ENV 797 - Time Series Analysis for Energy and Environment Applications | Spring 2026

Assignment 4 - Due date 02/10/26

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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. And to do so you will need to fork our repository and link it to your RStudio.

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_A04_Sp26.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).

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

R packages needed for this assignment: "xlsx" or "readxl", "ggplot2", "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)
library(tseries)
library(Kendall)
library(dplyr)
library(readxl)
library(lubridate)
library(ggplot2)
library(cowplot)
```

Questions

Consider the same data you used for A3 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. **For this assignment you will work only with the column "Total Renewable Energy Production"**.

```
#Importing data set - you may copy your code from A3
#Importing data set
energy_data <- read_excel("/home/guest/TSA_Sp26/Data/Table_10.1_Renewable_Energy_Production_and_Consumpt
```

```r
#Now let's extract the column names from row 11
read_col_names <- read_excel("/home/guest/TSA_Sp26/Data/Table_10.1_Renewable_Energy_Production_and_Cons

#Assign the column names to the data set
colnames(energy_data) <- read_col_names

#make date column a date data type
energy_data$Month <- as.Date(ymd(energy_data$Month))

#Create a data frame structure with these two time series only.
Renewable <- energy_data %>%
  select('Month','Total Renewable Energy Production')


ts_renewable<- ts(Renewable[,2],
                     start=c(1973,1),
                     frequency=12)
```

Stochastic Trend and Stationarity Tests

For this part you will work only with the column Total Renewable Energy Production.

Q1

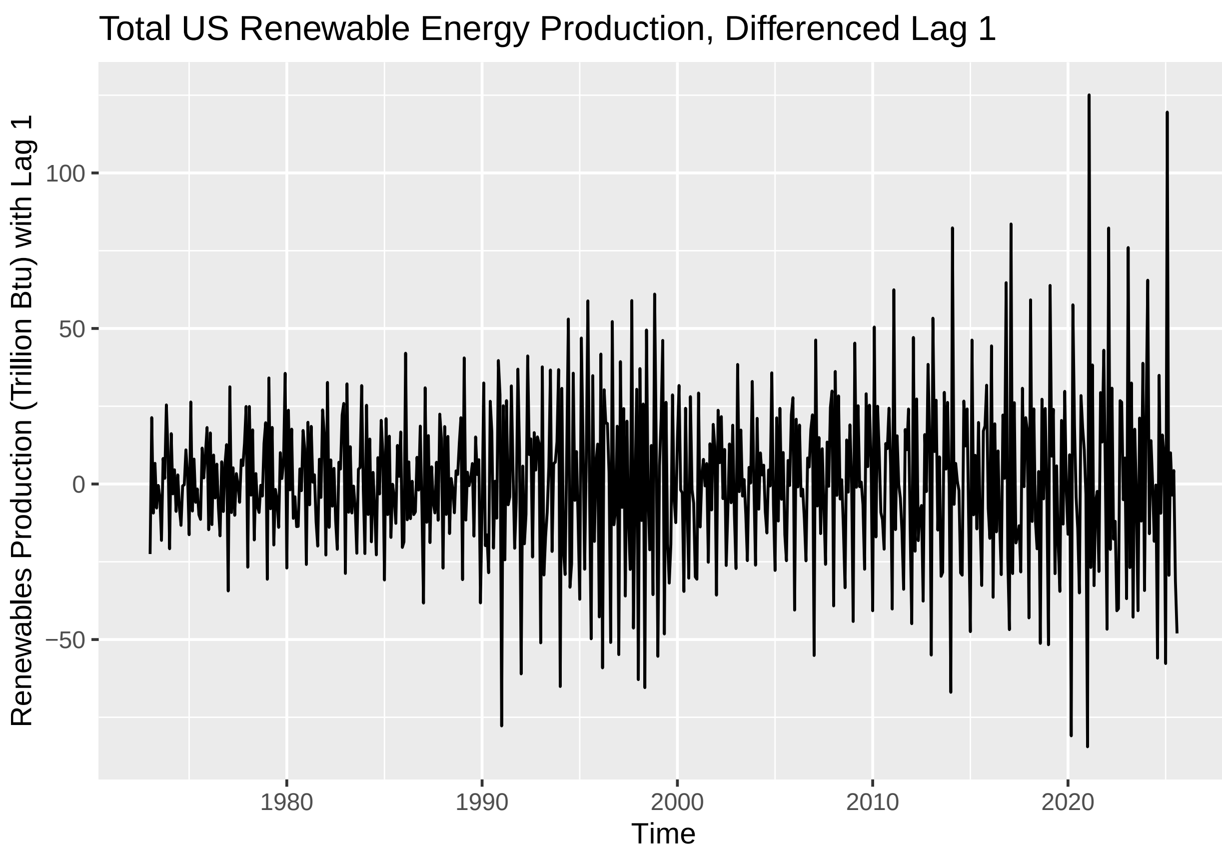
Difference the "Total Renewable Energy Production" series using function diff(). Function diff() is from package base and take three main arguments: * *x* vector containing values to be differenced; * *lag* integer indicating with lag to use; * *differences* integer indicating how many times series should be differenced.

Try differencing at lag 1 only once, i.e., make `lag=1` and `differences=1`. Plot the differenced series. Do the series still seem to have trend?

```r
differenced_lag1<-diff(Renewable[[2]], lag=1,differences=1)
ts_differenced_lag1<- ts(differenced_lag1,
                     start=c(1973,1),
                     frequency=12)

ts_differenced_lag1_plot<- autoplot(ts_differenced_lag1) +
  xlab("Time") +
  ylab("Renewables Production (Trillion Btu) with Lag 1")+
  ggtitle("Total US Renewable Energy Production, Differenced Lag 1")

ts_differenced_lag1_plot
```



There does not seem to be an overall trend. There seems to be more extreme differences (both negative and positive) in later years, but not a consistent positive or negative trend.

Q2

Copy and paste part of your code for A3 where you run the regression for Total Renewable Energy Production and subtract that from the original series. This should be the code for Q3 and Q4. make sure you use assign same name for the time series object that you had in A3, otherwise the code will not work.

```
t <- c(1:nrow(Renewable))

renewable_lm <- lm(Renewable$`Total Renewable Energy Production` ~ t)
summary(renewable_lm)
```

```
##
## Call:
## lm(formula = Renewable$`Total Renewable Energy Production` ~
##     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
```

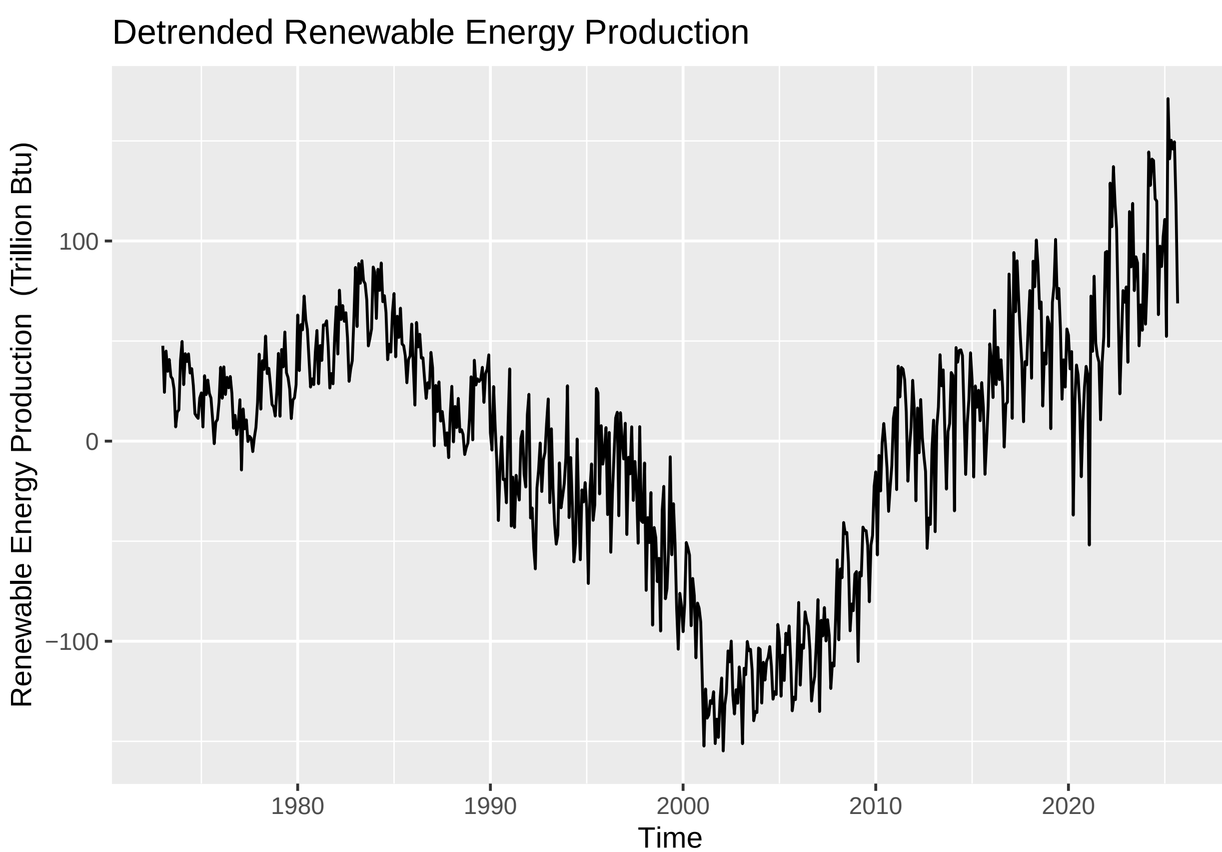
```
renew_int <- as.numeric(renewable_lm$coefficients[1])
renew_slope <- as.numeric(renewable_lm$coefficients[2])

#renewables
detrend_renew <- Renewable[,2] - (renew_int+renew_slope*t)

ts_detrend_renew <- ts(detrend_renew,
                     start=c(1973,1),
                     frequency=12)

detrend_renew_plot<- autoplot(ts_detrend_renew) +
  xlab("Time") +
  ylab("Renewable Energy Production  (Trillion Btu)")+
  ggtitle("Detrended Renewable Energy Production")

detrend_renew_plot
```



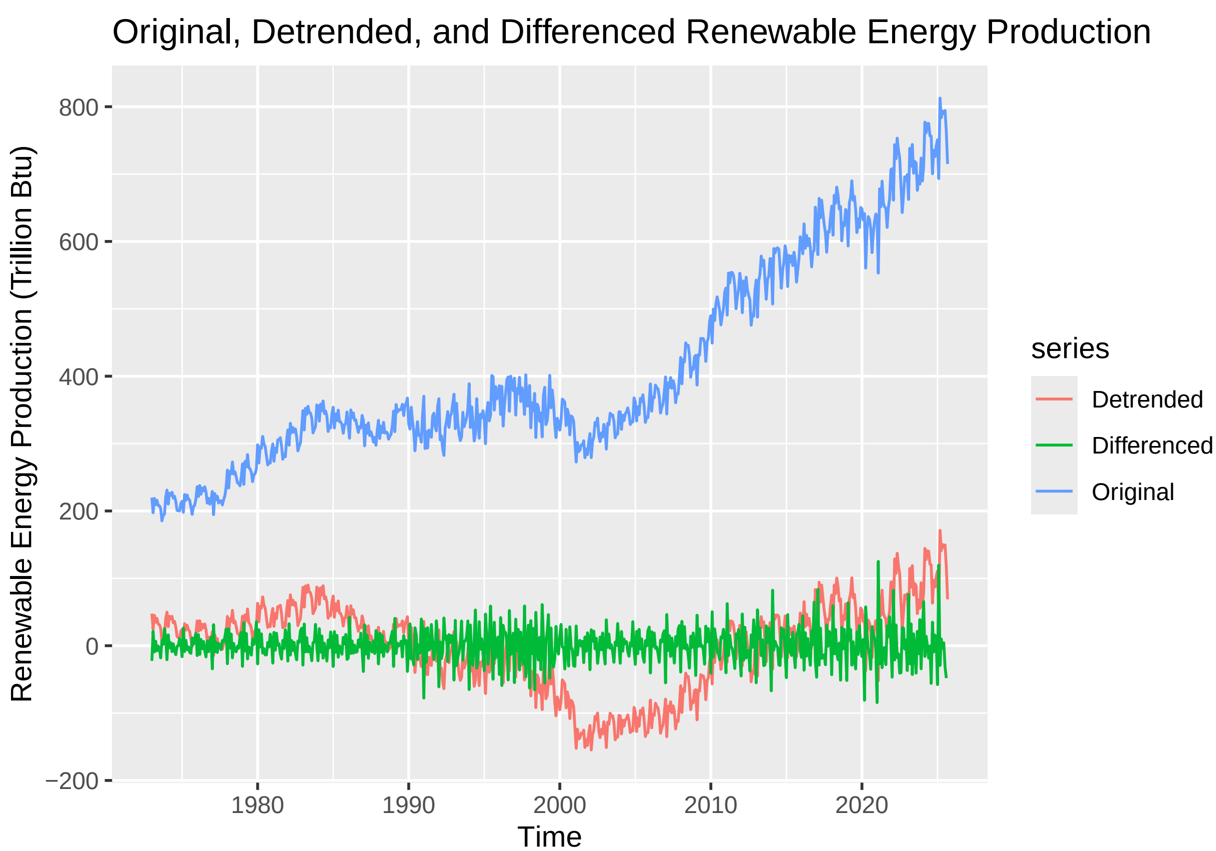
Q3

Now let's compare the differenced series with the detrended series you calculated on A3. In other words, for the "Total Renewable Energy Production" compare the differenced series from Q1 with the series you detrended in Q2 using linear regression.

Using autoplot() + autolayer() create a plot that shows the three series together (i.e. "Original", "Differenced", "Detrended lm()"). Make sure your plot has a legend. The easiest way to do it is by adding the `series=` argument to each autoplot and autolayer function. Look at the key for A03 for an example on how to use autoplot() and autolayer().

What can you tell from this plot? Which method seems to have been more efficient in removing the trend?

```
Comparison_plot<- autoplot(ts_renewable, series = "Original")+
  autolayer(ts_detrend_renew, series = "Detrended")+
  autolayer(ts_differenced_lag1, series = "Differenced")+
  xlab("Time")+
  ylab("Renewable Energy Production (Trillion Btu)")+
  ggtitle("Original, Detrended, and Differenced Renewable Energy Production")
Comparison_plot
```

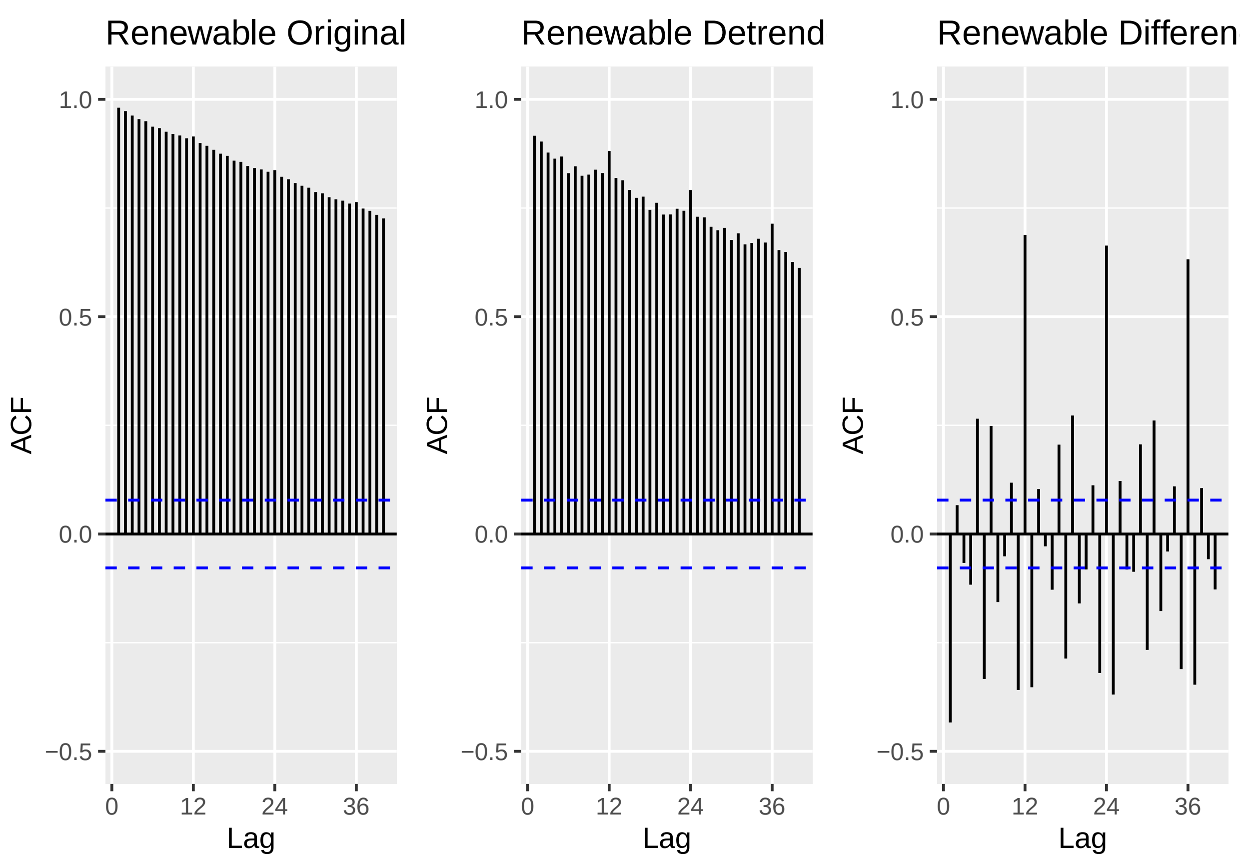


Answer: It seems that the differenced method removes the trend more effectively. The detrended line still shows a slight overall trend and has a significant dip, while the differenced line has variation but returns to 0.

Q4

Plot the ACF for the three series and compare the plots. Add the argument `ylim=c(-0.5,1)` to the autoplot() or Acf() function - whichever you are using to generate the plots - to make sure all three y axis have the same limits. Looking at the ACF which method do you think was more efficient in eliminating the trend? The linear regression or differencing?

```
plot_grid(
  autoplot(Acf(ts_renewable, lag.max = 40, plot =FALSE))+
    ggtitle("Renewable Original")+
    ylim(-0.5,1),
  autoplot(Acf(ts_detrend_renew, lag.max = 40, plot =FALSE))+
    ggtitle("Renewable Detrended")+
    ylim(-0.5,1),
  autoplot(Acf(ts_differenced_lag1, lag.max = 40, plot =FALSE))+
    ggtitle("Renewable Differenced")+
    ylim(-0.5,1),
  nrow = 1
)
```



Answer: It seems that the differenced method is more effective because the ACF plot drops very quickly while in the lm detrended version, the ACF still has a very slow decline.

Q5

Compute the Seasonal Mann-Kendall and ADF Test for the original "Total Renewable Energy Production" series. Ask R to print the results. Interpret the results for both test. What is the conclusion from the Seasonal Mann Kendall test? What's the conclusion for the ADF test? Do they match what you observed in Q3 plot? Recall that having a unit root means the series has a stochastic trend. And when a series has stochastic trend we need to use differencing to remove the trend.

```
SMK_original<- SeasonalMannKendall(ts_renewable)
SMK_original
```

```
## tau = 0.799, 2-sided pvalue =< 2.22e-16
```

```
ADF_original<- adf.test(ts_renewable)
ADF_original
```

```
##
##  Augmented Dickey-Fuller Test
##
## data:  ts_renewable
## Dickey-Fuller = -1.0247, Lag order = 8, p-value = 0.9347
## alternative hypothesis: stationary
```

> Answer: The seasonal Mann Kendall resulted in a significant p value indicating that there is a trend in the data. However we need to use the ADF to determine if the series is a stochastic trend. The ADF did not result in a significant p value which means we will retain our null hypothesis that there is a unit root and therefore a stochastic trend. This matches what I observed in the Q3 plot since its seemed that the differencing was more effective in removing the trend and differencing is required to remove a trend for stochastic data.

Q6

Aggregate the original "Total Renewable Energy Production" series by year. You can use the same procedure we used in class. Store series in a matrix where rows represent months and columns represent years. And then take the columns mean using function colMeans(). Recall the goal is the remove the seasonal variation from the series to check for trend. Convert the accumulates yearly series into a time series object and plot the series using autoplot().

```
#take the mean of each year
renew_matrix <- matrix(ts_renewable,byrow=FALSE,nrow=12)
```

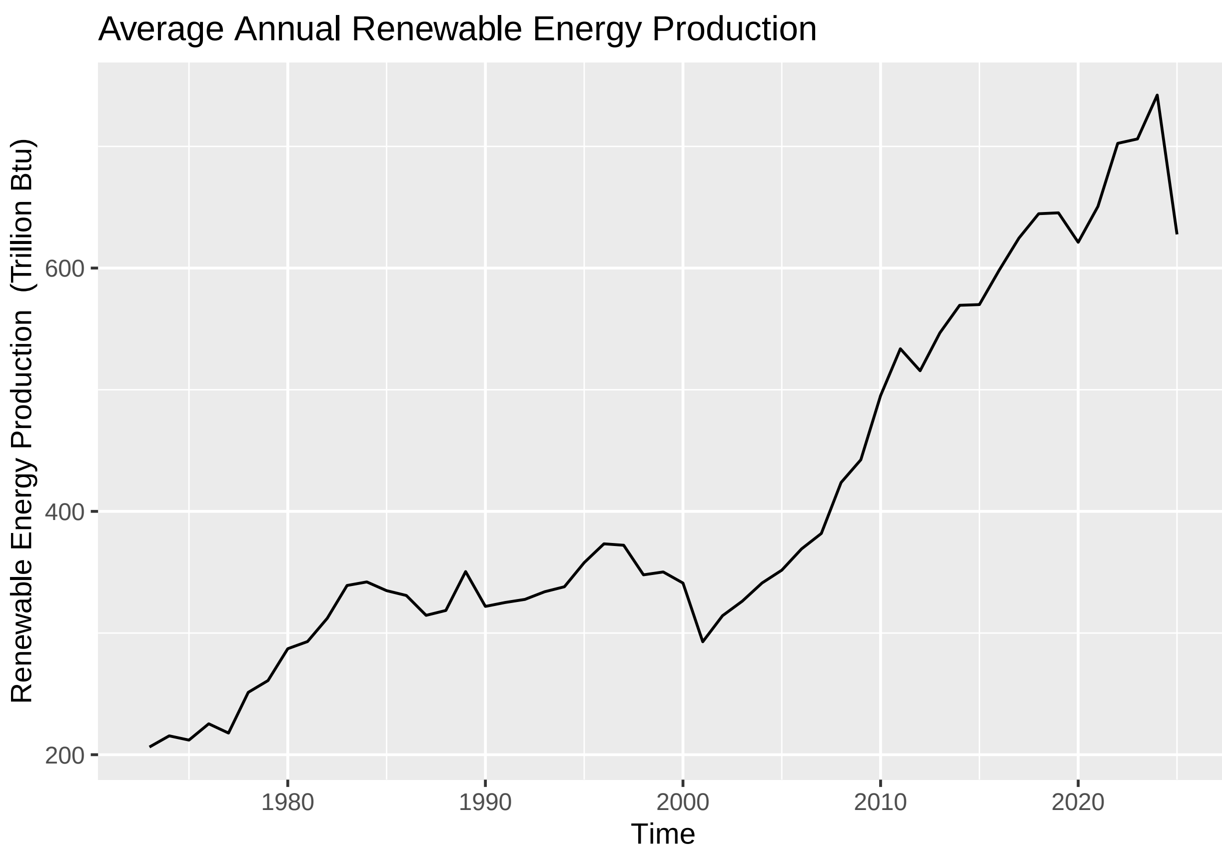
```
## Warning in matrix(ts_renewable, byrow = FALSE, nrow = 12): data length [633] is
## not a sub-multiple or multiple of the number of rows [12]
```

```
renew_data_yearly <- colMeans(renew_matrix)
ts_yearly <- ts(renew_data_yearly,start=c(1973,1),
                     frequency=1)

yearly_plot<- autoplot(ts_yearly) +
  xlab("Time") +
  ylab("Renewable Energy Production  (Trillion Btu)")+
```

```
  ggtitle("Average Annual Renewable Energy Production")

yearly_plot
```



Q7

Apply the Mann Kendall, Spearman correlation rank test and ADF. Are the results from the test in agreement with the test results for the monthly series, i.e., results for Q5?

```
SMK_yearly<- SeasonalMannKendall(ts_yearly)
SMK_yearly
```

```
## tau = 0.816, 2-sided pvalue =< 2.22e-16
```

```
ADF_yearly<- adf.test(ts_yearly)
ADF_yearly
```

```
##
##  Augmented Dickey-Fuller Test
##
## data:  ts_yearly
## Dickey-Fuller = -1.6789, Lag order = 3, p-value = 0.7037
## alternative hypothesis: stationary
```

Answer: Yes, the SMK and ADF tests yielded the same results for the yearly data as they did for the original monthly data. The SMK was signficant, indicating a trend, and the ADF was not, indicating that there is a unit root and therefore a stochastic trend.