EVALUATION OF DÜZCE URBAN FORESTS' CLIMATE CHANGE MITIGATION POTENTIAL WITH MEASURING URBAN CARBON FOOTPRINT

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Abstract

Carbon-source and carbon-sink estimations are crucial important for carbon-emissions reduction. Although urban areas cover less than 2% of the earth's surface they are known carbon sources responsible of 80% of the world's anthropogenic greenhouse gases (GHGs). The methodologies for carbon footprint calculations are expressed a measure used to assess the amount of anthropogenic greenhouse gas emissions based on tons of CO_2 equivalent, and emerging as an important tool for greenhouse gas management. Besides increased efforts to reduce carbon footprint from cities, there is the alternative possibility to remove some atmospheric CO_2 by sequestering it within forest ecosystems. Forest ecosystems can sequester and store a large amount of carbon in cities. In this study, it is focused on potentially do Duzce city green gas emissions and available sinks assessment. In the first step, it is calculated "Carbon Footprint" by using greenhouse gas emission calculator that developed by UNFCCC. Then it is identified urban carbon sources such as human respiration, industrial fossil-fuel consumption, electricity-heating-cooling consumption, water consumption and transportation. In the second step, it is estimated potential of carbon storage forest ecosystems urban and sub urban areas by used a GIS-based approach. Although forest areas cover 50,2% of Düzce, industrial and agricultural activities and rapid urbanization, overconsumption lead to increase greenhouse gas emission and ecological balance is disturbed. The most effective way to reduce emissions is afforestation.

When evaluating in the context of climate change mitigation, sustainable afforestation studies in urban forests should be accelerated. Within the scope of the study, it is recommended for a sustainable future to give importance to industrial afforestation studies with fast-growing domestic or foreign forest tree species in forest and non-forest areas in urban areas.

Keywords: *climate change mitigation, carbon footprint, GIS-based approach, planting for future, urban forests*

1. INTRODUCTION

All living organisms on Earth are involved in the carbon (C) cycle in processes that provide food, fibre and fuel (Finzi et al., 2007). Atmospheric CO_2 contained in light is used in the production of organic matter, which is the basic nutrient for living organisms (Gajda, 2000; Hutyra, 2014). However, exceeding the limits of CO2 concentrations, which ranks 2nd in the atmosphere after water vapour, causes overheating and climate change (IPCC, 2021). With the industrial revolution, urbanisation has increased rapidly. Today, cities covering only 2% of the world are responsible for 80% of carbon emissions (Parry, 2010; IPCC, 2014). Cities rank first in land conversion, energy consumption, transport, overuse of natural resources and Carbon (C) emissions (Churkina, 2008; Churkina, 2016). In some parts of the world, urban sprawl, deforestation and land use change account for about 5% of global emissions (Seto et al., 2012; Curkina, 2016).

Around 70% of carbon emissions occur within urban cores and settlement boundaries. Fossil fuel use, structures built with carbon-intensive materials and motor vehicles are the main actors of carbon emissions (Cutting global carbon emissions 2022). In terms of sectors; it is possible to divide into subgroups as the transport sector, electricity generation, industry, housing, agriculture, land use and forestry (EPA 2022). Cities are the most difficult systems to adapt to climate change and other environmental problems caused by carbon emissions (World Bank, 2022). Therefore, it is important to determine the carbon footprint of cities.

The term "carbon footprint", derived from the concept of "ecological footprint" in the 90s, refers to the impact of human activities on the environment and especially on climate conditions in terms of greenhouse gas emissions (Wiedmann and Minx, 2008; Ercin and Hoekstra, 2012). Carbon footprint calculation methods focus on estimating carbon emissions from a range of activities (Rees and Wackernagel, 2008). The relationship between human activities such as fuel consumption, electricity consumption, heating-cooling and water consumption, carbon emissions and global climate change helps to understand and address climate change (Chatterton et al., 2009; Mulrow et al., 2019). Carbon footprint calculations can be performed at the individual, organisation and nation levels for both public and private sectors (Mulrow et al., 2017). Previous studies have focused on the carbon footprint of commercial buildings, public buildings and households (Sharma et al., 2011; Chau et al., 2015; Wang et al. 2016; Atmaca and Atmaca, 2022). In addition, other studies are on the carbon footprint calculation of agriculture (Snyder et al., 2009; Holka et al., 2022), manufacturing (Huang et al., 2022) and various services (Tennison et al., 2022; Campos et al., 2022). The built environment is the most dominant sector responsible for the total carbon footprint (Kibert, 2016). In addition to new infrastructure and buildings, residents' demand for goods and services accelerates the increase in global greenhouse gas (GHG) emissions and triggers climate change (Ottelin et al., 2019).

The first steps towards climate change have started to be taken with the United Nations Framework Convention on Climate Change (1992),. In addition, there are efforts towards carbon footprint, carbon emissions and climate change with agreements such as Kyoto Protocol, Bali road map, Copenhagen Agreement and Paris agreement (IPCC, 20014; Gao et al., 2014). Goal 13 of the Sustainable Development Goals (SDGs) prepared by the United Nations General Assembly in 2015 focuses on climate change (Yanez et al., 2019). The main purpose of these efforts is to keep the average temperature increase in the world within the 2 degree limit due to climate change. In order to achieve the 2-degree targets of the 2015 Paris Climate Agreement, large budgets are allocated to mitigation efforts (McCrone et al., 2017). At the core of most existing sustainable strategies is associated with reducing the overall carbon footprint. In recent years, carbon budgets have become an important policy tool for climate change mitigation (Almutairi et al., 2021). In addition to efforts to reduce carbon emissions in cities, which play a key role in global climate change, the possibility of sequestering atmospheric carbon through green spaces appears as a second alternative (Nowak et al., 2002).

Globally, oceans and then forests are known as the largest carbon pools (Kinnunen et al., 2022). However, urban green infrastructure and forests within or on the periphery of city boundaries are proposed as a way to reduce the global greenhouse gas impacts of cities (Shigeto et al., 2012; Paloheimo et al., 2013). The concept of urban forest is currently defined as green areas, parks, gardens and roadside trees within and around settlements (Nowak et al. , 2002b). The carbon sequestered by urban green infrastructure consisting of parks, community gardens, private gardens and street trees is underrepresented compared to the carbon emissions of cities (Velasco et al., 2016). However, forested areas within municipal boundaries can be equivalent to the total carbon footprint of residents (Paloheimo and Salmi, 2013; Ariluoma et al, 2021). Considering that carbon sequestration decreases with increasing forest age, the contribution of urban forests to carbon sequestration cannot be ignored (Nowak et al., 2013; Riikonen et al., 2017). In the context of carbon footprint and cycling, trees in urban forests have a temporary effect. For this reason, some studies (Levasseur et al., 2011) explain that the reduction of carbon footprint impacts cannot be sustained by temporary methods. However, forests created through afforestation, especially in the urban periphery and in rural areas close to the city, can be separated from this situation (Ottelin et al., 2018). Although there are studies in the literature where carbon footprint and carbon sequestration are considered together, there are very few studies where the relationships between these two are taken together. The main purpose of this study is to determine the extent to which the forest created through afforestation reduces the effects of carbon emissions emitted in the urban core. In this context, the main hypothesis of the study is that the carbon sequestration/storage of the forests constructed in the city or in the urban periphery is equivalent to the carbon footprint of the city dwellers.

2. MATERIALS AND METHODS

2.1. Materials

Düzce Province is located between 40º 37' - 41º 07' north latitudes and 30º 49' - 31º 50' east longitudes in the Western Black Sea Region of Türkiye. The surface area of Düzce province is 2.593 km^2. The province has 8 districts (Şenik and Uzun, 2021). Within the scope of this study, 56 neighbourhoods in the provincial centre of Düzce, where settlement and working centres are the densest, were examined (Figure 1).

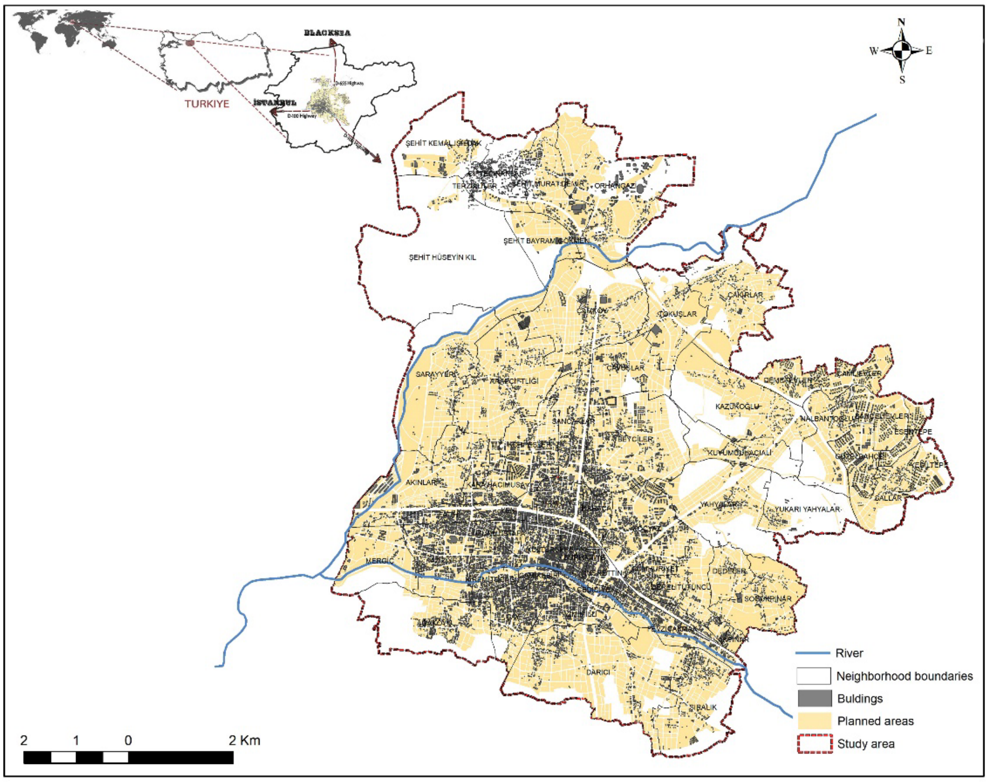

Fig. 1. Study area

After the 1999 earthquake, urbanisation has increased in Düzce province, which has experienced a rapid transformation, and natural and semi-natural areas have been destroyed. Urbanisation has brought along population increase. Today, the number of people living in the study area is 194.097 and the number of people per square kilometre in the study area is 358. There are 2 small industrial zones within the study area (Siyacavus, 2021). In addition, the D-100 motorway divides the study area, which is located at the transition point of two metropolises between Istanbul and Ankara.

The study area consists of 40.8% forests and waterways, 76.1% agricultural areas and 22.1% settlements. The dominant woody crop pattern in agricultural areas is hazelnut and poplar. Other agricultural areas are dominated by annual crops. The forests of the study area, 54.5 % are mixed forests and 45.5% are broad-leaved forests. Artificial areas consist of continuous urban fabric, discontinuous urban fabric, industrial or commercial units and public facilities and construction sites. Discontinuous urban fabric areas contain agricultural and natural areas.

2.2. Methods

2.2.1. Carbon footprint calculation

Carbon footprint estimates can usually be determined by equations based on activity data multiplied by emission factors. The carbon footprint calculation was made according to the calculation stage, which is the sum of annual electricity use and annual transport, using the parameters on the website www.carbonfootprint.com. In the carbon footprint calculation, in addition to the electricity use, water consumption, waste and transport parameters, emissions due to heating are also added (Table 1).

Category	Formula	Source
Electricity usage carbon footprint	(Electricity usage per year in kWh/1000) x 0.84	Türkiye Statistical Institute (TUIK)
Transportation per year (Shuttle)	Number of the shuttle bus x total trips for shuttle bus service each day x approximate travel distance of a vehicle each day (in kilometers) x 365/100) x 0.01	Duzce municipality
Transportation per year (Car)	(Number of cars x 2 x approximate travel distance of a vehicle each day inside campus only (in kilometers) x 365/100) x 0.02	Duzce Municipality
Transportation per year (Motorcycle)	(Number of motorcycles entering your university x 2 x approximate travel distance of a vehicle each day inside campus only (in kilometers) x 365/100) x 0.01	Duzce Municipality/ Türkiye Statistical Institute (TUIK)
Water	Average daily water consumption x wastewater treatment rate x 360/100) x 0.272	Türkiye Statistical Institute (TUIK)
Waste	Average daily waste x 365/1000) x 446	Ministry Of Environment, Urbanization and Climate Change
Total emission per year	= total emission from electricity usage + transportation (bus, car, motorcycle)+ Water+Waste	

Table 1. Carbon footprint Calculation

Source: Gyarmati 2022; Greenmetric 2022.

The calculation method given in Table 1 is used in the green metric ranking system and in many studies (Gyarmati, 2022; Presekal et al., 2028). The constant 0.84 in the table is the coefficient for converting kWh to metric tonnes. 365 is the number of days in a year. The coefficient 0.01 is the emission in metric tonnes per 100 km for buses and motorbikes. The coefficient 0.02 is the emission in metric tonnes per 100 km for cars. Since the settlements in the study area are heated with natural gas, heating emissions are not included in the calculation. In the calculation system used by the green metric ranking system, water and waste are ignored. However, water and waste are included in the calculation system prepared by the United Nations Climate Change Conference (UNFCCC) IPCC (2006) (UNFCCC, 2023). In this study, these formulas were used in the calculation of carbon footprint related to water and waste. The emission factor used for the carbon footprint calculation arising from average daily water consumption is 0.272, while the emission factor used for domestic waste generated is 446.

2.2.2. Carbon sequestration calculation

Determination of Tree Cover

Using Sentinel-2 satellite imagery, different vegetation cover and forest/tree cover can be distinguished (Immitzer et al., 2016; Clevers et al., 2017; Persson et al., 2018). Using the Sentinel-2 satellite, analyses on the Normalised Difference Vegetation Index (NDVI) are performed. NDVI determines whether the target image contains vegetation (Table 2) (Recanatesi et al.,2018).

Plant index	Formula	Sentinel – 2 bands
NDVI	**(B8 - B4) / (B8 + B4)**	(NIR - Red) / (NIR + Red)

Table 2. Sentinel - 2 bands and band ratio formula used for Normalised Difference Vegetation Index (NDVI) Algorithm.

The raster data of the green area determined by the NDVI method contains digital numbers in the range of 0-255. Digital numbers give the brightness value of each pixel with positive numbers. Within the scope of this study, the values in the range of 0-255 were reclassified in Arc Map 10.4 programme and a classification was made from areas covered with dense vegetation to sparse areas. In the next step, the raster data were polygonised and the area was calculated. Thus, the tree cover within the study boundaries were calculated spatially.

2.2.3. Carbon Storage

In order to calculate carbon storage, Crown cover area method developed for settlements by IPCC (2006) was used. This formula is based on estimating annual biomass growth from the percentage of total crown coverage.

$$\Delta_{C_G} = \sum_{\mathrm{i},J} AT_{\mathrm{i},J} * CRW_{\mathrm{i},J}$$

ΔCG = annual carbon accumulation attributed to biomass increment in Settlements Remaining Settlements, tonnes C yr-1

AT_{ij} = total crown cover area of class i in woody [1] type j, ha

CRW_{ij} = crown cover area-based growth rate of class i in woody perennial type j, tonnes C (ha crown cover)$^{-1}$ yr^{-1}

3. RESULTS

3.1.1. Carbon footprint distribution

Carbon footprint calculation was made for 56 neighbourhoods in the central district of Düzce by using the data on electricity use, transportation and water use obtained from Turkish Statistical Institute (TUIK), Düzce Municipality and Ministry of Environment, Urbanisation and Climate Change. Electricity consumption provides the highest contribution to the total carbon footprint in residential areas, while wastewater provides the lowest contribution (Table 3).

Neighbourhood	CO_2 (Electricity)	CO_2 (Transportation)	CO_2 (Water/Waste)	CO_2 (Total)	Neighbourhood	CO_2 (Electricity)	CO_2 (Transportation)	CO_2 (Water/Waste)	CO_2 (Total)	Neighbourhood	CO_2 (Electricity)	CO_2 (Transportation)	CO_2 (Water/Waste)	CO_2 (Total)
Ağaköyü	9441,1	9441,1	823,9	8315,1	Dedeler	766,3	766,3	66,9	674,9	Orhangazi	8338,3	10232,5	727,7	9012,0
Akinlar	3913,3	3913,3	341,5	3446,6	Demetevler	5493,7	5493,7	479,4	4838,5	Sallar	2369,4	8338,3	206,8	7343,8
Akpinar	1171,0	1171,0	102,2	1031,4	Derelitütüncü	7387,8	7387,8	644,7	6506,7	Sancaklar	8636,2	2369,4	753,6	2086,8
Arapçiftliği	5336,8	5336,8	465,7	4700,3	Esentepe	8581,6	8581,6	748,9	7558,1	Sarayyeri	6123,6	8636,2	534,4	7606,2
Aziziye	24289,6	24289,6	2119,7	21392,6	Fatih	3656,4	3656,4	319,1	3220,3	Soğukpinar	1912,3	6123,6	166,9	5393,2
Azmimilli	17629,4	17629,4	1538,5	15526,7	Fevziçakmak	11790,1	11790,1	1028,9	10383,9	Ş.B. Gökmen	7137,7	1912,3	622,9	1684,3
Bahçelievler	10976,0	10976,0	957,8	9666,9	Güzelbahçe	13750,2	13750,2	1199,9	12110,2	Ş.Hüseyin Kil	1876,0	7137,7	163,7	6286,4
Beyciler	24858,1	24858,1	2169,3	21893,3	Hamidiye	17377,0	17377,0	1516,4	15304,5	Ş.Kemal şildak	1314,3	1876,0	114,7	1652,2
Burhaniye	6767,1	6767,1	590,5	5960,0	Kara Hacimusa	11724,1	11724,1	1023,1	10325,8	Ş.Murat Demir	5768,8	1314,3	503,4	1157,5
Camikebir	3135,7	3135,7	273,6	2761,7	Karaca	9311,5	9311,5	812,6	8201,0	Şerefiye	7785,8	5768,8	679,4	5080,8
Cedidiye	8154,1	8154,1	711,6	7181,6	Kazukoğlu	3065,2	3065,2	267,5	2699,6	Şiralik	4393,1	7785,8	383,4	6857,2
Cumhuriyet	6889,9	6889,9	601,3	6068,1	Kiremitocaği	8174,6	8174,6	713,4	7199,6	Terzialiler	1325,7	4393,1	115,7	3869,2
Çakirlar	2178,4	2178,4	190,1	1918,6	Koçyazi	35242,9	35242,9	3075,5	31039,5	Tokuşlar	1248,4	1325,7	108,9	1167,6
Çamköy	5209,5	5209,5	454,6	4588,1	Körpeşler	12867,9	12867,9	1122,9	11333,1	Uzunmustafa	14525,5	1248,4	1267,6	1099,5
Çamlievler	8404,3	8404,3	733,4	7401,9	Kuyumcuhaciali	1018,7	1018,7	88,9	897,2	Yahyalar	3872,4	3872,4	337,9	12793,1
Çavuşlar	5029,8	5029,8	438,9	4429,9	Kültür	15664,8	15664,8	1367,0	13796,4	Yeni	1521,2	1521,2	132,8	3410,6
Çay	18529,8	18529,8	1617,0	16319,8	Mergiç	2148,8	2148,8	187,5	1892,5	Yeşiltepe	6123,6	6123,6	534,4	1339,8
Çiftepinarlar	4047,5	4047,5	353,2	3564,8	Nalbantoğlu	2646,8	2646,8	231,0	2331,1	Yukariyahyalar	700,4	700,4	61,1	5393,2
Darici	11512,7	11512,7	1004,7	10139,5	Nusrettin	10232,5	766,3	892,9	674,9	**Total**	**443.347,5**	**146.819,9**	**390.469,8**	**623.772,3**

Table 3. Carbon footprint distribution at the neighbourhood level

According to Table 3, the total carbon footprint of 56 neighbourhoods is 623,772.3 metric tonnes. The average annual electricity consumption per capita in Düzce province is 3038 kWh. Total annual electricity consumption in 56 neighbourhoods is 591,356,142 kWh. The amount of CO_2 due to electricity consumption is 443,347.5 metric tonnes per year on average. When making calculations for the transport sector, which contributes to the carbon footprint in the 2nd place, it is determined that the share of passenger cars is higher than the other two groups in separate calculations for passenger cars, motorcycles and public transport vehicles. The share of the transport sector in CO_2 emissions is 146,819.9 metric tonnes per year. Carbon emission per capita is 0.76 metric tonnes. The amount of wastewater produced per capita in Düzce is 59,860 litres per year on average. The total share of wastewater in the carbon footprint corresponds to 15%. The spatial distribution of the carbon footprint of the study area is given in Figure 2.

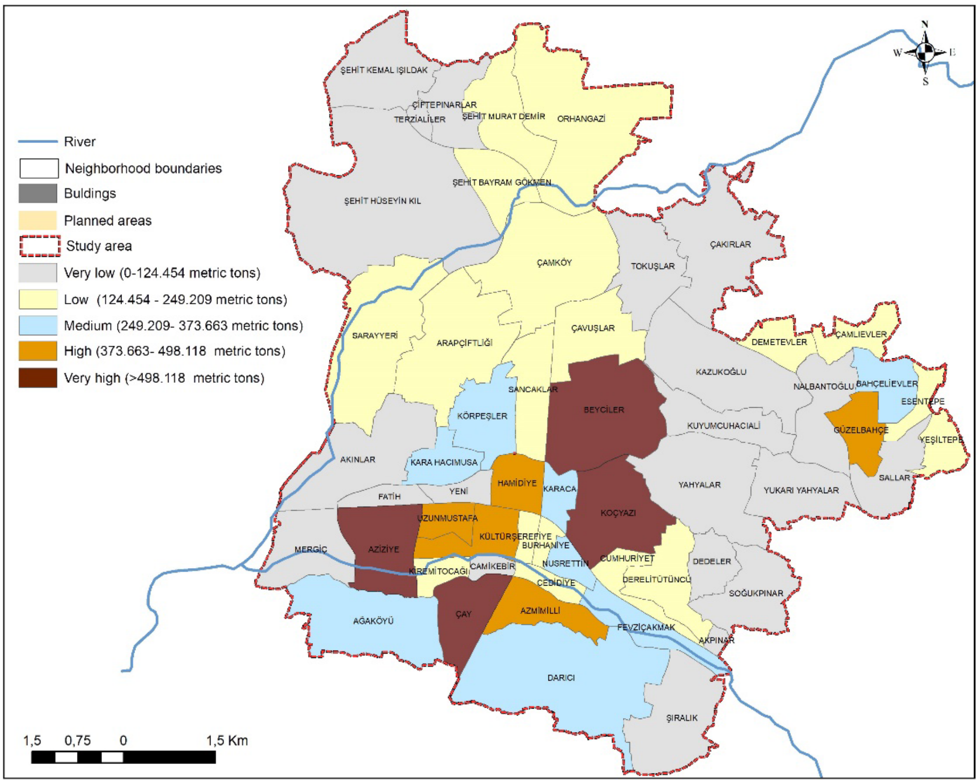

Fig. 2. Duzce city center carbon footprint distribution of 56 neighbourhoods

The total carbon footprint in the study area is 623,772.3 metric tonnes in terms of carbon dioxide. Koçyazı, Aziziye and Beyciler and Çay neighbourhoods have a population over 10,000, which increases the per capita carbon footprint share. While these neighbourhoods have the highest share, the neighbourhoods covering 41.9% of the area and having a population density below 1800 have the lowest share. In 19 neighbourhoods covering 29.3% of the area, the carbon footprint is in the range of 195,110-390,221 metric tonnes.

3.1.2. Carbon sequestration

In order to estimate carbon sequestration within the scope of this study, canopy-dependent estimation formulas were used among the carbon sequestration estimation methods published in the IPCC (2006) report. In this context, the tree cover of the study area was determined. The central district of Düzce has a structure intertwined with agricultural lands. Natural spots support this structure. The plantation areas in the area contribute to the tree cover (Table 4).

Neighbourhood	Area (H)	Tree cover (H)	Tree cover (%)	T-C per person (m^2)	Amount of CO_2 (Ton/Year)	Neighbourhood	Area (H)	Tree cover (H)	Tree cover (%)	T-C per person (m^2)	Amount of CO_2 (Ton/Year)	Neighbourhood	Area (H)	Tree cover (H)	Tree cover (%)	T-C per person (m^2)	Amount of CO_2 (Ton/Year)
Ağaköyü	257,3	116,1	45,1	279,6	1302,5	Dedeler	69,8	26,5	37,9	786,0	297,2	Orhangazi	405,4	86,0	21,2	234,6	965,2
Akinlar	256,6	38,7	15,1	224,6	433,7	Demetevler	66,1	18,8	28,5	78,0	211,4	Sallar	110,6	31,8	28,8	305,5	357,1
Akpinar	13,3	3,1	23,4	60,2	34,8	Derelitütüncü	124,9	40,8	32,7	125,7	458,3	Sancaklar	122,0	30,6	25,1	80,7	343,7
Arapçiftliği	288,4	90,9	31,5	387,2	1019,7	Esentepe	43,5	16,6	38,2	44,0	186,2	Sarayyeri	313,8	92,6	29,5	343,8	1038,9
Aziziye	161,6	18,3	11,3	17,1	205,4	Fatih	42,4	2,0	4,6	12,2	22,0	Soğukpinar	153,7	68,1	44,3	809,6	763,9
Azmimilli	99,2	20,0	20,2	25,8	224,2	Fevziçakmak	98,4	14,3	14,5	27,5	160,2	Ş.B. Gökmen	101,9	26,8	26,3	85,4	300,8
Bahçelievler	86,0	28,2	32,8	58,4	316,1	Güzelbahçe	79,5	23,6	29,7	39,1	265,3	Ş.Hüseyin Kil	653,8	218,1	33,4	2643,5	2446,9
Beyciler	295,4	70,5	23,9	64,5	791,5	Hamidiye	73,5	25,4	34,5	33,2	284,6	Ş.Kemal Işildak	186,8	24,9	13,3	431,1	279,6
Burhaniye	22,9	1,3	5,8	4,5	15,0	Kara Hacimusa	76,0	8,7	11,4	16,9	97,5	Ş.Murat Demir	147,0	15,0	10,2	59,2	168,4
Camikebir	23,3	1,6	6,8	11,4	17,7	Karaca	46,7	15,8	33,9	38,6	177,4	Şerefiye	25,6	0,3	1,2	0,9	3,4
Cedidiye	36,6	2,2	6,0	6,1	24,7	Kazukoğlu	284,7	77,8	27,3	576,9	872,6	Şiralik	210,6	72,4	34,4	374,5	811,8
Cumhuriyet	61,5	15,1	24,5	49,8	169,3	Kiremitocaği	40,9	4,4	10,7	12,2	49,2	Terzialiler	17,8	6,0	33,5	102,1	66,8
Çakirlar	275,3	62,3	22,6	649,8	698,5	Koçyazi	201,3	45,8	22,7	29,5	513,4	Tokuşlar	161,3	55,9	34,7	1018,2	627,2
Çamköy	330,3	53,6	16,2	233,9	601,1	Körpeşler	130,3	36,2	27,8	64,0	406,5	Uzunmustafa	49,3	3,1	6,3	4,8	34,6
Çamlievler	73,8	25,4	34,4	68,7	284,9	Kuyumcuhaciali	122,7	58,8	48,0	1313,2	660,1	Yahyalar	270,6	123,1	45,5	722,7	1380,8
Çavuşlar	146,0	27,7	19,0	125,3	310,9	Kültür	91,5	5,4	6,0	7,9	61,1	Yeni	41,7	2,4	5,7	35,5	26,6
Çay	118,9	24,4	20,5	30,0	274,0	Mergiç	151,1	50,4	33,3	532,8	565,0	Yeşiltepe	59,3	30,4	51,3	112,9	341,1
Çiftepinarlar	104,6	34,5	33,0	193,9	387,3	Nalbantoğlu	140,8	31,8	22,6	273,3	356,9	YukariYahyalar	155,7	38,3	24,6	1243,3	429,7
Darici	463,1	195,3	42,2	385,8	2191,8	Nusrettin	38,8	2,1	5,5	4,7	23,8	**Total**	**8223,4**	**2260,1**	**1373,4**	**15500,5**	**25.358,3**

Table 4. Düzce city center plantation fields and tree cover belonging to 56 neighbourhoods

The total tree cover in the study area was determined as 2,260.1 ha. This amount corresponds to 27.5 of the total area. Tree cover provides the removal of 25,358.3 tons of atmospheric CO_2. This rate corresponds to 5% of the total carbon emitted. Urban green areas, agricultural areas (orchards and poplars), natural patches and plantation areas in the study area contribute to carbon sequestration. The tree cover of Şehit Hüseyin Kıl neighbourhood, which has the highest tree cover in the study area, is 281 hectares, while the tree cover of Şerefiye neighbourhood, which has the lowest tree cover, is 0,3 hectares (Figure 3).

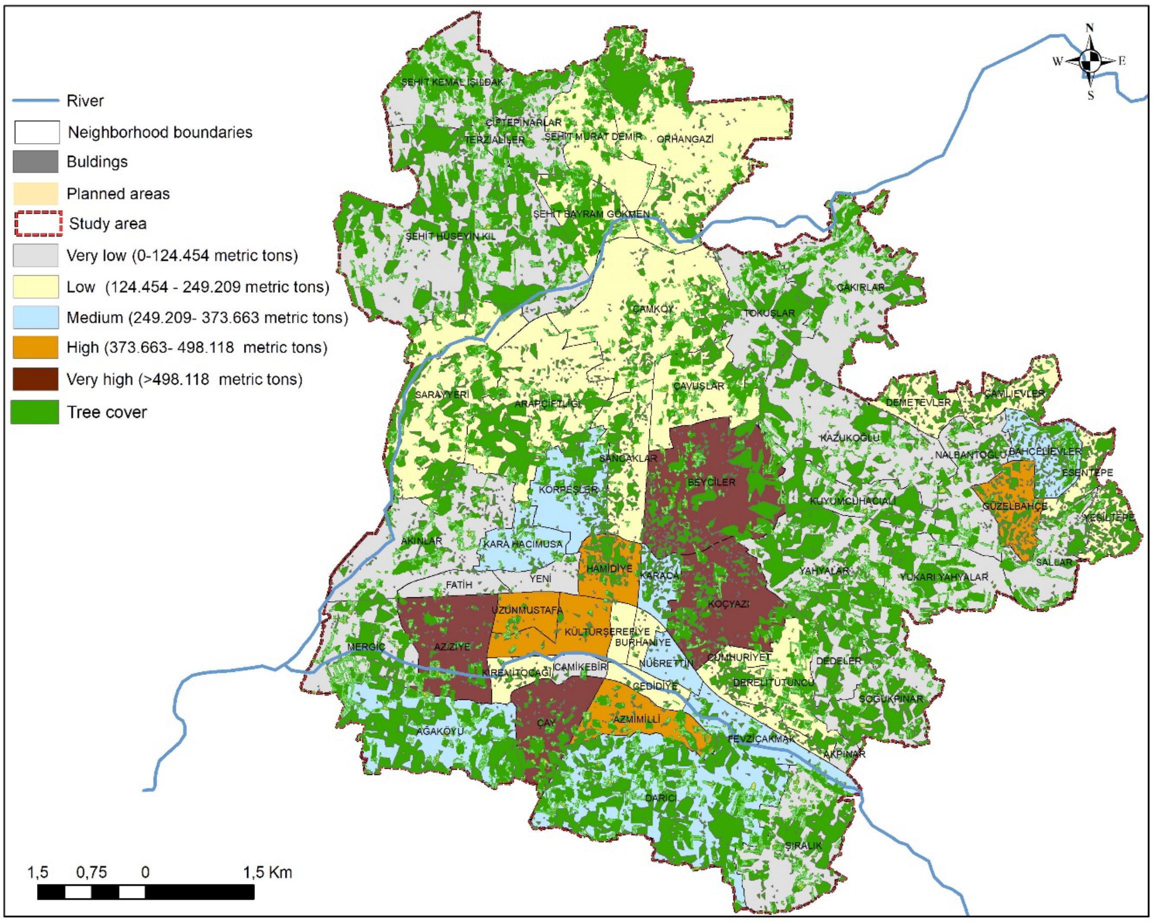

Fig 3. Duzce city center tree cover distribution of 56 neighbourhoods

According to Fig 3, carbon sequestration in the neighbourhoods with the highest carbon emission is below the average with 800 tonnes/year. The presence of forest areas in the area, especially in the north of the city, increases the tree cover. In addition, plantation works in and around Güzelbahçe, Çamlıevler and Demetevler neighbourhoods have increased the tree cover to a great extent (Table 5).

Vegetation type	**Areas (Hectares)**	**(%)**
Natural forest	40,8	1,8
Non-native Plantation	500,4	22,1
Non-Forest areas (Pasture, grassland)	1720,3	76,1

Table 5. Distribution of tree cover according to vegetation types

According to Table 5, natural forests constitute 1.8 of the tree cover in the study area, while plantation areas constitute 22.1. Their contribution to the total carbon sequestration in the area is 5604.7 tonnes. The main reason why the plantation areas, which are especially concentrated in and around residential areas, are low compared to agricultural areas is due to the general configuration of Düzce city. Located in the agricultural plain, 76.1% of the tree cover of Düzce city is found in pasture and agricultural areas. Mixed agricultural areas constitute 53% of the total area. The tree cover in this land cover consists of hazelnuts, poplars and trees found in natural spots.

4. DISCUSSION

Within the scope of this study, predictable data on total carbon sequestration were produced by considering natural and plantation areas together in reducing the carbon footprint. The carbon emission of 56 neighbourhoods in Düzce city centre was estimated as 623,772.3 metric tonnes. The average carbon footprint of rural areas is higher than the average carbon footprint of urban areas. The main reason for this can be explained by population density, number of vehicles and amount of waste (Heinonen and Junnila, 2011). Similarly, in this study, although the carbon footprint decreases from the urban core to the urban periphery, it is observed at the lowest rate in rural neighbourhoods. Neighbourhoods with low population density and rural typology such as Soğukpınar, Dedeler and Sallar are the least responsible for carbon footprint, while Beyciler and Koçyazı neighbourhoods in the urban core have the highest carbon footprint. Koçyazı and Beyciler neighbourhoods remove over 77,000 and 54,000 metric tonnes of carbon emissions, respectively. However, carbon emissions due to coal or wood heating could not be calculated in this study due to lack of data. Therefore, when these inputs are included in the study, it is predicted that the carbon footprint in rural neighbourhoods will increase relatively. Carbon footprint calculation modules developed by different organisations and scientists use different coefficients for different sectors (C, 2019; World Wide Fund for Nature, 2023; EPA; 2023). In this study, IPCC (2006) formulae aiming to calculate CO_2 emissions based on energy, industry, transport, land use, agriculture and waste activities were utilised. Due to limitations in data access, the study is based on average values. For example, grouped data of vehicles by fuel type at neighbourhood and province level could not be accessed. In future studies, elaborating the content of the study and increasing the number of parameters will increase the level of accuracy.

Hall (2012) analysed the relationship between increases in tree cover (i.e., natural and planted tree land cover) and changes in forest carbon storage and associated biodiversity, and found that while plantation areas support carbon sequestration, there are decreases in carbon storage. The main reason for this is that natural old-growth forests store carbon at a higher rate. The use of data obtained by quantitative measurements within the scope of the study facilitated the comparison. However, there is no local measurement of carbon sequestration within the scope of this study. Nowak et al. (2013) measured the contribution of plantations in urban areas to carbon sequestration and found that the total tree carbon storage in US urban areas was 643 million tonnes. The average annual carbon storage of urban trees was found to be 7.69 kg C m^{-2} per individual. Analysis of the urban forest in Oakland, California (21% tree cover) reveals a tree carbon storage level of 11.0 metric tonnes/hectare (Nowak et al., 2002). Asfaw and Zergaw (2022) calculated the carbon sequestration of trees in residential areas and found that a total of 1220 trees contributed 64.35 tonnes of above-ground carbon stock per hectare. 50.4% of the carbon sequestration is from fruit trees and the rest is from forest trees. Plantation-derived areas covering 22% of the study area sequester 5604.7 tonnes of carbon per year. This corresponds to 0.05% of the total carbon emissions.

Trees release about 75 percent of the carbon they sequester within 100 years (Dhiman, 2009). Poplar cutting in the study area, which covers over 8% of the tree cover, emits carbon. In this study, carbon emissions from carbon production were ignored.

5. CONCLUSIONS

The contribution of plantation afforestation, which is seen as an ecological solution to reduce carbon emissions, is an undeniable fact. Although carbon sinks created through plantations have low carbon sequestration efficiency compared to natural forests in the first years, this efficiency approaches natural forests in the following years. Although the tree cover in the city and on the urban periphery contributes to carbon sequestration in cities, the general configuration of the city may affect the structure and density of the tree cover and its contribution to carbon sequestration may be minimal or moderate. In cities built on agricultural areas such as Düzce, the dominant tree cover is trees such as hazelnut or poplar, which are produced for production purposes. In future studies, in settlements where this type of tree cover is widespread, carbon emission calculations should definitely include carbon emission calculations arising from production. Innovative climate adaptive forest restoration and reforestation activities in cities and periphery can decrease carbon emissions. Scientific projects such as Horizon Europe projects, COST Action CA19128 Pan-European Network for Climate Adaptive Forest Restoration and Reforestation (PEN-CAFoRR) and their outcomes can be pioneer in terms of climate change mitigation and adaptation.

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