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Identifying The Role of Green Spaces in Air Quality Regulation: The Case of Trakya University Balkan Campus

Hava Kalitesinin Düzenlenmesinde Yeşil Alanların Rolünün Belirlenmesi: Trakya Üniversitesi Balkan Yerleşkesi Örneği

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Abstract

This research aims to investigate the ecological benefits and economic value of the vegetation cover on the Balkan Campus of Trakya University. The distribution of land cover classes, carbon storage capacity and air pollution mitigation effects of the campus area were assessed using the i-Tree Canopy tool. The results showed that the vegetation canopy, covering 23.93% of the area, removes 2375 kg of gases and particulate matter from the air. The economic benefit of improving the air quality of the campus area was estimated to be $1144. In addition, the amount of carbon sequestered by the canopy was 107.61 tons, while the amount of carbon stored was 2702.45 tons. The results indicate that the canopy cover of trees/shrubs on campus contributes significantly to the ecosystem by improving air quality. This study also highlights that increasing green space and promoting planting efforts can provide significant environmental and economic benefits in creating sustainable and climate-friendly campuses.

Keywords: Air quality, Balkan campus, Carbon storage, i-Tree canopy, Urban trees

Özet

Bu araştırma, Trakya Üniversitesi Balkan Yerleşkesi'ndeki bitki taç örtüsünün ekolojik faydalarını ve ekonomik değerini incelemeyi amaçlamaktadır. Kampüs alanı arazi örtüsü sınıflarının dağılımı, karbon depolama/tutma kapasitesi ile hava kirliliğinin azaltılması etkileri i-Tree Canopy aracı ile değerlendirildi. Sonuçlar, alanın %23.93'ünü kaplayan taç örtüsünün havadan 2375 kg gaz ve partikül maddeyi uzaklaştırdığını göstermiştir. Kampüs alanının hava kalitesini iyileştirmeye yönelik ekonomik fayda değeri 1144$ olarak hesaplanmıştır. Ayrıca, taç örtüsü tarafından yakalanan karbon miktarı 107,61 ton, depolanan karbon miktarı ise 2702,45 ton olarak belirlenmiştir. Elde edilen sonuçlar, kampüs ağaç/çalılarının taç örtüsünün hava kalitesini iyileştirmede ekosisteme önemli katkılar sağladığını göstermiştir. Bu çalışma aynı zamanda sürdürülebilir ve iklim dostu kampüs oluşturma çabalarında, yeşil alanların artırılması ve ağaçlandırma çalışmalarının teşvik edilmesinin çevresel ve ekonomik faydalar sağlayabileceğini vurgulamaktadır.

Anahtar Kelimeler: Hava kalitesi, Balkan yerleşkesi, Karbon depolama, i-Tree Canopy, Kent ağaçları

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1. Introduction

Urban green spaces face numerous challenges due to the rapidly increasing population and urbanization. The decline in both the quantity and quality of green areas due to urbanization's increase may trigger a cascade of issues, including habitat depletion, reduced biodiversity, increased air pollution, decreased carbon storage, and intensification of urban heat islands (McKinney, 2002; Livesley et al., 2016). These environmental challenges/problems also negatively affect human welfare and health. According to a study conducted in China, one of the most densely populated countries, air pollution can cause the death of approximately 1 million people annually (Yue et al., 2020). The World Health Organization (WHO) estimates that urban air pollution results in the annual loss of 6.4 million lives globally (Jayasooriya et al., 2017). Therefore, understanding the role of green spaces and vegetation in cities is crucial to improve the urban landscape and address such environmental challenges (Livesley et al., 2016). Previous research has shown that urban trees are an important component of landscapes, contributing to the environmental quality of cities, towns, and university campuses (O'Brien et al., 2017; Wolf et al., 2020). Numerous research findings have also indicated that urban trees reduce stormwater runoff (Walsh et al., 2012; Wang et al., 2021), mitigate urban heat island effects (Bowler et al., 2010; Heaviside et al., 2017), provide habitat (Scholz et al., 2018), and help to reduce air pollution and greenhouse gas emissions (Nowak et al., 2007; Grote et al., 2016; Salmond et al., 2016; Sheng et al., 2019). In particular, urban trees perform a critical function by sequestering carbon through photosynthesis and accumulating excess carbon as biomass where greenhouse gases are increasing (CO_2, NO_2, O_3, SO_2, PM10 and PM2.5) as a result of urbanization and the use of fossil fuels (Nowak & Crane, 2002).

Urban trees offer a set of benefits for human health and well-being. These encompass enhanced air quality, the filtration of air pollutants and particulate matter (PM), regulation of temperatures through shading, management of water, augmentation of biodiversity, contribution to mental health and aesthetics, and noise mitigation (Pataki et al., 2021). By absorbing pollutants through their leaves, urban trees enhance air quality, while their shade mitigates urban temperatures, and their root systems help control water flow to reduce flood risks (Yang et al., 2005). They support biodiversity, providing a natural landscape that positively influences mental health, and their presence reduces noise, thereby enhancing environmental comfort (Escobedo et al., 2011). Airborne pollutants are often deposited on plant surfaces or absorbed through stomata. Urban trees and green spaces can influence atmospheric CO_2 concentrations and accumulate biomass above and below ground to help reduce greenhouse gases (Nowak & Crane, 2002; Escobedo et al., 2011; Strohbach & Haase, 2012). Leaves within the canopy serve as a natural filter for gaseous pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), as well as particulate matter including PM2.5 and PM10 (Scholz et al., 2018). Expanding the quantity and diversity of trees within urban areas holds promise in mitigating various environmental issues by offering a range of ecosystem benefits. Nevertheless, despite the acknowledged significance of these benefits and damages, there is a gap in understanding the full potential of trees in mitigating urban environmental challenges and the fundamental mechanisms behind tree-atmosphere interactions. This knowledge deficit stems from the intricate nature of the physical and chemical processes governing such interactions, compounded by the absence of robust numerical models designed to quantify these phenomena accurately. Consequently, tools like i-Tree have emerged to facilitate the systematic quantification and thorough examination of the ecological services furnished by urban trees (Selmi et al., 2016; Tuğluer & Gül, 2018). Researchers have assessed the role of urban green spaces in regulating air quality within the existing body of literature: Australia (Jayasooriya et al., 2017), Turkey (Tuğluer & Gül, 2018; Tonyaloğlu et al., 2021; Selim et al., 2023; Üstün Topal & Demirel, 2023; Şahin Körmeçli & Seçkin Gündoğan, 2024), Netherlands/Wageningen (Tülek, 2022), USA (Hepcan & Hepcan, 2021), Irish (Mills et al., 2015), China (Wu et al., 2019), Ireland (Riondato et al., 2020), Hong Kong (Yao et al., 2022).

In recent years, the environmental impact of university campuses has received increasing attention. Often referred to as "small cities," university campuses are critical to cities because of their high building densities, large populations, and well-equipped facilities (Wang et al., 2021). University campuses offer an ideal environment for both learning and creating intricate and dynamic semi-natural ecosystems because of their expansive surface areas (Tudorie et al., 2020). The green spaces and trees within the campus not only contribute to the vegetation cover, air quality, microclimate, and ecological indicators (Aghamolaei & Fallahpour, 2023) but also safeguard the physical and mental well-being of faculty staff and students (Tudorie et al., 2020; Wang et al., 2021), as well as increasing the capacity for long-term attention (Berto, 2005). In this sense, university campuses provide local ecological benefits (Wang et al., 2021) and guide local governments in terms of sustainability. However, although many studies have been conducted in urban green spaces, there are limited studies in the literature that examine the ecological benefits of trees in campuses (Cox, 2012; Dilaver et al., 2017; Ritchie, 2017; Wang et al., 2021; Şahin Körmeçli & Seçkin

Gündoğan, 2024) and the assessment of ecosystem services provided by urban trees in Edirne is lacking.

This study aims to quantify in monetary terms the ecological benefits (carbon storage and air quality) and ecosystem services provided by trees on the Balkan Campus of Trakya University. The study analysed the land cover of the campus using the i-Tree Canopy tool and made predictions of the ecological benefits provided by the trees. The research aims to guide practitioners in the management of campus trees and contribute to the vision of a sustainable, climate-friendly and carbon-neutral campus. At the same time, it takes an innovative approach by quantifying the ecological benefits of campus trees in monetary terms and using this data as a sound basis for the development of environmentally friendly campus policies. In this context, the study will seek to answer the question: "To what extent does the campus vegetation of Trakya University Balkan Campus benefit the ecosystem in terms of carbon sequestration/storage and air pollution reduction?".

2. Material and Method

2.1. Study Area

The study area is the Balkan Campus of Trakya University in Edirne, Turkey (Figure 1). The city of Edirne, where Trakya University was founded, is located in the Marmara region of northwestern Turkey. Due to its geopolitical location, Edirne borders Greece and Bulgaria. Trakya University consists of 34 academic units, including 14 Faculties, 4 Colleges, 10 Vocational Colleges, 5 Institutes, and 1 State Conservatory. The University has 43196 students, 1763 academic staff, and 2935 administrative staff. Trakya University Balkan Campus is the first and largest campus of the University. Balkan Campus is located at 41°38'13.66" latitude and 26°36'38.46" longitude in the Kocasinan district of Edirne province, central district, and is a transition area between the urban and rural environment of the city. There are various faculties, colleges, research centers, hospitals, rectorate, library, cultural center, social living areas, dormitories and accommodation buildings on the Balkan Campus. The distance from the campus to the city center is 7.8 km. The campus has been constantly developing and changing since its establishment. In addition, due to its location, the University, with its national and international students, makes an important contributions to the city through scientific research and positive relations with the Balkan countries.

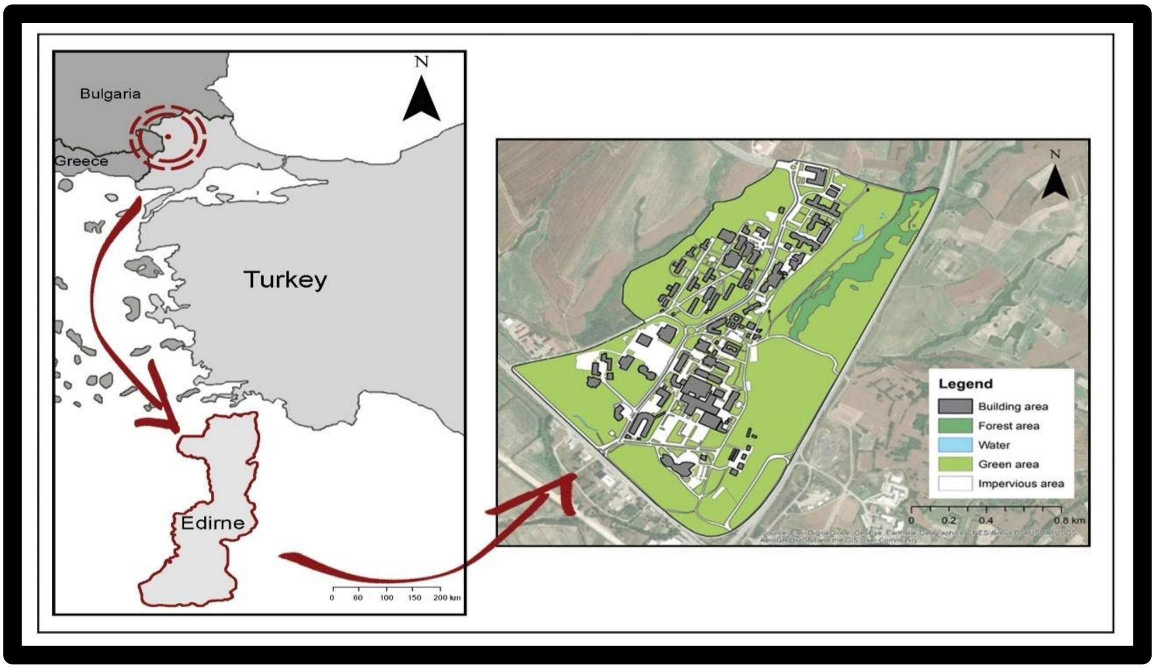

Figure 1. Location and land use distribution of Trakya University Balkan Campus.

This study focused on the existing development boundary of the Balkan Campus of Trakya University. Agricultural areas within the boundaries of the university was not taken into account. The Balkan Campus covers an area of approximately 147 hectares. Approximately 80% of the total area of the campus is covered with green areas. 20% of the developed area consists of buildings and impervious surfaces.

2.2. Method

The i-Tree Canopy tool, used by numerous researchers globally, was created by the US Department of Agriculture Forest Service in collaboration with several partner organizations (USDA, 2021). This web-based tool, available at no cost, was employed in the study to compute the regulation of ecosystem services such as carbon sequestration and storage and air pollution mitigation. Generally, the model aids in estimating and assessing the value of ecosystem services rendered by urban trees and forests. As of the end of 2020, it has been used by more than 510,000 researchers in 159 countries (Nowak, 2021). Studies have focused on a range of topics, including the local ecosystem services and values provided by vegetation, the development of urban green spaces and sustainable forest management plans, the determinination of environmental management strategies, and the assessment of the tendency of green spaces to reduce air pollution (Selim et al., 2023).

The i-Tree Canopy tool has been extensively employed in national and international research studies use due to its ease of, free availability, and minimal data requirements.

The tool can quickly and easily process Google aerial imagery and make statistical predictions and calculations about land types (Nowak, 2021). In addition, the model can estimate the removal of gases (CO, NO_2, O_3, SO_2, PM2.5, PM10) from the atmosphere by plants, as well as the ecological and economic values for the capture and storage of atmospheric carbon, taking into account the values for the land class (Hepcan & Hepcan, 2021; Nowak, 2021).

This study used the i-Tree Canopy v7.1 tool to assess the impact of campus trees on enhancing air quality. This tool plays a significant role in shaping the framework for establishing integrated green space management and sustainable policies aimed at mitigating air pollution on the Balkan campus of Trakya University. The tool works in three stages: (1) site selection (determining the boundaries of the study area on Google Maps), (2) the determination of random sampling points, and (3) the assessment of the ecological contribution of vegetation by determining the land types at these points. In this tool, it is recommended to place at least 500-1000 random points for the estimates, but it is also reminded that the more points used, the better estimates can be obtained (USDA, 2021). Parmehr et al. (2016) stated that the confidence level is less than 1% as the number of points increases. In addition, many studies in the literature indicate that increasing the number of points increases the accuracy rate (Parmehr et al., 2016; Ersoy Tonyaloğlu & Atak, 2021; Tonyaloğlu et al., 2021; Körmeçli, 2023; Üstün Topal & Demirel, 2023). In this study, 10,000 random sample points were determined. Land cover classes were defined in order to ensure the accuracy of the results given the size of the area. The study area was divided into seven classes based on the existing land cover categories, including trees and/or shrubs, impervious buildings, impervious roads, other impervious surfaces, soil and/or bare ground, grass and/or herbaceous plants, and water. The definitions of the land cover classes and sampling points of the study area are shown in Table 1 and Figure 2.

Table 1. Land cover classes of the study area.

Land Cover Class	Description
Tree and/or Shrub	Areas covered with trees and tall shrub vegetation
Impervious Buildings	Impervious covered areas occupied by buildings
Impervious Surfaces	Other impermeable pavements (sidewalks, concrete areas)
Impervious Roads	Asphalt, concrete or compacted roads
Soil and/or Bare Ground	Soil surface and bare areas without vegetation
Grass and/or Herbaceous	Areas covered with grass and other herbaceous ground cover
Water	Artificial and natural water surfaces without vegetation

The i-Tree Canopy tool employs a specific algorithm to determine statistical estimations regarding area percentages, according to the following formula (USDA, 2021).

$$p = \frac{n}{N} \tag{2.1}$$

In the formula, n is the number of points corresponding to the land cover class, and N is the total number of points analyzed among all cover classes. The standard error of the estimate is calculated according to the following formula.

$$SE = \sqrt{pq / N} \tag{2.2}$$

Where p:n/N and q=1-p (Lindgren et al., 1966).

Thus in this work, tree cover in the university is estimated at 23% with a SE of 1.7%. Based on the SE formula, SE is greatest when p=0.5 and least when p is very small or very large (https://canopy.itreetools.org/). The calculation of the total tree cover area involves the multiplication of the percentage of tree cover by the analyzed area. Based on this tree cover data, estimates of carbon storage, air pollution removal, and hydrological effects are derived (USDA, 2021). Coefficient values for carbon estimates are based on the average carbon density per unit of canopy cover in urban areas. In addition, US-based averages, statistically standardised according to US case studies, were used in the i-Tree Eco model to calculate air pollutant removal rates, carbon sequestration, carbon storage and economic benefits provided by a single tree or shrub.

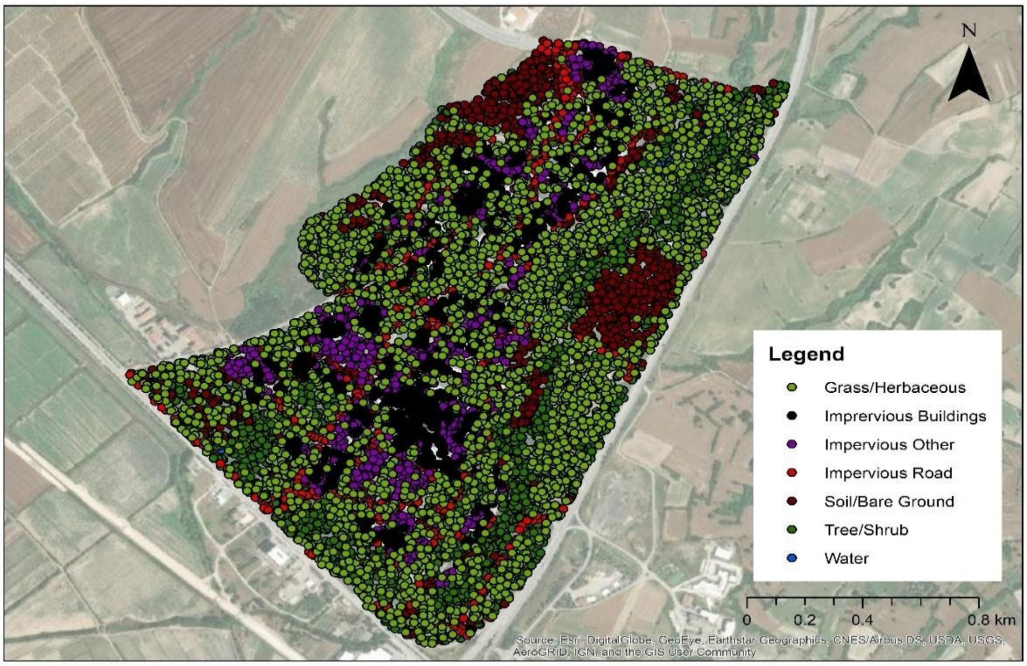

Figure 2. Distribution of random point sampling points in the study area.

In addition to the i-Tree Canopy v7.1 software, ArcGIS 10.8 software was used for visualisation and mapping of the data.

3. Results and Discussion

3.1. Results

Trakya University Balkan Campus was assessed with the i-Tree Canopy tool, and 10,000 sample points were randomly generated. In the study area, 3459 points representing grass/ herbaceous covers covered 34.59% (50.83 ha) of the area. Impervious buildings with 1095 points covered 10.95% (16.09 ha), other impervious surfaces with 1033 points covered 10.33% (15.18 ha), impervious roads with 837 points covered 8.37% (12.30 ha), soil/ bare ground with 1171 points covered 11.71% (17.21 ha), trees/shrubs with 2393 points covered 23.93% (35.17 ha) and water with 12 points covered 0.12% (0.18 ha). In general, 58.52% of the Balkan campus was covered by trees/shrubs and grass/herbaceous cover, while impervious surfaces accounted for 29.65% of the area, and soil/ bare ground accounted for 11.71%. The analysis revealed that the standard deviation value for each land cover class within the area was less than 1%, indicating an equal distribution of point data across all classes. Figure 2 depicts the distribution of randomly sampled points in the study region, with Figure 3 and Table 2 presenting the results of the land cover assessment.

Table 2. The results of the i-Tree canopy analysis.

Cover class types	Points	% Cover ± SE	Area (ha) ± SE
Grass/Herbaceous	3459	34.59 ± 0.48	50.83 ± 0.70
Impervious buildings	1095	10.95 ± 0.32	16.09 ± 0.46
Impervious other	1033	10.33 ± 0.30	15.18 ± 0.45
Impervious road	837	8.37 ± 0.28	12.30 ± 0.41
Soil/Bare ground	1171	11.71 ± 0.32	17.21 ± 0.47
Three/Shrub	2393	23.93 ± 0.43	35.17 ± 0.63
Water	12	0.12 ± 0.03	0.18 ± 0.05
Total	10000	100.0	146.95

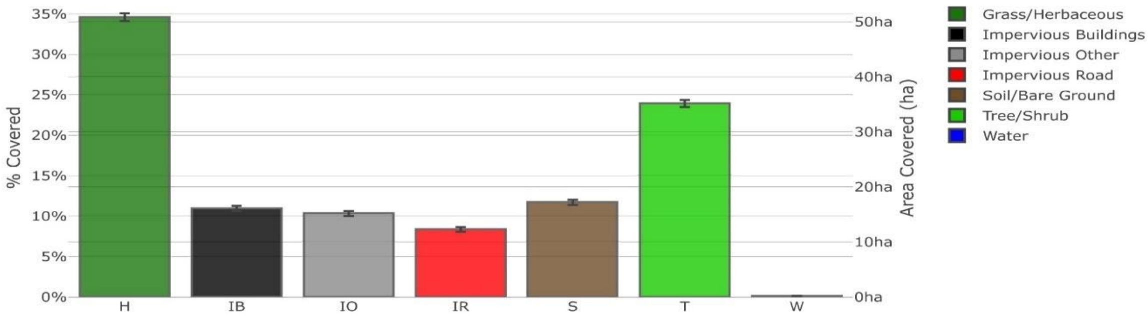

Figure 3. Distribution of land cover classes in the study area.

One of the i-Tree Canopy analysis results is the total annual amount of pollutant gases and particles released into the atmosphere by the Balkan campus area. The campus annually removes 2375.39 kg of pollutant gases (CO, NO_2, O_3, SO_2) and particulates (PM2.5 and PM10), with an economic value of $1144. It was also found that 107.61 tons of carbon is sequestered, and 2702.45 tons of carbon is stored by trees annually (Table 3).

Table 3. i-Tree canopy estimations for air quality benefits.

Pollutants removed from the air (annually)	Amount	±SE	Value ($)	±SE
Carbon monoxide, CO (kg)	35.54	0.63	3	0
Nitrogen dioxide, NO_2 (kg)	193.80	3.46	6	0
Ozone, O_3 (kg)	1930.13	34.41	299	5
Sulfur dioxide, SO_2 (kg)	122.13	2.18	1	0
Particulate matter, PM2.5 (kg)	93.79	1.67	618	11
Particulate matter, PM10 (kg)	646.52	11.53	217	4
Sequestered in trees, CO_2seq (tonnes)	107.61	1.92	20.230	361
Stored in trees, CO_2stor (tonnes) (not annually)	2702.45	48.18	508.060	9.058

SE— Standard deviation

Campus trees had the highest removal capacity for O_3, PM10, NO_2, SO_2, PM2.5, and CO among air pollutants. The economic benefit of carbon storage and sequestration provided by the tree canopy in the study area, which represents 23.93% of the whole campus tree canopy, was $528,290.

Carbon sequestration capacity is significantly higher in campus areas with dense tree and shrub cover, particularly in arboretum areas with a high concentration of broadleaf and coniferous tree species and in forested areas near campus entrances. In contrast, areas with extensive impermeable surfaces, such as asphalt and concrete, particularly around faculty buildings and other densely developed campus sections, exhibit lower carbon sequestration rates due to limited vegetation cover. In the central, southern, and southwestern parts of the campus, high PM10 levels have been observed in association with dense building clusters and increased vehicle traffic. Due to vehicle emissions and dust accumulation on asphalt surfaces, this situation leads to increased particulate matter concentrations, particularly on large impermeable surfaces such as roads and parking lots. On the other hand, in areas with vegetation-particularly those densely vegetated with trees, shrubs, and extensive grassy areas-PM10 levels were significantly lower due to plants' particulate matter capture properties. This demonstrates that vegetation directly contributes to air filtration and improved air quality. In conclusion, differences in carbon sequestration capacity and PM10 levels across the campus are directly related to the type and density of land cover. Areas rich in trees and shrubs provide significant advantages in carbon storage capacity and air pollutant filtration. In contrast, extensive impervious surfaces and bare soil areas reduce carbon sequestration potential and negatively impact air quality.

3.2. Discussion

Universities have a significant impact on society through educating and training people and participating in governance at national and regional levels. This is crucial in shaping socio-cultural environments and creating sustainable environments (Tudorie et al., 2020; Ramírez et al., 2023). The rapid increase of atmospheric carbon stands as a pivotal catalyst for contemporary climate change issues. The mitigation of these issues involve two primary strategies: decreasing carbon emissions and increasing carbon sequestration. Trees, serving as integral urban components, hold significant role in mitigating atmospheric CO_2 increase through the capture, fixation, and storage of carbon dioxide both above and below ground (Liang & Huang, 2023). As the environmental impact of university campuses becomes increasingly important, the contribution of campus trees to the ecosystems cannot be ignored. Campus trees also provide various regulating ecosystem services, such as reducing air temperature, removing pollutants, capturing and storing carbon dioxide, releasing oxygen, and retaining water. In addition to these tasks, trees on college campuses play various other roles, such as improving mental health by reducing pressure on students and teachers (Gulwadi et al., 2019; Guo et al., 2020).

The trees on the Balkan campus sequestered a total of 2702.45 tons of carbon and provided an ecological benefit of $508.06. Studies draw attention to the ecological and economic benefits of urban and campus trees, noting that species diversity is important in campus areas (Wang et al., 2021). Wang et al. (2021) found that trees on university campuses also provide significant energy conservation benefits and can reduce air pollutants and greenhouse gas emissions by contributing to electricity and natural gas cost savings. Nowak et al. (2006) observed a correlation between the number of trees in U.S. urban forests and the carbon storage capacity, highlighting that ozone (O_3) exhibited the highest pollutant removal rate, trailed by PM10, NO_2, SO_2, and CO. Their research further asserts that urban forests eliminate around 711,000 metric tons of air pollutants annually. The findings of this investigation closely parallel those reported by Nowak et al. (2006). Körmeçli (2023), in a study conducted in Altın Park, Ankara, found that the tree canopy covering 39.89% of the park removes 2094,52 kg of pollutant gases and particulate matter. It was also found that 74.58 tons of carbon is captured and 1873.10 tons of carbon is stored by the trees every year. The park was found to make a significant contribution to the city, especially in terms of removing O_3, which is a greenhouse gas in climate change. The value of economic benefits for improving air quality was calculated to be $366956 and this high value contribution was highlighted. Ersoy Tonyaloğlu & Atak (2021) investigated the ecosystem services and benefits of tree cover in the city of Aydın and found that tree cover contributes significantly to carbon sequestration and storage as well as the removal of NO_2, O_3, SO_2, PM2.5 and PM10. Furthermore, by examining the temporal variation, it was found that the 61.38 ha change in land cover in the city resulted in a decrease in carbon and air pollution benefits and economic value. Since the Balkan campus areas, which are the study area, are open to continuous change, planting and increasing the canopy cover, especially in areas where there is no ground surface or vegetation cover, will contribute to ecosystem services, while at the same time providing significant benefits to the city in terms of adaptation to climate change.

Urban trees reduce air pollution and contribute to ecosystem services by absorbing and sequestering air pollutants. Nevertheless, the effectiveness of pollution reduction may fluctuate based on factors such as the extent of tree cover and the concentration of pollutants, the length of leaf season, the amount of precipitation, as well as the transpiration and deposition rates of trees (Jim & Chen, 2008; Nesbitt et al., 2015; Grote et al., 2016; Salmond et al., 2016). The distribution and density of forest, shrub, and herbaceous plant cover in the campus area contribute to developing regulatory ecosystem services in cleaning air quality by removing pollutant gases and particulate matter. The contribution of the campus area to the ecosystem is realized through the annual removal of 2375.39 kg of pollutant gases and particulate matter, as shown in Table 3. In terms of carbon storage and removal of pollutant gases, tree cover should be increased for the campus to contribute to zero carbon and sustainable development goals. University campuses are defined in the literature as "small cities" (Wang et al., 2021). They can be subject to similar impacts as urban areas, such as heavy vehicle traffic, exhaust fumes, and fossil fuels used for heating. However, with the advantage of being open to development and developable space, campus areas can enable these impacts to be reduced in the future. Campus areas can have similar environmental impacts as urban areas, such as heavy vehicle traffic, exhaust emissions, and fossil fuel use. However, the developable and retrofittable characteristics of these areas can potentially mitigate these impacts in the future. Creating sustainable campuses should focus on sustainable building design (e.g., green roofs and green walls), water management (especially natural water treatment systems and/or stormwater management systems), improving ecosystem services (protecting native vegetation and supporting pollinators), increasing green space and permeable surfaces, setting carbon neutrality goals, reducing energy consumption, promoting green transportation solutions, and developing climate change adaptation strategies. These strategies can enable universities to become pilot sites that significantly contribute to cities in line with the Sustainable Development Goals.

The main plant species used on the Balkan Campus are as follows conifers (*Cupressus sempervirens* L.*, Pinus nigra* Arnold. subsp. pallasiana (Lamb.) Holmboe., *Cedrus atlantica* (Endl.) Manetti ex Carr.*, Cupressus arizonica* Greene*, and Platycladus orientalis* L.), broad-leaved trees (*Prunus amygdalus* Batsch*, Tilia tomentosa* Moench*, Acer negundo* L.*, Fraxinus excelsior* L.*, Platanus orientalis* L.*, Acer platanoides* L.), shrubs (*Spirea x vanhouetti* (Briot) Zab.*, Juniperus horizontalis* Moench.*, Ligustrum vulgare* L.*, Photinia x fraseri* Dress cv. “Red Robin”*, Euonymus japonica* L.) (Mısırlı, 2023). The Balkan Campus is currently in good condition in terms of its open and green space potential. However, there is also a lack of tree and shrub species that contribute to carbon storage, which is particularly apparent in road and sidewalk plantings. Among the tree species in the Cascine Park in Florence, *Aesculus hippocastanum, Pinus alba, and Pinus pinea* were the most important for removing total pollutants, according to their ability to control air quality. *Tilia tomentosa*, on the other hand, was reported to remove moderate levels of pollutants (Paoletti et al., 2011). Therefore, species selection is important in campus planting. At the same time, the ecosystem services trees provide are closely related to their structure. Studies show that trees with larger crown size and leaf area can provide more services (Cox, 2012; Wang et al., 2021). Deciduous trees can store more carbon and regulate microclimate than evergreen trees due to their larger canopy width (Liang & Huang, 2023). Specifically, *Cedrus* sp. *and Platanus* sp. tree species are reported to sequester approximately 300 to 550 kg of CO_2 per year (Cox, 2012). The carbon sequestered within the tree cover of the Balkan campus, totally 2702.45 tons, can effectively offset and absorb a considerable portion of the city's carbon emissions released into the atmosphere. Therefore, planting efforts on the campus should focus on increasing the number of tree species and selecting local species, favoring deciduous trees, and considering their role in improving air quality. This suggests that more emphasis should be placed on campus re-plantation and that species selection should favor tree species with high carbon storage. By increasing the tree canopy cover in the campus area, the amount of soil/bare ground (17.21 ha), which occupies a significant area in the area, will increase the open and green space potential of the area, and this will contribute to an increasing the amount of air quality and carbon storage benefits of trees. In addition, as shown in Figure 4, the area of tree cover in the campus area is significantly less than the area of ground cover and herbaceous vegetation. Considering the impact of tree cover on carbon storage, it is important to strategize for the expansion of these areas in forthcoming plans.

Figure 4. Distribution of areas covered with ground cover, herbaceous, and tree cover in Balkan Campus.

Increasing the vegetative cover of campus areas can not only provide ecological benefits but can also have a positive impact on the health of campus users. In this context, it would be important to increase the amount of wooded areas and plant species diversity on campus, expand the campus arboretum, develop rain gardens and drought-tolerant landscaping practices, and improve the maintenance and health of campus street trees. In addition, campus trees serve the region in which they are located and play an important role in reducing the heat island effect and regulating urban microclimate. This positively impacts both campus and urban health and increases ecological comfort.

This study utilizes the i-Tree Canopy model, which provides a simple, fast, and practical method for calculating regulatory ecosystem services and their economic values. The model effectively illustrates the ecosystem benefits of areas covered by trees and tall shrubs in a clear and tangible manner. Although widely used in the United States (U.S.), the model has also been applied in other countries such as Australia, Canada, the United Kingdom, and Switzerland. Its applicability in Turkey depends on the compatibility of the climatic, air pollution, and vegetation characteristics of the studied cities with those referenced by the model (Coşkun Hepcan & Hepcan, 2017). However, the study has certain limitations. First, the i-Tree Canopy tool was not employed to determine the role of tree species in carbon sequestration and air quality improvement. As a result, it does not provide detailed insights into the environmental contributions of specific species. To address this limitation, other tools within the i-Tree suite, such as i-Tree Eco and i-Tree Street, should be used to comprehensively evaluate tree species' benefits regarding energy savings, carbon storage, air quality, stormwater management, and aesthetic enhancement. Additionally, the classification of randomly selected points can be challenging, necessitating the verification of these points' accuracy using supplementary tools like Google Earth Pro, which impacts the reliability of the data. Another significant limitation lies in the lack of comparable tools in Turkey that assess comprehensive ecosystem services and environmental benefits, restricting the study's applicability in a local context. Furthermore, the data underpinning the model, such as climate, air pollution, and vegetation, are calculated based on U.S.-specific standards and statistically generalized. This reliance on U.S. datasets means that the results only provide approximate values. Nonetheless, these findings represent a valuable starting point for evaluating regulatory ecosystem services and developing a general understanding of the subject. For tools like i-Tree Canopy and i-Tree Eco to be used with greater accuracy and precision in Turkey, extensive research must be conducted, and coefficients tailored to local conditions should be developed. Otherwise, continued reliance on U.S.-based coefficients may hinder the results from fully reflecting actual values (Coşkun Hepcan & Hepcan, 2017; Tuğluer & Gül, 2018; Çakmak & Can, 2020; Tonyalıoğlu et al., 2021). Despite these limitations, this study marks a significant step towards developing sustainable campus plans and quantitatively assessing the benefits of ecosystem services.

4. Conclusions

In the context of sustainable development, the potential of university campuses to support ecological conditions is of great importance when considering the goals of cities and issues such as climate change and biodiversity loss. University campuses typically cover large areas of land and provide many ecological benefits by acting as a model for cities. This research explored how campus trees contribute to air quality regulation, a crucial ecosystem service they provide. Employing the i-Tree Canopy tool, their impact was analyzed, considering both their ecological advantages and economic significance. As a result, it was estimated that the 23.93% tree/shrub cover, which constitutes the majority of the land cover, removes 2375.39 kg of pollutant gases and particulate matter from the air annually, with an economic benefit value of $1144 for improved air quality. In addition, the canopy cover was found to store 2702.45 tons of carbon, and the economic benefit value of this ecological service was $508,060. In addition to all these benefits, it indirectly contributes to many ecosystem services (regulation of stormwater runoff, aesthetic benefits, etc.). This study can contribute to creating campus plans and management policies to guide future assessments. It highlights the importance of ecosystem services in creating sustainable campuses and the need to increase carbon sequestration to promote carbon neutrality. In this context, it has a guiding role in campus planning and design.

In addition, it is recognized that university campuses have issues similar to those in cities. Therefore, the impact of urban trees on air quality should not be underestimated. However, this alone is not enough in today's anthropogenic age. Therefore, in addition to increasing reforestation activities, reducing pollutant emissions in cities should be one of the primary goals. Especially in campuses with intensive use activities (due to factors such as hospitals, etc.), the focus should be on reducing emissions that cause air pollution. In this context, it will be important to take steps towards a sustainable and carbon-neutral campus through the development of planning strategies.

With issues such as global climate change and environmental sustainability, the potential of campus trees to improve air quality becomes even more important. Therefore, it is critical to protect green spaces on campus, create new ones, and implement effective policies to achieve carbon neutrality goals. As a result, the role of campus trees in improving air quality should not be overlooked. It should be considered part of environmental sustainability efforts, positively impacting the campus and the broader community and leaving a healthier habitat for future generations.

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