ENV 790.30 - Time Series Analysis for Energy Data | Spring 2021

Assignment 4 - Due date 02/25/21

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Directions

You should open the .rmd file corresponding to this assignment on RStudio. The file is available on our class repository on Github. And to do so you will need to fork our repository and link it to your RStudio.

Once you have the project open the first thing you will do is change "Student Name" on line 3 with your name. Then you will start working through the assignment by **creating code and output** that answer each question. Be sure to use this assignment document. Your report should contain the answer to each question and any plots/tables you obtained (when applicable).

When you have completed the assignment, **Knit** the text and code into a single PDF file. Rename the pdf file such that it includes your first and last name (e.g., "LuanaLima_TSA_A04_Sp21.Rmd"). Submit this pdf using Sakai.

Questions

Consider the same data you used for A2 from the spreadsheet "Table_10.1_Renewable_Energy_Production_and_Consumption
The data comes from the US Energy Information and Administration and corresponds to the January 2021 Monthly Energy Review.

R packages needed for this assignment:"forecast","tseries", and "Kendall". Install these packages, if you haven't done yet. Do not forget to load them before running your script, since they are NOT default packages.\

```
#Load/install required package here
library(forecast)
```

```
## Registered S3 method overwritten by 'quantmod':
##   method            from
##   as.zoo.data.frame zoo
```

```
library(tseries)
library(Kendall)
library(readxl)
library(readr)
library(lubridate)
```

```
##
## Attaching package: 'lubridate'
```

```
## The following objects are masked from 'package:base':
##
##     date, intersect, setdiff, union
```

```
library(outliers)
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.0 --
## v ggplot2 3.3.3     v dplyr   1.0.3
## v tibble  3.0.5     v stringr 1.4.0
## v tidyr   1.1.2     v forcats 0.5.0
## v purrr   0.3.4
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x lubridate::as.difftime() masks base::as.difftime()
## x lubridate::date()        masks base::date()
## x dplyr::filter()          masks stats::filter()
## x lubridate::intersect()   masks base::intersect()
## x dplyr::lag()             masks stats::lag()
## x lubridate::setdiff()     masks base::setdiff()
## x lubridate::union()       masks base::union()
```

Stochastic Trend and Stationarity Test

For this part you will once again work only with the following columns: Total Biomass Energy Production, Total Renewable Energy Production, Hydroelectric Power Consumption. Create a data frame structure with these three time series and the Date column. Don't forget to format the date object.

```
Renewable.df <- read.csv("/Users/benculberson/Documents/Duke /Spring 2021/Time Series Analysis/ENV790_3

Renewable_date<-Renewable.df[12:585,1]

Renewable_altered.df<-Renewable.df[12:585,4:6]



colnames(Renewable_altered.df)=c("Total Biomass Energy Production","Total Renewable Energy Production",

Renewable_altered.df$Date<-Renewable_date

Renewable_altered.df$`Total Biomass Energy Production`<-as.numeric(Renewable_altered.df$`Total Biomass
```

```
## Warning: NAs introduced by coercion
```

```
Renewable_altered.df$`Total Renewable Energy Production`<-as.numeric(Renewable_altered.df$`Total Renewa
```

```
## Warning: NAs introduced by coercion
```

```
Renewable_altered.df$`Hydroelectric Power Consumption`<-as.numeric(Renewable_altered.df$`Hydroelectric
```

```
## Warning: NAs introduced by coercion
```

```
#using package lubridate
my_date <- paste(Renewable_altered.df[,4])
my_date <- ym(my_date)  #function my from package lubridate, my is short for month, year
```

```
## Warning: 2 failed to parse.
```

```
head(my_date)
```

```
## [1] NA           NA           "1973-01-01" "1973-02-01" "1973-03-01"
## [6] "1973-04-01"
```

```
#add that to inflow_data and store in a new data frame
Renewable_altered.df <- cbind(my_date,Renewable_altered.df[,1:3])
```

```
head(Renewable_altered.df)
```

```
##       my_date Total Biomass Energy Production Total Renewable Energy Production
## 12       <NA>                              NA                                NA
## 13       <NA>                              NA                                NA
## 14 1973-01-01                         129.787                           403.981
## 15 1973-02-01                         117.338                           360.900
## 16 1973-03-01                         129.938                           400.161
## 17 1973-04-01                         125.636                           380.470
##    Hydroelectric Power Consumption
## 12                              NA
## 13                              NA
## 14                         272.703
## 15                         242.199
## 16                         268.810
## 17                         253.185
```

```
ncolumns <- ncol(Renewable_altered.df)

nmonths <- nrow(Renewable_altered.df)

Renewable_ts.df<-ts(Renewable_altered.df[,2:4], start=c(1973, 1), end=c(2020,10), frequency=12)
Renewable_ts.df<-cbind(my_date,Renewable_ts.df)
```

Q1

Now let's try to difference these three series using function diff(). Start with the original data from part (b). Try differencing first at lag 1 and plot the remaining series. Did anything change? Do the series still seem to have trend?

```
Renewable_ts.df
```

```
##          my_date Renewable_ts.df.Total Biomass Energy Production
## Jan 1973      NA                                              NA
## Feb 1973      NA                                              NA
## Mar 1973    1096                                         129.787
## Apr 1973    1127                                         117.338
## May 1973    1155                                         129.938
## Jun 1973    1186                                         125.636
## Jul 1973    1216                                         129.834
## Aug 1973    1247                                         125.611
## Sep 1973    1277                                         129.787
## Oct 1973    1308                                         129.918
## Nov 1973    1339                                         125.782
## Dec 1973    1369                                         129.970
## Jan 1974    1400                                         125.643
## Feb 1974    1430                                         129.824
## Mar 1974    1461                                         130.807
## Apr 1974    1492                                         118.091
## May 1974    1520                                         130.727
## Jun 1974    1551                                         126.583
## Jul 1974    1581                                         130.789
## Aug 1974    1612                                         126.611
## Sep 1974    1642                                         130.756
## Oct 1974    1673                                         130.763
```

```
## Nov 1974    1704                                    126.637
## Dec 1974    1734                                    130.718
## Jan 1975    1765                                    126.506
## Feb 1975    1795                                    130.674
## Mar 1975    1826                                    127.269
## Apr 1975    1857                                    114.942
## May 1975    1885                                    127.251
## Jun 1975    1916                                    123.139
## Jul 1975    1946                                    127.303
## Aug 1975    1977                                    123.241
## Sep 1975    2007                                    127.288
## Oct 1975    2038                                    127.321
## Nov 1975    2069                                    123.210
## Dec 1975    2099                                    127.312
## Jan 1976    2130                                    123.180
## Feb 1976    2160                                    127.277
## Mar 1976    2191                                    145.049
## Apr 1976    2222                                    135.695
## May 1976    2251                                    145.051
## Jun 1976    2282                                    140.363
## Jul 1976    2312                                    145.047
## Aug 1976    2343                                    140.405
## Sep 1976    2373                                    145.088
## Oct 1976    2404                                    145.110
## Nov 1976    2435                                    140.436
## Dec 1976    2465                                    145.114
## Jan 1977    2496                                    140.651
## Feb 1977    2526                                    145.364
## Mar 1977    2557                                    156.220
## Apr 1977    2588                                    141.176
## May 1977    2616                                    156.217
## Jun 1977    2647                                    151.161
## Jul 1977    2677                                    156.186
## Aug 1977    2708                                    151.153
## Sep 1977    2738                                    155.920
## Oct 1977    2769                                    156.081
## Nov 1977    2800                                    151.110
## Dec 1977    2830                                    156.172
## Jan 1978    2861                                    151.000
## Feb 1978    2891                                    155.935
## Mar 1978    2922                                    173.128
## Apr 1978    2953                                    156.387
## May 1978    2981                                    173.136
## Jun 1978    3012                                    167.349
## Jul 1978    3042                                    172.923
## Aug 1978    3073                                    167.340
## Sep 1978    3103                                    172.912
## Oct 1978    3134                                    173.189
## Nov 1978    3165                                    167.455
## Dec 1978    3195                                    173.169
## Jan 1979    3226                                    167.557
## Feb 1979    3256                                    173.060
## Mar 1979    3287                                    182.600
## Apr 1979    3318                                    165.096
```

```
## May 1979    3346                                    182.881
## Jun 1979    3377                                    176.844
## Jul 1979    3407                                    182.782
## Aug 1979    3438                                    176.833
## Sep 1979    3468                                    182.700
## Oct 1979    3499                                    182.808
## Nov 1979    3530                                    176.891
## Dec 1979    3560                                    182.752
## Jan 1980    3591                                    176.949
## Feb 1980    3621                                    182.770
## Mar 1980    3652                                    209.829
## Apr 1980    3683                                    196.310
## May 1980    3712                                    209.727
## Jun 1980    3743                                    202.894
## Jul 1980    3773                                    209.548
## Aug 1980    3804                                    202.723
## Sep 1980    3834                                    209.554
## Oct 1980    3865                                    209.675
## Nov 1980    3896                                    202.905
## Dec 1980    3926                                    209.717
## Jan 1981    3957                                    202.945
## Feb 1981    3987                                    209.671
## Mar 1981    4018                                    220.544
## Apr 1981    4049                                    199.248
## May 1981    4077                                    220.595
## Jun 1981    4108                                    213.467
## Jul 1981    4138                                    220.433
## Aug 1981    4169                                    213.237
## Sep 1981    4199                                    220.392
## Oct 1981    4230                                    220.428
## Nov 1981    4261                                    213.480
## Dec 1981    4291                                    220.581
## Jan 1982    4322                                    213.437
## Feb 1982    4352                                    220.440
## Mar 1982    4383                                    226.251
## Apr 1982    4414                                    204.375
## May 1982    4442                                    226.157
## Jun 1982    4473                                    218.821
## Jul 1982    4503                                    226.135
## Aug 1982    4534                                    218.866
## Sep 1982    4564                                    226.202
## Oct 1982    4595                                    226.168
## Nov 1982    4626                                    218.947
## Dec 1982    4656                                    226.373
## Jan 1983    4687                                    218.948
## Feb 1983    4717                                    226.210
## Mar 1983    4748                                    246.575
## Apr 1983    4779                                    222.738
## May 1983    4807                                    246.610
## Jun 1983    4838                                    238.625
## Jul 1983    4868                                    246.647
## Aug 1983    4899                                    238.736
## Sep 1983    4929                                    246.651
## Oct 1983    4960                                    246.695
```

```
## Nov 1983    4991                                    238.755
## Dec 1983    5021                                    246.732
## Jan 1984    5052                                    238.780
## Feb 1984    5082                                    246.871
## Mar 1984    5113                                    251.483
## Apr 1984    5144                                    235.169
## May 1984    5173                                    251.529
## Jun 1984    5204                                    243.277
## Jul 1984    5234                                    251.408
## Aug 1984    5265                                    243.303
## Sep 1984    5295                                    251.632
## Oct 1984    5326                                    251.638
## Nov 1984    5357                                    243.596
## Dec 1984    5387                                    251.974
## Jan 1985    5418                                    244.068
## Feb 1985    5448                                    252.042
## Mar 1985    5479                                    256.315
## Apr 1985    5510                                    231.512
## May 1985    5538                                    256.336
## Jun 1985    5569                                    247.599
## Jul 1985    5599                                    255.881
## Aug 1985    5630                                    247.643
## Sep 1985    5660                                    256.159
## Oct 1985    5691                                    256.301
## Nov 1985    5722                                    247.997
## Dec 1985    5752                                    256.175
## Jan 1986    5783                                    248.070
## Feb 1986    5813                                    256.246
## Mar 1986    5844                                    249.178
## Apr 1986    5875                                    224.922
## May 1986    5903                                    248.837
## Jun 1986    5934                                    240.788
## Jul 1986    5964                                    248.822
## Aug 1986    5995                                    240.837
## Sep 1986    6025                                    249.011
## Oct 1986    6056                                    249.176
## Nov 1986    6087                                    241.074
## Dec 1986    6117                                    248.974
## Jan 1987    6148                                    241.122
## Feb 1987    6178                                    249.352
## Mar 1987    6209                                    244.137
## Apr 1987    6240                                    220.511
## May 1987    6268                                    244.157
## Jun 1987    6299                                    236.139
## Jul 1987    6329                                    244.007
## Aug 1987    6360                                    236.522
## Sep 1987    6390                                    244.359
## Oct 1987    6421                                    244.396
## Nov 1987    6452                                    236.298
## Dec 1987    6482                                    244.059
## Jan 1988    6513                                    236.197
## Feb 1988    6543                                    244.104
## Mar 1988    6574                                    255.331
## Apr 1988    6605                                    238.853
```

```
## May 1988    6634                                    255.385
## Jun 1988    6665                                    247.241
## Jul 1988    6695                                    255.188
## Aug 1988    6726                                    247.340
## Sep 1988    6756                                    255.582
## Oct 1988    6787                                    255.815
## Nov 1988    6818                                    247.357
## Dec 1988    6848                                    255.517
## Jan 1989    6879                                    247.096
## Feb 1989    6909                                    255.345
## Mar 1989    6940                                    266.572
## Apr 1989    6971                                    243.927
## May 1989    6999                                    268.315
## Jun 1989    7030                                    251.946
## Jul 1989    7060                                    241.235
## Aug 1989    7091                                    248.447
## Sep 1989    7121                                    261.318
## Oct 1989    7152                                    276.985
## Nov 1989    7183                                    264.811
## Dec 1989    7213                                    276.462
## Jan 1990    7244                                    276.819
## Feb 1990    7274                                    282.520
## Mar 1990    7305                                    236.692
## Apr 1990    7336                                    226.266
## May 1990    7364                                    244.248
## Jun 1990    7395                                    232.640
## Jul 1990    7425                                    210.108
## Aug 1990    7456                                    178.544
## Sep 1990    7486                                    219.713
## Oct 1990    7517                                    245.632
## Nov 1990    7548                                    239.932
## Dec 1990    7578                                    235.437
## Jan 1991    7609                                    220.256
## Feb 1991    7639                                    245.644
## Mar 1991    7670                                    269.531
## Apr 1991    7701                                    204.535
## May 1991    7729                                    214.374
## Jun 1991    7760                                    190.452
## Jul 1991    7790                                    206.579
## Aug 1991    7821                                    209.721
## Sep 1991    7851                                    210.055
## Oct 1991    7882                                    250.834
## Nov 1991    7913                                    267.735
## Dec 1991    7943                                    249.408
## Jan 1992    7974                                    241.541
## Feb 1992    8004                                    267.033
## Mar 1992    8035                                    279.197
## Apr 1992    8066                                    230.468
## May 1992    8095                                    221.177
## Jun 1992    8126                                    210.172
## Jul 1992    8156                                    190.537
## Aug 1992    8187                                    230.985
## Sep 1992    8217                                    250.150
## Oct 1992    8248                                    269.662
```

```
## Nov 1992    8279                                    251.511
## Dec 1992    8309                                    269.545
## Jan 1993    8340                                    264.383
## Feb 1993    8370                                    263.891
## Mar 1993    8401                                    274.257
## Apr 1993    8432                                    240.964
## May 1993    8460                                    263.204
## Jun 1993    8491                                    226.859
## Jul 1993    8521                                    196.012
## Aug 1993    8552                                    197.445
## Sep 1993    8582                                    212.707
## Oct 1993    8613                                    262.322
## Nov 1993    8644                                    250.551
## Dec 1993    8674                                    257.383
## Jan 1994    8705                                    262.183
## Feb 1994    8735                                    264.559
## Mar 1994    8766                                    306.708
## Apr 1994    8797                                    244.594
## May 1994    8825                                    261.461
## Jun 1994    8856                                    236.035
## Jul 1994    8886                                    202.480
## Aug 1994    8917                                    215.744
## Sep 1994    8947                                    274.451
## Oct 1994    8978                                    251.577
## Nov 1994    9009                                    238.967
## Dec 1994    9039                                    271.599
## Jan 1995    9070                                    261.436
## Feb 1995    9100                                    262.482
## Mar 1995    9131                                    243.462
## Apr 1995    9162                                    206.657
## May 1995    9190                                    239.820
## Jun 1995    9221                                    267.571
## Jul 1995    9251                                    227.439
## Aug 1995    9282                                    226.934
## Sep 1995    9312                                    294.251
## Oct 1995    9343                                    301.628
## Nov 1995    9374                                    268.791
## Dec 1995    9404                                    292.175
## Jan 1996    9435                                    267.659
## Feb 1996    9465                                    262.694
## Mar 1996    9496                                    272.584
## Apr 1996    9527                                    226.038
## May 1996    9556                                    259.039
## Jun 1996    9587                                    205.729
## Jul 1996    9617                                    231.211
## Aug 1996    9648                                    254.182
## Sep 1996    9678                                    281.656
## Oct 1996    9709                                    294.581
## Nov 1996    9740                                    259.345
## Dec 1996    9770                                    310.461
## Jan 1997    9801                                    295.562
## Feb 1997    9831                                    264.912
## Mar 1997    9862                                    275.641
## Apr 1997    9893                                    226.521
```

```
## May 1997    9921                                    251.136
## Jun 1997    9952                                    252.010
## Jul 1997    9982                                    268.515
## Aug 1997   10013                                    231.690
## Sep 1997   10043                                    259.985
## Oct 1997   10074                                    264.422
## Nov 1997   10105                                    250.744
## Dec 1997   10135                                    305.656
## Jan 1998   10166                                    264.591
## Feb 1998   10196                                    256.998
## Mar 1998   10227                                    278.211
## Apr 1998   10258                                    212.209
## May 1998   10286                                    240.963
## Jun 1998   10317                                    240.612
## Jul 1998   10347                                    250.239
## Aug 1998   10378                                    186.089
## Sep 1998   10408                                    246.326
## Oct 1998   10439                                    254.237
## Nov 1998   10470                                    248.270
## Dec 1998   10500                                    267.922
## Jan 1999   10531                                    230.488
## Feb 1999   10561                                    273.362
## Mar 1999   10592                                    272.260
## Apr 1999   10623                                    220.539
## May 1999   10651                                    212.177
## Jun 1999   10682                                    249.920
## Jul 1999   10712                                    289.264
## Aug 1999   10743                                    236.090
## Sep 1999   10773                                    264.292
## Oct 1999   10804                                    258.854
## Nov 1999   10835                                    244.140
## Dec 1999   10865                                    228.256
## Jan 2000   10896                                    254.125
## Feb 2000   10926                                    235.215
## Mar 2000   10957                                    222.067
## Apr 2000   10988                                    246.169
## May 2000   11017                                    263.209
## Jun 2000   11048                                    254.609
## Jul 2000   11078                                    254.678
## Aug 2000   11109                                    227.712
## Sep 2000   11139                                    255.348
## Oct 2000   11170                                    254.942
## Nov 2000   11201                                    240.331
## Dec 2000   11231                                    270.472
## Jan 2001   11262                                    261.335
## Feb 2001   11292                                    254.788
## Mar 2001   11323                                    228.434
## Apr 2001   11354                                    202.849
## May 2001   11382                                    219.649
## Jun 2001   11413                                    213.628
## Jul 2001   11443                                    211.506
## Aug 2001   11474                                    213.950
## Sep 2001   11504                                    221.842
## Oct 2001   11535                                    225.897
```

```
## Nov 2001   11566                                    214.229
## Dec 2001   11596                                    227.319
## Jan 2002   11627                                    219.773
## Feb 2002   11657                                    225.088
## Mar 2002   11688                                    228.396
## Apr 2002   11719                                    198.932
## May 2002   11747                                    217.568
## Jun 2002   11778                                    212.852
## Jul 2002   11808                                    225.155
## Aug 2002   11839                                    215.107
## Sep 2002   11869                                    235.713
## Oct 2002   11900                                    224.400
## Nov 2002   11931                                    230.855
## Dec 2002   11961                                    243.767
## Jan 2003   11992                                    230.328
## Feb 2003   12022                                    242.334
## Mar 2003   12053                                    237.044
## Apr 2003   12084                                    212.693
## May 2003   12112                                    233.288
## Jun 2003   12143                                    228.516
## Jul 2003   12173                                    229.756
## Aug 2003   12204                                    228.254
## Sep 2003   12234                                    242.533
## Oct 2003   12265                                    239.928
## Nov 2003   12296                                    230.968
## Dec 2003   12326                                    236.938
## Jan 2004   12357                                    233.698
## Feb 2004   12387                                    251.160
## Mar 2004   12418                                    255.574
## Apr 2004   12449                                    236.689
## May 2004   12478                                    248.532
## Jun 2004   12509                                    247.253
## Jul 2004   12539                                    244.383
## Aug 2004   12570                                    244.075
## Sep 2004   12600                                    257.042
## Oct 2004   12631                                    254.446
## Nov 2004   12662                                    243.019
## Dec 2004   12692                                    253.520
## Jan 2005   12723                                    247.286
## Feb 2005   12753                                    264.199
## Mar 2005   12784                                    264.707
## Apr 2005   12815                                    247.271
## May 2005   12843                                    260.043
## Jun 2005   12874                                    246.929
## Jul 2005   12904                                    255.790
## Aug 2005   12935                                    252.466
## Sep 2005   12965                                    266.332
## Oct 2005   12996                                    266.097
## Nov 2005   13027                                    255.348
## Dec 2005   13057                                    261.121
## Jan 2006   13088                                    256.532
## Feb 2006   13118                                    268.550
## Mar 2006   13149                                    276.647
## Apr 2006   13180                                    247.274
```

```
## May 2006   13208                    265.069
## Jun 2006   13239                    250.384
## Jul 2006   13269                    261.125
## Aug 2006   13300                    261.960
## Sep 2006   13330                    274.809
## Oct 2006   13361                    277.063
## Nov 2006   13392                    267.952
## Dec 2006   13422                    275.120
## Jan 2007   13453                    270.475
## Feb 2007   13483                    283.636
## Mar 2007   13514                    290.845
## Apr 2007   13545                    261.666
## May 2007   13573                    285.146
## Jun 2007   13604                    278.386
## Jul 2007   13634                    286.010
## Aug 2007   13665                    281.995
## Sep 2007   13695                    295.653
## Oct 2007   13726                    295.523
## Nov 2007   13757                    287.603
## Dec 2007   13787                    299.416
## Jan 2008   13818                    297.828
## Feb 2008   13848                    312.007
## Mar 2008   13879                    331.138
## Apr 2008   13910                    300.535
## May 2008   13939                    321.487
## Jun 2008   13970                    314.073
## Jul 2008   14000                    324.185
## Aug 2008   14031                    313.335
## Sep 2008   14061                    330.507
## Oct 2008   14092                    333.607
## Nov 2008   14123                    318.840
## Dec 2008   14153                    330.125
## Jan 2009   14184                    327.317
## Feb 2009   14214                    323.102
## Mar 2009   14245                    318.353
## Apr 2009   14276                    294.389
## May 2009   14304                    319.356
## Jun 2009   14335                    303.489
## Jul 2009   14365                    319.032
## Aug 2009   14396                    321.739
## Sep 2009   14426                    343.841
## Oct 2009   14457                    348.551
## Nov 2009   14488                    332.374
## Dec 2009   14518                    346.472
## Jan 2010   14549                    348.333
## Feb 2010   14579                    360.689
## Mar 2010   14610                    377.071
## Apr 2010   14641                    347.952
## May 2010   14669                    384.094
## Jun 2010   14700                    368.922
## Jul 2010   14730                    376.012
## Aug 2010   14761                    372.328
## Sep 2010   14791                    385.443
## Oct 2010   14822                    389.064
```

```
## Nov 2010   14853                                377.355
## Dec 2010   14883                                386.771
## Jan 2011   14914                                386.602
## Feb 2011   14944                                400.917
## Mar 2011   14975                                400.130
## Apr 2011   15006                                359.201
## May 2011   15034                                394.547
## Jun 2011   15065                                373.224
## Jul 2011   15095                                384.288
## Aug 2011   15126                                389.076
## Sep 2011   15156                                398.608
## Oct 2011   15187                                401.827
## Nov 2011   15218                                386.447
## Dec 2011   15248                                397.089
## Jan 2012   15279                                400.207
## Feb 2012   15309                                419.677
## Mar 2012   15340                                398.833
## Apr 2012   15371                                372.611
## May 2012   15400                                387.374
## Jun 2012   15431                                368.516
## Jul 2012   15461                                386.825
## Aug 2012   15492                                377.323
## Sep 2012   15522                                379.041
## Oct 2012   15553                                385.552
## Nov 2012   15584                                366.465
## Dec 2012   15614                                373.472
## Jan 2013   15645                                368.172
## Feb 2013   15675                                382.521
## Mar 2013   15706                                391.206
## Apr 2013   15737                                353.773
## May 2013   15765                                397.238
## Jun 2013   15796                                385.899
## Jul 2013   15826                                404.043
## Aug 2013   15857                                400.577
## Sep 2013   15887                                417.027
## Oct 2013   15918                                411.328
## Nov 2013   15949                                392.654
## Dec 2013   15979                                414.632
## Jan 2014   16010                                413.361
## Feb 2014   16040                                433.893
## Mar 2014   16071                                418.976
## Apr 2014   16102                                379.971
## May 2014   16130                                420.974
## Jun 2014   16161                                406.459
## Jul 2014   16191                                417.246
## Aug 2014   16222                                420.030
## Sep 2014   16252                                434.940
## Oct 2014   16283                                430.195
## Nov 2014   16314                                409.688
## Dec 2014   16344                                422.001
## Jan 2015   16375                                416.969
## Feb 2015   16405                                442.916
## Mar 2015   16436                                423.312
## Apr 2015   16467                                382.846
```

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## May 2015   16495                                415.134
## Jun 2015   16526                                401.278
## Jul 2015   16556                                418.828
## Aug 2015   16587                                416.506
## Sep 2015   16617                                431.961
## Oct 2015   16648                                428.805
## Nov 2015   16679                                407.021
## Dec 2015   16709                                415.534
## Jan 2016   16740                                416.219
## Feb 2016   16770                                434.134
## Mar 2016   16801                                424.372
## Apr 2016   16832                                403.858
## May 2016   16861                                425.011
## Jun 2016   16892                                395.813
## Jul 2016   16922                                419.210
## Aug 2016   16953                                420.069
## Sep 2016   16983                                430.196
## Oct 2016   17014                                436.909
## Nov 2016   17045                                412.641
## Dec 2016   17075                                420.363
## Jan 2017   17106                                423.015
## Feb 2017   17136                                463.404
## Mar 2017   17167                                435.062
## Apr 2017   17198                                391.897
## May 2017   17226                                433.480
## Jun 2017   17257                                403.555
## Jul 2017   17287                                421.799
## Aug 2017   17318                                419.407
## Sep 2017   17348                                430.602
## Oct 2017   17379                                440.802
## Nov 2017   17410                                411.947
## Dec 2017   17440                                428.203
## Jan 2018   17471                                433.495
## Feb 2018   17501                                448.499
## Mar 2018   17532                                445.080
## Apr 2018   17563                                407.868
## May 2018   17591                                443.437
## Jun 2018   17622                                419.576
## Jul 2018   17652                                439.621
## Aug 2018   17683                                434.512
## Sep 2018   17713                                451.901
## Oct 2018   17744                                454.811
## Nov 2018   17775                                420.524
## Dec 2018   17805                                441.384
## Jan 2019   17836                                432.494
## Feb 2019   17866                                447.277
## Mar 2019   17897                                436.639
## Apr 2019   17928                                396.188
## May 2019   17956                                425.258
## Jun 2019   17987                                414.210
## Jul 2019   18017                                430.776
## Aug 2019   18048                                424.141
## Sep 2019   18078                                439.406
## Oct 2019   18109                                439.032
```

```
## Nov 2019   18140                                              407.577
## Dec 2019   18170                                              422.058
## Jan 2020   18201                                              421.487
## Feb 2020   18231                                              443.469
## Mar 2020   18262                                              435.632
## Apr 2020   18293                                              406.933
## May 2020   18322                                              413.749
## Jun 2020   18353                                              331.662
## Jul 2020   18383                                              363.894
## Aug 2020   18414                                              377.859
## Sep 2020   18444                                              401.014
## Oct 2020   18475                                              402.983
##          Renewable_ts.df.Total Renewable Energy Production
## Jan 1973                                                NA
## Feb 1973                                                NA
## Mar 1973                                           403.981
## Apr 1973                                           360.900
## May 1973                                           400.161
## Jun 1973                                           380.470
## Jul 1973                                           392.141
## Aug 1973                                           377.232
## Sep 1973                                           367.325
## Oct 1973                                           353.757
## Nov 1973                                           307.006
## Dec 1973                                           323.453
## Jan 1974                                           337.817
## Feb 1974                                           406.694
## Mar 1974                                           437.467
## Apr 1974                                           399.942
## May 1974                                           423.474
## Jun 1974                                           422.323
## Jul 1974                                           427.657
## Aug 1974                                           409.281
## Sep 1974                                           409.719
## Oct 1974                                           386.101
## Nov 1974                                           353.910
## Dec 1974                                           343.703
## Jan 1975                                           351.633
## Feb 1975                                           376.642
## Mar 1975                                           392.756
## Apr 1975                                           368.278
## May 1975                                           423.490
## Jun 1975                                           405.368
## Jul 1975                                           421.283
## Aug 1975                                           411.622
## Sep 1975                                           398.459
## Oct 1975                                           368.230
## Nov 1975                                           341.957
## Dec 1975                                           368.786
## Jan 1976                                           383.196
## Feb 1976                                           403.696
## Mar 1976                                           421.775
## Apr 1976                                           396.173
## May 1976                                           427.044
```

```
## Jun 1976 396.931
## Jul 1976 415.728
## Aug 1976 411.555
## Sep 1976 421.425
## Oct 1976 398.129
## Nov 1976 356.984
## Dec 1976 369.186
## Jan 1977 351.386
## Feb 1977 360.834
## Mar 1977 378.521
## Apr 1977 304.328
## May 1977 368.966
## Jun 1977 351.301
## Jul 1977 356.923
## Aug 1977 336.485
## Sep 1977 336.903
## Oct 1977 335.881
## Nov 1977 328.075
## Dec 1977 341.368
## Jan 1978 370.168
## Feb 1978 400.048
## Mar 1978 438.983
## Apr 1978 391.866
## May 1978 433.459
## Jun 1978 434.379
## Jul 1978 475.883
## Aug 1978 432.628
## Sep 1978 431.461
## Oct 1978 408.417
## Nov 1978 392.287
## Dec 1978 379.436
## Jan 1979 379.078
## Feb 1979 407.564
## Mar 1979 447.796
## Apr 1979 390.487
## May 1979 457.799
## Jun 1979 445.932
## Jul 1979 489.080
## Aug 1979 441.683
## Sep 1979 424.513
## Oct 1979 409.210
## Nov 1979 378.903
## Dec 1979 397.602
## Jan 1980 414.740
## Feb 1980 425.109
## Mar 1980 478.943
## Apr 1980 424.298
## May 1980 469.134
## Jun 1980 477.356
## Jul 1980 517.456
## Aug 1980 497.768
## Sep 1980 471.331
## Oct 1980 429.358
## Nov 1980 401.712
```

```
## Dec 1980 402.564
## Jan 1981 409.876
## Feb 1981 448.546
## Mar 1981 462.381
## Apr 1981 427.043
## May 1981 443.808
## Jun 1981 438.020
## Jul 1981 480.423
## Aug 1981 496.995
## Sep 1981 491.304
## Oct 1981 454.028
## Nov 1981 407.220
## Dec 1981 416.966
## Jan 1982 418.476
## Feb 1982 477.024
## Mar 1982 514.440
## Apr 1982 489.624
## May 1982 544.724
## Jun 1982 517.128
## Jul 1982 525.795
## Aug 1982 518.974
## Sep 1982 519.267
## Oct 1982 483.203
## Nov 1982 433.748
## Dec 1982 439.874
## Jan 1983 469.930
## Feb 1983 522.930
## Mar 1983 562.279
## Apr 1983 523.276
## May 1983 572.853
## Jun 1983 561.458
## Jul 1983 581.741
## Aug 1983 569.493
## Sep 1983 550.993
## Oct 1983 528.288
## Nov 1983 476.173
## Dec 1983 474.251
## Jan 1984 507.035
## Feb 1984 587.773
## Mar 1984 570.081
## Apr 1984 535.239
## May 1984 579.040
## Jun 1984 566.019
## Jul 1984 593.504
## Aug 1984 553.321
## Sep 1984 547.618
## Oct 1984 524.053
## Nov 1984 470.910
## Dec 1984 479.620
## Jan 1985 486.110
## Feb 1985 532.347
## Mar 1985 555.205
## Apr 1985 511.838
## May 1985 525.002
```

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## Jun 1985                    512.937
## Jul 1985                    542.968
## Aug 1985                    507.330
## Sep 1985                    489.577
## Oct 1985                    475.912
## Nov 1985                    454.274
## Dec 1985                    475.406
## Jan 1986                    499.606
## Feb 1986                    533.960
## Mar 1986                    486.064
## Apr 1986                    479.122
## May 1986                    558.538
## Jun 1986                    539.897
## Jul 1986                    545.072
## Aug 1986                    527.412
## Sep 1986                    513.292
## Oct 1986                    482.847
## Nov 1986                    472.114
## Dec 1986                    482.113
## Jan 1987                    492.321
## Feb 1987                    532.346
## Mar 1987                    521.265
## Apr 1987                    452.878
## May 1987                    498.782
## Jun 1987                    477.656
## Jul 1987                    509.032
## Aug 1987                    466.873
## Sep 1987                    467.691
## Oct 1987                    448.986
## Nov 1987                    437.201
## Dec 1987                    442.655
## Jan 1988                    423.208
## Feb 1988                    475.580
## Mar 1988                    495.132
## Apr 1988                    446.663
## May 1988                    469.098
## Jun 1988                    455.993
## Jul 1988                    486.212
## Aug 1988                    453.891
## Sep 1988                    442.602
## Oct 1988                    437.214
## Nov 1988                    426.312
## Dec 1988                    422.602
## Jan 1989                    448.903
## Feb 1989                    472.132
## Mar 1989                    509.147
## Apr 1989                    461.435
## May 1989                    532.715
## Jun 1989                    530.097
## Jul 1989                    562.701
## Aug 1989                    546.136
## Sep 1989                    525.098
## Oct 1989                    513.154
## Nov 1989                    487.949
```

```
## Dec 1989                                    511.060
## Jan 1990                                    521.324
## Feb 1990                                    533.841
## Mar 1990                                    511.272
## Apr 1990                                    508.361
## May 1990                                    567.935
## Jun 1990                                    530.430
## Jul 1990                                    525.673
## Aug 1990                                    503.363
## Sep 1990                                    499.495
## Oct 1990                                    497.455
## Nov 1990                                    447.349
## Dec 1990                                    460.199
## Jan 1991                                    459.565
## Feb 1991                                    528.927
## Mar 1991                                    569.477
## Apr 1991                                    465.116
## May 1991                                    519.109
## Jun 1991                                    492.912
## Jul 1991                                    540.589
## Aug 1991                                    513.638
## Sep 1991                                    499.535
## Oct 1991                                    512.229
## Nov 1991                                    491.722
## Dec 1991                                    467.135
## Jan 1992                                    467.743
## Feb 1992                                    528.581
## Mar 1992                                    535.605
## Apr 1992                                    449.194
## May 1992                                    482.783
## Jun 1992                                    445.954
## Jul 1992                                    455.238
## Aug 1992                                    497.881
## Sep 1992                                    486.977
## Oct 1992                                    491.440
## Nov 1992                                    458.262
## Dec 1992                                    472.679
## Jan 1993                                    498.631
## Feb 1993                                    545.912
## Mar 1993                                    564.643
## Apr 1993                                    477.337
## May 1993                                    543.313
## Jun 1993                                    527.476
## Jul 1993                                    537.102
## Aug 1993                                    506.688
## Sep 1993                                    491.684
## Oct 1993                                    502.290
## Nov 1993                                    461.700
## Dec 1993                                    468.760
## Jan 1994                                    482.149
## Feb 1994                                    518.766
## Mar 1994                                    546.055
## Apr 1994                                    474.597
## May 1994                                    530.492
```

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## Jun 1994                    515.824
## Jul 1994                    494.547
## Aug 1994                    497.431
## Sep 1994                    538.297
## Oct 1994                    484.333
## Nov 1994                    433.624
## Dec 1994                    476.301
## Jan 1995                    482.931
## Feb 1995                    512.711
## Mar 1995                    516.505
## Apr 1995                    478.622
## May 1995                    550.407
## Jun 1995                    536.526
## Jul 1995                    533.621
## Aug 1995                    560.146
## Sep 1995                    601.277
## Oct 1995                    582.282
## Nov 1995                    499.493
## Dec 1995                    558.496
## Jan 1996                    554.287
## Feb 1996                    585.644
## Mar 1996                    606.652
## Apr 1996                    571.304
## May 1996                    627.925
## Jun 1996                    556.068
## Jul 1996                    594.906
## Aug 1996                    607.617
## Sep 1996                    610.096
## Oct 1996                    594.878
## Nov 1996                    513.259
## Dec 1996                    568.744
## Jan 1997                    561.307
## Feb 1997                    598.134
## Mar 1997                    629.798
## Apr 1997                    563.285
## May 1997                    628.987
## Jun 1997                    603.776
## Jul 1997                    642.247
## Aug 1997                    607.803
## Sep 1997                    611.214
## Oct 1997                    566.984
## Nov 1997                    513.212
## Dec 1997                    581.272
## Jan 1998                    526.466
## Feb 1998                    541.767
## Mar 1998                    591.525
## Apr 1998                    534.593
## May 1998                    585.345
## Jun 1998                    550.085
## Jul 1998                    606.593
## Aug 1998                    538.492
## Sep 1998                    565.999
## Oct 1998                    537.288
## Nov 1998                    487.111
```

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## Dec 1998 485.978
## Jan 1999 456.086
## Feb 1999 553.640
## Mar 1999 596.138
## Apr 1999 533.206
## May 1999 564.564
## Jun 1999 551.655
## Jul 1999 610.254
## Aug 1999 571.951
## Sep 1999 593.682
## Oct 1999 547.076
## Nov 1999 482.163
## Dec 1999 456.717
## Jan 2000 492.906
## Feb 2000 515.277
## Mar 2000 505.150
## Apr 2000 499.959
## May 2000 558.005
## Jun 2000 568.524
## Jul 2000 558.724
## Aug 2000 509.114
## Sep 2000 526.262
## Oct 2000 503.686
## Nov 2000 443.376
## Dec 2000 468.215
## Jan 2001 482.866
## Feb 2001 477.785
## Mar 2001 444.970
## Apr 2001 404.069
## May 2001 455.780
## Jun 2001 425.366
## Jul 2001 435.516
## Aug 2001 454.616
## Sep 2001 436.066
## Oct 2001 447.902
## Nov 2001 396.469
## Dec 2001 409.918
## Jan 2002 401.771
## Feb 2002 449.328
## Mar 2002 476.543
## Apr 2002 428.357
## May 2002 459.464
## Jun 2002 488.511
## Jul 2002 527.649
## Aug 2002 533.572
## Sep 2002 525.246
## Oct 2002 469.661
## Nov 2002 431.895
## Dec 2002 445.453
## Jan 2003 455.854
## Feb 2003 488.697
## Mar 2003 470.089
## Apr 2003 437.335
## May 2003 508.207
```

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## Jun 2003 509.640
## Jul 2003 557.612
## Aug 2003 549.082
## Sep 2003 524.613
## Oct 2003 501.519
## Nov 2003 447.111
## Dec 2003 451.922
## Jan 2004 460.811
## Feb 2004 524.525
## Mar 2004 514.255
## Apr 2004 474.095
## May 2004 510.691
## Jun 2004 488.747
## Jul 2004 522.597
## Aug 2004 531.784
## Sep 2004 523.858
## Oct 2004 502.480
## Nov 2004 479.391
## Dec 2004 472.887
## Jan 2005 484.745
## Feb 2005 557.141
## Mar 2005 537.035
## Apr 2005 489.393
## May 2005 524.494
## Jun 2005 514.339
## Jul 2005 567.464
## Aug 2005 559.554
## Sep 2005 561.835
## Oct 2005 514.654
## Nov 2005 464.168
## Dec 2005 475.814
## Jan 2006 484.901
## Feb 2006 527.161
## Mar 2006 590.884
## Apr 2006 529.231
## May 2006 553.158
## Jun 2006 577.819
## Jul 2006 611.342
## Aug 2006 598.581
## Sep 2006 568.553
## Oct 2006 531.447
## Nov 2006 478.075
## Dec 2006 489.353
## Jan 2007 515.797
## Feb 2007 542.004
## Mar 2007 592.160
## Apr 2007 488.001
## May 2007 574.760
## Jun 2007 566.514
## Jul 2007 594.208
## Aug 2007 555.751
## Sep 2007 562.032
## Oct 2007 542.044
## Nov 2007 483.318
```

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## Dec 2007 500.596
## Jan 2008 503.177
## Feb 2008 547.807
## Mar 2008 597.548
## Apr 2008 542.194
## May 2008 604.394
## Jun 2008 607.199
## Jul 2008 668.768
## Aug 2008 675.460
## Sep 2008 646.244
## Oct 2008 599.201
## Nov 2008 531.925
## Dec 2008 552.128
## Jan 2009 551.737
## Feb 2009 614.750
## Mar 2009 626.672
## Apr 2009 545.223
## May 2009 625.284
## Jun 2009 651.263
## Jul 2009 693.147
## Aug 2009 685.792
## Sep 2009 645.637
## Oct 2009 618.027
## Nov 2009 570.906
## Dec 2009 628.228
## Jan 2010 642.567
## Feb 2010 692.188
## Mar 2010 684.564
## Apr 2010 622.652
## May 2010 696.585
## Jun 2010 675.623
## Jul 2010 732.650
## Aug 2010 768.894
## Sep 2010 717.520
## Oct 2010 677.960
## Nov 2010 641.005
## Dec 2010 661.275
## Jan 2011 695.959
## Feb 2011 739.075
## Mar 2011 755.268
## Apr 2011 718.247
## May 2011 826.703
## Jun 2011 824.252
## Jul 2011 844.606
## Aug 2011 836.734
## Sep 2011 804.736
## Oct 2011 754.488
## Nov 2011 688.692
## Dec 2011 719.072
## Jan 2012 747.237
## Feb 2012 779.516
## Mar 2012 773.134
## Apr 2012 695.351
## May 2012 796.681
```

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## Jun 2012                    770.234
## Jul 2012                    812.443
## Aug 2012                    778.948
## Sep 2012                    750.086
## Oct 2012                    719.598
## Nov 2012                    650.584
## Dec 2012                    682.912
## Jan 2013                    686.847
## Feb 2013                    769.199
## Mar 2013                    797.741
## Apr 2013                    711.752
## May 2013                    779.063
## Jun 2013                    828.095
## Jul 2013                    869.011
## Aug 2013                    832.404
## Sep 2013                    823.306
## Oct 2013                    750.860
## Nov 2013                    705.477
## Dec 2013                    748.438
## Jan 2014                    767.298
## Feb 2014                    804.457
## Mar 2014                    829.877
## Apr 2014                    712.919
## May 2014                    864.639
## Jun 2014                    872.368
## Jul 2014                    869.210
## Aug 2014                    867.499
## Sep 2014                    834.735
## Oct 2014                    768.361
## Nov 2014                    722.957
## Dec 2014                    772.211
## Jan 2015                    816.747
## Feb 2015                    834.995
## Mar 2015                    828.694
## Apr 2015                    771.267
## May 2015                    837.382
## Jun 2015                    833.853
## Jul 2015                    827.107
## Aug 2015                    792.408
## Sep 2015                    818.244
## Oct 2015                    792.096
## Nov 2015                    742.621
## Dec 2015                    775.185
## Jan 2016                    827.144
## Feb 2016                    882.764
## Mar 2016                    875.088
## Apr 2016                    864.281
## May 2016                    941.359
## Jun 2016                    891.190
## Jul 2016                    901.615
## Aug 2016                    858.269
## Sep 2016                    870.081
## Oct 2016                    821.794
## Nov 2016                    788.108
```

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## Dec 2016                                                 835.099
## Jan 2017                                                 835.016
## Feb 2017                                                 940.971
## Mar 2017                                                 926.632
## Apr 2017                                                 873.587
## May 2017                                                1026.651
## Jun 2017                                                 997.275
## Jul 2017                                                1034.318
## Aug 2017                                                 989.713
## Sep 2017                                                 923.984
## Oct 2017                                                 868.653
## Nov 2017                                                 844.056
## Dec 2017                                                 898.917
## Jan 2018                                                 890.499
## Feb 2018                                                 921.636
## Mar 2018                                                 972.470
## Apr 2018                                                 917.637
## May 2018                                                1011.223
## Jun 2018                                                1018.357
## Jul 2018                                                1049.282
## Aug 2018                                                1029.846
## Sep 2018                                                 945.119
## Oct 2018                                                 948.886
## Nov 2018                                                 865.466
## Dec 2018                                                 901.608
## Jan 2019                                                 905.400
## Feb 2019                                                 943.070
## Mar 2019                                                 943.541
## Apr 2019                                                 873.434
## May 2019                                                 990.413
## Jun 2019                                                1030.384
## Jul 2019                                                1063.768
## Aug 2019                                                1000.405
## Sep 2019                                                 987.828
## Oct 2019                                                 944.649
## Nov 2019                                                 902.923
## Dec 2019                                                 930.498
## Jan 2020                                                 901.364
## Feb 2020                                                 939.392
## Mar 2020                                                 995.264
## Apr 2020                                                 995.532
## May 2020                                                 994.615
## Jun 2020                                                 918.395
## Jul 2020                                                1036.515
## Aug 2020                                                1050.542
## Sep 2020                                                1006.388
## Oct 2020                                                 965.785
##          Renewable_ts.df.Hydroelectric Power Consumption
## Jan 1973                                              NA
## Feb 1973                                              NA
## Mar 1973                                         272.703
## Apr 1973                                         242.199
## May 1973                                         268.810
## Jun 1973                                         253.185
```

```
## Jul 1973 260.770
## Aug 1973 249.859
## Sep 1973 235.670
## Oct 1973 222.077
## Nov 1973 179.733
## Dec 1973 191.723
## Jan 1974 210.285
## Feb 1974 274.435
## Mar 1974 304.506
## Apr 1974 279.950
## May 1974 290.582
## Jun 1974 293.702
## Jul 1974 294.828
## Aug 1974 280.695
## Sep 1974 276.772
## Oct 1974 253.175
## Nov 1974 225.274
## Dec 1974 210.955
## Jan 1975 222.713
## Feb 1975 243.428
## Mar 1975 263.371
## Apr 1975 251.317
## May 1975 293.961
## Jun 1975 279.947
## Jul 1975 291.504
## Aug 1975 285.310
## Sep 1975 268.081
## Oct 1975 237.557
## Nov 1975 215.793
## Dec 1975 238.068
## Jan 1976 256.706
## Feb 1976 272.990
## Mar 1976 273.323
## Apr 1976 257.277
## May 1976 278.567
## Jun 1976 253.482
## Jul 1976 267.732
## Aug 1976 268.088
## Sep 1976 273.026
## Oct 1976 249.759
## Nov 1976 213.376
## Dec 1976 220.990
## Jan 1977 208.138
## Feb 1977 212.507
## Mar 1977 219.069
## Apr 1977 160.329
## May 1977 209.549
## Jun 1977 197.287
## Jul 1977 197.656
## Aug 1977 182.303
## Sep 1977 177.779
## Oct 1977 176.863
## Nov 1977 173.821
## Dec 1977 181.908
```

```
## Jan 1978                    215.864
## Feb 1978                    240.826
## Mar 1978                    262.529
## Apr 1978                    232.625
## May 1978                    257.965
## Jun 1978                    265.041
## Jul 1978                    301.188
## Aug 1978                    263.109
## Sep 1978                    256.107
## Oct 1978                    232.357
## Nov 1978                    221.801
## Dec 1978                    204.012
## Jan 1979                    208.974
## Feb 1979                    231.275
## Mar 1979                    262.096
## Apr 1979                    222.855
## May 1979                    271.516
## Jun 1979                    265.941
## Jul 1979                    303.134
## Aug 1979                    261.646
## Sep 1979                    238.414
## Oct 1979                    222.695
## Nov 1979                    198.794
## Dec 1979                    211.243
## Jan 1980                    234.286
## Feb 1980                    238.063
## Mar 1980                    265.618
## Apr 1980                    224.631
## May 1980                    255.676
## Jun 1980                    270.552
## Jul 1980                    303.305
## Aug 1980                    290.604
## Sep 1980                    257.106
## Oct 1980                    214.693
## Nov 1980                    194.301
## Dec 1980                    187.730
## Jan 1981                    201.929
## Feb 1981                    233.998
## Mar 1981                    236.553
## Apr 1981                    223.123
## May 1981                    217.976
## Jun 1981                    219.717
## Jul 1981                    255.200
## Aug 1981                    278.976
## Sep 1981                    265.656
## Oct 1981                    228.409
## Nov 1981                    188.516
## Dec 1981                    191.231
## Jan 1982                    200.541
## Feb 1982                    252.071
## Mar 1982                    284.215
## Apr 1982                    281.593
## May 1982                    315.347
## Jun 1982                    295.061
```

```
## Jul 1982                    295.887
## Aug 1982                    295.552
## Sep 1982                    288.273
## Oct 1982                    252.259
## Nov 1982                    210.219
## Dec 1982                    208.623
## Jan 1983                    245.861
## Feb 1983                    292.668
## Mar 1983                    310.615
## Apr 1983                    296.625
## May 1983                    321.730
## Jun 1983                    318.603
## Jul 1983                    331.656
## Aug 1983                    326.237
## Sep 1983                    298.715
## Oct 1983                    274.189
## Nov 1983                    230.650
## Dec 1983                    220.423
## Jan 1984                    261.940
## Feb 1984                    335.876
## Mar 1984                    313.504
## Apr 1984                    293.845
## May 1984                    320.670
## Jun 1984                    315.985
## Jul 1984                    335.607
## Aug 1984                    303.719
## Sep 1984                    289.982
## Oct 1984                    264.894
## Nov 1984                    220.536
## Dec 1984                    220.205
## Jan 1985                    234.699
## Feb 1985                    272.166
## Mar 1985                    290.793
## Apr 1985                    273.175
## May 1985                    260.344
## Jun 1985                    258.039
## Jul 1985                    279.498
## Aug 1985                    252.373
## Sep 1985                    225.387
## Oct 1985                    211.206
## Nov 1985                    198.288
## Dec 1985                    211.589
## Jan 1986                    242.115
## Feb 1986                    267.386
## Mar 1986                    226.352
## Apr 1986                    245.152
## May 1986                    300.280
## Jun 1986                    290.609
## Jul 1986                    287.656
## Aug 1986                    277.260
## Sep 1986                    254.396
## Oct 1986                    223.810
## Nov 1986                    222.779
## Dec 1986                    225.018
```

```
## Jan 1987 244.175
## Feb 1987 273.692
## Mar 1987 267.809
## Apr 1987 223.722
## May 1987 245.143
## Jun 1987 232.573
## Jul 1987 255.627
## Aug 1987 220.689
## Sep 1987 213.340
## Oct 1987 194.652
## Nov 1987 191.635
## Dec 1987 189.215
## Jan 1988 177.943
## Feb 1988 222.161
## Mar 1988 230.477
## Apr 1988 199.789
## May 1988 204.359
## Jun 1988 200.293
## Jul 1988 222.701
## Aug 1988 197.723
## Sep 1988 177.420
## Oct 1988 172.238
## Nov 1988 170.174
## Dec 1988 158.144
## Jan 1989 192.932
## Feb 1989 208.016
## Mar 1989 224.040
## Apr 1989 199.310
## May 1989 242.358
## Jun 1989 257.728
## Jul 1989 300.240
## Aug 1989 277.046
## Sep 1989 242.678
## Oct 1989 216.086
## Nov 1989 202.515
## Dec 1989 214.892
## Jan 1990 226.777
## Feb 1990 233.595
## Mar 1990 253.277
## Apr 1990 262.555
## May 1990 301.333
## Jun 1990 276.175
## Jul 1990 291.917
## Aug 1990 300.121
## Sep 1990 257.581
## Oct 1990 230.354
## Nov 1990 187.254
## Dec 1990 203.213
## Jan 1991 219.084
## Feb 1991 263.525
## Mar 1991 280.572
## Apr 1991 240.524
## May 1991 282.566
## Jun 1991 281.008
```

```
## Jul 1991                    309.826
## Aug 1991                    280.947
## Sep 1991                    266.050
## Oct 1991                    237.525
## Nov 1991                    201.861
## Dec 1991                    193.296
## Jan 1992                    202.130
## Feb 1992                    239.639
## Mar 1992                    235.950
## Apr 1992                    196.021
## May 1992                    237.660
## Jun 1992                    212.719
## Jul 1992                    242.426
## Aug 1992                    244.966
## Sep 1992                    214.207
## Oct 1992                    198.457
## Nov 1992                    183.300
## Dec 1992                    180.270
## Jan 1993                    212.065
## Feb 1993                    259.394
## Mar 1993                    268.521
## Apr 1993                    216.725
## May 1993                    253.399
## Jun 1993                    274.886
## Jul 1993                    316.469
## Aug 1993                    287.581
## Sep 1993                    254.885
## Oct 1993                    216.292
## Nov 1993                    188.068
## Dec 1993                    187.590
## Jan 1994                    195.571
## Feb 1994                    231.625
## Mar 1994                    220.026
## Apr 1994                    210.850
## May 1994                    243.412
## Jun 1994                    254.767
## Jul 1994                    267.130
## Aug 1994                    258.029
## Sep 1994                    241.004
## Oct 1994                    209.396
## Nov 1994                    171.008
## Dec 1994                    180.671
## Jan 1995                    197.506
## Feb 1995                    229.658
## Mar 1995                    256.445
## Apr 1995                    258.244
## May 1995                    294.609
## Jun 1995                    253.408
## Jul 1995                    286.483
## Aug 1995                    311.683
## Sep 1995                    283.275
## Oct 1995                    251.378
## Nov 1995                    206.520
## Dec 1995                    238.738
```

```
## Jan 1996 263.386
## Feb 1996 301.139
## Mar 1996 317.658
## Apr 1996 328.772
## May 1996 350.334
## Jun 1996 329.254
## Jul 1996 343.915
## Aug 1996 330.103
## Sep 1996 298.560
## Oct 1996 271.592
## Nov 1996 228.911
## Dec 1996 233.632
## Jan 1997 243.572
## Feb 1997 313.353
## Mar 1997 336.616
## Apr 1997 321.859
## May 1997 357.387
## Jun 1997 327.586
## Jul 1997 349.120
## Aug 1997 351.899
## Sep 1997 323.304
## Oct 1997 274.788
## Nov 1997 238.970
## Dec 1997 252.613
## Jan 1998 242.156
## Feb 1998 264.160
## Mar 1998 293.860
## Apr 1998 305.870
## May 1998 323.122
## Jun 1998 291.715
## Jul 1998 338.499
## Aug 1998 329.782
## Sep 1998 292.237
## Oct 1998 256.055
## Nov 1998 212.368
## Dec 1998 192.567
## Jan 1999 204.150
## Feb 1999 256.829
## Mar 1999 301.877
## Apr 1999 293.419
## May 1999 328.047
## Jun 1999 279.566
## Jul 1999 296.517
## Aug 1999 312.577
## Sep 1999 303.567
## Oct 1999 263.077
## Nov 1999 213.640
## Dec 1999 203.526
## Jan 2000 216.417
## Feb 2000 255.344
## Mar 2000 258.518
## Apr 2000 229.354
## May 2000 272.397
## Jun 2000 290.623
```

```
## Jul 2000 279.719
## Aug 2000 256.913
## Sep 2000 246.155
## Oct 2000 224.228
## Nov 2000 181.584
## Dec 2000 175.315
## Jan 2001 195.459
## Feb 2001 200.852
## Mar 2001 194.798
## Apr 2001 180.547
## May 2001 211.591
## Jun 2001 186.128
## Jul 2001 198.142
## Aug 2001 214.179
## Sep 2001 186.812
## Oct 2001 195.436
## Nov 2001 157.641
## Dec 2001 157.418
## Jan 2002 159.262
## Feb 2002 199.905
## Mar 2002 221.720
## Apr 2002 205.410
## May 2002 213.723
## Jun 2002 246.661
## Jul 2002 271.240
## Aug 2002 287.009
## Sep 2002 259.113
## Oct 2002 214.487
## Nov 2002 173.824
## Dec 2002 174.684
## Jan 2003 200.714
## Feb 2003 220.434
## Mar 2003 208.576
## Apr 2003 200.271
## May 2003 245.048
## Jun 2003 250.685
## Jul 2003 297.627
## Aug 2003 289.436
## Sep 2003 251.536
## Oct 2003 232.592
## Nov 2003 187.115
## Dec 2003 186.588
## Jan 2004 199.617
## Feb 2004 243.449
## Mar 2004 230.201
## Apr 2004 209.471
## May 2004 229.509
## Jun 2004 209.214
## Jul 2004 240.581
## Aug 2004 252.927
## Sep 2004 233.556
## Oct 2004 216.265
## Nov 2004 205.581
## Dec 2004 188.930
```

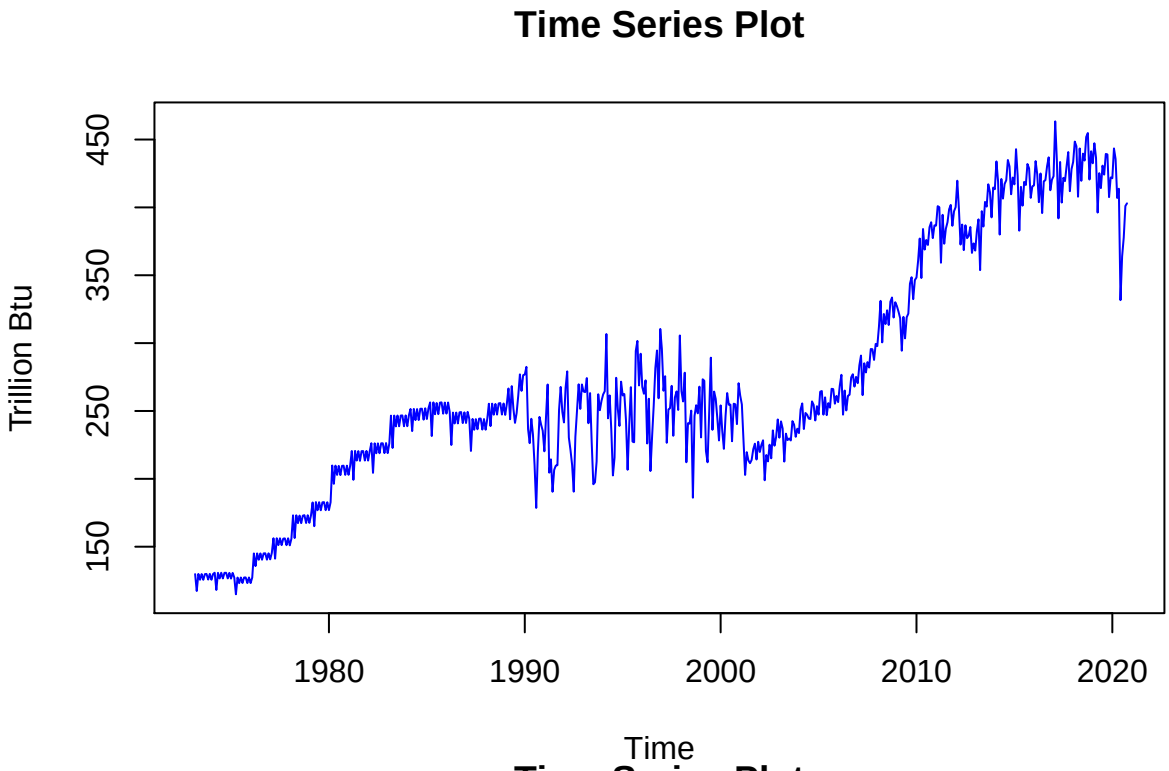
```
## Jan 2005 209.705
## Feb 2005 262.527
## Mar 2005 242.697
## Apr 2005 216.046
## May 2005 229.338
## Jun 2005 230.561
## Jul 2005 272.758
## Aug 2005 267.803
## Sep 2005 259.542
## Oct 2005 215.635
## Nov 2005 173.619
## Dec 2005 180.046
## Jan 2006 193.507
## Feb 2006 221.389
## Mar 2006 272.144
## Apr 2006 245.611
## May 2006 244.251
## Jun 2006 283.244
## Jul 2006 305.688
## Aug 2006 295.163
## Sep 2006 252.333
## Oct 2006 215.524
## Nov 2006 170.621
## Dec 2006 169.170
## Jan 2007 201.075
## Feb 2007 214.210
## Mar 2007 257.426
## Apr 2007 183.513
## May 2007 238.832
## Jun 2007 236.135
## Jul 2007 257.448
## Aug 2007 225.519
## Sep 2007 222.170
## Oct 2007 197.092
## Nov 2007 145.715
## Dec 2007 146.248
## Jan 2008 155.001
## Feb 2008 181.289
## Mar 2008 204.758
## Apr 2008 185.146
## May 2008 213.526
## Jun 2008 219.093
## Jul 2008 268.237
## Aug 2008 287.514
## Sep 2008 251.820
## Oct 2008 209.193
## Nov 2008 159.420
## Dec 2008 152.441
## Jan 2009 154.392
## Feb 2009 205.569
## Mar 2009 229.265
## Apr 2009 173.845
## May 2009 213.036
## Jun 2009 251.513
```

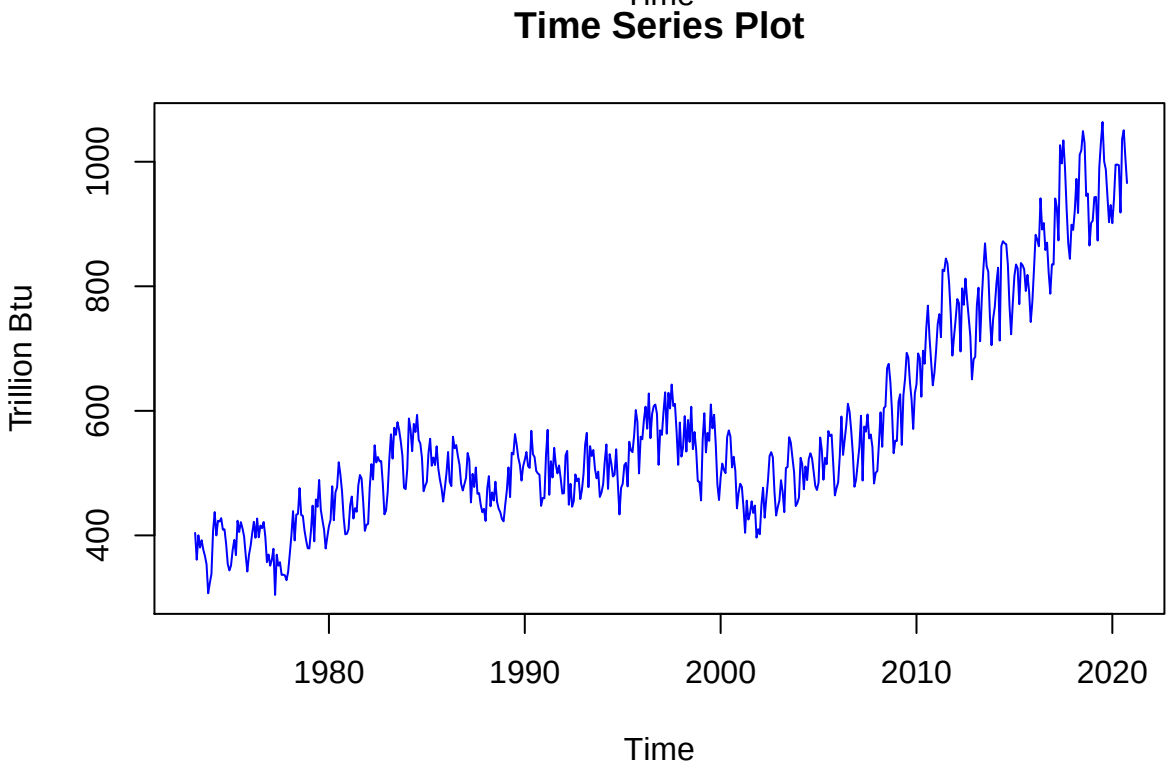
```
## Jul 2009 288.502
## Aug 2009 285.318
## Sep 2009 228.235
## Oct 2009 191.105
## Nov 2009 169.421
## Dec 2009 192.185
## Jan 2010 205.035
## Feb 2010 241.363
## Mar 2010 218.369
## Apr 2010 200.874
## May 2010 203.761
## Jun 2010 186.307
## Jul 2010 244.673
## Aug 2010 291.254
## Sep 2010 239.186
## Oct 2010 196.283
## Nov 2010 168.439
## Dec 2010 172.515
## Jan 2011 190.842
## Feb 2011 226.037
## Mar 2011 248.060
## Apr 2011 234.459
## May 2011 302.503
## Jun 2011 303.084
## Jul 2011 316.615
## Aug 2011 312.381
## Sep 2011 303.962
## Oct 2011 250.319
## Nov 2011 207.705
## Dec 2011 192.254
## Jan 2012 200.932
## Feb 2012 230.580
## Mar 2012 219.888
## Apr 2012 193.017
## May 2012 246.546
## Jun 2012 250.215
## Jul 2012 272.562
## Aug 2012 253.685
## Sep 2012 252.091
## Oct 2012 219.192
## Nov 2012 167.517
## Dec 2012 157.020
## Jan 2013 178.257
## Feb 2013 218.713
## Mar 2013 236.889
## Apr 2013 194.813
## May 2013 195.918
## Jun 2013 239.451
## Jul 2013 271.442
## Aug 2013 261.271
## Sep 2013 260.036
## Oct 2013 206.403
## Nov 2013 161.826
## Dec 2013 164.092
```

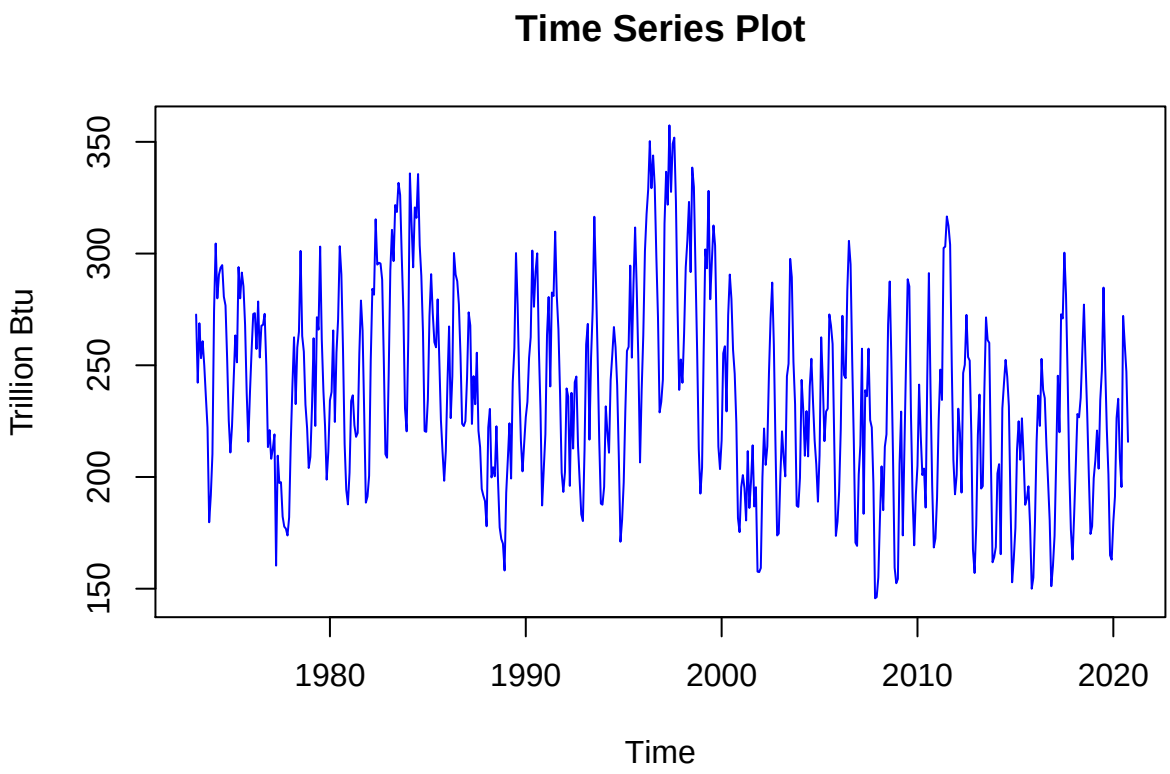
```
## Jan 2014 168.655
## Feb 2014 201.585
## Mar 2014 205.737
## Apr 2014 165.437
## May 2014 230.685
## Jun 2014 241.934
## Jul 2014 252.432
## Aug 2014 244.824
## Sep 2014 231.639
## Oct 2014 188.367
## Nov 2014 152.867
## Dec 2014 163.184
## Jan 2015 177.123
## Feb 2015 212.347
## Mar 2015 224.946
## Apr 2015 207.684
## May 2015 226.274
## Jun 2015 209.407
## Jul 2015 187.549
## Aug 2015 190.239
## Sep 2015 195.832
## Oct 2015 178.199
## Nov 2015 149.981
## Dec 2015 154.979
## Jan 2016 180.209
## Feb 2016 215.880
## Mar 2016 236.473
## Apr 2016 222.851
## May 2016 252.863
## Jun 2016 238.906
## Jul 2016 235.290
## Aug 2016 214.523
## Sep 2016 198.076
## Oct 2016 180.666
## Nov 2016 151.106
## Dec 2016 160.072
## Jan 2017 173.638
## Feb 2017 207.976
## Mar 2017 245.323
## Apr 2017 220.023
## May 2017 272.826
## Jun 2017 270.949
## Jul 2017 300.409
## Aug 2017 281.690
## Sep 2017 245.050
## Oct 2017 202.998
## Nov 2017 176.445
## Dec 2017 163.053
## Jan 2018 183.231
## Feb 2018 204.969
## Mar 2018 228.183
## Apr 2018 226.710
## May 2018 235.435
## Jun 2018 255.960
```

```
## Jul 2018                                    277.165
## Aug 2018                                    251.248
## Sep 2018                                    228.506
## Oct 2018                                    200.442
## Nov 2018                                    174.484
## Dec 2018                                    177.967
## Jan 2019                                    199.493
## Feb 2019                                    207.545
## Mar 2019                                    220.800
## Apr 2019                                    203.728
## May 2019                                    234.478
## Jun 2019                                    247.711
## Jul 2019                                    284.768
## Aug 2019                                    250.004
## Sep 2019                                    221.491
## Oct 2019                                    201.040
## Nov 2019                                    164.953
## Dec 2019                                    162.995
## Jan 2020                                    180.017
## Feb 2020                                    191.242
## Mar 2020                                    226.383
## Apr 2020                                    235.003
## May 2020                                    208.559
## Jun 2020                                    195.508
## Jul 2020                                    272.098
## Aug 2020                                    259.445
## Sep 2020                                    247.114
## Oct 2020                                    215.725
```

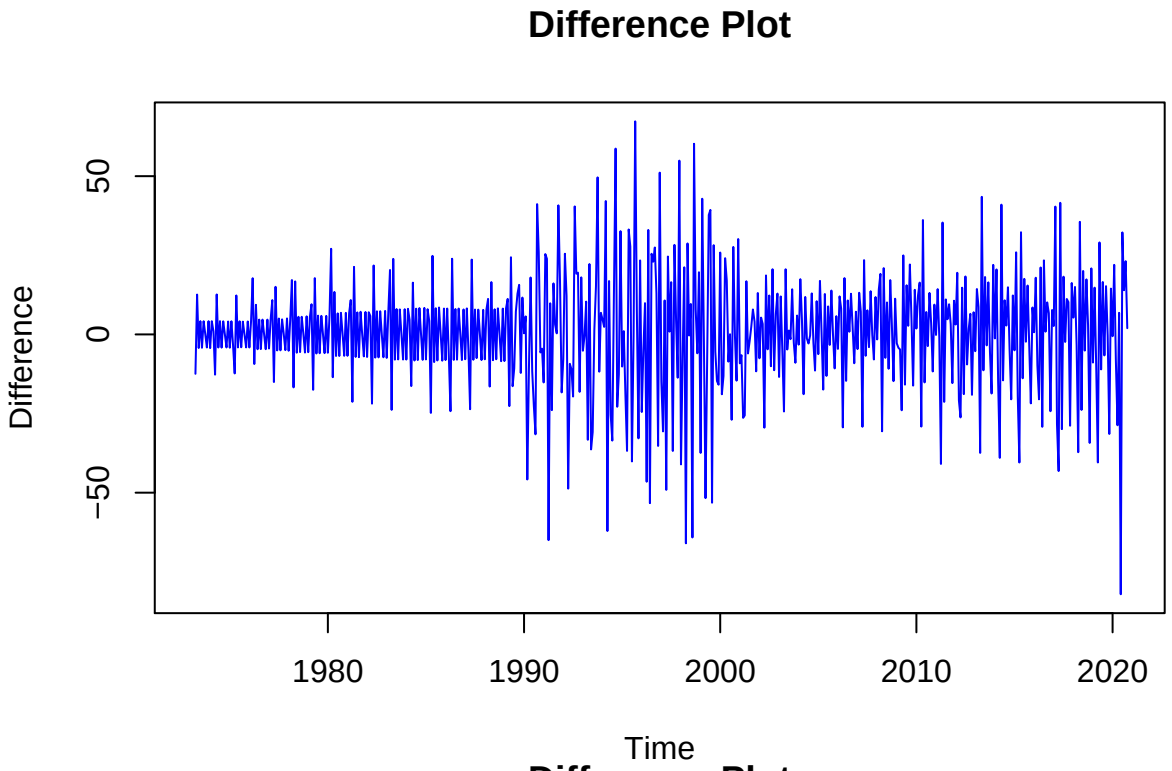
```r
Renewable_diff.df<-diff(Renewable_ts.df, lag=1)

for(i in 2:4){
  #par(mfrow=c(1,3))  #place plot side by side
  plot(Renewable_ts.df[,i], ylab="Trillion Btu",  col=c("blue"))+abline(h=mean(Renewable_ts.df[,i]), col
  #Acf(Renewable_ts.df[,i],lag.max=40,main=paste("Column",i,"ACF",sep=""))
  # because I am not storing Acf() into any object, I don't need to specify plot=TRUE
  #Pacf(Renewable_ts.df[,i],lag.max=40,main=paste("Coumn",i,"PACF",sep=""))
}
```

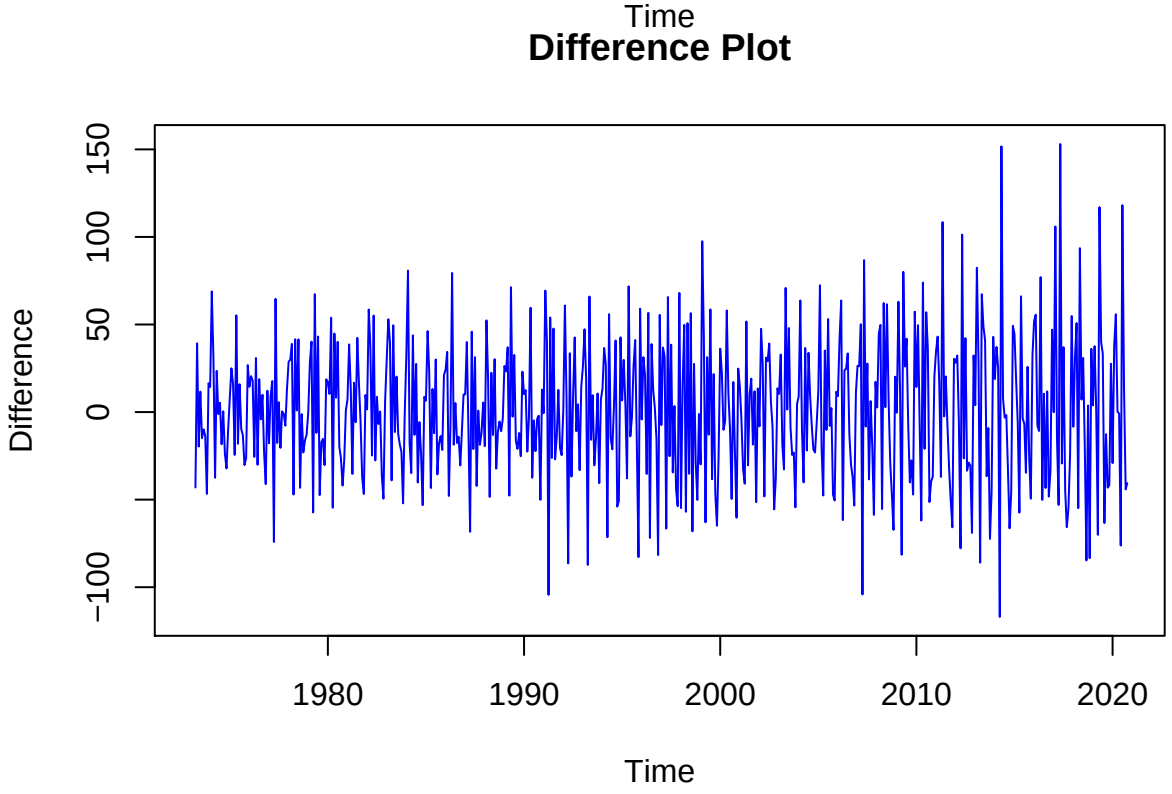

Time Series Plot
Trillion Btu
150
250
350
450
1980
1990
2000
2010
2020
Time

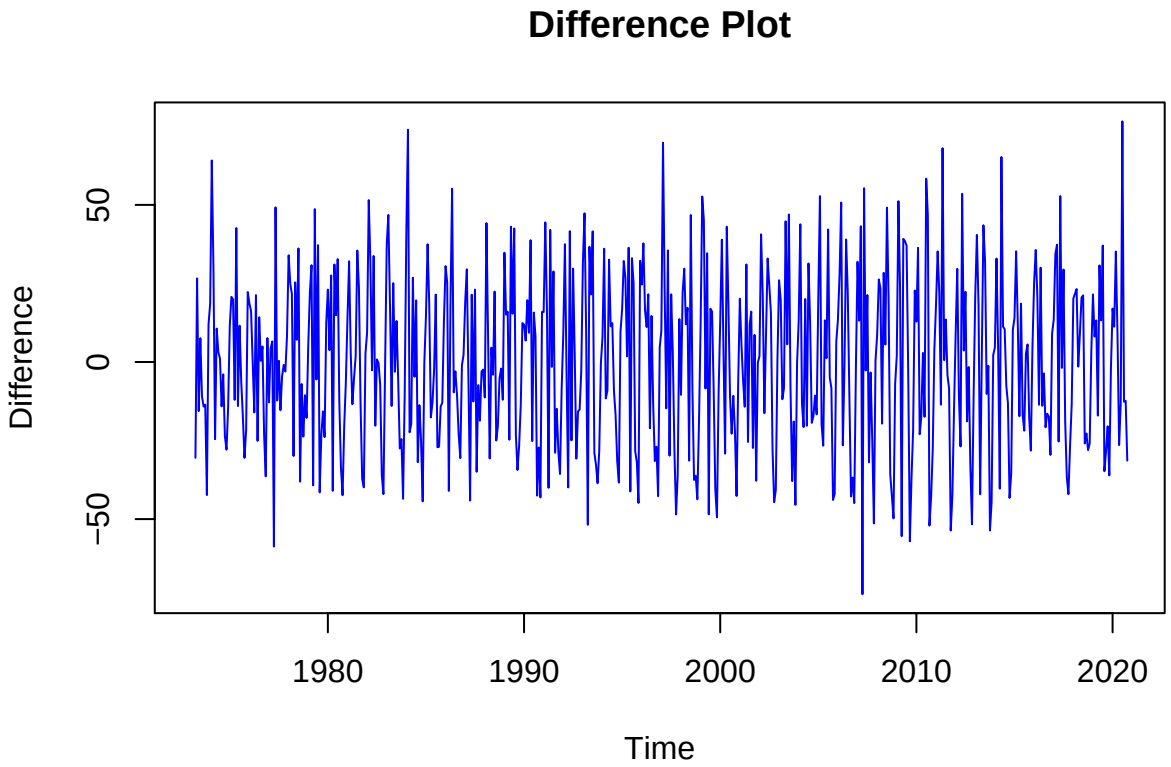

Time Series Plot
Trillion Btu
400
600
800
1000
1980
1990
2000
2010
2020
Time




```
for(i in 2:4){
  #par(mfrow=c(1,3))  #place plot side by side
  plot(Renewable_diff.df[,i], ylab="Difference",  col=c("blue"))+abline(h=mean(Renewable_diff.df[,i]),
  #Acf(Renewable_diff.df[,i],lag.max=40,main=paste("Column",i,"ACF",sep=""))
  # because I am not storing Acf() into any object, I don't need to specify plot=TRUE
  #Pacf(Renewable_diff.df[,i],lag.max=40,main=paste("Coumn",i,"PACF",sep=""))
}
```


Difference Plot
Difference
50
0
−50
1980
1990
2000
2010
2020
Time


Difference Plot
Difference
150
100
50
0
−100
1980
1990
2000
2010
2020
Time



After differencing these plots with a lag of 1, the Total Biomass Energy Production series still seems to have an obvious trend-the difference along the x axis is close to 0 for a significant stretch of time. The other two series seem to lose their trend after being differenced. Their seasonality is still clear, but only the first trend appears to obviously maintain its trend. However, as the lag increases to larger values (ex: 50), the trends in all three series become more apparent.

Q2

Compute Mann-Kendall and Spearman's Correlation Rank Test for each time series. Ask R to print the results. Interpret the results.

```
MannKendall(Renewable_ts.df[,2])
```

```
## tau = 0.71, 2-sided pvalue =< 2.22e-16
```

```
MannKendall(Renewable_ts.df[,3])
```

```
## tau = 0.652, 2-sided pvalue =< 2.22e-16
```

```
MannKendall(Renewable_ts.df[,4])
```

```
## tau = -0.182, 2-sided pvalue =7.6024e-11
```

```
cor.test(Renewable_ts.df[,2], Renewable_ts.df[,1],
                    method = "pearson")
```

```
##
##  Pearson's product-moment correlation
##
## data:  Renewable_ts.df[, 2] and Renewable_ts.df[, 1]
## t = 47.027, df = 570, p-value < 2.2e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.8735456 0.9073260
```

```
## sample estimates:
##       cor
## 0.8916705
```

```
cor.test(Renewable_ts.df[,3], Renewable_ts.df[,1],
                    method = "pearson")
```

```
##
##  Pearson's product-moment correlation
##
## data:  Renewable_ts.df[, 3] and Renewable_ts.df[, 1]
## t = 35.248, df = 570, p-value < 2.2e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.8002917 0.8520960
## sample estimates:
##      cor
## 0.827952
```

```
cor.test(Renewable_ts.df[,4], Renewable_ts.df[,1],
                    method = "pearson")
```

```
##
##  Pearson's product-moment correlation
##
## data:  Renewable_ts.df[, 4] and Renewable_ts.df[, 1]
## t = -6.7038, df = 570, p-value = 4.892e-11
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  -0.3446805 -0.1926255
## sample estimates:
##       cor
## -0.270338
```

Each of the Mann-Kendall tests have a null hypothesis of series stationarity and an alternate hypothesis of a series trend. In each of the three series, Total Biomass Energy Production, Total Renewable Energy Production, and Hydroelectric Power Consumption we reject the null hypothesis of stationarity with p values of very close to 0. In all three series, I am confident that each series has a trend: the first two are positive, Hydro is negative.

The Spearman's Rank Correlation test has a null hypothesis that says the two tested variables do not covary and an alternate hypothesis that says they do. In all three of my tests, which compare my three series of note to the date, we reject the null hypothesis with p-values very close to zero. I am confident all three of my series: Total Biomass Energy Production, Total Renewable Energy Production, and Hydroelectric Power Consumption covary with time.

Decomposing the series

For this part you will work only with the following columns: Solar Energy Consumption and Wind Energy Consumption.

Q3

Create a data frame structure with these two time series only and the Date column. Drop the rows with *Not Available* and convert the columns to numeric. You can use filtering to eliminate the initial rows or conver to numeric and then use the drop_na() function. If you are familiar with pipes for data wrangling, try using it!

```
Renewable.df <- read.csv("../Data/Table_10.1_Renewable_Energy_Production_and_Consumption_by_Source.csv")

Renewable_date<-Renewable.df[14:585,1]
Renewable_SolarWind.df<-Renewable.df[14:585,8:9]

colnames(Renewable_SolarWind.df)=c("Solar Energy Consumption","Wind Energy Consumption")
Renewable_SolarWind.df$Date<-Renewable_date

Renewable_SolarWind.df$`Solar Energy Consumption`<-as.numeric(Renewable_SolarWind.df$`Solar Energy Consu
```

```
## Warning: NAs introduced by coercion
```

```
Renewable_SolarWind.df$`Wind Energy Consumption`<-as.numeric(Renewable_SolarWind.df$`Wind Energy Consump
```

```
## Warning: NAs introduced by coercion
```

```
Renewable_SolarWind.df<-drop_na(Renewable_SolarWind.df)

my_date <- paste(Renewable_SolarWind.df[,3])
my_date <- ym(my_date)  #function my from package lubridate, my is short for month, year

Renewable_SolarWind.df <- cbind(my_date,Renewable_SolarWind.df[,1:2])
#head(Renewable_SolarWind.df)
```

Q4

Plot the Solar and Wind energy consumption over time using ggplot. Explore the function scale_x_date() on ggplot and see if you can change the x axis to improve your plot. Hint: use *scale_x_date(date_breaks = "5 years", date_labels = "%Y")")*

Try changing the color of the wind series to blue. Hint: use *color = "blue"*

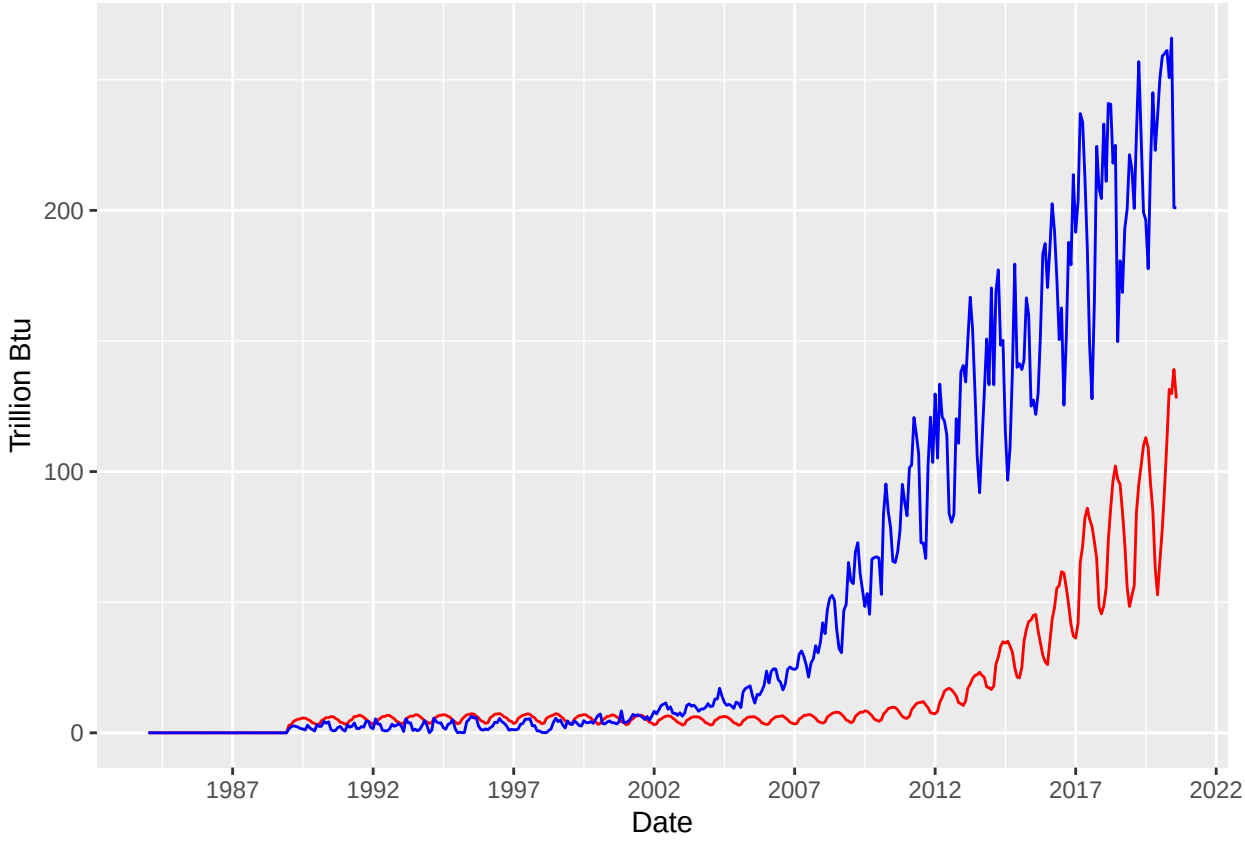
```
ggplot(Renewable_SolarWind.df) +
  geom_line(aes(x = Renewable_SolarWind.df$my_date, y = Renewable_SolarWind.df$`Solar Energy Consumptio
  geom_line(aes(x = Renewable_SolarWind.df$my_date, y = Renewable_SolarWind.df$`Wind Energy Consumption
  ylab("Trillion Btu") +
  xlab("Date") +
  scale_x_date(date_breaks = "5 years", date_labels = "%Y")
```

```
## Warning: Use of `Renewable_SolarWind.df$my_date` is discouraged. Use `my_date`
## instead.
```

```
## Warning: Use of `Renewable_SolarWind.df$`Solar Energy Consumption`` is
## discouraged. Use `Solar Energy Consumption` instead.
```

```
## Warning: Use of `Renewable_SolarWind.df$my_date` is discouraged. Use `my_date`
## instead.
```

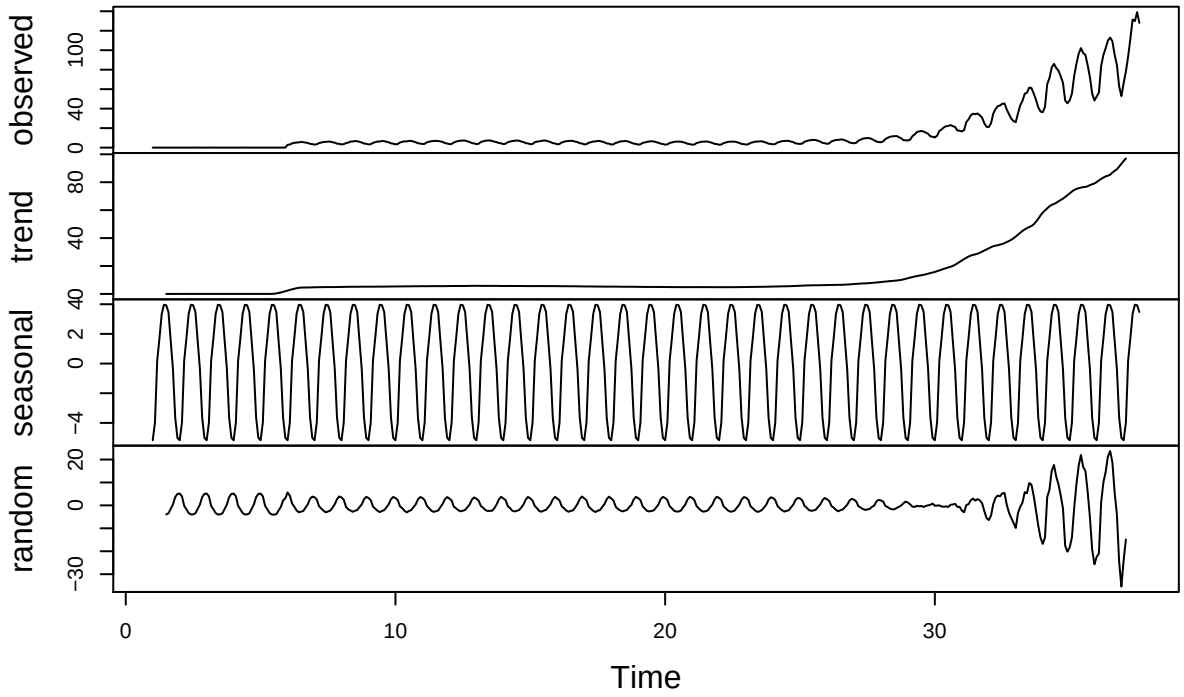
```
## Warning: Use of `Renewable_SolarWind.df$`Wind Energy Consumption`` is
## discouraged. Use `Wind Energy Consumption` instead.
```



Q5

Transform wind and solar series into a time series object and apply the decompose function on them using the additive option. What can you say about the trend component? What about the random component? Does the random component look random? Or does it appear to still have some seasonality on it?

```
Renewable_SolarWind_ts<-ts(Renewable_SolarWind.df, frequency=12)
#SOLAR PLOT

#Using R decompose function
decompose_Solar=decompose(Renewable_SolarWind_ts[,2], "additive")
plot(decompose_Solar)
```



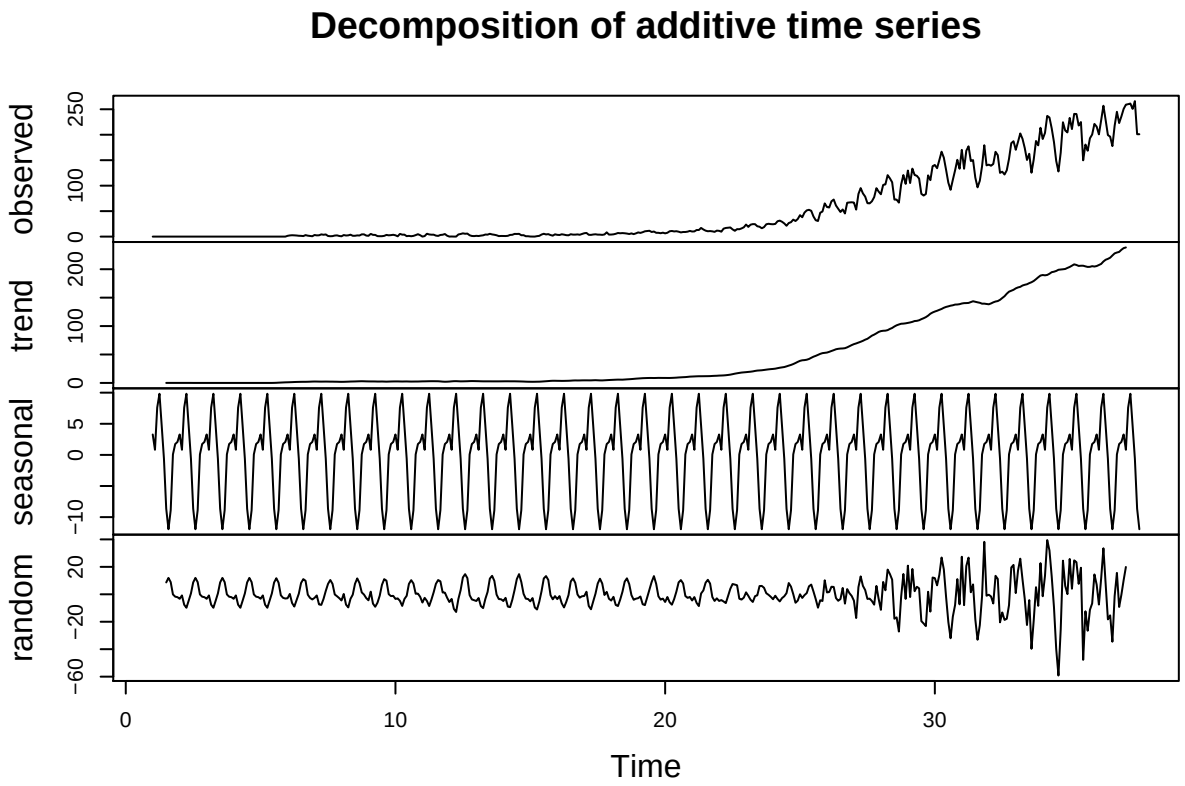

```
#Inspect random component
Solar_random <- decompose_Solar$random   #this would just be the random component then
mean_Solar <- mean(Solar_random)
sd_Solar <- sd(Solar_random)

cat(mean_Solar,sd_Solar)
```

```
## NA NA
```

```
#Note random series has some missing values, that is why we got NAs

#Compute mean and standard deviation without missing values
mean_Solar <- mean(na.exclude(Solar_random))  #exclude NA or missing observation to compute mean and st
sd_Solar <- sd(na.exclude(Solar_random))

cat(mean_Solar,sd_Solar)
```

```
## -0.1401871 5.59249
```

```
#WIND PLOT

#Using R decompose function
decompose_Wind=decompose(Renewable_SolarWind_ts[,3], "additive")
plot(decompose_Wind)
```




```
#Inspect random component
Wind_random <- decompose_Wind$random   #this would just be the random component then
mean_Wind <- mean(Wind_random)
sd_Wind <- sd(Wind_random)

cat(mean_Wind,sd_Wind)
```

```
## NA NA
```

```
#Note random series has some missing values, that is why we got NAs

#Compute mean and standard deviation without missing values
mean_Wind <- mean(na.exclude(Wind_random))  #exclude NA or missing observation to compute mean and std
sd_Wind <- sd(na.exclude(Wind_random))

cat(mean_Wind,sd_Wind)
```

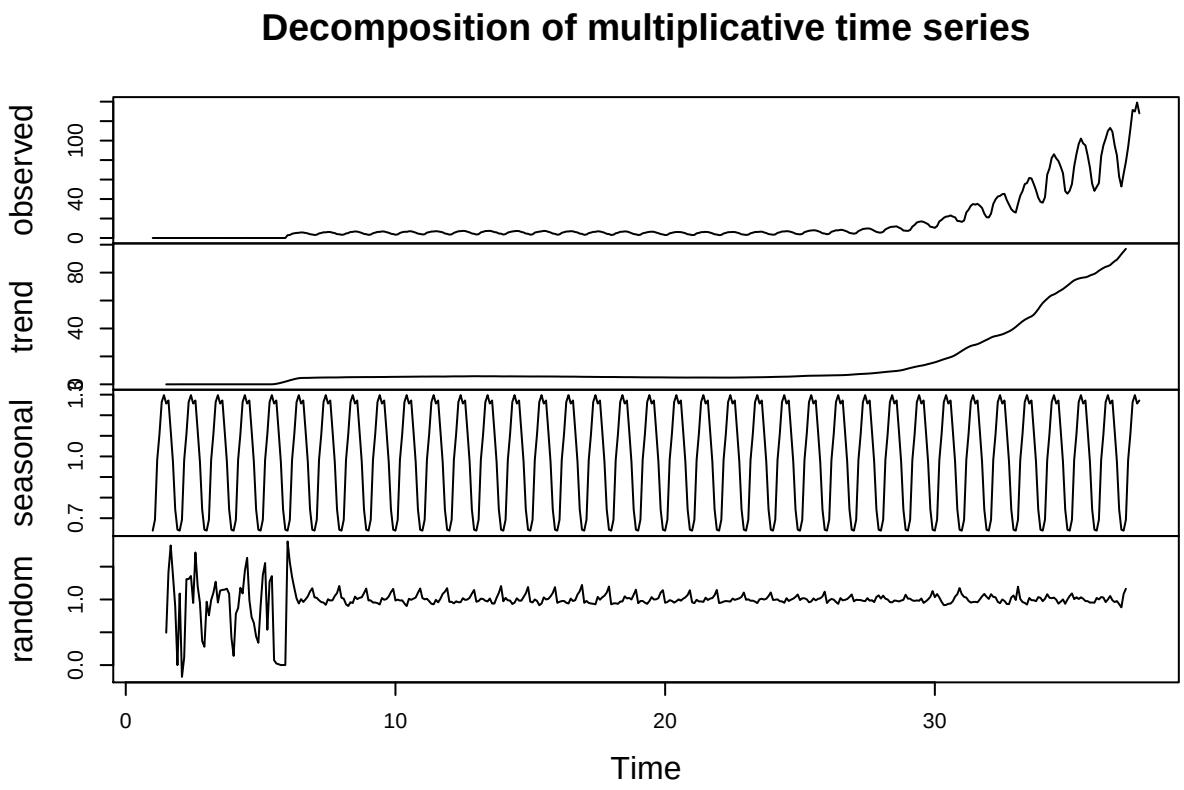
```
## 0.02325102 11.03871
```

The trend component of the Solar (1st plot) and Wind (2nd plot) energy consumption both appear to be steady close to 0 and then linearly increasing at around 2005 for wind energy and 2012 for solar energy. The random components appear to be rather seasonal for both series for the entire plot, however it does seem that the magnitude of the random component increases at the same time their respective trends begin increasing linearily.

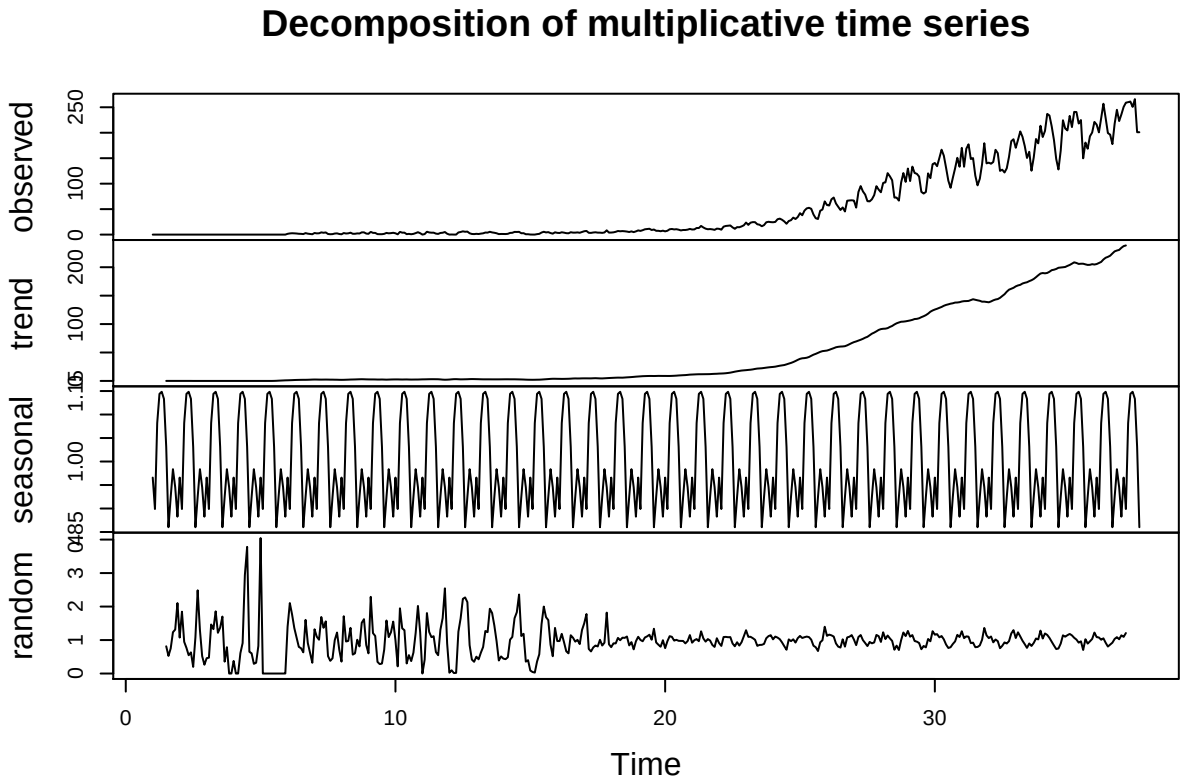
Q6

Use the decompose function again but now change the type of the seasonal component from additive to multiplicative. What happened to the random component this time?

```
decompose_Solar_m=decompose(Renewable_SolarWind_ts[,2], "multiplicative")
plot(decompose_Solar_m)
```




```
decompose_Wind_m=decompose(Renewable_SolarWind_ts[,3], "multiplicative")
plot(decompose_Wind_m)
```



After decomposing both the series using the multiplicative seasonal component, the random component changes significantly. What previously appeared to be a seasonally varying component has become more erratic and less seasonal. The random component is particularly more erratic at earlier times (when the data had smaller observed values). As the observed values increase, the random values diminish in variability significantly and become somewhat seasonally varying. ### Q7

When fitting a model to this data, do you think you need all the historical data? Think about the date from 90s and early 20s. Are there any information from those year we might need to forecast the next six months of Solar and/or Wind consumption. Explain your response.

When fitting a model to this data, it appears that we only need data starting at around 2000 for the Wind Power Consumption and around 2010 for Solar Power Consumption. Prior to those dates, the trends for these two energy sources remain constant and close to 0. Any more information prior to those dates is not very useful if we were to fit a model to the data.