Gazi Üniversitesi
Fen Bilimleri Dergisi
PART C: TASARIM VE TEKNOLOJİ

Gazi University
Journal of Science
PART C: DESIGN AND TECHNOLOGY

GU J Sci, Part C, 13(1): 308-329 (2025)

CO_2 Emission Inventory in Türkiye and Estimation of CO_2 Concentration over Türkiye by Using Dispersion Modelling

Ali CAN[1*], Aysel T. ATIMTAY[2], Turgut TOKDEMİR[2]

[1]*Karabuk University, Faculty of Engineering, Mechanical Engineering Department, Karabük, Türkiye*

[2]*Middle East Technical University, Engineering Facuklty, Environmental Engineering Faculty, Ankara, Türkiye*

Article Info

Research article
Received: 20/10/2024
Revision: 21/12/2024
Accepted: 25/01/2025

Keywords

Energy
CO_2 Emission Inventory
CO_2 Contours
ISCLT3
IPCC Methods

Makale Bilgisi

Araştırma makalesi
Başvuru: 20/10/2024
Düzeltme: 21/12/2024
Kabul: 25/01/2025

Anahtar Kelimeler

Enerji
CO_2 Emisyon Envanteri
CO_2 Konturları
ISCLT3
IPCC Yöntemleri

Graphical Abstract (Grafik Özet)

In the future if the fossil fuels are continued to be used for energy generation, the CO_2 emission will expected to increase. / Fosil yakıtlar kullanıldığı sürece CO_2 konsantrasyonu gelecekte de artmaya devam edeceği öngörülmektedir.

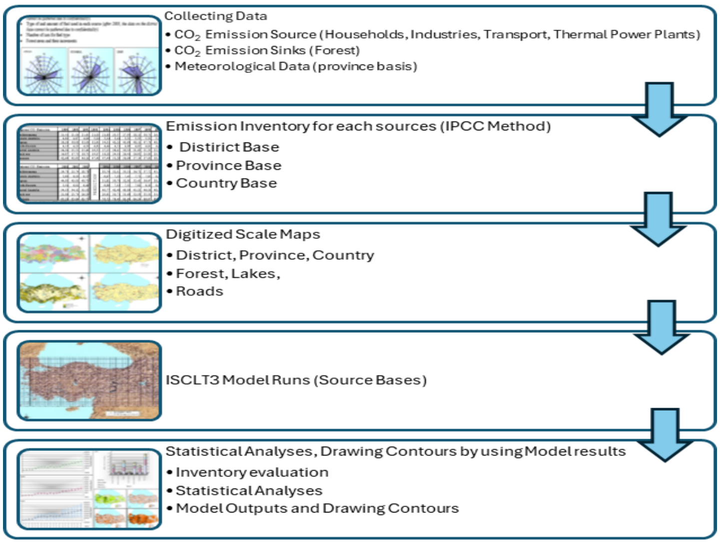


Figure A: *Methodological Approach /**Şekil A:**Metodolojik Yaklaşım*

Highlights (Önemli noktalar)

- *The highest recorded CO_2 emissions, amounting to 207.97 million tons/year was in the year 2000. / En yüksek CO_2 emisyonun 2000 yılında 207.97 milyon ton/yıl'dır.*
- *The Marmara Region emitted the highest regional CO_2 emission throughout the years with a mean value of 54.76 million tons/year. /Marmara Bölgesi'nin yıllar boyunca ortalama 54.76 milyon ton/yıl değeri ile en yüksek bölgesel CO_2 emisyonunu yaratmıştır.*
- *Between 1990 and 2003, the contribution of Households to the ground-level CO_2 concentration had risen approximately 7%. / 1990 ile 2003 yılları arasında, Hanelerin yer seviyesindeki CO_2 konsantrasyonuna katkısı yaklaşık %7 oranında artmıştır.*
- *The trend shows an increase in CO_2 pollution from road vehicles. / Karayolu araçlarından kaynaklanan CO_2 kirliliğinde net bir artış tespit edilmiştir.*

Aim (Amaç): *To assess the results of CO_2 inventories and obtain the CO_2 concentration distribution in Türkiye in province and in district bases for the period of 1990 – 2003 by using dispersion modelling. / 1990 - 2003 döneminde il ve ilçe bazında CO_2 envanterini oluşturmak ve dağılım modellemesi yardımıyla Türkiye il ve ilçelerindeki CO_2 konsantrasyonunun dağılımını elde etmektir.*

Originality (Özgünlük): *The CO_2 emission inventory and the dispersion modelling calculations in this detail (regional, provincial, and district level) have not been done previously in Türkiye. / Türkiye'de daha önce bu detayda (bölge, il ve ilçe düzeyinde) CO_2 emisyon envanteri ve dağılım modellemesi hesaplamaları yapılmamıştır.*

Results (Bulgular): *The maximum annual average ground level CO_2 concentration in Marmara Region was observed in 2001 with a 22.3×10^3 µg/m^3. / En yüksek yer seviyesi CO_2 konsantrasyonları Marmara Bölgesi'nde 2001 yılında 22.3×10^3 µg/m^3 olarak gözlemlenmiştir.*

Conclusion (Sonuç): *It was concluded that Marmara and Aegean Regions are responsible for half of the CO_2 pollution of Türkiye. / Türkiye'deki CO_2 kirliliğinin yarısından fazlasının Marmara ve Ege Bölgeleri'nden kaynaklandığı sonucuna varılmıştır.*

*Corresponding author, e-mail: alican@karabuk.edu.tr
DOI: 10.29109/gujsc.1590432

GU J Sci, Part C, 13(1): 308-329 (2025)

Gazi Üniversitesi
Fen Bilimleri Dergisi
PART C: TASARIM VE TEKNOLOJİ

Gazi University
Journal of Science
PART C: DESIGN AND TECHNOLOGY

http://dergipark.gov.tr/gujsc

CO_2 Emission Inventory in Türkiye and Estimation of CO_2 Concentration over Türkiye by Using Dispersion Modelling

Ali CAN[1*], Aysel T. ATIMTAY[2], Turgut TOKDEMİR[2]

[1]*Karabuk University, Faculty of Engineering, Mechanical Engineering Department, Karabük, Türkiye*

[2]*Middle East Technical University, Engineering Facuklty, Environmental Engineering Faculty, Ankara, Türkiye*

Article Info

Research article
Received: 20/10/2024
Revision: 21/12/2024
Accepted: 25/01/2025

Keywords

Energy
CO_2 Emission Inventory
CO_2 Contours
ISCLT3
IPCC Methods

Abstract

The main scope of this study is to assess the results of CO_2 inventories and obtain the CO_2 concentration distribution in Türkiye in province and district bases for the period of 1990 – 2003 by using dispersion modelling. The collected data from households, transportation, industry, and thermal power plants were used to estimate district base emissions for CO_2. However, after the year 2004, the collected data is not permitted to be used to estimate ground-level CO_2 concentrations due to the confidentiality of the data. Following the emission inventory, the dispersion of CO_2 in Türkiye was studied by using the USEPA's Industrial Source Complex Long Term Model, Version 3 ISCLT3. The results of the CO_2 emission inventory conducted in this study between 1990 and 2003 showed that the CO_2 emission in 1990 was 142.45 million tons/year. Notably, the highest recorded emissions, amounting to 207.97 million tons/year, was in the year 2000. The territorial distributions of CO_2 emission have shown that the Marmara Region emitted the highest regional CO_2 emission throughout the years with a mean value of 54.76 million tons/year. It was also concluded that the Aegean and Marmara Regions are responsible for half of the total CO_2 emission in Türkiye. The highest ground-level CO_2 concentrations were always obtained in the Marmara Region. It is predicted that this condition will still be maintained in the future if fossil fuels continue to be used for energy generation. Between 1990 and 2003, the contribution of Households to the ground-level CO_2 concentration had risen approximately 7%. There are serious local variations in the CO_2 concentrations when thermal power plants are considered. Although the percentage seems small, the registered number of vehicles has increased sharply since 1990. In conclusion, it can be stated that the trend shows an increase in CO_2 pollution from road vehicles.

Türkiye'de CO_2 Emisyon Envanteri ve CO_2 Konsantrasyonunun Dağılım Modeli Kullanılarak Hesaplanması

Makale Bilgisi

Araştırma makalesi
Başvuru: 20/10/2024
Düzeltme: 21/12/2024
Kabul: 25/01/2025

Anahtar Kelimeler

Enerji
CO_2 Emisyon Envanteri
CO_2 Konturları
ISCLT3
IPCC Yöntemleri

Öz

Bu çalışmanın amacı, 1990 - 2003 döneminde il ve ilçe bazında CO_2 envanterini oluşturmak ve dağılım modellemesi yardımıyla Türkiye il ve ilçelerindeki CO_2 konsantrasyonunun dağılımını elde etmektir. Hane halkı, ulaşım, sanayi ve termik santrallerden toplanan veriler ilçe düzeyinde CO_2 toplam emisyonlarını hesaplamak için kullanılmıştır. Ancak 2004 yılından sonra elde edilen veriler çalışmaları devam ettirmek için yeterli değildir. Emisyon envanteri kullanılarak, Ülkemizdeki CO_2 dağılımı, US Çevre Koruma Ajansı (EPA) tarafından geliştirilen Endüstriyel Kaynak Kompleksi Uzun Vadeli Modeli, Sürüm 3 ISCLT3 kullanılarak hesaplanmıştır. Bu çalışmada 1990-2003 yılları arasında yürütülen CO_2 emisyon envanteri sonuçları, 1990 yılında CO_2 emisyonunun 142.45 milyon ton/yıl olduğunu ve en yüksek emisyonun 2000 yılında 207.97 milyon ton/yıl değeriyle hesaplandığını göstermiştir. CO_2 emisyonlarının bölgesel dağılımı, Marmara Bölgesi'nin yıllar boyunca ortalama 54.76 milyon ton/yıl değeri ile en yüksek bölgesel CO_2 emisyonu yarattığını göstermiştir. Ayrıca, Marmara ve Ege Bölgelerinden Türkiye'nin toplam CO_2 emisyonunun yaklaşık yarısının atıldığı sonucuna da ulaşılmıştır. En yüksek yer seviyesi CO_2 konsantrasyonları her zaman Marmara Bölgesi'nde elde edilmiştir. Fosil yakıtlar kullanıldığı sürece bu durumun gelecekte de böyle devam edeceği öngörülmektedir. 1990 ile 2003 yılları arasında, Hanelerin yer seviyesindeki CO_2 konsantrasyonuna katkısı yaklaşık %7 oranında artmıştır. Termik santraller göz önüne alındığında CO_2 konsantrasyonunda ciddi yerel farklılıklar görülmüştür. Oransal olarak küçük görünse de, kayıtlı araç sayısı 1990'dan itibaren yoğun bir şekilde artmıştır. Ayrıca karayolu araçlarından kaynaklanan CO_2 kirliliğinde net bir artış tespit edilmiştir.

Corresponding author, e-mail: alican@karabuk.edu.tr
DOI: 10.29109/gujsc.1590432

1. INTRODUCTION (GİRİŞ)

It is an observational fact that atmospheric CO_2 concentration, mainly formed during energy generation with combustion reactions, is increasing continuously and will keep growing in the future [1]. The rise of atmospheric CO_2 concentration derived from global sources over time is due to its long life [2]. The Industrial Revolution was considered the beginning of the growth of CO_2 concentration over the years [3]. This pollutant is highly released into the atmosphere owing to burning fossil fuels [4, 5]. The global CO_2 budget is complicated and involves the CO_2 transfer between the biosphere, the atmosphere and the oceans [6]. Together with CO_2 many other pollutants are generated. However, CO_2 cannot be removed from exhaust gases like other pollutants, and it causes the Green House (GH) effect. It is estimated that CO_2 concentration is responsible for approximately 60% of the total greenhouse (GH) effect [7, 8].

The quantity of growth is determined by the global carbon cycle of carbon sources and sinks or reservoirs [9, 10]. The increasing CO_2 concentration in the atmosphere means a significant CO_2 cycle through the atmosphere, biosphere, and ocean [11]. The main relationship between CO_2 emissions and atmospheric concentrations is mostly examined by carbon cycle models that consider all of the important sources and sinks [12]. The main CO_2 sources are the burning of fossil fuels and changes in land use. The main sinks of CO_2 are the forests and oceans [13]. However, there are still large uncertainties as to whether the coastal zones act as sinks or sources [14].

The most important atmospheric exchange of carbon is the one between the biosphere and the atmosphere. The biosphere removes carbon from the CO_2 of the atmosphere by photosynthesis. It again releases CO_2 into the atmosphere during the decay of plants [15]. The rate is equal to about 20-25 % of the total annual human-induced CO_2 emissions. Therefore, a significant proportion of global emissions come from this source. The overall strategy is to stabilize the atmospheric CO_2 concentration, and this must include forest protection as a key component [16].

Atmospheric climate change is taking an increasingly important place in the policy programs and decision-making process in both the private sector and the public, countries have designed to meet their national goals, are extremely diverse [17]. The main international agreement is the United Nations Framework Convention on Climate Change (FCCC) [18]. 189 Parties including Türkiye have ratified the FCCC. Türkiye is formally in the Convention Annex I list [19]. The main objective of the Convention is to poise the concentration of greenhouse gases in the atmosphere to a level that will prevent dangerous anthropogenic emissions [20, 21].

In December 1997, the UNFCCC Conference of Parties (COP) held in Kyoto adopted the Kyoto Protocol. Kyoto conference has been accepted as a high-profile event because, for the first time, industrialized countries adopted emission reduction targets that are legally binding [22]. The Protocol offers no guidelines for implementation at the national level; rather, it provides freedom in respect of types of national legislation and policy. There are strict quantity norms in the Protocol. Improvement of energy efficiency, carbon storage in forests, and forming sustainable agriculture are some of the important topics [23]. Türkiye was included in the list of countries under the Kyoto Protocol in 2009. After the ratification of the protocol in 2009 without any target, Türkiye began to study Climate Change mitigation activities under the sustainable development plans' strategies [24, 25, 50, 51].

In this study, the emission inventory of CO_2 for Türkiye was done based on districts and provinces. The CO_2 inventory with this detail has not been done in Turkiye previously. This inventory was prepared by considering all possible emission sources. The basic source of CO_2 is fossil fuel combustion in households, manufacturing industries, thermal power plants, and road vehicles. The carbon content and emission factors of the fuels used were the main points for the estimation of CO_2 emissions. The inventory has been calculated between 1990 and 2003. Emissions in 1990 are important because the Kyoto Protocol adopts 1990 as the base year for CO_2 reductions. The CO_2 uptake rate of forests in Türkiye based on provinces and districts is also studied to determine the net CO_2 emission and ground-level concentrations. Following the emission inventory, the dispersion of CO_2 was studied by using the ISCLT3 model [26]. Based on the results of modeling calculations, the ground-level CO_2 concentration maps were prepared and superimposed on the geographical map of Türkiye by using Geographic Information System (GIS) techniques [27]. GIS techniques were used to map all the information [28].

2. METHODOLOGY (METODOLOJİ)

IPCC methods integrated with GIS techniques and statistical methods were used to predict the emission and uptake inventories. The inventories were calculated for each district, province, and region of

Türkiye. The following data types were gathered as a time series between 1990 and 2003.

- The households' number and the population in districts
- Industries concerning its size and its place (*after 2003, the data on the district base cannot be gathered due to confidentiality*)
- Type of and amount of fuel used in each source (*after 2003, the data on the district base cannot be gathered due to confidentiality*)
- Number of cars for fuel type
- Forest areas and their increments

The data for the annual fuel use from various sources between 1990-2003 was obtained from TurkStat (Turkish Statistical Institute), ENRM (Energy and Natural Resources Ministry), and MAF (Ministry of Agriculture and Forestry).

The data is gathered from many sources as described in the related sections. After gathering, the study period was decided. The study period is important for the determination of the base year and industrial development of districts in Türkiye because the energy consumption is one main consideration for economic inputs. Within this context, this study can be used locally in terms of energy consumption and its effect on the environment, especially on climate.

Emission Inventory: The IPCC methods were used to estimate national inventories of greenhouse gas emissions resulting from human activities. The primary technical guidelines for national inventories are based on the IPCC Guidelines [4, 5]. The IPCC establishes a standard framework for the categorization of emission sources. According to the IPCC, activities that originate naturally and do not create net greenhouse gas emissions are intentionally excluded from this study.

The general formula according to the IPCC for the CO_2 emission is given as:

CO_2 emissions =Σ Fuel consumption in energy units (TJ) for each sector * Carbon Emission Factor * Fraction Oxidized * Convert Carbon Emission to CO_2.

Road Vehicles: The amount of fuel consumed on the roads of each district of Türkiye was calculated by using the following formula (Equ. 1).

$$H_a = \frac{A}{B} \times \frac{C}{D} \times F_a \tag{1}$$

A : The number of households in districts
B : The number of households in the province
C : The number of cars in the province
D : Total number of car
H_a: Fuel consumption in the district according to fuel type a (tons)
F_a : Fuel consumption by car according to fuel type a (tons)
a : Gasoline or diesel

Households: The regional fuel consumption factors were used per household to estimate the total amount of fuel consumption in districts, provinces, and regions for the years 1990-2010. (Equ. 2). The following equation was used:

$$C = A \times B \tag{2}$$

A : The number of households in districts (households number/region)
B : Regional fuel consumption factors per household (tons/household)
C : Fuel consumption in districts (Meteorological parameters are considered) (tons/region)

Manufacturing Industries: In this study, different types of data were gathered from the SIS and MOE. These data are:

- The number of manufacturing industries according to the size of establishments between 1990 and 2003 in each district [29].
- The total energy consumption (TOE) of the manufacturing industries in Türkiye according to the size of establishments [30, 31, 32, 33, 34, 35].
- The fuel consumption within the manufacturing industries across each province [36].
- The overall fuel consumption by manufacturing industries in Türkiye [37].

The annual fuel consumption across districts' manufacturing industries was estimated using the following formula (Eqn. 3).

$$D = \frac{A}{B} \times C \quad G_t = \frac{F}{C} \times D_n \times E \tag{3}$$

A : The energy consumption factor of the manufacturing industries according to its size (TOE)
B : Total number of manufacturing industries according to their size
C : Total number of manufacturing industries in provinces according to its size
D : The energy consumption factor of the manufacturing industries in provinces according to its size (TOE)
Dn: The normalized energy consumption factor of the manufacturing industries in provinces according to their size
E : The number of manufacturing industries in districts according to their size
F : Total fuel consumption in provinces (tons)
Gt: The fuel consumption in manufacturing industries in districts according to their size
t : year (1990 – 2010)

GIS Techniques: The following scaled maps, given in Table 1, were digitized.

Their projection was Lambert Conformal Conic [38].

Table 1. The digitized scaled maps (Sayılaştırılmış ölçekli haritalar)

Maps	Scale	Description
Provinces	1/1 000 000	80 provinces (Düzce taken as Bolu)
Districts	1/1 000 000	911 districts
Lakes*1	1/1 000 000	All lakes and Dams
Forest*2	1/1 000 000	According to 4 classes: Empty Land, Poor Forest, Intermediate Forest, Good Forest
Roads*3	1/100 000	According to 3 classes: Railway, Highway, Others
Thermal Power Plants*4	-	According to X and Y coordinate

Sources: [1] Water Hydraulic Works; [2] Ministry of Agriculture and Forestry; [3] General Directorate of Highways; [4] Turkish Electricity Generation - Transmission Corporation

Uncertainty Analysis: In this study, the probability density function of the annual emission is assumed as the normal distribution, and the range of uncertainty is expressed within 95% confidence intervals according to the IPCC Good Practice Guidance [39].

The probability density function of the differences of the mean values for the emissions of districts, provinces and regions in years X and Y is also normal with the following equations. Here, y is the base year series and x is the series of any year between 1991 and 2003 (Eqn 4. - 9.)

$$\text{mean} = \bar{x} - \bar{y} \quad (4)$$

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} X_i \; ; \; \bar{y} = \frac{1}{N}\sum_{i=1}^{N} Y_i \quad (5)$$

$$\text{standard deviation} = (S_x^2 + S_y^2)^{1/2} \quad (6)$$

where,

$$S_x^2 = \frac{1}{N}\sum_{i=1}^{N}(X_i - \bar{X}) \; ; \; S_y^2 = \frac{1}{N}\sum_{i=1}^{N}(Y_i - \bar{Y}) \quad (7)$$

then, the standard error of the mean (SEM) is given as:

$$\text{SEM} = \frac{\text{s tan dard deviation}}{\sqrt{N}} \quad (8)$$

finally, the uncertainty interval from the set of data is estimated using classical method [39, 40].

$$\text{mean} \pm \text{SEM} \times t_{0.05,df} \quad (9)$$

N : Sample Size
df : Degrees of freedom
t0.05,df : Student t-table value for (N-1) degrees of freedom and 95% of the confidence interval

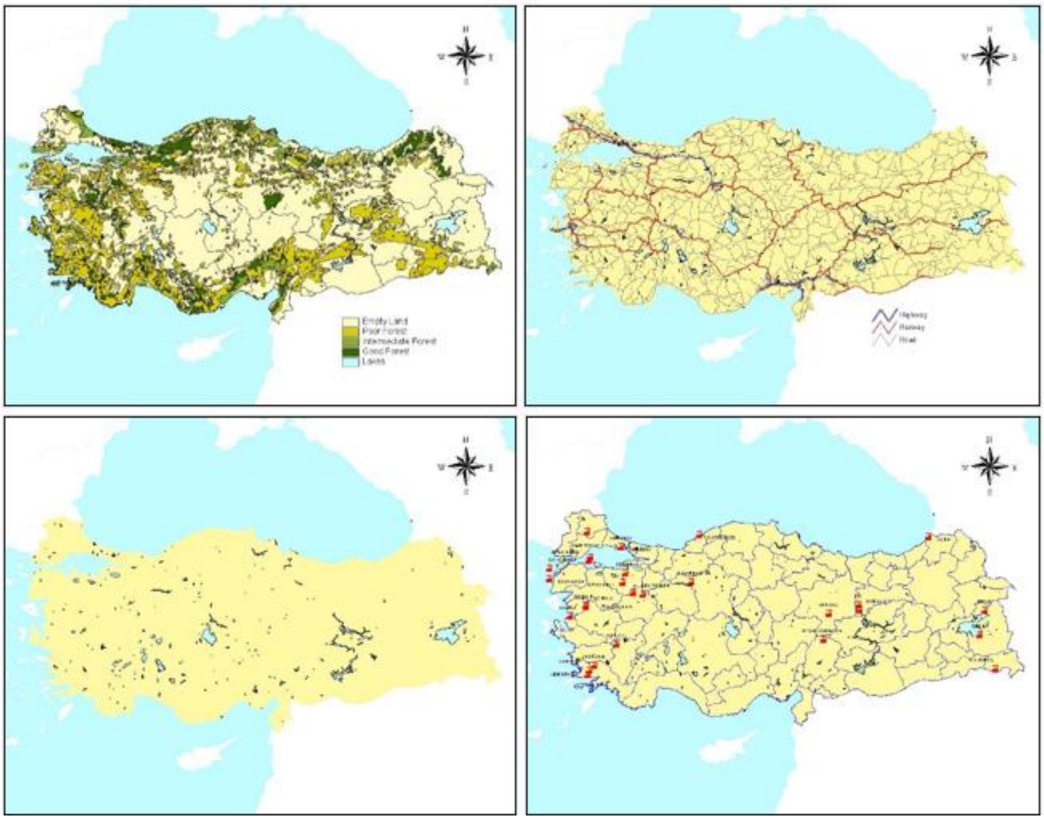


Figure 1. Forest, Roads, Lakes, and Thermal Power Plants in Türkiye (Türkiye'deki Ormanlar, Yollar, Göller ve Termik Santraller)

Forest Inventory: The net uptake of CO_2 is usually calculated by estimating the total forest area and the annual increment of biomass [4, 5].

The IPCC method for CO_2 uptake is defined as (Eqn 10. – 13.):

$$B = I \times D \quad (10)$$

$$TB = B \times (1 + RF) \quad (11)$$

$$CS = TB \times 0.45 \text{ (ton C/ton dry biomass)} \quad (12)$$

$$U = CS \times 44/12 \quad (13)$$

B : The volume of biomass (tons)
I : Annual increment (m3)
D : Dry biomass density (tons/m^3)
TB: Total biomass including roots
RF : Root Factor (%)
CS : Carbon Storage (tons)
U : CO_2 uptake (tons)

ISCLT3 Dispersion Model: The basis of the ISCLT3 dispersion model is the steady-state GPE (Gaussian Plume Equation) [41]. The fundamental parameters for calculating the concentration of pollutants in the surrounding air at ground level are the emissions from the sources into the atmosphere, the meteorological variables, topography, and the parameters describing removal and transformation processes [42]. Then the results were superimposed to the GIS maps of the districts and provinces. The primary purpose of GIS in this study was to show the variations and changes in the districts and provinces as seen in Figure 2.

Basically, the ISCLT3 model inputs have been divided into two parts: “Runstream File” and “Meteorological Input File (STARDATA)”. The Runstream File contains modeling options, source location, receptor information, meteorological properties, and output options.

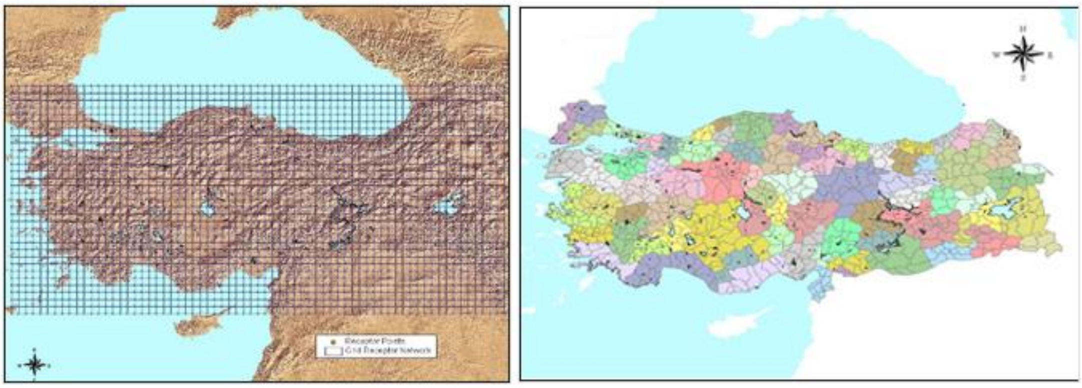


Figure 2. Determination of source and receptors for districts and provinces in Türkiye (Türkiye'de ilçe ve iller için emisyon kaynak ve yutakların tespiti)

The meteorological Input File contains wind speed, wind directions, mixing height (morning and afternoon values), and stability classes depending on many meteorological parameters such as sunbathing and cloudiness data. The meteorological variables are very important parameters in air pollution modeling. Each meteorological variable (an example is given in Table 2.) was studied carefully on a province basis.

Table 2. Selected meteorological parameters for some provinces (Bazı iller için seçilmiş meteorolojik parametreler)

	Temperature (°C)		Mixing Height (m)				Wind Speed (m/s)	
			Z_{AM}		Z_{PM}			
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Value	4.3	19.5	166.2	784.1	911.0	2020.0	0	189
Province	Erzurum	Mersin	Diyarbakır	İstanbul	Samsun	Diyarbakır	Hakkari	Çanakkale

The usage of each meteorological parameter has some criteria. Mixing heights are determined according to the EPA standards [26] as given in Table 3. The stability classes have different mixing height calculations for the model. The annual average morning value (Z_{AM}) and average afternoon value (Z_{PM}) mixing heights were obtained from the synoptic meteorological stations' measurements. Wind roses were plotted to show the frequency distribution of wind direction for each province (Figure 3).

Table 3. EPA Standards for Mixing Height (EPA Karışım Yüksekliği Standartları)

Stability Class	A	B	C	D	E	F
Mixing Heights	$1.5xZ_{PM}$	Z_{PM}	Z_{PM}	$(Z_{PM+ZAM})/2$	Z_{AM}	Z_{AM}

Model Evaluation: There isn't any CO_2 concentration measurement station in Türkiye. Therefore, the CO_2 concentration over Türkiye is estimated by using the measured CO_2 concentration data of the nearest CO_2 measurement stations around Türkiye by using the Kriging Method [43]. These data are used to compare model outputs using statistical methods.

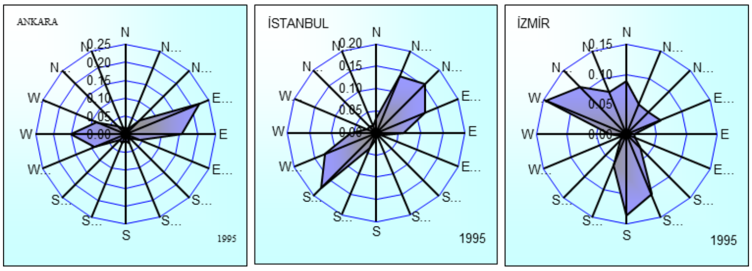


Figure 3. Wind roses of Ankara, İstanbul and İzmir provinces, 1995 (Ankara, İstanbul ve İzmir illerine ait rüzgar gülleri, 1995)

Dlugokency et al. [44] have used such types of approaches. Besides the trend analysis, "R^2 values" and "Correlation Coefficient" relationship between the two data sets were also tested [45]. The statistical methods are listed as follows: K-mean cluster analysis is used to identify the irrelevance of the value in the series [46]; Cronbach Alfa (α) Reliability Analysis determines the internal consistency of the model [47] and Mann-Kendall Rank correlation test is a non-parametric method used to identify any potential increasing or decreasing trends in the series [48].

3. RESULTS AND DISCUSSIONS (SONUÇLAR VE TARTIŞMA)

3.1. Emission Inventory (Emisyon Envanteri)

The CO_2 emission inventory is the basic requirement of the ISCLT3 model. The fuel consumption data at district, provincial, and regional levels have been studied in detail to prepare the input data for the modeling program. This inventory covers four types of sources. The sources are industrial, residential, road transportation, and energy production.

According to the inventory results of districts, the İskenderun district of Hatay province, Afşin district of K.Maraş province, and Üsküdar district of İstanbul province have emitted the highest quantity of CO_2 in Türkiye. İskenderun has the highest CO_2 emission for the durations of 1990-1998 and 2002-2003 with 5.7, 7.4, 7.1, 7.0, 10.8, 10.9, 10.4, 7.2 and 8.5 million tons, respectively. In 2000 and 2001, the highest levels of CO_2 emissions were observed in Üsküdar (7.5 and 8.1 million tons, respectively).

In the provincial emission series, the maximum annual CO_2 emission was observed in İstanbul with an average value of 30 million tons per year between 1990-2003. The amount of increase in the CO_2 emission of İstanbul in 2003 compared with 1990 (base year) was 47.3%. The future increase in the emission of İstanbul will obviously continue and will probably reach 80 million tons in 2020. The second highest CO_2 emissions were observed in Ankara, İzmir, Hatay, and Manisa provinces with 12.3 (in 2001), 16.5 (in 1999), 12.1 (in 1997), and 8.3 (in 1994) million tons, respectively. The primary reason is the high fuel consumption in thermal power plants and industries present in these provinces.

During this study, GIS techniques were used to obtain the changes in the emission series in graphical forms. The CO_2 emissions from districts and the CO_2 emission from provinces are given in Figure 4 for 2003.

Analysis of the regional results, as illustrated in Figure 5, in the **Marmara Region** shows that the highest CO_2 emission was 65.8 million tons in 2002. The percentage emission increase as compared to the base year was found as 54.4%. The contribution of households, industries, power plants, and road vehicles in this region to the annual total CO_2 emission of Türkiye is 13.9%, 7.8%, 6.3%, and 4.1%, respectively. In the **Aegean Region**, the annual average CO_2 load from all the sources is around 40 million tons. Thermal power plants produce the highest levels of emissions. The CO_2 emissions from thermal power plants range from a minimum emission value of 11.9 million tons in 1990 to a maximum value of 21.8 million tons in 1999. The maximum emission increase compared to the base year is observed to be 77.0% in 2000. The contribution to the annual CO_2 emissions was 4.7 % for households, 6.3% for industries, 10.8% for power plants, and 2.3% for road vehicles in that year.

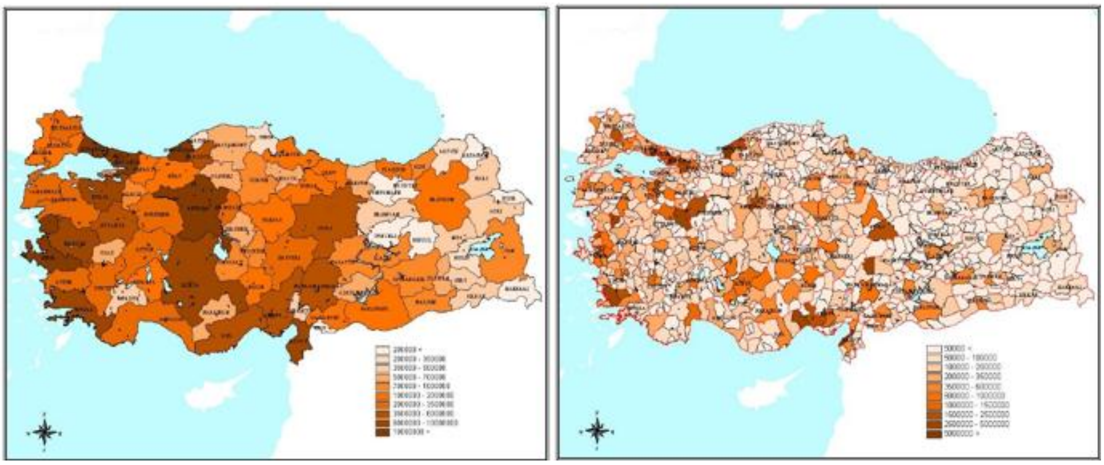


Figure 4. The CO_2 emission from provinces and districts for 2003 (2003 yılı il ve ilçelere ait CO_2 emisyonu)

In the Central Anatolia Region, the emission trend has been increasing since 2000. The total annual emission is around 30 million tons. The highest total emission is observed in 2000 with a value of 35.6 million tons and the lowest emission value is observed as 24.3 million tons in 1990. The maximum emission increase relative to the base year is 46.5%. According to the inventory results between 1990-2003, the annual CO_2 loads of households, industries, power plants, and road vehicles are 18.6, 4.9, 3.3, and 6.3 million tons, respectively. It is evident from the annual averages; the highest emission comes from households. The annual contribution of the households to the total CO_2 emissions in this region is around 10.0 %.

The regional CO_2 emission data is estimated for the years 2004 and 2010. After year 2010, the uncertainty value is increasing considerably as seen in Figure 11. Therefore, the projections were cancelled after the year 2010 (Figure 5).

In the **Mediterranean Region**, the results of inventory show that the highest emission is observed from the industries. Industries are responsible for 57.3% of the regional CO_2 emission with a value of 16.5 million tonnes in 2003. The regional contribution to the annual CO_2 emissions from all sources is around 28.8 million tons (13.8 % of total CO_2 emissions). In the **Black Sea Region**, the regional CO_2 emission trend of industries has shown peak values for the period of 1990-2003. These are 15.8 million tons in 1997 and 15.1 million tons in 2003. The contribution of this region to the annual CO_2 emission of Türkiye is around 12.0%. However, in the **South-Eastern Anatolia Region**, the total CO_2 emission is approximately 5 million tons per year. The total contribution of this region to the CO_2 emission of Türkiye is not more than 3.0% throughout the years. The inventory of the **Eastern Anatolia Region** shows a 3.0% regional contribution to the total CO_2 emissions in Türkiye. However, the CO_2 emission trend is increasing. In 2003, the CO_2 emission was 6.6 million tons. Households are responsible for 61.5% of the regional CO_2 emissions because the climate is cold, and people burn a lot of fossil fuel during winter to warm up their houses. As an overall evaluation, the lowest CO_2 emission of all the regions was observed in 1990 and the highest in 2000. Although the Marmara and Aegean regions are responsible for half of the emissions of Türkiye, the other regions also show an increasing trend in CO_2 emissions. These results can be observed easily in Figure 6 and Table 4.

The CO_2 emission from **industries** is approximately 35% of the total emissions. The regional contribution to the total industrial CO_2 emission varies greatly from region to region. The highest emissions were observed in Marmara, Mediterranean, Black Sea, and Aegean regions with annual average values of 12.6, 12.3, 11.6, and 9.6 million tons, respectively, for the period of 1990-2003 (Figure 7). **Domestic heating** is another important source of CO_2 emissions in Türkiye.

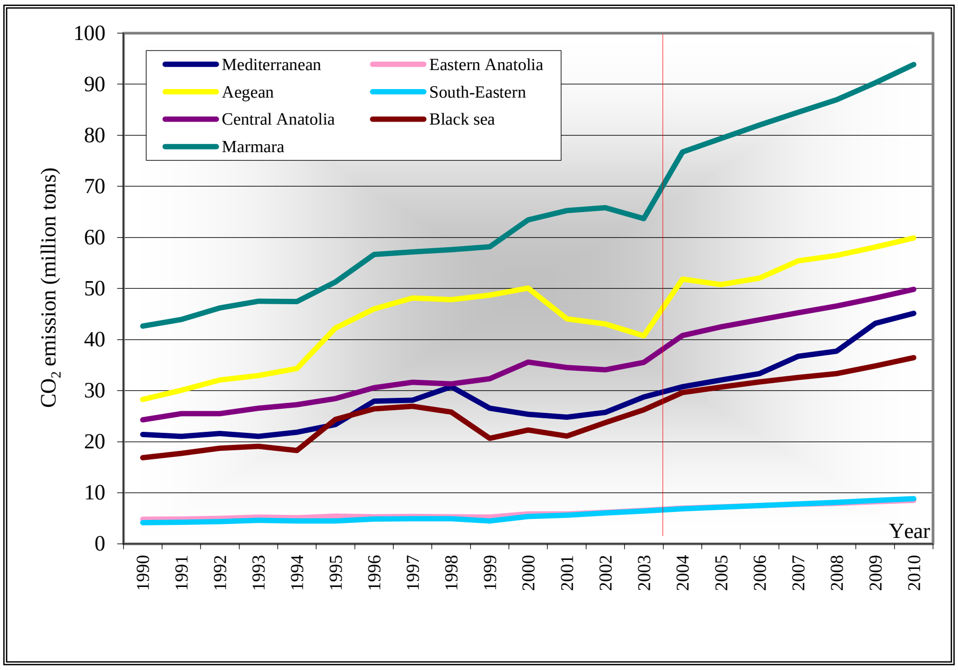


Figure 5. Regional CO_2 emission trend (Bölgesel CO_2 emisyon eğilimi)

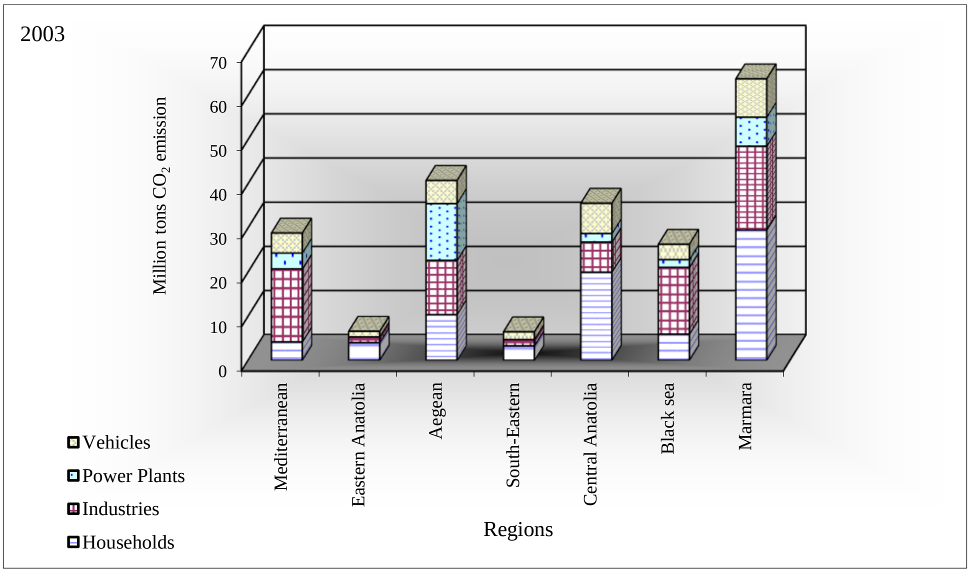


Figure 6. The regional CO_2 emission for 2003 (2003 yılı için bölgesel CO_2 emisyonu)

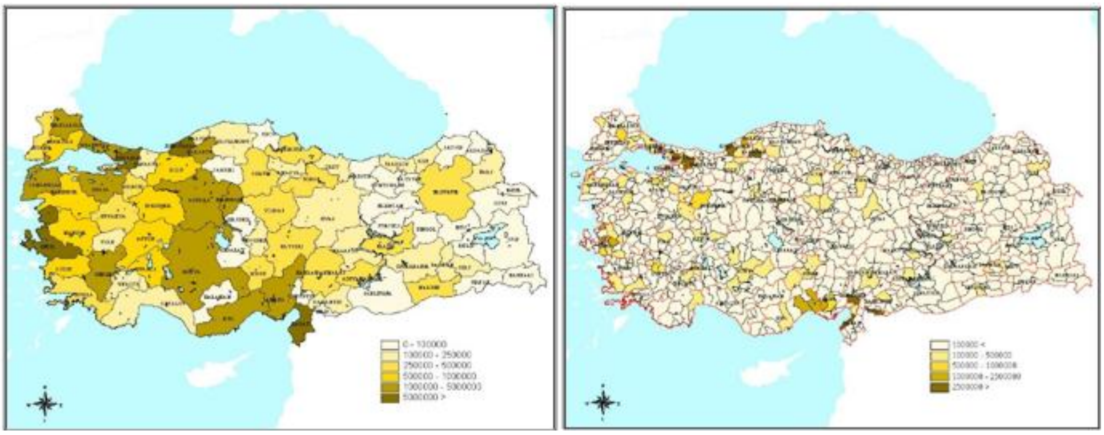


Figure 7. The industrial CO_2 emission for 2003 (2003 yılı endüstriyel CO_2 emisyonu)

Approximately 34.22% of total CO_2 emissions in Türkiye is due to households. CO_2 emissions from households mostly depend on the population density and the fuel type used for domestic heating.

Mainly, coal is burned in households for domestic heating. In large cities, like Ankara, İstanbul, Bursa, and Eskişehir, natural gas is commonly used for heating wherever it is available. The highest regional contribution to the total residential CO_2 load was determined in the Marmara Region. It is about 35%. The next region is Central Anatolia, which accounts approximately for 25% (Figure 8).

Thermal power plants are the third important CO_2 source in Türkiye. Approximately 20.0 % of total CO_2 emission in Türkiye is attributed to the thermal power plants. The highest emissions for two plants were observed in 1999 with 8.4 million tons from Afşin-Elbistan and 6.5 million tons from Soma. The annual average CO_2 emissions from the two plants are 11.0 million tons in total (Figure 9).

Generally, local emission inventories are not available in Türkiye. Also, no data is available for **active traffic** even on the provincial level. Only the main highways were included in this inventory to fulfil the traffic option. The highest regional contribution to CO_2 emissions by traffic is obtained in Aegean Region, Central Anatolia Region and with annual average values of 4.4, 5.8 and 8.3 million tons per year. According to the inventory results in 2003, Konak district of İzmir, Çankaya district of Ankara and Bakırköy district of İstanbul show the highest emission with values of 0.5, 0.7 and 1.0 million tons CO_2 emissions. The approximate increments in the CO_2 emission of Bakırköy, Çankaya and Konak compared with the base year are obtained 9.4 %, 26.8 % and 17.6 % for the year 2003 (Figure 10).

Table 4. The regional CO_2 emission between the years 1990-2010 (1990-2010 yılları arasındaki bölgesel CO_2 emisyonu)

	Regional CO_2 Emission	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
million tons	Mediterranean	21,41	21,06	21,61	21,05	21,88	23,37	27,93	28,11	30,75	26,57	25,39
	Eastern Anatolia	4,82	4,87	4,96	5,24	5,14	5,41	5,30	5,35	5,31	5,26	5,87
	Aegean	28,28	30,08	32,09	32,95	34,31	42,25	45,98	48,11	47,79	48,70	50,05
	South-Eastern	4,16	4,20	4,38	4,62	4,49	4,51	4,86	4,95	4,91	4,46	5,35
	Central Anatolia	24,29	25,51	25,48	26,53	27,25	28,47	30,56	31,63	31,33	32,32	35,59
	Black sea	16,87	17,70	18,70	19,07	18,29	24,35	26,41	26,92	25,83	20,70	22,32
	Marmara	42,64	43,90	46,16	47,49	47,44	51,29	56,64	57,14	57,60	58,14	63,41

	Regional CO_2 Emission	2001	2002	2003		2004	2005	2006	2007	2008	2009	2010
million tons	Mediterranean	24,78	25,74	28,78	PREDICTION	30,74	32,10	33,31	36,71	37,72	43,16	45,13
	Eastern Anatolia	5,83	6,20	6,55		6,97	7,22	7,47	7,72	7,95	8,23	8,52
	Aegean	44,05	43,06	40,70		51,81	50,78	52,00	55,40	56,47	58,11	59,90
	South-Eastern	5,59	6,02	6,41		6,86	7,18	7,50	7,82	8,13	8,48	8,84
	Central Anatolia	34,53	34,12	35,53		40,77	42,49	43,84	45,25	46,56	48,13	49,83
	Black sea	21,08	23,76	26,24		29,61	30,71	31,68	32,58	33,35	34,83	36,46
	Marmara	65,28	65,84	63,70		76,72	79,40	81,99	84,54	86,97	90,27	93,85

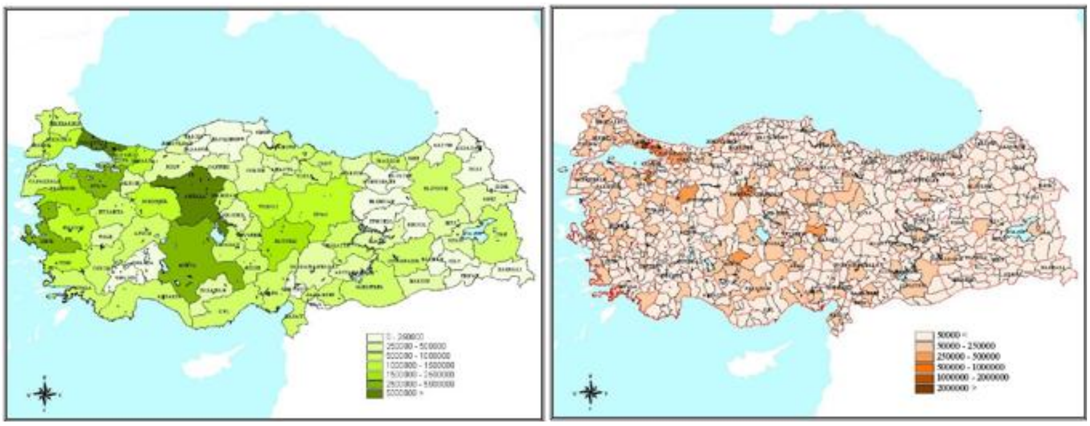


Figure 8. The CO_2 emission from households for 2003 (2003 yılı için hanelerden kaynaklanan CO_2 emisyonu)

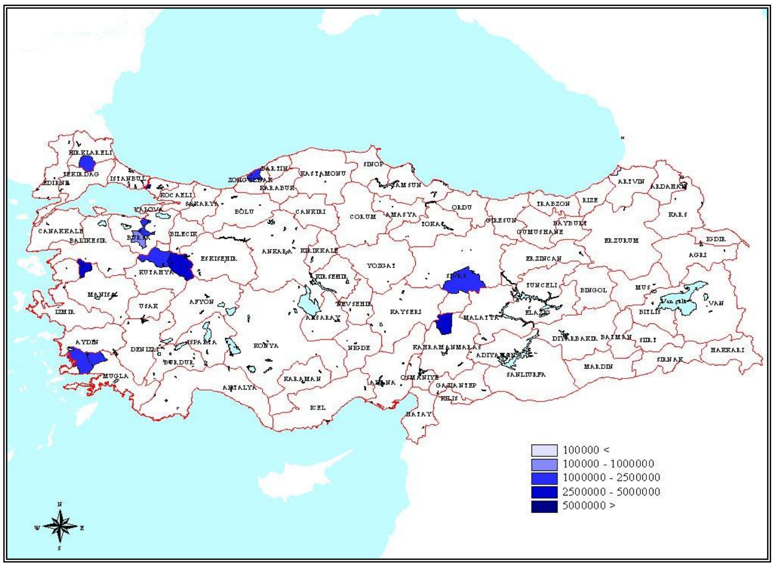


Figure 9. The CO_2 emission of thermal power plants for 2003 (2003 yılı için termik santrallerin CO_2 emisyonu)

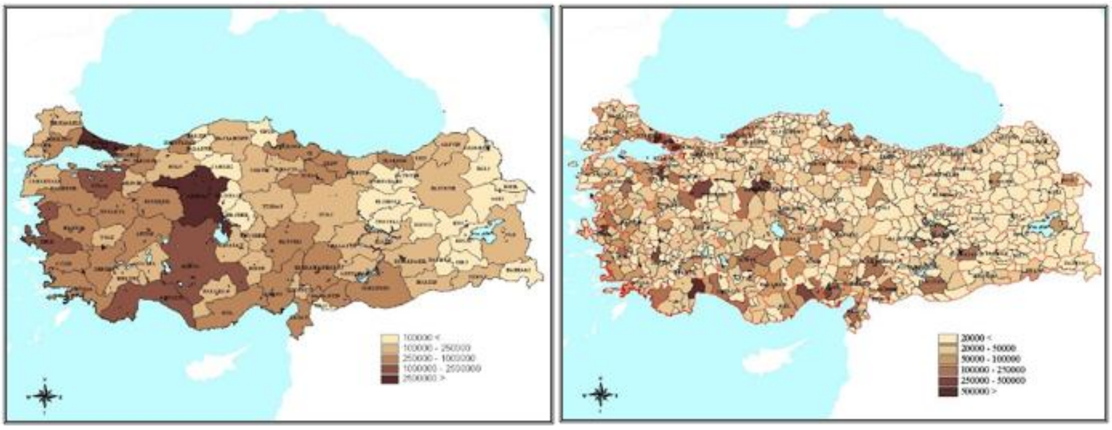


Figure 10. The CO_2 emission of road vehicles for 2003 (2003 yılı karayolu taşıtlarının CO_2 emisyonu)

Statistical and Uncertainty Analysis: By using the results of the statistical evaluations, it is concluded that the correlations between CO_2 emission of base year and that of each related year between 1991-2010 are very high for regional and provincial emission series. The highest correlation implies that there is an association between the series. However, the correlations of districts' emission series throughout the years compared to the base year are not high as regional and provincial ones.

Another important statistical variable is the SEM, which is the indication of the spread of the mean. The SEM of the annual emission series is decreasing while the number of the sample size is increasing. Briefly, the more the data are gathered, the less the uncertainty is observed in the measurement. Therefore, the uncertainty in the emissions data of the district is less than that of regions (Figure 11).

The used method in this study determines the significance of year-to-year differences and it considers the long-term trends in the inventories. A key issue in the compilation of uncertainties within inventories is the difference between the standard error of the sample mean and the standard deviation of the data set. The standard deviation's role in estimating confidence interval limits relies on the probability distribution of the data set.

Although it is recognized that there are many causes of uncertainties, the most important ones in this study are thought to be caused by the following:

- Application of IPCC emission factors associated with uncertainties since the fuel data characteristics are changing locally and regionally.
- The quality of the fuel consumption data is also changing from source to source. Although the official data sets are used for emission estimates.
- There is inconsistency in gathering the data. Because the total fuel consumptions are obtained from the different annual fuel consumption reports of sectors by MOE. And it is possible to change in the data within the following years.
- For future cases, the fuel consumption data do not exist. Therefore, the future estimation means some amount of uncertainties.

The uncertainties in emission estimates of greenhouse gases are a major concern to the countries. And most countries state that the uncertainty of the CO_2 emission is very low compared to the other gases because of the very small differences between the measured and estimated CO_2 emission.

3.2. CO_2 Uptake by Forests (Ormanların CO_2 Alımı)

The statistical data to calculate the CO_2 uptake over time is not easy to obtain. The inventories are not periodical and based on field surveys. For that reason, all possible sources of data are to be collected to form the CO_2 uptake inventories. The IPCC supplies a common framework to categorize CO_2 sinks. According to the IPCC [4, 5, 39] the following areas should be evaluated in the inventories to improve the comparability of the CO_2 uptake inventories.

- Forest and biomass stocks: CO_2 removals are estimated from biomass growth.
- Grassland conversion: CO_2 removals and emissions change seasonally. The net emission or uptake should be considered.
- Land-use change: According to the cultivated land, it could result in either CO_2 emission or CO_2 uptake. Satellite images, aerial photography, and land-based surveys are the possible sources of data. Natural forest fires (not anthropogenic in origin) are also not considered.

- Agricultural growing: Burning of agricultural biomass produces CO_2 emissions. However, the burned biomass is replaced by regrowth over the following year. The net CO_2 uptake and emissions are considered equal to zero.

The inventory of the annual increment of biomass started in the 1980s and finished in 1999. The entire forest area in Türkiye is covered. This inventory is not periodical, and the main aim is not the determine the increment of forest area. For that reason, there are some uncertainties and errors associated with this information. However, this inventory is the only data source to estimate the CO_2 uptake of forests.

The data categorized for each type of forest biomass are gathered from MOE at the province level. Then, the inventory is linked by a provincial forest map. This map is intersected with the district map in order to obtain the inventory at the district level. (Figure 12 and Table 5).

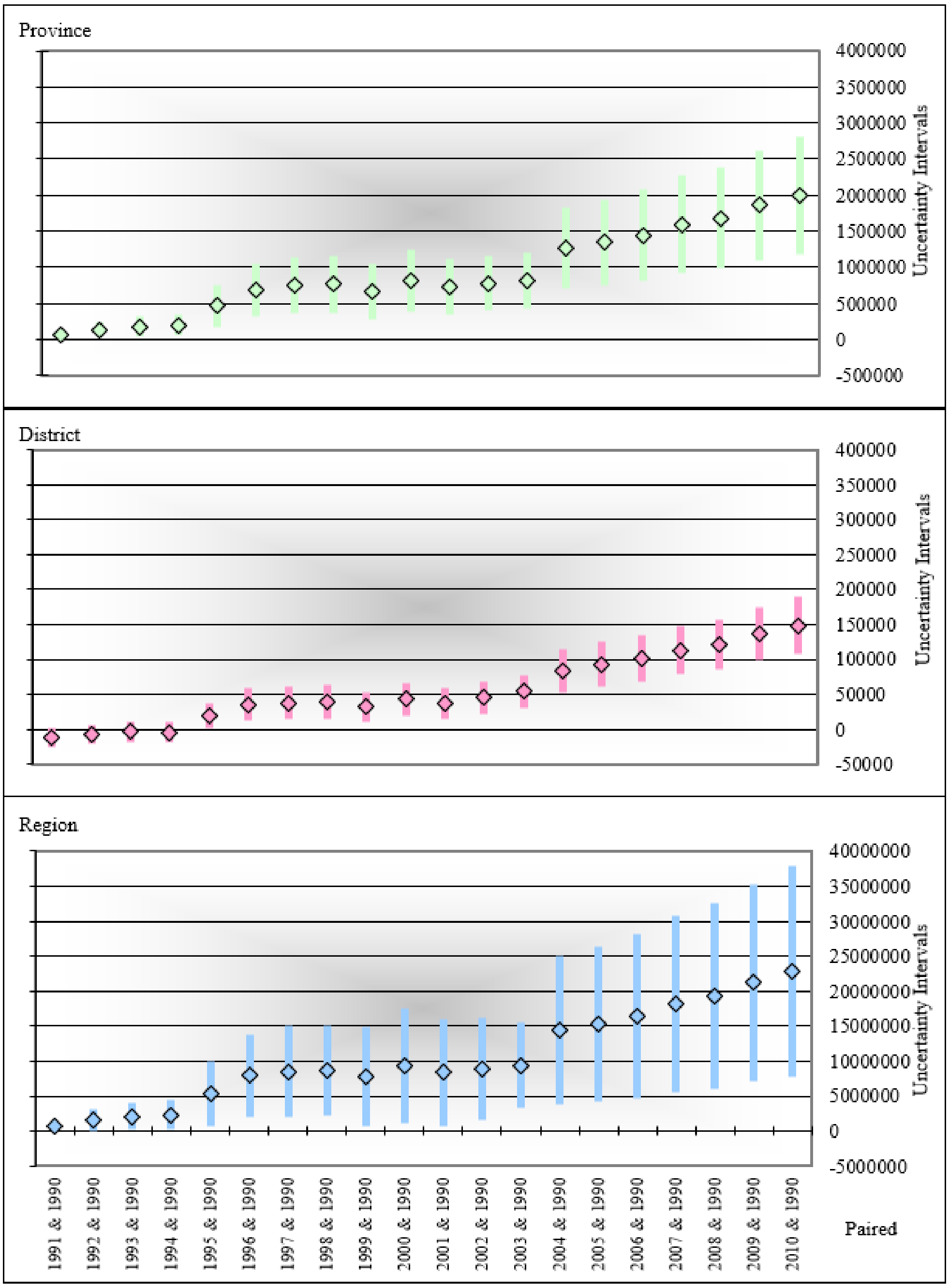


Figure 11. The uncertainty interval of the districts, provinces, and regions (İlçe, il ve bölgelerin belirsizlik aralıkları)

Table 5. Distribution of the forest area within regions and regional CO_2 uptake (Orman alanlarının bölgeler içindeki dağılımı ve bölgesel CO_2 alımı)

REGIONS	Empty Land	Poor Forest	Intermediate Forest	Good Forest	Lake	Total (unit: km^2)	CO_2 Uptake (tons)
Mediterranean	32615	38889	8060	8952	1302	89818	6066457
Eastern Anatolia	119927	20167	1965	2393	1878	146330	1900288
Aegean	34863	44538	4808	4809	862	89881	5749523
South-Eastern	49815	25106	271	0	1316	76509	1093184
Central Anatolia	155657	23086	1754	3925	3630	188052	2635381
Black sea	59616	32574	7640	15931	479	116240	16351045
Marmara	36987	20312	8970	5846	913	73027	12014619
Total	**489480**	**204672**	**33468**	**41856**	**10381**	**779857**	**45810497**

Figure 12 (digitized map) and Table 5 show that, the coastline of Türkiye is covered with forest. The forest area is not broad enough in South-Eastern Anatolia, Eastern Anatolia and Central Anatolia regions. The total forest area in Türkiye is around 280000 km^2.

The forests are classified into three different kinds: Bad Forest area, standard coppice area, and high forest area. The bad forest and standard coppice areas spread in the Mediterranean, Aegean, and Marmara regions. High forest areas are present densely in the Mediterranean and Blacksea regions.

The uptake of CO_2 in coastal zones exceeds that of inland zones as seen in Figure 12. The CO_2 uptake in the South-Eastern Anatolia, Eastern Anatolia, and Central Anatolia regions are 1.1, 1.9, and 2.6 million tons/year, respectively. The maximum CO_2 uptake is in the Black Sea region with a value of 16.4 million tons/year. The Marmara region has the second biggest CO_2 uptake value which is 12.0 million tons/year. It is also observed that CO_2 uptake in the Aegean and Mediterranean regions is 5.7 and 6.1 million tons/year, respectively.

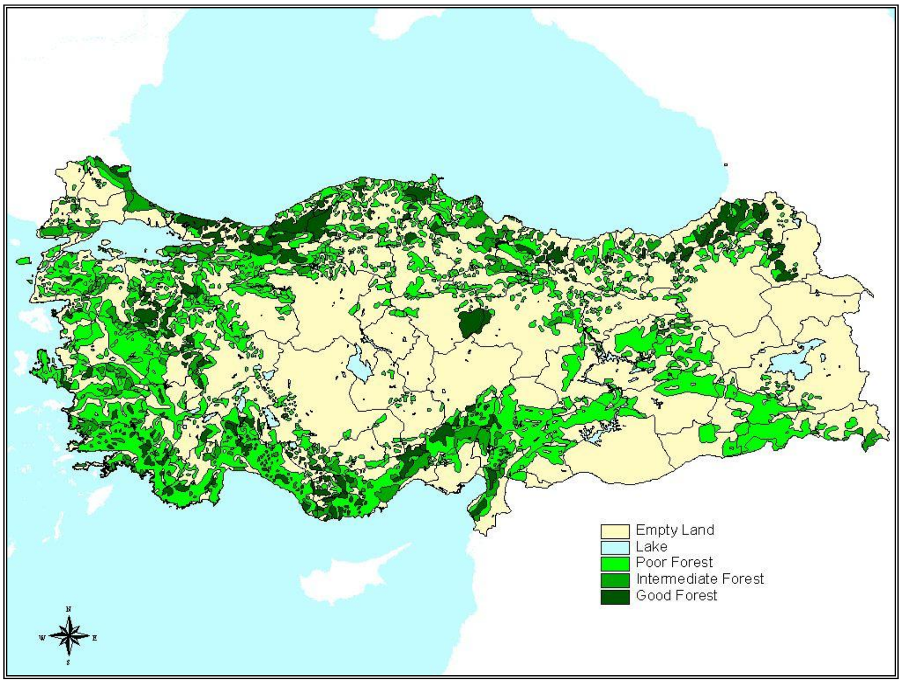


Figure 12. The land cover of Türkiye (Türkiye'nin arazi örtüsü)

The maximum CO_2 uptake values observed in the Demirköy district of Kırklareli province, Dursunbey of Balıkesir, Can of Çanakkale are 1.16, 0.96, and 0.90 million tons/year (Figure 13).

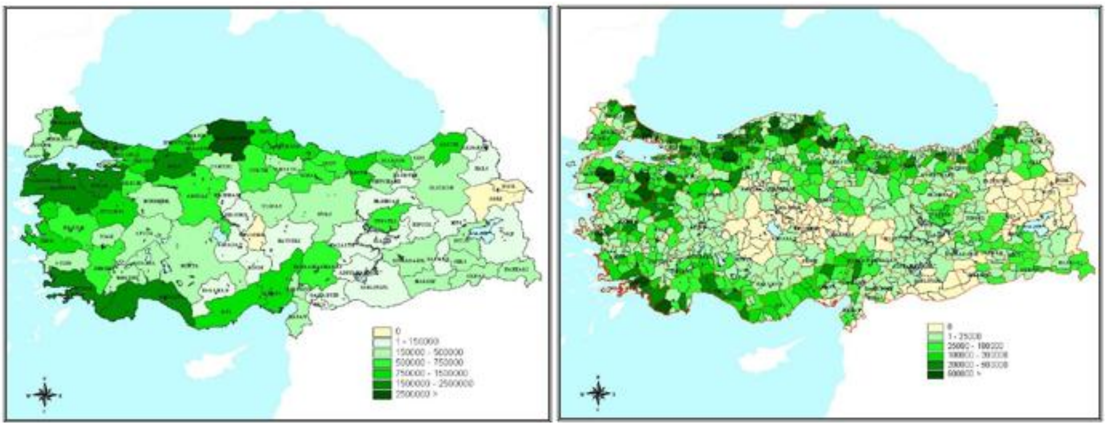


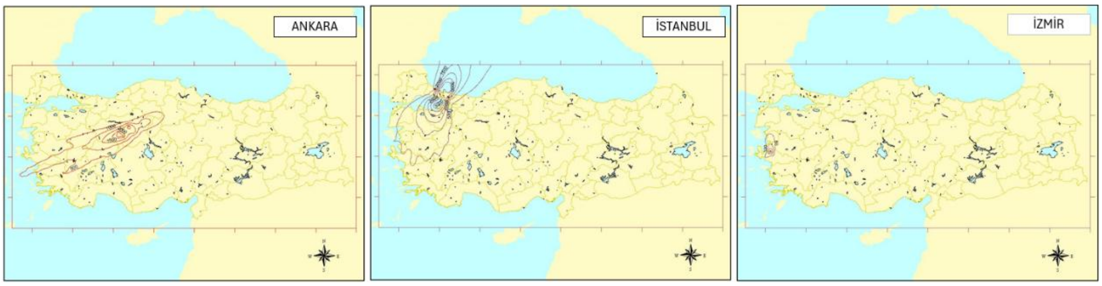
Figure 13. The CO_2 uptake of the provinces and the districts (İl ve ilçelerin CO_2 alımı)

3.3. Dispersion Model (Dağılım Modeli)

The ground-level estimation of CO_2 concentration has been based on CO_2 emission and uptake inventory. A reliable model estimation can only be expected with good meteorological data [47]. The wind speed and the wind direction are important for transferring and diluting the gases. However, other meteorological data, such as air temperature, cloudiness, and sunbathing are also important for the stability or instability of the atmosphere. Therefore, the model estimation can be considered as the artificial state of the atmospheric transportation of CO_2 [46].

For the years 1990 to 2003, the CO_2 ground level concentrations are obtained separately for each source at the district level. The total CO_2 concentrations at the receptor points from each source were obtained by superimposing. Additionally, the continuity of each model run was maintained by defining the receptors across the country. The model cannot be run for the years between 2005 and 2010. The main reason is the inadequacy of meteorological data for district basis model runs and emission source descriptions.

The model is only run for the projection year of 2004 by estimating and assuming many data. The model estimations due to projections of 2004 years' data for three big cities are given in Figure 14. The city maps are also obtained by using their district-level run for the entire Türkiye's receptor for each source separately by superimposing. Therefore, after the years 2004, the uncertainty levels and the model errors will be very high due to data assumptions. Therefore, the model results for the years between 1990 and 2003 are used for the ground-level concentrations.



Note: Detail maps are given in Appendix

Figure 14. The ISCLT3 output for the three big cities in the predicted year 2004 (Üç büyük şehir için tahmin edilen 2004 yılındaki ISCLT3 çıktısı)

The results of **dispersion modeling** calculations for CO_2 from different sources on an annual basis are given below. Total ground level CO_2 concentrations are given in Figure 15 for the year 1990. As shown in Figure, it may be concluded that some regions were affected highly by the ground-level concentrations. In 1990, the east of Mediterranean Region (around K.Maraş province), the west of Marmara Region (around Edirne province), the east of Central Anatolia Region (around Kırıkkale and Kırşehir provinces) and the west of Aegean Region (around İzmir Provinces) were determined as the maximum polluted areas with the respective values of 18.2, 26.0, 20.0 and 16.0 x 10^3 $\mu g/m^3$. In Marmara Region, the observed result seems markedly noticeable. Although the industrial zones, the thermal power plants, and the areas with high population and traffic density seem to be in the center and east of Marmara Region, high CO_2 pollution was observed in the west of the Marmara

Region. The primary reason for this outcome could be summarized as the high transporting capacity of the winds and mainly due to the winds blowing from the North-East (NE) direction.

In comparison to the results from the 1990s, the high concentration regions seemed to be changed in 1995. 8 x 10^3 μg/m^3 contour CO_2 concentration line passing over the Central and the Eastern Anatolia Regions was also due to the high-frequency winds blowing in the Eastern (E) and Western(W) directions. The maximum concentrations in these regions were obtained as 30.0 x 10^3 μg/m^3 in Cihanbeyli district of Konya province and 26.0 x 10^3 μg/m^3 in Tatvan district of Bitlis province, respectively. In 1998, Zonguldak province and Kastamonu province in the Blacksea Region and the intersection region of Ankara, Konya, and Eskişehir provinces in the Central Anatolia Region were also highly polluted areas with the respective maximum CO_2 concentrations that were 38.0 and 24.0 x 10^3 μg/m^3. The CO_2 pollution is also increasing gradually in 1999 and 2000. The Aegean, Central Anatolia, Blacksea, and Marmara Regions were also polluted with CO_2 in these years. For 1999, the maximum ground-level CO_2 concentrations in the Aegean, Central Anatolia, Blacksea, and Marmara Regions were 24.0, 24.0, 30.0, and 36.7 x 10^3 μg/m^3, respectively. The respective concentrations for 2000 were 26.0, 25.0, 38.0, and 26.0 x 10^3 μg/m^3 as seen in Figure 16. The results indicate that there was a significant decrease in CO_2 concentration in 2002. The Marmara (around Kırklareli province) and Eagean Region (around Manisa province) were the highest polluted areas.

Although the total CO_2 emission in 2002 and 2004 was as high as that in 2000 and 2001, the average ground level CO_2 concentration in these years was lower than in other years. This outcome can be attributed to the local winds as well as other meteorological conditions, like precipitation. In other words, the contribution of some nearby sources to the concentration of some receptor points in the district could be determined as zero or very small value owing to the transportation of the pollutant into the different areas by wind.

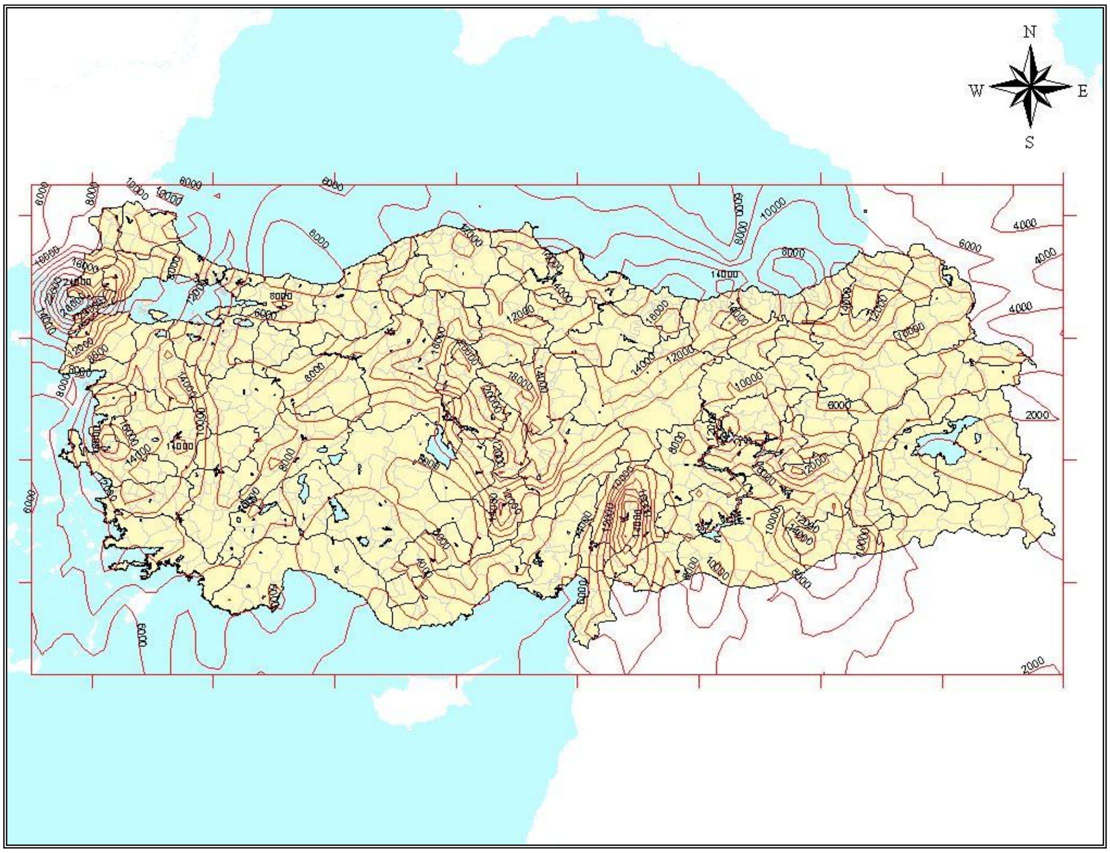


Figure 15. Total ground level CO_2 concentrations in 1990 (1990'da toplam yer seviyesi CO_2 konsantrasyonu)

According to the annual ground level concentrations of CO_2 estimated from the **industrial sources**, the CO_2 concentrations in Marmara Region, especially Istanbul province, were always the highest throughout the years. The values obtained were 14.30 in 1995; 8.02, 8.71, 7.4 in 1998; 7.0 in 2000; 14.0, 8.0 μg/m^3 in 2002. In fact, the industries in Istanbul Province have accounted for 35% of the total industries in the country. The total numbers of industries employing more than 10 and employing more than 500 people are shown in Figure 17. The data presented in these figures clearly illustrates that the total numbers of industries in both categories show an increasing trend. About 33.3% of the (10+) industries are located in İstanbul area. However, the number of (500+) industries located in İstanbul area is less, about 15-20%.

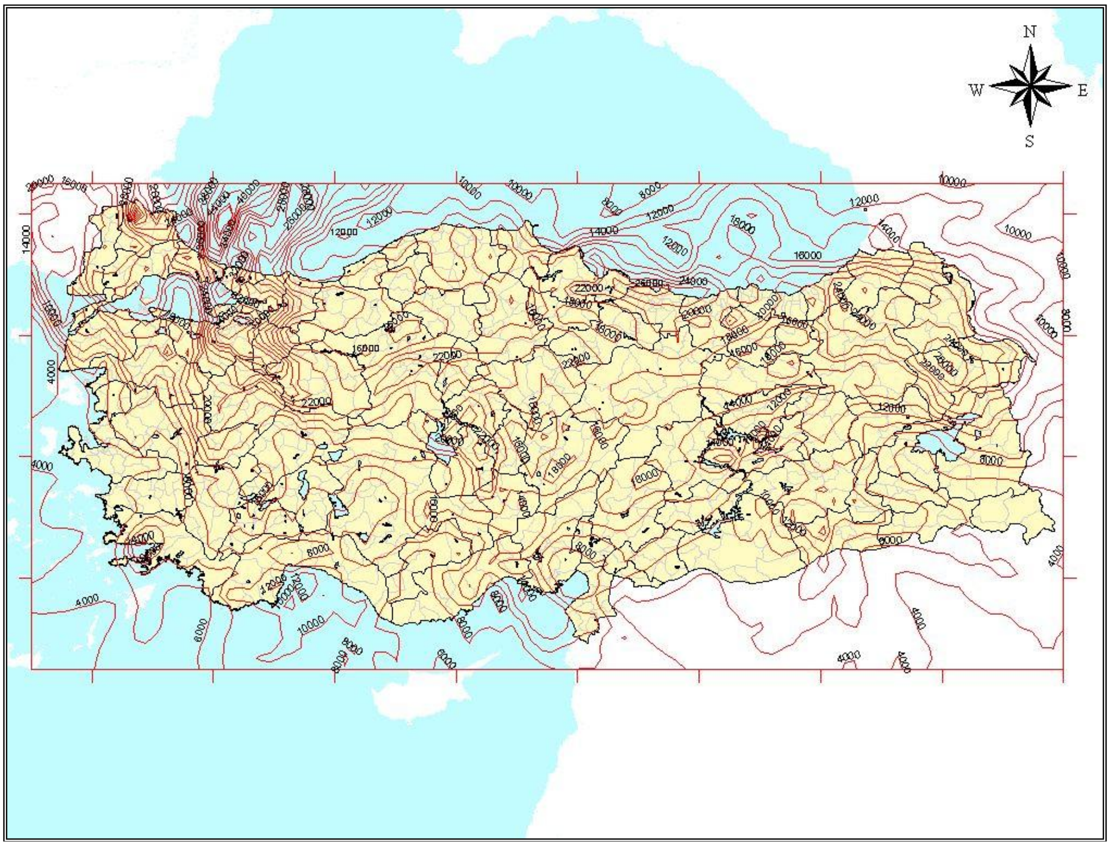


Figure 16. Total ground level CO_2 concentrations in 2000 (2000'de toplam yer seviyesi CO_2 konsantrasyonu)

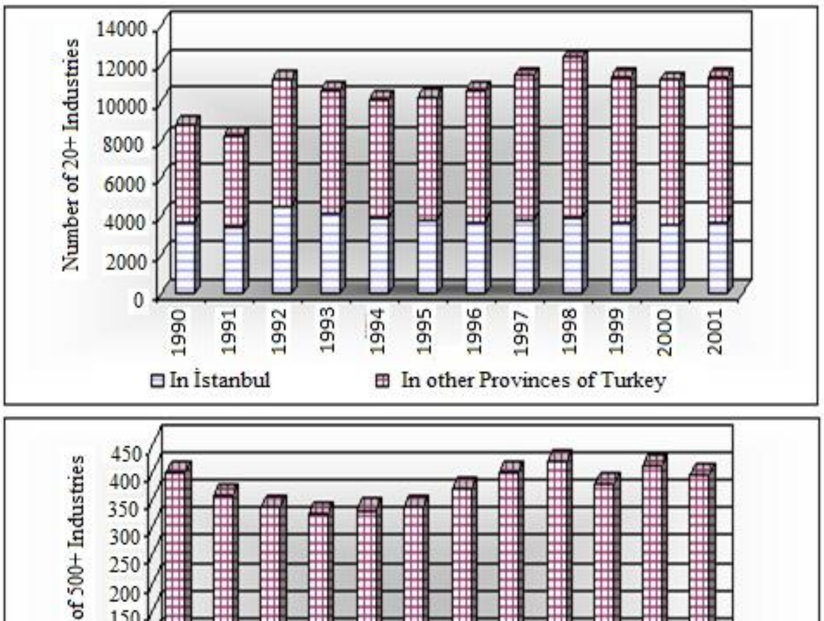


Figure 17. Number of the industries according to its size in Türkiye [30, 35] (Türkiye'de büyüklüklerine göre sanayi sayısı)

Between 1990-1993, the industries contributed approximately 28% of the total CO_2 emission. This percentage has increased to approximately 35% in 2003.

Between 1990 and 2003, the contribution of **Households** to the ground-level CO_2 concentration had risen approximately 7%. Compared with the overall results, the Marmara Region was also highly polluted with CO_2 from the households. The primary reason is the high population of the Marmara Region. In the 2000 census, the population of Türkiye was 67.8 million people and approximately 26% of this population was living in the Marmara Region [49].

There are serious local variations in the CO_2 concentrations when thermal power plants are considered. Between the years 1990 and 2003, the contribution of thermal power plants to the total CO_2 pollution was approximately 20%. Moreover, there was no thermal power plant in the South-Eastern Anatolia Region and Eastern Anatolia Region for the period of this study. Therefore, the concentration of CO_2 measured in these regions was the result of the transport of the pollutant from the other regions by winds.

Dispersion of ground-level CO_2 concentration was also studied for road vehicles. Although high ground-level CO_2 concentration was not observed due to road vehicles during the period between 1990 and 2003, some dispersion results gave high ground-level CO_2 concentrations. The highest polluted region was determined to be the Marmara Region throughout the years. Between the years 1990 and 2003, the contribution of road vehicles to the ground-level CO_2 concentration was approximately 15%. Although the percentage seems small, the registered number of vehicles has increased sharply since 1990. In conclusion, it can be stated that the trend shows an increase in CO_2 pollution from road vehicles.

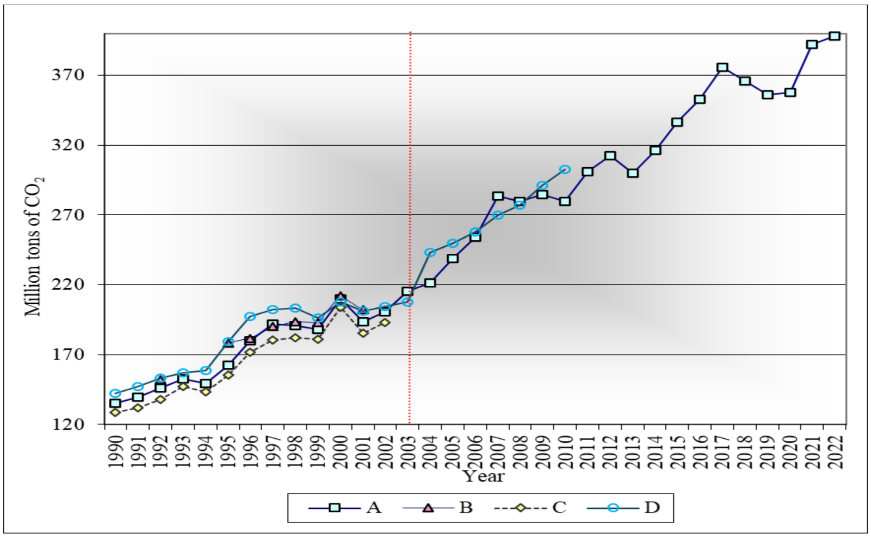
3.4. Evaluation of Model Results (Model Sonuçlarının Değerlendirilmesi)

The determination of the model performance is very important because several assumptions made during the prediction of the ground-level CO_2 concentrations may cause some significant errors. In order to decrease this error, the concentration data sets are compared statistically by observed values. The observed values are estimated by using CO_2 station measurements around Türkiye. There is no CO_2 concentration measurement station in Türkiye. The CO_2 concentration over Türkiye was obtained by using the Kriging Method [43]. The total number of CO_2 measurement stations around Türkiye is 12. Some station data were not included in the calculation of observed values due to missing data. The grid base average CO_2 concentrations over Türkiye have risen approximately 1.5 ppm/year. The highest CO_2 concentration interval which is the difference between the minimum and maximum concentration over Türkiye was observed in the years 1997 and 1999 with a value of 5 ppm.

The observed CO_2 concentration over Türkiye is estimated by using the measured CO_2 concentration of the nearest stations around Türkiye on grid bases. These values, however, are the upper atmospheric values. When the data are considered by using K-Cluster Analysis, the 1995, 1996, 1997, and 1998 data formed a homogeneous group. If the data set for 2002 is excluded, then the highest Cronbach Alfa Reliability values, which is 0.93, are obtained between the two data sets. The correlation coefficients between series also show that omitting the data from 2002 increased the relationship between series to 0.88, which shows a high relationship between the two series. Trend analyses of the series, using the Mann-Kendall Rank correlation test shows that the observed series have a statistically significant increasing trend, and the predicted series shows no trend with 2002 data. However, without 2002 data, both predicted and observed series show a statistically significant increasing trend according to the 0.05 significance level. Therefore, it can be concluded that the findings of the study are very reliable and acceptable.

3.5. The comparison of the study (Çalışmanın karşılaştırılması)

The inventory of this study has been also considered with many sources, and it is concluded that even the predicted emissions for this study are very close to the National Inventory Report as given in Figure 18.



A: SIS - TurkStat ; B: MOE; C: IEA; D: Study Result

Figure 18. The comparisons of study with other inventories (Çalışmanın diğer envanterlerle karşılaştırılması)

4. CONCLUSIONS (SONUÇLAR)

The CO_2 emission inventory and the dispersion modeling calculations in this detail (regional, provincial, and district level) have not been done previously in Türkiye. This type of study is very important, especially for regional and provincial development programs of the government. Therefore, this study could be used by policymakers, provincial authorities, air dispersion modelers, national inventory reporters, and some scientists. The results of the CO_2 emission inventory conducted in this study between 1990 and 2003 showed that the CO_2 emission in 1990 was 142.45 million tons/year and the highest recorded emissions occurred in 2000, reaching a value of 207.97 million tons/year for the period of this study. The Marmara Region consistently has the highest CO_2 emissions, averaging 54.76 million tons per year. It was also concluded that Marmara and Aegean Regions are responsible for half of the CO_2 emission of Türkiye. The predicted CO_2 emissions for the years 2004 and 2010 are also showing an increasing trend.

The highest ground-level CO_2 concentrations have been obtained in the Marmara Region for years under study. The maximum annual average ground level CO_2 concentration in this region was observed in 2001 with a 22.3 x 10^3 µg/m^3. The results obtained must be correlated with measured values. However, there isn't any CO_2 measurement station in Türkiye. The measured CO_2 concentration data of the nearest stations around Türkiye (Hungary (2), Italy (3), Romania (2), Kazakhstan (2), Malta (1), Kırgızstan (1) and Israel (1)) were used to estimate the synoptic CO_2 concentration over Türkiye. Without 2002 data, both predicted and observed series were statistically correlated and it was found that there was an internal consistency between them.

DISCLOSURE (AÇIKLAMA): This article is produced by using the thesis "Can A. 2006. Investigation of Turkey's carbon dioxide (CO_2) problem by numerical modeling". Web address: http://etd.lib.metu.edu.tr/upload/3/12607088/index.pdf".

Bu makale "Can A. 2006. Türkiye'nin karbondioksit (CO_2) probleminin sayısal modelleme ile araştırılması" adlı tezden yararlanılarak üretilmiştir. Web adresi: http://etd.lib.metu.edu.tr/upload/3/12607088/index.pdf".

DECLARATION OF ETHICAL STANDARDS
(ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

Ali CAN: He conducted collecting data, digitized maps, analyzed data and performed the writing process.

Veri toplama, haritaların sayısallaştırılması, verilerin analizi ve yazım aşamalarını gerçekleştirdi.

Aysel T. ATIMTAY: She edited the article, advised and commented on the inventory.

Makeleyi düzenleme, danışmanlık yapma ve envanteri yorumlama aşamalarını gerçekleştirdi.

Turgut TOKDEMİR: He advised the article and commented on the used modelling.

Makleleyi danışmanlık yapma ve kullanılan modeli yorumlama aşamalarını gerçekleştirdi.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

REFERENCES (KAYNAKLAR)

[1] Hummel, J.R., Reck, R.A. Carbon dioxide and climate: the effects of water transport in radiative-convective models. J. Geophys. Res. 86. 1981; 12035–12038.

[2] Herzog, H., Carbon Dioxide Capture and Storage in the Economics and Politics of Climate Change. 2015.

[3] Alcamo, J. Stabilizing greenhouse gases: global and regional consequences. Clim. Chang. Res. Eval. policy Implic. Proc. Int. Clim. Chang. Conf. Maastricht, 1995; Two vols 135–149.

[4] IPCC. Revised 1996 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories. 1996; Volume 3, 1- 145.

[5] IPCC. 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories. 2006; Volume 2, 2.1-2.45

[6] Xu, Y., Cui, G. Influence of spectral characteristics of the Earth’s surface radiation on the greenhouse effect: Principles and mechanisms. Atmos. Environ. 2021; 244.

[7] Sakata, S., A. Aklilu and R. Pizarro. "Greenhouse gas emissions data: Concepts and data availability", OECD Statistics Working Papers, No. 2024/03, OECD Publishing, Paris.

[8] Soon, W., Baliunas, S.L., Robinson, A.B., Robinson, Z.W. Environmental effects of increased atmospheric carbon dioxide. Energy Environ. 1999; 10, 439–468.

[9] IPCC. Climate Change 2022 – Impacts, Adaptation and Vulnerability, Climate Change 2022 – Impacts, Adaptation and Vulnerability.

[10] Holmén, K. The Global Carbon Cycle. Int. Geophys. 1992; 50, 239–262.

[11] Mutiibwa, D., Strachan, S., Albright, T. Land Surface Temperature and Surface Air Temperature in Complex Terrain. IEEE Journal. 2015; 8, 4762–4774.

[12] Friedlingstein, P. Carbon cycle feedback and future climate change. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 2015.

[13] Balch, J.K., Nagy, R.C., Archibald, S., Bowman, D.M.J.S., Moritz, M.A., Roos, C.I., Scott, A.C., Williamson, G.J. Global combustion: The connection between fossil fuel and biomass burning emissions (1997–2010). Philos. Trans. R. Soc. B Biol. Sci. 2016; 371. https://doi.org/10.1098/rstb.2015.0177

[14] Borges, A. V., Delille, B., Frankignoulle, M. Budgeting sinks and sources of CO_2 in the coastal ocean: Diversity of ecosystem counts. Geophys. Res. Lett. 2005; 32, 1–4.

[15] Schimel, D.S., House, J.I., etc. all. Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. Nature 414. 2001; 169–172.

[16] Kasting, J.F. The Carbon Cycle, Climate, and the Long-Term Effects of Fossil Fuel Burning. web address: http://www.atmo.arizona.edu/students/courselinks/fall0/atmo551a/ pdf/CarbonCycle.html (date: 12.10.24).

[17] IEA. International Energy Agency - CO_2 Emissions from Fueş Combustion (1971-2003). 2005 Edition – OECD/IEA. II. 74 – II.386.

[18] Janerio, R. De. United Nations Conference on Environment & Development Rio de Janerio , Brazil , 3 to 14 June 1992. Reproduction 351. ISBN: 9211005094.

[19] MOEF. Information Concerning To The Multilateral Environment Agreements, Which Turkey Is A Party To. Ministry of Environment, Urbanization and Climate Change. 2024; web address: https://ab.csb.gov.tr/en/agreements-i-100215 (date: 18.07.24).

[20] France, P.B., Uk, N.P.G., Marengo, J.A., Brazil, O. Understanding and Attributing Climate Change. Change. 2007.

[21] Sinha, U.K. Climate change: Process and politics. Strateg. Anal. 2010; 34, 858–871. https://doi.org/10.1080/09700161.2010.512482

[22] İncecik S., Yardım P., Topçu S. Kyoto Protocol and Critical Review of Greenhouse Gas Emissions in Turkey. Proceedings of Second International Symposium on Air Quality Management at Urban, Regional and Global Scales. (25-28 September 2001, İstanbul – Turkey). 2001; 538 - 543.

[23] National Climate Policies and the Kyoto Protocol, National Climate Policies and the Kyoto Protocol. OECD. 1999; https://doi.org/10.1787/9789264174450-en

[24] F., Alkan-olsson, J. Turkey's Signature of the Kyoto Protocol. İstanbul Üniversitesi Siyasal Bilgiler Fakültesi Derg. 2013; İ.Ü.S., Dergisi.

[25] DOCC, Kyoto Protocol. Ministry of Environment, Urbanization and Climate Change – Directorate of Climate Change. 2024; Web address: https://iklim.gov.tr/en/kyoto-protocol-i-118 (date: 22.08.24).

[26] U.S. EPA. User Guide for the Industrial Source Complex (Isc3) Dispersion Models. Volume I-User Instructions; Volume II-Description of Model Algorithms. 1995; Vol I.p.1.1 –H.1; Vol II.p.1.1-3.1.

[27] Leake, C., Malczewski, J. GIS and Multicriteria Decision Analysis. J. Oper. Res. 2000; Soc. 51, 247. https://doi.org/10.2307 /254268.

[28] Black, F.A., MacDonald, B.H., Black, J.M.W. Geographic Information Systems: A New Research Method for Book History. B. Hist. 1998; 1, 11–31. https://doi.org/10.1353 /bh.1998.0001

[28] Kirby, R.S., Delmelle, E., Eberth, J.M. Advances in spatial epidemiology and geographic information systems. Ann. Epidemiol. 2017 27, 1–9. https://doi.org /10.1016/j.annepidem.2016.12.001

[29] SIS. The number of manufacturing industries according to the size of establishments between 1990 and 2003 in each district. Industrial Statistics Division in State Institute of Statistics database, Republic of Turkey, Prime Ministry. 2004.

[30] SIS. Energy Consumption in the Manufacturing Industry (1992) - (SIS-State Institute of Statistics), Republic of Turkey, Prime Ministry. 1992; (book). p.13.

[31] SIS. Energy Consumption in the Manufacturing Industry - (SIS-State Institute of Statistics), Republic of Turkey, Prime Ministry. 1995; (book). p.11.

[32] SIS. Energy Consumption in the Manufacturing Industry - (SIS-State Institute of Statistics), Republic of Turkey, Prime Ministry, 1996; (book). p.19.

[33] SIS. Energy Consumption in the Manufacturing Industry - (SIS-State Institute of Statistics), Republic of Turkey, Prime Ministry, 1997; (book). p.23.

[34] SIS. Energy Consumption in the Manufacturing Industry - (SIS-State Institute of Statistics), Republic of Turkey, Prime Ministry, 1998; (book). p.23.

[35] SIS. Energy Consumption in the Manufacturing Industry (1999-2001) - (SIS-State Institute of Statistics), Republic of Turkey, Prime Ministry, 2001; (book). p.28.

[36] SIS. The Fuel Consumption in the Manufacturing Industries of each Province. Mining and Energy Statistics Division in State Institute of Statistics' database, Prime Ministry Republic of Turkey. 2001.

[37] MOE. The annual Energy and Petroleum Balance Tables - 1990-2010, Ministry of Energy. 2003; Web address: https://enerji .gov.tr/eigm-raporlari (date: 05.06.2001)

[38] Snyder, J.P. Labelling projections on published maps. Am. Cartogr. 1987; 14, 21–27.

[39] IPCC. Conceptual Basis for Uncertainty Analysis. IPCC Good Pract. Guid. Uncertain. Manag. Natl. Greenh. Gas Invent. 2000; 2.8 – 2.94.

[40] Robinson, J.M. On uncertainty in the computation of global emissions from biomass burning. Clim. Change. 1989; 14, 243–261. https://doi.org/10.1007/BF00134965

[41] de Nevers D. N. Air Pollution Control Engineering, USA, McGraw Hill,Inc. 1995; 105-125.

[42] EPA. Air Quality Models. U.S. Environmental Protection Agency. 2024; Web address: https://www.epa.gov/scram/air-quality-models. (date: 10.10.24).

[43] Delfiner P., Delhomme J.P. Optimum Interpolation by Kriging. In: Davis, J.C., McCullagh, M.J.(Eds.), Display and Analysis of Spatial Data.Wiley, London. 1975; 94 - 114.

[44] Dlugokency E.J., Steele L.P., LangP.M., Mesarie K.A.M. The Growth Rate and Distribution of Atmospheric CH4. J.Geophys.Res., 1994; 99, 17021-17043.

[45] Draper, N.R., Smith, H. Applied regression analysis, Applied Regression Analysis. https://doi.org/10.1002/9781118625590. 2014; 1-35.

[46] Wu, J. Advances in K-means Clustering. Adv. K-means Clust. A Data Min. Think.2012; 1 - 175.

[47] Douglas, G.B., Thomas, A.W. Cronbach's alpha reliability: Interval estimation, hypothesis testing, and sample size planning. J. Organ. Behav. 2014; 36, 1–15.

[48] Time Series Analysis - Data, Methods, and Applications. Time Series Analysis - Data, Methods, and Applications. https://doi.org /10.5772/intechopen.78491. 2019.

[49] SIS. Census of Population, Social and Economic Characteristics of Population – (SIS - State Institute of Statistics), Republic of Turkey, Prime Ministry, 2000 (book), 113-133.

[50] Sunay, N., Turgut, E.T. Eklemeli İmalat Teknolojilerinin Havacılık Sektöründe Enerji Verimliliğini Artırma ve Emisyon Azaltma Potansiyeli. GÜ Fen Bil. Der. Part C. Tas. Tek., 2024; 12.2, p. 548-566. https://doi.org /10.29109/gujsc.1437824

[51] Yıldız, C. Binalarda Enerji Verimliliğinde Son Gelişmeler: Türkiye Örneği. GÜ Fen Bil. Der. Part C. Tas. Tek., 12.1, 2024; 176-213. https://doi.org/10.29109/gujsc. 1293759.

APPENDIX: