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Research Article

Belgrad forest carbon sequestration and life cycle carbon footprints of İstanbul

İnci Çağlayan[1,*], Aysel Sadak Mercan[2], Fatmagül Kılıç Gül[2]

[1] Department of Forest Management, Faculty of Forestry, İstanbul University-Cerrahpaşa, İstanbul, Türkiye
[2] Department of Geomatics Engineering Department, Faculty of Construction, Yildiz Technical University, İstanbul, Türkiye

* Corresponding author: İ. Çağlayan
E-mail: inciyaylaci@iuc.edu.tr

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Abstract

Increases in the carbon dioxide (CO_2) concentration in the atmosphere is one of the most important environmental problems of today. In addition to the increases due to industry, human activities such as heating, transportation, and electricity consumption contribute to this increase gradually. There are different measures to reduce the amount of carbon concentration in the atmosphere, one of which is the use of terrestrial ecosystems such as forests, which gain importance due to their carbon sequestration potential. On the other hand, the values of greenhouse gas emissions (GHGs), especially CO_2, and the carbon values of forest sinks and sequestrations (FS) also vary spatially. We examined the quantities of the human activities' annual carbon footprint (CF) with the FS carbon value of the largest forest area of İstanbul's two districts as a sample calculation. CF values were calculated by using life cycle survey data made for another study in 2014. The survey applied to geomatic engineers concerning six categories: houses, flights, cars, motorbikes, bus and rail, and secondary data (food, clothing, services, trade, etc.). The sink value and the annual carbon sequestration for the Belgrad forest were calculated using the formulas set by the Intergovernmental Panel on Climate Change (IPCC) and the values of local coefficients and forest plans inventories. According to the results of the study, approximately 6 475 500 t CO_2e was released annually in two neighboring districts. The forest continues to store an average of 13 171 tons of carbon or 48 294 tons of CO_2e each year.

Keywords: Carbon footprint, Forest carbon sequestration, GIS, Belgrad forest

Introduction

Global warming which has become a commonly used term recently represents one of the most important environmental issues. The contribution of humans to global warming continues to increase as humans maintain and increase energy use such as heating, transportation, and electricity consumption (Solomon et al., 2007). In other words, all people contribute to global warming. There is different greenhouse gases (GHGs) in the atmosphere that affect global warming. Among them after the water vapor, the contribution of carbon dioxide (CO_2), which is one of the most important greenhouse gases to global warming, is about 26%, (Kiehl and Trenberth, 1997; Ulker et al., 2018). The GHGs emitted by human activities are CO_2, methane, nitrous oxide, fluorinated gases, perfluorocarbons, and sulfur hexafluoride. Among all these greenhouse gases, CO_2 represents a lead role as it contributes to 65% of the total greenhouse effect (Pachauri et al., 2014; Çelekli and Zariç, 2023).

Various approaches have been developed to measure the contribution to carbon emissions of human activities. One of these is the calculation of the carbon footprint (CF). CF is a measure of the total amount of greenhouse gases (such as CO_2) emitted into the atmosphere by an individual, organization, or community (Wiedmann and Minx, 2008). It is usually measured in units of CO_2 equivalents and is used as an indicator of the impact of human activities on climate change. Studies show that time spent on daily activities significantly affects household carbon footprints, with eating contributing the most and transportation showing the largest regional inequalities (Huang et al., 2023). Therefore, CF provides a comprehensive understanding of how different activities, structured through time use, contribute to varying levels of greenhouse gas emissions. On the other hand, with the increasing concern about global climate change and carbon emissions, many companies and organizations are curious about their share in global climate change. They have conducted research into their CF value to get information about their share. CF is defined as the CO_2 that results from the use of energy to perform human activities (Wiedmann and Minx, 2008). The CF creates a footprint of varying magnitude depending on the type and amount of energy we use every step of the way. Consequently, we have been adding GHGs, primarily CO_2, to the atmosphere at a steadily increasing rate.

To measure the effect of carbon footprints on global warming, it is first necessary to understand how much of the released carbon is sequestered. These measurements have been made at the global, national, regional, and local levels in the world. Two main measures are taken to reduce the CO_2 concentration in the atmosphere. The first is to decrease the amount of CO_2 and the second is to increase the carbon sequestration capacity of forests, a feature which has recently come to the fore with global warming (Mısır et al., 2012). Nonetheless, deforestation in tropical regions has demonstrated that forests, under certain conditions, can shift from being carbon sinks to carbon sources (Swamy et al., 2023). Consequently, restoration efforts are critical to achieving carbon neutrality. For instance, land use changes within

Ethiopia's Majang Forest Biosphere Reserve have led to declines in carbon stocks, underscoring the need for immediate and sustainable forest management interventions (Tadese et al., 2023). Forests can play important roles in this process, from carbon sequestration to carbon storage. They transform into biomass that sequesters carbon by capturing CO_2 from the atmosphere. The carbon stored in trees is carbon that is captured from the atmosphere through the process of photosynthesis. Trees use CO_2 from the air, along with water and sunlight, to produce energy and grow (Lackner et al., 2014). In this process, they convert CO_2 into organic matter such as wood, leaves, and roots. Trees are an important part of the carbon cycle because they help remove CO_2 from the atmosphere and store it in organic matter (Post et al., 1990). This can help mitigate the greenhouse effect and combat climate change, as CO_2 is a significant contributor to global warming.

This study aims to compare the annual carbon footprint with the annual carbon sequestration of Belgrad forest which is the largest forest in İstanbul. We used the life cycle questionnaire survey by (Sariturk et al., 2017) to calculate carbon footprint that consists of six categories of data such as house, flight, car, motorbike, bus, rail, and secondary data (food, clothing, services, trade, etc.) in 2014. The carbon sequestration for the Belgrad forest was calculated by the formula set by the Intergovernmental Panel on Climate Change (IPCC) by the values of local coefficients and forest plan inventories (IPCC, 2006). The results of CF and FS were visualized in GIS software.

Materials and Methods

The Belgrad Forest in northern Istanbul was studied for carbon sequestration, while carbon footprint calculations were conducted for the Eyüp and Sarıyer districts (Fig. 1). Eyüp is on the historic European side of the city, while Sarıyer is on the northern coast of the European side and known for its natural beauty and proximity to the Black Sea. The Belgrad Forest is one of the largest green spaces in Istanbul, covering an area of 5660.26 ha. The necessary data to calculate of carbon footprint were obtained from the previous survey. The survey that questioned geomatics engineers in Türkiye is used to determine the carbon footprint (Sariturk et al., 2017). The Turkish Chamber of Survey and Cadastre Engineers in Istanbul has 3,157 geomatics engineers. 145 members of the union from İstanbul answered the surveys.

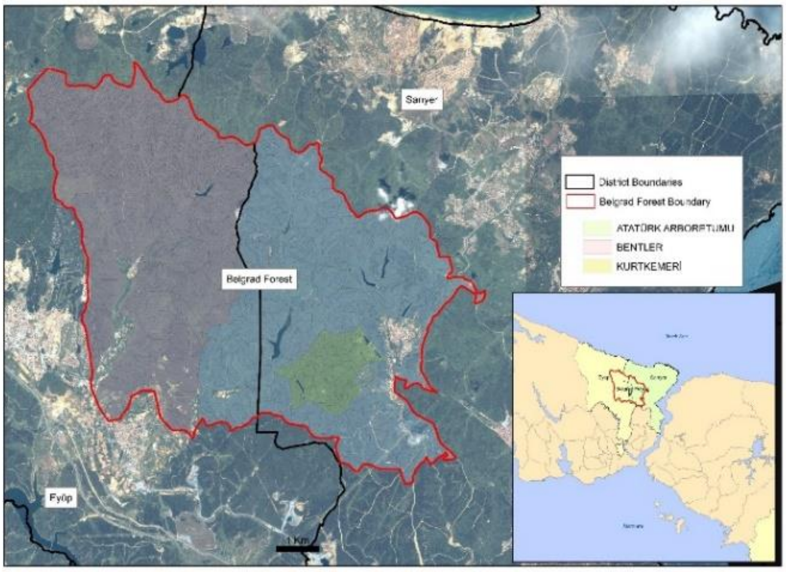

Fig. 1. Study area

In this study, the carbon footprint calculator available on the internet was used to calculate the carbon footprint for each person by entering the survey data. The calculator analyses six categories of data: houses, flights, cars, motorbikes, bus and rail, and secondary data (food, clothing, services, trade, etc.). The steps in the process are as follows (Fig. 2).

The district in which people reside was taken into consideration, and the average amount of the carbon footprint of the people who participated in the survey was calculated in terms of the district. The average carbon footprint values calculated for the Eyüp and Sarıyer districts were multiplied by the 2014 district population. The calculated values were added to the district data in the ArcGIS environment.

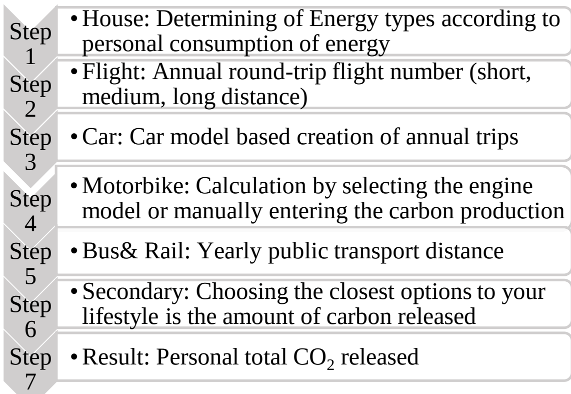

Fig. 2. Steps to calculate personal carbon footprint.

The study area for carbon sequestration calculation is Belgrad Forest which is geographically situated to the northern of İstanbul. Belgrad Forest stored approximately 1.2 million tons of C or (4.5 million tons of CO_2e) from the past to the present (Caglayan et al., 2023). There are three management areas of the forest; Atatürk Orberatumu, Bentler, and Kurtkemeri. Carbon sequestration can be calculated using five steps which measure the amount of carbon above and below the ground biomass, soil, litter, and coarse woody debris pools in forest ecosystems (Tolunay, 2011).

The above and belowground biomass of Belgrad Forest stands were determined through rigorous calculations, and the obtained results were integrated into the stands layer using ArcGIS (Fig 3). The biomass calculations were based on inventory data sourced from the Forest Management Plans provided by the Turkish Forestry Office (GDF, 2012). The biomass quantification followed the formulas Eq. (1), (2), and (3) as stipulated by IPCC (2006). Table 1 displays the species-specific Biomass Expansion Factor (BEF) and Wood Density (WD) coefficients, as outlined by Tolunay (2019). The coefficients for other coniferous and deciduous species were obtained from the General Directorate of Forest (GDF, 2017).

$$AGB = I_v \times WD \times BEF \qquad \text{(Eq.1)}$$

Equation (1) expresses the calculation of aboveground biomass (AGB) as a function of volume increment (Iv), wood density (WD), and biomass expansion factor (BEF). Here, AGB represents the aboveground biomass, and Iv denotes the volume increment measured in cubic meters per hectare (m^3/ha).

Table 1. Wood density values and BEF coefficients of the main tree species in Türkiye (Tolunay, 2019)

	Tree Species	WD (t/m^3)	BEF_1
Coniferous	*Pinus brutia (Çz)*	0.478	1.319
	Pinus nigra	0.470	1.071
	Pinus sylvestris	0.426	1.247
	Pinus pinea	0.470	1.212
	Pinus halepensis	0.480	1.212
	Pinus pinaster (Çm)	0.440	1.212
	Pinus radiata	0.380	1.212
	Abies sp.	0.350	1.345
	Picea orientalis	0.358	1.132
	Cedrus libani	0.430	1.300
	Juniperus sp.	0.460	1.212
	Other Coniferous*	0.446	1.212
Deciduous	*Fagus orientalis*	0.530	1.305
	Quercus sp. (M)	0.570	1.322
	Carpinus sp. (Gn)	0.630	1.482
	Alnus sp.	0.407	1.103
	Populus sp,	0.350	1.310
	Castanea sativa (Ks)	0.480	1.320
	Fraxinus sp.	0.562	1.310
	Robinia pseudoacacia	0.680	1.315
	Liquidambar orientalis	0.468	1.310
	Other deciduous*	0.541	1.310

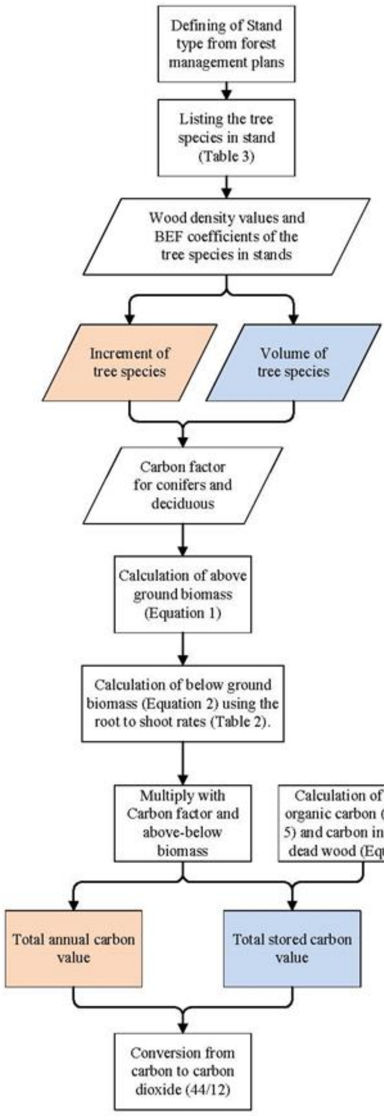

Fig. 3. Calculation of forest carbon values

$$BGB = AGB \times R \qquad \text{(Eq.2)}$$

The determination of belowground biomass (BGB) is outlined in Equation (2), where BGB is computed by multiplying AGB by the root-to-shoot ratio (R). The values for R are summarized in Table 2.

$$C_{Total} = (AGB + BGB) \times CF \qquad \text{(Eq.3)}$$

The overall carbon sequestration (C_{Total}) is calculated in Equation (3) by summing the above and belowground biomass and subsequently multiplying the result by the carbon factor (CF). The specific CF values used are 0.510 for coniferous trees and 0.480 for deciduous trees, as per the Turkish national coefficients (IPCC, 2006; Tolunay, 2019).

The carbon sequestration for Belgrad Forest is determined by calculating the amount of carbon sequestered per hectare for each stand type, which is then multiplied by the respective stand area. An illustrative example of this calculation is presented in

Table 3, where the total carbon sequestration for the given stand is 3.799 tones root.

Table 2. The -to-shoot ratios for different vegetation types in temperate zone forests (IPCC, 2006).

Vegetation types	Above ground biomass (t/ha)	The root to shoot ratio (R)
Coniferous	< 50	0.40
	50-150	0.29
	> 150	0.20
Oak(Quercus)	> 70	0.30
Deciduous	< 75	0.46
	75-150	0.23
	> 150	0.24

Table 3. A calculation of total carbon for sample stand

Tree Type	I_v	AGB	BGB	C_{Total}
Pinus brutia	6.001	3.784	1.097	2.489
Pinus pinaster	0.319	0.170	0.068	0.121
Quercus sp.	2.077	1.565	0.470	0.977
Carpinus sp.	0.227	0.212	0.097	0.149
Castane sativa	0.142	0.090	0.041	0.063
Total				3.799

Carbon stored in litter and deadwood follows coefficients established by Tolunay and Çömez (2008). Litter carbon is considered constant at 5.8 tons/ha. Deadwood biomass is estimated at 1% of the aboveground biomass, following Food and Agriculture Organization- Forest Resources Assessment (FAO, 2010) and Forest Planning Regulations aimed at biodiversity preservation (Equation 4).

$$C_{DeadWood} = AGB \times 0.01 \times 0.47 \qquad \text{(Eq.4)}$$

Equation (4) further delineates the calculation of carbon content in deadwood (C_DeadWood), where AGB represents aboveground biomass for carbon storage, and the constants 0.01 and 0.47 are employed for the estimation.

Results

The study aimed to estimate the carbon footprint of two districts in İstanbul, Eyüp and Sarıyer from the survey, and compare it with the carbon sequestration of Belgrad forest. The population of Eyüp in 2014 was 367,824 with a per capita carbon emission of 11.2 tons (Tab. 5). On the other hand, the population of Sarıyer was 337,681 with a per capita carbon emission of 6.9 tons (Tab. 4). The total CF of the two districts was 6,449,628 tons (Tab. 4), with Eyüp having a higher CF compared to Sarıyer.

Table 4 details the carbon footprints for the two districts and the carbon sequestration metrics for the Belgrad Forest, highlighting the relatively modest proportion of emissions captured by the forest. Tables 4 illustrate the carbon footprints of Türkiye, providing insight into the variations between estimations by Hertwich and Peters (2009), and Worldbank (2014), while consistently portraying the Belgrad Forest's role in mitigating carbon emissions. This data serves as a quantitative foundation for the comprehensive analysis and comparison of carbon dynamics between urban districts and forest ecosystems, contributing valuable insights to the scientific discourse on carbon management and environmental sustainability.

Belgrad forest have an annual carbon sequestration of 13,170.97 tons (Tab. 4 and Fig. 4), but it only sequestered nearly 1% of the carbon emissions from Eyüp and Sarıyer. The carbon footprint per person for Türkiye was calculated by Hertwich and Peters (2009) as 4.6 (Tab. 4) and by Worldbank (2014) as 4.5 (Tab. 4). Despite being higher than the world average, the carbon footprint from Eyüp and Sarıyer was not balanced, with Belgrad forest only capturing nearly 1.5% of their emissions.

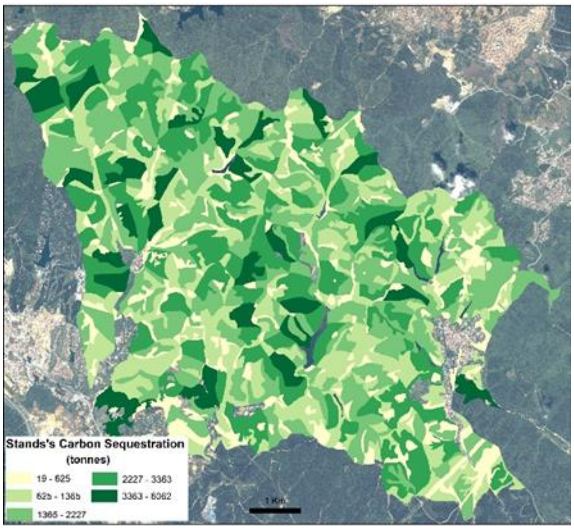

Fig. 4. The carbon sequestration values of Belgrad forest's stands

Table 4. Carbon footprints and carbon sequestration for Belgrad forest

Ton CO_2e	The survey	Hertwich and Peters (2009)	Worldbank (2014)
CF per person	11,2 & 6,9	4,6	4,5
CF total	6449628	3245323	3174773
Carbon sequestration	48294		
Ratio	0,75%	1,49%	1,52%

Discussion and Conclusion

Calculation of Carbon Footprint in Districts

In this study, we conducted an assessment of the carbon footprint per capita and total carbon values for two Istanbul districts, Eyüp and Sarıyer, resulting in values of 11.2 and 6.9, respectively. Due to the unavailability of district-specific carbon inventory data, we utilized information from an existing survey study.

Upon comparing our calculated carbon footprint values with those reported by Hertwich and Peters (2009), and Worldbank (2014) for Türkiye, our values were found to be higher. In 2014, Eyüp had a population of 367,824, with an estimated per capita carbon emission of 6,963 tons, while Sarıyer, with a population of 337,681, showed an estimated per capita carbon emission of 11,212.5 tons. The total carbon footprint for both districts combined was 6,475,500 tons, indicating a higher per capita carbon footprint for Eyüp compared to Sarıyer.

Additional sources, such as Hertwich and Peters (2009), and Worldbank (2014), calculated the carbon footprint per person for Türkiye, reporting values of 4.6 and 4.5, respectively. Despite our study's carbon footprint values being considered above the world average, the results indicate that the Belgrad forest is unable to fully offset the carbon emissions from Eyüp and Sarıyer.

Comparison of Carbon Footprint Across Districts

Tabulated data presents carbon footprint metrics for Eyüp and Sarıyer from three sources: the survey, Hertwich and Peters (2009), and Worldbank (2014). Notably, Eyüp exhibits a higher carbon footprint per person compared to Sarıyer, with respective total carbon footprints of 4,124,227 CO_2e and 2,351,273 CO_2e. This discrepancy from Hertwich and Peters (2009), and Worldbank (2014), further emphasizes the need for comprehensive research to understand the underlying factors influencing these variations.

The study suggests that the number of questionnaires, exclusively from geomatic engineers, may be insufficient, limiting the inclusivity of the calculations. Despite higher per capita carbon footprints in Eyüp, it is essential to consider multiple factors influencing these figures, such as population density and economic activity, highlighting the need for further research.

Carbon Sequestration and Emissions in Districts

The average carbon footprint calculated for Eyüp and Sarıyer districts is less than the average carbon footprint for Istanbul. However, the higher per capita carbon footprint in Eyüp compared to Sarıyer does not necessarily imply greater environmental irresponsibility or consciousness. Factors like population density and economic activity could influence these figures. The data, capturing a snapshot of carbon emissions in 2014, underscores the necessity for additional research to comprehend the underlying causes of this difference and devise effective strategies.

Conclusion and Insights for Carbon Management

In conclusion, our study revealed that the carbon footprint of Eyüp and Sarıyer, as determined by the survey, surpasses the world average, with the Belgrad forest unable to fully offset their emissions. The study provides valuable insights for developing strategies to reduce carbon emissions and enhance carbon sequestration in the region.

Additionally, the study emphasizes the calculation of carbon sequestration in the Belgrad forest, showing that it falls short of meeting even 1% of the carbon released in the Eyüp and Sarıyer districts. The annual carbon sequestration of stands in the Belgrad forest is determined to be 13,170.97 tons. In comparing carbon emissions and sequestration, the results indicate that the Belgrad forest cannot sequester even 2% of the carbon emitted by Eyüp and Sarıyer.

All these steps are used to calculate carbon footprint, which is a measure of the total amount of greenhouse gases emitted into the atmosphere as a result of human activities, such as the burning of fossil fuels and deforestation. This calculation can be used as a starting point for individuals to identify areas of their lifestyle where they can reduce their carbon footprint and take steps to reduce their impact on the environment.
The gross primary productivity is used when calculating the amount of carbon sequestration annually. The reason for this is that it can be said that raw inventory data is required to calculate net primary productivity.

The provided data shows the 2021 population for the districts of Sarıyer and Eyüp as 349,968 and 417,360 respectively (TÜİK, 2021). The data provided shows the population and carbon footprint of the districts of Eyüp and Sarıyer in both 2014 and 2021. In 2021, the population of Eyüp increased by 49,536 people compared to 2014, while the population of Sarıyer increased by 12,287 people. As a result, the total carbon footprint for Eyüp increased to 2,003,328, and for Sarıyer, it increased to 1,679,846.4. The carbon footprint per person increased by 6.66% from 2014 to 2021. The total carbon footprint for Eyüp increased by 18.4% and the total carbon footprint for Sarıyer increased by 8.1% from 2014 to 2021.

Overall, the increase in population from 2014 to 2021 and the increase in carbon footprint per person from 4.5 to 4.8 increased the total carbon footprint for both districts, indicating that the carbon footprint increased with the growth of population and increased carbon footprint per person.

Despite Belgrad forest's efforts in capturing CO_2 through carbon sequestration, the overall carbon footprint for both Eyüp and Sarıyer has still risen. To decrease this impact, sustained efforts to reduce emissions and encourage sustainability are crucial. Nevertheless, the annual carbon sequestration rate remains unchanged.

Acknowledgements

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