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Production of fuel-based carbon footprint distribution map using spatial interpolation methods based on GIS

Ebru Çolak [1], Tuğba Memişoğlu Baykal*[2], Nihal Genç [3]

[1] *Karadeniz Technical University, Department of Geomatics Engineering, Türkiye, ecolak@ktu.edu.tr*
[2] *Ankara Hacı Bayram Veli University, School of Land Registry and Cadastre, Türkiye, tugbamemisoglu@gmail.com*
[3] *Giresun University, Department of Geomatics Engineering, Türkiye, nhlgnc95@hotmail.com*

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Abstract

The Earth is a complex system where living and non-living elements coexist in a delicate balance. Climate change is the primary factor responsible for the degradation of this system over time. The far-reaching consequences of climate change impact various aspects of our lives, including the physical environment, urban settings, human activities, economy, technology, agriculture, food production, access to clean water, and public health, all of which are widely acknowledged. Human-induced greenhouse gas emissions in these areas significantly trigger global climate change. Hence, addressing and mitigating the environmental damage from these emissions and the interconnected climate change phenomena is imperative. This situation is where the concept of "carbon footprint" gains prominence in assessing the extent of this damage. Carbon footprint serves as an essential measure in managing and curbing climate change. This study focused on controlling and mitigating carbon emissions, one of the primary greenhouse gasses responsible for climate change, by implementing spatial interpolation techniques based on Geographic Information Systems (GIS). The investigation targeted the Beşirli neighborhood in the Ortahisar district of Trabzon province. Data concerning electricity and natural gas usage were acquired from relevant institutions to perform carbon footprint calculations. Subsequently, carbon footprint calculations were conducted utilizing the acquired data within the specified region. The resulting outputs were systematically organized, integrated into the GIS environment, and linked to their respective geographical locations. Eventually, region-specific carbon footprint distribution maps were generated using selected spatial interpolation methods. These maps enabled a spatial observation of points exhibiting variability in terms of carbon emissions, thereby highlighting the carbon footprints evident in the region. The ultimate goal of this endeavor is to propose practical measures for minimizing the adverse environmental impacts by suggesting strategies to reduce and prevent carbon footprints associated with carbon emissions in the relevant areas.

1. Introduction

Global warming is characterized by the gradual rise in the Earth's temperature, stemming from various factors and surpassing what is deemed normal. The primary driver of this phenomenon is climate change, which stands as one of the most significant and perilous global challenges [1]. Climate change manifests both through natural occurrences and, more significantly, as a consequence of human activities. In this context, climate change refers to long-term alterations in meteorological parameters, such as temperature, humidity, precipitation, and wind, arising from both natural conditions and the combustion of fossil fuels [2]. Furthermore, the United Nations Framework Convention on Climate Change (UNFCCC) provides a comprehensive definition, characterizing climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods." [3].

The main factor in climate change is the greenhouse effect. The greenhouse effect, which provides the temperature balance of the Earth, occurs when the gases and water vapor in the atmosphere retain the heat from the sun to the Earth [4]. The most critical component of the greenhouse effect is greenhouse gases. Some of the greenhouse gases added to the atmosphere by various human activities are CO, CO_2, H_2O, NO, CH_4, NO_2, and O_3. CO_2, which retains the most heat, significantly impacts climate change. The increase in the need for energy in the world due to increasing industrialization with the industrial revolution has increased the use of fossil fuels, especially carbon-based ones.

On the other hand, changes in land use have occurred, soil structure has deteriorated, and deforestation has emerged. These negativities have increased the emission of CO_2, the most important greenhouse gas. As a result of these activities, the primary source of which is human beings, the amount of CO_2 in the atmosphere has increased and started to accumulate with rapidly increasing CO_2 emissions. This situation has led to the carbon cycle disruption that provides the world's climate balance and temperature changes [5]. This warming of the Earth and the accumulation of gases released into the atmosphere have formed the basic fundamentals of climate change [6].

Climate change has multiple and diverse negative impacts on the earth and people. The severity of these impacts increases over time. In the latest assessment report prepared by the Intergovernmental Panel on Climate Change (IPCC), it is stated that with climate change, there will be sudden changes in the intensity and duration of weather events, and sea levels will rise [7]. When we look at the present day, it is seen that with the impact of human activities, severe increases in temperature values have started, while decreases in cold temperatures have also occurred [8]. On the other hand, many regions face the threat of desertification due to drought caused by decreases in precipitation. On the other hand, the combination of heat and drought conditions increases the risk of forest fires [9]. Rising sea levels cause damage to the structures and arrangements in the coastal zone and the people in this region. Another negative impact of climate change is on seasons. Shifts in the seasons affect agriculture in the first degree, causing the time balance in the growing cycle of crops to be disrupted [10]. In addition, climate change, which affects the ecological balance, jeopardizes the lives of many species and reduces biodiversity [11–13]. Socio-economic concepts such as human health, migration, tourism, transportation, water resources, forestry, fisheries, energy, agriculture, and animal husbandry are also effective in climate change [14]. The situations that arise from all these situations affecting climate change and being affected by change constitute the main source of carbon emissions into the atmosphere. With the increasing carbon emission and accumulation, the world's stable balance is being damaged. Figure 1 shows the graph of CO_2 emissions in the world between 1990 and 2020, prepared based on World Bank data [15]. According to the graph, CO_2 emissions are generally upward, but entered a downward trend in 2020. The reason for this is thought to be the pandemic experienced that year. On the other hand, Figure 2 shows a map of countries' carbon emissions produced from World Bank data [15]. Looking at the map, it is seen that China, the USA, Canada, Germany, India, and Russia are the countries that stand out with high carbon emissions. The countries with the lowest carbon emissions are located in South Africa.

Many approaches are put forward to reduce CO_2 emissions, which have the largest share in climate change. One of these is economic stagnation and a slowdown in growth. It has been observed that the slowdown in the economy due to the collapse of Soviet Russia, the 2009 crisis in the United States and the pandemic in 2020 reduced carbon emissions. However, this is not a preferred approach as it negatively affects the welfare level [14]. Another approach is to reduce intensive carbon production. Especially in developing countries, carbon emissions from electricity and heat generation are high due to production processes [16]. Therefore, the preference for renewable energy sources in production will reduce carbon production. On the other hand, practices such as improving efficiency, preferring renewable energy sources and imposing a carbon emission tax are considered one of the main approaches to reduce energy consumption using fossil fuels [17, 18]. Finally, the use of carbon capture and sequestration systems to remove carbon emissions from the atmosphere resulting from the combustion of fossil fuels is suggested as a preferable, although complex and costly, approach [2].

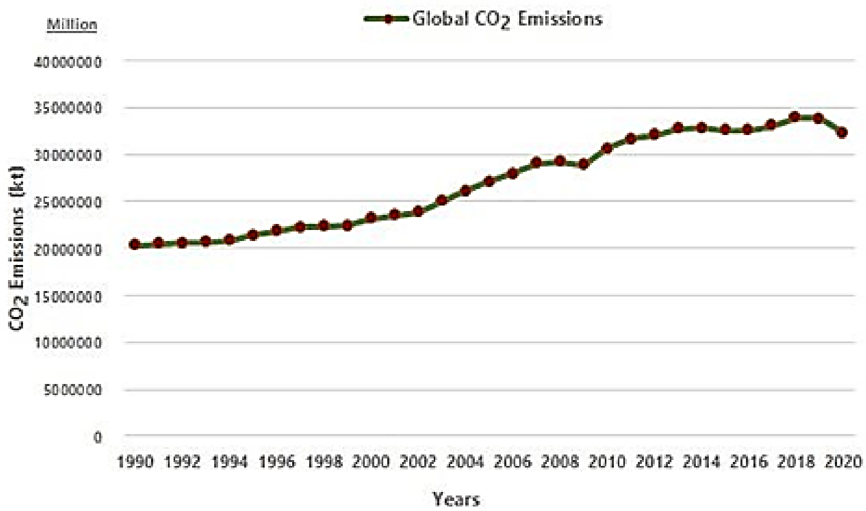

Figure 1. Global CO_2 emissions for the period 1990-2020.

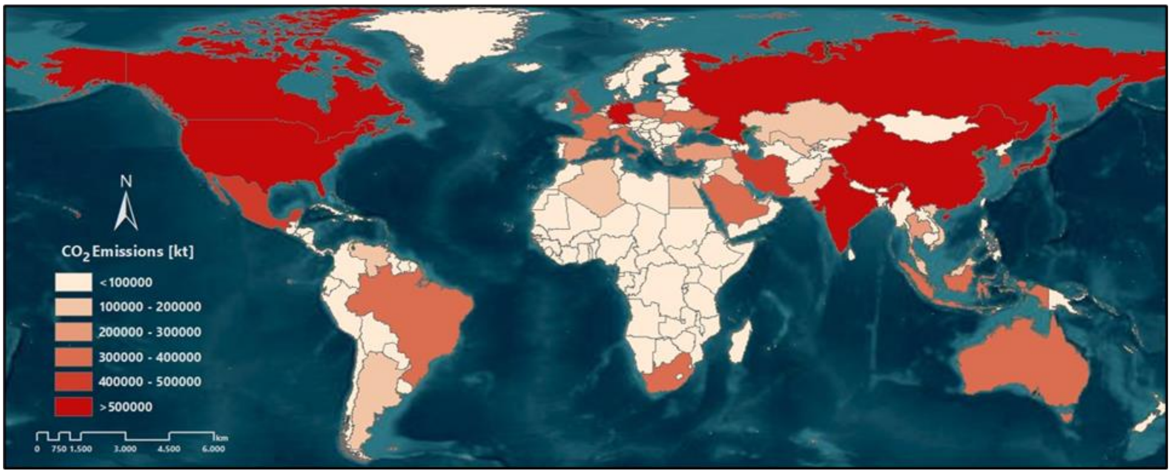

Figure 2. Average CO_2 emissions by country for the period 1990-2020.

A quantitative indicator is used to understand better the adverse effects of carbon emissions that affect the world and people and determine the environmental damage it causes. This indicator, called carbon footprint, is a guiding source for activities to prevent and reduce carbon emissions.

1.1. Carbon footprint

Carbon footprint is the measurement of greenhouse gases emitted into the atmosphere by a person, a specific activity or a country due to transportation, heating activities, energy consumption or every product and service purchased, in CO_2 equivalent [19]. With the concept of carbon footprint, the damage to the environment is defined. The carbon footprint, calculated in units of carbon dioxide, is generally used to measure the trace of the damage left by a person in nature and the environment (Figure 3).

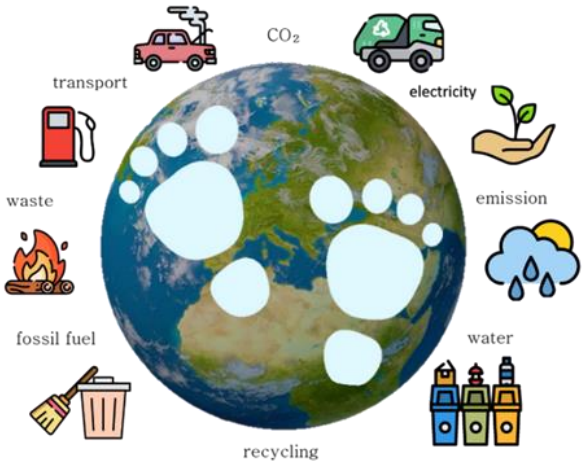

Figure 3. Activities representing carbon footprint.

The concept is generally analyzed under primary and secondary carbon footprint. Primary carbon footprint is the environmental damage directly caused by one's daily habits. It measures the amount of CO_2 generated by activities that use fossil fuels, such as energy consumption through household items and the use of vehicles. The secondary footprint is characterized as the measure of CO_2 emissions from the production phase of all products used until they are destroyed [20]. For example, vehicles used daily or on vacation fall under the primary carbon footprint status. The damage caused to the atmosphere by the car or airplane is part of the person's carbon footprint [21]. The car used daily also appears as a secondary carbon footprint. All the resources spent for the production of that vehicle and all the resources that vehicle parts will spend until they disappear from the world constitute the person's secondary carbon footprint.

The amount of carbon emissions is obtained by determining the carbon footprint. Therefore, both concepts are interrelated. When we look at the literature, it is seen that there are many studies on carbon footprint from different disciplines. The studies aim to determine the carbon footprint of an individual, community, or organization worldwide, that is, to measure the amount of carbon emissions they emit to nature. Lee [22] aimed to measure carbon footprint left to nature based on direct and indirect consumption in Taiwan. Song et al. [23] investigated the amount of carbon emitted directly and indirectly by individuals in the process of scientific studies. In this context, they concluded that literature review and writing process have a high carbon footprint. Lombardi et al. [24] proposed the concept of urban carbon footprint and revealed its relationship with global climate change. Within the scope of the concept, he evaluated climate strategies and put forward suggestions for their development. Chen et al. [25] evaluated the reflections of the textile industry on climate change by performing carbon footprint and water footprint calculations to evaluate the environmental impacts of cashmere fabric. Huang and Tang [26] produced carbon capacity models by investigating the carbon footprint caused by tourism in the Heilongjiang region of China. As a result of the outputs obtained from the models, they revealed that the environmental impacts of tourism-related carbon footprint are small and acceptable. Uzunali and Yazıcı [27] conducted a comparative study to evaluate the effects of the COVID-19 pandemic on carbon emissions. In this context, the environmental impacts of Turkey's carbon footprint before and after COVID-19 were comprehensively analyzed and social and economic consumption habits were emphasized. Another study was conducted by Islam et al. [28] on the construction sector. The impact and importance of material selection on the environment are emphasized by evaluating the carbon emissions of different building materials on nature. In addition to these studies, it is possible to come across many studies evaluating the amount and effects of different concepts, materials, and sectors on the carbon footprint in nature [29–37].

1.2. Policies for carbon footprint

Various protocols and standards have been developed internationally for carbon footprint calculation. The Kyoto Protocol, the Paris Agreement, the ISO 14064 standard established by the International Organization for Standardization (ISO) for limiting greenhouse gas emissions [38], The Greenhouse Gas Emission Protocol (GHG) put forward by the World Business Council for Sustainability and the World Resources Institute (WRI) [39, 40], and the assessment reports published by the Intergovernmental Panel on Climate Change (IPCC) guide carbon footprint calculations and mitigation strategies.

The Kyoto Protocol is a part of the United Nations Framework Convention on Climate Change (UNFCCC). This protocol, which serves the same purpose as the UNFCCC, includes obligations set forth depending on the level of development of the industrialized countries that are parties to it. The main purpose of the Kyoto Protocol is to prevent global warming and reduce its effectiveness and negative effects. Within the scope of the measures taken for this purpose, it aims to reduce the carbon footprint by limiting greenhouse gas emissions [41].

The Paris Agreement was also organized as a part of the UNFCCC. With this agreement, which was signed due to the Kyoto Protocol not progressing as expected, new targets were put forward in terms of global warming and climate change. The agreement, which aims to control greenhouse gas emissions and achieve zero emission levels by 2080, also aims to reduce the carbon footprint by providing financial support [42].

The International Organization for Standardization (ISO) is established to conduct studies to determine technical and non-technical standards. ISO gathers standards for environmental management under the umbrella of ISO 14000. The ISO 14064 standard published in this context describes the measurement, monitoring, reporting, and evaluation of greenhouse gas emissions. In line with these objectives, the standard aims to contribute to developing carbon footprint reduction strategies [43].

The Greenhouse Gas Emission Protocol (GHG) provides a framework for calculating, reporting, and managing greenhouse gas emissions resulting from electricity consumption and the activities of organizations. In this context, GHG provides an environment for reducing the carbon footprint [44].

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The IPCC, whose main purpose is to combat climate change, comprehensively evaluates the global climate change problem worldwide, and expresses the role of the carbon footprint resulting from greenhouse gas emissions. The reports presented aim to reduce the carbon footprint with recommendations and strategies to reduce greenhouse gas emissions from different sectors such as energy, industry, agriculture, and transportation.

All these protocols and standards aim to make the future sustainable by effectively combating climate change. At the point where these objectives converge is the reduction of the carbon footprint based on carbon emissions.

1.3. Carbon footprint and GIS

Geographic Information System (GIS) is a technology and discipline used to store, manage, analyze and visualize spatial and non-spatial data [45]. The ability of GIS to organize data based on location helps to make more accurate decisions. For this reason, it can be integrated into the studies of many different disciplines. One of the areas where GIS can be used effectively is carbon footprint applications, which play an important role in climate change. Utilizing the effective storage feature of GIS in carbon footprint applications, which include a large number of data and different types of parameters, facilitates the management of complex data.

On the other hand, applying advanced methods based on location with its analysis capability provides a more comprehensive regional understanding of the effects of carbon emissions. In this context, GIS is an effective and powerful tool for monitoring the sources of carbon emissions, observing their distribution, analyzing and calculating carbon footprints, and presenting all of these all these location-based. Another advantage of GIS is its mapping capability. Thanks to its superior visualization power, it enables the production of maps from the outputs obtained from the analysis, helping to better understand and interpret the results. Thanks to the carbon footprint maps produced in the GIS environment after analyzing carbon emissions, the spatial distribution and potentials of emissions can be revealed. On the other hand, easy monitoring of the emission situation by utilizing maps guides decision-makers in implementing policies for reducing and preventing emissions. As a result, the use of GIS in carbon foot printing studies contributes to achieving sustainability goals by helping the implementation of emission reduction strategies.

2. Material and Method

2.1. Method

Analysis for the selected study region was carried out in the following steps (Figure 4):

- Determination of the study area
- Obtaining data from relevant institutions
- Organizing data and associating with the location
- Determination of the carbon footprint for each building in the selected pilot region
- Presentation of maps
- Producing the carbon footprint distribution map in ArcGIS 10.8 using spatial interpolation methods

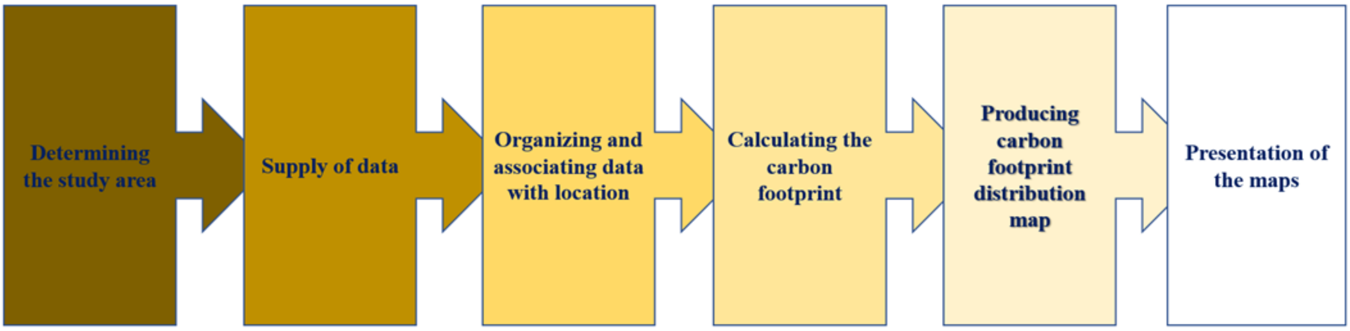

Figure 4. Methodology.

2.2. Study Area

This study was conducted in the Ortahisar district of Trabzon Province, located in the Black Sea Region. Besirli District No. 1, an urban and densely populated neighborhood, is considered the district's application area. 160 buildings were selected as a sample from the region, and data for 2019 on electricity and natural gas consumption were obtained from the relevant institutions. Figure 5 shows the study area.

2.3. Data supply and geographical database creation

In order to calculate the amount of carbon emissions, the data on the electricity consumption of 160 buildings in 2019 were obtained from Çoruh Electricity Distribution Joint Stock Company, and the data on natural gas consumption was obtained from Aksa Karadeniz Natural Gas Distribution Joint Stock Company in Microsoft Excel format. The data were transferred to the GIS environment and matched with the buildings they were related. At this stage, ArcGIS 10.8 software was used. The matched data were transferred to the geographic database and made ready for application. The edited data is shown in Figure 6.

2.4. Carbon footprint calculation methods

Intergovernmental Panel on climate change (IPCC) shared methodologies that calculate greenhouse gas emissions in 3 different tiers [46]. The stages indicate the complexity of the methodology. The carbon footprint is calculated using Tier 1, Tier 2, or Tier 3 methods, depending on the complexity of the data and methodology required [46]. Tier 2 and Tier 3 are often referred to as higher-tier methods and are considered more accurate than Tier 1 because they value more information and yield more data [46, 47]. The method to calculate the carbon footprint may vary in general. For example, when calculating carbon emissions, the Tier 2 method can be used when electricity consumption is considered, and the Tier 1 method can be used for emissions caused by natural gas consumption [48, 49]. To briefly explain the methods;

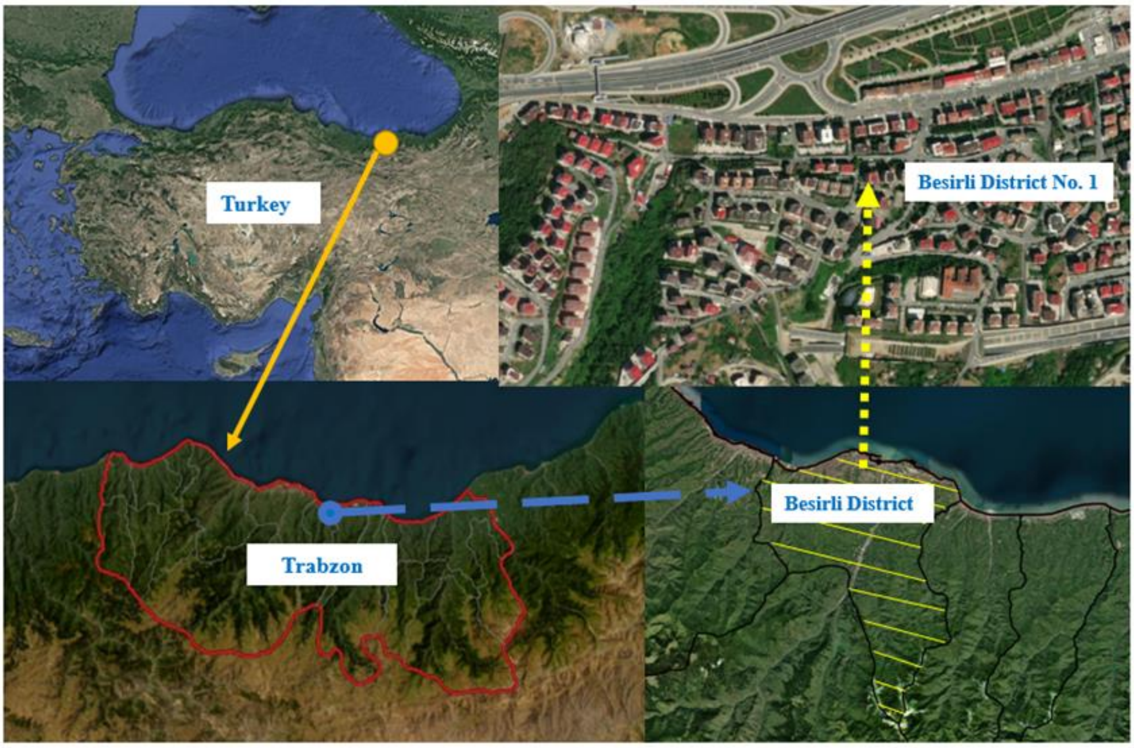

Figure 5. Study area.

Figure 6. Data that contains electricity and natural gas information associated with location.

Tier 1: Calculations made using the standard emission factor determined according to the amount of fuel consumed and fuel type [46]. It uses emission factors and other parameters described in the IPCC manual. This method has some simplifying assumptions and may combine some external data with its findings. This method requires two data pieces: the fuel consumed and the standard emission factor. The calculation for Tier 1 is as shown in Equation 1 [46]:

Emission GHG, FUEL (kg GHG) = Fuel Consumption (TJ) x Emission Factor (Kg GHG/TJ) (1)

Tier 2: Calculations made using country-specific emission factors determined according to the amount of fuel consumed and combustion technology that varies from country to country, operating conditions, control technology, maintenance quality, and the age of the equipment used while burning fuel [46, 48]. It has the same approach as Tier 1 but uses country-specific emission factors and other parameters. Country-specific emission factors and parameters are better suited to that country's forests, climate zones, and land use systems. Some of these parameters are the quality of the fuel, its carbon content, and the combustion technology used [47]. This method requires two data. These; the amount of fuel consumed and the country-specific emission factor for each fuel. The calculation for Tier 2 is as shown in Equation 2 [46]:

Emission GHG, FUEL (kg GHG) = Fuel consumption (TJ) x Emission Factor (Kg GHG/TJ) (2)

Tier 3: These are calculations that require more detailed data and expertise, such as the thermal power of combustion plants and feeding type. It contains more complex models and requires more data. It was developed to increase the results' transparency and the data's integration with the model. It is generally accepted that it calculates more accurately than the lower stages. The Tier 3 method calculates the fuel consumption and emission factor specific to the facility. For this reason, it is considered that the calculation is close to the truth. The method considers the fuel consumption values and the distance traveled by vehicles or the load carried in ton-km units and calculates with appropriate emission factors [46, 50].

2.5. Calculating carbon footprint

The carbon footprint is revealed by the calculated amounts of greenhouse gas emissions CO_2, N_2O, HFCs, PFCs, and SF_6 based on the CO_2 type. Since carbon dioxide has a 76% share in greenhouse gas emissions and is directly related to fuel combustion, a carbon footprint calculation based on carbon dioxide emissions has been made in this study to make a more precise calculation [33]. When the literature is examined, it is seen that carbon footprint calculations are made based on electricity, natural gas, solid fuel, gasoline, diesel, fuel oil, and LPG data [51, 52]. This study calculated carbon footprint with the Tier 2 method based on natural gas and electricity consumption data. Table 1 shows the emission factors and net calorific values used in applying the method.

The Equation 3 is used when calculating the carbon footprint based on electricity consumption

Table 1. Emission factors and net calorific values used in carbon footprint calculation.

	Data	Unit	Emission Factor	Net Calorific Value
Tier-2	Electricity	MWh	0,6993 ton CO2e/MWh	-
	Natural Gas	Sm3	0,202 kg CO2e/kWh	9,59 kWh/m^3

$$CO_2 \text{ Emission (t } CO_2e\text{/Year)} = \text{Energy consumption (MWh)} \times \text{Emission factor } (tCO_2e/MWh) \quad (3)$$

The application used the electricity consumption values obtained from the relevant institution for the energy consumption data contained herein. The value in the Turkish National Electricity Grid Emission Factor report prepared by the Ministry of Energy and Natural Resources has been taken as the basis for the emission factor that changes specific to countries [52].

The Equation 4 is used when calculating the carbon footprint based on natural gas consumption [46]:

$$\text{Energy Consumption (kWh)} = \text{Fuel consumption } (m^3) \times \text{Net Calorific Value } (kWh/m^3) \quad (4)$$

The natural gas consumption data obtained from the relevant institution was used for the fuel consumption data in the formula. In contrast, the value determined by the Ministry of Energy and Natural Resources was used for the net calorific value. Net calorific value is the unit of heat energy produced by burning fuel. Using the energy consumption data revealed, carbon emissions were calculated with the help of the Equation 5 [46];

$$CO_2 \text{ Emission (kg } CO_2\text{/Yıl)} = \text{Energy consumption (kWh)} \times \text{Emission factor } (kgCO_2e/kWh) \quad (5)$$

Here, the value in the United Nations Framework Convention on Climate Change (UNFCC) is used for the emission factor.

2.6. Spatial interpolation methods

2.6.1. Kriging interpolation method

The Kriging interpolation method is a method that allows the values of new points to be estimated by taking the weighted average of the values of known close points. The Kriging interpolation method determines the value of unknown points by calculating a variance value for each point to be estimated. It differs from other interpolation methods because it measures the confidence level of the estimated value with variance. This method achieves more unbiased results than other interpolation techniques; investigates the accuracy of the estimation in terms of the minimum variance and the calculation of the standard deviation of the realized estimation [53–55].

Kriging interpolation calculates the properties of unobserved points by reference to the properties of observed points. The main problem in this method is to determine the weights. The most important feature of the Kriging method that distinguishes it from other methods is that instead of using a standard weight, it performs the estimation by determining a weight, and the estimation made and the error resulting from this estimation can be easily detected. The Equation 6 is used in the application of the Kriging method [54];

$$N_p = \sum_{i=1}^{n} P_i * N_i \quad (6)$$

Considering the formula; n represents the number of points, the geoid corrugation used to calculate the Ni value Np, the Np the sought corrugation value, and the weight value corresponding to each Ni value used in the calculation of Pi N [54].

2.6.2. Inverse distance weighted interpolation method (IDW)

Inverse Distance Weighted interpolation is a type of deterministic method used for multivariate interpolation with scattered points known as Inverse Distance Weighted (IDW). In this method, the values assigned to the unknown points are calculated by a weighted average of the values available at the known points with a simple algorithm [56]. While calculating, the anchor points close to the cut-off points have a more significant effect on the calculation, while those of the far points are less [53]. In short, the IDW interpolation technique is based on the fact that on the surface to be interpolated, nearby points have more weight than distant points [57]. In addition, this method is used to define constantly changing data belonging to the same field. Shaperd's is the most widely used and well-known IDW method [57, 58]. Shaperd's Equation 7 is as follows:

$$f(x,y) = \sum_{i}^{n} w_i f_i \quad (7)$$

In this formula, n is the number of scattered points on the surface, fi is the function that defines the sampling points, and wi is the weights.

3. Results

3.1. Calculating the carbon footprint in the selected pilot region

For the selected pilot region, Beşirli District No. 1, the carbon footprint was calculated using the electricity consumption data as a reference. Since the data obtained belongs to 2019, 0,6993 was taken as the emission factor in the calculations. The energy consumption data for each building is multiplied by this emission factor to obtain the carbon emissions of the buildings and added to the database. An example of the values obtained is shown in Figure 7, and the carbon emission amount map obtained from electricity consumption data is shown in Figure 8. When Figure 8 is examined, the amount of carbon emissions in the study area varies between 565,200 and 235492,82 tons; it is seen that carbon emission is relatively high in some buildings and less than in others some buildings.

Looking at this map, it can be concluded that carbon emissions are high-medium level in this selected region; some buildings emit very high carbon emissions and have a large carbon footprint, as well as buildings that emit less.

For the selected pilot region, Beşirli District No1, the carbon footprint was calculated using the natural gas consumption data as a reference. Since the data obtained belongs to 2019, 0.202 was taken as the emission factor and 9.59 as the net calorific value in the calculations. For each building, natural gas energy consumption was first calculated by multiplying the natural gas fuel consumption with the net calorific values. Then, the carbon emission of the buildings was obtained by multiplying the emission factor with the obtained value and added to the database. An example of the values obtained is shown in Figure 9, and the carbon emission amount map obtained from natural gas consumption data is shown in Figure 10. When Figure 10 is examined, it is seen that the amount of carbon emission in the study area varies between 469,177 and 146208,914 kg; it is seen that carbon emission is relatively high in some buildings and less than others in some buildings. Looking at the map, it can be concluded that carbon emissions in this selected region are at high-medium levels, as in electricity, but are at higher levels than electricity-induced carbon emissions; there are buildings with very high carbon emissions and high carbon footprints, as well as buildings with low emissions.

Table

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FID	Shape	OBJECTID	BINA_ID	Enerji Tüketim Değerleri	Emisyon_Fa	CO2 Salınım Miktarı
0	Point	8	10000020901900	13753,74	0,6993	9617,990382
1	Point	9	10000020924800	29785,99	0,6993	20829,342807
2	Point	10	10000020920100	33968,37	0,6993	23754,081141
3	Point	12	10000020931900	20204,61	0,6993	14129,083773
4	Point	15	10000020943200	48001,31	0,6993	33567,316083
5	Point	21	10000020968800	13689,07	0,6993	9572,766651
6	Point	23	10000020966100	30075,03	0,6993	21031,468479
7	Point	26	10000020984000	26317,06	0,6993	18403,520058
8	Point	27	10000020989200	39348,74	0,6993	27516,573882
9	Point	33	10000021017400	808,25	0,6993	565,209225
10	Point	38	10000021020700	12949	0,6993	9055,2357
11	Point	41	10000021043500	35936,34	0,6993	25130,282562
12	Point	42	10000021046500	266585,86	0,6993	186423,491898
13	Point	45	10000021062500	34608,89	0,6993	24201,996777
14	Point	49	10000021071900	42889,42	0,6993	29992,571406
15	Point	51	10000021084800	24700,42	0,6993	17273,003706
16	Point	54	10000021100900	36912,47	0,6993	25812,890271
17	Point	63	10000021113800	33944,9	0,6993	23737,66857
18	Point	69	10000051938800	24729,42	0,6993	17293,283406
19	Point	70	10000051938800	121572,79	0,6993	85015,852047
20	Point	74	10000053226700	40759,86	0,6993	28503,370098

Figure 7. Example result display of carbon emission amount according to electricity consumption data.

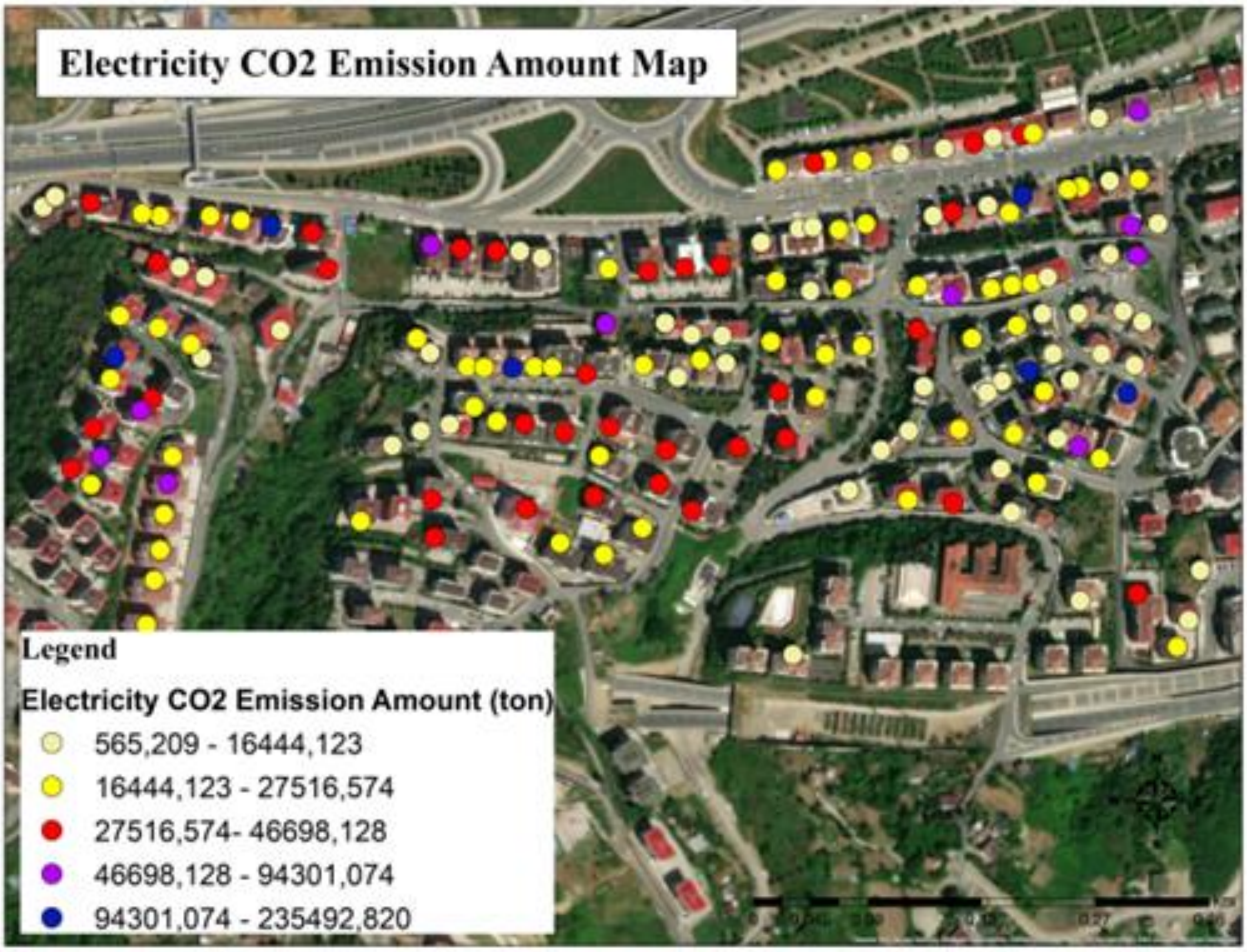


Figure 8. Distribution map of carbon emission amount according to electricity consumption data.

Table

dogalgaz

KASIM	ARALIK	Y_Yakıt_T	Net_Kal_De	Enerji_Tü	Emisyon_fa	CO2
1883,619	2551,357	20766,943	9,59	199154,98337	0,202	40229,306641
1525,827	2383,551	19637,204	9,59	188320,78636	0,202	38040,798845
1005,31	1713,689	16538,773	9,59	158606,83307	0,202	32038,58028
606,502	1010,053	8517,735	9,59	81685,07865	0,202	16500,385887
1396,179	2095,997	16184,618	9,59	155210,48662	0,202	31352,518297
379,574	821,249	6341,434	9,59	60814,35206	0,202	12284,499116
694,02	1282,949	8933,368	9,59	85670,99912	0,202	17305,541822
910,419	1539,539	11979,447	9,59	114882,89673	0,202	23206,34514
1056,428	1609,291	13054,898	9,59	125196,47182	0,202	25289,687308
597,345	1007,879	8306,498	9,59	79659,31582	0,202	16091,181796
634,996	1277,721	7142,057	9,59	68492,32663	0,202	13835,449979
1030,719	1733,269	13551,217	9,59	129956,17103	0,202	26251,146548
902,444	1674,153	14982,83	9,59	143685,3397	0,202	29024,438619
1656,69	2617,284	20726,697	9,59	198769,02423	0,202	40151,342894
1504,523	2232,205	18044,504	9,59	173046,79336	0,202	34955,452259
1211,55	1718,429	15243,731	9,59	146187,38029	0,202	29529,850819
1630,214	2659,671	19898,784	9,59	190829,33856	0,202	38547,526389
1032,477	1617,524	12723,532	9,59	122018,67188	0,202	24647,77172
1548,821	2196,266	18368,47	9,59	176153,6273	0,202	35583,032715
934,178	1338,596	10051,553	9,59	96394,39327	0,202	19471,667441
690,965	1151,047	8924,96	9,59	85590,3664	0,202	17289,254013
928,072	1295,314	10819,089	9,59	103755,06351	0,202	20958,522829

Figure 9. Example result display of carbon emission amount according to natural gas consumption data.

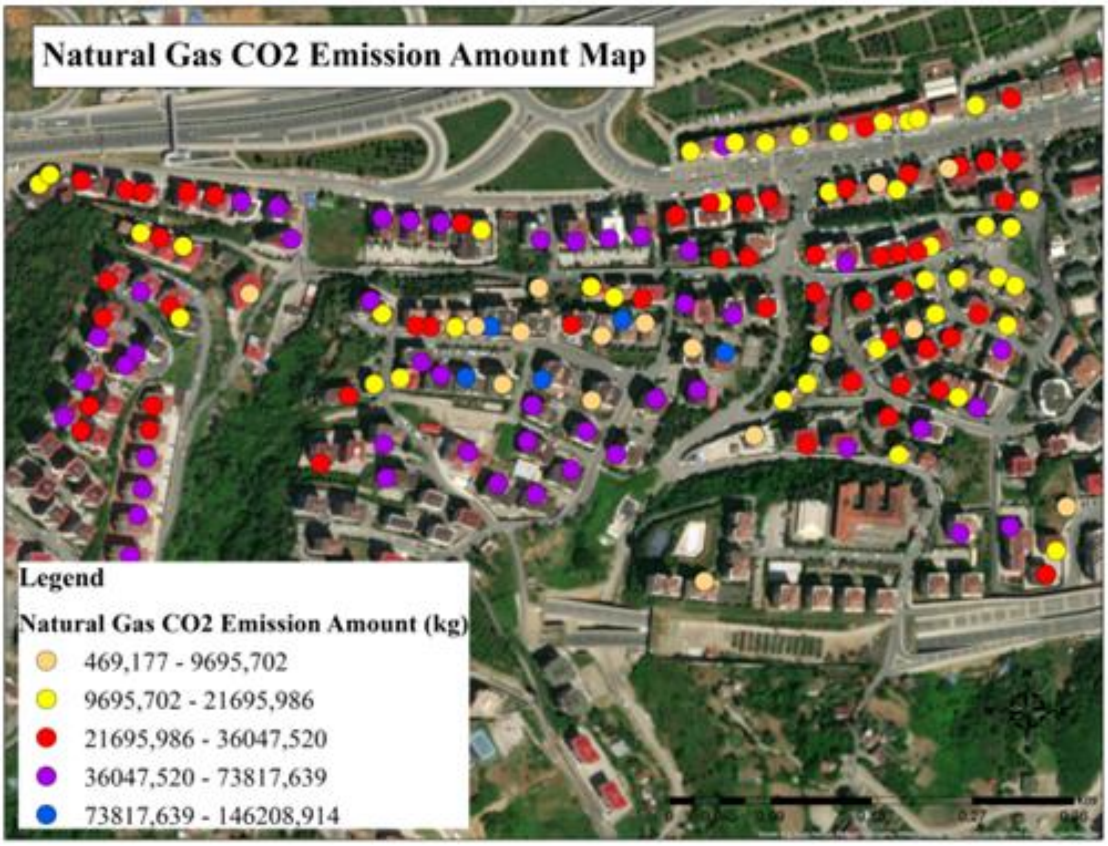


Figure 10. Distribution map of carbon emission amount according to natural gas consumption data.

3.2. Mapping the carbon footprint with spatial interpolation methods

In this study, which was carried out to determine the carbon footprint, set up scenarios accordingly, and increase awareness, the resulting product is maps produced with spatial interpolation analyses based on GIS. At this stage of the study, using the carbon footprint calculation results, carbon emission distribution maps of the selected region were produced using spatial interpolation analysis.

In the study, first of all, a natural gas carbon footprint distribution map was produced. Kriging (Figure 11) and IDW (Figure 12) analyses were performed separately, and the results were mapped.

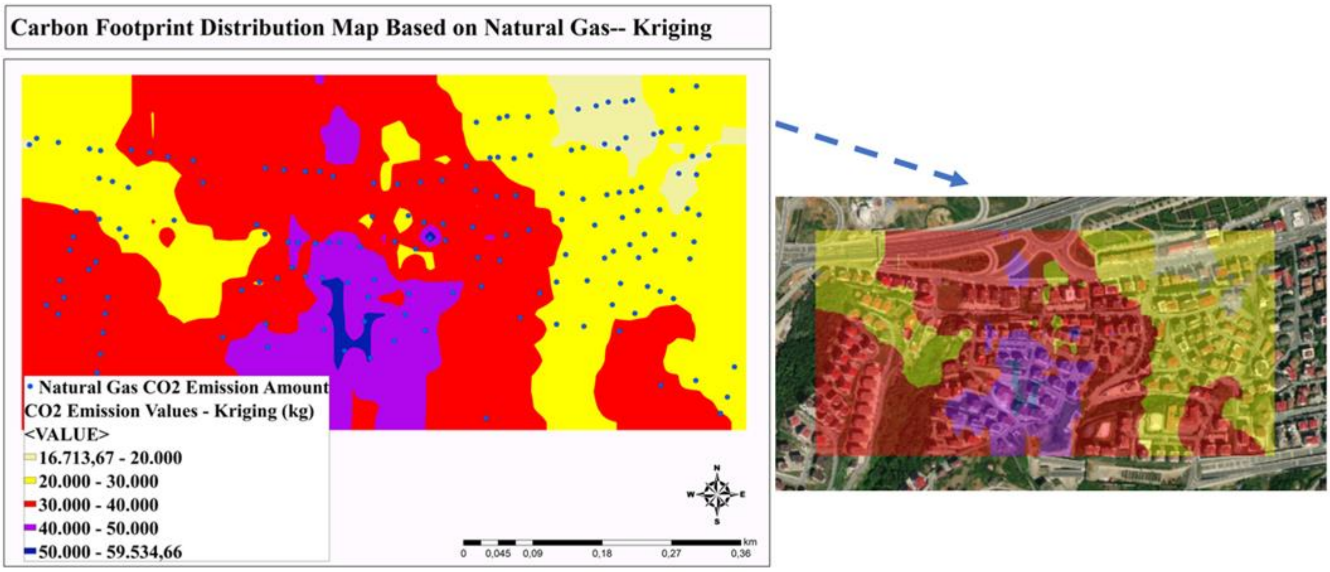


Figure 11. Carbon footprint distribution map based on natural gas according to Kriging analysis.

Looking at Figure 11, it is seen that the carbon emission based on natural gas, according to the Kriging analysis, has increased gradually in the parts corresponding to the south-central part of the selected pilot region. Especially in the eastern part of the region, there is a lower carbon emission compared to other places; Similarly, in some areas corresponding to the western parts of the region, it can be said that the carbon footprint is at a better level than in other areas. Generally, there is moderate carbon emission in the middle part of the region. As a result, when an evaluation is carried out in general, it can be concluded that the selected region is in a medium-high risk position regarding carbon footprint.

Figure 12 shows that carbon emission based on natural gas is more intense in the parts corresponding to the south-central part of the selected pilot region, according to the IDW analysis. Especially in the eastern part of the region, there is a lower carbon emission compared to other places; In addition, it is observed that carbon emissions are still at better levels in some parts of the western parts. Generally, there is moderate carbon emission in the middle part of the region. As a result, when an assessment is carried out in general, it can be concluded that the selected region is in a medium-high risk position regarding carbon footprint, as in the other analysis.

When the analysis results of both methods are compared, it is concluded that the IDW analysis outputs reveal the carbon footprint results more clearly than the kriging analysis outputs. It is more appropriate to consider the IDW method in determining the carbon footprint distribution based on natural gas. This situation is because it gives more precise results in the region, and the mathematical model gives better results in determining the distribution of carbon emissions.

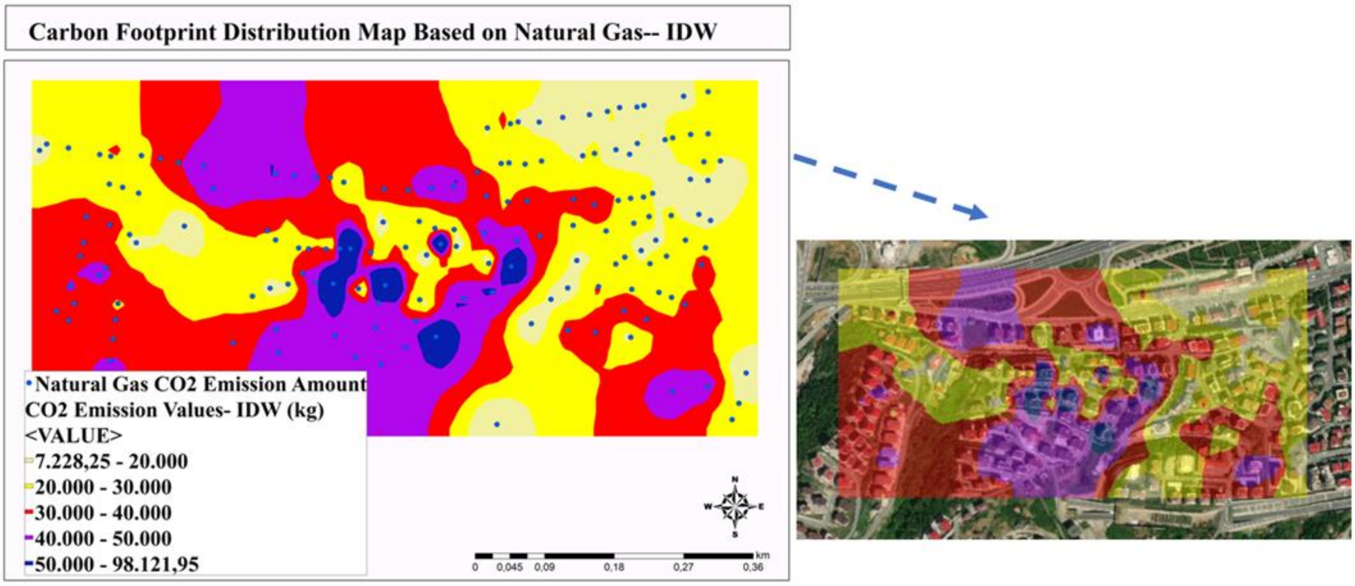


Figure 12. Carbon footprint distribution map based on natural gas according to IDW analysis.

In the study, an electrical carbon footprint distribution map was produced. Kriging (Figure 13) and IDW (Figure 14) analyses were performed separately, and the results were mapped.

Figure 13 shows that carbon emission based on electricity is seen more intensely in the western parts of the selected pilot region, according to the kriging analysis. It is observed that carbon emissions are close to high levels in some parts of the northern, central, and eastern parts of the region.

Especially in the southern parts of the region, in some parts of the central and northern parts, generally much less or moderate carbon emissions were encountered. Therefore, the carbon footprint is at better levels. When an assessment is carried out in general, it can be concluded with this analysis that the selected region is in a medium-high risk position regarding carbon footprint.

Figure 14 shows that electricity-based carbon emissions are at very high levels in small areas in the eastern, western, southern, and central parts of the selected pilot region, according to the IDW analysis. Especially in the southern part of the region, there is a lower carbon emission compared to other places; Similarly, in some parts of the northern parts of the region and the areas corresponding to the middle parts, it can be said that the carbon footprint is at a better level than other areas. As a result, when an evaluation is carried out in general, it can be concluded that the selected region is in a medium-high risk position regarding carbon footprint.

When the results of both analysis methods are compared, it is concluded that the IDW analysis outputs also reveal the electricity-based carbon footprint results more clearly than the kriging analysis outputs. The result shows that the carbon footprint distribution based on electricity applied, especially in this region, is more prominent. In addition, it has been determined that the mathematical model gives better results in determining the region's carbon emissions distribution. Therefore, preferring the IDW method in the evaluation seems more appropriate.

In the Kriging and IDW analysis results carried out for both factors, it was concluded that both methods produced meaningful results and could be used, but when a comparison is made between each other, IDW analysis results would be better to choose because they gave much better results in distinguishing the outputs. By combining the analysis carried out for both factors in Figure 15 and Figure 16, the areas where the selected region is at risk in terms of both natural gas and electricity have been tried to be shown on a single map. Obtained maps reveal the necessity of taking measures for carbon emissions in this region.

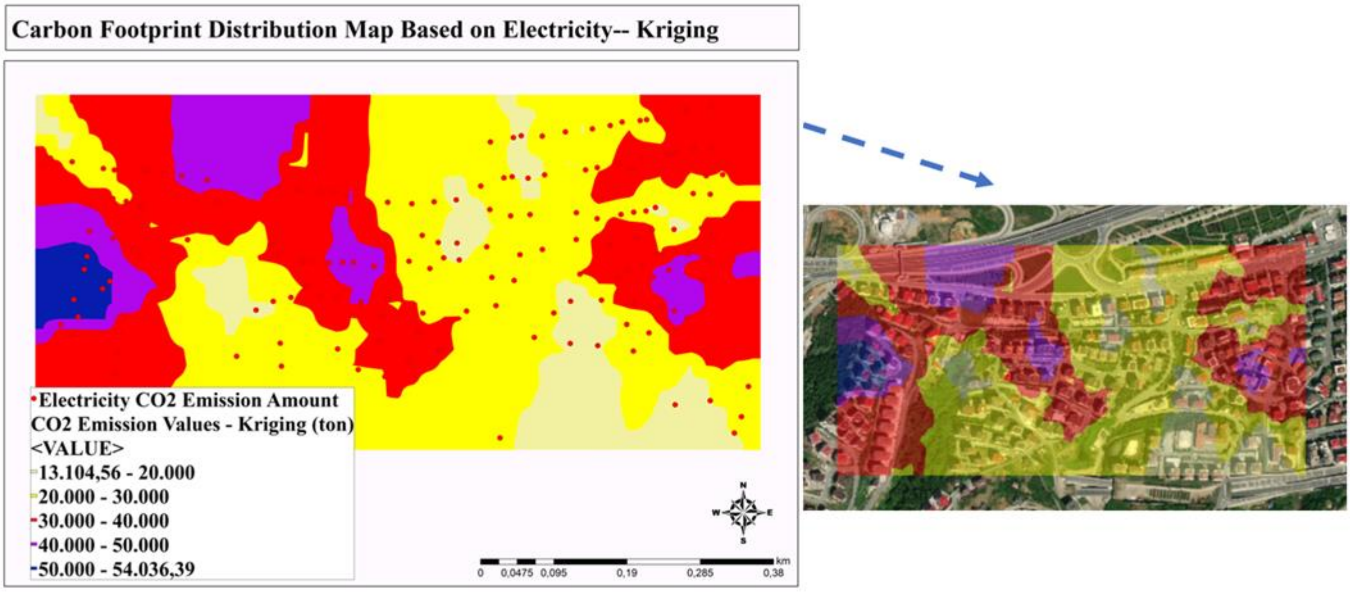


Figure 13. Electricity based carbon footprint distribution map according to Kriging analysis.

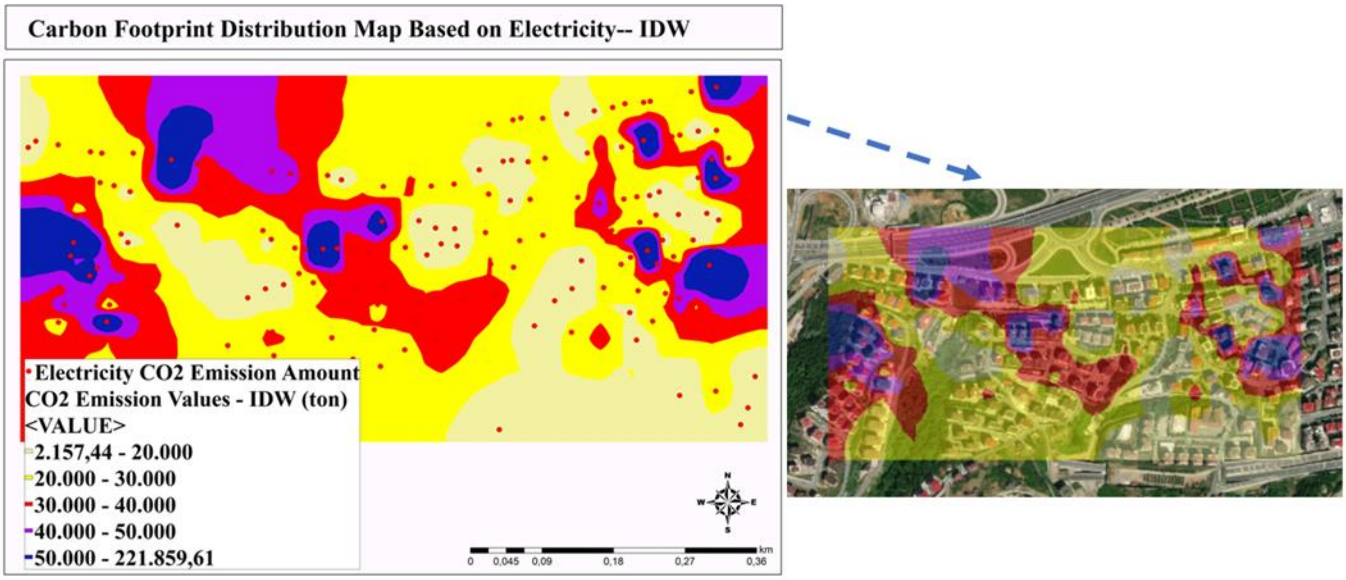


Figure 14. Electricity based carbon footprint distribution map according to IDW analysis.

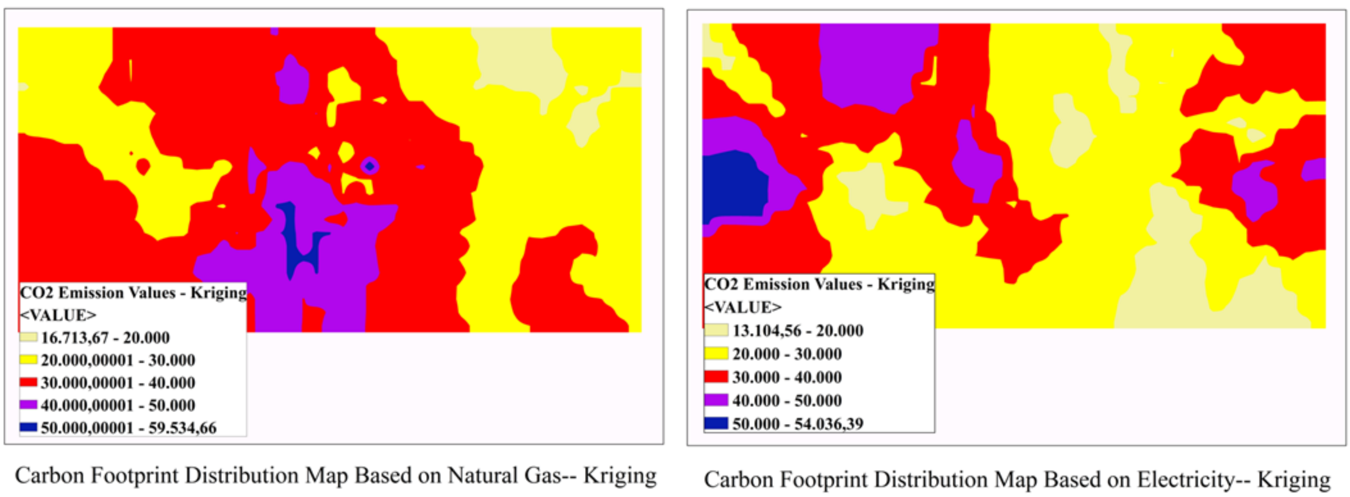
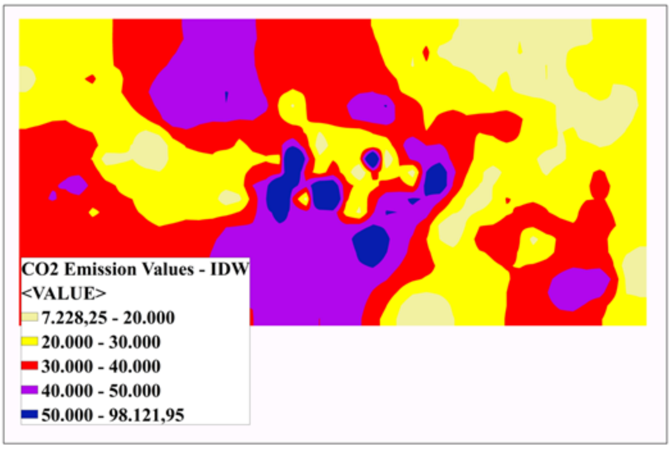
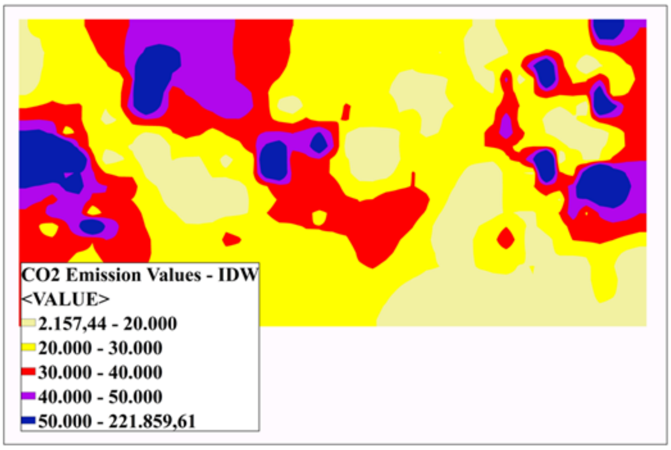


Figure 15. Display of carbon footprint distribution map based on natural gas and electricity according to Kriging analysis.



Carbon Footprint Distribution Map Based on Natural Gas-- IDW



Carbon Footprint Distribution Map Based on Electricity-- IDW

Figure 16. Display of carbon footprint distribution map based on natural gas and electricity according to IDW analysis.

4. Discussion

The world, our living space, is a complex ecosystem with many physical, chemical, and biological features. The atmosphere surrounding the Earth plays a fundamental role in sustaining life. Atmosphere contains various gasses such as nitrogen, oxygen, carbon dioxide, and water vapor. Thanks to these gases, they absorb the rays from the sun and warm the world. The temperature of the Earth is associated with climate and weather events. Therefore, temperature changes cause climate change. One of the primary reasons for these changes is greenhouse gas emissions. The amount of greenhouse gasses released into the atmosphere by the effects of various activities carried out by people and areas, such as industrialization, transportation, and agriculture, has increased and is increasing over time. The fact that this situation disrupts the natural order of the atmosphere negatively affects global warming and prepares the environment for climate change.

The prominent greenhouse gas in climate change is CO_2. In particular, using fossil fuels caused by land changes, deforestation resulting from fires, and the energy demand brought by industrialization has increased carbon emissions. Awareness of carbon emissions will reduce the adverse effects of climate change and ensure that nature is sustainably transferred to the future. In this context, the concept of carbon footprint is used to evaluate the impact of carbon emissions on the environment. A carbon footprint is an indicator that measures the impact of an individual, product, activity, or industry on carbon emissions. Carbon footprint measurement contributes to evaluating the environmental effects of carbon emissions, determining the triggering factors, taking measures against climate change, developing constructive strategies and policies by relevant institutions and organizations, and ensuring sustainability. Therefore, carbon footprint is an important tool for combating climate change.

This study aims to determine the carbon footprint in the selected region by measuring the amount of carbon emissions based on electricity and natural gas. 160 buildings were determined in Beşirli District, No. 1 in Ortahisar district of Trabzon province, and data on electricity and natural gas consumption were obtained from relevant institutions. In order to determine the carbon footprint in the region, carbon emission amounts based on electricity and natural gas were calculated based on the Tier-2 method. Spatial interpolation analysis was performed to see the region's carbon emissions distribution. Using the ArcGIS program, a GIS software, the distribution of carbon emissions based on the region's electricity and natural gas consumption was analyzed with Kriging and IDW methods, and the outputs were mapped. The results show that the carbon footprint due to natural gas consumption increases in the middle and southern parts of the study area according to both Kriging and IDW analysis. While the carbon footprint due to electricity consumption is on the increase in the western part of the study area in Kriging analysis, it is at high levels in certain areas in IDW analysis, being widespread throughout the study area. When these maps showing the spatial distribution of carbon footprint in the study area are evaluated in general, it is concluded that the region is in a medium-high risk position due to both electricity and natural gas consumption. This situation is likely due to the high population and settlement in the region, the intense use of the transportation network, and the presence of many workplaces. The main action that should be taken to reduce the carbon emissions in the region is to raise people's awareness. For this purpose, encouraging people to use public transportation, promoting recycling and ensuring that renewable energy sources are preferred will be effective in reducing the carbon footprint. On the other hand, as a result of the analyzes based on both consumptions, it was understood that the IDW method produced more precise results than the kriging method. It is thought that this situation arises from the mathematical models of the methods.

Carbon emissions are one of the main drivers of climate change, which is one of the most important problems of the world today. In this study, an application has been realized on such an important issue. With this study, the negative impact of natural gas and electricity consumption on carbon footprint has been proved with the application. In this context, it is thought that the study will contribute to the studies on climate change and emphasize the importance of carbon emissions.

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Author contributions

Ebru Colak: Conceptualization, Data Collection, Reviewing and Editing **Tugba Memişoğlu Baykal:** Conceptualization, Data Collection, Methodology, Software, Visualization, Investigation, Writing-Reviewing and Editing **Nihal Genç:** Conceptualization, Data Collection, Methodology, Software, Visualization, Investigation, Writing-Reviewing and Editing

Conflicts of interest

The authors declare no conflicts of interest.

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