Sustainability Goals in Türkiye: Energy, Emissions, and the Future

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1. Project Overview and Scope

Energy production and consumption are among the primary drivers of climate change, as they are major sources of carbon emissions. The continuous rise in energy demand, fueled by economic growth and industrialization, directly accelerates carbon emissions. In this study, we aim to investigate the relationship between energy consumption and carbon emissions originating from the energy sector in Turkey over the years.

First, correlation and regression analyses will be conducted to reveal the linear relationship between energy consumption and carbon emissions. Then, time series analysis will be applied to evaluate the trends of emissions and energy consumption over the years, the sectoral distribution of carbon emissions from the energy sector will also be examined, with a particular focus on emissions from electricity generation due to its dominant share.
Additionally, the relationships between key indicators—such as energy intensity (primary energy consumption/GDP), per capita energy consumption, and per capita carbon emissions—will be analyzed to assess the potential for decoupling carbon emissions from economic growth.

2. Data

2.1 Data Source

- Sera Gazı Emisyon İstatistikleri
- Gayri Safi Yurtiçi Hasıla ve Kişi Başına Gayri Safi Yurtiçi Hasıla
- IEA Türkiye Enerji İstatistikleri
- IEA Enerji Kaynaklı Emisyonlar
- IEA Elektrik Üretim ve Tüketim Verileri
- IEA Türkiye Yenilenebilir Enerji Kaynakları Verisi

2.2 General Information About Data

The data obtained from TÜİK provide information on the sectoral distribution of carbon emissions in Türkiye over the years, as well as GDP figures necessary for calculating energy intensity. Additionally, the data gathered from the IEA include Türkiye's total primary energy supply, annual energy amounts by source, energy-related carbon emissions, the carbon intensity of the energy mix, per capita carbon emissions, electricity generation and consumption figures, and the share of renewable energy sources in electricity generation.

2.3 Reason of Choice

This study has been selected with the aim of contributing to sustainable development goals in line with energy and climate policies.
In order to shed light on the extent to which carbon-free growth is achievable and how Turkey's trends over the years align with these goals, this topic has been chosen from the perspectives of energy, environment, and society, particularly given that energy-related emissions constitute a major portion of global warming.
Raising awareness on this issue is also one of the primary motivations behind the study.

2.4 Preprocessing

Emissions.RData

```r
library(readr)
library(readxl)
library(dplyr)
library(ggplot2)
library(reshape2)
library(tidyverse)
library(ggthemes)
library(knitr)
Co2_emissions_by_sector <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-NimetS
kable(head(Co2_emissions_by_sector))
```

CO2 emissions by sector	Value	Year
Electricity and heat producers	68.358	2000
Electricity and heat producers	69.831	2001
Electricity and heat producers	64.531	2002
Electricity and heat producers	65.531	2003
Electricity and heat producers	66.620	2004
Electricity and heat producers	74.515	2005

```r
str(Co2_emissions_by_sector)
```

```
tibble [207 x 3] (S3: tbl_df/tbl/data.frame)
 $ CO2 emissions by sector: chr [1:207] "Electricity and heat producers" "Electricity and hea
 $ Value                  : num [1:207] 68.4 69.8 64.5 65.5 66.6 ...
 $ Year                   : num [1:207] 2000 2001 2002 2003 2004 ...
```

```r
Co2_emissions_fuel_combustion <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-N

str(Co2_emissions_fuel_combustion)
```

```
tibble [23 x 2] (S3: tbl_df/tbl/data.frame)
 $ Year                              : num [1:23] 2000 2001 2002 2003 2004 ...
 $ CO2 emissions from fuel combustion: num [1:23] 201 183 193 203 207 ...
```

```r
Co2_emissions_per_cap <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-NimetSev

str(Co2_emissions_per_cap)
```

```
tibble [23 x 2] (S3: tbl_df/tbl/data.frame)
 $ Year                   : num [1:23] 2000 2001 2002 2003 2004 ...
 $ CO2 emissions per capita: num [1:23] 3.13 2.8 2.92 3.04 3.07 ...
```

```r
electricity_cons_per_cap <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-Nimet

str(electricity_cons_per_cap)
```

```
tibble [24 x 2] (S3: tbl_df/tbl/data.frame)
 $ Year                                   : num [1:24] 2000 2001 2002 2003 2004 ...
 $ Electricity consumption per capita (MWh): num [1:24] 1.63 1.59 1.65 1.75 1.88 ...
```

```r
electricity_final_consumption <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-


str(electricity_final_consumption)
```

```
tibble [134 x 3] (S3: tbl_df/tbl/data.frame)
 $ Electricity final consumption (TJ): chr [1:134] "Industry" "Industry" "Industry" "Industry
 $ Value                             : num [1:134] 165920 161992 175953 193309 208951 ...
 $ Year                              : num [1:134] 2000 2001 2002 2003 2004 ...
 - attr(*, "na.action")= 'omit' Named int [1:4] 116 117 118 119
  ..- attr(*, "names")= chr [1:4] "116" "117" "118" "119"
```

```r
sum(is.na(electricity_final_consumption))
```

```
[1] 0
```

```r
electricity_generation_sources <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-

str(electricity_generation_sources)
```

```
tibble [226 x 3] (S3: tbl_df/tbl/data.frame)
 $ Electricity generation sources (GWh): chr [1:226] "Coal" "Coal" "Coal" "Coal" ...
 $ Value                               : num [1:226] 38187 38416 32149 32252 34448 ...
 $ Year                                : num [1:226] 2000 2001 2002 2003 2004 ...
 - attr(*, "na.action")= 'omit' Named int [1:14] 169 170 171 172 173 174 175 176 177 178 ...
  ..- attr(*, "names")= chr [1:14] "169" "170" "171" "172" ...
```

```r
renewables <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-NimetSevinc/project_

str(renewables)
```

```
tibble [23 x 2] (S3: tbl_df/tbl/data.frame)
 $ Year                                          : num [1:23] 2000 2001 2002 2003 2004 ...
 $ Renewables share of electricity generation (%): num [1:23] 24.9 19.8 26.2 25.3 30.7 24.5 2
```

```r
modern_renewables <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-NimetSevinc/p


str(modern_renewables)
```

```
tibble [22 x 2] (S3: tbl_df/tbl/data.frame)
 $ Year                 : num [1:22] 2000 2001 2002 2003 2004 ...
 $ Modern renewables(%): num [1:22] 17.3 18.1 17.5 16.3 16.8 ...
```

```r
electricity_production <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-NimetSev

str(electricity_production)
```

```
tibble [24 x 2] (S3: tbl_df/tbl/data.frame)
 $ Year                              : num [1:24] 2000 2001 2002 2003 2004 ...
 $ Total electricity production (GWh): num [1:24] 124922 122725 129400 140581 150698 ...
```

```r
total_energy_supply <- read_csv("C:/Users/DELL/Documents/GitHub/emu660-spring2025-NimetSevinc
  rename("Total energy supply (TJ)" = "total energy supply in Türkiye") |> select(-4)


str(total_energy_supply)
```

```
tibble [144 x 3] (S3: tbl_df/tbl/data.frame)
 $ Total energy supply (TJ): chr [1:144] "Coal" "Coal" "Coal" "Coal" ...
 $ Value                   : num [1:144] 956056 789821 820271 923904 930636 ...
 $ Year                    : num [1:144] 2000 2001 2002 2003 2004 ...
```

```r
gdp_per_capita <- read_excel("C:/Users/DELL/Documents/GitHub/emu660-spring2025-NimetSevinc/pr

gdp_per_capita <- gdp_per_capita |> select(c(-3,-4))

str(gdp_per_capita)
```

```
tibble [27 x 4] (S3: tbl_df/tbl/data.frame)
 $ Year               : chr [1:27] "1998" "1999" "2000" "2001" ...
 $ mid_year_population: num [1:27] 62464 63364 64269 65166 66003 ...
 $ value_usd          : num [1:27] 4445 4010 4249 3108 3608 ...
 $ change_rate_usd    : chr [1:27] "-" "-9.7809580133305047" "5.9503199199296262" "-26.86682
```

```
emissions_by_sector <- read_excel("C:/Users/DELL/Documents/GitHub/emu660-spring2025-NimetSev


str(emissions_by_sector)
```

```
tibble [26 x 6] (S3: tbl_df/tbl/data.frame)
 $ Year                                 : num [1:26] 1998 1999 2000 2001 2002 ...
 $ Total                                : num [1:26] 289 286 307 288 293 ...
 $ Energy                               : num [1:26] 200 198 220 203 210 ...
 $ Industrial processes and product use: num [1:26] 27.8 26.2 26.6 26.3 27.3 ...
 $ Agriculture                          : num [1:26] 47.7 48.2 46 43.7 40.7 ...
 $ Waste                                : num [1:26] 13.5 14 14.5 15.1 15.5 ...
```

```
emissions <- read_excel("C:/Users/DELL/Documents/GitHub/emu660-spring2025-NimetSevinc/projec

str(emissions)
```

```
tibble [26 x 6] (S3: tbl_df/tbl/data.frame)
 $ Year       : num [1:26] 1998 1999 2000 2001 2002 ...
 $ Total      : num [1:26] 289 286 307 288 293 ...
 $ CO2        : num [1:26] 216 211 233 217 224 ...
 $ CH4        : num [1:26] 50.2 51.8 51.5 50.6 47.9 ...
 $ N2O        : num [1:26] 22.5 22.8 22 20.1 20.1 ...
 $
F-gases: num [1:26] 0.382 0.382 0.487 0.594 0.768 ...
```

```
save(Co2_emissions_by_sector, Co2_emissions_fuel_combustion, Co2_emissions_per_cap, electric
```

```
gdp_per_capita$Year <- as.integer(gdp_per_capita$Year)
Co2_emissions_by_sector$Year <- as.integer(Co2_emissions_by_sector$Year)
Co2_emissions_fuel_combustion$Year <- as.integer(Co2_emissions_fuel_combustion$Year)
Co2_emissions_per_cap$Year <- as.integer(Co2_emissions_per_cap$Year)
electricity_cons_per_cap$Year <- as.integer(electricity_cons_per_cap$Year)
electricity_final_consumption$Year <- as.integer(electricity_final_consumption$Year)
```

```r
electricity_generation_sources$Year <- as.integer(electricity_generation_sources$Year)
electricity_production$Year <- as.integer(electricity_production$Year)
emissions <- emissions |> mutate(Year = as.integer(Year))
emissions_by_sector$Year <- as.integer(emissions_by_sector$Year)
modern_renewables$Year <- as.integer(modern_renewables$Year)
renewables$Year <- as.integer(renewables$Year)
total_energy_supply$Year <- as.integer(total_energy_supply$Year)
```

```r
master_data <- gdp_per_capita |>
  left_join(Co2_emissions_fuel_combustion, by="Year") |>
  left_join(Co2_emissions_per_cap, by="Year") |>
  left_join(electricity_cons_per_cap, by="Year") |>
  left_join(electricity_production, by="Year") |>
  left_join(emissions, by="Year") |>
  left_join(emissions_by_sector, by="Year") |>
  left_join(modern_renewables, by="Year") |>
  left_join(renewables, by="Year")

master_data <- master_data |> mutate(Year = ifelse(is.na(Year), 2024, Year))
str(master_data)
```

```
tibble [27 x 20] (S3: tbl_df/tbl/data.frame)
 $ Year                                     : num [1:27] 1998 1999 2000 2001 2002 ...
 $ mid_year_population                      : num [1:27] 62464 63364 64269 65166 66003
 $ value_usd                                : num [1:27] 4445 4010 4249 3108 3608 ...
 $ change_rate_usd                          : chr [1:27] "-" "-9.7809580133305047" "5.9
 $ CO2 emissions from fuel combustion       : num [1:27] NA NA 201 183 193 ...
 $ CO2 emissions per capita                 : num [1:27] NA NA 3.13 2.8 2.92 ...
 $ Electricity consumption per capita (MWh) : num [1:27] NA NA 1.63 1.59 1.65 ...
 $ Total electricity production (GWh)       : num [1:27] NA NA 124922 122725 129400 ...
 $ Total.x                                  : num [1:27] 289 286 307 288 293 ...
 $ CO2                                      : num [1:27] 216 211 233 217 224 ...
 $ CH4                                      : num [1:27] 50.2 51.8 51.5 50.6 47.9 ...
 $ N2O                                      : num [1:27] 22.5 22.8 22 20.1 20.1 ...
 $
F-gases                             : num [1:27] 0.382 0.382 0.487 0.594 0.768 ...
 $ Total.y                                  : num [1:27] 289 286 307 288 293 ...
 $ Energy                                   : num [1:27] 200 198 220 203 210 ...
 $ Industrial processes and product use     : num [1:27] 27.8 26.2 26.6 26.3 27.3 ...
 $ Agriculture                              : num [1:27] 47.7 48.2 46 43.7 40.7 ...
 $ Waste                                    : num [1:27] 13.5 14 14.5 15.1 15.5 ...
```

```
 $ Modern renewables(%)                          : num [1:27] NA NA 17.3 18.1 17.5 ...
 $ Renewables share of electricity generation (%): num [1:27] NA NA 24.9 19.8 26.2 25.3 30.7
```

```r
summary(master_data)
```

```
      Year      mid_year_population   value_usd     change_rate_usd
 Min.   :1998   Min.   :62464       Min.   : 3108   Length:27
 1st Qu.:2004   1st Qu.:68017       1st Qu.: 6698   Class :character
 Median :2011   Median :74224       Median : 9735   Mode  :character
 Mean   :2011   Mean   :74358       Mean   : 9000
 3rd Qu.:2018   3rd Qu.:80860       3rd Qu.:11052
 Max.   :2024   Max.   :85519       Max.   :15463

 CO2 emissions from fuel combustion CO2 emissions per capita
 Min.   :182.7                      Min.   :2.803
 1st Qu.:228.1                      1st Qu.:3.311
 Median :285.2                      Median :3.794
 Mean   :287.5                      Mean   :3.816
 3rd Qu.:352.5                      3rd Qu.:4.333
 Max.   :400.8                      Max.   :4.763
 NA's   :4                          NA's   :4
 Electricity consumption per capita (MWh) Total electricity production (GWh)
 Min.   :1.589                            Min.   :122725
 1st Qu.:2.121                            1st Qu.:172713
 Median :2.708                            Median :234445
 Mean   :2.627                            Mean   :229244
 3rd Qu.:3.271                            3rd Qu.:298932
 Max.   :3.587                            Max.   :334723
 NA's   :3                                NA's   :3
    Total.x           CO2              CH4              N2O
 Min.   :286.2   Min.   :211.2   Min.   :47.90   Min.   :20.08
 1st Qu.:328.1   1st Qu.:252.8   1st Qu.:52.16   1st Qu.:22.65
 Median :421.2   Median :331.5   Median :60.30   Median :24.93
 Mean   :425.2   Mean   :334.1   Mean   :60.69   Mean   :26.83
 3rd Qu.:514.6   3rd Qu.:406.3   3rd Qu.:67.00   3rd Qu.:31.28
 Max.   :598.9   Max.   :486.9   Max.   :73.92   Max.   :36.11
 NA's   :1       NA's   :1       NA's   :1       NA's   :1
   \r\nF-gases        Total.y          Energy
 Min.   : 0.3815   Min.   :286.2   Min.   :197.8
 1st Qu.: 1.2755   1st Qu.:328.1   1st Qu.:234.2
 Median : 3.3702   Median :421.2   Median :303.9
 Mean   : 3.5416   Mean   :425.2   Mean   :303.8
```

```
 3rd Qu.: 4.8051   3rd Qu.:514.6   3rd Qu.:367.5  
 Max.   :10.4001   Max.   :598.9   Max.   :442.2  
 NA's   :1         NA's   :1       NA's   :1      
 Industrial processes and product use  Agriculture        Waste      
 Min.   :26.20                        Min.   :40.71   Min.   :13.51  
 1st Qu.:32.09                        1st Qu.:46.09   1st Qu.:15.65  
 Median :52.19                        Median :49.22   Median :16.94  
 Mean   :49.33                        Mean   :55.47   Mean   :16.55  
 3rd Qu.:63.15                        3rd Qu.:65.17   3rd Qu.:17.59  
 Max.   :76.54                        Max.   :76.44   Max.   :18.43  
 NA's   :1                            NA's   :1       NA's   :1      
 Modern renewables(%) Renewables share of electricity generation (%)
 Min.   :11.40        Min.   :17.30                                 
 1st Qu.:12.57        1st Qu.:24.70                                 
 Median :13.53        Median :26.40                                 
 Mean   :14.03        Mean   :28.27                                 
 3rd Qu.:15.06        3rd Qu.:32.05                                 
 Max.   :18.12        Max.   :43.50                                 
 NA's   :5            NA's   :4                                     
```

3. Analysis

In the first stage of this section, exploratory data analysis was conducted to better understand the details of the data. The datasets prepared for the analysis were visualized to make them interpretable and suitable for drawing insights. After understanding the data details and their relationships, time series and regression analyses were applied to make predictions about CO2 emissions.

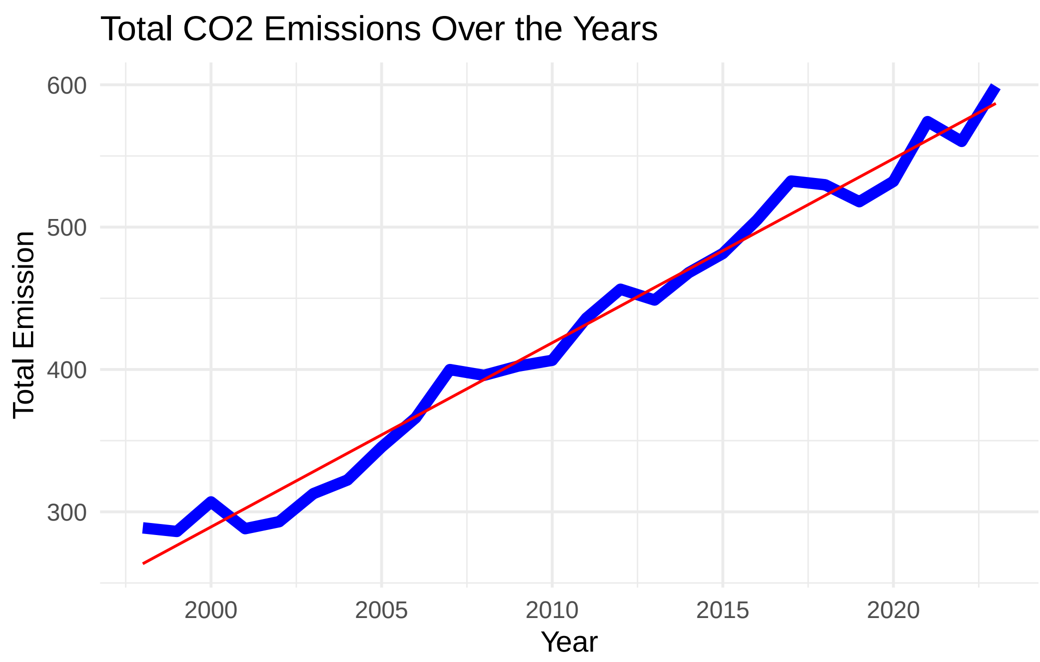
3.1 Exploratory Data Analysis

When examining the change in CO2 emissions over the years, an increasing trend is observed. Population growth also plays a role in this rise.

Emissions from the electricity sector have increased significantly, reaching the highest levels among all sectors. This is followed by the transportation and industry sectors, both with high emission values. Emissions related to the residential sector have increased at a slower pace. Emission values in other sectors remain relatively low.

The change in total carbon emissions over the years in Turkey has been analyzed along with the trend line.

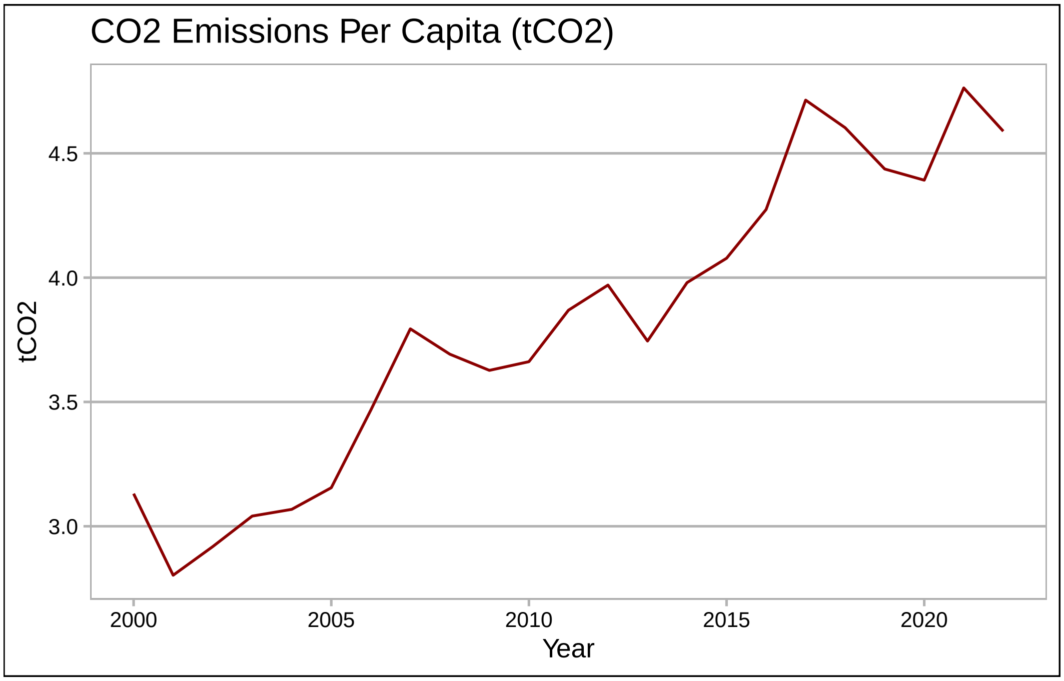
```
emissions_by_sector |> ggplot(aes(x=Year, y=Total)) + geom_line(color="blue", size=2) + theme
```



We observe that the industrial sector is the largest consumer of electricity. The residential and commercial sectors also have high levels of electricity consumption. In recent years, with the increasing use of electric vehicles, small increases have been observed in the transportation sector. In contrast, almost no increase has been seen in the agriculture and fisheries sectors. The low electricity consumption in these two sectors despite population growth may indicate a decline in their operational capacity.

```
library(ggplot2)
library(ggrepel)
library(ggthemes)
library(moderndive)

Co2_emissions_by_sector |>  ggplot(aes(x=Year, y=Value, color=`CO2 emissions by sector`)) + g
```


```r
master_data <- master_data |> filter(!is.na(`CO2 emissions per capita`))

ggplot(master_data,aes(x = Year, y = `CO2 emissions per capita`)) +
  geom_line(color = "darkred") +
  labs(title = "CO2 Emissions Per Capita (tCO2)", x = "Year", y = "tCO2") +
  theme_calc()
```



The annual distribution of energy sources used for electricity generation has changed as follows:

```
library(dplyr)
library(tidyr)
library(ggplot2)
library(ggstream)
library(streamgraph)
library(plotly)


colnames(total_energy_supply) <- c("Sector", "Value", "Year")

aa <- plot_ly(total_energy_supply, x = ~Sector, y=~Value, frame=~Year, color=~Sector)
aa
```

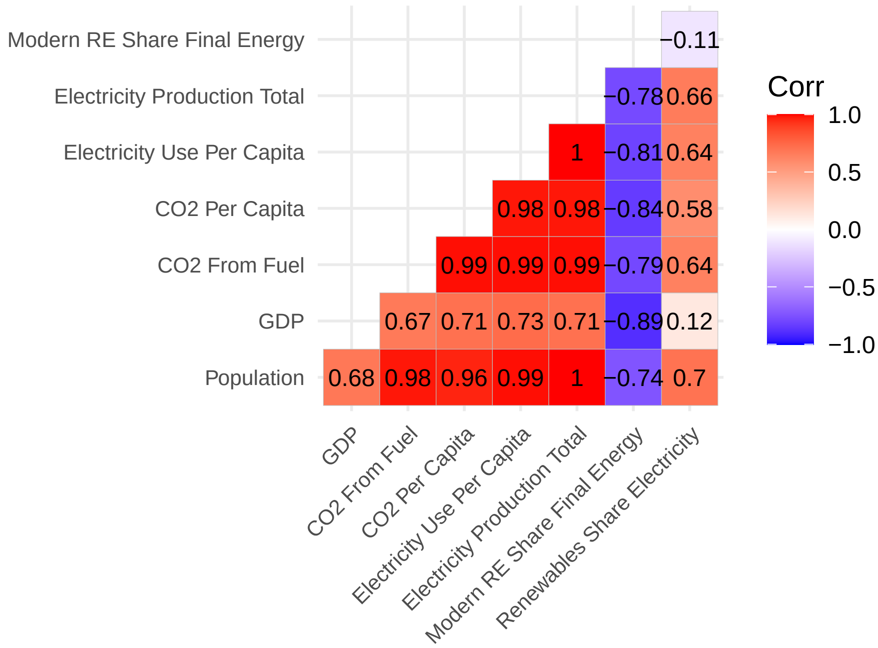
The percentage change in emissions by sector is as follows:

```
emissions_by_sector <-master_data |> group_by(Year) |> pivot_longer(cols = Energy:Waste,
                            names_to = "Emissions_sector",
                            values_to = "Value") |> mutate(Percentage = Value/sum(Value)*100)

plot_ly(emissions_by_sector,
```

```
        labels = ~Emissions_sector,
        values = ~Value,
        frame = ~Year,
        type = 'pie',
        textinfo = 'percent',
        insidetextorientation = 'radial')
```

Strong correlation results have shown that as the population increases, CO emissions from fuel sources also rise. Additionally, as per capita electricity consumption increases, per capita CO emissions also increase. A strong positive relationship has been observed between electricity generation and economic growth (GDP).
The share of renewable energy sources has not shown a directly negative relationship with other variables in the system at this stage. This may be due to its relatively low share in total energy usage.

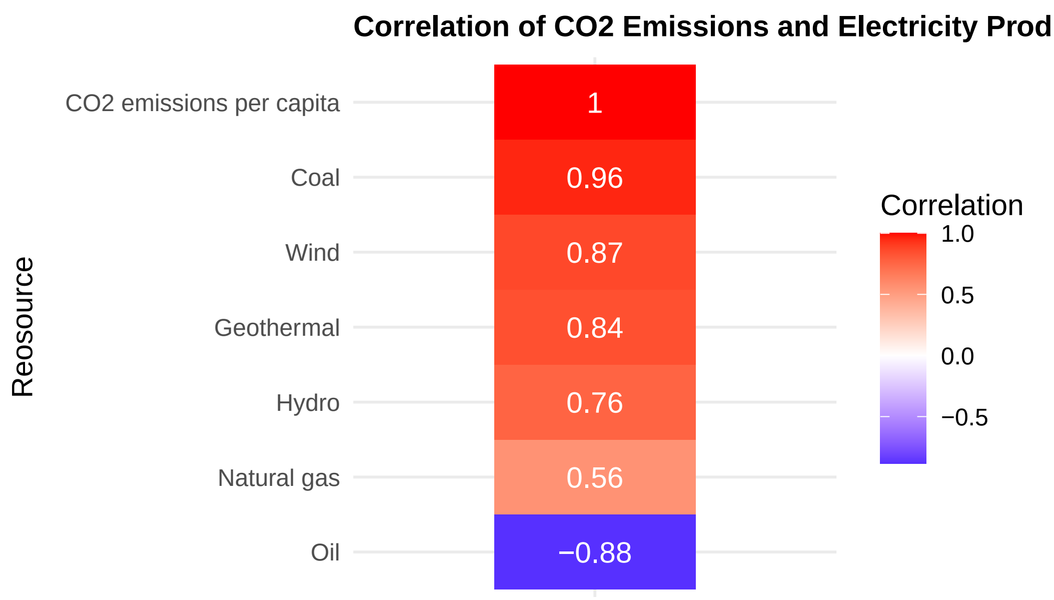
```
library(ggcorrplot)
veri <- master_data[,c("mid_year_population",
                      "value_usd",
                      "CO2 emissions from fuel combustion",
                      "CO2 emissions per capita",
                      "Electricity consumption per capita (MWh)",
                      "Total electricity production (GWh)",
                      "Modern renewables(%)",
                      "Renewables share of electricity generation (%)")]

core_1 <-cor(veri, use="complete.obs")



kisaltma <- c("Population","GDP","CO2 From Fuel","CO2 Per Capita","Electricity Use Per Capita

colnames(core_1) <- kisaltma
rownames(core_1) <- kisaltma

ggcorrplot(core_1,lab=T,lab_size=3,type="lower",tl.cex=8,tl.srt=45)
```



The heatmap below shows the correlations between per capita CO emissions and electricity generation sources. The graph indicates a very high correlation coefficient between coal and CO emissions, suggesting that coal use in electricity production is one of the main contributors to the increase in emissions. Renewable sources such as wind, geothermal, and hydro also show a positive correlation. However, this may not be due to their direct contribution to emissions, but rather because their increasing share in electricity production coincides with an overall rise in total generation and emissions. A negative correlation is observed for oil ($r = -0.88$). Since oil has a relatively small share in electricity production, its reduction has little effect on decreasing total emissions.

```
library(dplyr)
library(ggplot2)
library(tibble)

co2 <- Co2_emissions_per_cap
elec <- electricity_generation_sources

elec_wide <- elec |>
  pivot_wider(names_from = `Electricity generation sources (GWh)`,
              values_from = Value)

# Verileri yıl üzerinden birleştir
yil_ortakli_2 <- left_join(co2, elec_wide, by = "Year")
```

```r
core_2 <- yil_ortakli_2 %>%
  select(`CO2 emissions per capita`, Coal, `Natural gas`, Oil, Hydro, Wind, Geothermal) %>%
  mutate(across(everything(), as.numeric))

kore_matris <- cor(core_2, use = "complete.obs")

corr <- as.data.frame(kore_matris[, "CO2 emissions per capita"])
corr <- rownames_to_column(corr, var = "Source")
colnames(corr)[2] <- "Correlation"


corr <- corr %>% filter(Source != "CO2_per_capita") #kendiyle kıyası kaldırdık

ggplot(corr, aes(x = "CO2_per_capita", y = reorder(Source, Correlation), fill = Correlation)
  geom_tile(width = 0.5) +
  geom_text(aes(label = round(Correlation, 2)), color = "white", size = 4) +
  scale_fill_gradient2(low = "blue", high = "red", mid = "white", midpoint = 0) +
  labs(title = "Correlation of CO2 Emissions and Electricity Production Sources",
       x = "", y = "Reosource") +
  theme_minimal() +
  theme(axis.text.x = element_blank(),
        axis.ticks.x = element_blank(),
        axis.title.x = element_text(margin = margin(t = 10)),
        axis.title.y = element_text(margin = margin(r = 10)),
        plot.title = element_text(size = 11
                                  , face = "bold"))
```



3.2 Trend Analysis

As electricity consumption per capita increases, carbon emissions also rise in a strong and statistically significant manner. Specifically, for each 1 MWh increase in per capita electricity consumption, carbon emissions increase by approximately 0.92 units.

```
library(broom)
library(dplyr)
library(ggplot2)

regres_1 <- lm(`CO2 emissions per capita` ~ `Electricity consumption per capita (MWh)`, data=
summary(regres_1)
```

```
Call:
lm(formula = `CO2 emissions per capita` ~ `Electricity consumption per capita (MWh)`,
    data = master_data)

Residuals:
     Min       1Q   Median       3Q      Max
-0.21830 -0.08504 -0.01996  0.04434  0.27805
```

```
Coefficients:
                                           Estimate Std. Error t value Pr(>|t|)
(Intercept)                                 1.44127    0.10439   13.81 5.27e-12
`Electricity consumption per capita (MWh)`  0.91777    0.03919   23.42  < 2e-16

(Intercept)                                ***
`Electricity consumption per capita (MWh)` ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.119 on 21 degrees of freedom
Multiple R-squared:  0.9631,    Adjusted R-squared:  0.9614
F-statistic: 548.5 on 1 and 21 DF,  p-value: < 2.2e-16
```

```r
tidy(regres_1)
```

```
# A tibble: 2 x 5
  term                                     estimate std.error statistic  p.value
  <chr>                                       <dbl>     <dbl>     <dbl>    <dbl>
1 (Intercept)                                 1.44     0.104       13.8 5.27e-12
2 `Electricity consumption per capita (MW~    0.918    0.0392      23.4 1.56e-16
```

```r
regres_1 |> glance() |> pull(r.squared)
```

```
[1] 0.9631286
```

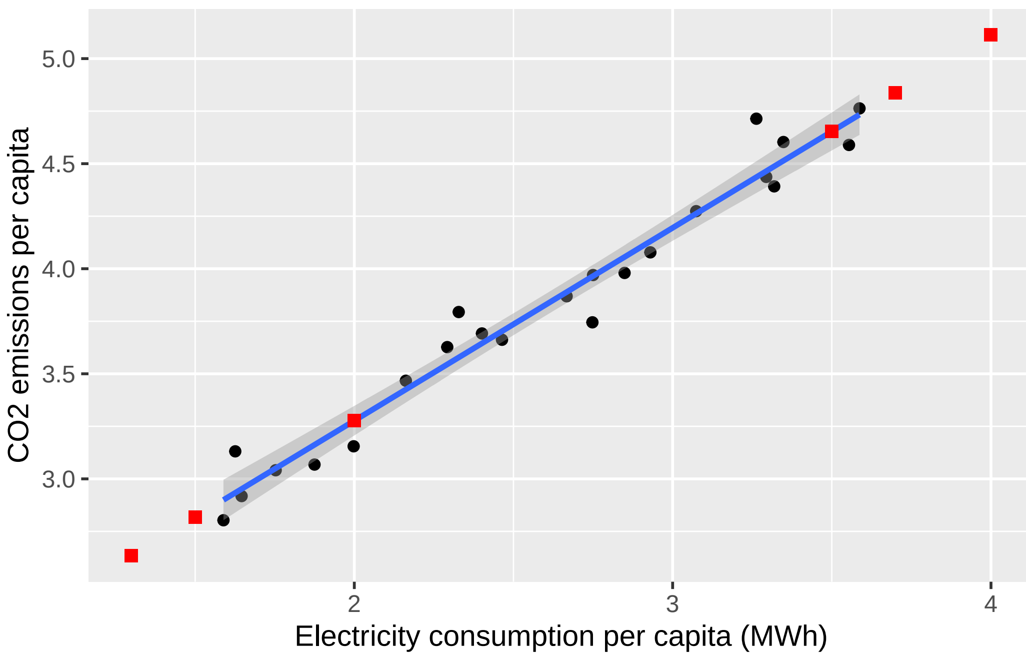
```r
regres_1 |> glance() |> pull(sigma)
```

```
[1] 0.1190368
```

```r
explanatory_data <- tibble(`Electricity consumption per capita (MWh)`= c(1.3, 1.5,2,3.5,3.7,4
predict(regres_1,explanatory_data)
```

```
       1        2        3        4        5        6 
2.634369 2.817923 3.276806 4.653457 4.837010 5.112340 
```

```r
prediction_data <- explanatory_data |> mutate(
  `CO2 emissions per capita` = predict(regres_1,explanatory_data ))

ggplot(master_data, aes(x = `Electricity consumption per capita (MWh)`, y=`CO2 emissions per
  geom_point() +
  geom_smooth(method="lm") + geom_point(data=prediction_data, shape=15, size=2,color="red")
```



CO emissions are primarily explained by electricity production and the share of renewable energy. Since GDP was found to have no significant effect, it was excluded from the analysis.

```r
master_data <- master_data |> mutate(gross_domestic = value_usd*mid_year_population)
lin_reg_2 = lm(Total.x ~ `Total electricity production (GWh)`+`Renewables share of electrici

summary(lin_reg_2)
```

```
Call:
lm(formula = Total.x ~ `Total electricity production (GWh)` +
    `Renewables share of electricity generation (%)` + gross_domestic,
    data = master_data)

Residuals:
```

```
    Min      1Q  Median      3Q     Max 
-7.3985 -5.5831 -0.3761  3.9333 13.3644 

Coefficients:
                                                     Estimate Std. Error t value
(Intercept)                                         1.425e+02  6.280e+00  22.688
`Total electricity production (GWh)`                1.357e-03  6.038e-05  22.468
`Renewables share of electricity generation (%)` -8.177e-01  3.418e-01  -2.393
gross_domestic                                      7.359e-09  1.296e-08   0.568
                                                   Pr(>|t|)    
(Intercept)                                        3.18e-15 ***
`Total electricity production (GWh)`               3.80e-15 ***
`Renewables share of electricity generation (%)`   0.0272 *  
gross_domestic                                       0.5769    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6.418 on 19 degrees of freedom
Multiple R-squared:  0.9957,	Adjusted R-squared:  0.995 
F-statistic:  1459 on 3 and 19 DF,  p-value: < 2.2e-16
```

Since multiple regression analysis showed that carbon emissions can be accurately explained by total electricity production and the share of renewable energy sources in electricity generation, the analysis was carried out using this linear model. The model explains 99% of the variation in the data (R-squared), and its very low p-value indicates strong statistical significance.

In terms of relationships:

A 1% increase in the share of renewable energy in electricity generation leads to an average decrease of 0.94 units in carbon emissions, while each 1 GWh increase in total electricity production results in an average increase of 0.001 units in carbon emissions.

```r
library(broom)
library(dplyr)
regres_1 <- lm(Total.x ~ `Total electricity production (GWh)`+`Renewables share of electrici
summary(regres_1)
```

```
Call:
lm(formula = Total.x ~ `Total electricity production (GWh)` + 
    `Renewables share of electricity generation (%)`, data = master_data)

Residuals:
```

```
    Min      1Q  Median      3Q     Max 
-7.5851 -5.8446 -0.9368  3.9378 13.0079 

Coefficients:
                                                   Estimate Std. Error t value
(Intercept)                                       1.442e+02  5.460e+00  26.401
`Total electricity production (GWh)`              1.387e-03  2.754e-05  50.360
`Renewables share of electricity generation (%)` -9.417e-01  2.582e-01  -3.647
                                                 Pr(>|t|)    
(Intercept)                                        <2e-16 ***
`Total electricity production (GWh)`               <2e-16 ***
`Renewables share of electricity generation (%)`   0.0016 ** 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6.308 on 20 degrees of freedom
Multiple R-squared:  0.9956,	Adjusted R-squared:  0.9952 
F-statistic:  2265 on 2 and 20 DF,  p-value: < 2.2e-16
```

```r
tidy(regres_1)
```

```
# A tibble: 3 x 5
  term                                    estimate std.error statistic  p.value
  <chr>                                      <dbl>     <dbl>     <dbl>    <dbl>
1 (Intercept)                              1.44e+2 5.46           26.4 5.09e-17
2 `Total electricity production (GWh)`     1.39e-3 0.0000275      50.4 1.52e-22
3 `Renewables share of electricity genera~ -9.42e-1 0.258         -3.65 1.60e- 3
```

```r
regres_1 |> glance() |> pull(r.squared)
```

```
[1] 0.9956048
```

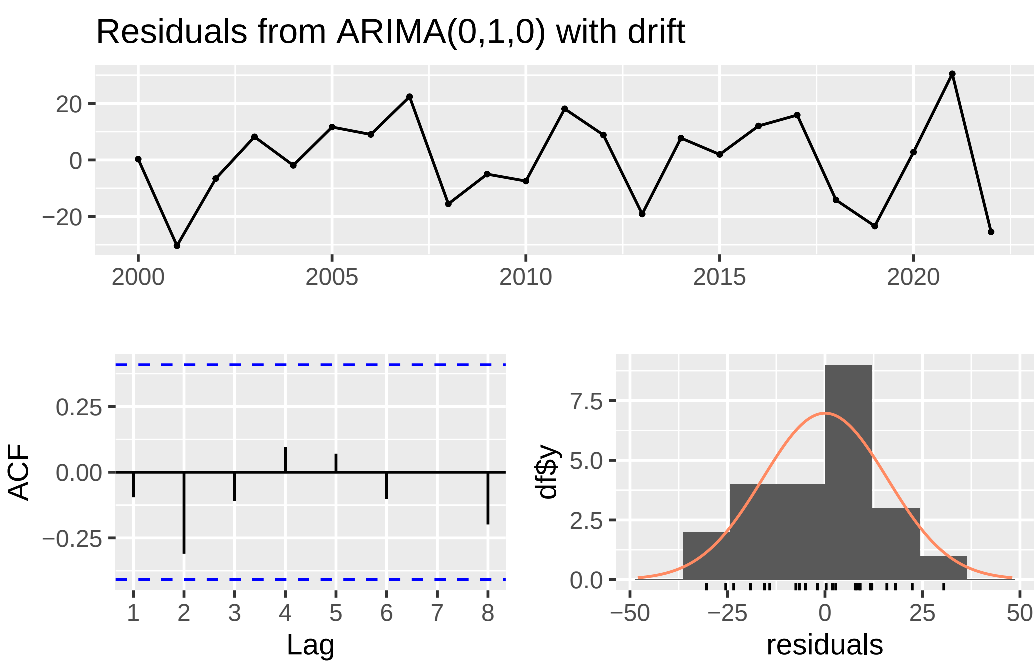
```r
regres_1 |> glance() |> pull(sigma)
```

```
[1] 6.308056
```

3.3 Model Fitting

A time series analysis of carbon emissions was conducted. The model's coefficient was found to be 11.5, indicating an average annual increase of 11.5 units in emissions. The model demonstrated strong forecasting performance (MAPE = 3%). If the current trend continues, carbon emissions are expected to reach around 700 units, as shown in the forecast table.

```
library(forecast)
library(fpp2)
emission <- master_data$Total.x
emission_ts <- ts(data=emission, start = c(2000), frequency = 1)


fitting <- auto.arima(emission_ts)

checkresiduals(fitting)
```




```
    Ljung-Box test

data:  Residuals from ARIMA(0,1,0) with drift
Q* = 3.6457, df = 5, p-value = 0.6015
```

```
Model df: 0.   Total lags used: 5
```

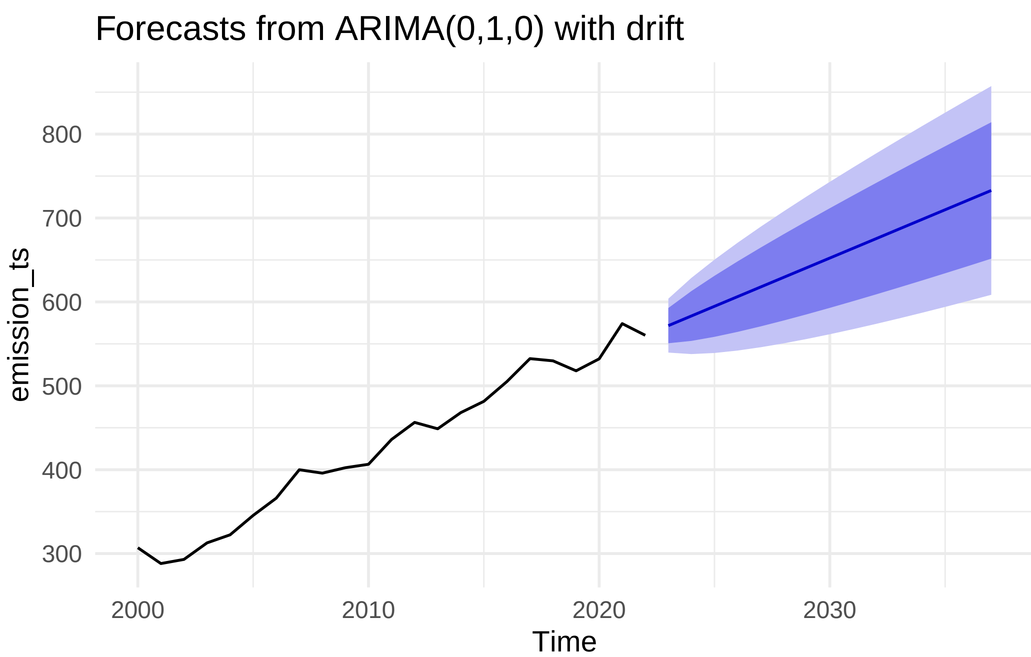
```r
auto.arima(emission_ts)
```

```
Series: emission_ts
ARIMA(0,1,0) with drift

Coefficients:
        drift
      11.5105
s.e.   3.4128

sigma^2 = 268.4:  log likelihood = -92.22
AIC=188.45   AICc=189.08   BIC=190.63
```

```r
summary(fitting)
```

```
Series: emission_ts
ARIMA(0,1,0) with drift

Coefficients:
        drift
      11.5105
s.e.   3.4128

sigma^2 = 268.4:  log likelihood = -92.22
AIC=188.45   AICc=189.08   BIC=190.63

Training set error measures:
                    ME     RMSE      MAE        MPE     MAPE      MASE
Training set 0.0128461 15.65551 12.96707 -0.1260035 3.036878 0.7687117
                    ACF1
Training set -0.09557549
```

```r
fitting |> forecast(h=15) |> autoplot(color="red") + theme_minimal()
```




```
predict(emission_ts)
```

```
     Point Forecast    Lo 80    Hi 80    Lo 95    Hi 95
2023       588.9250 570.5998 607.2502 560.8990 616.9510
2024       602.2172 583.8920 620.5424 574.1912 630.2431
2025       615.5093 597.1841 633.8346 587.4834 643.5353
2026       628.8015 610.4763 647.1267 600.7755 656.8275
2027       642.0937 623.7685 660.4189 614.0677 670.1197
2028       655.3859 637.0607 673.7111 627.3599 683.4119
2029       668.6781 650.3528 687.0033 640.6521 696.7041
2030       681.9702 663.6450 700.2955 653.9442 709.9962
2031       695.2624 676.9372 713.5876 667.2364 723.2884
2032       708.5546 690.2294 726.8798 680.5286 736.5806
```

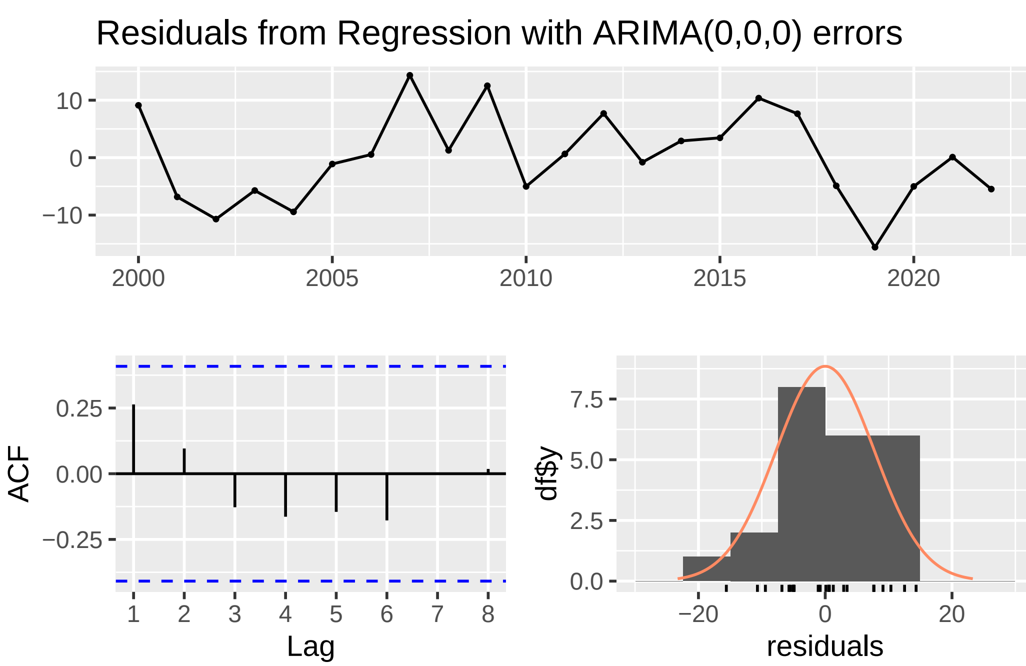
The structure of emission changes based on electricity production has been analyzed. This change depends on the scenario of external factors, particularly the amount of electricity produced.

```
library(dplyr)
library(ggplot2)

total_electric <- master_data[["Total electricity production (GWh)"]]
```

```r
electric_emission <- master_data$Total.x
Emission <- ts(data=electric_emission, start = c(2000), frequency = 1)
fit <- auto.arima(Emission, xreg = total_electric)
fit
```

```
Series: Emission
Regression with ARIMA(0,0,0) errors

Coefficients:
      intercept    xreg
       133.4205  0.0013
s.e.     5.5343  0.0002

sigma^2 = 63.1:  log likelihood = -79.25
AIC=164.51   AICc=165.77   BIC=167.91
```

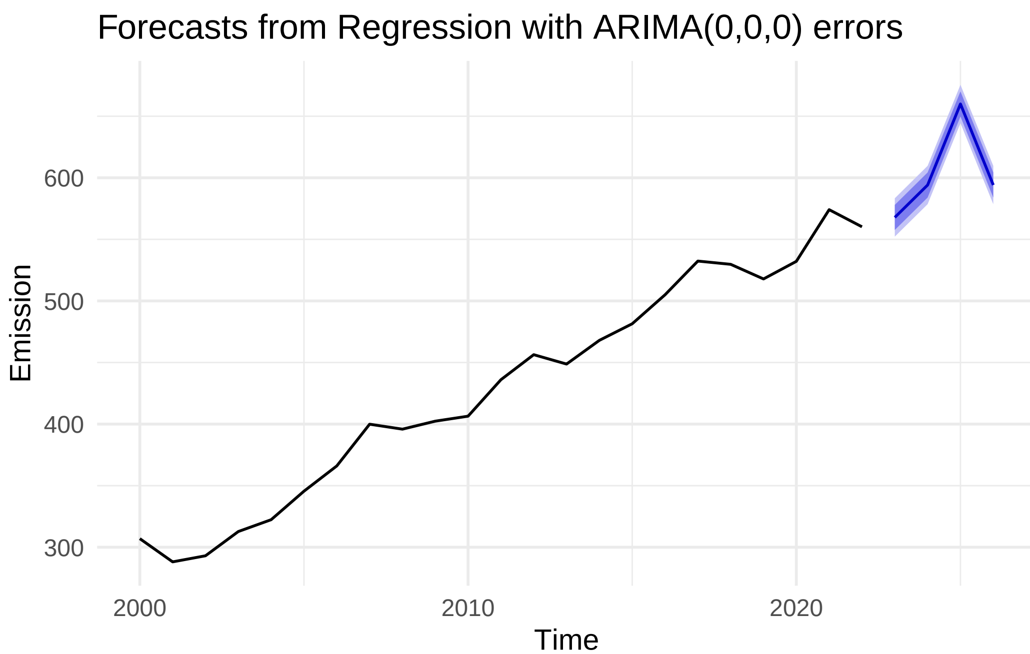
```r
checkresiduals(fit)
```




```
    Ljung-Box test
```

```
data:  Residuals from Regression with ARIMA(0,0,0) errors
Q* = 4.0203, df = 5, p-value = 0.5465

Model df: 0.   Total lags used: 5
```

```
future_electric_production <- c(330000,350000, 400000, 350000)
forecast(fit, xreg = future_electric_production) |> autoplot() + theme_minimal()
```



The forecast of carbon emissions was conducted based on the relationship identified in the previous trend analysis. While carbon emissions were initially modeled as dependent on these two variables, data for the next six years were entered, and future carbon emissions were predicted accordingly.

```
lin_reg_1 = lm(Total.x ~ `Total electricity production (GWh)`+`Renewables share of electrici

fitted_values <- predict(lin_reg_1)

length(master_data$Year)
```

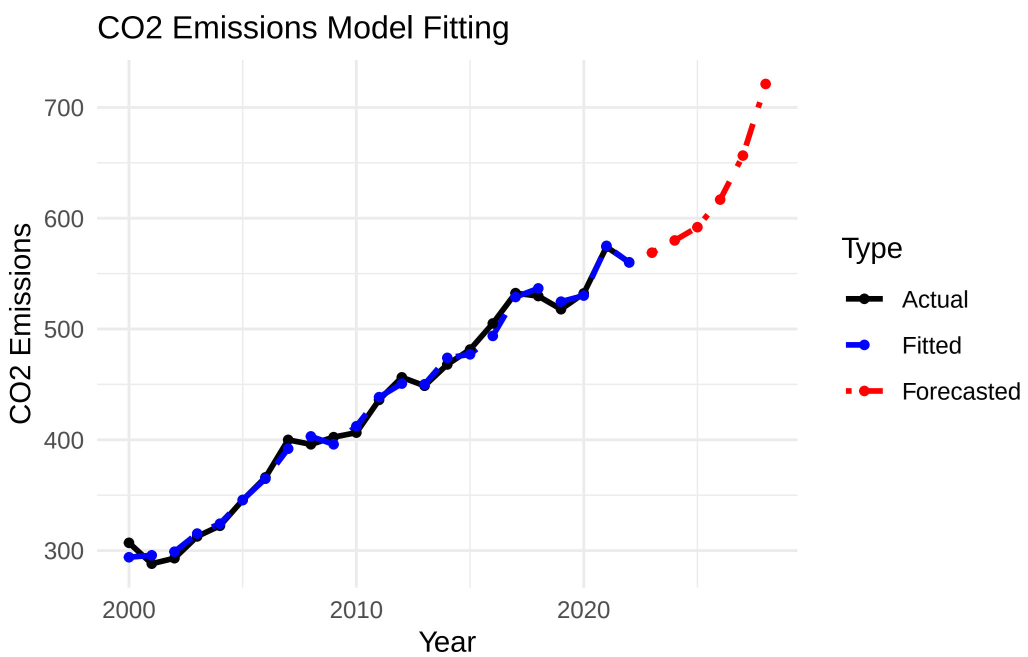
```
[1] 23
```

```r
length(fitted_values)
```

```
[1] 23
```

```r
future_data <- data.frame(
  check.names = FALSE,
  `Total electricity production (GWh)` = c(330000,340000, 350000, 370000, 400000,450000),
  `Renewables share of electricity generation (%)` = c(35, 38, 40, 43, 45,50)
)
forecasted_values <- predict(lin_reg_1, newdata = future_data)
future_years <- 2023:2028

df_actual <- data.frame(
  Year = master_data$Year,
  CO2 = master_data$Total.x,
  Type = "Actual"
)

df_fitted <- data.frame(
  Year = master_data$Year,
  CO2 = fitted_values,
  Type = "Fitted"
)

df_forecasted <- data.frame(
  Year = future_years,
  CO2 = forecasted_values,
  Type = "Forecasted"
)

# Hepsini birleştir
df_all <- rbind(df_actual, df_fitted, df_forecasted)

library(ggplot2)

ggplot(df_all, aes(x = Year, y = CO2, color = Type, linetype = Type)) +
  geom_line(size = 1) +
  geom_point(size = 1.2) +
  scale_color_manual(values = c("Actual" = "black", "Fitted" = "blue", "Forecasted" = "red")
  scale_linetype_manual(values = c("Actual" = "solid", "Fitted" = "dashed", "Forecasted" = "
  ggtitle("CO2 Emissions Model Fitting") +
```

```
  ylab("CO2 Emissions") + xlab("Year") +
  theme_minimal() +
  theme(plot.title = element_text(size = 12))
```




```
df_forecasted
```

```
  Year      CO2       Type
1 2023 568.8835 Forecasted
2 2024 579.9277 Forecasted
3 2025 591.9137 Forecasted
4 2026 616.8274 Forecasted
5 2027 656.5522 Forecasted
6 2028 721.1908 Forecasted
```

3.4 Results

The analyses conducted within the scope of this study reveal that between 2000 and 2022, the primary source of CO emissions in Turkey has been electricity and heat production. The industrial sector stands out as the largest consumer of electricity, followed by residential and public services, which also account for significant portions of consumption. In contrast, electricity use and emissions in the agriculture and fisheries sectors have remained relatively stable.

Correlation analyses identified very strong positive relationships between per capita CO emissions and per capita electricity consumption (r = 0.98), total electricity production (r = 0.94), and overall emissions. Source-based analysis showed that coal consumption had the strongest positive correlation with CO emissions (r = 0.96), while petroleum use was found to have a significant negative correlation (r = –0.88).

Regression modeling indicated that per capita electricity consumption was a highly accurate predictor of CO emissions (R^2 0.97). A multivariate regression model projected that, with continued growth in production, CO emissions could reach approximately 730 MtCO by 2029.

Although the increasing share of renewable energy is a positive trend, it has not been sufficient to offset the overall growth in production. The time series analysis using the ARIMA(0,1,0) with drift model passed all residual diagnostics and forecasted a steady rise in production over the next decade. When compared to the ETS model, ARIMA delivered better performance with lower error margins. Based on the regression analysis linking total emissions to total electricity production and the share of renewables, future emission levels were estimated. These findings clearly indicate that, if current production and consumption patterns persist, CO emissions are likely to continue rising.

4. Results and Key Takeaways

In our analysis, we examined the relationship between Turkey's electricity production, the distribution of energy sources, and CO emissions. We defined our data range as the last 20 years and used exploratory analysis, correlation studies, regression models, and time series forecasting methods. The key findings are as follows:

Electricity production in Turkey has been continuously increasing, and the rise in population and demand from the industrial sector has significantly contributed to the increase in CO emissions.

Additionally, CO emissions are strongly associated with electricity generation based on fossil fuels, especially coal. Our findings indicate that coal use in electricity production is still remarkably high in Turkey.

Although the use of renewable energy sources is growing day by day, this increase has not been sufficient to offset the rise in total electricity production and therefore has not had a significant effect on reducing emissions.

Both regression and time series models show that if current trends continue, CO emissions will increase sharply in the coming years.

It is not enough to simply invest in clean energy sources. Although such investments have begun to grow in recent years, no downward trend in CO emissions has been observed. Reducing the use of fossil fuels is essential.