Global CO2 Emissions Data Analysis

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Total CO2 Emission Analysis using data from 1750-2020

The code below analyzes CO2 emission data from Kaggle. The three main goals are: 1. to understand the historical cumulative emissions,
2. Present day emission analysis,
3. Using this data for future emission predictions.

Libraries needed for this analysis:

Data Cleaning

```
data <- getURL("https://raw.githubusercontent.com/jliuob/QBSsquad/main/CO2_emission_by_countries.csv")
rawDat <- read.csv(text = data)
```

```
rawCO2<-rawDat
rawCO2%>% summarise_all(~ sum(is.na(.)))
```

```
##   Country Code Calling.Code Year CO2.emission..Tons. Population.2022. Area
## 1       0  271            0    0                   0             6504 4336
##   X..of.World Density.km2.
## 1           0            0
```

```
#Find all the countries that has NA in each column
naCode <- rawCO2 %>% filter(is.na(Code)) %>% distinct(Country)
naCall <- rawCO2 %>% filter(is.na(Calling.Code)) %>% distinct(Country)
naPopu <- rawCO2 %>% filter(is.na(Population.2022.)) %>% distinct(Country)
naArea <- rawCO2 %>% filter(is.na(Area)) %>% distinct(Country)
naXPre <- rawCO2 %>% filter(is.na(X..of.World)) %>% distinct(Country)
naDens <- rawCO2 %>% filter(is.na(Density.km2.)) %>% distinct(Country)
allNA <- bind_rows(naCode,naCall,naPopu,naArea,naXPre,naDens)
allNA <- distinct(allNA) %>% arrange(Country)
head(allNA,10) #In total of 41 countries have different missing values
```

```
##             Country
## 1          Anguilla
## 2        Antarctica
## 3             Aruba
```

```
## 4           Bermuda
## 5            Brunei
## 6        Cape Verde
## 7  Christmas Island
## 8             Congo
## 9      Cook Islands
## 10    Cote d'Ivoire
```

Combine all the table above to better see which values are missing.

```
nacheck<-function(str){
  #This function get the individual column data above,
  df<- get(str)
  df$UniC <- df$Country
  #create a second column to later join all the table together
  colnames(df)[1] = str
  #rename the country column as the abbreviation of the initial data frame
  return(df)
}
#run the function for all the column that had missing data
naCode<- nacheck("naCode")
naCall<- nacheck("naCall")
naPopu<- nacheck("naPopu")
naArea<- nacheck("naArea")
naXPre<- nacheck("naXPre")
naDens<- nacheck("naDens")
#Join all the column together
allNATable<-allNA %>% full_join(naCode,by = c("Country" = "UniC")) %>%
  full_join(naCall,by = c("Country" = "UniC")) %>%
  full_join(naPopu,by = c("Country" = "UniC")) %>%
  full_join(naArea,by = c("Country" = "UniC")) %>%
  full_join(naXPre,by = c("Country" = "UniC")) %>%
  full_join(naDens,by = c("Country" = "UniC"))
view(allNATable)
```

```
write.csv(allNATable, file = "OriginalNAs.csv",row.names = TRUE)
#Write out the table for future reference, can also see this data in Excel
```

```
dat20 <- rawCO2 %>% filter(Year == 2020)
summary(dat20$CO2.emission..Tons.)
```

```
##      Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
## 1.539e+05 4.506e+07 3.011e+08 7.519e+09 2.770e+09 4.170e+11
```

```
#decided on the first quartile
```

```
#Read in the cleaned version from excel
y <- getURL("https://raw.githubusercontent.com/jliuob/QBSsquad/main/CO2_Cleaned_V2.csv")
CO2 <- read.csv(text = y)
colnames(CO2)[1] = "Country"
#again, check for all the NA entries
CO2 %>% summarise_all(~ sum(is.na(.)))
```

```
##   Country Code Calling.Code Year CO2.emission..Tons. Population.2022. Area
## 1       0    0            0    0                   0             4065 1355
##   X..of.World Density.km2.
## 1           0            0
```

```
CO2 <- CO2 %>% dplyr::select(-c(8,9))
#omitted the last two column
head(CO2)
```

```
##       Country Code Calling.Code Year CO2.emission..Tons. Population.2022.
## 1 Afghanistan   AF           93 1750                   0         41128771
## 2 Afghanistan   AF           93 1751                   0         41128771
## 3 Afghanistan   AF           93 1752                   0         41128771
## 4 Afghanistan   AF           93 1753                   0         41128771
## 5 Afghanistan   AF           93 1754                   0         41128771
## 6 Afghanistan   AF           93 1755                   0         41128771
##     Area
## 1 652230
## 2 652230
## 3 652230
## 4 652230
## 5 652230
## 6 652230
```

```
#check the dimension of data
dim(CO2)
```

```
## [1] 59620     7
```

Please proceed with this CO2 (don't forget to omit.na)

Historical CO2 Data analysis and visualization

Aim 1.1 General overview of data, any visual or numerical differences.

Finding the first year in history that countries began emitting CO2

```
#finding and removing NAs
CO2 <- na.omit(CO2)
View(CO2)

#filter emissions 0 and use tidyverse groupby country minimum year
CO2_no0<-CO2 %>% group_by(min(Year)) %>% filter(CO2.emission..Tons.!=0)

CO2_no0 %>%
    group_by(Country) %>%
    slice(which.min(Year))
```

```
## # A tibble: 204 x 8
## # Groups:   Country [204]
##    Country             Code  Calling.Code  Year CO2.emi~1 Popul~2   Area min(Y~3
```

```
##    <chr>                <chr> <chr>        <int>     <dbl>   <int>  <int>   <int>
##  1 Afghanistan          AF    93            1949     14656 4.11e7 6.52e5    1750
##  2 Albania              AL    355           1933      7328 2.84e6 2.87e4    1750
##  3 Algeria              DZ    213           1916      3664 4.49e7 2.38e6    1750
##  4 Andorra              AD    376           1990    406704 7.98e4 4.68e2    1750
##  5 Angola               AO    244           1950    186864 3.56e7 1.25e6    1750
##  6 Antigua and Barbuda AG    1-268         1957     21984 9.38e4 4.42e2    1750
##  7 Argentina            AR    54            1887   1084544 4.55e7 2.78e6    1750
##  8 Armenia              AM    374           1830        42 2.78e6 2.97e4    1750
##  9 Aruba                AW    297           1926     33394 1.08e5 1.8 e2    1750
## 10 Australia            AU    61            1860    278464 2.62e7 7.69e6    1750
## # ... with 194 more rows, and abbreviated variable names
## #   1: CO2.emission..Tons., 2: Population.2022., 3: `min(Year)`
```

```
CO2_no0 <- data.table(CO2_no0)

#removing duplicates country names
CO2_noduplicates <- CO2_no0[!duplicated(CO2_no0$Country),]
CO2_noduplicates
```

```
##          Country Code Calling.Code Year CO2.emission..Tons. Population.2022.
##   1: Afghanistan   AF           93 1949               14656         41128771
##   2:     Albania   AL          355 1933                7328          2842321
##   3:     Algeria   DZ          213 1916                3664         44903225
##   4:     Andorra   AD          376 1990              406704            79824
##   5:      Angola   AO          244 1950              186864         35588987
##  ---
## 200:   Venezuela   VE           58 1904                3664         28301696
## 201:     Vietnam   VN           84 1892              212512         98186856
## 202:       Yemen   YE          967 1950               58624         33696614
## 203:      Zambia   ZM          260 1950             2330187         20017675
## 204:    Zimbabwe   ZW          263 1903              113584         16320537
##         Area min(Year)
##   1:  652230      1750
##   2:   28748      1750
##   3: 2381741      1750
##   4:     468      1750
##   5: 1246700      1750
##  ---
## 200:  916445      1750
## 201:  331212      1750
## 202:  527968      1750
## 203:  752612      1750
## 204:  390757      1750
```

```
CO2_no_year_min <- CO2_no0[, list(Year = min(Year)), by = Country]
#new data table to identify first year with non-zero CO2 emission value
CO2_no_year_min[]
```

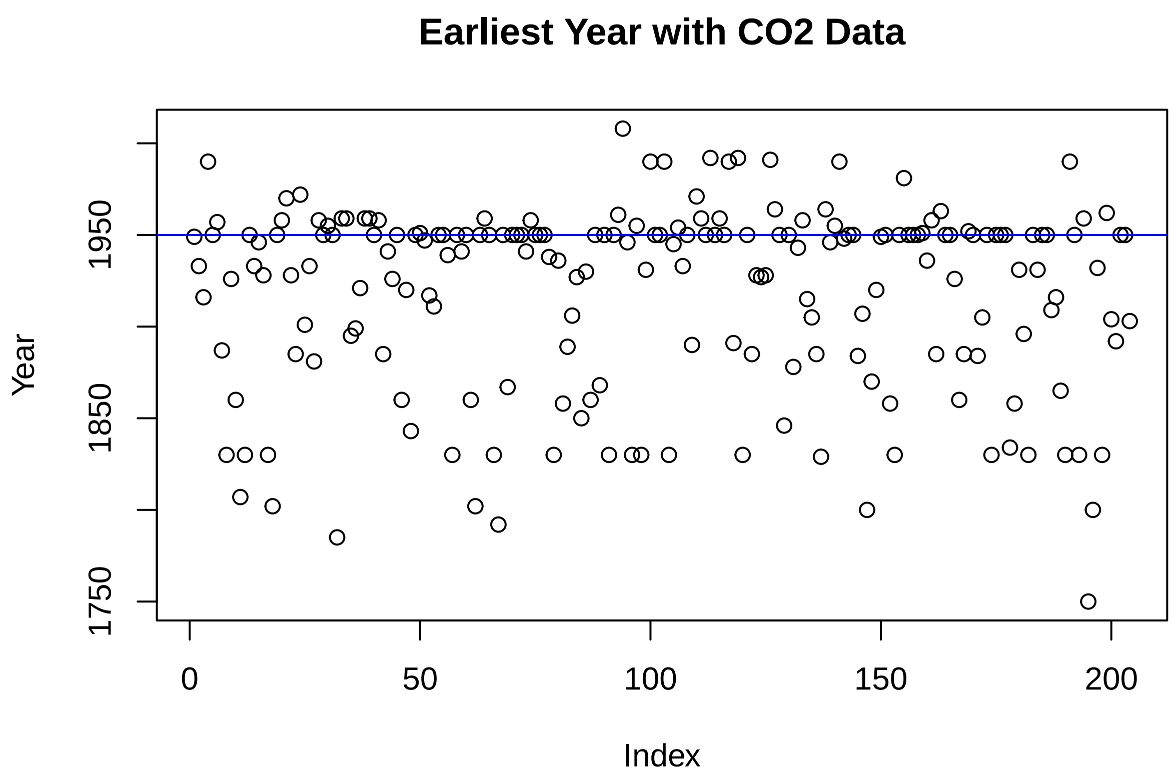
```
##          Country Year
##   1: Afghanistan 1949
##   2:     Albania 1933
##   3:     Algeria 1916
```

```
##   4:     Andorra 1990
##   5:      Angola 1950
##  ---
## 200:   Venezuela 1904
## 201:     Vietnam 1892
## 202:       Yemen 1950
## 203:      Zambia 1950
## 204:    Zimbabwe 1903
```

```
summary(CO2_no_year_min$Year)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    1750    1885    1944    1919    1950    2008
```

```
#scatter plot of the years with non-zero CO2 value for different countries, with line at 1950
plot(CO2_no_year_min$Year,main="Earliest Year with CO2 Data",xlab="Index",ylab="Year")+abline(h=1950,co
```




```
## integer(0)
```

Based on the scatter plot above, in our data, most countries have their first non-zero CO2 value at 1950.

Finding total CO2 emissions per country & CO2 emissions per country per person

```
#finding CO2 emission/population
CO2total_byCountry <- aggregate(CO2_no0$CO2.emission..Tons., by=list(Category=CO2_no0$Country), FUN=sum
```

```r
#renaming columns
colnames(CO2total_byCountry)[1] <- "Country"
colnames(CO2total_byCountry)[2] <- "CO2.Total"
CO2total_byCountry #checking that the column renaming worked
```

```
##                               Country    CO2.Total
## 1                         Afghanistan 3.754106e+09
## 2                             Albania 9.250246e+09
## 3                             Algeria 9.582024e+10
## 4                             Andorra 2.360722e+08
## 5                              Angola 1.143158e+10
## 6                 Antigua and Barbuda 6.376165e+08
## 7                           Argentina 2.632189e+11
## 8                             Armenia 1.430517e+10
## 9                               Aruba 2.357567e+09
## 10                          Australia 5.693351e+11
## 11                            Austria 3.074275e+11
## 12                         Azerbaijan 8.853483e+10
## 13                            Bahamas 5.773362e+09
## 14                            Bahrain 2.037107e+10
## 15                         Bangladesh 2.390055e+10
## 16                           Barbados 1.337450e+09
## 17                            Belarus 1.809370e+11
## 18                            Belgium 7.903086e+11
## 19                             Belize 4.207057e+08
## 20                              Benin 1.485290e+09
## 21                             Bhutan 2.066234e+08
## 22                            Bolivia 1.019115e+10
## 23             Bosnia and Herzegovina 2.886810e+10
## 24                           Botswana 2.362863e+09
## 25                             Brazil 3.713855e+11
## 26                             Brunei 1.074748e+10
## 27                           Bulgaria 1.331526e+11
## 28                       Burkina Faso 9.303006e+08
## 29                            Burundi 2.720993e+08
## 30                           Cambodia 1.866981e+09
## 31                           Cameroon 4.568516e+09
## 32                             Canada 1.255512e+12
## 33           Central African Republic 2.957916e+08
## 34                               Chad 4.866396e+08
## 35                              Chile 8.188228e+10
## 36                              China 4.162896e+12
## 37                           Colombia 9.086583e+10
## 38                            Comoros 9.363528e+07
## 39                              Congo 1.625597e+09
## 40                         Costa Rica 5.276408e+09
## 41                      Cote d'Ivoire 7.587251e+09
## 42                            Croatia 3.273520e+10
## 43                               Cuba 5.034312e+10
## 44                            Curacao 2.561368e+10
## 45                             Cyprus 6.666480e+09
## 46                            Czechia 6.045514e+11
## 47       Democratic Republic of Congo 7.464739e+09
```

```
## 48                    Denmark 1.823616e+11
## 49                   Djibouti 4.713698e+08
## 50                   Dominica 9.199167e+07
## 51         Dominican Republic 1.494841e+10
## 52                    Ecuador 2.562314e+10
## 53                      Egypt 1.264498e+11
## 54                El Salvador 5.108406e+09
## 55          Equatorial Guinea 1.776225e+09
## 56                    Eritrea 2.585497e+08
## 57                    Estonia 6.332375e+10
## 58                   Eswatini 8.891676e+08
## 59                   Ethiopia 4.277616e+09
## 60                       Fiji 1.275528e+09
## 61                    Finland 1.001889e+11
## 62                     France 2.238247e+12
## 63              French Guiana 6.071543e+08
## 64                      Gabon 6.993919e+09
## 65                     Gambia 2.716380e+08
## 66                    Georgia 2.531358e+10
## 67                    Germany 5.300531e+12
## 68                      Ghana 7.399346e+09
## 69                     Greece 1.036874e+11
## 70                  Greenland 9.928700e+08
## 71                    Grenada 1.607098e+08
## 72                 Guadeloupe 1.672795e+09
## 73                  Guatemala 8.902918e+09
## 74                     Guinea 1.924528e+09
## 75                     Guyana 2.930467e+09
## 76                      Haiti 1.564480e+09
## 77                   Honduras 4.863815e+09
## 78                  Hong Kong 3.593146e+10
## 79                    Hungary 2.273008e+11
## 80                    Iceland 4.174625e+09
## 81                      India 1.089952e+12
## 82                  Indonesia 2.936194e+11
## 83                       Iran 4.173757e+11
## 84                       Iraq 9.716365e+10
## 85                    Ireland 7.438604e+10
## 86                     Israel 5.355184e+10
## 87                      Italy 8.342234e+11
## 88                    Jamaica 1.248806e+10
## 89                      Japan 2.051064e+12
## 90                     Jordan 1.281551e+10
## 91                 Kazakhstan 4.539328e+11
## 92                      Kenya 1.081293e+10
## 93                   Kiribati 4.856884e+07
## 94                     Kosovo 7.308271e+08
## 95                     Kuwait 6.284507e+10
## 96                 Kyrgyzstan 3.493852e+10
## 97                       Laos 1.297428e+09
## 98                     Latvia 3.944943e+10
## 99                    Lebanon 1.560259e+10
## 100                   Lesotho 9.357852e+08
## 101                   Liberia 1.693776e+09
```

```
## 102                        Libya 4.855690e+10
## 103                Liechtenstein 1.034699e+08
## 104                    Lithuania 6.299174e+10
## 105                   Luxembourg 2.758179e+10
## 106                        Macao 1.169537e+09
## 107                   Madagascar 2.256616e+09
## 108                       Malawi 1.385338e+09
## 109                     Malaysia 1.030422e+11
## 110                     Maldives 2.781142e+08
## 111                         Mali 9.651067e+08
## 112                        Malta 2.596434e+09
## 113             Marshall Islands 4.552062e+07
## 114                   Martinique 1.971384e+09
## 115                   Mauritania 1.457707e+09
## 116                    Mauritius 2.135723e+09
## 117                      Mayotte 8.141350e+07
## 118                       Mexico 5.635544e+11
## 119                   Micronesia 5.337956e+07
## 120                      Moldova 6.240856e+10
## 121                     Mongolia 1.241428e+10
## 122                   Montenegro 3.032392e+09
## 123                      Morocco 3.494891e+10
## 124                   Mozambique 5.181102e+09
## 125                      Myanmar 1.545320e+10
## 126                      Namibia 9.355316e+08
## 127                        Nauru 1.510645e+08
## 128                        Nepal 1.965991e+09
## 129                  Netherlands 4.948726e+11
## 130                New Caledonia 3.816046e+09
## 131                  New Zealand 6.918458e+10
## 132                    Nicaragua 4.095118e+09
## 133                        Niger 9.251186e+08
## 134                      Nigeria 8.799022e+10
## 135                  North Korea 1.787941e+11
## 136              North Macedonia 2.145468e+10
## 137                       Norway 1.040229e+11
## 138                         Oman 1.781582e+10
## 139                     Pakistan 9.551340e+10
## 140                        Palau 2.788467e+08
## 141                    Palestine 7.420809e+08
## 142                       Panama 6.685614e+09
## 143             Papua New Guinea 3.285263e+09
## 144                     Paraguay 3.313264e+09
## 145                         Peru 6.016985e+10
## 146                  Philippines 7.225130e+10
## 147                       Poland 1.311554e+12
## 148                     Portugal 7.955163e+10
## 149                  Puerto Rico 2.109365e+07
## 150                        Qatar 3.334660e+10
## 151                      Reunion 2.138660e+09
## 152                      Romania 3.294970e+11
## 153                       Russia 4.080739e+12
## 154                       Rwanda 6.174393e+08
## 155        Saint Kitts and Nevis 9.972552e+07
```

```
## 156                       Saint Lucia 2.700456e+08
## 157 Saint Vincent and the Grenadines 1.302473e+08
## 158                             Samoa 1.412329e+08
## 159             Sao Tome and Principe 6.885642e+07
## 160                      Saudi Arabia 2.933864e+11
## 161                           Senegal 4.788479e+09
## 162                            Serbia 8.595910e+10
## 163                        Seychelles 2.295101e+08
## 164                      Sierra Leone 1.098976e+09
## 165                         Singapore 5.106388e+10
## 166         Sint Maarten (Dutch part) 3.057584e+09
## 167                          Slovakia 1.946301e+11
## 168                          Slovenia 2.588703e+10
## 169                   Solomon Islands 2.125868e+08
## 170                           Somalia 8.926861e+08
## 171                      South Africa 6.347067e+11
## 172                       South Korea 3.337672e+11
## 173                       South Sudan 7.882633e+08
## 174                             Spain 4.764031e+11
## 175                         Sri Lanka 1.028981e+10
## 176                             Sudan 8.726657e+09
## 177                          Suriname 3.242840e+09
## 178                            Sweden 2.394784e+11
## 179                       Switzerland 1.281434e+11
## 180                             Syria 4.260710e+10
## 181                            Taiwan 1.862882e+11
## 182                        Tajikistan 2.000847e+10
## 183                          Tanzania 4.903444e+09
## 184                          Thailand 1.238806e+11
## 185                              Togo 1.314020e+09
## 186                             Tonga 9.236051e+07
## 187               Trinidad and Tobago 4.497699e+10
## 188                           Tunisia 1.884400e+10
## 189                            Turkey 2.201051e+11
## 190                      Turkmenistan 6.537110e+10
## 191                            Tuvalu 4.456110e+06
## 192                            Uganda 2.101097e+09
## 193                           Ukraine 1.213335e+12
## 194              United Arab Emirates 8.106576e+10
## 195                    United Kingdom 6.162082e+12
## 196                     United States 1.906877e+13
## 197                           Uruguay 1.221006e+10
## 198                        Uzbekistan 1.978867e+11
## 199                           Vanuatu 1.142344e+08
## 200                         Venezuela 2.335395e+11
## 201                           Vietnam 7.262503e+10
## 202                             Yemen 1.421732e+10
## 203                            Zambia 8.811259e+09
## 204                          Zimbabwe 2.936469e+10
```

```
#joining columns together to conduct calculations
CO2total_byCountry <- CO2total_byCountry %>% inner_join(CO2_noduplicates) %>% select("Country","CO2.Tot
```

```
## Joining, by = "Country"
```

```r
#dividing total CO2 emissions per country by the country's population
CO2total_byCountry$CO2perPop <- NULL
CO2total_byCountry$CO2perPop <- CO2total_byCountry$CO2.Total/CO2total_byCountry$Population.2022.
CO2total_byCountry
```

```
##                               Country    CO2.Total Population.2022.    CO2perPop
## 1                         Afghanistan 3.754106e+09         41128771     91.27688
## 2                             Albania 9.250246e+09          2842321   3254.46901
## 3                             Algeria 9.582024e+10         44903225   2133.92786
## 4                             Andorra 2.360722e+08            79824   2957.40938
## 5                              Angola 1.143158e+10         35588987    321.21110
## 6                 Antigua and Barbuda 6.376165e+08            93763   6800.29918
## 7                           Argentina 2.632189e+11         45510318   5783.71851
## 8                             Armenia 1.430517e+10          2780469   5144.87717
## 9                               Aruba 2.357567e+09           107825  21864.75420
## 10                          Australia 5.693351e+11         26177413  21749.09751
## 11                            Austria 3.074275e+11          8939617  34389.34208
## 12                         Azerbaijan 8.853483e+10         10358074   8547.42184
## 13                            Bahamas 5.773362e+09           409984  14081.92069
## 14                            Bahrain 2.037107e+10          1472233  13836.85123
## 15                         Bangladesh 2.390055e+10        171186372    139.61713
## 16                           Barbados 1.337450e+09           281635   4748.87638
## 17                            Belarus 1.809370e+11          9534954  18976.18109
## 18                            Belgium 7.903086e+11         11655930  67803.13847
## 19                             Belize 4.207057e+08           405272   1038.08245
## 20                              Benin 1.485290e+09         13352864    111.23381
## 21                             Bhutan 2.066234e+08           782455    264.07067
## 22                            Bolivia 1.019115e+10         12224110    833.69270
## 23             Bosnia and Herzegovina 2.886810e+10          3233526   8927.74655
## 24                           Botswana 2.362863e+09          2630296    898.32601
## 25                             Brazil 3.713855e+11        215313498   1724.85931
## 26                             Brunei 1.074748e+10           449002  23936.38157
## 27                           Bulgaria 1.331526e+11          6781953  19633.37493
## 28                       Burkina Faso 9.303006e+08         22673762     41.02983
## 29                            Burundi 2.720993e+08         12889576     21.11003
## 30                           Cambodia 1.866981e+09         16767842    111.34297
## 31                           Cameroon 4.568516e+09         27914536    163.66082
## 32                             Canada 1.255512e+12         38454327  32649.42101
## 33           Central African Republic 2.957916e+08          5579144     53.01738
## 34                               Chad 4.866396e+08         17723315     27.45759
## 35                              Chile 8.188228e+10         19603733   4176.87177
## 36                              China 4.162896e+12       1425887337   2919.51278
## 37                           Colombia 9.086583e+10         51874024   1751.66338
## 38                            Comoros 9.363528e+07           836774    111.90033
## 39                              Congo 1.625597e+09          5835340    278.57802
## 40                         Costa Rica 5.276408e+09          5180829   1018.44851
## 41                      Cote d'Ivoire 7.587251e+09         95930038     79.09150
## 42                            Croatia 3.273520e+10          4030358   8122.15727
## 43                               Cuba 5.034312e+10         11212191   4490.03454
## 44                            Curacao 2.561368e+10           165663 154613.13722
## 45                             Cyprus 6.666480e+09          1251488   5326.84308
## 46                            Czechia 6.045514e+11         10755398  56209.11827
## 47       Democratic Republic of Congo 7.464739e+09         95930038     77.81441
```

```
## 48                    Denmark 1.823616e+11          5882261  31001.94924
## 49                   Djibouti 4.713698e+08          1120849    420.54710
## 50                   Dominica 9.199167e+07            72737   1264.71636
## 51         Dominican Republic 1.494841e+10         11228821   1331.25350
## 52                    Ecuador 2.562314e+10         18001000   1423.42850
## 53                      Egypt 1.264498e+11        110990103   1139.28898
## 54                El Salvador 5.108406e+09          6336392    806.20113
## 55          Equatorial Guinea 1.776225e+09          1674908   1060.49079
## 56                    Eritrea 2.585497e+08          3684032     70.18116
## 57                    Estonia 6.332375e+10          1326062  47753.23364
## 58                   Eswatini 8.891676e+08          1201670    739.94322
## 59                   Ethiopia 4.277616e+09        123379924     34.67027
## 60                       Fiji 1.275528e+09           929766   1371.88029
## 61                    Finland 1.001889e+11          5540745  18082.21241
## 62                     France 2.238247e+12         64626628  34633.51398
## 63              French Guiana 6.071543e+08           304557   1993.56544
## 64                      Gabon 6.993919e+09          2388992   2927.56070
## 65                     Gambia 2.716380e+08          2705992    100.38387
## 66                    Georgia 2.531358e+10          3744385   6760.41120
## 67                    Germany 5.300531e+12         83369843  63578.51556
## 68                      Ghana 7.399346e+09         33475870    221.03522
## 69                     Greece 1.036874e+11         10384971   9984.37353
## 70                  Greenland 9.928700e+08            56466  17583.50129
## 71                    Grenada 1.607098e+08           125438   1281.18892
## 72                 Guadeloupe 1.672795e+09           395752   4226.87802
## 73                  Guatemala 8.902918e+09         17843908    498.93322
## 74                     Guinea 1.924528e+09         13859341    138.86142
## 75                     Guyana 2.930467e+09           808726   3623.56028
## 76                      Haiti 1.564480e+09         11584996    135.04364
## 77                   Honduras 4.863815e+09         10432860    466.20154
## 78                  Hong Kong 3.593146e+10          7488865   4797.98451
## 79                    Hungary 2.273008e+11          9967308  22804.63767
## 80                    Iceland 4.174625e+09           372899  11195.05680
## 81                      India 1.089952e+12       1417173173    769.10266
## 82                  Indonesia 2.936194e+11        275501339   1065.76379
## 83                       Iran 4.173757e+11         88550570   4713.41577
## 84                       Iraq 9.716365e+10         44496122   2183.64319
## 85                    Ireland 7.438604e+10          5023109  14808.76544
## 86                     Israel 5.355184e+10          9038309   5924.98426
## 87                      Italy 8.342234e+11         59037474  14130.40539
## 88                    Jamaica 1.248806e+10          2827377   4416.83733
## 89                      Japan 2.051064e+12        123951692  16547.28791
## 90                     Jordan 1.281551e+10         11285869   1135.53615
## 91                 Kazakhstan 4.539328e+11         19397998  23401.01517
## 92                      Kenya 1.081293e+10         54027487    200.13763
## 93                   Kiribati 4.856884e+07           131232    370.09905
## 94                     Kosovo 7.308271e+08          1802250    405.50819
## 95                     Kuwait 6.284507e+10          4268873  14721.70122
## 96                 Kyrgyzstan 3.493852e+10          6630623   5269.26585
## 97                       Laos 1.297428e+09          7529475    172.31326
## 98                     Latvia 3.944943e+10          1850651  21316.51367
## 99                    Lebanon 1.560259e+10          5489739   2842.13707
## 100                   Lesotho 9.357852e+08          2305825    405.83532
## 101                   Liberia 1.693776e+09          5302681    319.41874
```

```
## 102                     Libya 4.855690e+10    6812341   7127.78454
## 103             Liechtenstein 1.034699e+08      39327   2631.01454
## 104                 Lithuania 6.299174e+10    2750055  22905.63096
## 105                Luxembourg 2.758179e+10     647599  42590.84014
## 106                     Macao 1.169537e+09     670052   1745.44266
## 107                Madagascar 2.256616e+09   29611714     76.20688
## 108                    Malawi 1.385338e+09   20405317     67.89103
## 109                  Malaysia 1.030422e+11   33938221   3036.17044
## 110                  Maldives 2.781142e+08     523787    530.96816
## 111                      Mali 9.651067e+08   22593590     42.71595
## 112                     Malta 2.596434e+09     533286   4868.74661
## 113          Marshall Islands 4.552062e+07      41569   1095.06175
## 114                Martinique 1.971384e+09     367507   5364.20751
## 115                Mauritania 1.457707e+09    4736139    307.78380
## 116                 Mauritius 2.135723e+09    1299469   1643.53507
## 117                   Mayotte 8.141350e+07     326101    249.65732
## 118                    Mexico 5.635544e+11  127504125   4419.89154
## 119                Micronesia 5.337956e+07     114164    467.56909
## 120                   Moldova 6.240856e+10    3272996  19067.71588
## 121                  Mongolia 1.241428e+10    3398366   3653.01578
## 122                Montenegro 3.032392e+09     627082   4835.71903
## 123                   Morocco 3.494891e+10   37457971    933.01664
## 124                Mozambique 5.181102e+09   32969518    157.14825
## 125                   Myanmar 1.545320e+10   54179306    285.22329
## 126                   Namibia 9.355316e+08    2567012    364.44378
## 127                     Nauru 1.510645e+08      12668  11924.89304
## 128                     Nepal 1.965991e+09   30547580     64.35831
## 129               Netherlands 4.948726e+11   17564014  28175.37243
## 130             New Caledonia 3.816046e+09     291913  13072.54726
## 131               New Zealand 6.918458e+10    5185288  13342.47511
## 132                 Nicaragua 4.095118e+09    6948392    589.36198
## 133                     Niger 9.251186e+08   26207977     35.29912
## 134                   Nigeria 8.799022e+10  218541212    402.62529
## 135               North Korea 1.787941e+11   26069416   6858.38430
## 136           North Macedonia 2.145468e+10    2093599  10247.75238
## 137                    Norway 1.040229e+11    5434319  19141.84620
## 138                      Oman 1.781582e+10    4576298   3893.06290
## 139                  Pakistan 9.551340e+10  235824862    405.01837
## 140                     Palau 2.788467e+08      18055  15444.29022
## 141                 Palestine 7.420809e+08    5250072    141.34681
## 142                    Panama 6.685614e+09    4408581   1516.50029
## 143          Papua New Guinea 3.285263e+09   10142619    323.90677
## 144                  Paraguay 3.313264e+09    6780744    488.62835
## 145                      Peru 6.016985e+10   34049588   1767.12425
## 146               Philippines 7.225130e+10  115559009    625.23295
## 147                    Poland 1.311554e+12   39857145  32906.36461
## 148                  Portugal 7.955163e+10   10270865   7745.36844
## 149               Puerto Rico 2.109365e+07    3252407      6.48555
## 150                     Qatar 3.334660e+10    2695122  12372.94745
## 151                   Reunion 2.138660e+09     974052   2195.63209
## 152                   Romania 3.294970e+11   19659267  16760.39336
## 153                    Russia 4.080739e+12  144713314  28198.77848
## 154                    Rwanda 6.174393e+08   13776698     44.81765
## 155     Saint Kitts and Nevis 9.972552e+07      47657   2092.56806
```

```
## 156                       Saint Lucia 2.700456e+08         179857   1501.44622
## 157 Saint Vincent and the Grenadines 1.302473e+08         103948   1253.00450
## 158                             Samoa 1.412329e+08         222382    635.09138
## 159             Sao Tome and Principe 6.885642e+07         227380    302.82532
## 160                      Saudi Arabia 2.933864e+11       36408820   8058.11261
## 161                           Senegal 4.788479e+09       17316449    276.52777
## 162                            Serbia 8.595910e+10        7221365  11903.44211
## 163                        Seychelles 2.295101e+08         107118   2142.59121
## 164                      Sierra Leone 1.098976e+09        8605718    127.70296
## 165                         Singapore 5.106388e+10        5975689   8545.27034
## 166         Sint Maarten (Dutch part) 3.057584e+09          44015  69466.86402
## 167                          Slovakia 1.946301e+11        5643453  34487.76021
## 168                          Slovenia 2.588703e+10        2119844  12211.76174
## 169                   Solomon Islands 2.125868e+08         724273    293.51746
## 170                           Somalia 8.926861e+08       17597511     50.72797
## 171                      South Africa 6.347067e+11       59893885  10597.18638
## 172                       South Korea 3.337672e+11       51815810   6441.41619
## 173                       South Sudan 7.882633e+08       10913164     72.23050
## 174                             Spain 4.764031e+11       47558630  10017.17504
## 175                         Sri Lanka 1.028981e+10       21832143    471.31478
## 176                             Sudan 8.726657e+09       46874204    186.17185
## 177                          Suriname 3.242840e+09         618040   5246.97468
## 178                            Sweden 2.394784e+11       10549347  22700.78219
## 179                       Switzerland 1.281434e+11        8740472  14660.92604
## 180                             Syria 4.260710e+10       22125249   1925.72280
## 181                            Taiwan 1.862882e+11       23893394   7796.63988
## 182                        Tajikistan 2.000847e+10        9952787   2010.33831
## 183                          Tanzania 4.903444e+09       65497748     74.86432
## 184                          Thailand 1.238806e+11       71697030   1727.83503
## 185                              Togo 1.314020e+09        8848699    148.49862
## 186                             Tonga 9.236051e+07         106858    864.32939
## 187               Trinidad and Tobago 4.497699e+10        1531044  29376.67870
## 188                           Tunisia 1.884400e+10       12356117   1525.07447
## 189                            Turkey 2.201051e+11       85341241   2579.11750
## 190                      Turkmenistan 6.537110e+10        6430770  10165.36126
## 191                            Tuvalu 4.456110e+06          11312    393.92769
## 192                            Uganda 2.101097e+09       47249585     44.46804
## 193                           Ukraine 1.213335e+12       39701739  30561.26580
## 194              United Arab Emirates 8.106576e+10        9441129   8586.44735
## 195                    United Kingdom 6.162082e+12       67508936  91278.01797
## 196                     United States 1.906877e+13      338289857  56368.13240
## 197                           Uruguay 1.221006e+10        3422794   3567.27912
## 198                        Uzbekistan 1.978867e+11       34627652   5714.70143
## 199                           Vanuatu 1.142344e+08         326740    349.61854
## 200                         Venezuela 2.335395e+11       28301696   8251.78637
## 201                           Vietnam 7.262503e+10       98186856    739.66144
## 202                             Yemen 1.421732e+10       33696614    421.92130
## 203                            Zambia 8.811259e+09       20017675    440.17392
## 204                          Zimbabwe 2.936469e+10       16320537   1799.24804
```

```r
#renaming column names
colnames(CO2total_byCountry)[2] <- "CO2.Total.Per.Country"
colnames(CO2total_byCountry)[4] <- "CO2.per.Person.per.Country"
```

```
summary(CO2total_byCountry)
```

```
##    Country          CO2.Total.Per.Country Population.2022.
##  Length:204         Min.   :4.456e+06     Min.   :1.131e+04
##  Class :character   1st Qu.:1.373e+09     1st Qu.:1.516e+06
##  Mode  :character   Median :1.078e+10     Median :8.068e+06
##                     Mean   :3.024e+11     Mean   :3.938e+07
##                     3rd Qu.:8.813e+10     3rd Qu.:2.863e+07
##                     Max.   :1.907e+13     Max.   :1.426e+09
##  CO2.per.Person.per.Country
##  Min.   :     6.49
##  1st Qu.:   400.45
##  Median :  2113.25
##  Mean   :  9011.85
##  3rd Qu.: 10185.96
##  Max.   :154613.14
```

```
CO2total_byCountry
```

```
##                               Country CO2.Total.Per.Country Population.2022.
## 1                         Afghanistan          3.754106e+09         41128771
## 2                             Albania          9.250246e+09          2842321
## 3                             Algeria          9.582024e+10         44903225
## 4                             Andorra          2.360722e+08            79824
## 5                              Angola          1.143158e+10         35588987
## 6                 Antigua and Barbuda          6.376165e+08            93763
## 7                           Argentina          2.632189e+11         45510318
## 8                             Armenia          1.430517e+10          2780469
## 9                               Aruba          2.357567e+09           107825
## 10                          Australia          5.693351e+11         26177413
## 11                            Austria          3.074275e+11          8939617
## 12                         Azerbaijan          8.853483e+10         10358074
## 13                            Bahamas          5.773362e+09           409984
## 14                            Bahrain          2.037107e+10          1472233
## 15                         Bangladesh          2.390055e+10        171186372
## 16                           Barbados          1.337450e+09           281635
## 17                            Belarus          1.809370e+11          9534954
## 18                            Belgium          7.903086e+11         11655930
## 19                             Belize          4.207057e+08           405272
## 20                              Benin          1.485290e+09         13352864
## 21                             Bhutan          2.066234e+08           782455
## 22                            Bolivia          1.019115e+10         12224110
## 23             Bosnia and Herzegovina          2.886810e+10          3233526
## 24                           Botswana          2.362863e+09          2630296
## 25                             Brazil          3.713855e+11        215313498
## 26                             Brunei          1.074748e+10           449002
## 27                           Bulgaria          1.331526e+11          6781953
## 28                       Burkina Faso          9.303006e+08         22673762
## 29                            Burundi          2.720993e+08         12889576
## 30                           Cambodia          1.866981e+09         16767842
## 31                           Cameroon          4.568516e+09         27914536
## 32                             Canada          1.255512e+12         38454327
```

```
## 33          Central African Republic          2.957916e+08          5579144
## 34                              Chad          4.866396e+08         17723315
## 35                             Chile          8.188228e+10         19603733
## 36                             China          4.162896e+12       1425887337
## 37                          Colombia          9.086583e+10         51874024
## 38                           Comoros          9.363528e+07           836774
## 39                             Congo          1.625597e+09          5835340
## 40                        Costa Rica          5.276408e+09          5180829
## 41                     Cote d'Ivoire          7.587251e+09         95930038
## 42                           Croatia          3.273520e+10          4030358
## 43                              Cuba          5.034312e+10         11212191
## 44                           Curacao          2.561368e+10           165663
## 45                            Cyprus          6.666480e+09          1251488
## 46                           Czechia          6.045514e+11         10755398
## 47      Democratic Republic of Congo          7.464739e+09         95930038
## 48                           Denmark          1.823616e+11          5882261
## 49                          Djibouti          4.713698e+08          1120849
## 50                          Dominica          9.199167e+07            72737
## 51                Dominican Republic          1.494841e+10         11228821
## 52                           Ecuador          2.562314e+10         18001000
## 53                             Egypt          1.264498e+11        110990103
## 54                       El Salvador          5.108406e+09          6336392
## 55                 Equatorial Guinea          1.776225e+09          1674908
## 56                           Eritrea          2.585497e+08          3684032
## 57                           Estonia          6.332375e+10          1326062
## 58                          Eswatini          8.891676e+08          1201670
## 59                          Ethiopia          4.277616e+09        123379924
## 60                              Fiji          1.275528e+09           929766
## 61                           Finland          1.001889e+11          5540745
## 62                            France          2.238247e+12         64626628
## 63                     French Guiana          6.071543e+08           304557
## 64                             Gabon          6.993919e+09          2388992
## 65                            Gambia          2.716380e+08          2705992
## 66                           Georgia          2.531358e+10          3744385
## 67                           Germany          5.300531e+12         83369843
## 68                             Ghana          7.399346e+09         33475870
## 69                            Greece          1.036874e+11         10384971
## 70                         Greenland          9.928700e+08            56466
## 71                           Grenada          1.607098e+08           125438
## 72                        Guadeloupe          1.672795e+09           395752
## 73                         Guatemala          8.902918e+09         17843908
## 74                            Guinea          1.924528e+09         13859341
## 75                            Guyana          2.930467e+09           808726
## 76                             Haiti          1.564480e+09         11584996
## 77                          Honduras          4.863815e+09         10432860
## 78                         Hong Kong          3.593146e+10          7488865
## 79                           Hungary          2.273008e+11          9967308
## 80                           Iceland          4.174625e+09           372899
## 81                             India          1.089952e+12       1417173173
## 82                         Indonesia          2.936194e+11        275501339
## 83                              Iran          4.173757e+11         88550570
## 84                              Iraq          9.716365e+10         44496122
## 85                           Ireland          7.438604e+10          5023109
## 86                            Israel          5.355184e+10          9038309
```

```
## 87                               Italy         8.342234e+11          59037474
## 88                             Jamaica         1.248806e+10           2827377
## 89                               Japan         2.051064e+12         123951692
## 90                              Jordan         1.281551e+10          11285869
## 91                          Kazakhstan         4.539328e+11          19397998
## 92                               Kenya         1.081293e+10          54027487
## 93                            Kiribati         4.856884e+07            131232
## 94                              Kosovo         7.308271e+08           1802250
## 95                              Kuwait         6.284507e+10           4268873
## 96                          Kyrgyzstan         3.493852e+10           6630623
## 97                                Laos         1.297428e+09           7529475
## 98                              Latvia         3.944943e+10           1850651
## 99                             Lebanon         1.560259e+10           5489739
## 100                            Lesotho         9.357852e+08           2305825
## 101                            Liberia         1.693776e+09           5302681
## 102                              Libya         4.855690e+10           6812341
## 103                      Liechtenstein         1.034699e+08             39327
## 104                          Lithuania         6.299174e+10           2750055
## 105                         Luxembourg         2.758179e+10            647599
## 106                              Macao         1.169537e+09            670052
## 107                         Madagascar         2.256616e+09          29611714
## 108                             Malawi         1.385338e+09          20405317
## 109                           Malaysia         1.030422e+11          33938221
## 110                           Maldives         2.781142e+08            523787
## 111                               Mali         9.651067e+08          22593590
## 112                              Malta         2.596434e+09            533286
## 113                   Marshall Islands         4.552062e+07             41569
## 114                         Martinique         1.971384e+09            367507
## 115                         Mauritania         1.457707e+09           4736139
## 116                          Mauritius         2.135723e+09           1299469
## 117                            Mayotte         8.141350e+07            326101
## 118                             Mexico         5.635544e+11         127504125
## 119                         Micronesia         5.337956e+07            114164
## 120                            Moldova         6.240856e+10           3272996
## 121                           Mongolia         1.241428e+10           3398366
## 122                         Montenegro         3.032392e+09            627082
## 123                            Morocco         3.494891e+10          37457971
## 124                         Mozambique         5.181102e+09          32969518
## 125                            Myanmar         1.545320e+10          54179306
## 126                            Namibia         9.355316e+08           2567012
## 127                              Nauru         1.510645e+08             12668
## 128                              Nepal         1.965991e+09          30547580
## 129                        Netherlands         4.948726e+11          17564014
## 130                      New Caledonia         3.816046e+09            291913
## 131                        New Zealand         6.918458e+10           5185288
## 132                          Nicaragua         4.095118e+09           6948392
## 133                              Niger         9.251186e+08          26207977
## 134                            Nigeria         8.799022e+10         218541212
## 135                        North Korea         1.787941e+11          26069416
## 136                    North Macedonia         2.145468e+10           2093599
## 137                             Norway         1.040229e+11           5434319
## 138                               Oman         1.781582e+10           4576298
## 139                           Pakistan         9.551340e+10         235824862
## 140                              Palau         2.788467e+08             18055
```

```
## 141                        Palestine       7.420809e+08       5250072
## 142                           Panama       6.685614e+09       4408581
## 143                 Papua New Guinea       3.285263e+09      10142619
## 144                         Paraguay       3.313264e+09       6780744
## 145                             Peru       6.016985e+10      34049588
## 146                      Philippines       7.225130e+10     115559009
## 147                           Poland       1.311554e+12      39857145
## 148                         Portugal       7.955163e+10      10270865
## 149                      Puerto Rico       2.109365e+07       3252407
## 150                            Qatar       3.334660e+10       2695122
## 151                          Reunion       2.138660e+09        974052
## 152                          Romania       3.294970e+11      19659267
## 153                           Russia       4.080739e+12     144713314
## 154                           Rwanda       6.174393e+08      13776698
## 155            Saint Kitts and Nevis       9.972552e+07         47657
## 156                      Saint Lucia       2.700456e+08        179857
## 157 Saint Vincent and the Grenadines       1.302473e+08        103948
## 158                            Samoa       1.412329e+08        222382
## 159            Sao Tome and Principe       6.885642e+07        227380
## 160                     Saudi Arabia       2.933864e+11      36408820
## 161                          Senegal       4.788479e+09      17316449
## 162                           Serbia       8.595910e+10       7221365
## 163                       Seychelles       2.295101e+08        107118
## 164                     Sierra Leone       1.098976e+09       8605718
## 165                        Singapore       5.106388e+10       5975689
## 166        Sint Maarten (Dutch part)       3.057584e+09         44015
## 167                         Slovakia       1.946301e+11       5643453
## 168                         Slovenia       2.588703e+10       2119844
## 169                  Solomon Islands       2.125868e+08        724273
## 170                          Somalia       8.926861e+08      17597511
## 171                     South Africa       6.347067e+11      59893885
## 172                      South Korea       3.337672e+11      51815810
## 173                      South Sudan       7.882633e+08      10913164
## 174                            Spain       4.764031e+11      47558630
## 175                        Sri Lanka       1.028981e+10      21832143
## 176                            Sudan       8.726657e+09      46874204
## 177                         Suriname       3.242840e+09        618040
## 178                           Sweden       2.394784e+11      10549347
## 179                      Switzerland       1.281434e+11       8740472
## 180                            Syria       4.260710e+10      22125249
## 181                           Taiwan       1.862882e+11      23893394
## 182                       Tajikistan       2.000847e+10       9952787
## 183                         Tanzania       4.903444e+09      65497748
## 184                         Thailand       1.238806e+11      71697030
## 185                             Togo       1.314020e+09       8848699
## 186                            Tonga       9.236051e+07        106858
## 187              Trinidad and Tobago       4.497699e+10       1531044
## 188                          Tunisia       1.884400e+10      12356117
## 189                           Turkey       2.201051e+11      85341241
## 190                     Turkmenistan       6.537110e+10       6430770
## 191                           Tuvalu       4.456110e+06         11312
## 192                           Uganda       2.101097e+09      47249585
## 193                          Ukraine       1.213335e+12      39701739
## 194             United Arab Emirates       8.106576e+10       9441129
```

```
## 195                    United Kingdom          6.162082e+12          67508936
## 196                     United States          1.906877e+13         338289857
## 197                           Uruguay          1.221006e+10           3422794
## 198                        Uzbekistan          1.978867e+11          34627652
## 199                           Vanuatu          1.142344e+08            326740
## 200                         Venezuela          2.335395e+11          28301696
## 201                           Vietnam          7.262503e+10          98186856
## 202                             Yemen          1.421732e+10          33696614
## 203                            Zambia          8.811259e+09          20017675
## 204                          Zimbabwe          2.936469e+10          16320537
##     CO2.per.Person.per.Country
## 1                     91.27688
## 2                   3254.46901
## 3                   2133.92786
## 4                   2957.40938
## 5                    321.21110
## 6                   6800.29918
## 7                   5783.71851
## 8                   5144.87717
## 9                  21864.75420
## 10                 21749.09751
## 11                 34389.34208
## 12                  8547.42184
## 13                 14081.92069
## 14                 13836.85123
## 15                   139.61713
## 16                  4748.87638
## 17                 18976.18109
## 18                 67803.13847
## 19                  1038.08245
## 20                   111.23381
## 21                   264.07067
## 22                   833.69270
## 23                  8927.74655
## 24                   898.32601
## 25                  1724.85931
## 26                 23936.38157
## 27                 19633.37493
## 28                    41.02983
## 29                    21.11003
## 30                   111.34297
## 31                   163.66082
## 32                 32649.42101
## 33                    53.01738
## 34                    27.45759
## 35                  4176.87177
## 36                  2919.51278
## 37                  1751.66338
## 38                   111.90033
## 39                   278.57802
## 40                  1018.44851
## 41                    79.09150
## 42                  8122.15727
## 43                  4490.03454
```

```
## 44                154613.13722
## 45                  5326.84308
## 46                 56209.11827
## 47                    77.81441
## 48                 31001.94924
## 49                   420.54710
## 50                  1264.71636
## 51                  1331.25350
## 52                  1423.42850
## 53                  1139.28898
## 54                   806.20113
## 55                  1060.49079
## 56                    70.18116
## 57                 47753.23364
## 58                   739.94322
## 59                    34.67027
## 60                  1371.88029
## 61                 18082.21241
## 62                 34633.51398
## 63                  1993.56544
## 64                  2927.56070
## 65                   100.38387
## 66                  6760.41120
## 67                 63578.51556
## 68                   221.03522
## 69                  9984.37353
## 70                 17583.50129
## 71                  1281.18892
## 72                  4226.87802
## 73                   498.93322
## 74                   138.86142
## 75                  3623.56028
## 76                   135.04364
## 77                   466.20154
## 78                  4797.98451
## 79                 22804.63767
## 80                 11195.05680
## 81                   769.10266
## 82                  1065.76379
## 83                  4713.41577
## 84                  2183.64319
## 85                 14808.76544
## 86                  5924.98426
## 87                 14130.40539
## 88                  4416.83733
## 89                 16547.28791
## 90                  1135.53615
## 91                 23401.01517
## 92                   200.13763
## 93                   370.09905
## 94                   405.50819
## 95                 14721.70122
## 96                  5269.26585
## 97                   172.31326
```

```
## 98                    21316.51367
## 99                     2842.13707
## 100                     405.83532
## 101                     319.41874
## 102                    7127.78454
## 103                    2631.01454
## 104                   22905.63096
## 105                   42590.84014
## 106                    1745.44266
## 107                      76.20688
## 108                      67.89103
## 109                    3036.17044
## 110                     530.96816
## 111                      42.71595
## 112                    4868.74661
## 113                    1095.06175
## 114                    5364.20751
## 115                     307.78380
## 116                    1643.53507
## 117                     249.65732
## 118                    4419.89154
## 119                     467.56909
## 120                   19067.71588
## 121                    3653.01578
## 122                    4835.71903
## 123                     933.01664
## 124                     157.14825
## 125                     285.22329
## 126                     364.44378
## 127                   11924.89304
## 128                      64.35831
## 129                   28175.37243
## 130                   13072.54726
## 131                   13342.47511
## 132                     589.36198
## 133                      35.29912
## 134                     402.62529
## 135                    6858.38430
## 136                   10247.75238
## 137                   19141.84620
## 138                    3893.06290
## 139                     405.01837
## 140                   15444.29022
## 141                     141.34681
## 142                    1516.50029
## 143                     323.90677
## 144                     488.62835
## 145                    1767.12425
## 146                     625.23295
## 147                   32906.36461
## 148                    7745.36844
## 149                       6.48555
## 150                   12372.94745
## 151                    2195.63209
```

```
## 152                   16760.39336
## 153                   28198.77848
## 154                      44.81765
## 155                    2092.56806
## 156                    1501.44622
## 157                    1253.00450
## 158                     635.09138
## 159                     302.82532
## 160                    8058.11261
## 161                     276.52777
## 162                   11903.44211
## 163                    2142.59121
## 164                     127.70296
## 165                    8545.27034
## 166                   69466.86402
## 167                   34487.76021
## 168                   12211.76174
## 169                     293.51746
## 170                      50.72797
## 171                   10597.18638
## 172                    6441.41619
## 173                      72.23050
## 174                   10017.17504
## 175                     471.31478
## 176                     186.17185
## 177                    5246.97468
## 178                   22700.78219
## 179                   14660.92604
## 180                    1925.72280
## 181                    7796.63988
## 182                    2010.33831
## 183                      74.86432
## 184                    1727.83503
## 185                     148.49862
## 186                     864.32939
## 187                   29376.67870
## 188                    1525.07447
## 189                    2579.11750
## 190                   10165.36126
## 191                     393.92769
## 192                      44.46804
## 193                   30561.26580
## 194                    8586.44735
## 195                   91278.01797
## 196                   56368.13240
## 197                    3567.27912
## 198                    5714.70143
## 199                     349.61854
## 200                    8251.78637
## 201                     739.66144
## 202                     421.92130
## 203                     440.17392
## 204                    1799.24804
```

The results of `summary()` on the CO2total_byCountry data set indicate that the average total CO2 emissions in the data set is 3.024e+11 tons.

Aim 1.2 A: To visualize the cumulative CO2 emissions by country and continent

```
CO2total_byCountry$continent <- countrycode(sourcevar = CO2total_byCountry[,"Country"],
                                   origin = "country.name",
                                   destination = "continent")
```

```
## Warning in countrycode_convert(sourcevar = sourcevar, origin = origin, destination = dest, : Some val
```

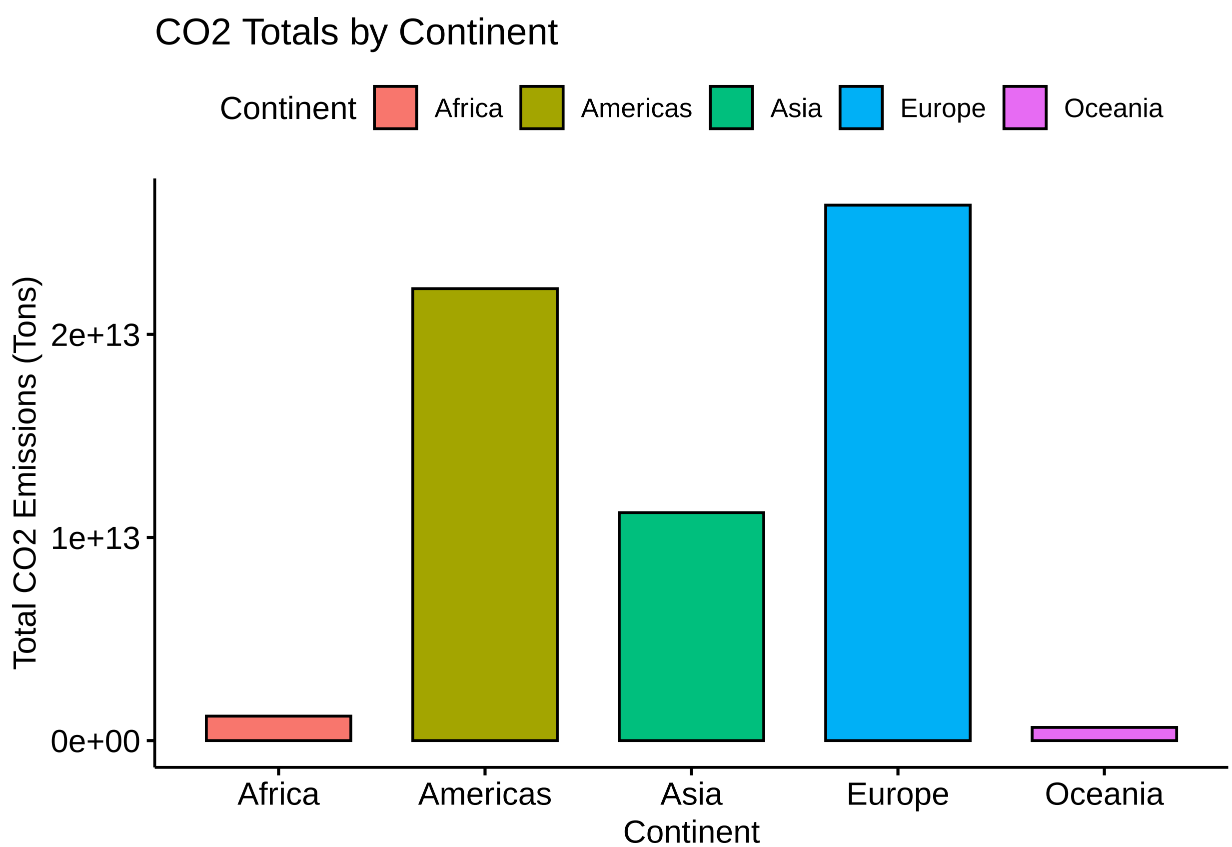
```
#summing the total CO2 emissions by geographic region: Oceania, Africa, Asia, Americas, and Europe (Ant
CO2total_byContinent <- aggregate(CO2total_byCountry$CO2.Total.Per.Country, by=list(Category=CO2total_by
CO2total_byContinent
```

```
##   Category            x
## 1   Africa 1.204794e+12
## 2 Americas 2.225088e+13
## 3     Asia 1.122400e+13
## 4   Europe 2.636167e+13
## 5  Oceania 6.479854e+11
```

```
colnames(CO2total_byContinent) <- c("Geographic_Region","Total_CO2_Emissions")

CO2total_byContinent <-as.data.frame(CO2total_byContinent)

continent_barplot <- ggbarplot(data=CO2total_byContinent,x="Geographic_Region",y="Total_CO2_Emissions",f
continent_barplot <- continent_barplot + labs(x="Continent",
y="Total CO2 Emissions (Tons)",title="CO2 Totals by Continent",fill="Continent")
continent_barplot
```



Create a map visualizing the amount of CO2 emission by country

To visualize the CO2 emissions by country using a world map, load in ggplot2's map data via the code below. This data set contains longitude, latitude, and country codes to plot the world map. The cleaned CO2 data set will merge with the world data set by country name.

```
world <- map_data("world")
#table(world) #world data codes country names differently. Change prior to joining
#Add the data you want to map countries by to world
#In this example, I add lengths of country names plus some offset
```

Creating a barplot & world map to display CO2 emissions per country

The world data set codes some country names differently. So, prior to joining the CO2 and world datasets, match the country names for "United States" and "Democratic Republic of the Congo" to the way the world dataset codes these countries.

```
which(CO2total_byCountry$Country=="United States")
```

```
## [1] 196
```

```
which(CO2total_byCountry$Country=="Democratic Republic of Congo")
```

```
## [1] 47
```

```r
CO2total_byCountry$Country[196] <- "USA" #renaming "United States" to "USA", to ensure uniformity in th
CO2total_byCountry$Country[47] <- "Democratic Republic of the Congo"
CO2total_byCountry[196,]
```

```
##     Country CO2.Total.Per.Country Population.2022. CO2.per.Person.per.Country
## 196     USA          1.906877e+13        338289857                   56368.13
##     continent
## 196  Americas
```

```r
#renaming "region" in the data we are importing to "country"
world <- inner_join(world,CO2total_byCountry,by=c("region"="Country"))
#remove duplicates
world <- world[!duplicated(world),]
world$CO2.Total.Per.Country[world$region=="USA"]
```

```
##    [1] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##    [6] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [11] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [16] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [21] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [26] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [31] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [36] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [41] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [46] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [51] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [56] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [61] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [66] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [71] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [76] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [81] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [86] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [91] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##   [96] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [101] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [106] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [111] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [116] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [121] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [126] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [131] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [136] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [141] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [146] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [151] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [156] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [161] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [166] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [171] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [176] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
##  [181] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
```

```
## [186] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [191] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [196] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [201] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [206] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [211] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
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## [221] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [226] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [231] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
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## [246] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [251] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [256] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [261] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
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## [391] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
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```

```
## [456] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
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## [471] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [476] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
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## [5656] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5661] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5666] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5671] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5676] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5681] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5686] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5691] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5696] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5701] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5706] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5711] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5716] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5721] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5726] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5731] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5736] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5741] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5746] 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13 1.906877e+13
## [5751] 1.906877e+13 1.906877e+13 1.906877e+13
```
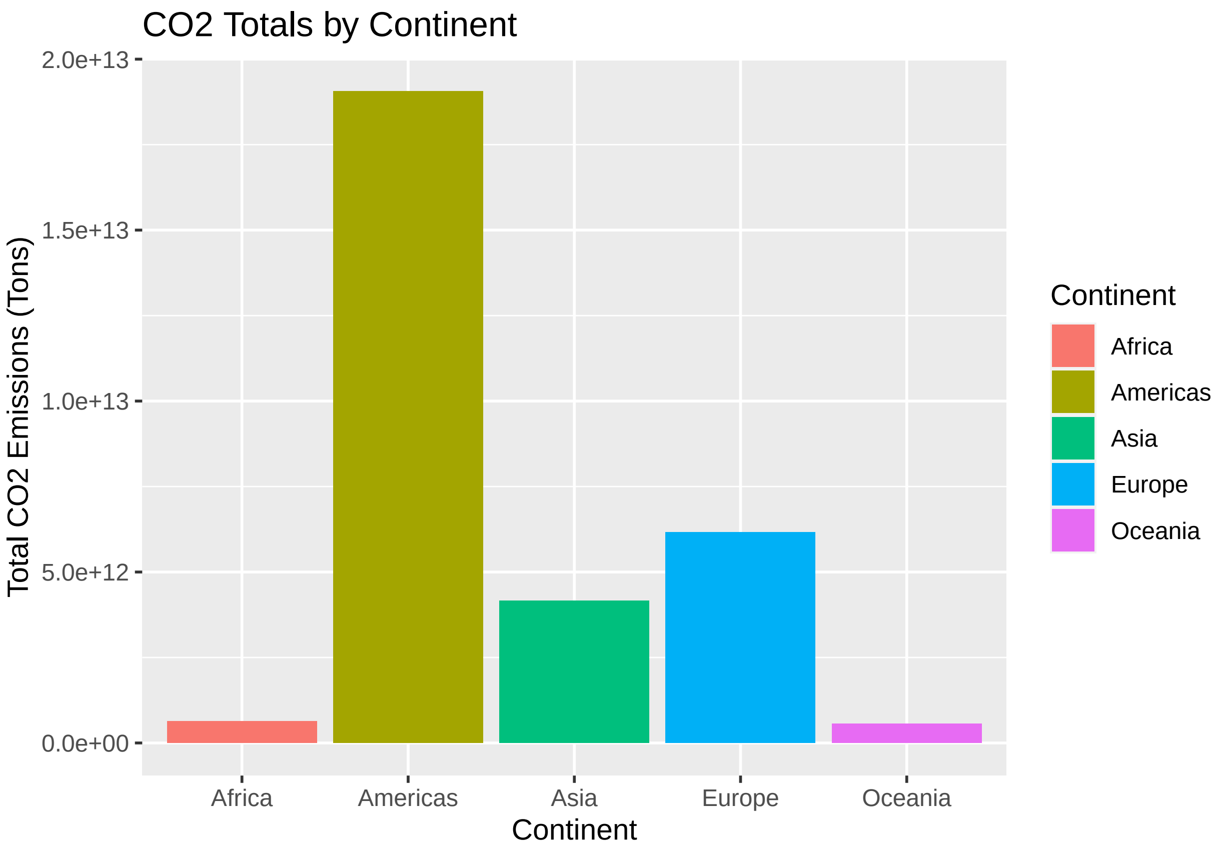
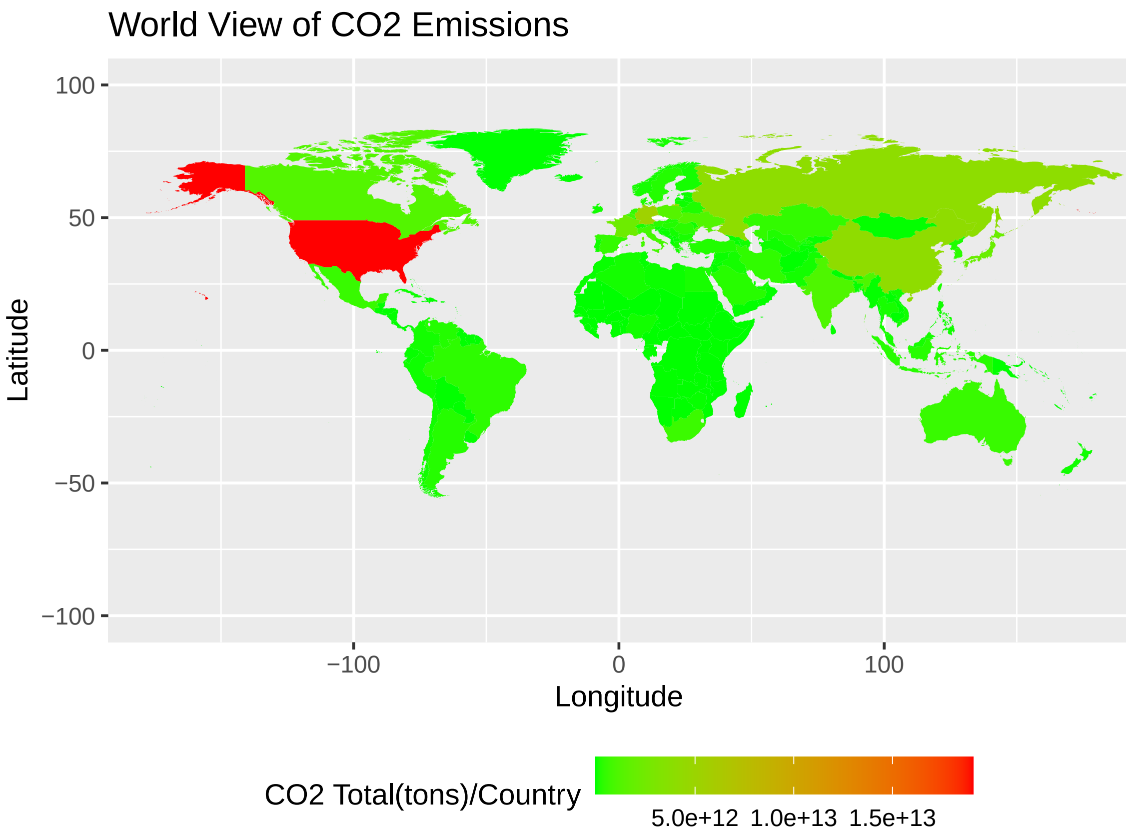

```r
#barplot of CO2 total emissions in world map
continent_barplot <- ggplot(data=subset(CO2total_byCountry,!is.na(continent)),aes(x=continent,y=CO2.Tota

continent_barplot <- continent_barplot + labs(x="Continent",y="Total CO2 Emissions (Tons)",title="CO2 To
continent_barplot
```




```
#graphically presenting CO2 emission in a world map
gg <- ggplot() + theme(legend.position="bottom",legend.key.size = unit(0.5, "cm"),legend.key.width = uni
gg <- gg + geom_map(data=world, map=world, aes(map_id=region,x=long, y=lat, fill=CO2.Total.Per.Country)
```

```
## Warning in geom_map(data = world, map = world, aes(map_id = region, x = long, :
## Ignoring unknown aesthetics: x and y
```

```
#changing features of world map (color, axes scales, adding a title, etc)
gg <- gg + scale_fill_gradient(low = "green", high = "red", guide = "colourbar",aesthetics = "fill") + s
gg <- gg + coord_equal() + ggtitle("World View of CO2 Emissions")
gg
```



Making a world map just for 2019 data:

To see if there's a difference between historical cumulative CO2 and 2019 CO2 emissions, we made a world map just for 2019 emissions data.

```
cleanedCO2 <- CO2
cleanedCO2_2019<-cleanedCO2[cleanedCO2$Year == "2019",] #below code is same as cumulative analysis
CO2total_byCountry_2019 <- aggregate(cleanedCO2_2019$CO2.emission..Tons., by=list(Category=cleanedCO2_2
colnames(CO2total_byCountry_2019)[1] <- "Country"
colnames(CO2total_byCountry_2019)[2] <- "CO2.Total"
CO2total_byCountry_2019<- CO2total_byCountry_2019 %>%
  inner_join(cleanedCO2_2019) %>%
  select("Country","CO2.Total","Population.2022.")
which(CO2total_byCountry_2019$Country=="United States")
```

```
## [1] 196
```

```
which(CO2total_byCountry_2019$Country=="Democratic Republic of Congo")
```

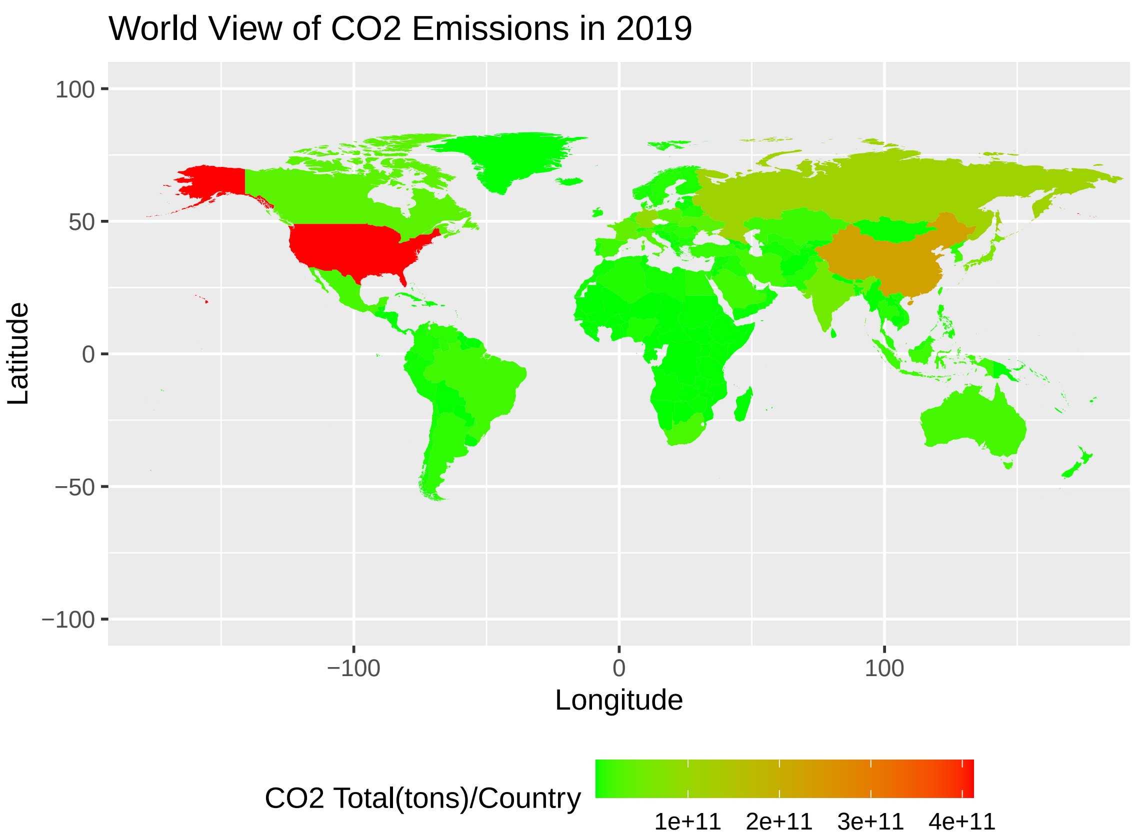
```
## [1] 47
```

```
CO2total_byCountry_2019$Country[196] <- "USA"#coding USA differently #because world data has it as USA,
CO2total_byCountry_2019$Country[47] <- "Democratic Republic of the Congo"
world2 <- map_data("world")
world2 <- inner_join(world2,CO2total_byCountry_2019,by=c("region"="Country"))
```

```r
gg2 <- ggplot() + theme(legend.position="bottom",legend.key.size = unit(0.5, "cm"),legend.key.width = ur
gg2 <- gg2 + geom_map(data=world2, map=world2, aes(map_id=region,x=long, y=lat, fill=CO2.Total))
```

```
## Warning in geom_map(data = world2, map = world2, aes(map_id = region, x =
## long, : Ignoring unknown aesthetics: x and y
```

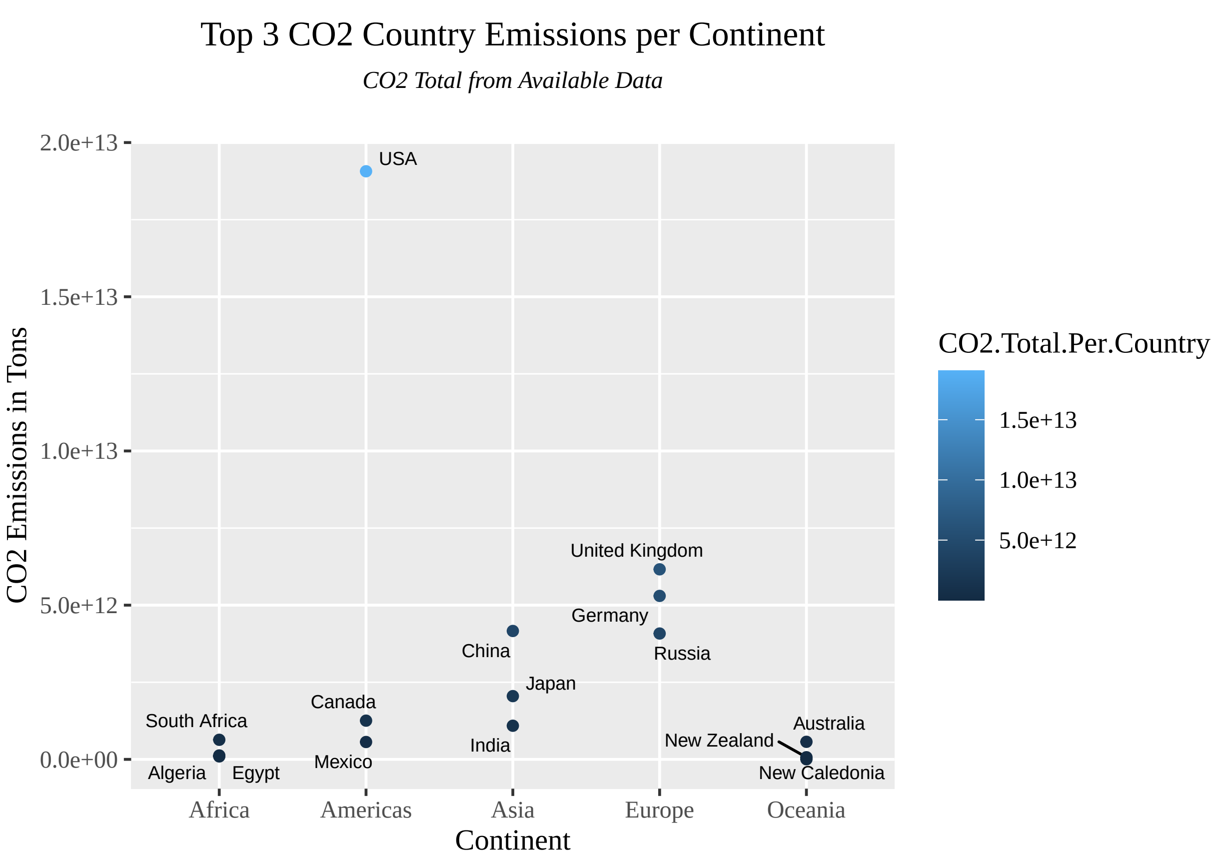
```r
#changing features of world map (color, axes scales, adding a title, etc)
gg2 <- gg2 + scale_fill_gradient(low = "green", high = "red", guide = "colourbar",aesthetics = "fill") +
gg2 <- gg2 + coord_equal() + ggtitle("World View of CO2 Emissions in 2019")
gg2
```



Analyze the top 3 countries that emit the most CO2 by geographic region

```r
#finding and plotting the top 3 countries in each geographic region that emit the most CO2
topCountries <- CO2total_byCountry[order(-CO2total_byCountry$CO2.Total.Per.Country),] #get CO2 emission

#finding the top 3 countries in each geographic region that emit the most CO2
top3Africa<-head(topCountries[topCountries$continent=="Africa",],3)
top3Americas<-head(topCountries[topCountries$continent=="Americas",],3)
top3Asia<-head(topCountries[topCountries$continent=="Asia",],3)
top3Europe<-head(topCountries[topCountries$continent=="Europe",],3)
top3Oceania<-head(topCountries[topCountries$continent=="Oceania",],3)
```

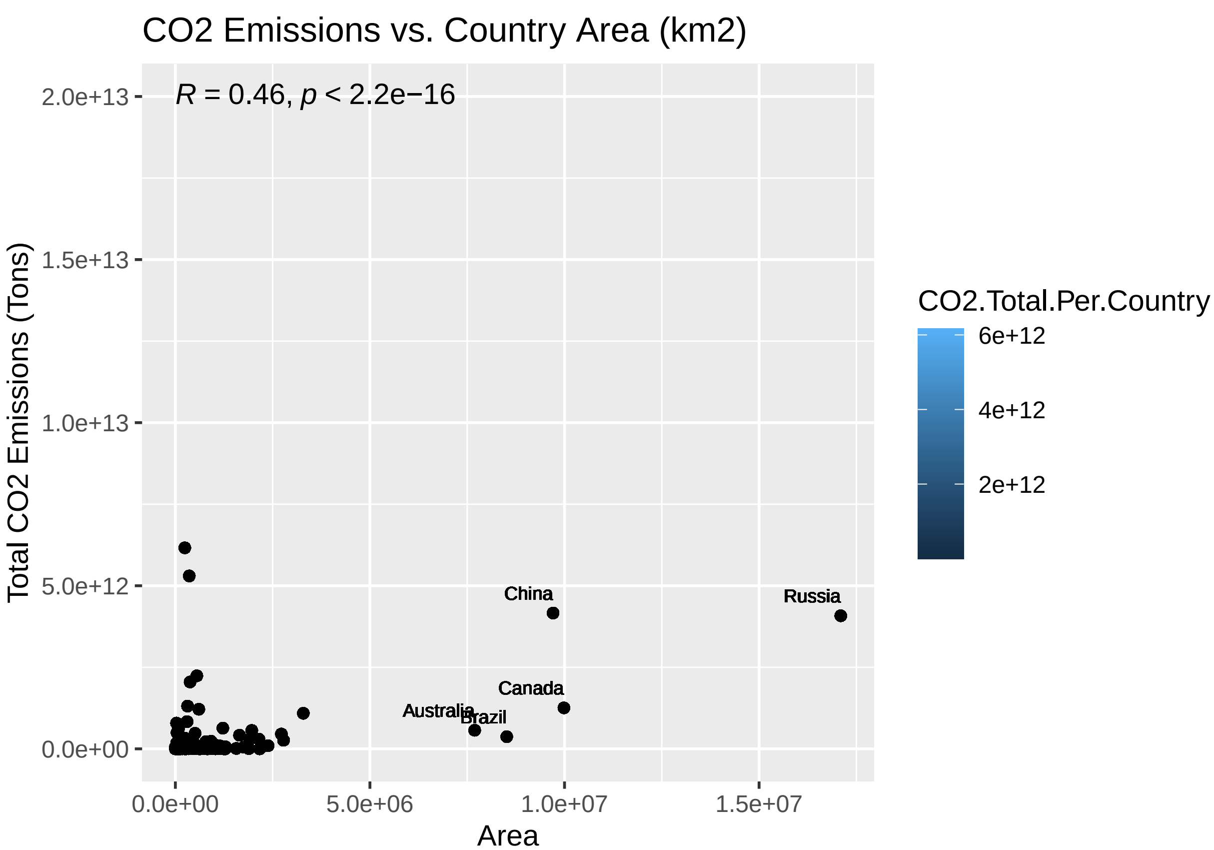
```r
top3pContinent <- rbind(top3Africa,top3Americas,top3Asia,top3Europe,top3Oceania)

#soring the data into a variable for plotting
mostEmissions <- ggplot(top3pContinent,aes(x=continent,y=CO2.Total.Per.Country))

#plotting the data
mostEmissions<- mostEmissions +
  geom_text_repel(aes(label = Country), size = 2.5)+
  geom_point(aes(colour=CO2.Total.Per.Country))+
  ggtitle(expression(atop("Top 3 CO2 Country Emissions per Continent",
                          atop(italic("CO2 Total from Available Data"),""))))+
  xlab("Continent") +
  ylab("CO2 Emissions in Tons")+
  theme(text = element_text(family = 'serif'))+
  theme(plot.title = element_text(hjust=0.5))

mostEmissions
```



1.2B: C02 Emissions by Area:

```r
cleanedCO2 <- CO2
#identified countries with NA values, then excluded the lower 50% of the countries who contributed the
```

```r
#joining country, total area of each country, percent of global land mass that the country takes up, an

cleanedCO2 <- inner_join(cleanedCO2,CO2total_byCountry) %>% select("Country","Area","CO2.Total.Per.Coun

#plotting a scatter plot for country land mass vs. total CO2 emissions per, and finding the correlation
areavsco2plot <- ggplot(data=cleanedCO2,aes(x=Area,y=CO2.Total.Per.Country))+
  geom_point(aes(fill=CO2.Total.Per.Country)) +
  ggtitle("Country Area vs. Total CO2 Emission") +
  labs(x="Area",y="Total CO2 Emissions (Tons)",
       title="CO2 Emissions vs. Country Area (km2)") +
  geom_text(aes(label=ifelse(Area>5e6,as.character(Country),'')),size=2.5,hjust=1,vjust=-1) +
  stat_cor(method = "pearson",label.x = 0e0, label.y = 2e13)

areavsco2plot
```



C02 Emissions in Developed vs. Non-developed:

```r
x <- getURL("https://raw.githubusercontent.com/owid/co2-data/master/owid-co2-data.csv")
dat2 <- read.csv(text = x)
y <- getURL("https://raw.githubusercontent.com/jliuob/QBSsquad/main/CO2_Cleaned_V2.csv")
dat1 <- read.csv(text = y)
dat1 <- dat1[,1:7]
class(dat1)
```

```
## [1] "data.frame"
```

```r
class(dat2)
```

```
## [1] "data.frame"
```

```r
colnames(dat1)[1] <- "Country"
```

```r
merged.dat <- sqldf("SELECT d1.Country, d1.year, d1.'CO2.emission..Tons.',
d2.gdp, d2.co2_per_gdp, d2.co2_per_capita, d2.coal_co2, d2.coal_co2_per_capita
      FROM 'dat1' AS d1
      JOIN 'dat2' AS d2
      ON d1.Country=d2.country
      AND d1.Year=d2.year")
dim(merged.dat)
```

```
## [1] 21731     8
```

```r
merged.dat <- na.omit(merged.dat)
View(merged.dat)
```

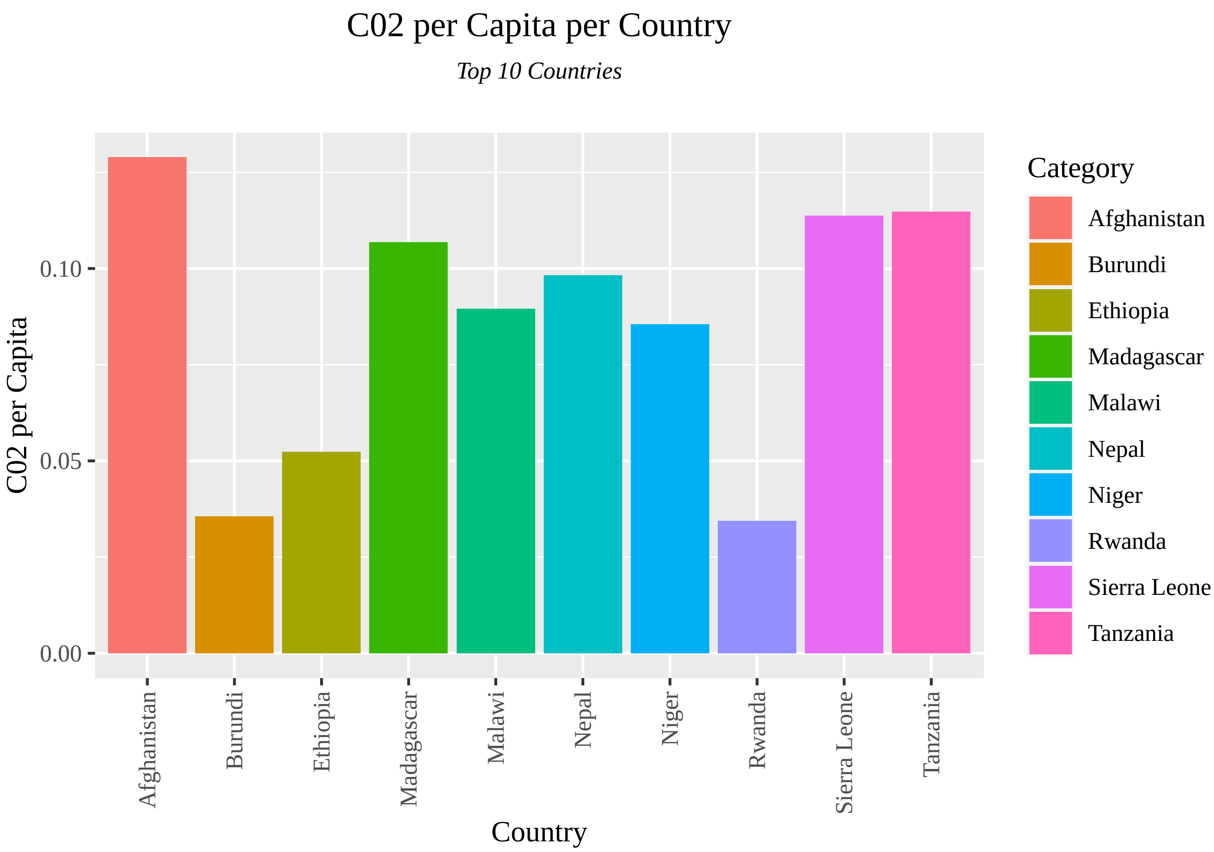
Finding CO2 per capita per country:

```r
#finding the average CO2 emissions per country
avgCO2byCountry <- aggregate(merged.dat$CO2.emission..Tons.,by=list(Category=merged.dat$Country), FUN=me

#finding the average gdp per country
#recode NAs to zero to run mean functions
merged.dat$gdp[is.na(merged.dat$gdp)] <- 0
avgGDP <- aggregate(merged.dat$gdp,by=list(Category=merged.dat$Country), FUN=mean)

merged.dat$gdp[merged.dat$Country=="Aruba"]
```

```
## numeric(0)
```

```r
#calculating the gdp per capita for each country
avgCO2perCapita <- aggregate(merged.dat$co2_per_capita,by=list(Category=merged.dat$Country), FUN=mean)

#omitting na values and finding the top 10 CO2 emissions per capita per country
avgCO2perCapita <-na.omit(avgCO2perCapita)
avgCO2perCapita_10 <- avgCO2perCapita[order(avgCO2perCapita$x),]
avgCO2perCapita_10 <- head(avgCO2perCapita_10,10)

#plotting top 10 CO2 emissions per capita per country
capitaplot <- ggplot(avgCO2perCapita_10,
                     aes(Category,x,fill=Category))+
  geom_bar(stat="identity")+
  scale_x_discrete(guide=guide_axis(angle = 90))+
  xlab("Country")+
```

```
  ylab("C02 per Capita")+
  ggtitle(expression(atop("C02 per Capita per Country",
                           atop(italic("Top 10 Countries"),"")))) +
  theme(plot.title = element_text(hjust=0.5))+
  theme(text = element_text(family = 'serif'))
capitaplot
```



C02 by GDP:

```
colnames(avgGDP) <- c("Country","GDP_Average") #renaming column names

#merging country, GDP_Average, and Population 2022 columns into one table
avgGDP <- avgGDP %>% inner_join(cleanedC02) %>% select("Country","GDP_Average","Population.2022.")
```

```
## Joining, by = "Country"
```

```
avgGDP <- avgGDP %>% mutate(GDPperCapita = GDP_Average/Population.2022.)

#creating ordinal data for developed vs. developing
#changed developed threshold to $9000 per capita because original GDP threshold was too conservative
develop_ord <- ifelse(avgGDP$GDPperCapita>=9000,"developed",
                      ifelse(avgGDP$GDPperCapita<9000,"developing",0))
avgGDP$DevelopStatus <- develop_ord
```

```
table(avgGDP$Country[avgGDP$GDPperCapita>=9000])
```

```
##
##              Armenia               Austria               Belarus
##                  271                   271                   271
##              Belgium                Canada            Costa Rica
##                  271                   271                   271
##              Croatia                Cyprus               Czechia
##                  271                   271                   271
##              Denmark               Estonia               Finland
##                  271                   271                   271
##               France               Georgia               Germany
##                  271                   271                   271
##            Hong Kong               Hungary               Iceland
##                  271                   271                   271
##              Ireland                Israel                 Italy
##                  271                   271                   271
##                Japan            Kazakhstan                Latvia
##                  271                   271                   271
##            Lithuania            Luxembourg                 Malta
##                  271                   271                   271
##          Netherlands                Norway                Russia
##                  271                   271                   271
##            Singapore              Slovakia              Slovenia
##                  271                   271                   271
##               Sweden           Switzerland                Taiwan
##                  271                   271                   271
##              Ukraine United Arab Emirates        United Kingdom
##                  271                   271                   271
##              Uruguay
##                  271
```

```
table(avgGDP$Country[avgGDP$GDPperCapita<9000])
```

```
##
##            Afghanistan                Albania                Algeria
##                    271                    271                    271
##                 Angola              Argentina              Australia
##                    271                    271                    271
##             Azerbaijan                Bahrain             Bangladesh
##                    271                    271                    271
##               Barbados                  Benin                Bolivia
##                    271                    271                    271
## Bosnia and Herzegovina               Botswana                 Brazil
##                    271                    271                    271
##               Bulgaria                Burundi               Cambodia
##                    271                    271                    271
##               Cameroon                  Chile                  China
##                    271                    271                    271
##               Colombia                   Cuba     Dominican Republic
##                    271                    271                    271
##                  Egypt            El Salvador               Eswatini
```

```
##                  271                 271                 271
##             Ethiopia               Ghana              Greece
##                  271                 271                 271
##            Guatemala               Haiti            Honduras
##                  271                 271                 271
##                India           Indonesia                Iran
##                  271                 271                 271
##                 Iraq             Jamaica              Jordan
##                  271                 271                 271
##                Kenya          Kyrgyzstan                Laos
##                  271                 271                 271
##              Lebanon             Lesotho               Libya
##                  271                 271                 271
##           Madagascar              Malawi            Malaysia
##                  271                 271                 271
##           Mauritania           Mauritius              Mexico
##                  271                 271                 271
##              Moldova            Mongolia          Montenegro
##                  271                 271                 271
##              Morocco          Mozambique             Myanmar
##                  271                 271                 271
##              Namibia               Nepal         New Zealand
##                  271                 271                 271
##                Niger             Nigeria         North Korea
##                  271                 271                 271
##      North Macedonia            Pakistan              Panama
##                  271                 271                 271
##             Paraguay                Peru         Philippines
##                  271                 271                 271
##               Poland            Portugal             Romania
##                  271                 271                 271
##               Rwanda             Senegal              Serbia
##                  271                 271                 271
##         Sierra Leone        South Africa         South Korea
##                  271                 271                 271
##                Spain           Sri Lanka               Syria
##                  271                 271                 271
##           Tajikistan            Tanzania            Thailand
##                  271                 271                 271
##  Trinidad and Tobago             Tunisia              Turkey
##                  271                 271                 271
##         Turkmenistan          Uzbekistan           Venezuela
##                  271                 271                 271
##              Vietnam               Yemen              Zambia
##                  271                 271                 271
##             Zimbabwe
##                  271
```

```
avgGDP$GDP_Average
```

```
##     [1] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##     [6] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##    [11] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##    [16] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
```

```
##  [21] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [26] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [31] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [36] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [41] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [46] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [51] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [56] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [61] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [66] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [71] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [76] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [81] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [86] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [91] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
##  [96] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [101] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [106] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [111] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [116] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [121] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [126] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [131] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [136] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [141] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [146] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [151] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [156] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [161] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [166] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [171] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [176] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [181] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [186] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [191] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [196] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [201] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [206] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [211] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [216] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [221] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [226] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [231] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [236] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [241] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [246] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [251] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
## [256] 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10 2.146437e+10
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## [36066] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36071] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36076] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36081] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36086] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36091] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36096] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36101] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36106] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36111] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36116] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36121] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36126] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36131] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36136] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36141] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36146] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36151] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36156] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36161] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36166] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36171] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36176] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36181] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36186] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36191] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36196] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
```
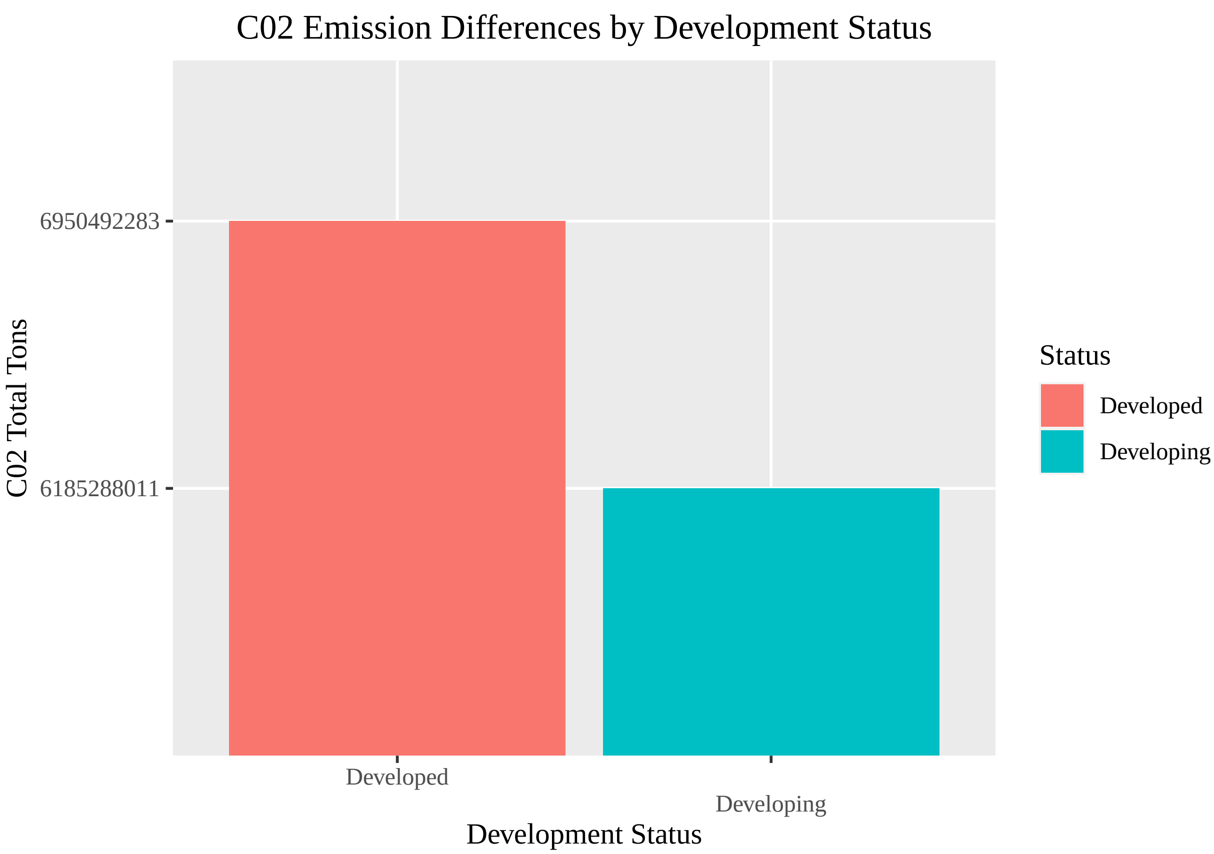

```
## [36201] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36206] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36211] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36216] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36221] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36226] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36231] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36236] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36241] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36246] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36251] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36256] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36261] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36266] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36271] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36276] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36281] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36286] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36291] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36296] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36301] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36306] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
## [36311] 1.542784e+10 1.542784e+10 1.542784e+10 1.542784e+10
```

```r
#merging CO2 Data
avgGDP <- avgGDP %>% inner_join(CO2_noduplicates) %>% select("Country","GDP_Average","Population.2022."
```

```
## Joining, by = c("Country", "Population.2022.")
```

```r
#categorizing developed nations into a developed variable
#categorizing developing nations into a developing variable
developed <- avgGDP[avgGDP$DevelopStatus=="developed",]
developing <- avgGDP[avgGDP$DevelopStatus=="developing",]
sumCO2Developed <- sum(developed$CO2.emission..Tons.)
sumCO2Developing <- sum(developing$CO2.emission..Tons.)

#creating a table and a barplot comparing developed vs developing nations total CO2 emissions
DevelopvsDeveloping <- matrix(ncol=2,nrow=2)
DevelopvsDeveloping <- as.data.frame(DevelopvsDeveloping)
colnames(DevelopvsDeveloping)<-c("CO2_Total","Status")
DevelopvsDeveloping[1,] <- c(as.numeric(sumCO2Developed),"Developed")
DevelopvsDeveloping[2,] <- c(as.numeric(sumCO2Developing),"Developing")

DevelopvDevelopingplot <- ggplot(DevelopvsDeveloping,
                                aes(x=Status,y=CO2_Total,fill=Status))+
  geom_bar(stat="identity") +
  theme(axis.text.x = element_text(size = 11)) +
  scale_x_discrete(guide = guide_axis(n.dodge = 3))+
  xlab(c("Development Status"))+
  ylab("CO2 Total Tons")+
  ggtitle("CO2 Emission Differences by Development Status")+
  theme_gray()+
  theme(plot.title = element_text(hjust=0.5))+
```

```r
  theme(text = element_text(family = 'serif'))+
  stat_cor(method = "pearson", label.x = 0, label.y = 0)

DevelopvDevelopingplot
```



Aim 2.1 COVID CO2 emission analysis

First, to examine global CO2 emission in pre-pandemic and pandemic years, a subset of data about 2018, 2019, and 2020 CO2 emission in all countries is created.

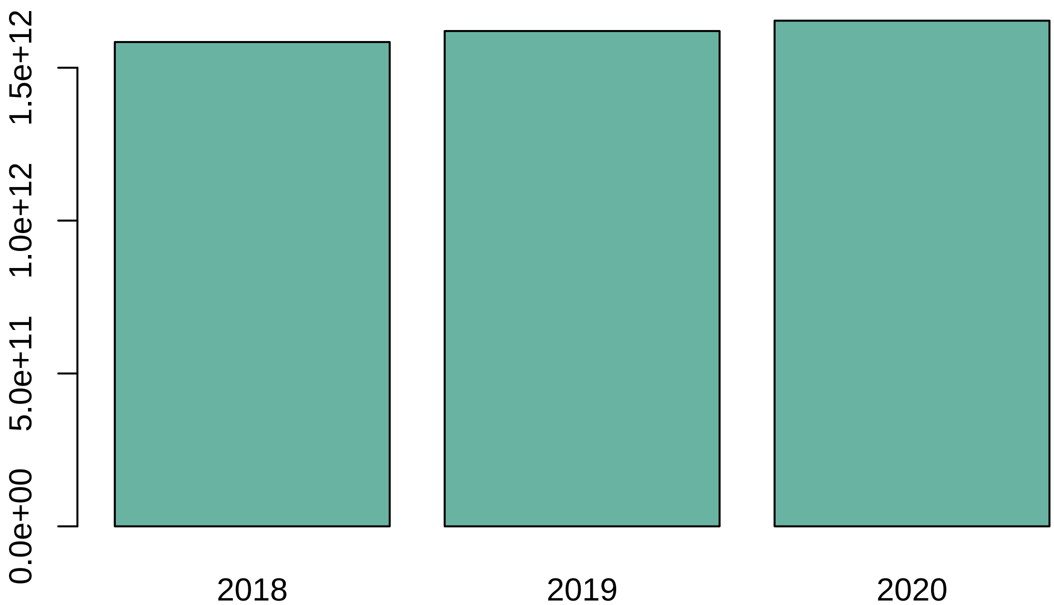
```r
pandemic.CO2 <- CO2 %>%
  filter(Year >= 2018, na.rm = TRUE)
head(pandemic.CO2)
```

```
##       Country Code Calling.Code Year CO2.emission..Tons. Population.2022.
## 1 Afghanistan   AF           93 2018           168541787         41128771
## 2 Afghanistan   AF           93 2019           180688461         41128771
## 3 Afghanistan   AF           93 2020           192848747         41128771
## 4     Albania   AL          355 2018           276104384          2842321
## 5     Albania   AL          355 2019           280967834          2842321
## 6     Albania   AL          355 2020           285502507          2842321
##     Area
## 1 652230
## 2 652230
```

```
## 3 652230
## 4  28748
## 5  28748
## 6  28748
```

Then, we want to explore the general trend of changes in CO2 emission in all countries due to the pandemic. Thus, we presented the global cumulative CO2 emission during these three years.

```
cum.2018 <- sum(pandemic.CO2[which(pandemic.CO2$Year=='2018'), 5])
cum.2019 <- sum(pandemic.CO2[which(pandemic.CO2$Year=='2019'), 5])
cum.2020 <- sum(pandemic.CO2[which(pandemic.CO2$Year=='2020'), 5])

barplot(tapply(pandemic.CO2$CO2.emission..Tons., format(pandemic.CO2$Year), FUN=sum), col="#69b3a2")
```



We could see from the graph that there's not much change in global cumulative CO2 emission during the pandemic years. Here we want to separately analyze the top5 emission countries and see if there's any difference.

```
# dataframe for top 5 co2 emission countries each year
CO2.a <- pandemic.CO2 %>%
  filter(Year == "2018") %>%
  arrange(desc(CO2.emission..Tons.)) %>%
  slice_head(n = 5)
CO2.a
```

```
##           Country Code Calling.Code Year CO2.emission..Tons. Population.2022.
## 1  United States   US            1 2018        407000000000        338289857
## 2          China   CN           86 2018        214000000000       1425887337
## 3         Russia   XX            7 2018        112000000000        144713314
## 4        Germany   DE           49 2018         91279876936         83369843
## 5 United Kingdom   GB           44 2018         77462557032         67508936
##        Area
## 1  9372610
## 2  9706961
```

```
## 3 17098242
## 4   357114
## 5   242900
```

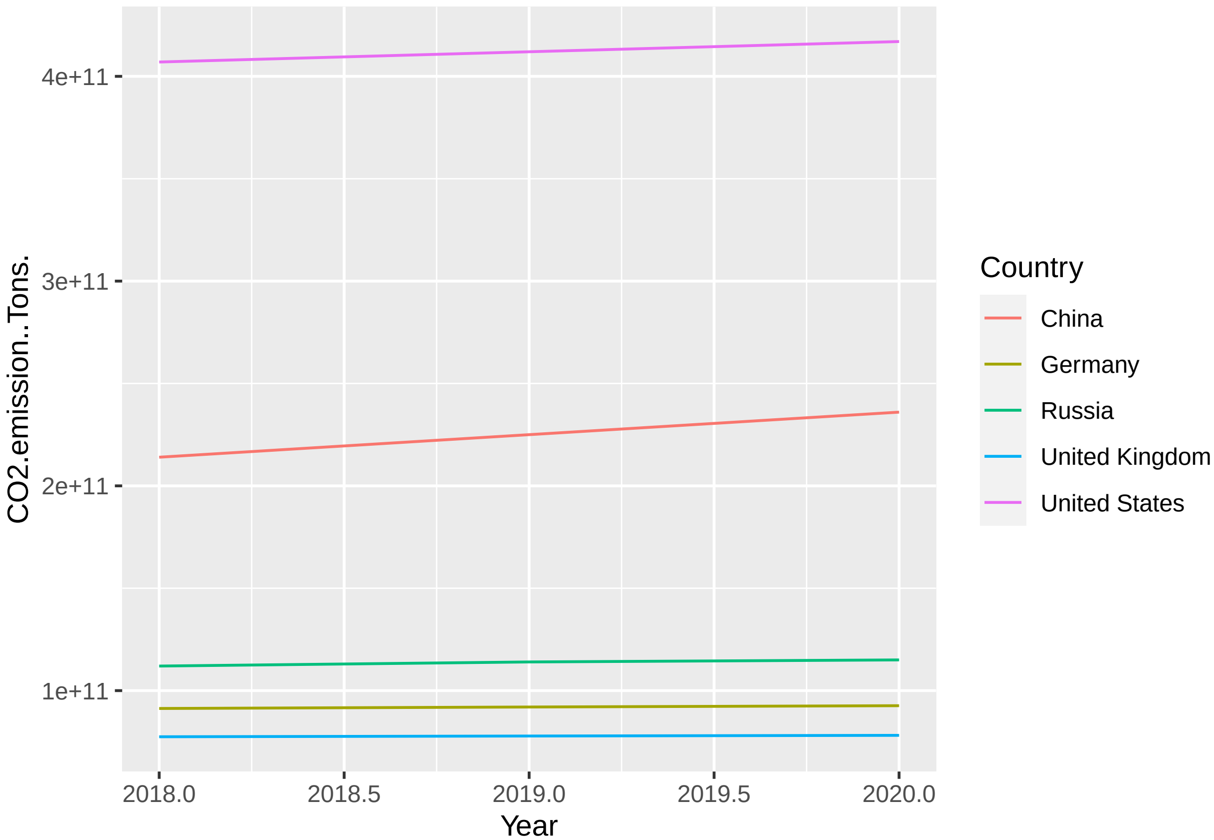
```
CO2.b <- pandemic.CO2 %>%
  filter(Year == "2019") %>%
  arrange(desc(CO2.emission..Tons.)) %>%
  slice_head(n = 5)
CO2.b
```

```
##          Country Code Calling.Code Year CO2.emission..Tons. Population.2022.
## 1  United States   US            1 2019        412000000000        338289857
## 2          China   CN           86 2019        225000000000       1425887337
## 3         Russia   XX            7 2019        114000000000        144713314
## 4        Germany   DE           49 2019         91991304745         83369843
## 5 United Kingdom   GB           44 2019         77831566725         67508936
##       Area
## 1  9372610
## 2  9706961
## 3 17098242
## 4   357114
## 5   242900
```

```
CO2.c <- pandemic.CO2 %>%
  filter(Year == "2020") %>%
  arrange(desc(CO2.emission..Tons.)) %>%
  slice_head(n = 5)
CO2.c
```

```
##          Country Code Calling.Code Year CO2.emission..Tons. Population.2022.
## 1  United States   US            1 2020        417000000000        338289857
## 2          China   CN           86 2020        236000000000       1425887337
## 3         Russia   XX            7 2020        115000000000        144713314
## 4        Germany   DE           49 2020         92635615097         83369843
## 5 United Kingdom   GB           44 2020         78161145636         67508936
##       Area
## 1  9372610
## 2  9706961
## 3 17098242
## 4   357114
## 5   242900
```

```
df.top5 = rbind(CO2.a,CO2.b,CO2.c)

# plot general trend
ggplot(df.top5, aes(x = Year, y = CO2.emission..Tons., color = Country)) +
  geom_line()
```



As shown in this graph, although the overall CO2 emission in these 5 top emission countries slightly increased during pandemic, there's still not much difference observed. This is not what we've expected before since we expect the emission rate to decrease during the pandemic.

Now we want to join another dataset with information about absolute growth of CO2 and other information about CO2 per capita/gdp/unit energy to explore further on pandemic-CO2 emission relationship.

First, we read our new dataset about owid-co2-data from github and filtered the wanted period.

```
res = GET("https://github.com/owid/co2-data")

x <- getURL("https://raw.githubusercontent.com/owid/co2-data/master/owid-co2-data.csv")
world.co2 <- read.csv(text = x)
class(world.co2)
```

```
## [1] "data.frame"
```

```
world.pandemic <- world.co2 %>%
  filter(year >= 1990, na.rm = TRUE)
```

Then we joined the two datasets based on country names. Here we used SQL to make the join.

```
# based on both country names and year
tot.dat <- sqldf("SELECT p.Country, p.year, p.'CO2.emission..Tons.' AS 'co2 emission(tons)', p.'Populati
      FROM 'pandemic.CO2' AS p
      JOIN 'world.pandemic' AS w
```

```
      ON p.Country=w.country
      AND p.Year=w.year")
```

Now we wanted to plot the absolute growth of co2 emission during the pandemic in a global perspective. First, let's check if there are any missing values in our interested data.

```
sum(is.na(tot.dat$co2_growth_abs))
```

```
## [1] 3
```

```
which(is.na(tot.dat$co2_growth_abs))
```

```
## [1] 442 443 444
```

```
# NAs are located at Antarctica, Christmas Island, and Puerto Rico. We noticed that there might be no d
tot.dat$co2_growth_abs[is.na(tot.dat$co2_growth_abs)] = 0

#check again
sum(is.na(tot.dat$co2_growth_abs))
```

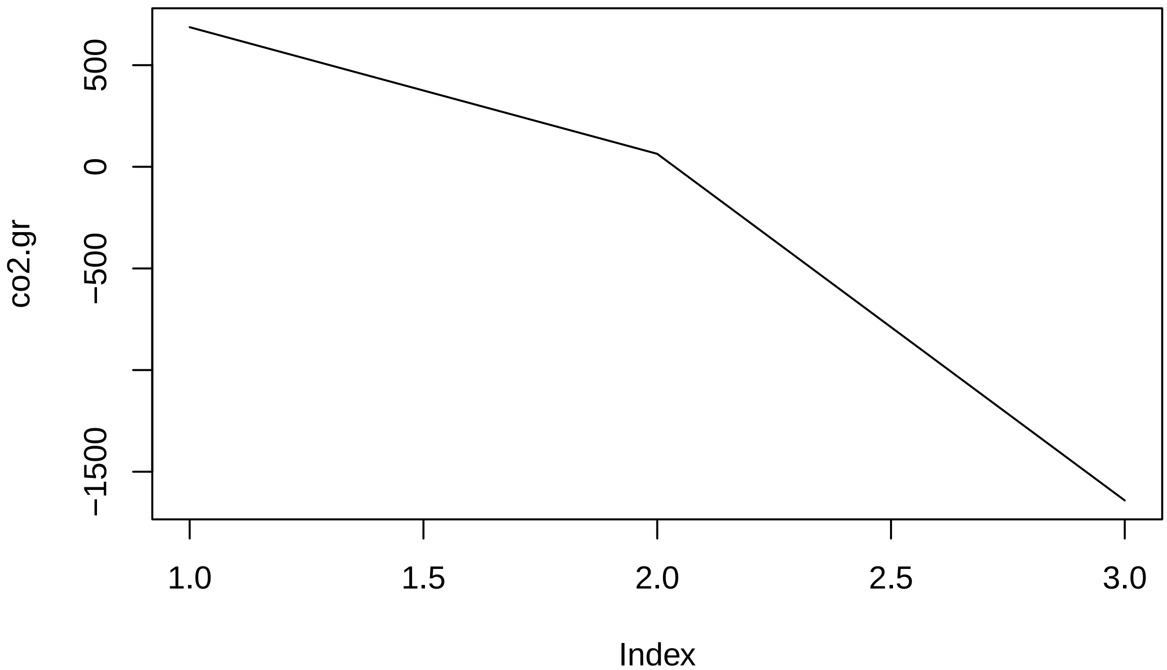
```
## [1] 0
```

Now we can visualize our results regarding absolute growth of CO2 emission. First, let's check if there's difference in the absolute CO2 growth during the pandemic.

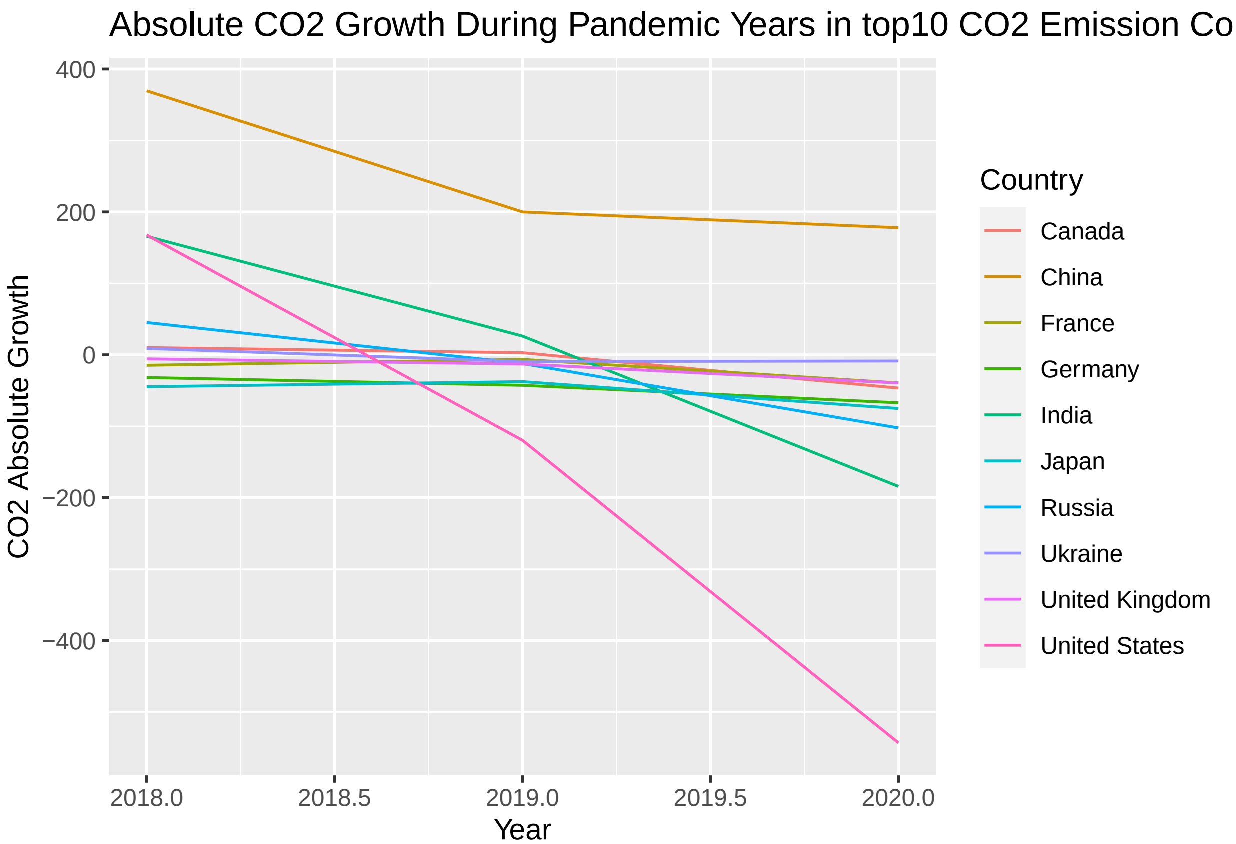
Then we plotted the absolute co2 growth and co2 emission per-capita during the pandemic in countries with the highest overall co2 emission these years.

```
# global trend in co2 absolute growth
a <- sum(tot.dat[which(tot.dat$Year=='2018'), 6])
b <- sum(tot.dat[which(tot.dat$Year=='2019'), 6])
c <- sum(tot.dat[which(tot.dat$Year=='2020'), 6])
co2.gr <- c(a,b,c)
plot(co2.gr, type = "line")
```

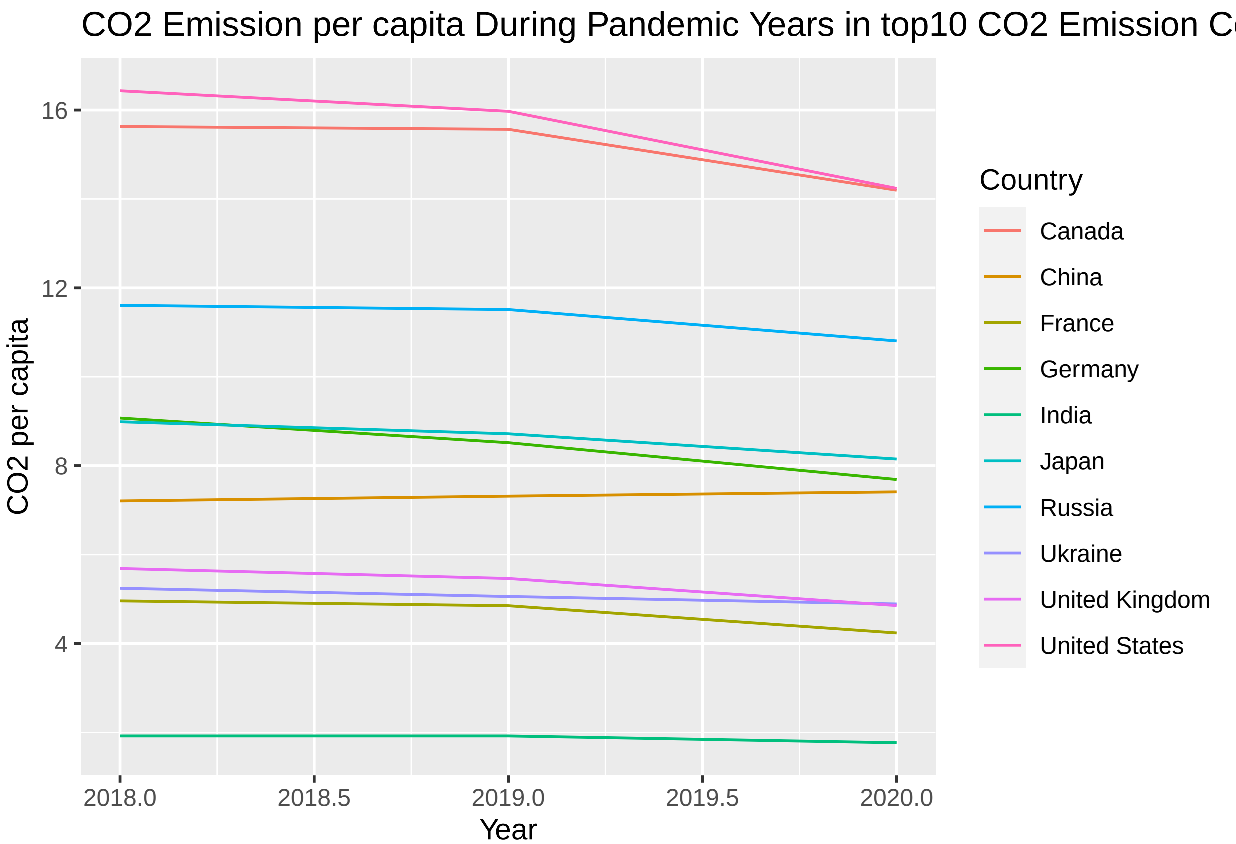
```
## Warning in plot.xy(xy, type, ...): plot type 'line' will be truncated to first
## character
```




```r
# trend in top 10 co2 emission countries
tot.dat <- tot.dat %>%
  arrange(desc(`co2 emission(tons)`))
top.co2 <- tot.dat[1:30,]

ggplot(top.co2, aes(x = Year, y = co2_growth_abs, color = Country)) +
   xlab("Year")+
  ylab("CO2 Absolute Growth")+
  ggtitle("Absolute CO2 Growth During Pandemic Years in top10 CO2 Emission Countries")+
  geom_line()
```




```
ggplot(top.co2, aes(x = Year, y = co2_per_capita, color = Country)) +
   xlab("Year")+
  ylab("CO2 per capita")+
  ggtitle("CO2 Emission per capita During Pandemic Years in top10 CO2 Emission Countries")+
  geom_line()
```



To further explore the relationship and intensity of different features in our dataset, we filtered out top 10 co2 emission countries each year and presented our observations in a heatmap.

```
# filtered out top 10 emission countries
CO2.1 <- tot.dat %>%
  filter(Year == "2018") %>%
  arrange(desc(`co2 emission(tons)`)) %>%
  slice_head(n = 10)


CO2.2 <- tot.dat %>%
  filter(Year == "2019") %>%
  arrange(desc(`co2 emission(tons)`)) %>%
  slice_head(n = 10)


CO2.3 <- tot.dat %>%
  filter(Year == "2020") %>%
  arrange(desc(`co2 emission(tons)`)) %>%
  slice_head(n = 10)

co2.top10 = rbind(CO2.1,CO2.2,CO2.3)
co2.top10$Country_Year <- paste(co2.top10$Country, co2.top10$Year)
rownames(co2.top10) <- co2.top10[, 9]

# each country along with the year should be distinctly represented
co2.top10 %<>% arrange(Country_Year)
```

```
# interactive heatmap
dir.create("folder")
```

```
## Warning in dir.create("folder"): 'folder' already exists
```

```
heatmaply(percentize(co2.top10)[-(1:2)],
          xlab = "Features",
          ylab = "Country Year",
          main = "Features related to CO2 emission during pandemic in top10 CO2 emission countries",
          margins = c(60,100,40,20),
          colors = colorRampPalette(brewer.pal(3, "RdBu"))(256),
          seriate = "OLO",
          heatmap_layers = theme(axis.line=element_blank()),
          file = "folder/CO2_plot.html")
```

```
## PhantomJS not found. You can install it with webshot::install_phantomjs(). If it is installed, please
```

```
# browseURL("folder/CO2_plot.html")
```

We did the same thing by filtered out top 10 populated countries each year and presented our observations in a heatmap.

```
# filtered out top 10 populated countries
pop1 <- tot.dat %>%
  filter(Year == "2018") %>%
  arrange(desc(population)) %>%
  slice_head(n = 10)


pop2 <- tot.dat %>%
  filter(Year == "2019") %>%
  arrange(desc(population)) %>%
  slice_head(n = 10)


pop3 <- tot.dat %>%
  filter(Year == "2020") %>%
  arrange(desc(population)) %>%
  slice_head(n = 10)

pop.top10 = rbind(pop1,pop2,pop3)
pop.top10$Country_Year <- paste(pop.top10$Country, pop.top10$Year)
rownames(pop.top10) <- pop.top10[, 9]

# each country along with the year should be distinctly represented
pop.top10 %<>% arrange(Country_Year)

# interactive heatmap
dir.create("folder")
```

```
## Warning in dir.create("folder"): 'folder' already exists
```

```
heatmaply(percentize(pop.top10)[-(1:2)],
          xlab = "Features",
          ylab = "Country Year",
          main = "Features related to CO2 emission during pandemic in top10 populated countries",
          margins = c(60,100,40,20),
          colors = colorRampPalette(brewer.pal(3, "RdBu"))(256),
          seriate = "OLO",
          heatmap_layers = theme(axis.line=element_blank()),
          file = "folder/pop_plot.html")
```

```
# browseURL("folder/pop_plot.html")
```

From the analysis of co2 emissions during COVID, although we cannot conclude an association between changes in co2 emissions and the pandemic because we ignored other variables, we thought it is interesting to display the result. The result might be more significant if we have updated data including 2021 and 2022.

Aim 2.2 Forecasting

We decided to predict the CO2 emissions in the next 30 years by using the data from 1992 to 2019, and fit in the proper ARIMA models to do the prediction. We choose six countries and five continents to do the prediction.

```
# select three columns to do forecasting
CO2_forecasting<-CO2 %>% dplyr::select(Country, Year, CO2.emission..Tons.)
# make sure there is no NA
dim(CO2_forecasting)
```

```
## [1] 55284     3
```

```
dim(na.omit(CO2_forecasting))
```

```
## [1] 55284     3
```

```
# see which year should we start for forecasting
CO2_no_year_min[which(CO2_no_year_min$Year==max(CO2_no_year_min[]$Year)),]
```

```
##    Country Year
## 1:  Kosovo 2008
```

```
# decided to use 1992-2019 data to do the forecasting
CO2_forecasting<-CO2_forecasting %>%
  filter(Year>1991&Year<2020) %>%
  group_by(Country)
# View(CO2_forecasting)
```

Predictions on selected countries

```r
# extract the six countries' data and fit in time series models separately
# US
CO2_US<-CO2_forecasting %>%
  filter(Country=="United States")
pred.us<-ts(CO2_US$CO2.emission..Tons., start=1992,frequency = 1) %>%
  auto.arima() %>%
  forecast(h=30)
# United Kingdom
CO2_UK<-CO2_forecasting %>%
  filter(Country=="United Kingdom")
pred.uk<-ts(CO2_UK$CO2.emission..Tons.,start=1992,frequency = 1) %>%
  auto.arima() %>%
  forecast(h=30)
# Germany
CO2_GE<-CO2_forecasting %>%
  filter(Country=="Germany")
pred.ge<-ts(CO2_GE$CO2.emission..Tons.,start=1992,frequency = 1) %>%
  auto.arima() %>%
  forecast(h=30)
# China
CO2_CH<-CO2_forecasting %>%
  filter(Country=="China")
pred.ch<-ts(CO2_CH$CO2.emission..Tons.,start=1992,frequency = 1) %>%
  auto.arima() %>%
  forecast(h=30)
# Russia
CO2_RU<-CO2_forecasting %>%
  filter(Country=="Russia")
pred.ru<-ts(CO2_RU$CO2.emission..Tons.,start=1992,frequency = 1) %>%
  auto.arima() %>%
  forecast(h=30)
# France
CO2_FR<-CO2_forecasting %>%
  filter(Country=="France")
pred.fr<-ts(CO2_FR$CO2.emission..Tons.,start=1992,frequency = 1) %>%
  auto.arima() %>%
  forecast(h=30)
```

Time series analysis based on six selected countries

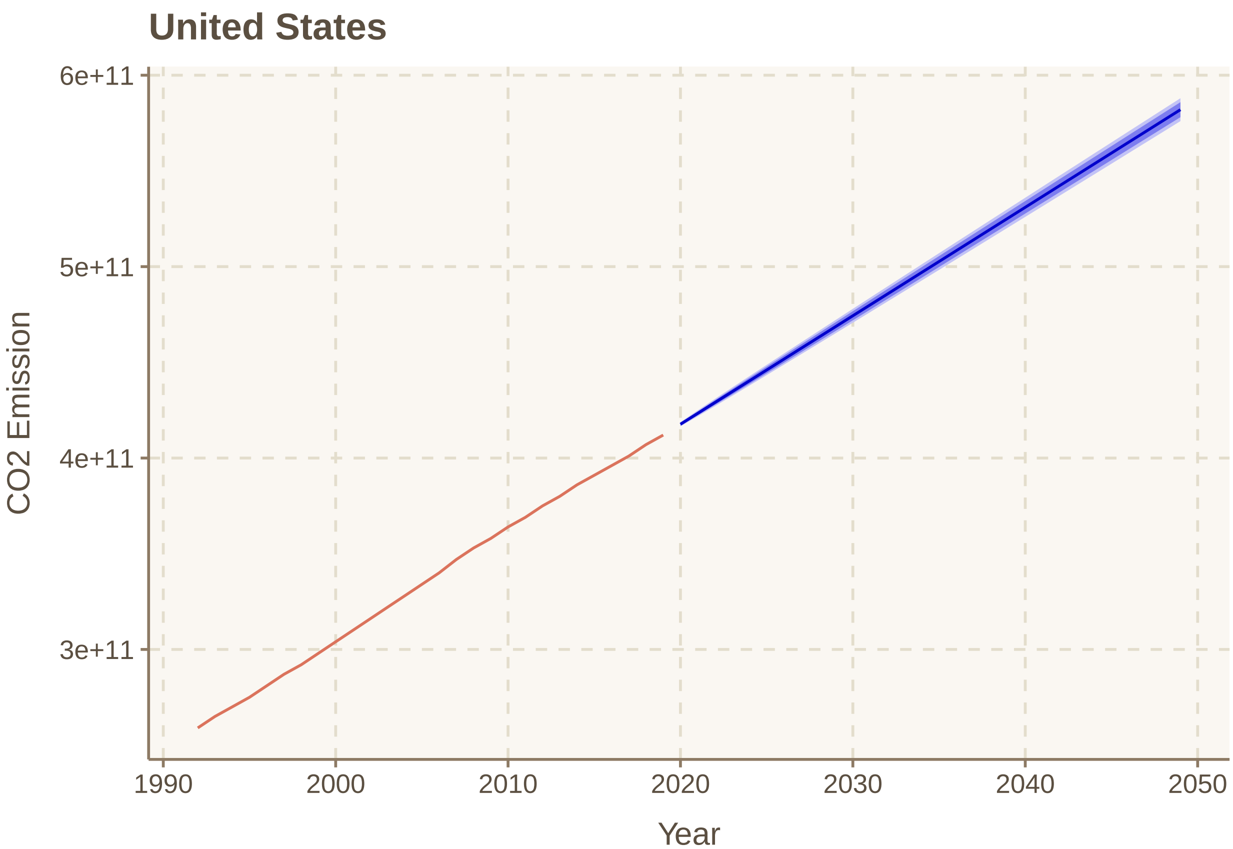
Plot the predicted CO2 emissions for the six countries We expect to see what's the increasing or decreasing trend of the CO2 emissions in the next 30 years.

```r
# devtools::install_github('cttobin/ggthemr')
library(ggthemr)
```

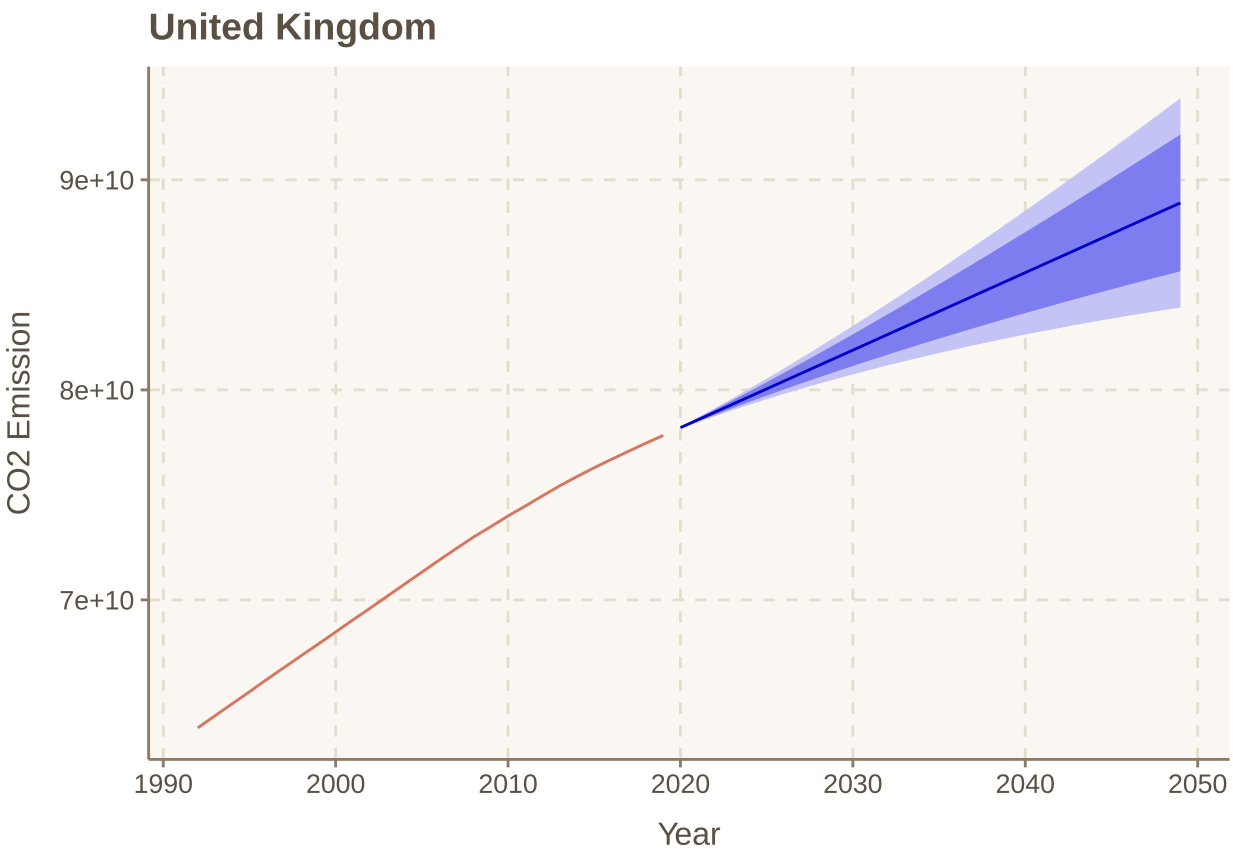
```
##
## Attaching package: 'ggthemr'

## The following objects are masked from 'package:ggpubr':
```

```
##
##     rotate_x_text, rotate_y_text
```

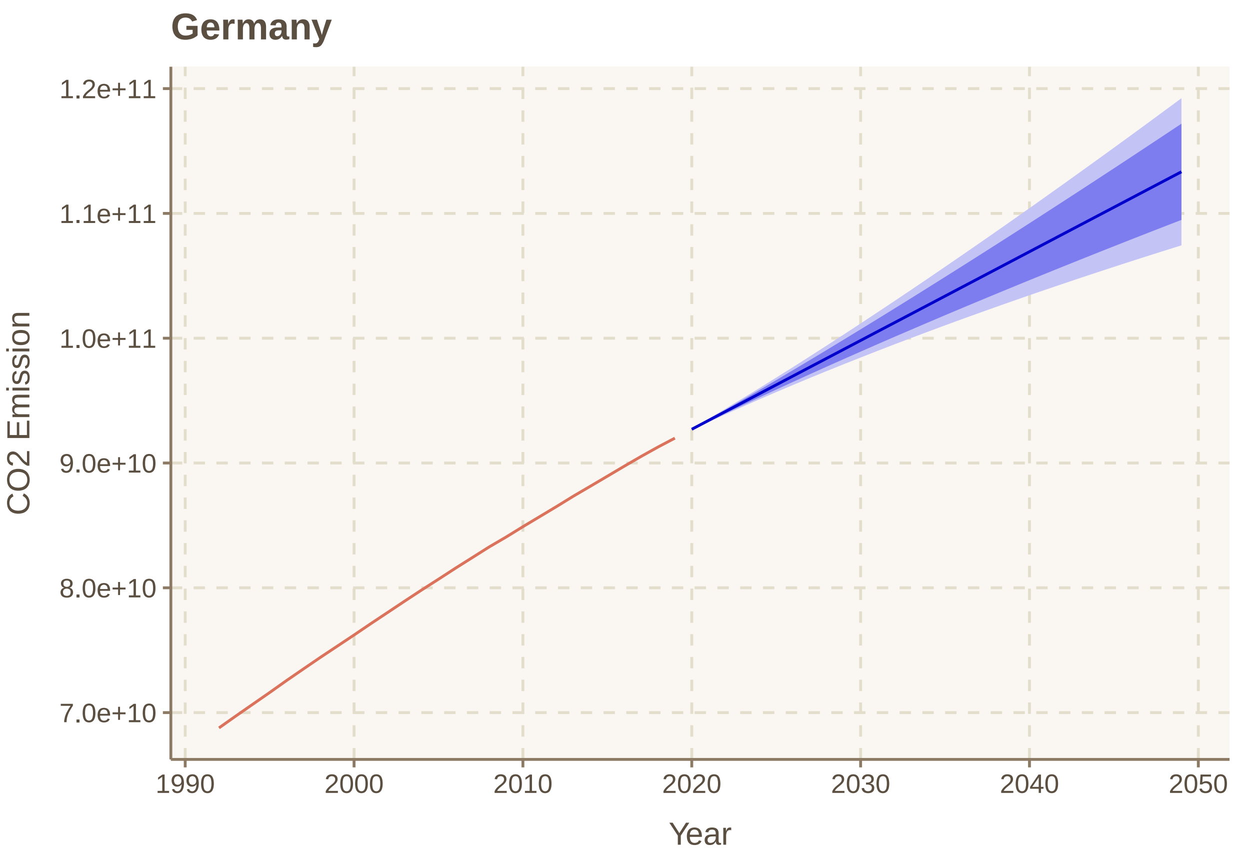
```
ggthemr("dust")
US.plot<-autoplot(pred.us)+
  ggtitle("United States")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

UK.plot<-autoplot(pred.uk)+
  ggtitle("United Kingdom")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

GE.plot<-autoplot(pred.ge)+
  ggtitle("Germany")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

CH.plot<-autoplot(pred.ch)+
  ggtitle("China")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

RU.plot<-autoplot(pred.ru)+
  ggtitle("Russia")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

FR.plot<-autoplot(pred.fr)+
  ggtitle("France")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

# Save the plots
ggsave("US.png",US.plot,width = 10,height = 7.5)
ggsave("UK.png",UK.plot,width = 10,height = 7.5)
ggsave("GE.png",GE.plot,width = 10,height = 7.5)
ggsave("CH.png",CH.plot,width = 10,height = 7.5)
ggsave("RU.png",RU.plot,width = 10,height = 7.5)
ggsave("FR.png",FR.plot,width = 10,height = 7.5)

# view the plots
US.plot
```


United States
6e+11
5e+11
4e+11
3e+11
CO2 Emission
1990
2000
2010
2020
2030
2040
2050
Year

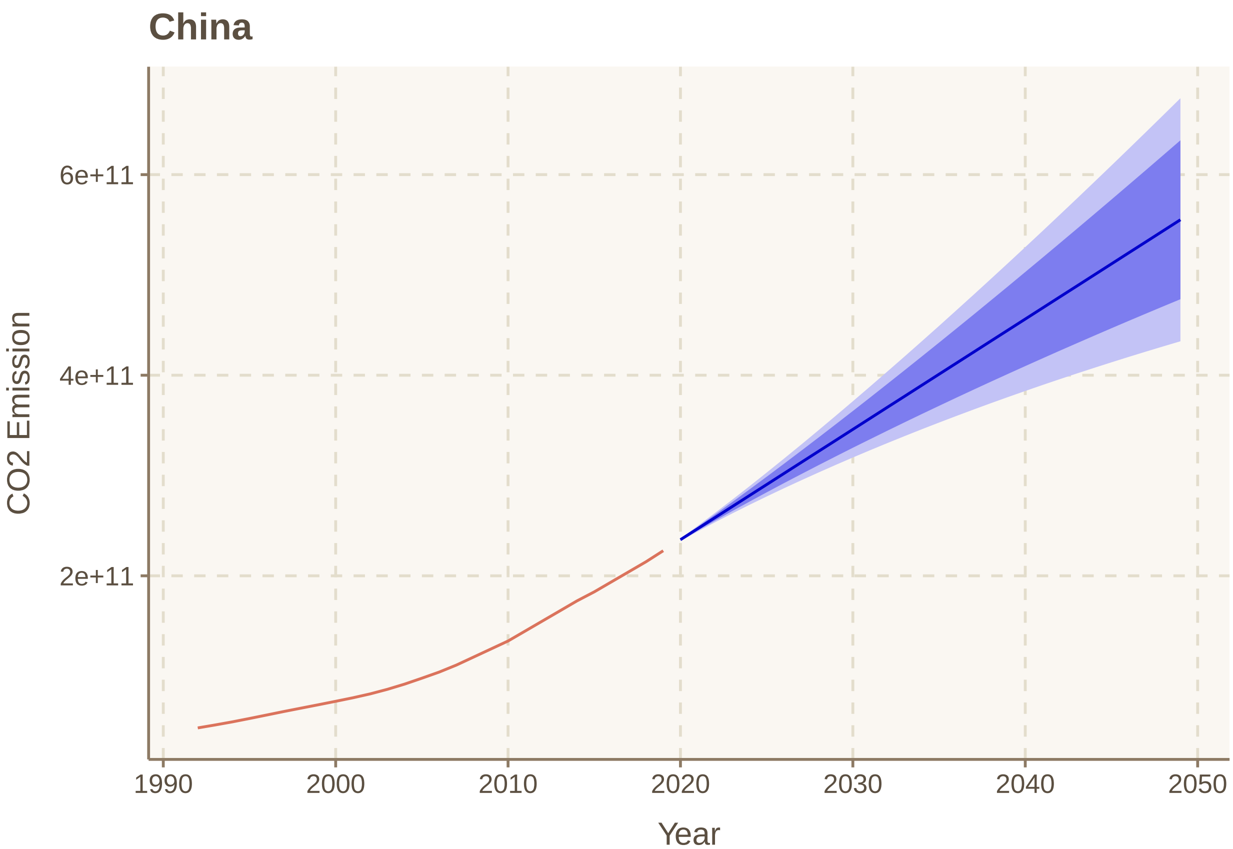
```
UK.plot
```


United Kingdom
CO2 Emission
9e+10
8e+10
7e+10
1990
2000
2010
2020
2030
2040
2050
Year

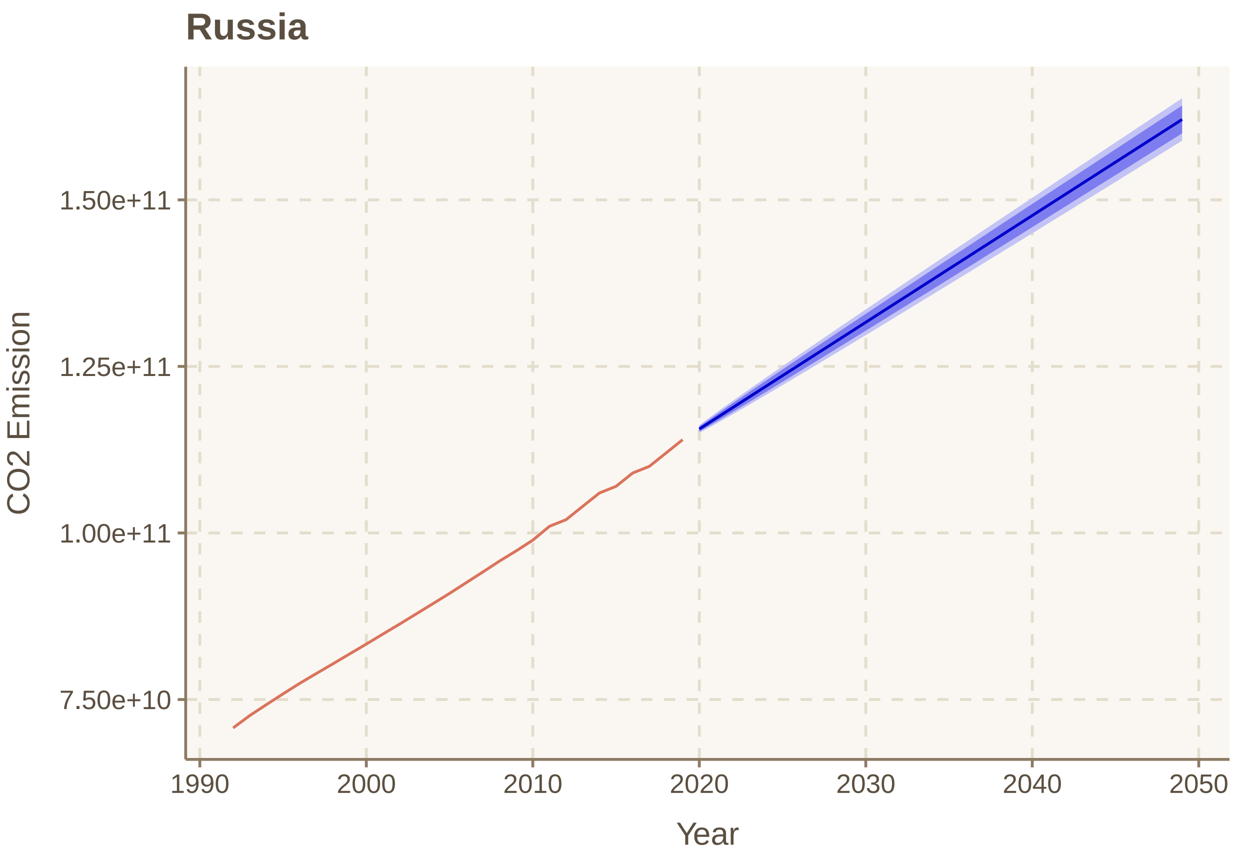
```
GE.plot
```


Germany
CO2 Emission
1.2e+11
1.1e+11
1.0e+11
9.0e+10
8.0e+10
7.0e+10
1990
2000
2010
2020
2030
2040
2050
Year

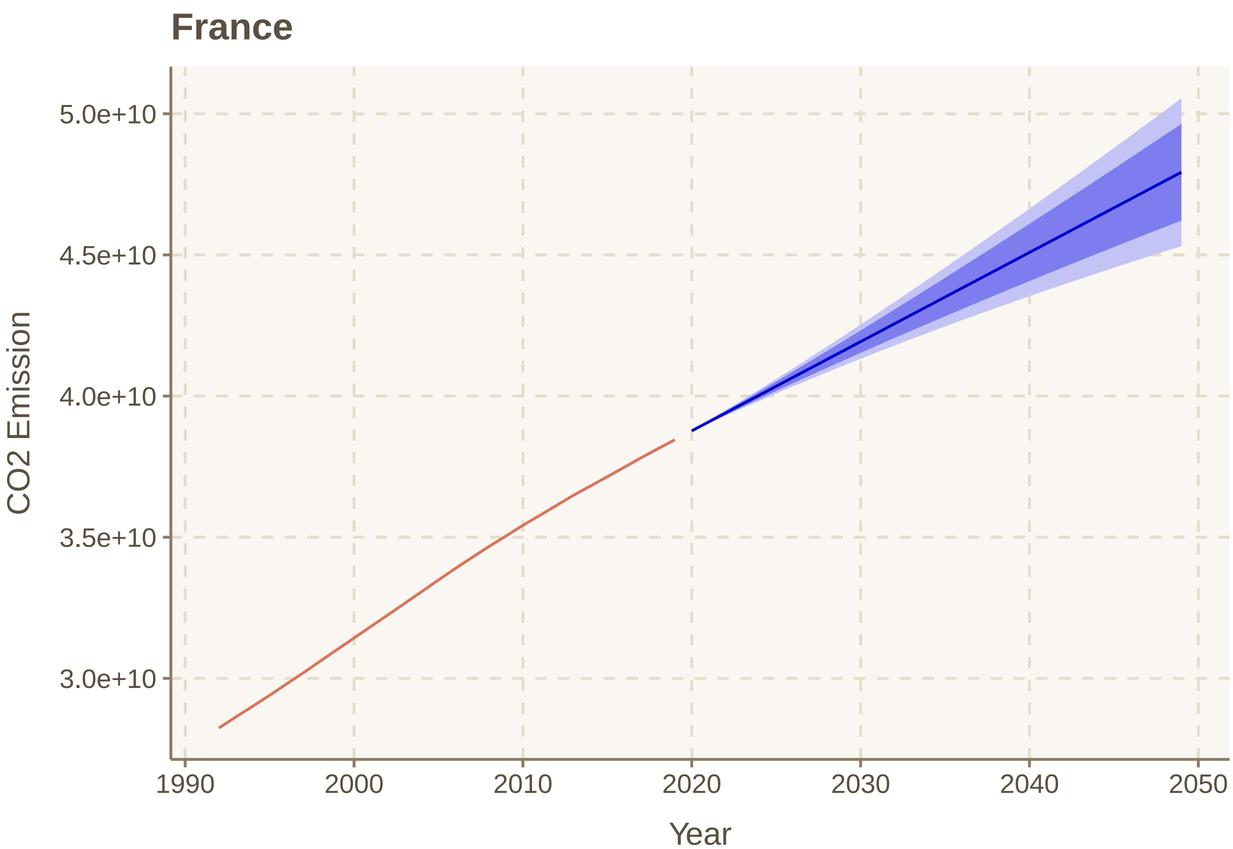
```
CH.plot
```


China
CO2 Emission
6e+11
4e+11
2e+11
1990
2000
2010
2020
2030
2040
2050
Year

```
RU.plot
```


Russia
CO2 Emission
1.50e+11
1.25e+11
1.00e+11
7.50e+10
1990
2000
2010
2020
2030
2040
2050
Year

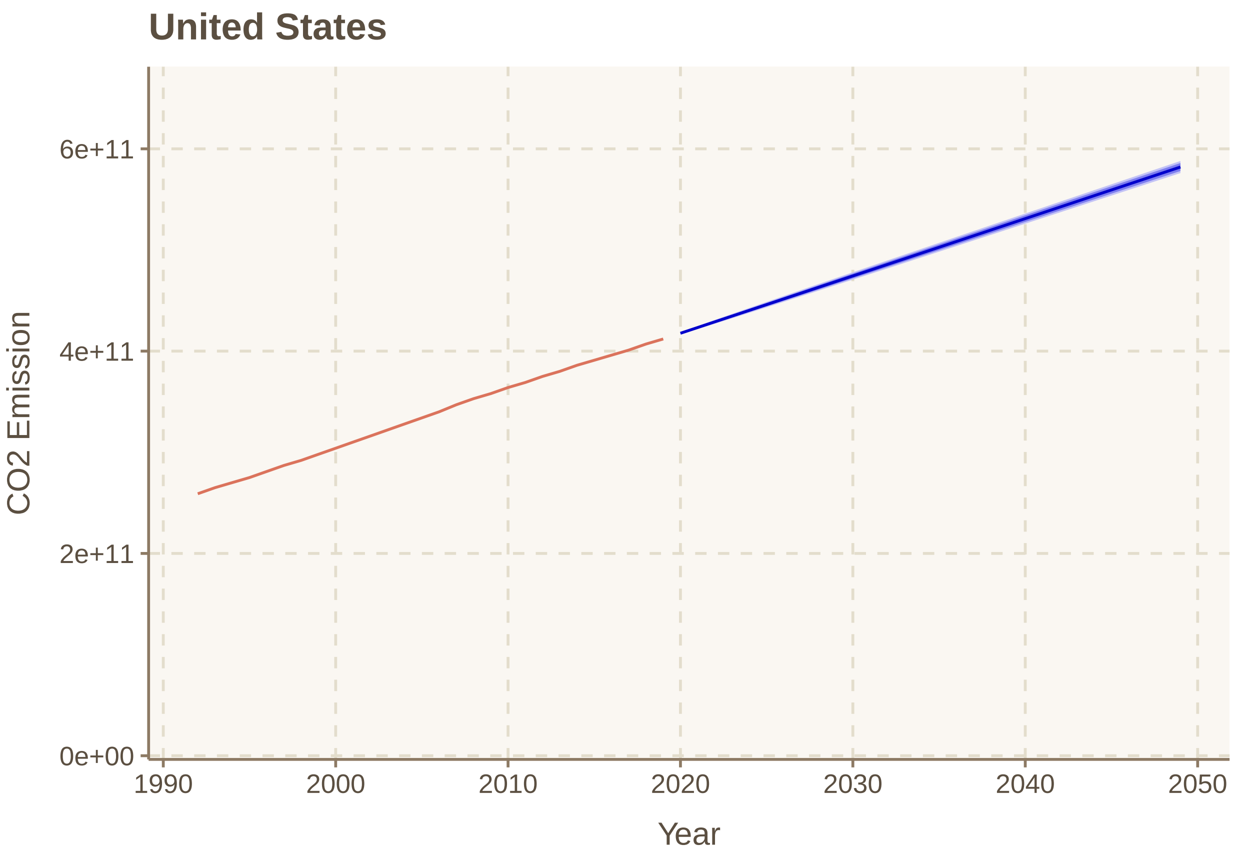
```
FR.plot
```



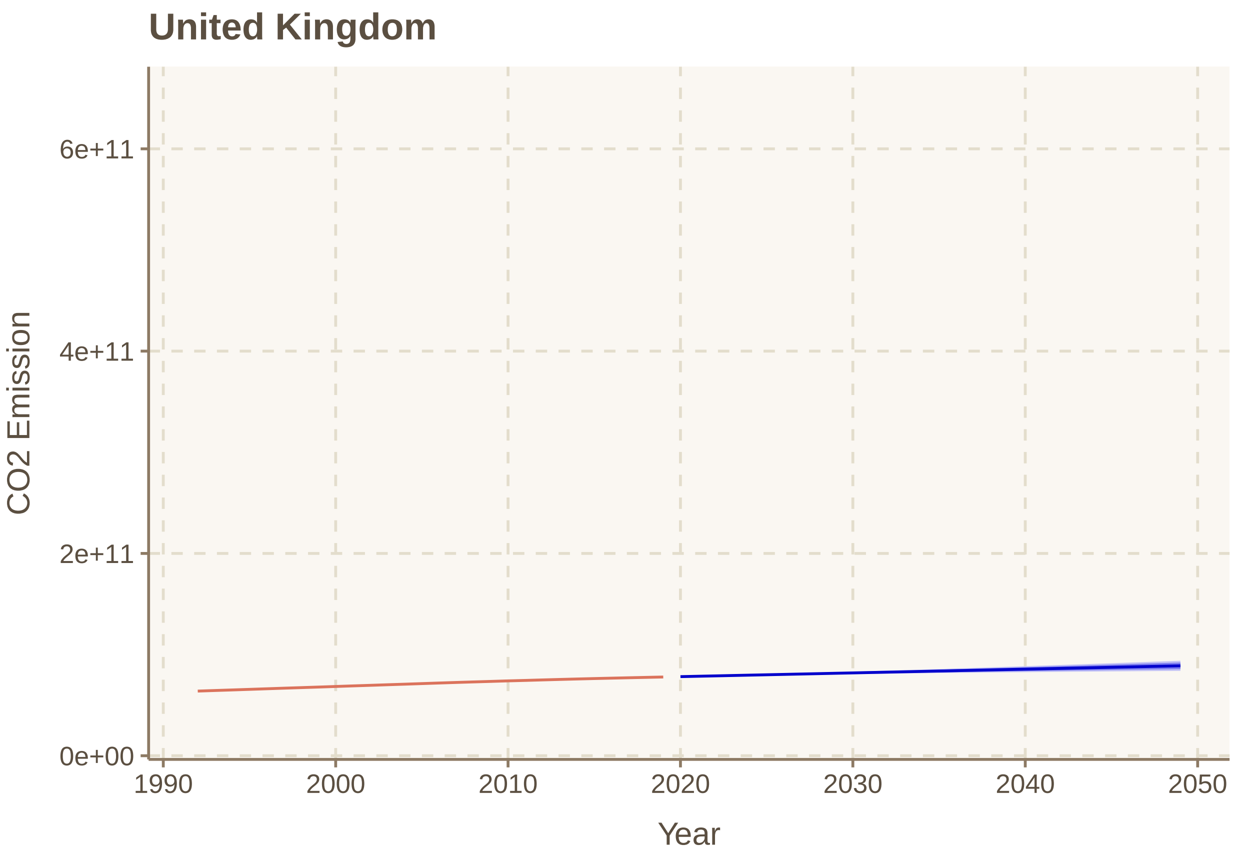
Next, plot the predictions on the same scales, from 2.75e+10 to 6.5e+11, to compare the predicted CO2 emissions among the six countries.

```
# devtools::install_github('cttobin/ggthemr')
US.scaled.plot<-autoplot(pred.us)+
  ggtitle("United States")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(2.75e+10, 6.5e+11))

UK.scaled.plot<-autoplot(pred.uk)+
  ggtitle("United Kingdom")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(2.75e+10, 6.5e+11))

GE.scaled.plot<-autoplot(pred.ge)+
  ggtitle("Germany")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(2.75e+10, 6.5e+11))

CH.scaled.plot<-autoplot(pred.ch)+
  ggtitle("China")+
```

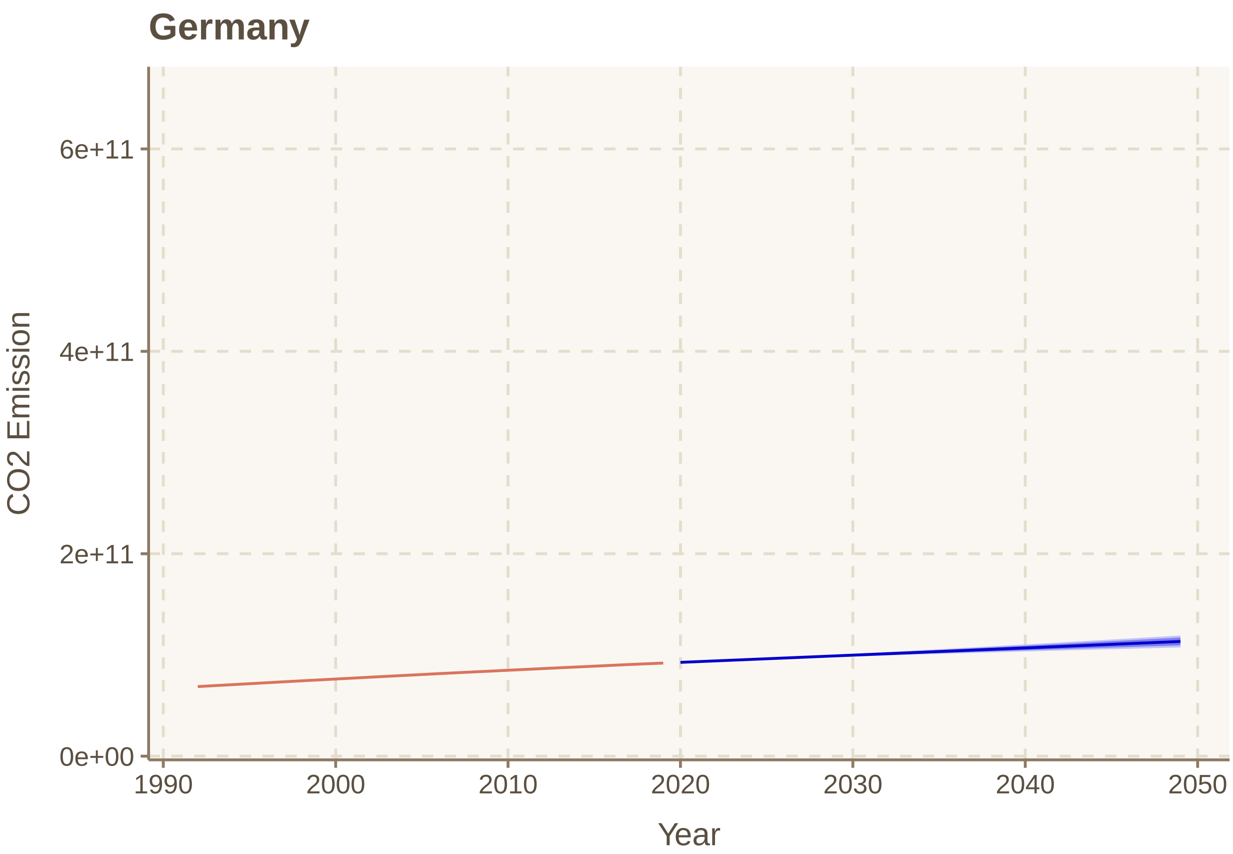
```r
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(2.75e+10, 6.5e+11))

RU.scaled.plot<-autoplot(pred.ru)+
  ggtitle("Russia")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(2.75e+10, 6.5e+11))

FR.scaled.plot<-autoplot(pred.fr)+
  ggtitle("France")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(2.75e+10, 6.5e+11))

# Save the plots
ggsave("US.scaled.png",US.scaled.plot,width = 10,height = 7.5)
ggsave("UK.scaled.png",UK.scaled.plot,width = 10,height = 7.5)
ggsave("GE.scaled.png",GE.scaled.plot,width = 10,height = 7.5)
ggsave("CH.scaled.png",CH.scaled.plot,width = 10,height = 7.5)
ggsave("RU.scaled.png",RU.scaled.plot,width = 10,height = 7.5)
ggsave("FR.scaled.png",FR.scaled.plot,width = 10,height = 7.5)

US.scaled.plot
```



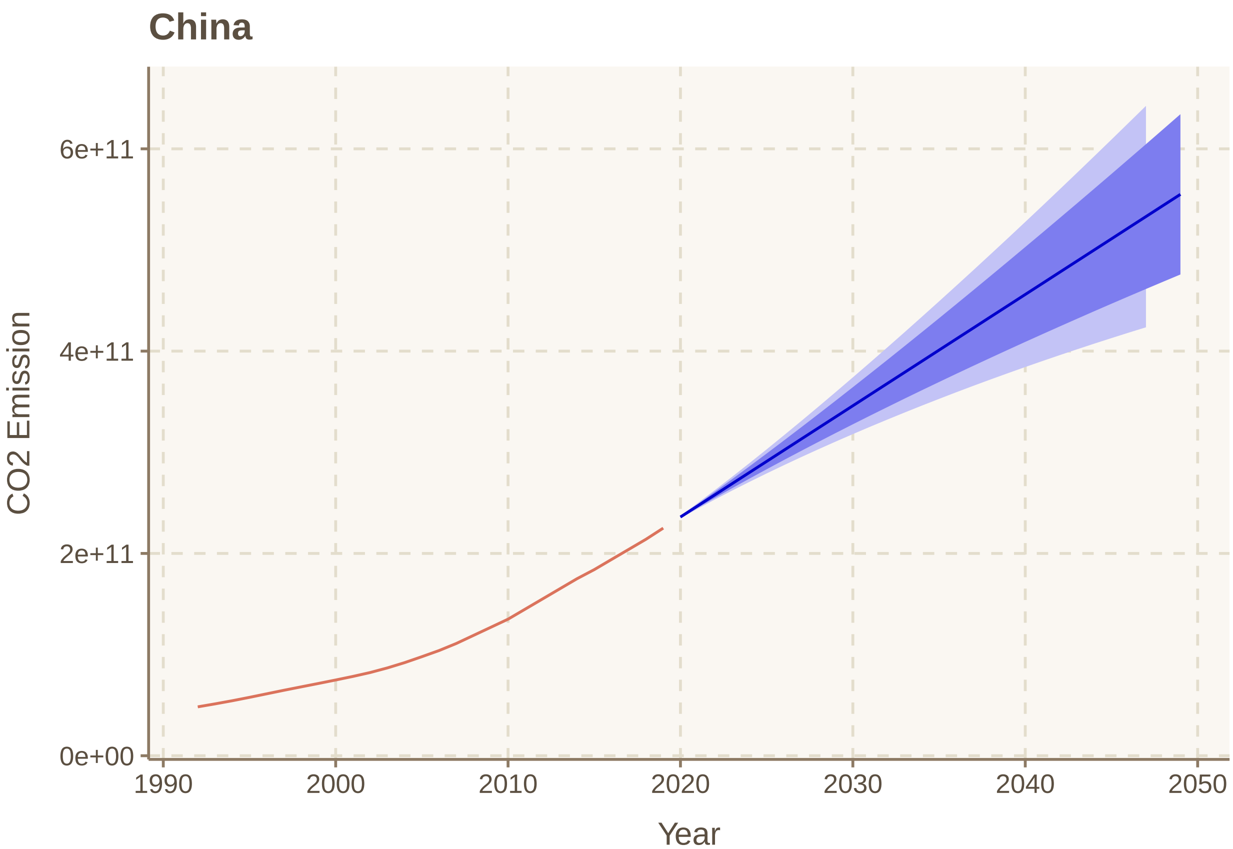

```
UK.scaled.plot
```



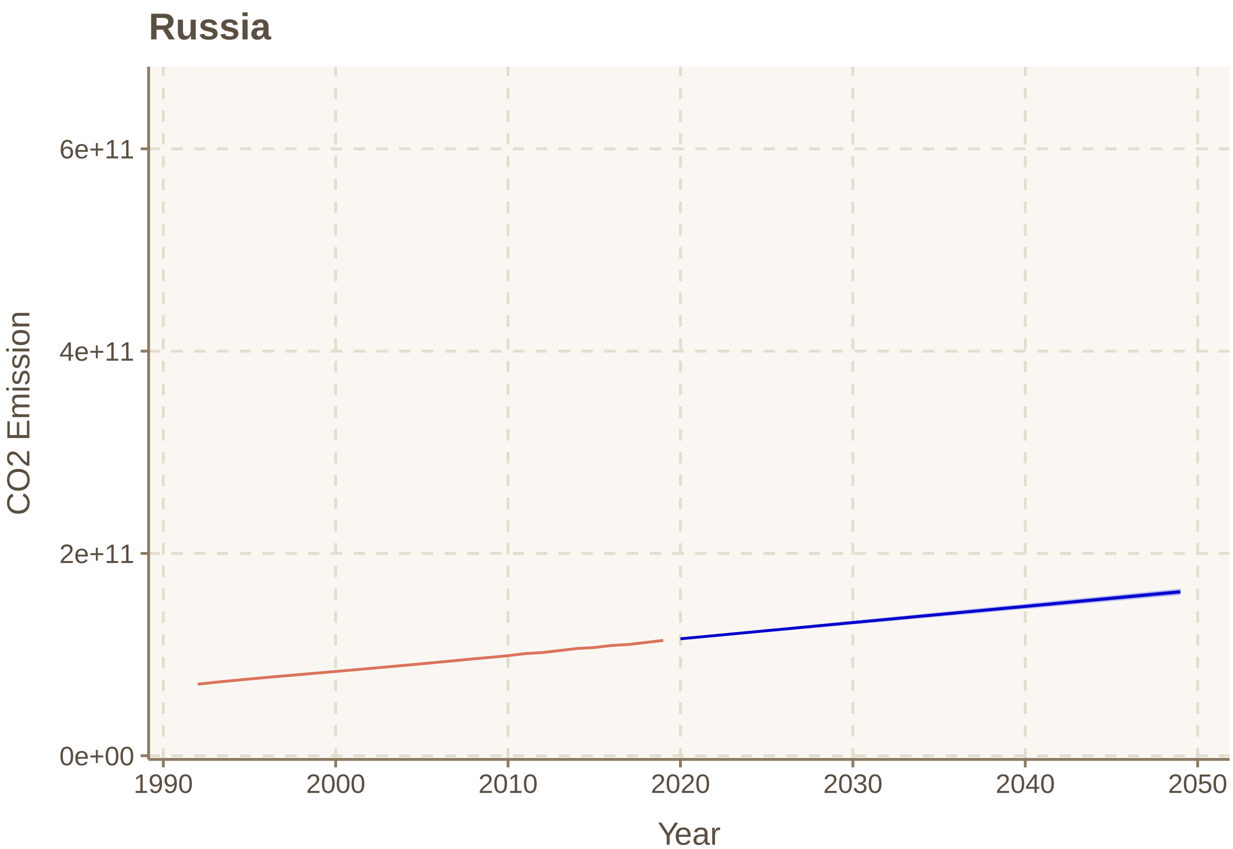

```
GE.scaled.plot
```



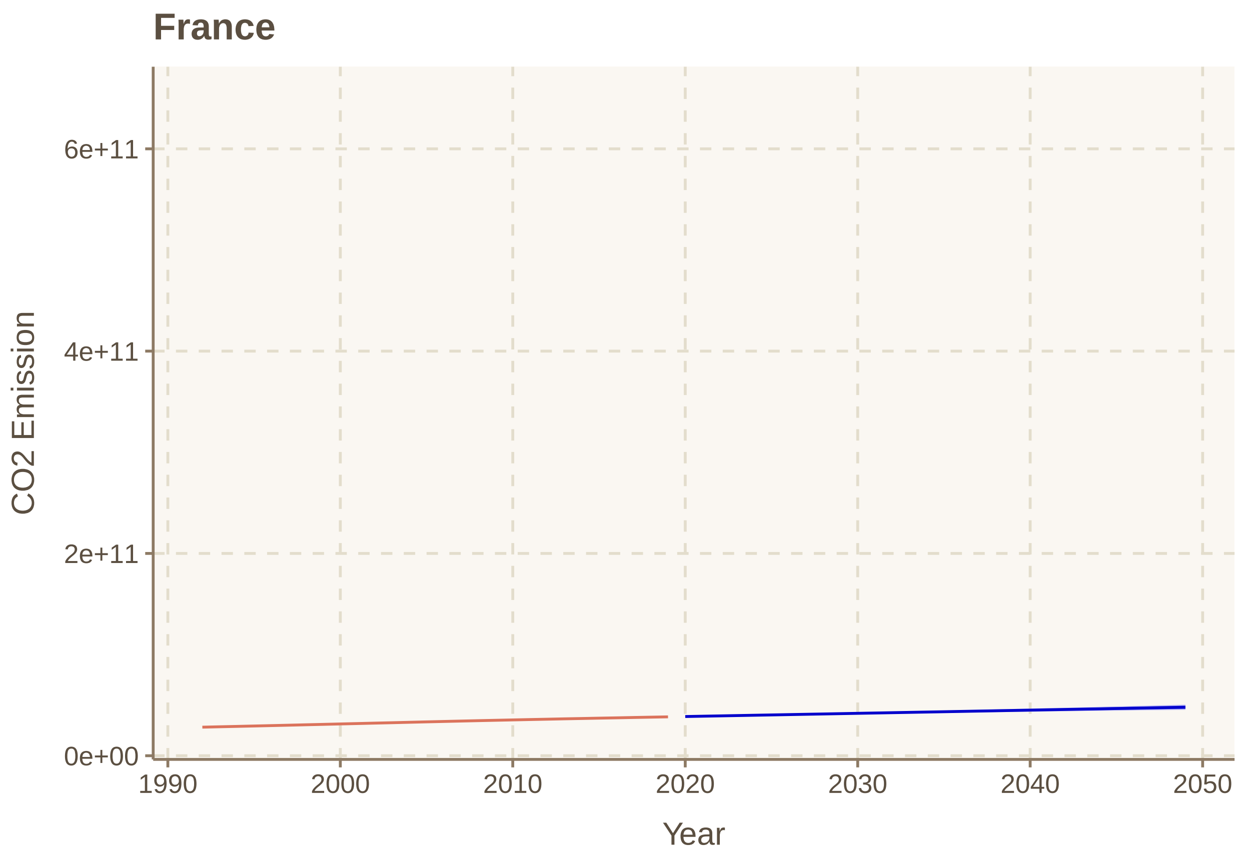

```
CH.scaled.plot
```




```
RU.scaled.plot
```




```
FR.scaled.plot
```



Predictions on continents

```
CO2$Continent <- countrycode(sourcevar = CO2[,"Country"],
                            origin = "country.name",
                            destination = "continent")
```

Time series analysis on five continents

```
## Warning in countrycode_convert(sourcevar = sourcevar, origin = origin, destination = dest, : Some val
```

```
CO2_forecasting<-CO2 %>%
  dplyr::select(Country, Year, CO2.emission..Tons.,Continent)
# make sure there is no NA
dim(CO2_forecasting)
```

```
## [1] 55284     4
```

```
dim(na.omit(CO2_forecasting))
```

```
## [1] 54742     4
```

```r
# Use 1992-2020 data to forecast
CO2_no_year_min[which(CO2_no_year_min$Year==max(CO2_no_year_min[]$Year)),]
```

```
##    Country Year
## 1:  Kosovo 2008
```

```r
CO2_forecasting<-CO2_forecasting %>%
  filter(Year>1991) %>%
  group_by(Country)
# select continent
CO2_forecasting_continent<-CO2_forecasting %>%
  dplyr::group_by(Year, Continent) %>%
  dplyr::summarise(Sum=sum(CO2.emission..Tons.))
```

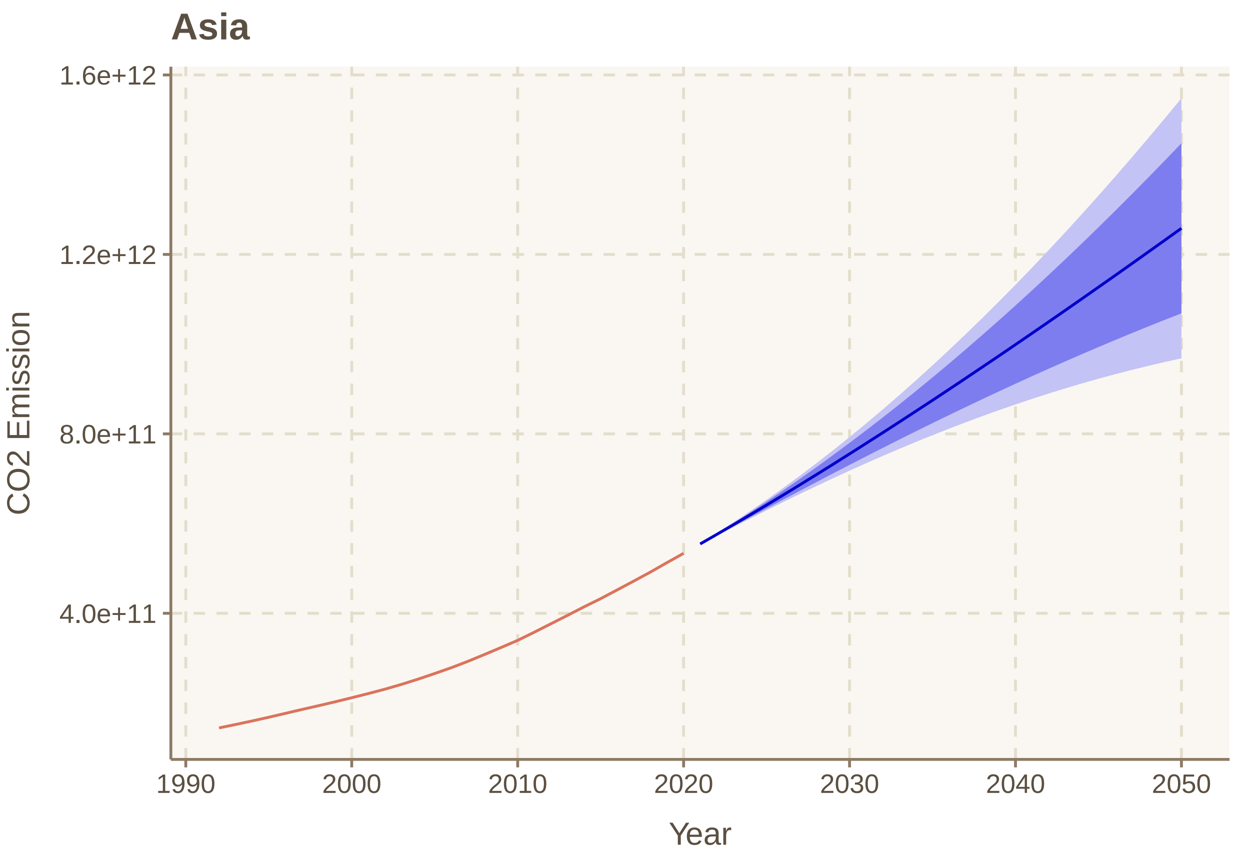
```
## `summarise()` has grouped output by 'Year'. You can override using the
## `.groups` argument.
```

```r
CO2_forecasting_continent<-na.omit(CO2_forecasting_continent)
# View(CO2_forecasting_continent)
```

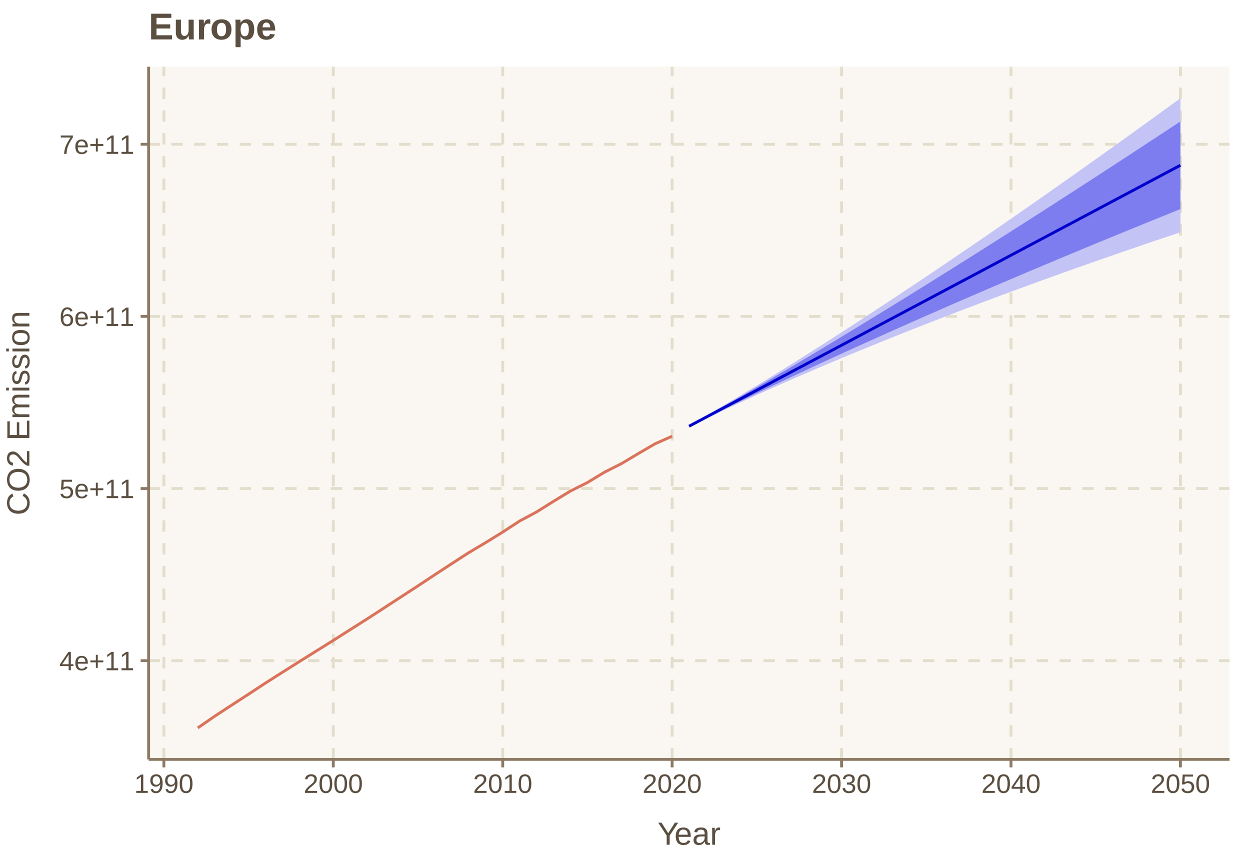
```r
Asia<-CO2_forecasting_continent %>%
  filter(Continent=="Asia")
Europe<-CO2_forecasting_continent %>%
  filter(Continent=="Europe")
Africa<-CO2_forecasting_continent %>%
  filter(Continent=="Africa")
Americas<-CO2_forecasting_continent %>%
  filter(Continent=="Americas")
Oceania<-CO2_forecasting_continent %>%
  filter(Continent=="Oceania")

# forecasting
# Asia
ts_data_as = ts(Asia$Sum,start=1992,frequency = 1)
arima.ts.as = auto.arima(ts_data_as)
pred.as = forecast(arima.ts.as,h=30)
# EU
ts_data_eu = ts(Europe$Sum,start=1992,frequency = 1)
arima.ts.eu = auto.arima(ts_data_eu)
pred.eu = forecast(arima.ts.eu,h=30)
# AF
ts_data_af = ts(Africa$Sum,start=1992,frequency = 1)
arima.ts.af = auto.arima(ts_data_af)
pred.af = forecast(arima.ts.af,h=30)
# AM
ts_data_am = ts(Americas$Sum,start=1992,frequency = 1)
arima.ts.am = auto.arima(ts_data_am)
pred.am = forecast(arima.ts.am,h=30)
# OC
ts_data_oc = ts(Oceania$Sum,start=1992,frequency = 1)
arima.ts.oc = auto.arima(ts_data_oc)
pred.oc = forecast(arima.ts.oc,h=30)
```

Plot the predicted CO2 emissions for the five continents We expect to see what's the increasing or decreasing trend of the CO2 emissions in the next 30 years.

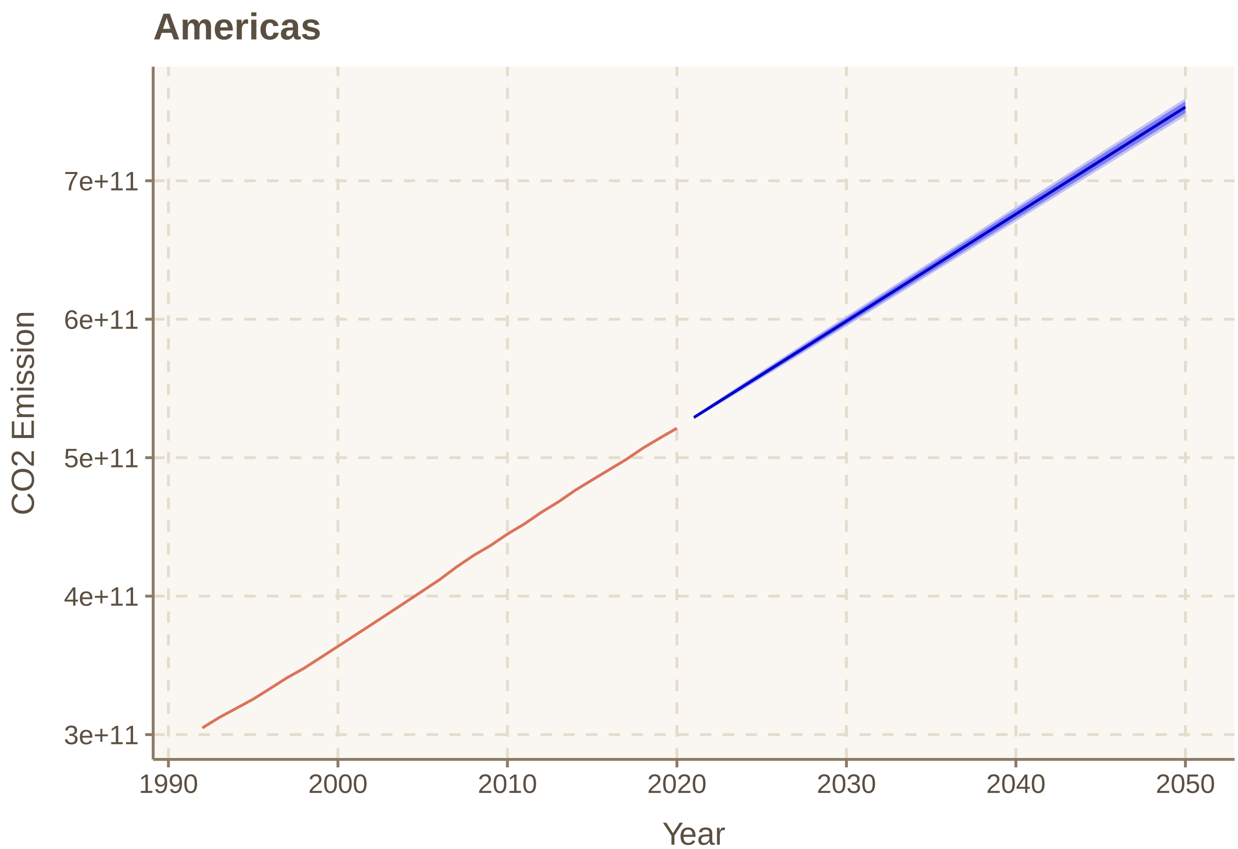
```
Asia.plot<-autoplot(pred.as)+
  ggtitle("Asia")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

Europe.plot<-autoplot(pred.eu)+
  ggtitle("Europe")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

Africa.plot<-autoplot(pred.af)+
  ggtitle("Africa")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

Americas.plot<-autoplot(pred.am)+
  ggtitle("Americas")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

Oceania.plot<-autoplot(pred.oc)+
  ggtitle("Oceania")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))

# save the plots
ggsave("Oceania.png",Oceania.plot,width = 10,height = 7.5)
ggsave("Asia.png",Asia.plot,width = 10,height = 7.5)
ggsave("Europe.png",Europe.plot,width = 10,height = 7.5)
ggsave("Africa.png",Africa.plot,width = 10,height = 7.5)
ggsave("Americas.png",Americas.plot,width = 10,height = 7.5)

Asia.plot
```


Asia
CO2 Emission
1.6e+12
1.2e+12
8.0e+11
4.0e+11
1990
2000
2010
2020
2030
2040
2050
Year

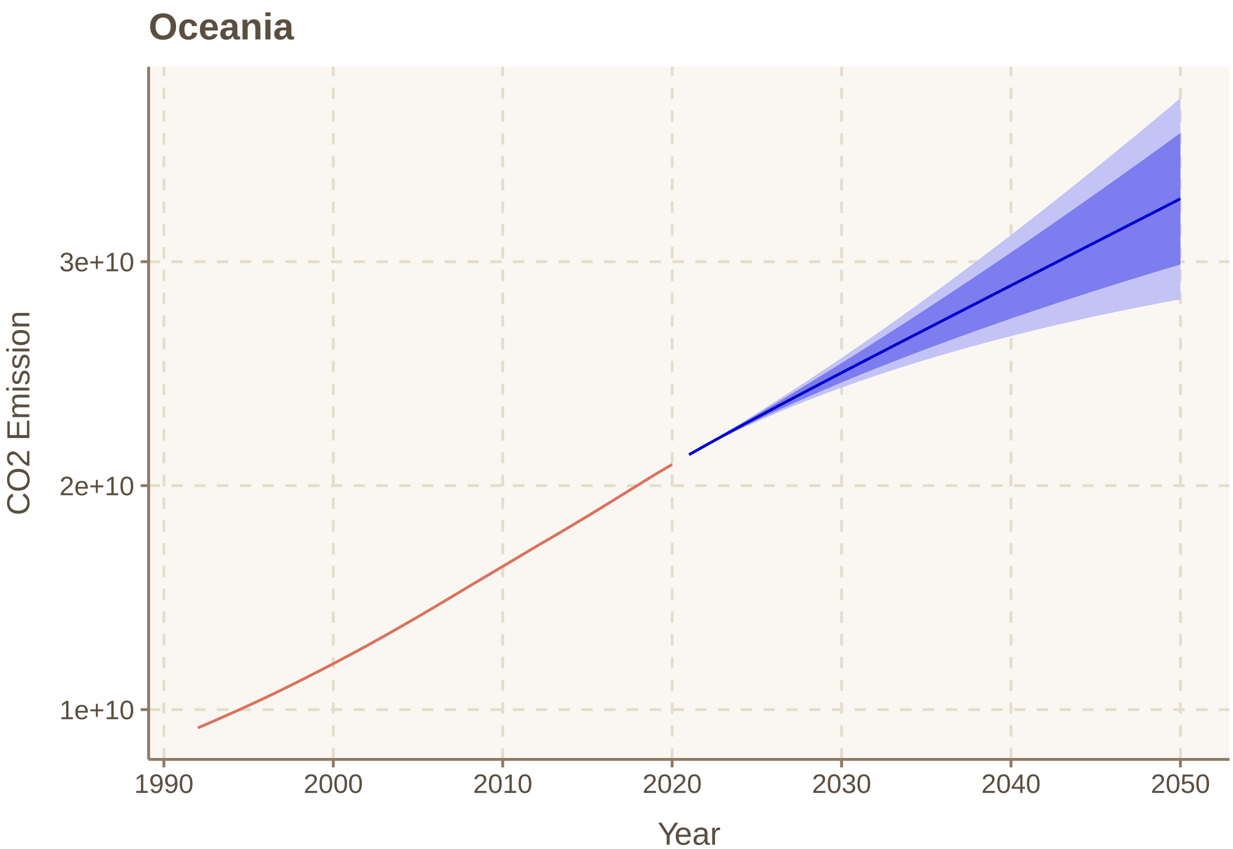
```
Europe.plot
```




```
Americas.plot
```

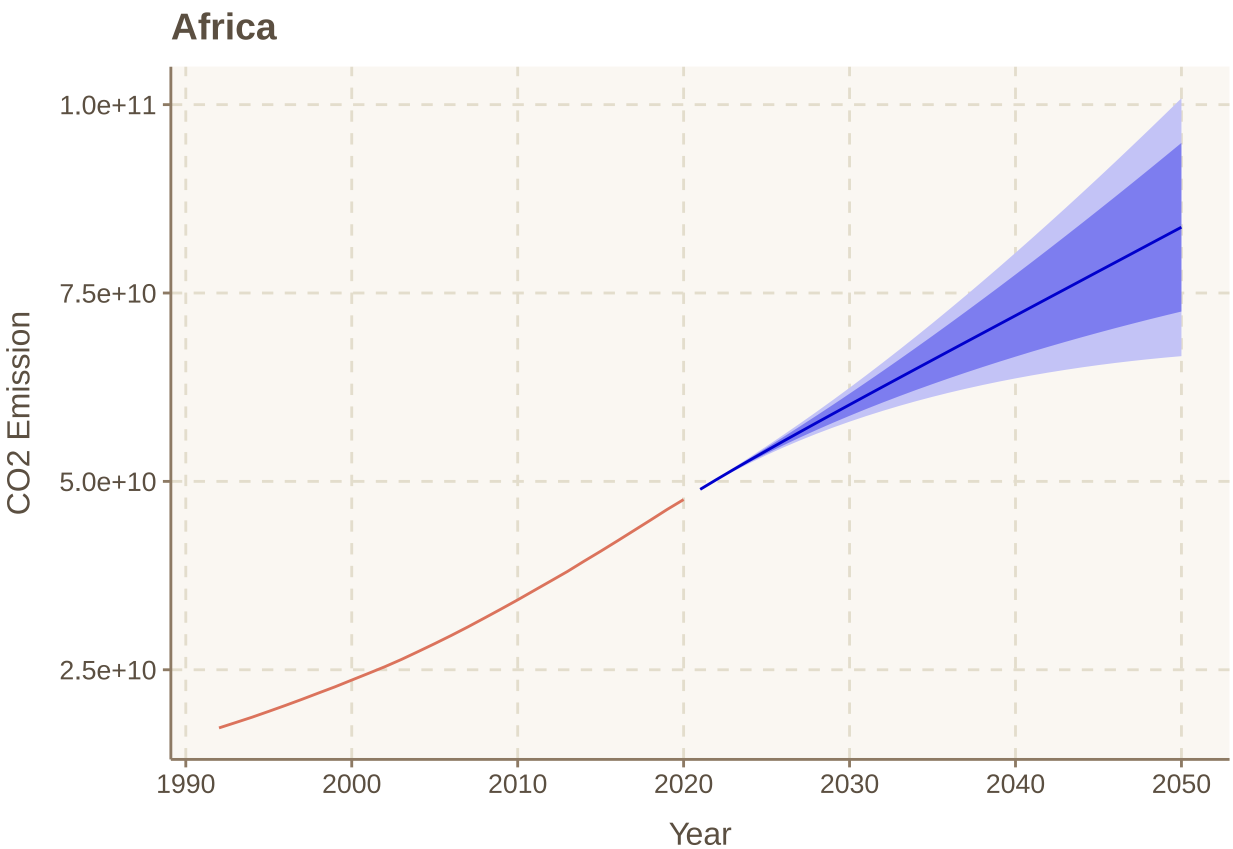



```
Oceania.plot
```



Oceania
CO2 Emission
3e+10
2e+10
1e+10
1990
2000
2010
2020
2030
2040
2050
Year


```
Africa.plot
```



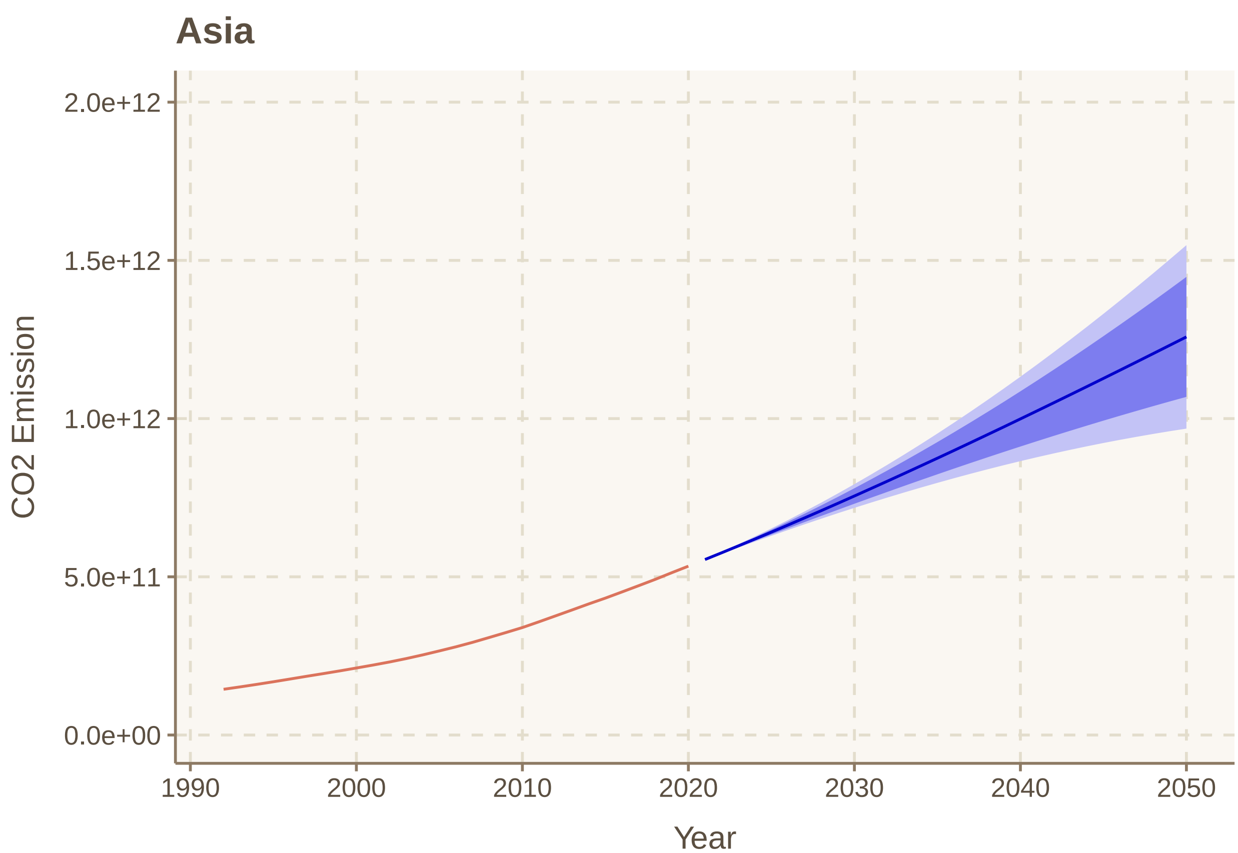
Next, plot the predictions on the same scales, from 1e+10 to 2e+12, to compare the predicted CO2 emissions among the five continents.

```
Asia.scaled.plot<-autoplot(pred.as)+
  ggtitle("Asia")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(1e+10,2e+12))

Europe.scaled.plot<-autoplot(pred.eu)+
  ggtitle("Europe")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(1e+10,2e+12))

Africa.scaled.plot<-autoplot(pred.af)+
  ggtitle("Africa")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(1e+10,2e+12))

Americas.scaled.plot<-autoplot(pred.am)+
  ggtitle("Americas")+
  labs(x = "Year", y = "CO2 Emission")+
```

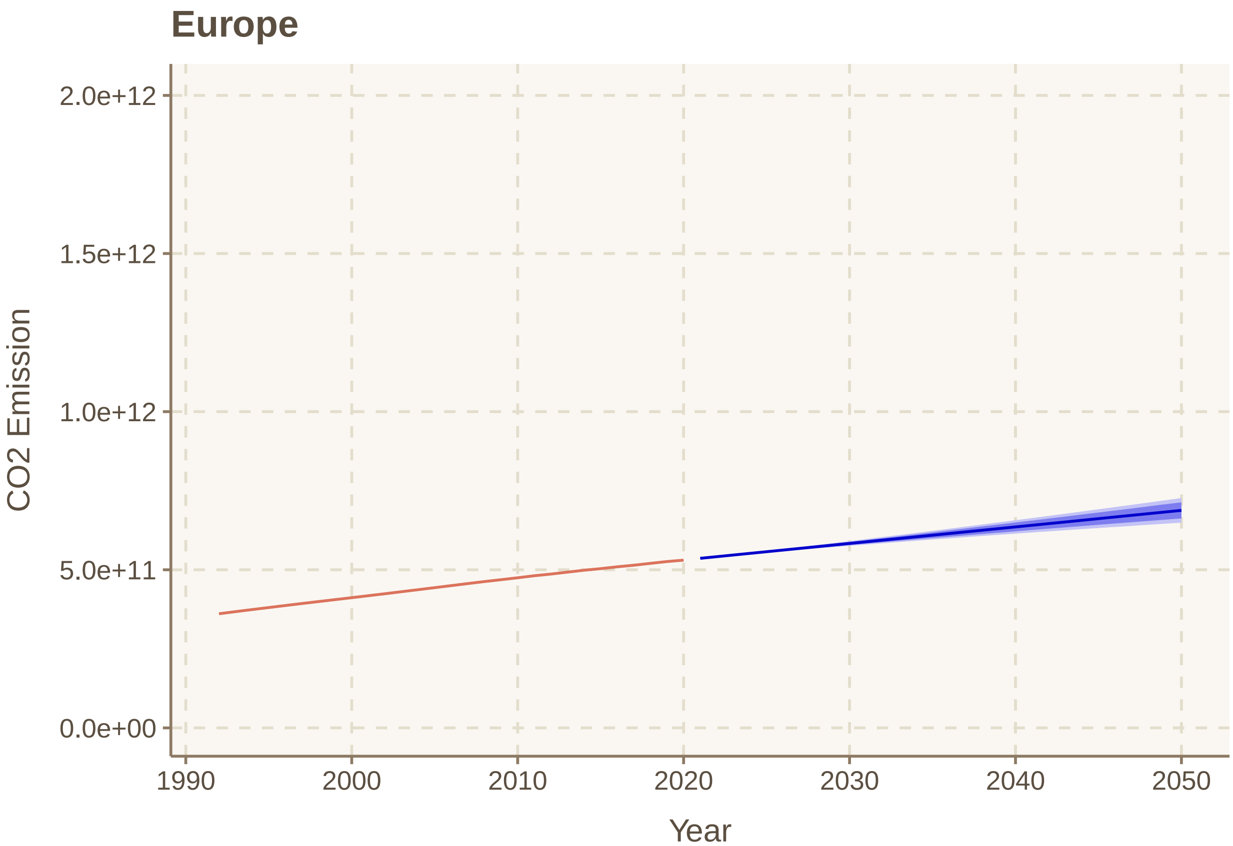
```
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(1e+10,2e+12))

Oceania.scaled.plot<-autoplot(pred.oc)+
  ggtitle("Oceania")+
  labs(x = "Year", y = "CO2 Emission")+
  theme(axis.title.x = element_text(vjust = 0),
        axis.title.y = element_text(vjust = 2))+
  ylim(c(1e+10,2e+12))

# save the plots
ggsave("Oceania.scaled.png",Oceania.scaled.plot,width = 10,height = 7.5)
```

```
## Warning: Removed 3 rows containing missing values (‘geom_line()‘).
```

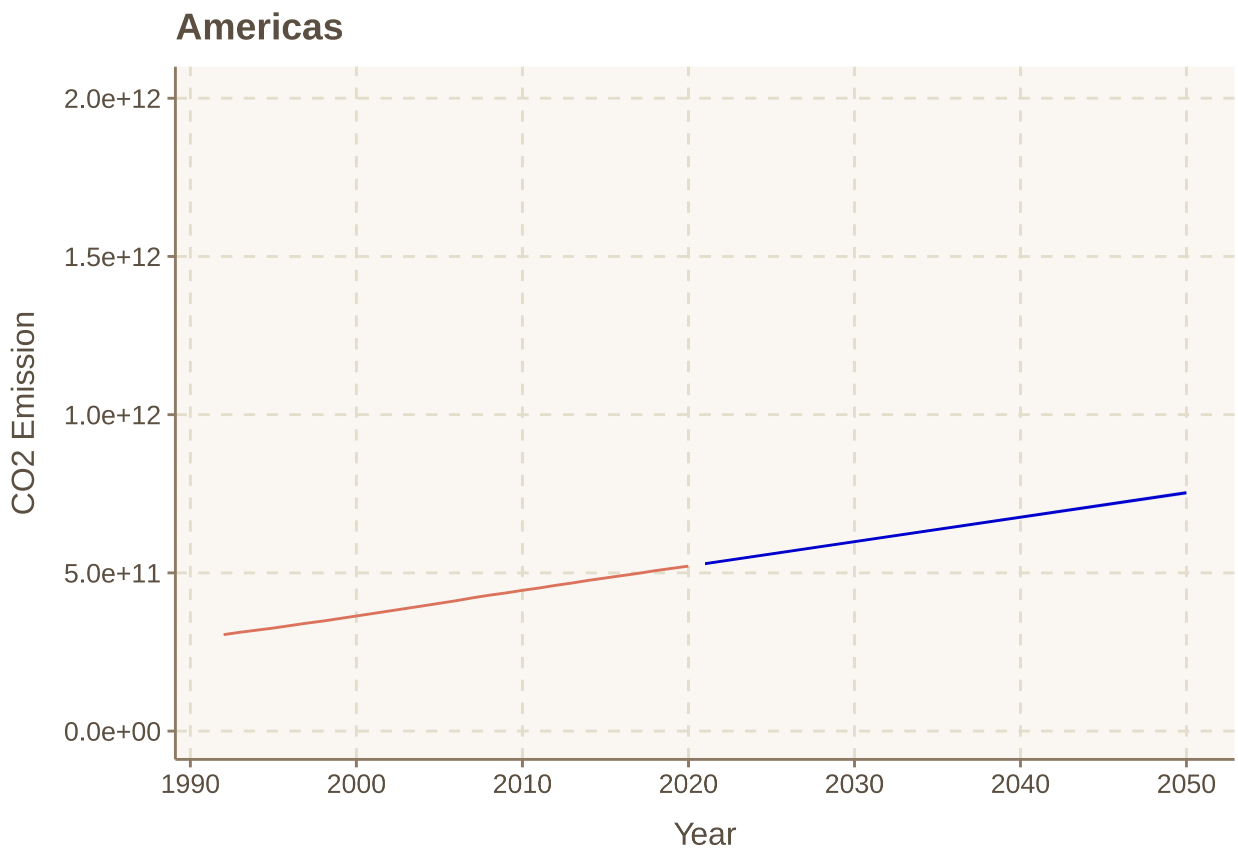
```
ggsave("Asia.scaled.png",Asia.scaled.plot,width = 10,height = 7.5)
ggsave("Europe.scaled.png",Europe.scaled.plot,width = 10,height = 7.5)
ggsave("Africa.scaled.png",Africa.scaled.plot,width = 10,height = 7.5)
ggsave("Americas.scaled.png",Americas.scaled.plot,width = 10,height = 7.5)

Asia.scaled.plot
```



```
Europe.scaled.plot
```

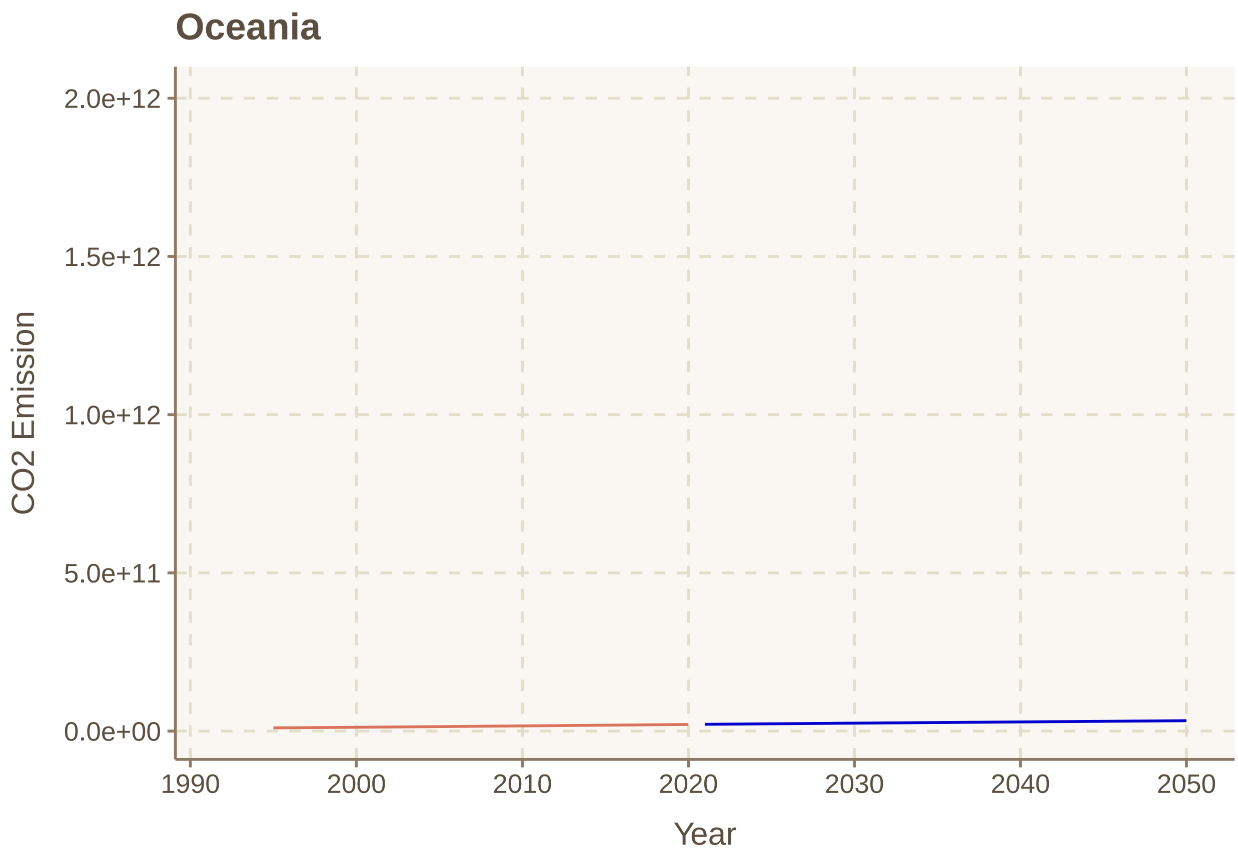



```
Americas.scaled.plot
```

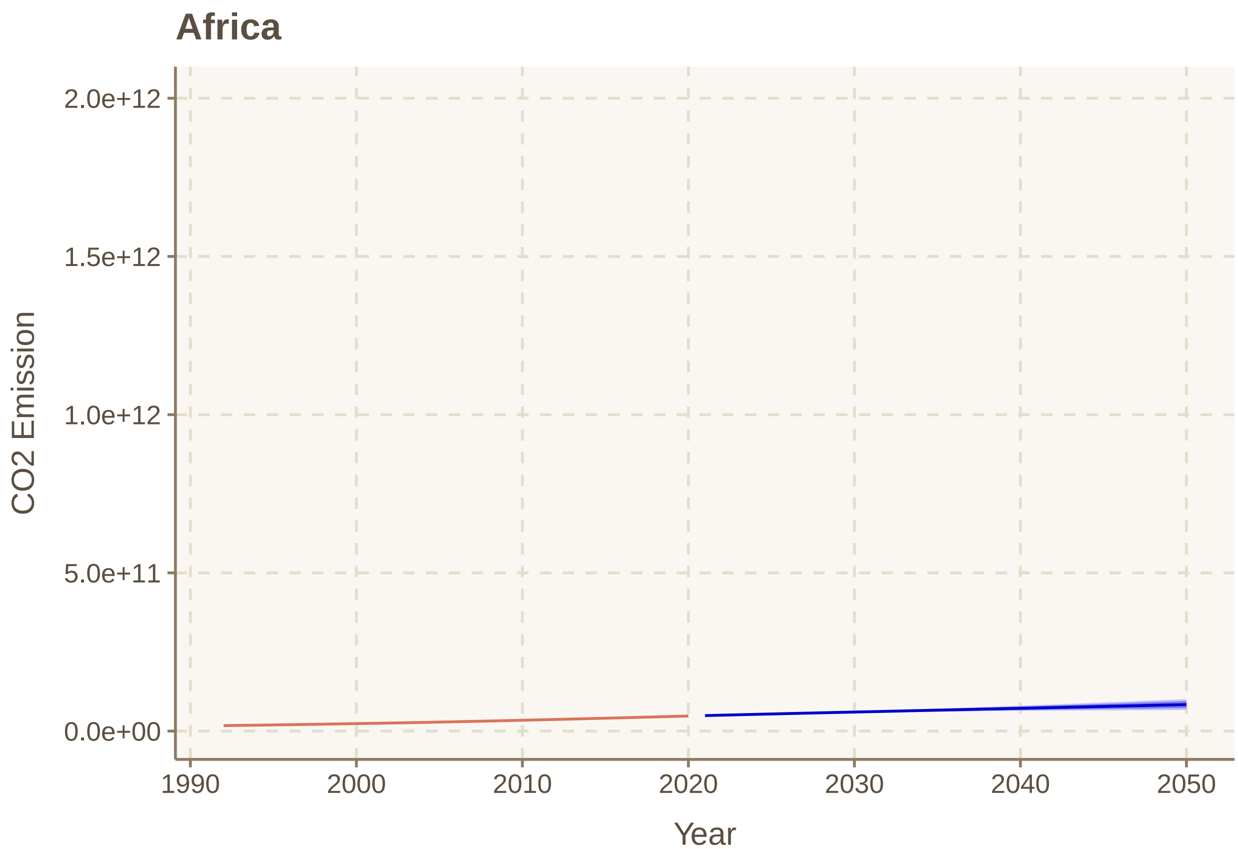



```
Oceania.scaled.plot
```

```
## Warning: Removed 3 rows containing missing values (‘geom_line()‘).
```




```
Africa.scaled.plot
```


Africa
2.0e+12
1.5e+12
1.0e+12
5.0e+11
0.0e+00
CO2 Emission
1990
2000
2010
2020
2030
2040
2050
Year