areas with water stress [93].

Table 6 shows the figures expressed according to the amount of water required by each species. Table 7 shows the amount of rainfall.

Table 6. Average amount of water required by each tree of a species during a year (source: own).

Arboreal Species (Individual)	Water Requirement (m^3/m^2/Year)
Ciruelo de Flor (*Prunus cerasifera Ehrh*)	0.66
Peumo (*Cryptocarya alba*)	0.10
Espino (*Acacia caven*)	0.10
Quillay (*Quillaja saponaria*)	0.15

Table 7. Rainfall in the Santiago Metropolitan Region in the years 2017, 2018 and 2019 (source: Chilean Meteorological Directorate [101]).

Item	2017	2018	2019
Rainfall ($m^3/m^2/year$)	0.28	0.15	0.08

4.8. Emissions of Biogenic Volatile Organic Compounds, BVOCs

Chileans do not know about the full extent of the consequences of BVOCs. In the proposed study area, there are no considerations in this regard, revealing the inexistence of public policies and clear proposals on the subject. This is worrisome, since a large percentage of existing trees are potentially BVOC emitters. There are studies [102–105] that reveal the detrimental effect that this compound has on the health of the population and the environment.

We analyzed the emission potentials (μmol m^{-2} s^{-2}) of each species to learn the impact that each one has on the environment [66]. The objective of this procedure was to lay the foundations for future projects with trees in the city, and thus, reduce the effects that these emissions have on the population's health. See Table 8.

Table 8. Emissions of Biogenic Volatile Organic Compounds, BVOCs, emitted by a tree of each species measured at two different times on each day of spring (sources: biogenic volatile organic compounds from the urban forest of the Metropolitan Region, Chile [66]; emission factors of biogenic volatile organic compounds in various stages of growth present in the urban forest of the Metropolitan Region, Chile [66]).

Arboreal Species (Individual)	BVOC Emissions (μmol m^{-2} s^{-2})
Ciruelo de Flor (*Prunus cerasifera Ehrh*)	853 ± 513
Peumo (*Cryptocarya alba*)	1228 ± 720
Espino (*Acacia caven*)	982 ± 228
Quillay (*Quillaja saponaria*)	1308.7 ± 87.8

5. Results

Chile's current urban landscape development system has deficiencies throughout the process, which requires us to search for new urban design alternatives that benefit the population and the environment based on their sustainable attributes. In this regard, this study sought to obtain data on the effective performance of the species regarding their maintenance, soil conservation and tree–environment relationship to later be implemented around areas with social housing and all the houses in the Metropolitan Region, studying the percentage and number of species [100,106].

5.1. Cases Proposed for the Study

This section will establish the results of the different tree configurations with respect to the four parameters studied, according to each proposed case. The following interactions will be addressed to do so:

Case 1, or the base case, reflects how the intervened area would change if all the trees in that area were replaced by one of the species proposed in the study, and this will be used to establish a comparison pattern.

Case 2 uses the number of existing social dwellings. It reflects what would happen if an individual of one of the tree species studied was planted for each existing social dwelling, repeating the procedure for each of the other species.

Case 3 follows the same structure as Case 2, but using all the existing dwellings.

5.1.1. Case 1, or Case Base

Table 9 presents the tree simulation according to the four study parameters, assuming that each species is the only one present.

Table 9. Tree species and the capacities they possess regarding the parameters proposed in the study, assuming that each of them is the only one present. Case 1—base case (source: own).

Tree Species	Assumed Quantity (Individuals)	CO_2 Capture (kg/Year)	PM2.5 Deposition (kg/Year)	Water Requirement (m^3/m^2/Year)	BVOC Emissions (μmol m^{-2} s^{-2}/Spring)	
					Maximum	Minimum
Ciruelo de Flor	6,292,000	30,045.7	8431.3	0.66	5,367,076,000	3,227,796,000
Peumo		12,584,000	12,923,768	0.10	7,726,576,000	4,530,240,000
Espino		4,970,341.1	4,628,395.2	0.10	6,178,744,000	1,434,576,000
Quillay		22,651,200	16,126,396	0.15	8,234,340,400	552,437,600

5.1.2. Case 2—Social Housing

In this case, a tree of each species, respectively, was evaluated according to the four parameters investigated, considering that one tree is planted for each of the existing social houses in the research area. The results are shown in Table 10.

Table 10. Tree species and their capacities regarding the parameters proposed in the study assuming that there is one tree planted for each existing social dwelling. Case 2—social housing (source: own).

Tree Species	Assumed Quantity (Individuals)	CO_2 Capture (kg/Year)	PM2.5 Deposition (kg/Year)	Water Requirement (m^3/m^2/Year)	BVOC Emissions (µmol m^{-2} s^{-2}/Spring)	
					Maximum	Minimum
Ciruelo de Flor	1,219,311	5822.479	1633.87	0.66	1,040,072,283	625,506,543
Peumo		27,556.428	2,504,464.79	0.10	1,497,313,908	877,903,920
Espino		1464.560	896,925.17	0.10	1,197,363,402	278,002,908
Quillay		49,644.297	3,125,094.09	0.15	1,595,712,306	107,055,505.8

5.1.3. Case 3—Total Dwellings

In Case 3, we performed the same process as in Case 2, but using the total number of dwellings in the Metropolitan Region. The results are shown in Table 11.

Table 11. Tree species and their capacities regarding the parameters proposed in the study assuming that there is one tree planted for all the dwellings. Case 3—total dwellings (source: own).

Tree Species	Total Dwellings	CO_2 Capture (kg/Year)	PM2.5 Deposition (kg/Year)	Water Requirement (m^3/m^2/Year)	BVOC Emissions (µmol m^{-2} s^{-2}/Spring)	
					Maximum	Minimum
Ciruelo de Flor	6,486,533	30,974.63	8691.9	0.664	5,533,012,649	3,327,591,429
Peumo		146,595.65	13,323,338.8	0.104	7,965,462,524	4,670,303,760
Espino		7791.22	4,771,493.7	0.100	6,369,775,406	1,478,929,524
Quillay		264,099.46	16,624,984.1	0.150	8,488,925,737	569,517,597

5.2. Graphs and Results of the Study

The graphs presented below correspond to the comparative analyzes between the tree species.

5.2.1. Results of Case 1 or Case Base

Figure 2 shows the cost of each projected tree species over a 50-year period.

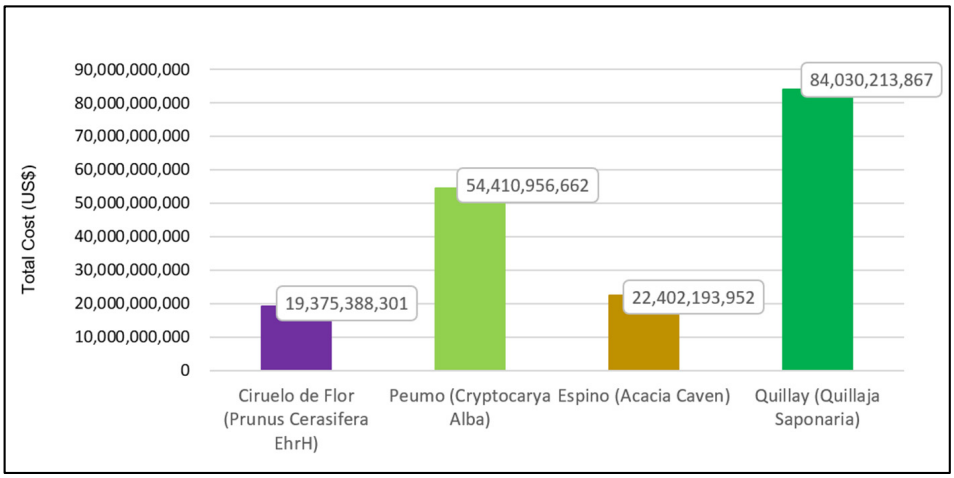


Figure 2. Graph of cost results per tree species for a 50-year projection (USD) according to maintenance criteria and assuming that each species of tree investigated replaces all existing trees (source: own).

Figure 3 shows the capture of Carbon Dioxide, CO_2 (%), according to the estimated average in one year and to the emissions reported for the years 2017, 2018 and 2019.

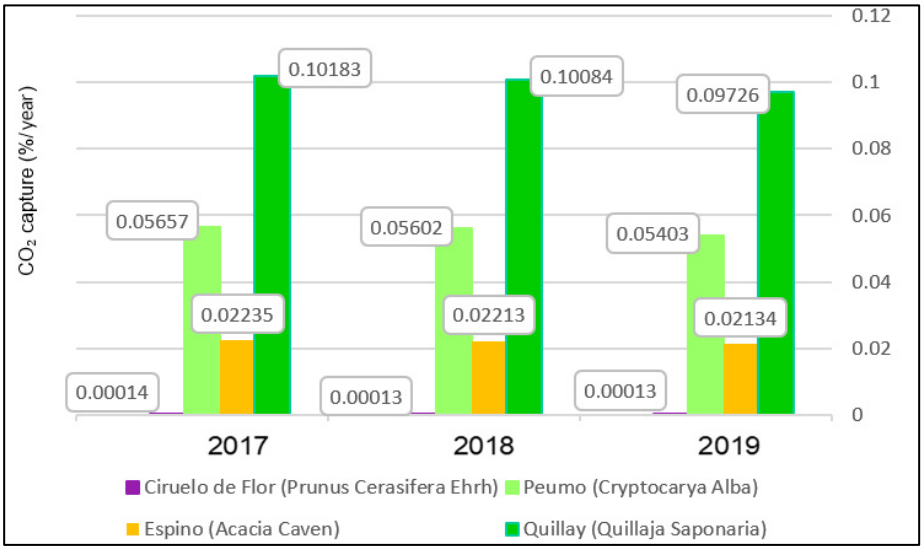


Figure 3. Graph of the result of CO_2 capture (%) versus emissions (kg) in the years 2017, 2018 and 2019 assuming that each species of tree replaces all the existing trees (source: own).

To know the deposition capacity of PM2.5 material according to the average capacity during a year, Figure 4 is presented.

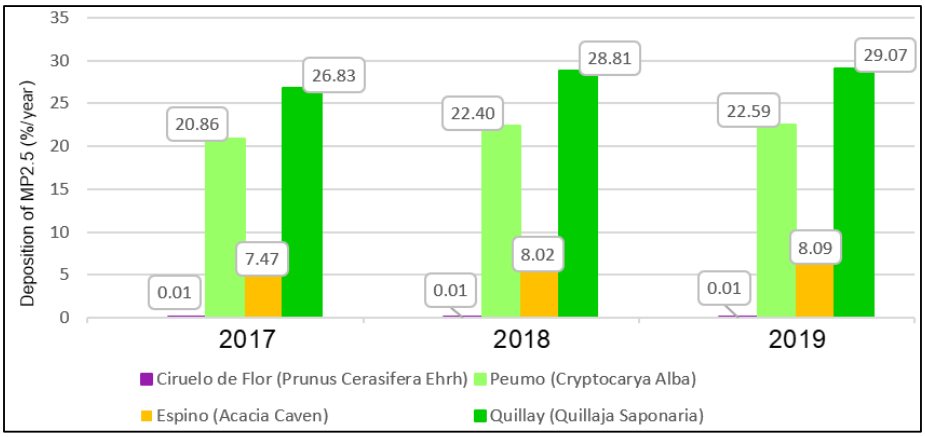


Figure 4. Deposition of MP 2.5 material over one year, assuming that each tree of a species replaces the total number of existing trees (source: own).

Figure 5 shows the incidence of Biogenic Volatile Organic Compounds generated during the spring season.

5.2.2. Results Case 2—Social Housing

To find out the cost difference between tree species projected over 50 years, Figure 6 is shown.

Figure 7 identifies the percentage capture of CO_2 according to the average obtained by tree species in one year in relation to existing emissions in 2017, 2018 and 2019.

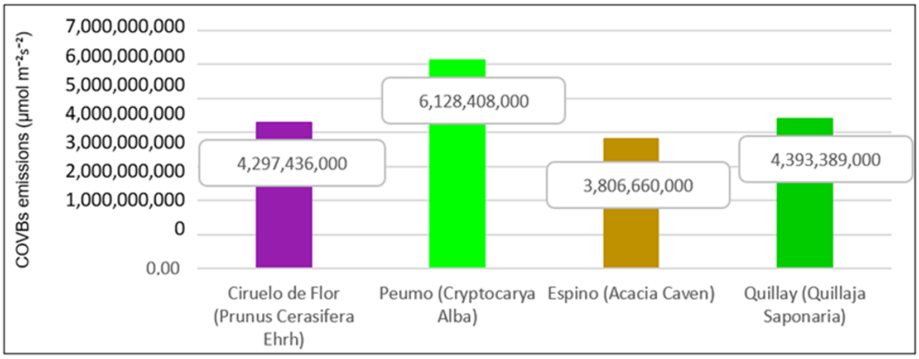


Figure 5. Graph of BVOC emissions (µmol m^{-2} s^{-2}) released by the species, expressed according to the average between their maximum and minimum amounts and assuming that each species of tree replaces all the existing trees (source: own).

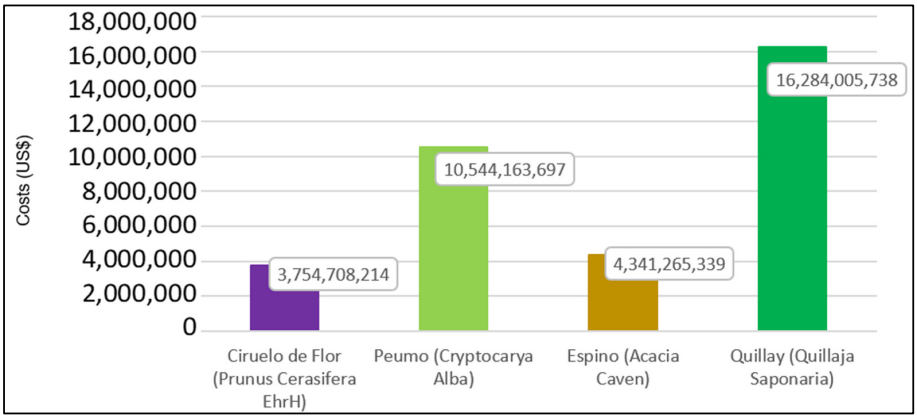


Figure 6. Graph of cost results per tree species for a 50-year projection (USD), according to maintenance criteria and assuming that each species of tree investigated replaces all the existing trees (source: own).

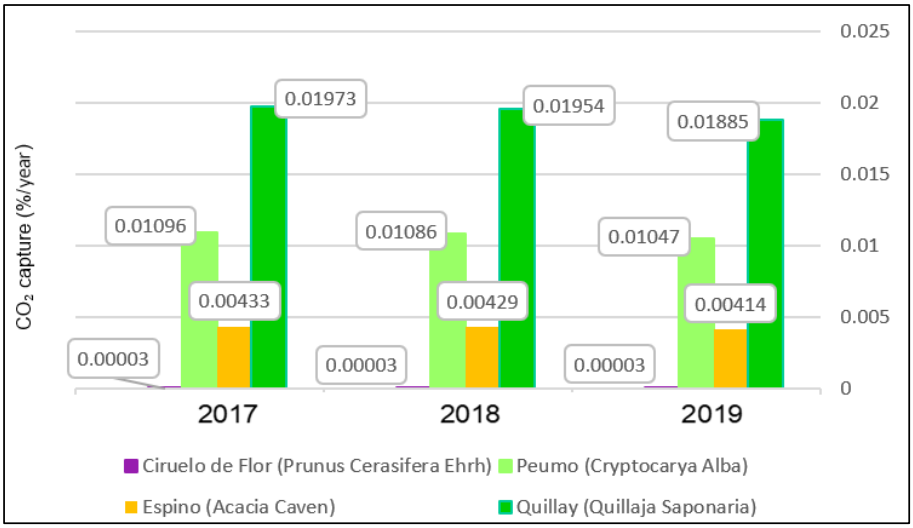


Figure 7. Graph of the result of CO_2 capture (%) versus emissions (kg) in the years 2017, 2018 and 2019, assuming that each tree of a species corresponds to social housing (source: own).

The percentage representation between the average deposition in one year for the species and the quantity of emissions of fine particulate matter, PM2.5, for the years 2017, 2018 and 2019 is shown in Figure 8.

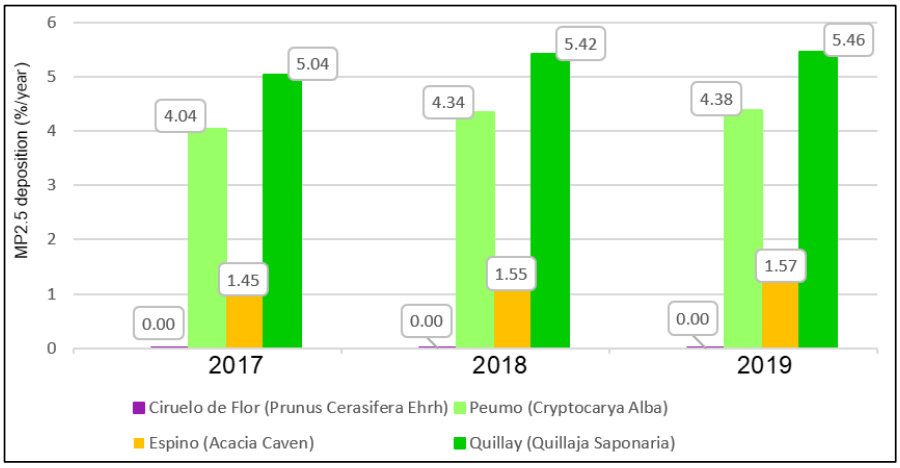


Figure 8. Graph of the result of the deposition of PM2.5 (%) according to emissions (kg) for the years 2017, 2018 and 2019, assuming that each tree of a species corresponds to social housing (source: own).

The averages between minimum and maximum emissions allow us to observe the differences between species, as shown in Figure 9.

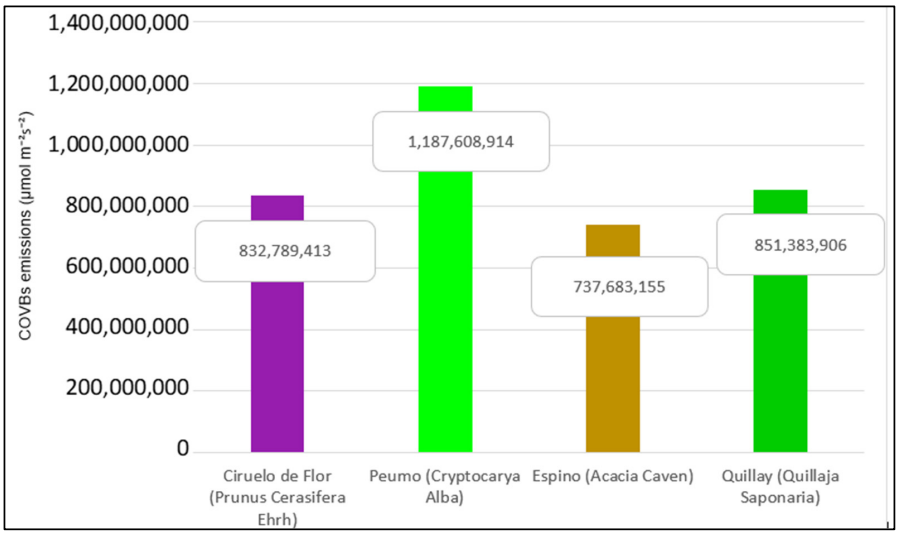


Figure 9. Graph of BVOC emissions (µmol m^{-2} s^{-2}) released by the species, expressed according to the average between their maximum and minimum amounts and assuming that each tree of a species corresponds to social housing (source: own).

5.2.3. Results Case 3—Total Dwellings

First of all, Figure 10 shows the projected costs for each of the adult tree species over 50 years.

For the Carbon Dioxide variable, CO_2, Figure 11 shows the percentage contribution to the average capture during a year that the species can achieve, with respect to the emissions report for the years 2017, 2018 and 2019.

Figure 12 shows the percentage contribution made by species according to the PM2.5 variable, when the capture is with respect to emissions during the years 2017, 2018 and 2019.

To easily visualize the different emission capacities of tree species, the averages between minimum and maximum are used, expressed in Figure 13.

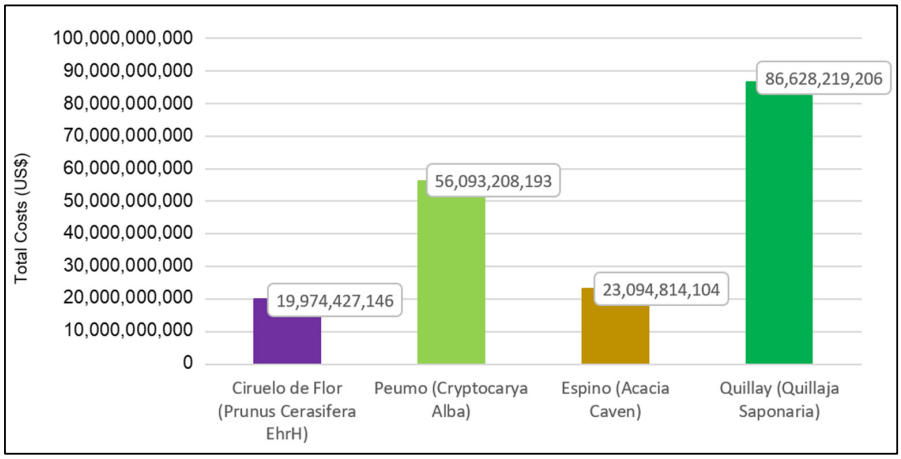


Figure 10. Graph of cost results per tree species for a 50-year projection (USD), according to maintenance criteria and in accordance with the total dwellings (source: own).

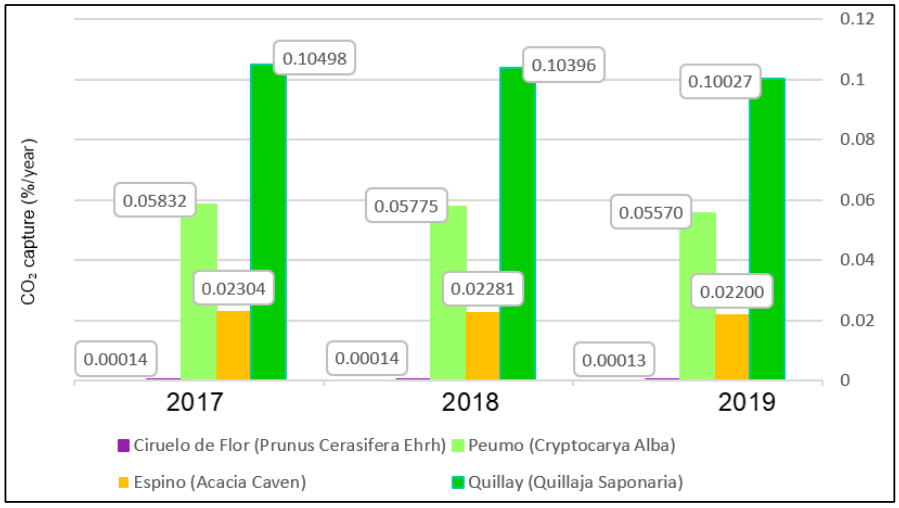


Figure 11. Graph of the result of CO_2 capture (%) versus emissions (kg) in the years 2017, 2018 and 2019, assuming that each tree of a species corresponds to one house out of the total dwellings (source: own).

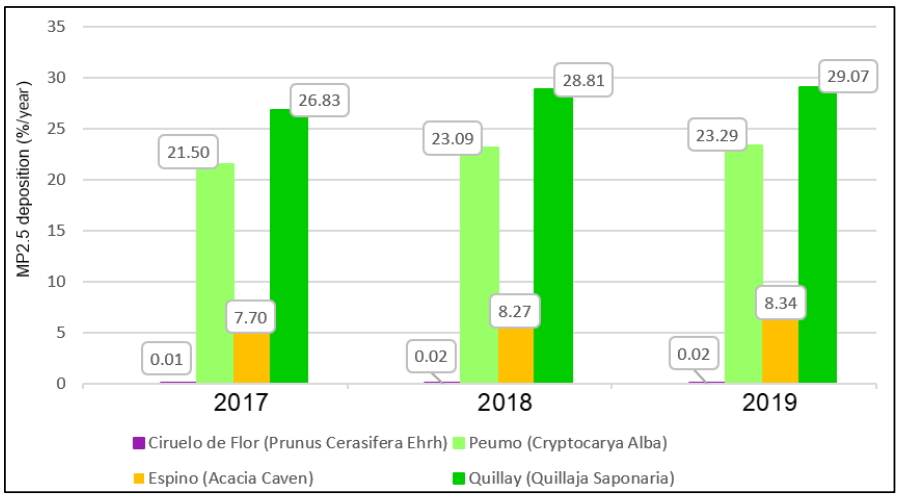


Figure 12. Graph of the result of the deposition of PM2.5 (%) according to emissions (kg) for the years 2017, 2018 and 2019, assuming that each tree of a species corresponds to one house out of the total dwellings (source: own).

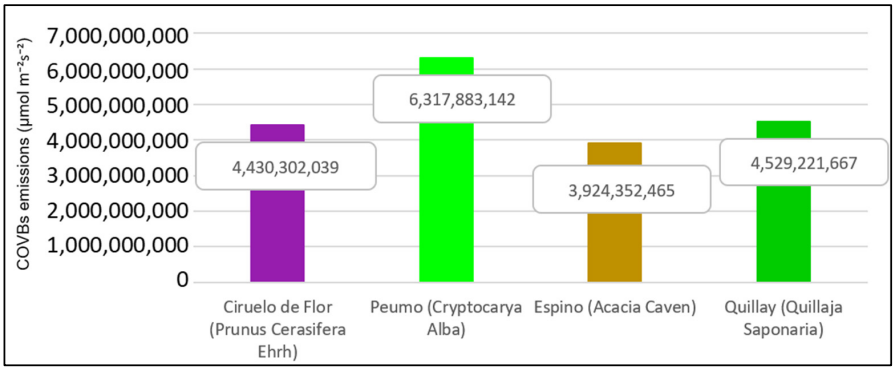


Figure 13. Graph of BVOC emissions (µmol m^{-2} s^{-2}) released by the species expressed according to the average between maximum and minimum quantities (source: own).

5.3. Water Analysis

The data used for the analysis will be expressed based on a surface unit (m^3/m^2/year), so they can be used interchangeably for the three cases (Case 1—base case; Case 2—social housing; Case 3—total number of dwellings). Then, we will show the water requirements of each individual of each species versus the amount of rainfall in the years 2017, 2018 and 2019 to represent both variables (required water versus rainfall).

Figure 14 compares the water consumption required by each adult tree of each species to find out the impact of each one of them in this regard.

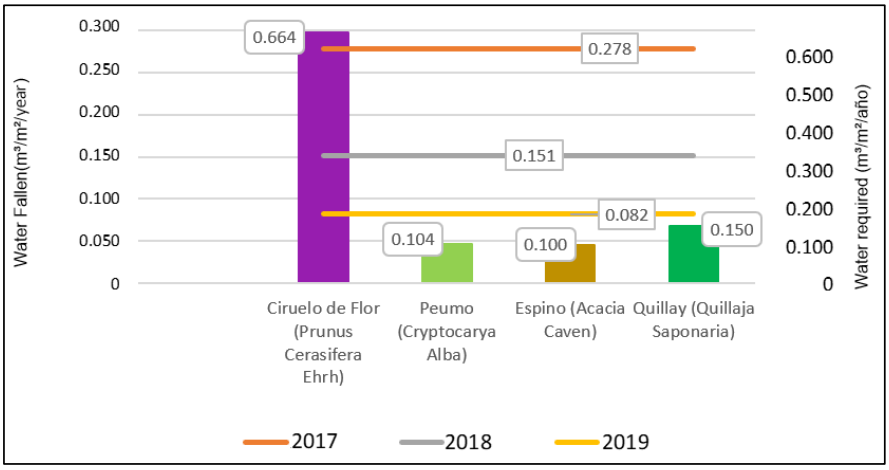


Figure 14. Graphic representation with lines of the annual amount of water required by each tree of each species (m^3/m^2) versus the representation in bars of the precipitation for the years 2017, 2018 and 2019 (source: own).

5.4. Equivalence between Tree Species according to Various Parameters

Figures 15–19 show the different capacities and equivalences, as percentages, that each adult tree species provides compared to the others and with respect to the parameters considered. The one with the greatest impact will be shown as 100% and will be used as a reference for the rest. Figure 15 shows the differences between the costs for the 50-year projected species.

The equivalences between species with respect to the capture of Carbon Dioxide, CO_2, on average over a year, will be established in Figure 16.

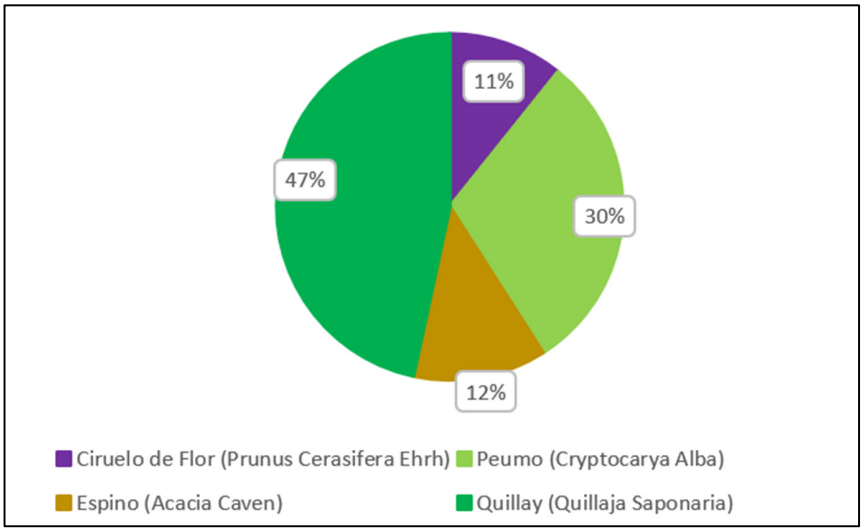


Figure 15. Graph of the economic parameter that shows the cost percentage of each tree species with respect to the most expensive one after 50 years (source: own).

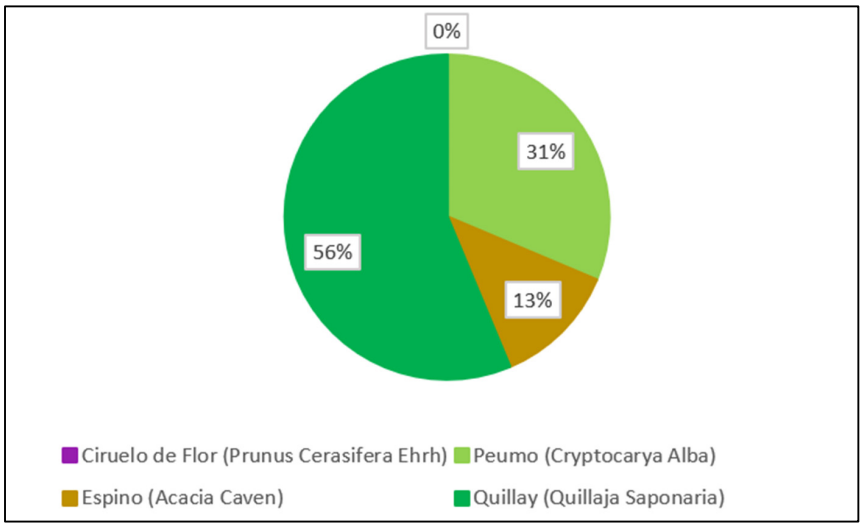


Figure 16. Graph with the CO_2 capture percentage that each tree species would have in a year with respect to the one with the greatest capacity (source: own).

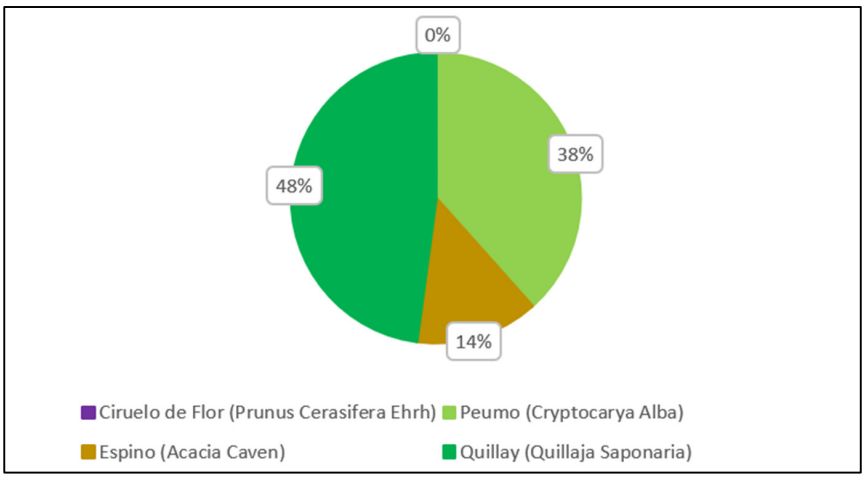


Figure 17. Graph with the percentage of deposition of PM2.5 that each tree species would have in a year with respect to the one with the greatest capacity (source: own).

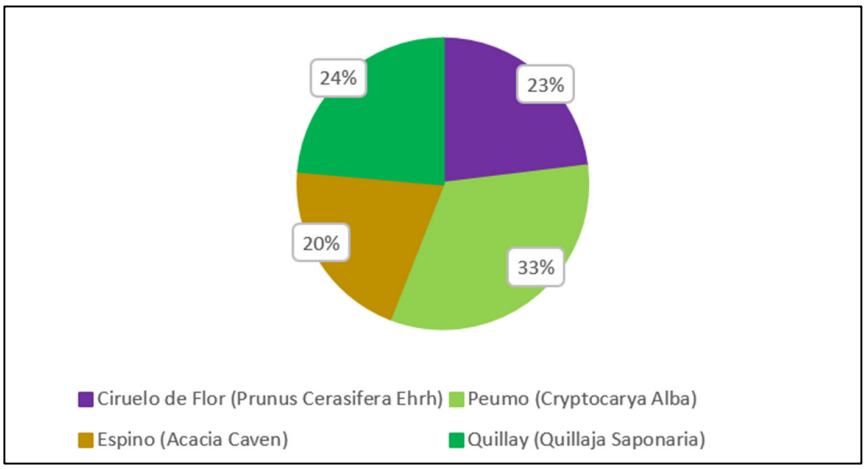


Figure 18. Graph with the average percentage of BVOC emissions that each tree species would have throughout the spring with respect to the one with the highest capacity (source: own).

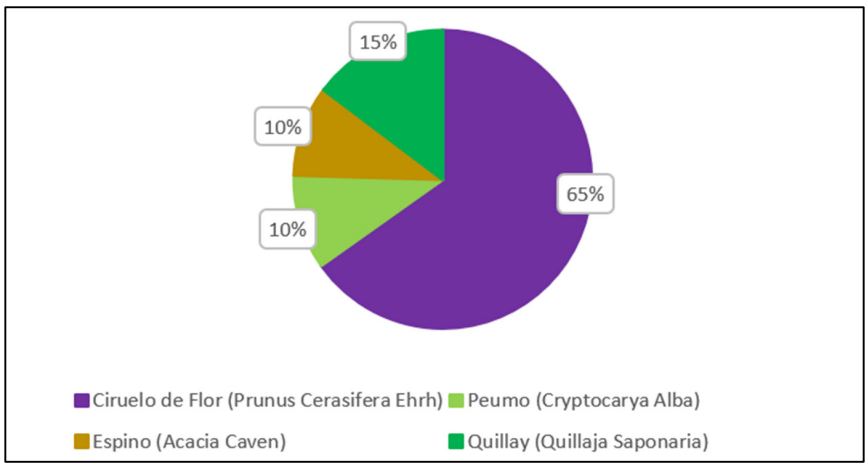


Figure 19. Graph with the percentage of water that each tree species would need in a year with respect to the one that requires the most (source: own).

The differences between species according to the deposition of PM2.5 obtained as an average in one year are proposed in Figure 17.

The influence of each species according to the emission capacity of biogenic volatile organic compounds during the spring season and according to the average between the time of greatest emission and the time of lower emission can be seen in Figure 18.

Figure 19 shows the difference between the water requirements for each species.

6. Discussion

Firstly, it is worth noting that there is not enough literature based on technical manuals, studies or reports that deal with the subject of the native trees studied, although they do exist for other types of trees [77,78,98]. The problem is that there are specific data, but there is no research base that supports decision making to design a city considering issues that improve the socioeconomic, environmental or health aspects linked to urban trees.

Today, with pollution and global warming representing national and global issues, we must increase the sustainability of our urban development [20,82,83]. However, scarce economic resources mean that these projects will always be limited by budgetary constraints [47,56]. In addition, the economic resources available for the addition of urban trees are not homogeneous in the area investigated, as each municipality has a limited amount related to the socioeconomic level of its inhabitants [12,48,49]. Therefore, the

way authorities, urban designers and the community as a whole approach development must change.

Trees in cities generate a series of beneficial effects that contribute to social, cultural or health-related well-being. However, there are also some negative aspects that must be taken into account in order to plan appropriately when allocating resources to this type of project and have a good management plan. These factors include BVOCs (addressed in this study), pollen, leaf loss, etc. [66,67,77].

Applying the proposed methodology makes it possible to analyze all the advantages and disadvantages of planting native tree species in urban areas associated with social housing. This is very important due to the current need for constructing this type of housing in Chile and the environmental, social, economic and health benefits that it entails.

7. Conclusions

The tree maintenance costs projected over time reveal that the origin of the species is not decisive. Instead, size plays a preponderant role, since the larger the tree is (roots, trunk, branches, leaves and crown), the greater the amount of money required is to keep it healthy.

Regarding their capacity of absorbing CO_2, the origin of the species will have an impact, as the exotic species' capacity is much lower compared to that of the native ones. It will also depend on factors such as foliage and size, making evergreen species that are larger (roots, trunk, branches, leaves and crown) more impactful in this sense, which makes the Espino species an unwise choice.

Regarding the deposition of PM2.5, the number of particles that the introduced species captures is insignificant compared to that of the native ones. Furthermore, the type of foliage and the volume (trunk, branches, leaves and crown) of the tree is impactful, adding greater importance to evergreen species than to deciduous ones and granting them the ability to capture larger volumes. Therefore, the introduced species falls short in this regard.

The exotic species Ciruelo de Flor (*Prunus Cerasifera Ehrh*) presented a higher level of water consumption than the native ones did, confirming the idea that introduced trees have a worse performance. This is emphasized in this species by the need to feed their fruits. Furthermore, the current climatic conditions do not favor the use of species that require abundant water due to recent water deficits in the area. Therefore, this species is not recommended, nor are any trees with edible fruits.

The average amount of BVOCs emitted by each species show that species that are dissimilar in size (Quillay and Ciruelo de Flor) have similar amounts of emissions. Moreover, there is no decisive difference between the emissions of the introduced species and the native ones. For the above reasons, the amount of emissions could be due to the leaf density of each tree. This makes the Espino, with less-abundant foliage than those of the other species, the most recommendable in this sense.

In line with the previous points on the variables that represent tree maintenance over time and emissions (CO_2, PM2.5 and BVOCs), the results show that the impact will be determined by the size of the tree and its foliage. On the other hand, the origin of the species is only impactful when analyzing the water resource variable.

Therefore, our conclusions are as follows. In small spaces within the city, such as passages or narrow streets, small species such as the Flower Plum (*Prunus cerasifera Ehrh*) or Hawthorn (*Acacia caven*) could be used, although the morphological variable must also be considered. In uncultivated areas, such as hills or places where irrigation is difficult, the Espino species (*Acacia caven*) can be recommended. For places that have larger spaces and are close to industries that work with fossil fuels or roads with heavy traffic, the Quillay species (*Quillaja saponaria*) will be recommended first, followed by the Peumo species (*Cryptocarya alba*). To control BVOC emissions in areas with health centers with patients with respiratory problems, we would recommend not planting Peumo species (*Quillaja saponaria*) and trying to mainly plant Hawthorn trees (*Acacia caven*).

Analyzing the environmental variables reveals that the contribution of the trees is irrelevant if the evaluation only includes the number of social houses, but this changes

when evaluating their number with respect to the total number of houses. However, for CO_2, the amount that they capture is still irrelevant, so we would not recommend using these tree species solely to combat the emissions of this gas.

Due to all the above, it will be necessary to create ordinances, statutes, codes, regulations, manuals or information that can be accessed by government agencies, private entities or by the residents themselves to give way to orderly and regulated tree planning, in addition to promoting the proper use of the city tree within communities.

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Conflicts of Interest: The authors declare no conflict of interest.

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