ENV 790.30 - Time Series Analysis for Energy Data | Spring 2025

Assignment 3 - Due date 02/03/26

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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.

Once you have the file open on your local machine the first thing you will do is rename the file such that it includes your first and last name (e.g., "LuanaLima_TSA_A03_Sp25.Rmd"). Then change "Student Name" on line 4 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).

Please keep this R code chunk options for the report. It is easier for us to grade when we can see code and output together. And the tidy.opts will make sure that line breaks on your code chunks are automatically added for better visualization.

When you have completed the assignment, **Knit** the text and code into a single PDF file. Submit this pdf using Sakai.

Questions

Consider the same data you used for A2 from the spreadsheet "Table_10.1_Renewable_Energy_Production_and_Consumpti
The data comes from the US Energy Information and Administration and corresponds to the December 2025 Monthly Energy Review. This time you will work only with the following columns: **Total Renewable Energy Production**; and **Hydroelectric Power Consumption**.

Create a data frame structure with these two time series only.

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(lubridate)
```

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

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

```r
library(ggplot2)
library(forecast)
```

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

```r
library(Kendall)
library(tseries)
library(readxl)
```

##Trend Component

Q1

For each series (Total Renewable Production and Hydroelectric Consumption) create three plots arranged in a row (side-by-side): (1) time series plot, (2) ACF, (3) PACF. Use cowplot::plot_grid() to place them in a grid.

```r
#import data
energy_data1 <- read_excel(path="/Users/xxx/R/Time Series_R/TSA/Data/Table_10.1_Renewable_Energy_Produc
```

```
## New names:
## * `` -> `...1`
## * `` -> `...2`
## * `` -> `...3`
## * `` -> `...4`
## * `` -> `...5`
## * `` -> `...6`
## * `` -> `...7`
## * `` -> `...8`
## * `` -> `...9`
## * `` -> `...10`
## * `` -> `...11`
## * `` -> `...12`
## * `` -> `...13`
## * `` -> `...14`
```

```r
read_col_names <- read_excel(path="/Users/xxx/R/Time Series_R/TSA/Data/Table_10.1_Renewable_Energy_Produ
```

```
## New names:
## * `` -> `...1`
## * `` -> `...2`
## * `` -> `...3`
## * `` -> `...4`
## * `` -> `...5`
## * `` -> `...6`
## * `` -> `...7`
## * `` -> `...8`
## * `` -> `...9`
```

```
## * `` -> `...10`
## * `` -> `...11`
## * `` -> `...12`
## * `` -> `...13`
## * `` -> `...14`
```

```r
colnames(energy_data1) <- read_col_names

head(energy_data1)
```

```
## # A tibble: 6 x 14
##   Month               `Wood Energy Production` `Biofuels Production`
##   <dttm>                                 <dbl> <chr>
## 1 1973-01-01 00:00:00                     130. Not Available
## 2 1973-02-01 00:00:00                     117. Not Available
## 3 1973-03-01 00:00:00                     130. Not Available
## 4 1973-04-01 00:00:00                     125. Not Available
## 5 1973-05-01 00:00:00                     130. Not Available
## 6 1973-06-01 00:00:00                     125. Not Available
## # i 11 more variables: `Total Biomass Energy Production` <dbl>,
## #   `Total Renewable Energy Production` <dbl>,
## #   `Hydroelectric Power Consumption` <dbl>,
## #   `Geothermal Energy Consumption` <dbl>, `Solar Energy Consumption` <chr>,
## #   `Wind Energy Consumption` <chr>, `Wood Energy Consumption` <dbl>,
## #   `Waste Energy Consumption` <dbl>, `Biofuels Consumption` <chr>,
## #   `Total Biomass Energy Consumption` <dbl>, ...
```

```r
ts_energy_data1 <- energy_data1[,5:6]

#transform data frame to time series object
ts_energy_data1 <- ts(ts_energy_data1, start = c(1973, 1),frequency = 12)
ts_energy_data1
```

```
##          Total Renewable Energy Production Hydroelectric Power Consumption
## Jan 1973                           219.839                          89.562
## Feb 1973                           197.330                          79.544
## Mar 1973                           218.686                          88.284
## Apr 1973                           209.330                          83.152
## May 1973                           215.982                          85.643
## Jun 1973                           208.249                          82.060
## Jul 1973                           207.800                          77.400
## Aug 1973                           203.432                          72.936
## Sep 1973                           185.300                          59.029
## Oct 1973                           193.514                          62.967
## Nov 1973                           195.326                          69.063
## Dec 1973                           220.755                          90.131
## Jan 1974                           231.010                          99.500
## Feb 1974                           210.188                          91.476
## Mar 1974                           226.384                          94.950
## Apr 1974                           223.218                          95.969
## May 1974                           227.793                          96.337
## Jun 1974                           218.976                          91.719
## Jul 1974                           221.909                          90.437
```

```
## Aug 1974                     214.197                     82.727
## Sep 1974                     200.900                     73.610
## Oct 1974                     200.312                     68.931
## Nov 1974                     200.068                     72.773
## Dec 1974                     211.046                     79.542
## Jan 1975                     214.319                     86.356
## Feb 1975                     198.008                     82.404
## Mar 1975                     224.384                     96.386
## Apr 1975                     215.679                     91.791
## May 1975                     223.695                     95.581
## Jun 1975                     217.798                     93.550
## Jul 1975                     216.202                     87.900
## Aug 1975                     206.312                     77.892
## Sep 1975                     194.934                     70.756
## Oct 1975                     206.489                     78.060
## Nov 1975                     208.436                     84.171
## Dec 1975                     217.911                     89.510
## Jan 1976                     236.073                     89.904
## Feb 1976                     221.374                     84.626
## Mar 1976                     237.807                     91.629
## Apr 1976                     224.756                     83.378
## May 1976                     234.082                     88.065
## Jun 1976                     229.595                     88.182
## Jul 1976                     235.984                     89.807
## Aug 1976                     228.336                     82.153
## Sep 1976                     211.665                     70.186
## Oct 1976                     218.818                     72.690
## Nov 1976                     209.968                     68.463
## Dec 1976                     216.239                     69.900
## Jan 1977                     228.907                     71.630
## Feb 1977                     194.523                     52.424
## Mar 1977                     225.781                     68.518
## Apr 1977                     216.602                     64.508
## May 1977                     221.823                     64.629
## Jun 1977                     211.752                     59.609
## Jul 1977                     215.097                     58.130
## Aug 1977                     214.871                     57.830
## Sep 1977                     208.974                     56.835
## Oct 1977                     216.727                     59.480
## Nov 1977                     222.663                     70.583
## Dec 1977                     235.754                     78.744
## Jan 1978                     260.677                     86.454
## Feb 1978                     233.933                     76.606
## Mar 1978                     258.863                     84.951
## Apr 1978                     255.285                     87.281
## May 1978                     272.691                     99.185
## Jun 1978                     254.703                     86.645
## Jul 1978                     258.056                     84.339
## Aug 1978                     250.652                     76.518
## Sep 1978                     241.494                     73.042
## Oct 1978                     241.095                     67.184
## Nov 1978                     237.214                     68.818
## Dec 1978                     250.285                     76.162
## Jan 1979                     270.000                     86.378
```

```
## Feb 1979                   239.377                  73.446
## Mar 1979                   273.485                  89.483
## Apr 1979                   265.526                  87.645
## May 1979                   283.727                  99.903
## Jun 1979                   264.118                  86.230
## Jul 1979                   262.394                  78.573
## Aug 1979                   257.423                  73.393
## Sep 1979                   243.468                  65.516
## Oct 1979                   253.559                  69.619
## Nov 1979                   255.317                  77.213
## Dec 1979                   262.637                  78.457
## Jan 1980                   298.221                  87.244
## Feb 1980                   271.194                  73.781
## Mar 1980                   294.931                  83.978
## Apr 1980                   293.043                  88.865
## May 1980                   310.682                  99.622
## Jun 1980                   299.633                  95.451
## Jul 1980                   295.537                  84.448
## Aug 1980                   281.831                  70.517
## Sep 1980                   268.204                  63.819
## Oct 1980                   273.058                  61.661
## Nov 1980                   270.913                  66.325
## Dec 1980                   288.131                  76.858
## Jan 1981                   299.483                  77.214
## Feb 1981                   273.604                  72.830
## Mar 1981                   293.454                  71.150
## Apr 1981                   286.764                  71.718
## May 1981                   305.297                  83.301
## Jun 1981                   305.860                  91.061
## Jul 1981                   308.821                  86.714
## Aug 1981                   296.678                  74.556
## Sep 1981                   276.720                  61.534
## Oct 1981                   284.684                  62.420
## Nov 1981                   280.364                  65.459
## Dec 1981                   304.193                  82.279
## Jan 1982                   320.311                  92.763
## Feb 1982                   297.475                  91.907
## Mar 1982                   330.131                 102.924
## Apr 1982                   316.183                  96.303
## May 1982                   323.939                  96.572
## Jun 1982                   316.816                  96.463
## Jul 1982                   321.854                  94.087
## Aug 1982                   310.059                  82.333
## Sep 1982                   289.054                  68.612
## Oct 1982                   296.056                  68.091
## Nov 1982                   300.864                  80.245
## Dec 1982                   323.054                  95.522
## Jan 1983                   348.969                 100.743
## Feb 1983                   320.213                  96.206
## Mar 1983                   352.422                 104.348
## Apr 1983                   343.331                 103.334
## May 1983                   355.330                 107.568
## Jun 1983                   346.012                 105.810
## Jul 1983                   345.359                  96.883
```

```
## Aug 1983                    338.025                    88.929
## Sep 1983                    315.758                    74.808
## Oct 1983                    320.524                    71.491
## Nov 1983                    325.785                    84.956
## Dec 1983                    357.437                   108.936
## Jan 1984                    355.607                   102.459
## Feb 1984                    333.238                    96.034
## Mar 1984                    358.566                   104.801
## Apr 1984                    348.756                   103.270
## May 1984                    363.212                   109.683
## Jun 1984                    344.623                    99.261
## Jul 1984                    348.366                    94.772
## Aug 1984                    340.669                    86.573
## Sep 1984                    317.887                    72.076
## Oct 1984                    326.373                    71.968
## Nov 1984                    323.172                    76.704
## Dec 1984                    343.652                    88.949
## Jan 1985                    353.933                    94.973
## Feb 1985                    323.067                    89.219
## Mar 1985                    344.083                    85.029
## Apr 1985                    334.259                    84.276
## May 1985                    349.644                    91.284
## Jun 1985                    332.457                    82.425
## Jul 1985                    332.393                    73.612
## Aug 1985                    328.026                    68.980
## Sep 1985                    315.367                    64.761
## Oct 1985                    327.776                    69.105
## Nov 1985                    330.222                    79.075
## Dec 1985                    346.947                    87.328
## Jan 1986                    326.552                    73.934
## Feb 1986                    307.952                    80.075
## Mar 1986                    349.995                    98.081
## Apr 1986                    338.487                    94.922
## May 1986                    345.587                    93.958
## Jun 1986                    334.442                    90.562
## Jul 1986                    335.334                    83.094
## Aug 1986                    325.501                    73.104
## Sep 1986                    316.539                    72.767
## Oct 1986                    325.125                    73.498
## Nov 1986                    323.172                    79.755
## Dec 1986                    341.787                    89.397
## Jan 1987                    334.890                    87.702
## Feb 1987                    296.606                    73.264
## Mar 1987                    327.541                    80.279
## Apr 1987                    315.231                    76.163
## May 1987                    330.797                    83.712
## Jun 1987                    311.957                    72.271
## Jul 1987                    317.495                    69.864
## Aug 1987                    311.395                    63.744
## Sep 1987                    302.090                    62.756
## Oct 1987                    309.095                    61.964
## Nov 1987                    297.439                    58.272
## Dec 1987                    319.908                    72.753
## Jan 1988                    334.583                    76.171
```

```
## Feb 1988                                307.533                          66.029
## Mar 1988                                326.015                          67.539
## Apr 1988                                316.232                          66.195
## May 1988                                331.539                          73.601
## Jun 1988                                315.603                          65.346
## Jul 1988                                317.391                          58.636
## Aug 1988                                315.766                          56.923
## Sep 1988                                306.500                          56.241
## Oct 1988                                310.737                          52.265
## Nov 1988                                313.792                          63.762
## Dec 1988                                326.992                          68.748
## Jan 1989                                348.321                          73.277
## Feb 1989                                317.572                          65.188
## Mar 1989                                358.115                          79.268
## Apr 1989                                346.511                          84.295
## May 1989                                350.304                          98.200
## Jun 1989                                349.753                          90.614
## Jul 1989                                351.720                          79.373
## Aug 1989                                358.320                          70.675
## Sep 1989                                341.553                          66.237
## Oct 1989                                356.682                          70.285
## Nov 1989                                359.731                          74.172
## Dec 1989                                367.555                          76.402
## Jan 1990                                329.327                          83.078
## Feb 1990                                321.465                          86.122
## Mar 1990                                353.956                          98.841
## Apr 1990                                334.136                          90.589
## May 1990                                317.791                          95.753
## Jun 1990                                289.276                          98.444
## Jul 1990                                315.872                          84.490
## Aug 1990                                332.580                          75.559
## Sep 1990                                311.965                          61.422
## Oct 1990                                312.873                          66.657
## Nov 1990                                301.883                          71.863
## Dec 1990                                341.584                          86.440
## Jan 1991                                370.278                          91.732
## Feb 1991                                292.511                          78.638
## Mar 1991                                317.683                          92.384
## Apr 1991                                293.309                          91.874
## May 1991                                320.120                         101.296
## Jun 1991                                313.437                          91.854
## Jul 1991                                309.257                          86.984
## Aug 1991                                340.813                          77.658
## Sep 1991                                345.122                          65.997
## Oct 1991                                324.454                          63.197
## Nov 1991                                318.757                          66.085
## Dec 1991                                355.690                          78.349
## Jan 1992                                366.577                          77.844
## Feb 1992                                305.537                          64.670
## Mar 1992                                311.299                          78.408
## Apr 1992                                292.073                          70.180
## May 1992                                282.361                          79.980
## Jun 1992                                323.546                          80.819
## Jul 1992                                333.005                          70.671
```

```
## Aug 1992                                     347.510                                    65.474
## Sep 1992                                     324.027                                    60.474
## Oct 1992                                     340.565                                    59.474
## Nov 1992                                     345.048                                    69.964
## Dec 1992                                     360.200                                    85.579
## Jan 1993                                     373.255                                    88.873
## Feb 1993                                     322.185                                    71.730
## Mar 1993                                     359.855                                    83.868
## Apr 1993                                     330.605                                    90.980
## May 1993                                     313.546                                   104.743
## Jun 1993                                     304.450                                    95.182
## Jul 1993                                     309.916                                    84.360
## Aug 1993                                     346.577                                    71.587
## Sep 1993                                     324.882                                    62.245
## Oct 1993                                     331.480                                    62.087
## Nov 1993                                     338.485                                    64.729
## Dec 1993                                     352.074                                    76.662
## Jan 1994                                     388.854                                    72.773
## Feb 1994                                     323.751                                    69.738
## Mar 1994                                     354.509                                    80.508
## Apr 1994                                     332.955                                    84.264
## May 1994                                     303.865                                    88.353
## Jun 1994                                     313.708                                    85.343
## Jul 1994                                     366.741                                    79.712
## Aug 1994                                     333.540                                    69.257
## Sep 1994                                     307.933                                    56.561
## Oct 1994                                     343.569                                    59.757
## Nov 1994                                     338.304                                    65.325
## Dec 1994                                     348.732                                    75.959
## Jan 1995                                     336.872                                    84.852
## Feb 1995                                     299.810                                    85.447
## Mar 1995                                     346.752                                    97.479
## Apr 1995                                     361.046                                    83.847
## May 1995                                     333.643                                    94.791
## Jun 1995                                     342.092                                   103.128
## Jul 1995                                     400.977                                    93.729
## Aug 1995                                     399.583                                    83.175
## Sep 1995                                     349.815                                    68.333
## Oct 1995                                     384.663                                    78.993
## Nov 1995                                     366.200                                    87.148
## Dec 1995                                     373.129                                    99.640
## Jan 1996                                     385.971                                   104.821
## Feb 1996                                     343.243                                   108.488
## Mar 1996                                     385.026                                   115.603
## Apr 1996                                     325.915                                   108.647
## May 1996                                     356.221                                   113.485
## Jun 1996                                     375.816                                   108.928
## Jul 1996                                     395.278                                    98.519
## Aug 1996                                     398.870                                    89.620
## Sep 1996                                     347.920                                    75.536
## Oct 1996                                     400.155                                    77.094
## Nov 1996                                     387.043                                    80.374
## Dec 1996                                     378.537                                   103.400
## Jan 1997                                     397.124                                   112.458
```

```
## Feb 1997                     342.279                     107.528
## Mar 1997                     381.623                     119.397
## Apr 1997                     374.093                     109.441
## May 1997                     398.347                     116.635
## Jun 1997                     362.325                     117.564
## Jul 1997                     382.540                     108.011
## Aug 1997                     370.673                      91.802
## Sep 1997                     343.197                      79.836
## Oct 1997                     402.188                      84.394
## Nov 1997                     355.868                      80.900
## Dec 1997                     355.807                      88.252
## Jan 1998                     386.269                      98.328
## Feb 1998                     323.378                     102.347
## Mar 1998                     360.492                     108.119
## Apr 1998                     348.763                      97.610
## May 1998                     374.487                     113.264
## Jun 1998                     309.019                     110.348
## Jul 1998                     358.537                      97.785
## Aug 1998                     354.150                      85.678
## Sep 1998                     332.989                      71.060
## Oct 1998                     345.379                      64.434
## Nov 1998                     309.809                      68.310
## Dec 1998                     370.867                      85.937
## Jan 1999                     383.582                     100.724
## Feb 1999                     328.183                      97.902
## Mar 1999                     334.062                     109.456
## Apr 1999                     355.198                      93.280
## May 1999                     401.370                      98.936
## Jun 1999                     353.158                     104.294
## Jul 1999                     379.433                     101.288
## Aug 1999                     360.215                      87.778
## Sep 1999                     328.356                      71.283
## Oct 1999                     308.985                      67.908
## Nov 1999                     337.650                      72.210
## Dec 1999                     332.407                      85.198
## Jan 2000                     319.978                      86.468
## Feb 2000                     334.369                      76.714
## Mar 2000                     366.040                      91.110
## Apr 2000                     364.110                      97.207
## May 2000                     361.267                      93.560
## Jun 2000                     326.724                      85.931
## Jul 2000                     351.077                      82.333
## Aug 2000                     343.214                      74.999
## Sep 2000                     312.937                      60.736
## Oct 2000                     341.025                      58.639
## Nov 2000                     339.223                      65.377
## Dec 2000                     333.069                      67.181
## Jan 2001                     303.197                      64.323
## Feb 2001                     272.585                      59.617
## Mar 2001                     301.844                      69.868
## Apr 2001                     288.028                      61.460
## May 2001                     290.338                      65.427
## Jun 2001                     298.272                      70.723
## Jul 2001                     297.654                      61.686
```

```
## Aug 2001                                304.239                              64.534
## Sep 2001                                279.069                              52.054
## Oct 2001                                292.015                              51.980
## Nov 2001                                283.668                              52.589
## Dec 2001                                302.843                              66.010
## Jan 2002                                314.861                              74.364
## Feb 2002                                279.136                              68.894
## Mar 2002                                302.856                              71.682
## Apr 2002                                309.709                              82.729
## May 2002                                331.378                              90.973
## Jun 2002                                326.674                              96.262
## Jul 2002                                337.792                              86.906
## Aug 2002                                311.593                              71.938
## Sep 2002                                302.858                              58.300
## Oct 2002                                315.739                              58.589
## Nov 2002                                309.716                              67.319
## Dec 2002                                328.629                              73.933
## Jan 2003                                318.956                              70.287
## Feb 2003                                291.767                              67.489
## Mar 2003                                330.201                              82.578
## Apr 2003                                327.749                              84.478
## May 2003                                345.099                             100.297
## Jun 2003                                341.209                              97.536
## Jul 2003                                342.647                              84.765
## Aug 2003                                333.101                              78.381
## Sep 2003                                308.470                              63.055
## Oct 2003                                313.818                              62.878
## Nov 2003                                314.096                              67.268
## Dec 2003                                347.074                              82.039
## Jan 2004                                347.154                              78.419
## Feb 2004                                321.055                              71.357
## Mar 2004                                342.168                              78.184
## Apr 2004                                334.068                              71.270
## May 2004                                344.066                              81.955
## Jun 2004                                346.968                              86.161
## Jul 2004                                353.034                              79.562
## Aug 2004                                344.004                              73.672
## Sep 2004                                328.252                              70.032
## Oct 2004                                332.739                              64.360
## Nov 2004                                332.106                              71.437
## Dec 2004                                367.856                              89.431
## Jan 2005                                361.269                              82.817
## Feb 2005                                333.479                              73.722
## Mar 2005                                354.763                              78.258
## Apr 2005                                342.863                              78.675
## May 2005                                367.186                              93.074
## Jun 2005                                362.264                              91.384
## Jul 2005                                372.396                              88.565
## Aug 2005                                356.107                              73.582
## Sep 2005                                331.447                              59.245
## Oct 2005                                339.018                              61.438
## Nov 2005                                338.541                              66.031
## Dec 2005                                360.826                              75.546
## Jan 2006                                388.583                              93.614
```

```
## Feb 2006                                    348.049                               84.487
## Mar 2006                                    368.883                               84.019
## Apr 2006                                    367.940                               97.432
## May 2006                                    386.890                              105.153
## Jun 2006                                    383.011                              101.532
## Jul 2006                                    381.340                               86.799
## Aug 2006                                    370.019                               74.137
## Sep 2006                                    345.317                               58.691
## Oct 2006                                    353.690                               58.192
## Nov 2006                                    359.164                               69.167
## Dec 2006                                    376.761                               73.685
## Jan 2007                                    399.004                               88.865
## Feb 2007                                    343.865                               63.349
## Mar 2007                                    390.167                               82.446
## Apr 2007                                    383.102                               81.515
## May 2007                                    398.044                               88.872
## Jun 2007                                    382.096                               77.850
## Jul 2007                                    393.450                               76.694
## Aug 2007                                    386.428                               68.037
## Sep 2007                                    360.587                               50.302
## Oct 2007                                    374.075                               50.485
## Nov 2007                                    373.327                               53.507
## Dec 2007                                    397.970                               62.582
## Jan 2008                                    427.860                               70.898
## Feb 2008                                    388.671                               64.108
## Mar 2008                                    424.851                               73.934
## Apr 2008                                    421.184                               75.862
## May 2008                                    449.522                               92.879
## Jun 2008                                    444.695                               99.553
## Jul 2008                                    446.062                               87.194
## Aug 2008                                    431.761                               72.434
## Sep 2008                                    398.411                               55.200
## Oct 2008                                    412.573                               52.783
## Nov 2008                                    409.976                               53.459
## Dec 2008                                    428.996                               71.179
## Jan 2009                                    431.011                               80.149
## Feb 2009                                    386.812                               60.775
## Mar 2009                                    432.104                               74.475
## Apr 2009                                    431.059                               87.927
## May 2009                                    456.231                              100.858
## Jun 2009                                    455.356                               99.744
## Jul 2009                                    455.962                               79.789
## Aug 2009                                    449.335                               66.808
## Sep 2009                                    421.927                               59.228
## Oct 2009                                    450.940                               67.186
## Nov 2009                                    456.527                               71.678
## Dec 2009                                    481.882                               84.378
## Jan 2010                                    489.844                               76.371
## Feb 2010                                    449.090                               70.252
## Mar 2010                                    499.560                               71.262
## Apr 2010                                    482.552                               65.158
## May 2010                                    507.544                               85.570
## Jun 2010                                    517.750                              101.861
## Jul 2010                                    508.593                               83.651
```

```
## Aug 2010                        497.073                        68.647
## Sep 2010                        476.105                        58.909
## Oct 2010                        489.125                        60.334
## Nov 2010                        500.488                        66.744
## Dec 2010                        524.855                        79.053
## Jan 2011                        530.909                        87.112
## Feb 2011                        490.715                        82.336
## Mar 2011                        553.169                       106.231
## Apr 2011                        538.506                       106.435
## May 2011                        554.011                       111.187
## Jun 2011                        553.885                       109.700
## Jul 2011                        549.374                       106.743
## Aug 2011                        534.036                        87.905
## Sep 2011                        500.175                        72.940
## Oct 2011                        517.691                        67.515
## Nov 2011                        528.710                        70.562
## Dec 2011                        552.823                        80.973
## Jan 2012                        539.030                        78.842
## Feb 2012                        494.125                        69.209
## Mar 2012                        541.241                        88.393
## Apr 2012                        519.625                        89.720
## May 2012                        546.973                        97.724
## Jun 2012                        528.767                        90.956
## Jul 2012                        520.173                        90.387
## Aug 2012                        513.269                        78.591
## Sep 2012                        475.611                        60.065
## Oct 2012                        491.520                        56.304
## Nov 2012                        489.081                        63.918
## Dec 2012                        527.555                        78.423
## Jan 2013                        542.692                        84.715
## Feb 2013                        487.697                        69.668
## Mar 2013                        541.012                        70.063
## Apr 2013                        551.448                        85.631
## May 2013                        578.378                        97.072
## Jun 2013                        563.561                        93.434
## Jul 2013                        572.289                        92.993
## Aug 2013                        542.610                        73.813
## Sep 2013                        514.219                        57.871
## Oct 2013                        543.689                        58.682
## Nov 2013                        548.475                        60.313
## Dec 2013                        574.712                        72.090
## Jan 2014                        574.074                        73.815
## Feb 2014                        507.104                        59.356
## Mar 2014                        589.448                        82.765
## Apr 2014                        582.906                        86.801
## May 2014                        589.532                        90.568
## Jun 2014                        590.551                        87.838
## Jul 2014                        588.452                        83.107
## Aug 2014                        559.856                        67.582
## Sep 2014                        530.545                        54.846
## Oct 2014                        557.212                        58.547
## Nov 2014                        569.440                        63.548
## Dec 2014                        593.582                        76.186
## Jan 2015                        580.459                        82.360
```

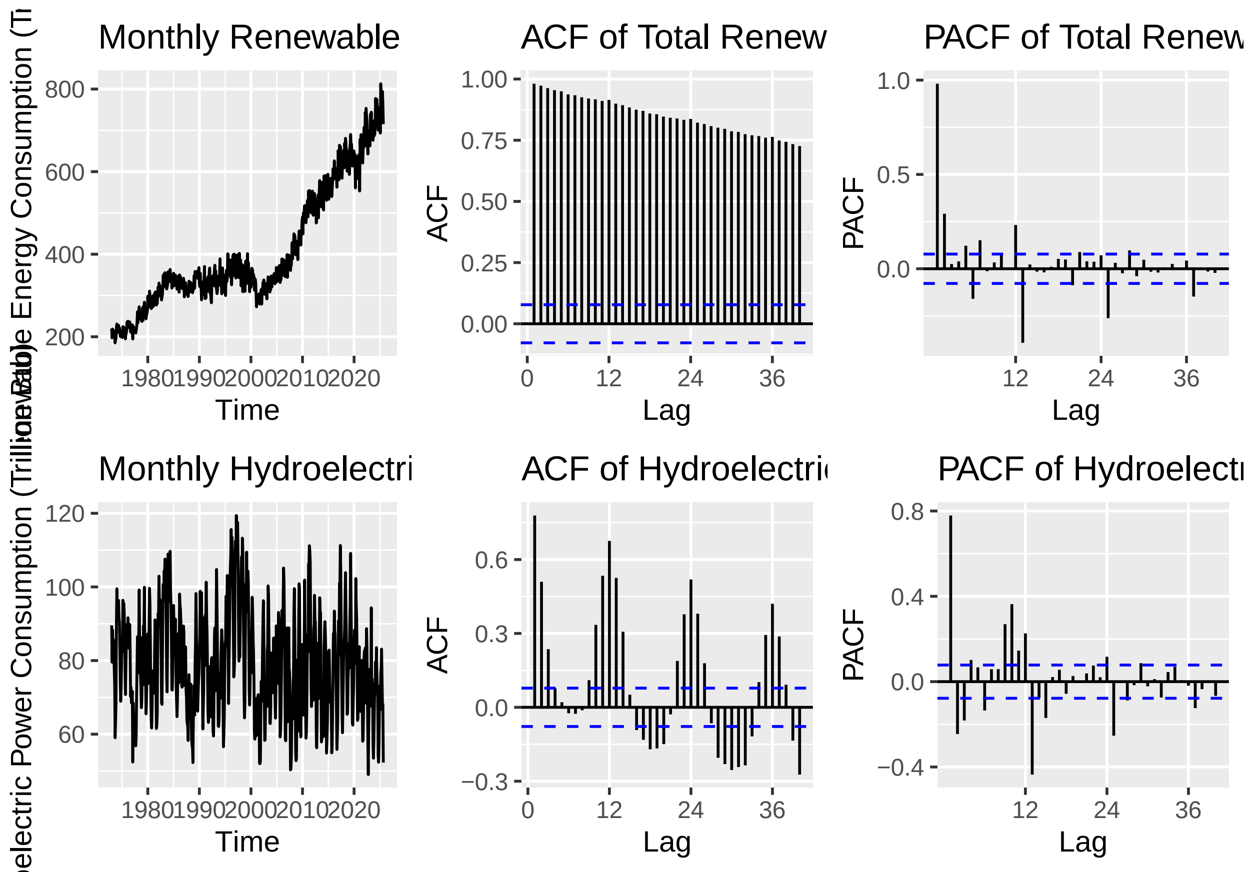
```
## Feb 2015                                    532.998                                  76.040
## Mar 2015                                    579.274                                  82.846
## Apr 2015                                    569.372                                  76.671
## May 2015                                    578.595                                  68.668
## Jun 2015                                    564.148                                  69.653
## Jul 2015                                    583.940                                  71.701
## Aug 2015                                    572.235                                  65.245
## Sep 2015                                    539.599                                  54.913
## Oct 2015                                    556.624                                  56.743
## Nov 2015                                    575.262                                  65.981
## Dec 2015                                    607.029                                  79.041
## Jan 2016                                    599.191                                  87.397
## Feb 2016                                    581.707                                  82.362
## Mar 2016                                    626.117                                  93.454
## Apr 2016                                    589.697                                  88.296
## May 2016                                    609.056                                  86.960
## Jun 2016                                    593.674                                  79.284
## Jul 2016                                    604.311                                  73.206
## Aug 2016                                    591.345                                  66.771
## Sep 2016                                    562.208                                  55.847
## Oct 2016                                    584.383                                  59.160
## Nov 2016                                    586.197                                  64.174
## Dec 2016                                    650.925                                  76.865
## Jan 2017                                    627.139                                  90.854
## Feb 2017                                    580.323                                  81.485
## Mar 2017                                    663.921                                 101.040
## Apr 2017                                    635.132                                 100.345
## May 2017                                    661.288                                 111.255
## Jun 2017                                    642.341                                 104.323
## Jul 2017                                    625.553                                  90.753
## Aug 2017                                    612.154                                  75.180
## Sep 2017                                    583.867                                  65.346
## Oct 2017                                    614.657                                  60.386
## Nov 2017                                    613.796                                  67.859
## Dec 2017                                    635.130                                  75.910
## Jan 2018                                    652.428                                  85.519
## Feb 2018                                    609.384                                  84.967
## Mar 2018                                    668.591                                  88.236
## Apr 2018                                    656.554                                  95.929
## May 2018                                    680.705                                 103.876
## Jun 2018                                    668.774                                  94.163
## Jul 2018                                    647.940                                  85.640
## Aug 2018                                    651.954                                  75.122
## Sep 2018                                    600.710                                  65.393
## Oct 2018                                    627.968                                  66.698
## Nov 2018                                    623.200                                  74.766
## Dec 2018                                    647.491                                  77.784
## Jan 2019                                    644.838                                  84.610
## Feb 2019                                    593.170                                  78.068
## Mar 2019                                    657.018                                  89.852
## Apr 2019                                    665.972                                  94.922
## May 2019                                    689.977                                 109.123
## Jun 2019                                    661.158                                  95.801
## Jul 2019                                    667.002                                  84.875
```

```
## Aug 2019                    647.658                    77.038
## Sep 2019                    613.133                    63.210
## Oct 2019                    633.573                    62.459
## Nov 2019                    620.685                    68.982
## Dec 2019                    650.482                    73.284
## Jan 2020                    648.215                    83.587
## Feb 2020                    632.039                    88.262
## Mar 2020                    641.447                    81.284
## Apr 2020                    560.486                    79.139
## May 2020                    618.100                   102.279
## Jun 2020                    636.973                    95.534
## Jul 2020                    632.799                    91.243
## Aug 2020                    618.428                    79.443
## Sep 2020                    583.405                    63.732
## Oct 2020                    611.837                    64.181
## Nov 2020                    629.861                    71.286
## Dec 2020                    640.797                    73.385
## Jan 2021                    637.522                    83.799
## Feb 2021                    553.037                    68.706
## Mar 2021                    678.149                    72.404
## Apr 2021                    651.301                    66.155
## May 2021                    689.586                    79.530
## Jun 2021                    656.900                    80.025
## Jul 2021                    651.325                    75.397
## Aug 2021                    648.963                    69.360
## Sep 2021                    620.842                    58.080
## Oct 2021                    650.243                    58.458
## Nov 2021                    663.731                    66.102
## Dec 2021                    706.750                    80.393
## Jan 2022                    707.979                    82.562
## Feb 2022                    661.288                    72.746
## Mar 2022                    743.597                    83.377
## Apr 2022                    722.551                    68.465
## May 2022                    753.369                    79.700
## Jun 2022                    735.657                    88.670
## Jul 2022                    723.656                    83.824
## Aug 2022                    682.908                    72.106
## Sep 2022                    642.820                    58.093
## Oct 2022                    669.622                    49.022
## Nov 2022                    695.918                    61.068
## Dec 2022                    690.850                    69.706
## Jan 2023                    699.219                    77.637
## Feb 2023                    662.356                    68.107
## Mar 2023                    738.376                    72.783
## Apr 2023                    711.502                    67.625
## May 2023                    743.971                    94.346
## Jun 2023                    701.163                    73.604
## Jul 2023                    718.784                    74.988
## Aug 2023                    716.526                    72.652
## Sep 2023                    675.796                    57.716
## Oct 2023                    697.000                    53.475
## Nov 2023                    685.076                    58.092
## Dec 2023                    723.896                    64.922
## Jan 2024                    689.644                    73.542
```

```
## Feb 2024                    711.645                    70.954
## Mar 2024                    777.166                    79.713
## Apr 2024                    761.186                    71.365
## May 2024                    775.130                    83.516
## Jun 2024                    775.144                    76.417
## Jul 2024                    756.708                    72.962
## Aug 2024                    756.385                    69.914
## Sep 2024                    700.397                    54.289
## Oct 2024                    735.345                    52.382
## Nov 2024                    725.928                    57.060
## Dec 2024                    741.701                    66.647
## Jan 2025                    750.981                    73.116
## Feb 2025                    693.266                    66.674
## Mar 2025                    812.838                    76.613
## Apr 2025                    783.482                    77.930
## May 2025                    793.521                    83.111
## Jun 2025                    789.933                    75.615
## Jul 2025                    794.256                    68.186
## Aug 2025                    763.036                    68.181
## Sep 2025                    715.006                    52.277
```

```r
#Total Renewable Energy Production
#time series plot
tsplot_renewable<-
  autoplot(ts_energy_data1[,1]) +
  xlab("Time") +
  ylab("Total Renewable Energy Consumption (Trillion Btu)") +
  ggtitle("Monthly Renewable Energy Consumption")

#ACF plot
acf_renewable <- ggAcf(ts_energy_data1[, 1], lag.max = 40) +
  ggtitle("ACF of Total Renewable Energy Consumption")

#PACF plot
pacf_renewable <- ggPacf(ts_energy_data1[, 1], lag.max = 40) +
  ggtitle("PACF of Total Renewable Energy Consumption")


#Hydroelectric Power Consumption
#time series plot
tsplot_hydro<-
  autoplot(ts_energy_data1[,2]) +
  xlab("Time") +
  ylab("Hydroelectric Power Consumption (Trillion Btu)") +
  ggtitle("Monthly Hydroelectric Power Consumption")

#ACF plot
acf_hydro <- ggAcf(ts_energy_data1[, 2], lag.max = 40) +
  ggtitle("ACF of Hydroelectric Power Consumption")

#PACF plot
pacf_hydro <- ggPacf(ts_energy_data1[, 2], lag.max = 40) +
  ggtitle("PACF of Hydroelectric Power Consumption")
```

```r
cowplot::plot_grid(
  tsplot_renewable, acf_renewable, pacf_renewable,
  tsplot_hydro,     acf_hydro,     pacf_hydro,
  ncol = 3
)
```



Q2

From the plot in Q1, do the series Total Renewable Energy Production and Hydroelectric Power Consumption appear to have a trend? If yes, what kind of trend?

A: Total renewable energy production exhibits a strong upward but non-linear trend, while hydroelectric power consumption shows no clear long-term trend and mainly fluctuates seasonally around a stable mean.

Q3

Use the *lm()* function to fit a linear trend to the two time series. Ask R to print the summary of the regression. Interpret the regression output, i.e., slope and intercept. Save the regression coefficients for further analysis.

```r
# number of observations
nobs <- length(ts_energy_data1[, 1])

# time index
```

```r
t <- c(1:nobs)

# linear trend models
lm_renewable <- lm(ts_energy_data1[, 1] ~ t)
lm_hydro     <- lm(ts_energy_data1[, 2] ~ t)

summary(lm_renewable)
```

```
##
## Call:
## lm(formula = ts_energy_data1[, 1] ~ t)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -154.81  -39.55   12.52   41.49  171.15
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 171.44868    5.11085   33.55   <2e-16 ***
## t             0.74999    0.01397   53.69   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 64.22 on 631 degrees of freedom
## Multiple R-squared:  0.8204, Adjusted R-squared:  0.8201
## F-statistic:  2883 on 1 and 631 DF,  p-value: < 2.2e-16
```

```r
summary(lm_hydro)
```

```
##
## Call:
## lm(formula = ts_energy_data1[, 2] ~ t)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -30.190 -10.214  -0.715   8.909  39.723
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 83.223802   1.110552  74.939  < 2e-16 ***
## t           -0.012199   0.003035  -4.019 6.55e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 13.95 on 631 degrees of freedom
## Multiple R-squared:  0.02496,    Adjusted R-squared:  0.02342
## F-statistic: 16.15 on 1 and 631 DF,  p-value: 6.547e-05
```

```r
#Store reg coefficient
beta0_renewable <- as.numeric(lm_renewable$coefficients[1]) #intercept
beta1_renewable <- as.numeric(lm_renewable$coefficients[2]) #slope
```

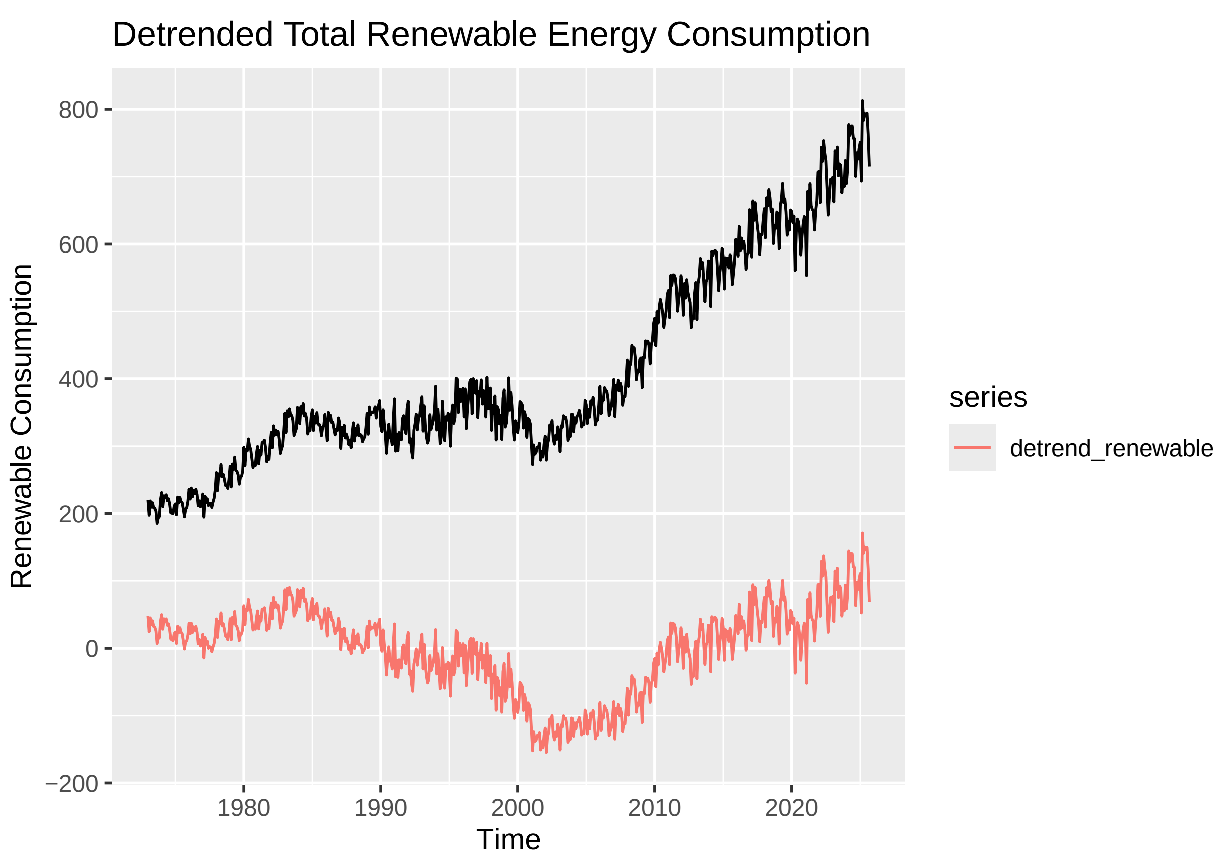
```r
beta0_hydro <- as.numeric(lm_hydro$coefficients[1]) #intercept
beta1_hydro <- as.numeric(lm_hydro$coefficients[2]) #slope
```

A: The regression results show a strong positive and statistically linear trend in total renewable energy consumption, with an average increase of ~0.75 units per month. The total renewable energy consumption is 171.4 unit in the beginning. In contrast, hydroelectric power consumption exhibits a very small but statistically significant negative trend, indicating near stability over time. The hydroelectric power consumption is 83.2 in the beginning. The high R^2 for renewable energy suggests time explains most of its long-run variation, while the low R^2 for hydroelectric power indicates that factors other than a linear trend dominate its behavior.

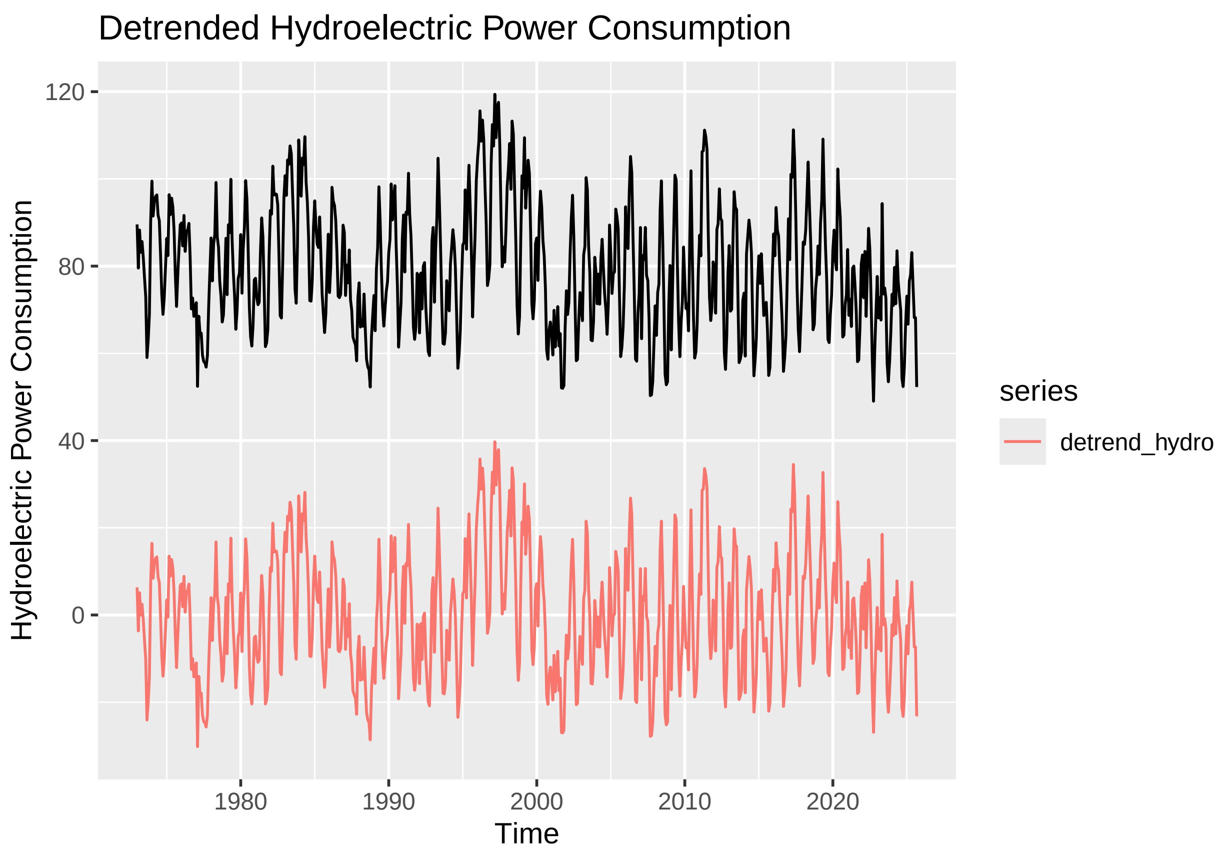
Q4

Use the regression coefficients to detrend each series (subtract fitted linear trend). Plot detrended series and compare with the original time series from Q1. Describe what changed.

```r
#remove the trend from series
detrend_renewable <- ts_energy_data1[, 1] - (beta0_renewable + beta1_renewable*t)
detrend_hydro <- ts_energy_data1[, 2] - (beta0_hydro + beta1_hydro*t)

#Plot detrended series
autoplot(ts_energy_data1[, 1])+
  autolayer(detrend_renewable)+
  ylab("Renewable Consumption")+
  ggtitle("Detrended Total Renewable Energy Consumption")
```



```r
autoplot(ts_energy_data1[, 2])+
  autolayer(detrend_hydro)+
  ylab("Hydroelectric Power Consumption")+
  ggtitle("Detrended Hydroelectric Power Consumption")
```



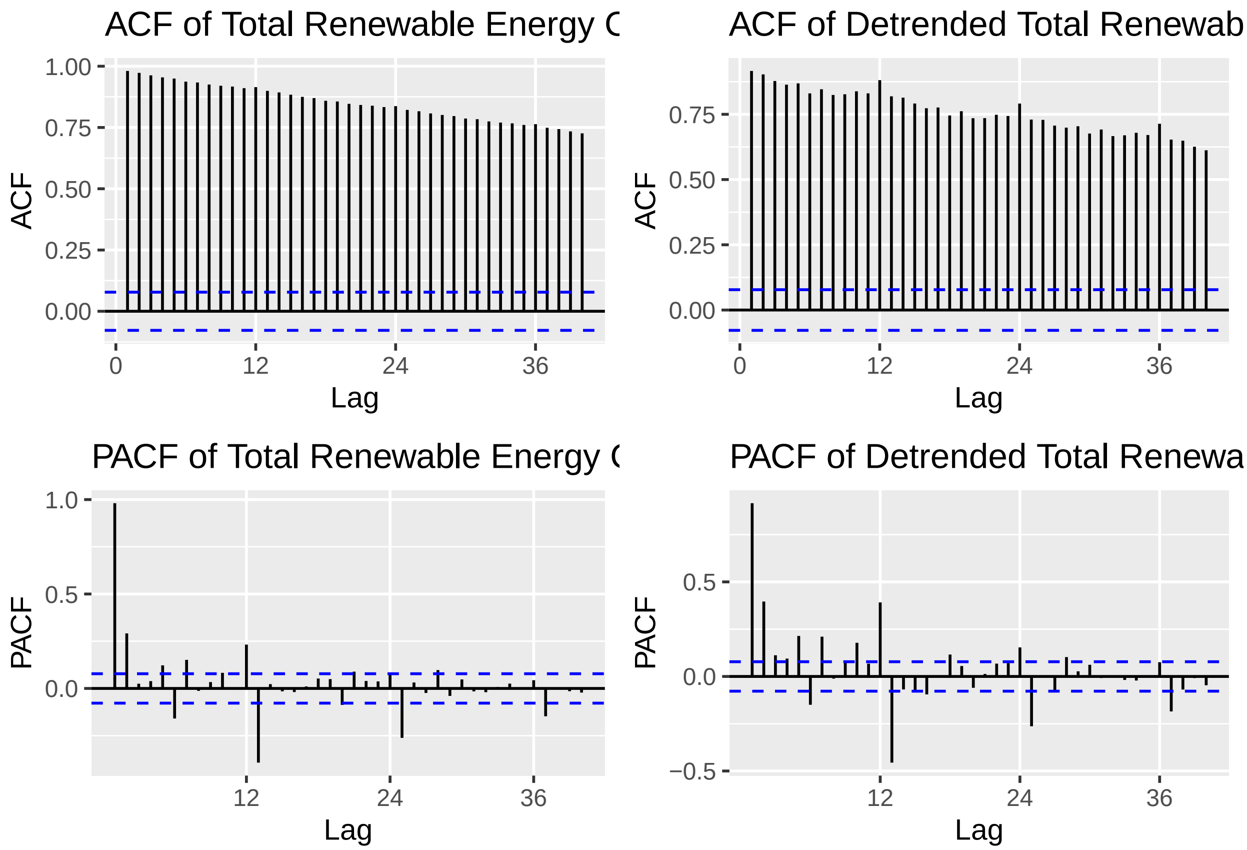
A: After detrending, the total renewable energy consumption series no longer exhibits a long-term upward trend and instead fluctuates around zero, making short-term variability more apparent. In contrast, hydroelectric power consumption shows little change after detrending, as the original series does not contain a strong trend and is primarily driven by seasonal fluctuations.

Q5

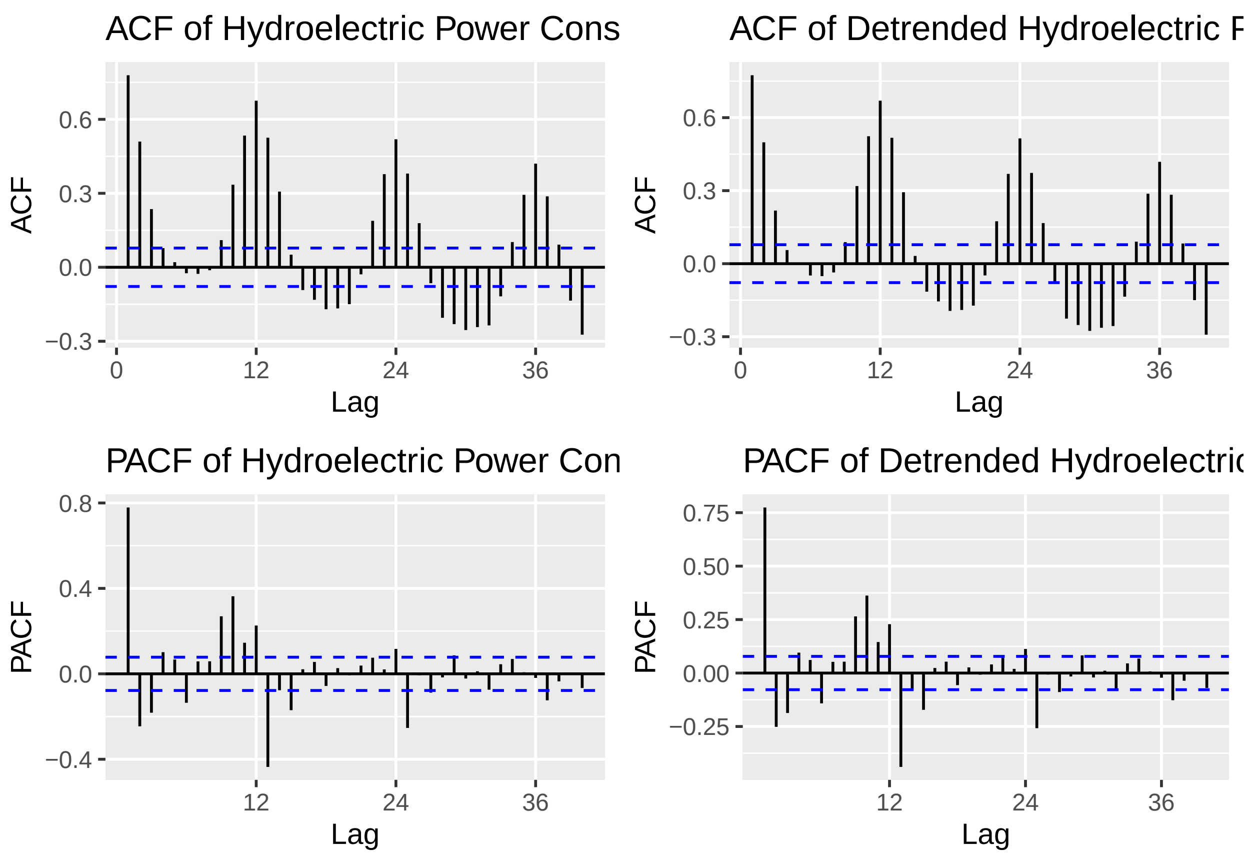
Plot ACF and PACF for the detrended series and compare with the plots from Q1. You may use plot_grid() again to get them side by side to make it easier to compare. Did the plots change? How?

```r
acf_renewable_de <- ggAcf(detrend_renewable, lag.max = 40) +
  ggtitle("ACF of Detrended Total Renewable Consumption")
acf_hydro_de <- ggAcf(detrend_hydro, lag.max = 40) +
  ggtitle("ACF of Detrended Hydroelectric Power Consumption")

pacf_renewable_de <- ggPacf(detrend_renewable, lag.max = 40) +
  ggtitle("PACF of Detrended Total Renewable Consumption")
pacf_hydro_de <- ggPacf(detrend_hydro, lag.max = 40) +
  ggtitle("PACF of Detrended Hydroelectric Power Consumption")
```

```
cowplot::plot_grid(
  acf_renewable, acf_renewable_de,
  pacf_renewable, pacf_renewable_de,
  ncol = 2)
```




```
cowplot::plot_grid(
  acf_hydro, acf_hydro_de,
  pacf_hydro, pacf_hydro_de,
  ncol = 2)
```



A:

- Renewable: 1) ACF: Before detrending, acf shows a slow, linear decay. After detrending, acf now decays much faster but reveals a rhythmic pattern with significant spikes at lag 12, 24, and 36. 2) PACF: Before the detrending, pacf is dominated by a single spike at Lag 1 (nearly 1), followed by some smaller spikes at lag 2, 11, 12, and 25. After detrending, spikes becomes stronger at lag 2, 5, 7, 11, and 12.
- Hydroelectric: 1) ACF: both original and detrended plots show similar seasonal pattern with positive spikes at lag 12, 24, and 36. 2) PACF: The before and after detrended plots are pretty identical with a large spike at lag 1 and seasonal spike around lag 13.

Seasonal Component

Set aside the detrended series and consider the original series again from Q1 to answer Q6 to Q8.

Q6

Just by looking at the time series and the acf plots, do the series seem to have a seasonal trend? No need to run any code to answer your question. Just type in you answer below.

> Answer: The bars in ACF plot of total renewable energy series stay very high and decay slowly. It may not has a seasonal trend. Unlike the renewable, the hydroelectric power series looks stationary between 50-120. And its ACF plot peaks at lag 12, 24, and 36, indicating a strong annual seasonal cycle.

Q7

Use function *lm()* to fit a seasonal means model (i.e. using the seasonal dummies) to the two time series. Ask R to print the summary of the regression. Interpret the regression output. From the results, which series have a seasonal trend? Do the results match you answer to Q6?

```
#dummies
dummies_renew <- seasonaldummy(ts_energy_data1[,1])
dummies_hydro <- seasonaldummy(ts_energy_data1[,2])

seas_renewable <- lm(ts_energy_data1[,1]~dummies_renew)
summary(seas_renewable)
```

```
##
## Call:
## lm(formula = ts_energy_data1[, 1] ~ dummies_renew)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -213.33  -97.36  -59.88  121.55  389.62
##
## Coefficients:
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)       417.265     21.096  19.779   <2e-16 ***
## dummies_renewJan    2.090     29.693   0.070    0.944
## dummies_renewFeb  -34.524     29.693  -1.163    0.245
## dummies_renewMar    5.956     29.693   0.201    0.841
## dummies_renewApr   -6.900     29.693  -0.232    0.816
## dummies_renewMay    8.162     29.693   0.275    0.784
## dummies_renewJun   -2.231     29.693  -0.075    0.940
## dummies_renewJul    3.864     29.693   0.130    0.897
## dummies_renewAug   -3.978     29.693  -0.134    0.893
## dummies_renewSep  -29.033     29.693  -0.978    0.329
## dummies_renewOct  -19.937     29.834  -0.668    0.504
## dummies_renewNov  -20.617     29.834  -0.691    0.490
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 152.1 on 621 degrees of freedom
## Multiple R-squared:  0.008243,   Adjusted R-squared:  -0.009324
## F-statistic: 0.4692 on 11 and 621 DF,  p-value: 0.9223
```

```
seas_hydro <- lm(ts_energy_data1[,2]~dummies_hydro)
summary(seas_hydro)
```

```
##
## Call:
## lm(formula = ts_energy_data1[, 2] ~ dummies_hydro)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -30.895  -6.368  -0.595   6.213  32.557
##
```

```
## Coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept)         79.724      1.436  55.511  < 2e-16 ***
## dummies_hydroJan     4.951      2.021   2.449 0.014591 *
## dummies_hydroFeb    -2.415      2.021  -1.195 0.232608
## dummies_hydroMar     7.116      2.021   3.520 0.000463 ***
## dummies_hydroApr     5.614      2.021   2.777 0.005649 **
## dummies_hydroMay    14.080      2.021   6.965 8.38e-12 ***
## dummies_hydroJun    10.780      2.021   5.333 1.36e-07 ***
## dummies_hydroJul     4.003      2.021   1.980 0.048091 *
## dummies_hydroAug    -5.320      2.021  -2.632 0.008710 **
## dummies_hydroSep   -16.598      2.021  -8.211 1.28e-15 ***
## dummies_hydroOct   -16.329      2.031  -8.040 4.56e-15 ***
## dummies_hydroNov   -10.782      2.031  -5.308 1.54e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.36 on 621 degrees of freedom
## Multiple R-squared:  0.4714, Adjusted R-squared:  0.4621
## F-statistic: 50.35 on 11 and 621 DF,  p-value: < 2.2e-16
```

```r
#remove the seasonal from series
detrend_renewable <- ts_energy_data1[, 1] - (beta0_renewable + beta1_renewable*t)
detrend_hydro <- ts_energy_data1[, 2] - (beta0_hydro + beta1_hydro*t)
```

A:

- Renewable: Almost all the monthly dummy variables (Jan through Nov) have very high p-values (e.g., Jan = 0.944, Feb = 0.245). This means these months are not significantly different from the reference month (December). Also, the model is statistically insignificant (p>0.05). So this series does not have a significant seasonal mean trend.
- Hydroelectric: Almost every month is highly significant except Feb with high p-value, showing a strong evidence of seasonal effects. The model is highly significant since the p-value<0.05. So there is a very strong seasonal trend.

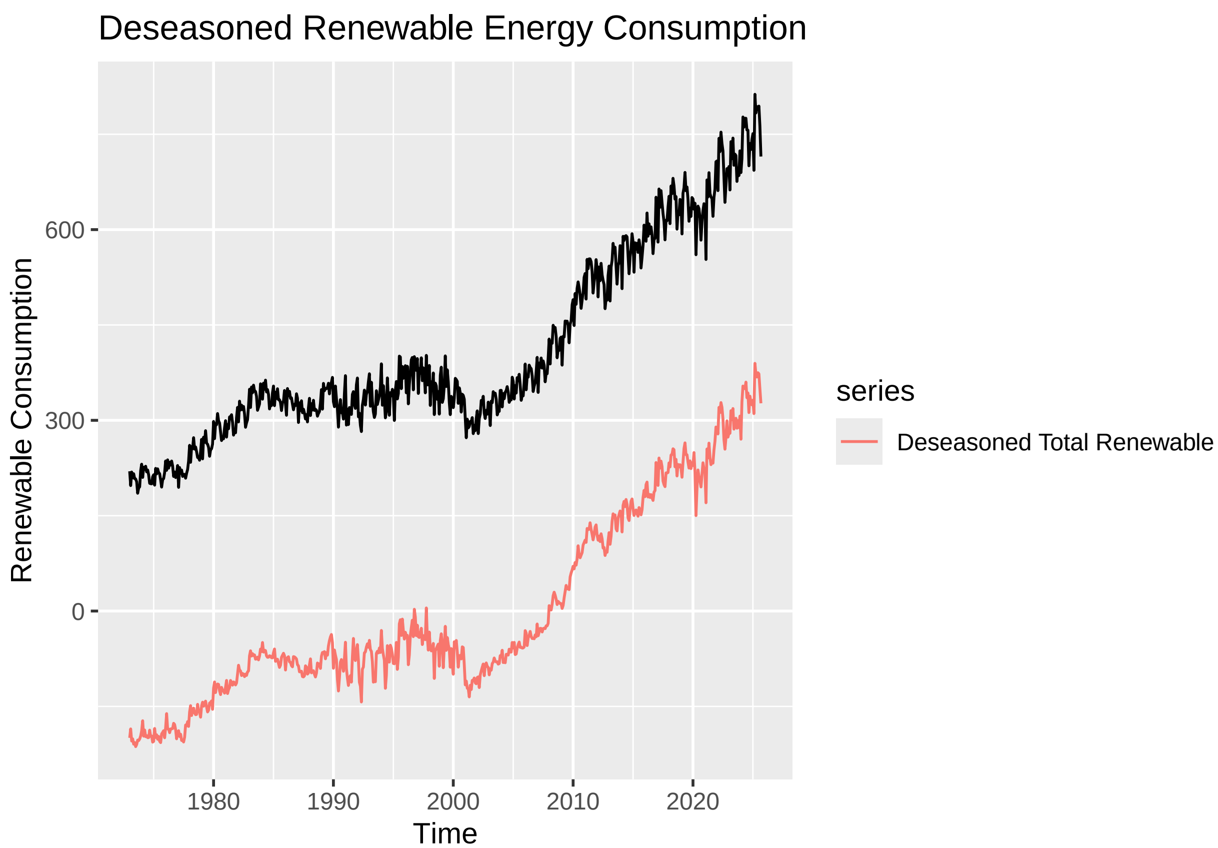
The result above is same with the answer in Q6.

Q8

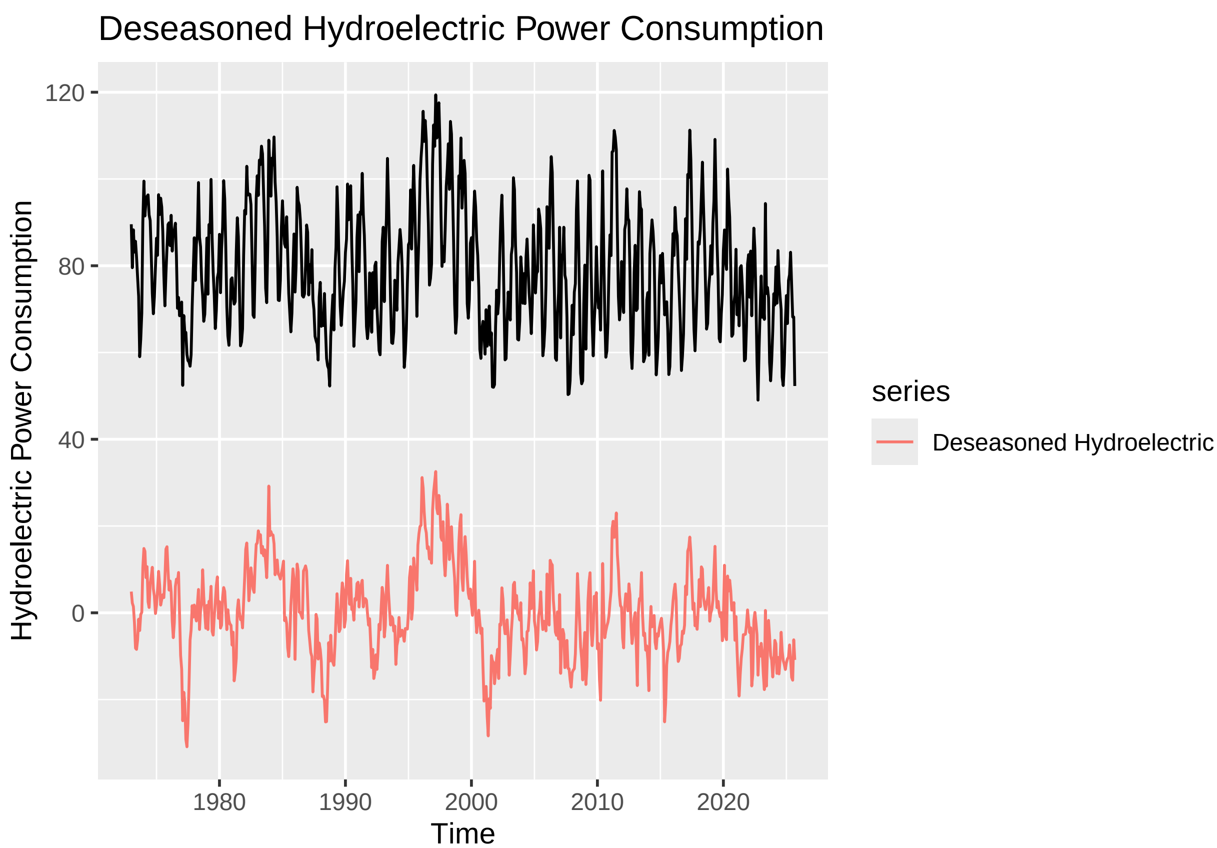
Use the regression coefficients from Q7 to deseason the series. Plot the deseason series and compare with the plots from part Q1. Did anything change?

```r
#compute seas component
seas_renewable_comp <- fitted(seas_renewable)
seas_hydro_comp <- fitted(seas_hydro)

#deseason
deseason_renewable <- ts_energy_data1[,1] - seas_renewable_comp
deseason_hydro <-  ts_energy_data1[,2] - seas_hydro_comp

#plot
```

```r
autoplot(ts_energy_data1[,1])+
  autolayer(deseason_renewable, series="Deseasoned Total Renewable")+
  ylab("Renewable Consumption")+
  ggtitle("Deseasoned Renewable Energy Consumption")
```




```r
autoplot(ts_energy_data1[,2])+
  autolayer(deseason_hydro, series="Deseasoned Hydroelectric")+
  ylab("Hydroelectric Power Consumption")+
  ggtitle("Deseasoned Hydroelectric Power Consumption")
```



A:

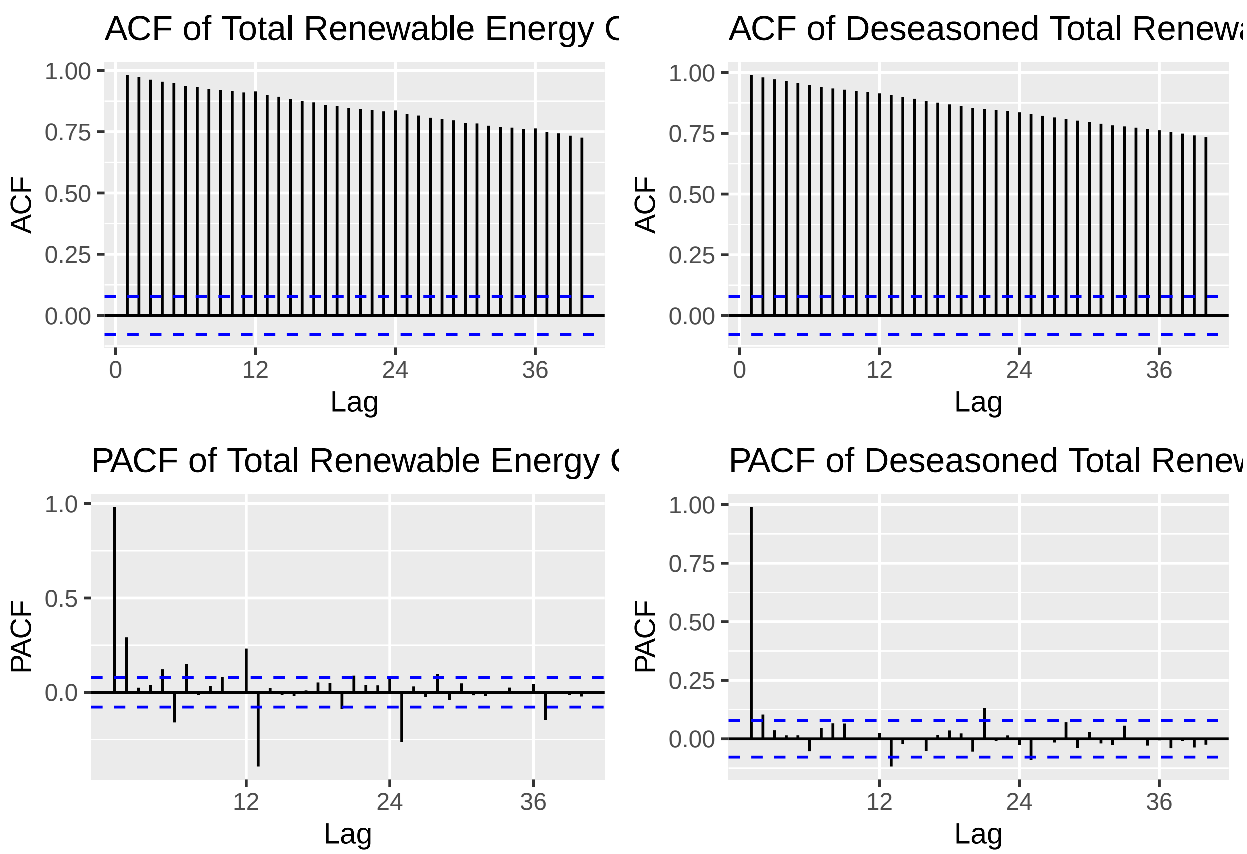
- Renewable: The overall trend is unchanged that both lines follow the same upward trend from 1970s to 2025. But the deseasoned red line is vertically shifted downward on Y-axis since I subtracted the seasonal mean.
- Hydroelectric: Unlike the previous black line that has regular peaks and valleys, the deseasoned red line shows that these annual cycles have been smoothed out. Also, the red line is vertically shifted downward on Y-axis like renewable one.

Q9

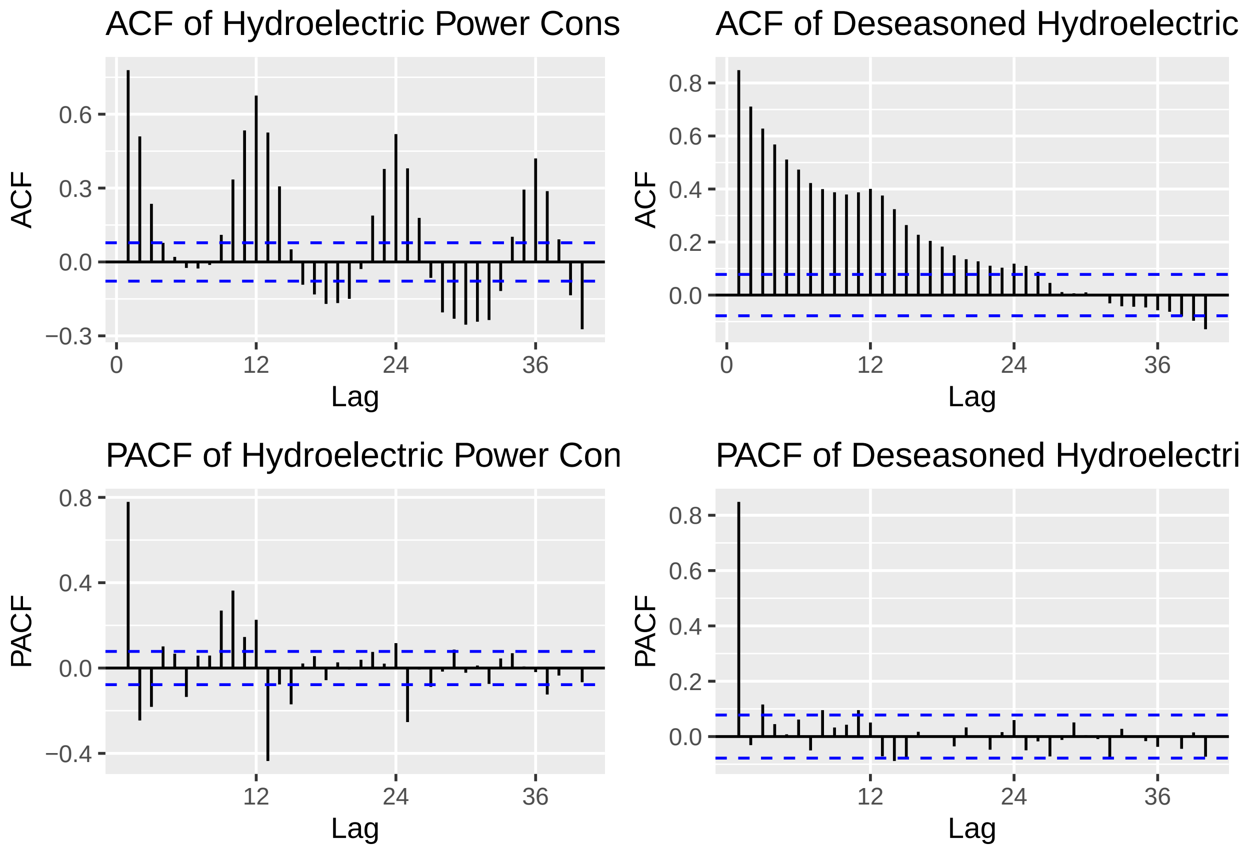
Plot ACF and PACF for the deseason series and compare with the plots from Q1. You may use plot_grid() again to get them side by side. Did the plots change? How?

```
acf_renewable_deseas<-ggAcf(deseason_renewable, lag.max = 40) +
  ggtitle("ACF of Deseasoned Total Renewable Consumption")
acf_hydro_deseas<-ggAcf(deseason_hydro, lag.max = 40) +
  ggtitle("ACF of Deseasoned Hydroelectric Power Consumption")

pacf_renewable_deseas<-ggPacf(deseason_renewable, lag.max = 40) +
  ggtitle("PACF of Deseasoned Total Renewable Consumption")
pacf_hydro_deseas<-ggPacf(deseason_hydro, lag.max = 40) +
  ggtitle("PACF of Deseasoned Hydroelectric Power Consumption")

cowplot::plot_grid(
```

```
  acf_renewable, acf_renewable_deseas,
  pacf_renewable, pacf_renewable_deseas,
  ncol = 2)
```




```
cowplot::plot_grid(
  acf_hydro, acf_hydro_deseas,
  pacf_hydro, pacf_hydro_deseas,
  ncol = 2)
```



A:

- Renewable: 1) ACF plots: The acf shows a very slow and linear decay before deseasoning (nono-stationary series with a strong trend). The acf after deseasoning remains almost identical. So removing the seasonal components doesn't much change the data trend. 2) PACF plots: Before deseasoning, there is a large spike at lag 1, followed by some smaller spikes at lag 2 and 13. After deseasoning, the major spike at lag 1 is unchanged. But the spikes at following lags are overall reduced.

- Hydroelectric: 1) ACF plots: The original acf shows a clear seasonal pattern which has significant positive peaks at lags 12, 24, and 36. After deseasoning, the wave pattern has disappeared. Instead, the acf shows a smooth decay. The remaining correlations are likely due to short-time persistence rather than seasonal cycles. 2) PACF: Before deseasoning, there are positive spikes at lag 1, 9, and 10 and negative spike at lag 13. After deseasoning, the pacf shows a single spike at lag 1. Other spikes are reduced or eliminated.