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Cluster and time series analyses: an application to CO_2 emissions in selected European countries

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ABSTRACT

Carbon dioxide (CO_2) is a greenhouse gas that contributes the most to climate change including global warming. The concentration of this gas in the atmosphere has been increasing steadily since the Industrial Revolution. We have currently reached levels that call for immediate action in order to avoid crossing the point of no return. CO_2 is released as a by-product of combustion and stays trapped in the atmosphere for a long time. This gas absorbs the light reflected from the surface and emits heat back, which is responsible for global warming. CO_2 can also be absorbed by water decreasing the pH and causing other issues. Here we analyze the emissions of selected European countries and divide them in three groups based on the CO_2 emissions from 1960 to 2014. Countries like the Netherlands, Poland, Belgium, Finland, Denmark, and the United Kingdom need to tighten their measures in order to mitigate this environmental problem as they are the ones that pollute the most. Based on predictions made from time series models, some of these countries will increase or stabilize their emissions in the future while what we currently need is the decrease of emissions.

Keywords: green-house gases, anthropogenic emissions, climate change, global warming, mitigation.

INTRODUCTION

Our planet is in constant change although it seems static to us. We will never be able to fully understand the Earth's timeline since ours is limited to a couple of decades. As a result, it seems difficult to believe that the planet has gone through periods of warming and cooling many times throughout its life (Schaffer, Olsen, & Bjerrum, 2004). Our planet has suffered rapid changes in temperature, composition of the atmosphere, concentration of compounds in the ocean, levels of radiation, eruptions, moving of land masses, and of course, changes in the concentration of greenhouse gases. Although these changes happened over extremely long periods of time, our current climate has changed so much in such a short period of time that we can actually see the consequences in our own lifetime. Since the Industrial Revolution, the concentration of greenhouse gases has increased steadily and has greatly changed the composition of the atmosphere (Yakir, 2011). This special type of emission created as a result of human activities is called anthropogenic and is causing rapid climate changes that affect not only the atmosphere, but also the oceans. Every organism either on land or in water is affected by a rapid change in the environment since natural selection and evolution cannot keep up with the changes. Current emissions surpassed 10 Gt C per year (Zeebe, Ridgwell, & Zachos, 2016) and the rate at which is increasing is faster than anything else that ever occurred on the planet for at least 22,00 years (Joos & Spahni, 2008). Some studies even suggest a lifetime of about 165.000 years of global warming induced as a result of anthropogenic activities (Zeebe, 2013). Therefore, it is imperative to identify the countries with the highest emissions in order to put in place policies to achieve a substantial reduction in carbon dioxide (CO_2) emissions. The European Union (EU) is considered a large emitter; therefore, it carries a high degree of responsibility for this environmental problem (Geden, Peters, & Scott, 2018). Other countries like China and the United States also share a substantial amount of the responsibility. The type of solution to mitigate emissions clearly depends on the capabilities of each country since some alternatives are not feasible based on economy, culture, or social conditions. It is also important to understand that this problem requires tight measures in order to achieve a significant reduction in a short period of time. Therefore, the purpose of this study is to analyze the CO_2 output per capita of most European countries. For those with the highest emissions, a time series has been modeled in order to predict future tendencies in emission. Finally, for those countries that pollute the most, alternatives are suggested that could lead to a major reduction of emissions overtime despite the vast success that the European Union has had in surpassing the targets established by the Paris Agreement signed in 2015.

FRAMEWORK

Anthropogenic Emissions & Carbon Sinks

The exploitation and use of fossil fuels has been expanding since the Industrial Revolution in the late 1700s. The process of combustion releases CO_2, which is one of the greenhouse gases (GHGs) together with methane (CH_4), nitrous oxide (N_2O), and halocarbons (HCs). There has been a debate for a long time about whether the current rise of CO_2 actually comes from combustion or if it is attributed to the normal cycles of warming of the planet. One of the methods used to pinpoint the excess of CO_2 to human activities is carbon-14 (^{14}C), a radioactive isotope of carbon. This isotope, due to its radioactive nature, has a half-life of 5,730 years; therefore, ^{14}C is not present in fossil fuels, but it is found naturally in the atmosphere. By analyzing and comparing CO_2 vs. ^{14}C levels, scientists can attribute the increase of CO_2 in the atmosphere to combustion since the vast majority of CO_2 released does not contain ^{14}C.

Another factor that contributes to anthropogenic emissions is deforestation. This phenomenon could account for up to one-third of anthropogenic emissions (Fearnside & Laurance, 2004). Vegetation and oceans are considered carbon sinks, which are reservoirs that absorb and process CO_2. The rapid transformation of forests into fields for harvesting and cattle raising are contributing to the increase of CO_2 molecules in the atmosphere. In 2001, natural carbon sinks were responsible for the sequestration of half of the CO_2 emitted by fossil-fuel combustion (Schimel et al., 2001). However, the biosphere is not able to keep up with the increasing global accumulation of CO_2 in the atmosphere. In 2014, the ocean was responsible for sequestering around 2.9 Gt C per year while forests were responsible for sequestering around 4.1 Gt C per year (Le Quéré et al., 2015). This amount of carbon flux represents an increase in the amount of CO_2 sequestered between 2005 and 2014 which was 2.6 Gt C per year and 3.0 Gt C per year (Le Quéré et al., 2015). These data might suggest that carbon sinks have the ability to increase CO_2 processing rates as atmospheric concentration of this gas increases. However, there is no clear evidence to suggest that rising atmospheric CO_2 stimulates carbon sequestration by forests (Beedlow, Tingey, Phillips, Hogsett, & Olszyk, 2004). Deforestation of large forests could result in much higher concentrations of atmospheric CO_2 than predicted which in turn would, inevitably accelerate climate change (Taylor & Lloyd, 1992). In addition to that, the oceans are not an ideal carbon sink. When CO_2 dissolves in water, it changes the chemistry of the ocean affecting a wide range of organisms (Lauvset & Gruber, 2014). There is enough evidence to suggest that current emissions are anthropogenic in nature and from all the CO_2 released in the atmosphere, 45% stays trapped and accounts for the green-house effect (Friedlingstein et al., 2011).

Climate Change, Humans at Its Origins

Anthropogenic climate change refers to the current disruption of the Earth's climate due to human activities, especially the release of GHGs. All of these gases have the ability to absorb electromagnetic radiation such as the light that is reflected from the surface of the planet and emitted back as heat. This allows the heat to stay trapped in the atmosphere and not be released into outer space. The more molecules of GHGs in the atmosphere, the more heat will be retained, increasing the overall temperature of the planet over time. Methane, nitrous oxide, halocarbons, carbon dioxide, and even water vapor have the potential to contribute to global warming. Just like CH_4, some of those gases are short-lived and can stay in the atmosphere for about a decade while CO_2 has an atmospheric lifetime up to 1.000 years (Zickfeld, Solomon, & Gilford, 2017). As a result, CO_2 is the major component responsible for anthropogenic climate change. The excess of this gas in the atmosphere doesn't only allow for rising surface temperatures but also for a wide range of environmental problems with catastrophic consequences. Global warming is only one face of climate change as it is often mistaken as the same phenomenon. While global warming tells the story of a planet warming up due to excess of CO_2, climate change refers to all the environmental challenges humanity faces right now such as ocean acidification, acid rain, hurricanes, sea level rising, and a wide range of other natural phenomena caused by emissions due to human activities.

The emission can be released into the atmosphere and taken by forests and oceans which act as carbon sinks. These are natural reservoirs that can process the excess of carbon dioxide and release oxygen back into the environment. However, as mentioned before, the activity of forests has been limited by deforestation and the oceans cannot keep processing CO_2 as the limit has been reached. As more CO_2 dissolves in water, carbonic acid (H_2CO_3) is formed posing a threat to marine life that depends on optimal water chemistry. Calcifiers, for example, are animals that depend on aragonite and calcite to build their shells. Both of these compounds are polymorphs of calcium carbonate ($CaCO_3$) which reacts with the H_2CO_3 present in the water. Just like ocean acidification, the vast majority of current natural phenomena can be traced back to the release of CO_2 directly or indirectly. Therefore, GHGs have been the main drivers of climate change, which refers to the warming of the atmosphere and ocean, the rise in sea level, and other phenomena (Stocker et al., 2013).

Initiatives for Mitigation

In 2015, the global issue of climate change unified all nations to create a legal binding and non-binding agreement known today as the Paris Agreement, the same agreement that has been on the news lately as the United States of America has officially withdrawn from it under the presidency of Donald Trump. The Paris Agreement is not the first attempt to face climate change although it is what we mostly hear about. In 1992, the United Nations Conference on Environment and Development, also known as the Earth Summit, took place. The United Nations Framework Convention on Climate Change (UNFCCC) is a multilateral environmental treaty signed at the summit by 154 states. The main goal of the first agreement was to commit to reductions in GHGs emissions by the year 2000 establishing different levels of responsibility as well as requirements moving forward depending on the country as they were classified into 3 categories: developed countries, developed countries with special financial responsibilities, and developing countries (United Nations Framework Convention on Climate Change, 1992). The Kyoto Protocol was an extension of the UNFCCC entered into force in February 2005 to further establish new goals up to 2020. The protocol targeted emissions based on two statements: a) the acceptance that global warming is a reality and b) it is likely that global warming is caused by human activities. The goal of The Kyoto Protocol is to limit global warming below 2°C relative to the preindustrial temperature level by preventing the increase of atmospheric concentration of GHGs above 450 ppm; after this point, there is a risk of up to 78% to exceed the 2°C target (Kyoto Protocol, 2005). Although the UNFCCC did not establish any legal binding enforcement mechanisms, the Kyoto Protocol did.

In 2016, the Paris Agreement became effective seven months after it was signed. The Paris Agreement is not an extension of the UNFCCC, rather, it is another instrument to tackle climate change. The agreement established new targets by 2020, known as the 20/20/20 plan which includes: a) 20% reduction in CO_2 emissions compared to the 1990 level, b) 20% increase of renewable energy's market shares, and c) 20% increase in energy efficiency by reducing the EU's energy consumption (Paris Agreement, 2015). Although the United States and Canada have shown certain level of disagreement and did not ratify for a long time, European countries have been strong supporters of the agreements since the Earth Summit. In fact, The EU surpassed its commitment to emissions reduction during the Kyoto Protocol (European Commission, 2014). However, in order to establish mitigation actions, it is imperative to understand how different sectors share the responsibility over CO_2 emissions. It is clear that the power sector contributes in large part to the overall emissions; therefore, it has a greater responsibility and should contribute more in order to achieve the targets established by The Paris Agreement (Karmellos, Kopidou, and Diakoulaki, 2016). Although companies are required to make changes in order to achieve the environmental goals, it is up to policy makers to step in and implement measures to enforce the targets and move towards greener practices (Castillo & Angelis-Dimakis, 2019). It is necessary to set up priorities that might lead to achieving the ambitious targets imposed by the Paris Agreement. Several green strategies in certain sectors rely on electrification; therefore, it is necessary to come up with low-emission technologies to generate electricity which can only occur with more investment in research, development, and finally deployment (Brown, Schäfer, and Greiner, 2019). The success of the EU in over-achieving its targets relies on good management, strategic resource allocation and policy makers willing to move towards a greener future. Europe has been a leader and a role model for the rest of the countries which remains relevant for the following years (Oberthür & Groen, 2017). China and the United States have challenged on several occasions the Paris Agreement despite the fact that both countries issued a joint statement in 2016 confirming the singing of the agreement. Nevertheless, future challenges are yet to come as the United States formally withdrew from the agreement in 2020.

METHODS

This study belongs to the area of international environmental policy and climate change. The database under study is quantitative in nature and was taken from the World Bank Organization. The variable to analyze was CO_2 emissions per capita of selected European countries. A number of countries had missing data points, so the database was reviewed and only the countries with information between 1960 and 2014 were used for the study. Luxembourg was also not taken into consideration as its emissions per capita are the highest in the European continent due to its low population. Russia was not included in the study either after the results of an analysis of principal components and also due to its location. This study only incudes countries with all their territories in European soil: 22 European countries in total. The statistical analysis included description of the variable and its behavior over time as well as the Dickey-Fuller nonstationary tests. Also, descriptive and analytic methods were used. The first part was an analysis of principal components using the cosine square and a hierarchical cluster analysis using the Euclidian distance and Ward's minimum variance method. The second part of the study was the adjustment of several univariate time series models using the Box-Jenkins method to estimate a model based on independence, autocorrelation, heteroscedasticity, and normality of errors. These models were used to predict future emissions of the European countries that release CO_2 the most.

RESULTS & DISCUSSION

Principal components and cluster analyses

The first part of the study is a general description of the database where several data such range, minimum, maximum, mean, median, standard deviation, and variance are given.

Table 1: Tons of CO_2 per country organized by range from highest to lowest from 1960 to 2014.

	Range	Min.	Max.	Mean	Median	Std	Variance
Russia	16.77	10.13	26.90	16.94	14.27	5.99	35.88
Finland	9.82	3.35	13.17	9.60	10.38	2.38	5.66
Norway	8.02	3.66	11.68	8.09	8.42	2.05	4.20
Greece	7.85	1.13	8.98	5.77	6.20	2.44	5.95
Denmark	7.84	5.87	13.71	10.15	10.39	1.75	3.06

Ireland	7.44	3.95	11.39	7.97	7.74	1.87	3.50
Bulgaria	7.38	2.83	10.22	7.11	6.76	1.81	3.28
Sweden	7.00	4.48	11.49	7.29	6.58	1.94	3.76
Netherlands	6.98	6.40	13.38	10.49	10.92	1.50	2.25
Spain	6.49	1.61	8.10	5.20	5.49	1.74	3.03
Malta	6.47	0.90	7.37	4.31	5.39	2.00	4.00
Romania	6.34	2.90	9.25	5.87	5.24	2.00	4.00
Poland	6.32	6.74	13.06	9.37	8.92	1.75	3.06
Italy	6.04	2.18	8.22	6.37	6.69	1.53	2.34
Belgium	5.91	8.35	14.26	11.22	11.08	1.43	2.05
Portugal	5.48	0.93	6.41	3.58	3.14	1.71	2.92
U.K.	5.33	6.50	11.82	9.84	9.87	1.31	0.41
France	5.14	4.57	9.71	6.89	6.46	1.33	1.77
Austria	4.60	4.37	8.97	7.20	7.42	1.10	1.21
Hungary	4.33	4.19	8.52	6.31	5.98	1.17	1.37
Switzerland	3.67	3.66	7.33	5.74	5.87	0.75	0.56
Iceland	2.96	5.84	8.80	7,27	7.41	0.70	0.49
Albania	2.41	0.49	2.90	1.65	1.52	0.66	0.44

Russia is the country with the highest range and therefore would impact the cluster analysis, while Albania and Iceland would possibly have no effect on the analysis if they were to be removed from the study

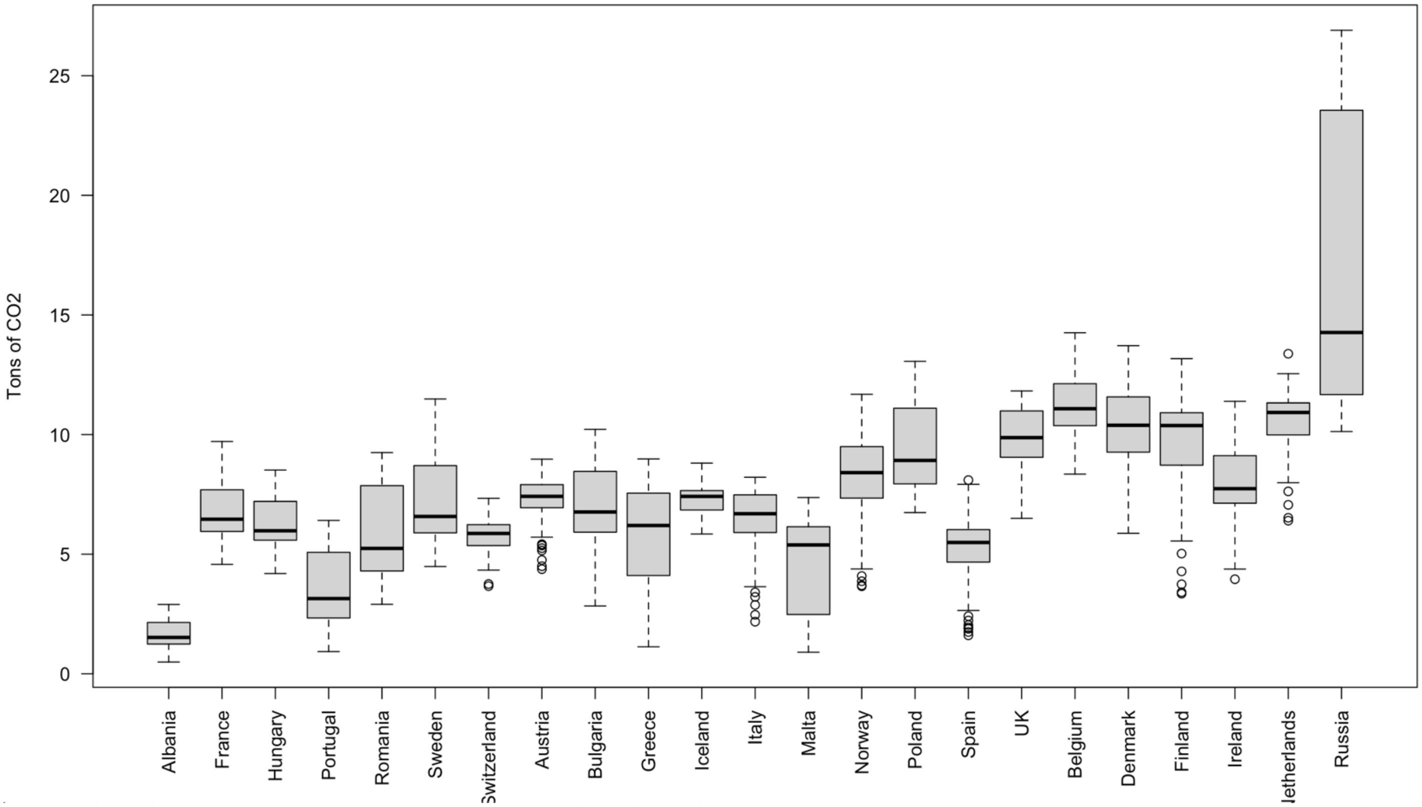

Figure 1: CO_2 emissions per capita in selected European Countries from 1960 to 2014

Not only does Russia have the largest rage of all countries, it is also disproportionate to the rest of the European countries. Also, the mean is well above the rest. This makes it necessary to perform an analysis of principal components in order to determine if it would be appropriate to remove Russia from the study. From the boxplot it is also worth to mention that countries such as the Netherlands, Finland, Denmark, Belgium, Poland, Norway, and the United Kingdom show a high trend of CO_2 emissions above the other countries but below Russia.

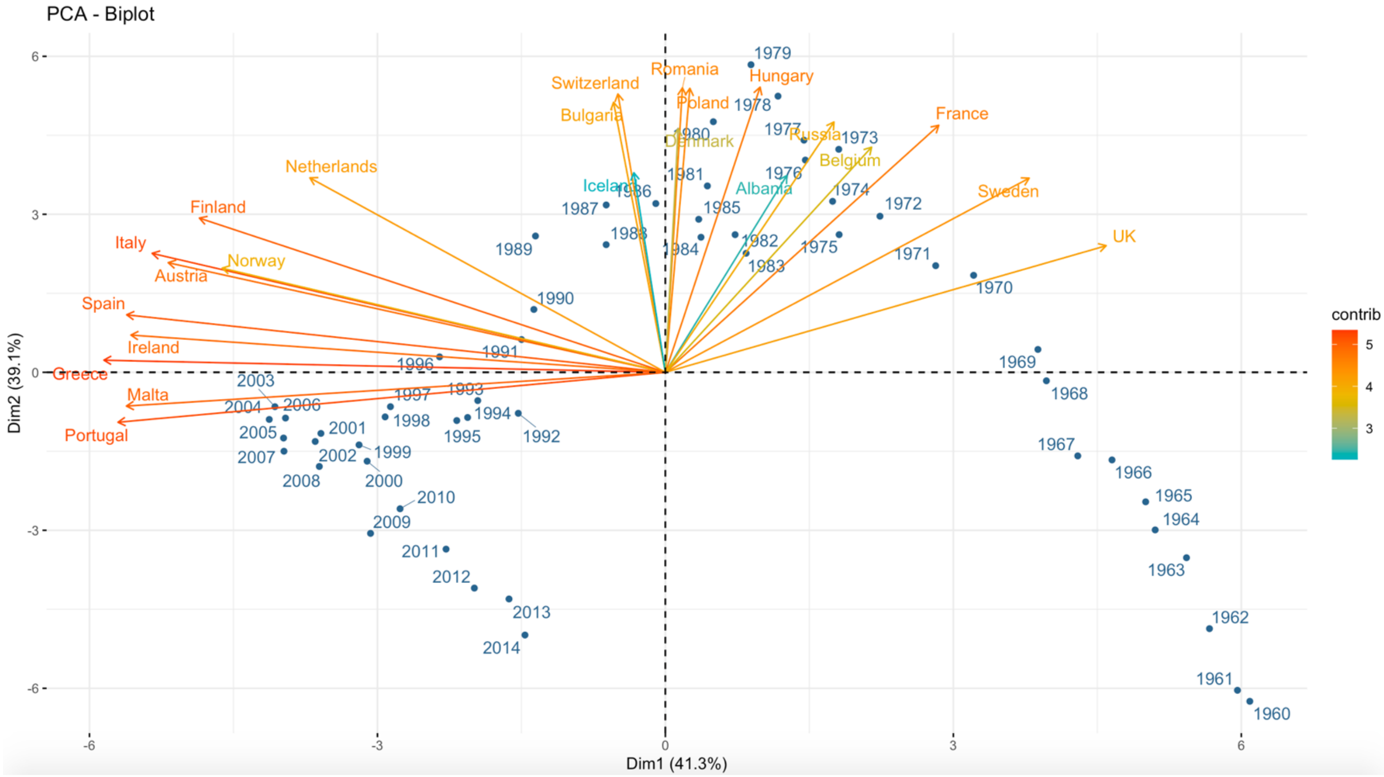

Figure 2: Graph of contribution vectors per countries in dimensions 1 and 2

Fig. 2 shows that the countries aggregate apparently in two different components. Also, as mentioned before, Albania and Iceland don't contribute in a major way to the overall distribution of the countries. Countries like Sweden, France, Belgium, Hungary, Poland, Romania, Bulgaria and Switzerland have emissions similar to those between 1970 and 1986 while the Netherlands, Finland, Norway, Austria, Italy, Spain, Ireland, Greece, Malta and Portugal have emissions similar to those between 1990 and 1998. These two dimensions explain 80.4% of the data

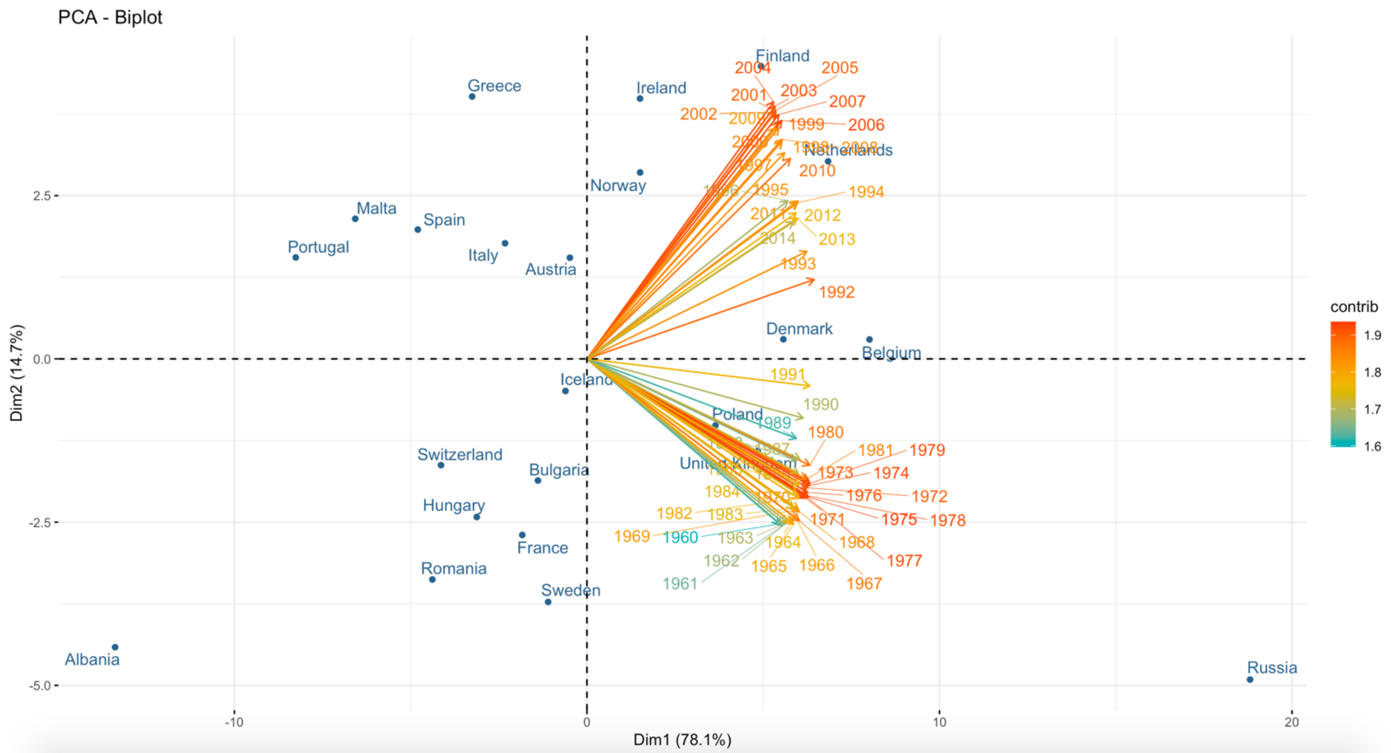

Figure 3: Graph of contribution vectors per year in dimensions 1 and 2

Fig. 3 shows that the time period between 1960 and 2014 can also be aggregated in two different groups where the time period between 1960 and 1991 aggregate into one group and from 1992 to 2014 into another group. These two dimensions explain 92.8% of the data. In fig. 3 Russia and Albania are far from the distribution of the years. Just like it was seen in fig. 2 Albania does not contribute significantly to the distribution of the data.

It is important to take into account that this study only includes countries which have territories located on European soil. Therefore, Russia should not be included although Moscow and Saint Peterburg are located in Europe. Based on the results of the principal components analysis and the atypical level of emissions, Russia was left out of the study. The following analyses exclude Russia from them.

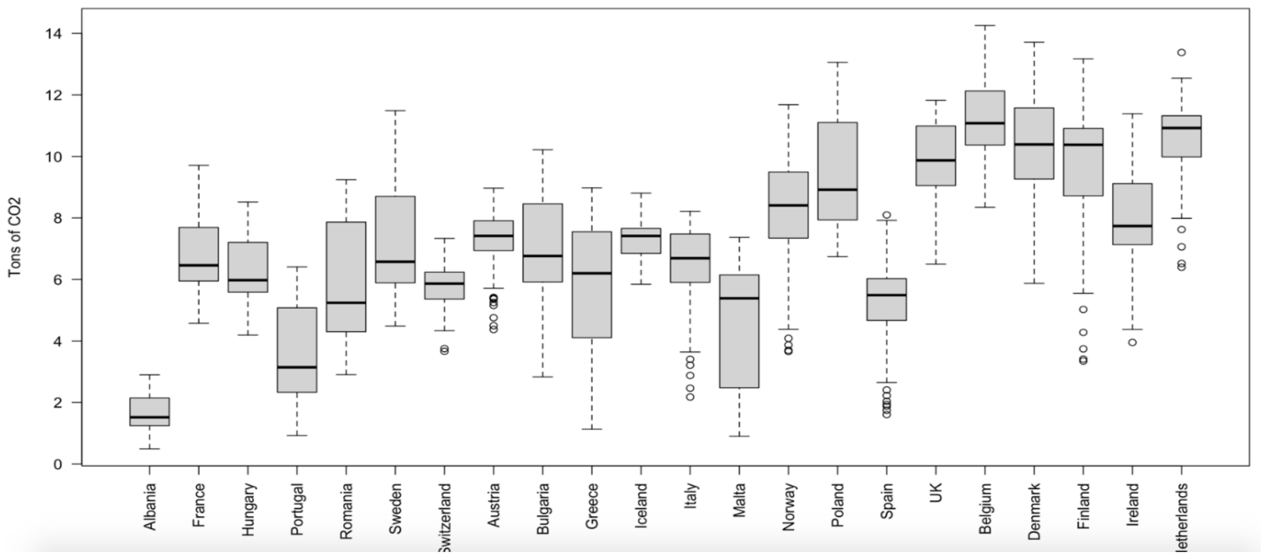

Figure 4: CO2 emissions per capita in selected European countries except Russia from 1960 to 2014

Fig. 4 shows a more consistent behavior in the distribution of the emissions once Russia is removed. In fact, countries like Norway, Poland, Belgium, Denmark, Finland, the Netherlands and the United Kingdom do show a fair increase than the rest of the European countries included in the study. On the other hand, Albania is the country that emits the least from the countries included in the study. Countries like Romania, Sweden, Greece, and Malta have a large range of emissions while the others have a smaller range. It is also important to analyze the change over the years of all the emissions of the countries in the study.

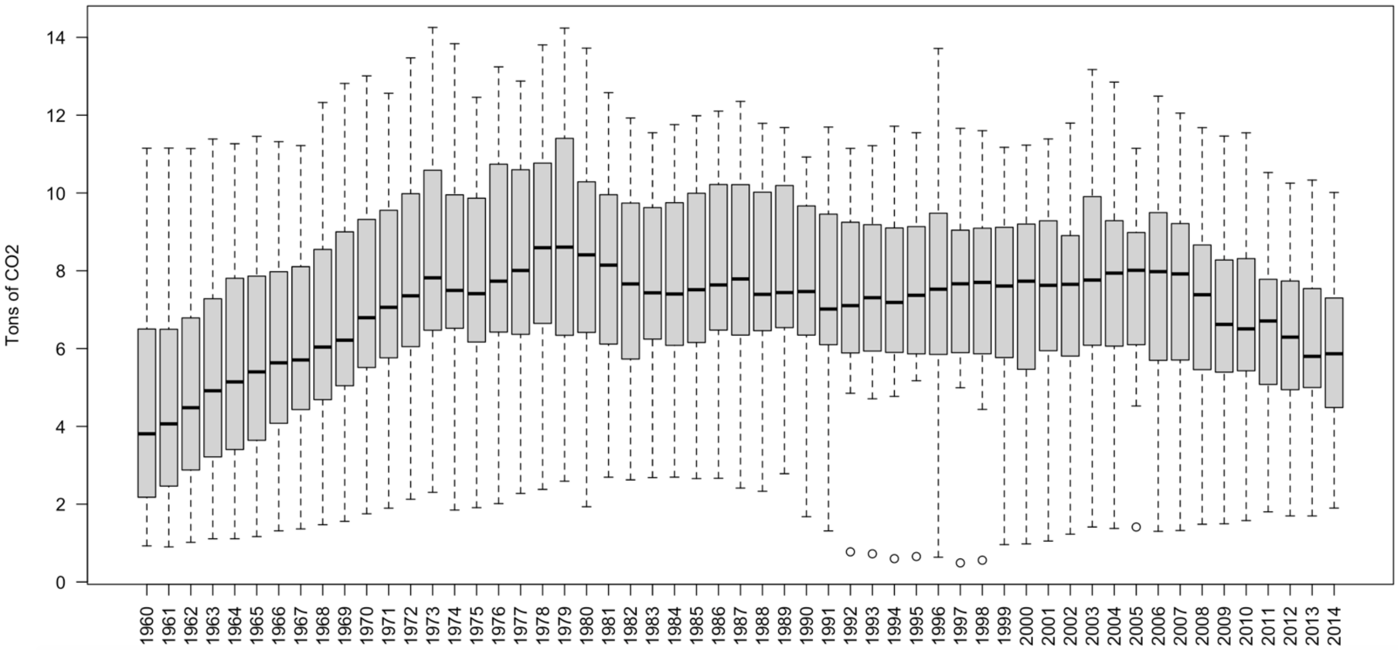

Figure 5: CO2 emissions per capita from 1960 to 2014 of selected European countries

Fig. 5 shows a steady increase up until 1973 with the same year with the overall highest emissions ever recorded within that timeframe. In 1979, the average emissions were the highest ever recorded. In 1980, the emissions decreased and stay stable until 1992 when the Earth Summit took place in Brazil. Right after UNFCCC was agreed upon, there was a significant decrease in the range of emissions. In fact, there were some outliers with extremely low emissions. The lowest emissions ever recorded between 1960 and 2014 happened right after the UNFCCC was put in place although it did not have any legally binding enforcement mechanisms. When the Kyoto Protocol entered into force in 2005, the emissions were also significantly reduced after a small increase since 1992. Since then, the total emissions in most Europe have been steadily decreasing year after year.

A hierarchical cluster analysis was performed using the Euclidean distance and the Ward's method minimum variance method in order to group the countries in 3 groups: a) low emissions; b) medium emissions; and c) high emissions.

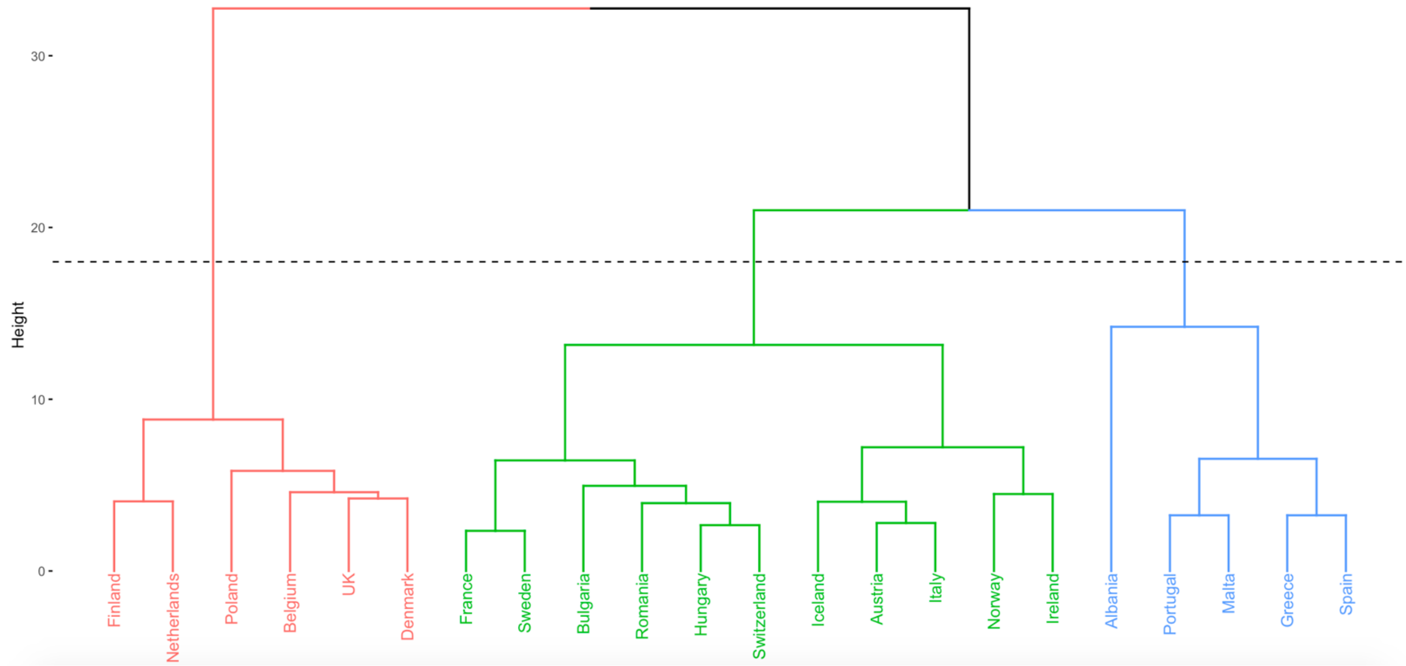

Figure 6: Hierarchical cluster using Euclidean distance, K=3

Fig. 6 shows the 3 groups of countries where Albania, Portugal, Malta, Greece, and Spain have the lowest emissions while Finland, the Netherlands, Poland, Belgium, the U.K. and Denmark have the highest emissions in all of Europe. Although environment-friendly countries like Finland, the Netherlands, Denmark, and Belgium have developed mechanisms to avoid the increasing demand of buying cars, their emissions come in great measure from agriculture and energy production as well as the processing of manure. The main cities of these countries have high standards for their public transportation to deter inhabitants to purchase vehicles which in turn would increase CO_2 emissions. Poland, on the other hand, is a country that specializes in coal production, being the second largest coal miner in Europe, after Germany (not included in this study). Although these countries have committed to the Paris agreement and have kept their emissions lower than what is required by that same agreement, among European countries, they have the highest emissions.

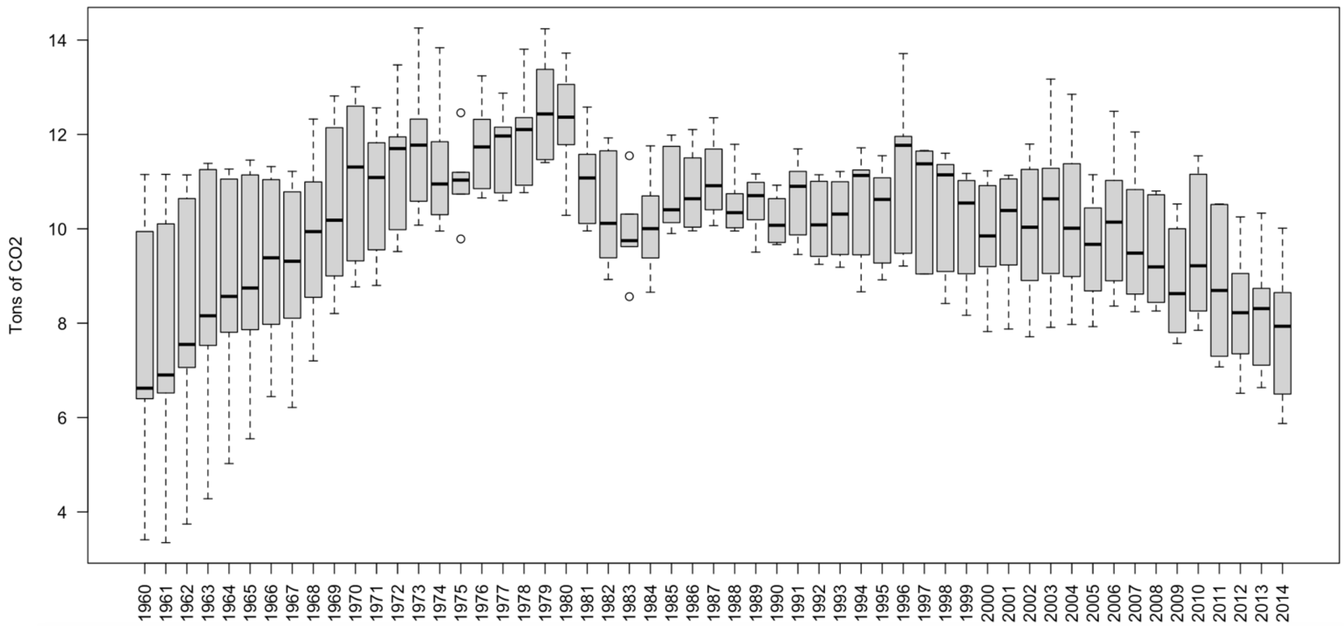

Figure 7: CO2 emissions per capita from 1960 to 2014 in Finland, the Netherlands, Poland, Belgium, U.K. and Denmark

Fig. 7 shows the emissions of the 5 countries that emit CO_2 the most together with the United Kingdom. These countries had an increasing tendency of emissions since 1960 up until 1980. Between 1981 and 1994, they had stable emissions and two years after the UNFCCC entered into force, the emissions started decreasing. In comparison to the emissions of all the countries during the same time period shown in fig. 5, these five countries the U.K. show a smaller range of emissions since 1969 up until 2014. While the average emissions are between 4 and 8 tons per capita for all the countries in the study, the average emissions of these 6 territories are between 6 and 12 tons per capita. This is significantly larger than the rest of the countries in Europe. Therefore, six univariate time series models were proposed to predict future emissions of these countries in order to suggest actions to mitigate climate change and stay within the parameters established by the Paris agreement.

Time series analyses

For Finland, the Netherlands, Poland, Belgium, the United Kingdom, and Denmark, six independent autoregressive integrated moving average (ARIMA) models have been proposed in order to analyze and predict future emissions.

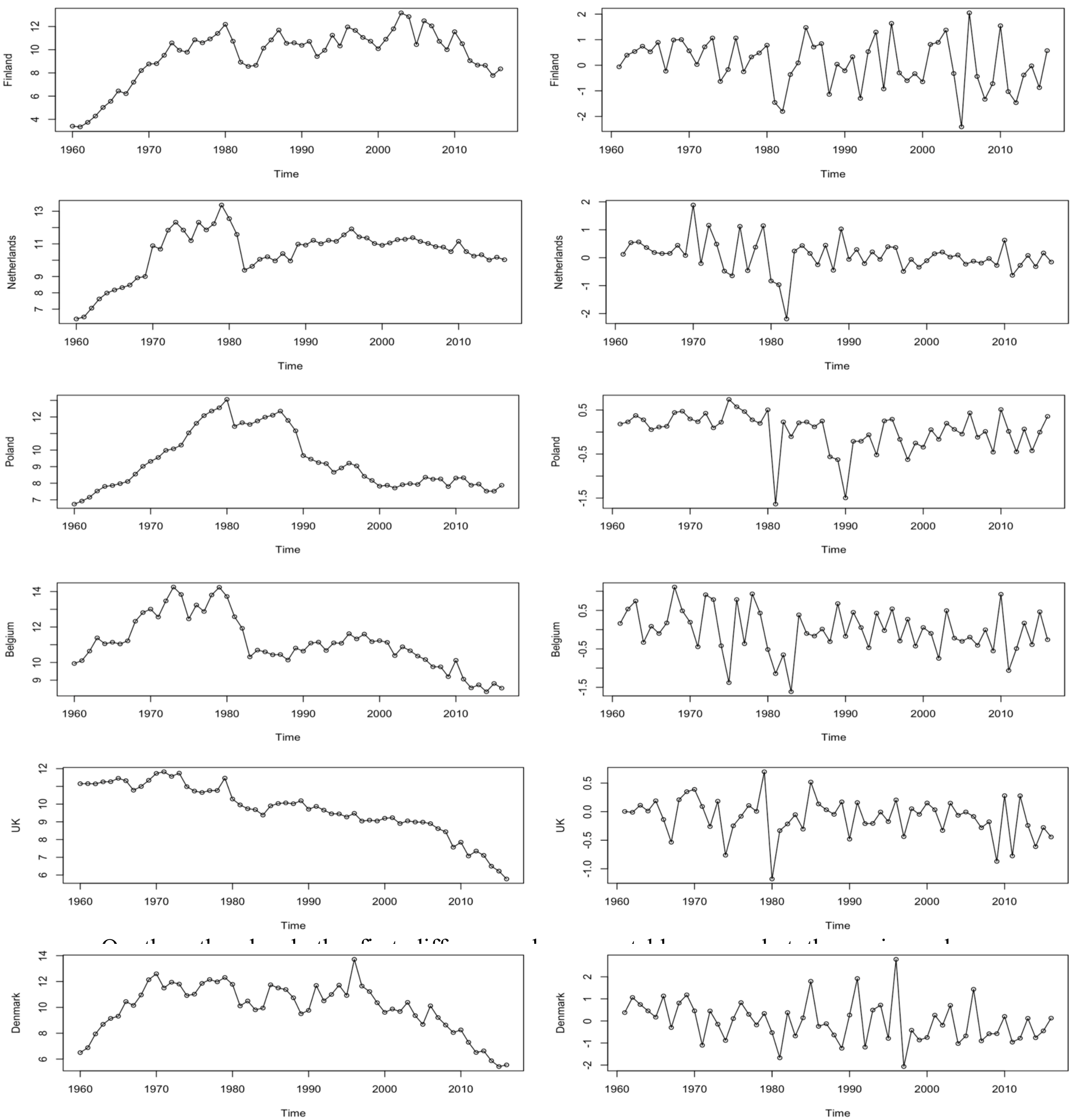

Figure 8: CO_2 emissions and their first difference between 1960 and 2014 in Finland, the Netherlands, Poland, Belgium, the United Kingdom, and Denmark

An augmented Dickey-Fuller test was performed to evaluate if the series were stationary and it was found that they were not, being necessary to apply a difference. Table 2 shows the results of the tests applied to the series and their first difference. The null hypothesis states that the series are not stationary.

Table 2: p-values of the series and their first difference of selected countries

	Series	First difference
Finland	0.6293	0.1
Netherlands	0.4124	0.01365
Poland	0.5352	0.1361
Belgium	0.4838	0.1
United Kingdom	0.8905	0.01
Denmark	0.5761	0.01

Each case except Poland shows p-values<0.05; therefore, providing enough evidence to reject the null hypothesis and accept the alternative hypothesis, which states that the series are stationary in the first difference. Poland though is not stationary in the first difference. In this case a second difference is necessary in order to proceed with the model. In the second difference, the augmented Dickey-Fuller test has a p-value=0.01.

(7,1,7) ARIMA model proposed for emissions in Finland

$$(1 + 0.371x_{t-1} - 0.381x_{t-2} - 0.206x_{t-3} - 0.226x_{t-4} - 0.496x_{t-5} - 0.155x_{t-6} - 0.171x_{t-7})(1 + B)x_t = \alpha + (1 + 0.362x_{t-1} - 0.433x_{t-2} - 0.204x_{t-3} - 0.225x_{t-4} - 0.491x_{t-5} - 0.290x_{t-6} - 0.357x_{t-7})w_t$$

(11,1,0) ARIMA model proposed for emissions in the Netherlands

$$(1 + 0.492x_{t-1} - 0.179x_{t-2} - 0.365x_{t-3} - 0.495x_{t-4} - 0.341x_{t-5} - 0.047x_{t-6} - 0.366x_{t-7} - 0.302x_{t-8} - 0.384x_{t-9} - 0.093x_{t-10} - 0.336x_{t-11})(1 + B)x_t = \alpha + w_t$$

(6,2,1) ARIMA model proposed for emissions in Poland

$$(1 + 0.073x_{t-1} - 0.231x_{t-2} - 0.027x_{t-3} - 0.089x_{t-4} - 0.055x_{t-5} - 0.002x_{t-6})(1 + B)x_t = \alpha + (1 + 0.0008x_{t-1})w_t$$

(0,1,13) ARIMA model proposed for emissions in Belgium

$$(1 + B)x_t = \alpha + (1 + 0.413x_{t-1} - 0.350x_{t-2} - 0.343x_{t-3} - 0.403x_{t-4} - 0.355x_{t-5} - 0.248x_{t-6} - 0.288x_{t-7} - 0.461x_{t-8} - 0.422x_{t-9} - 0.238x_{t-10} - 0.136x_{t-11} - 0.378x_{t-12} - 0.028x_{t-13})w_t$$

(0,1,11) ARIMA model proposed for emissions in the United Kingdom

$$(1 + B)x_t = \alpha + (1 + 0.098x_{t-1} - 0.440x_{t-3} - 0.438x_{t-4} - 0.211x_{t-5} - 0.076x_{t-7} - 0.122x_{t-8} - 0.411x_{t-9} - 0.380x_{t-10})w_t$$

(13,1,0) ARIMA model proposed for emissions in Denmark

$$(1 + 0.087x_{t-1} - 0.451x_{t-2} - 0.053x_{t-3} - 0.103x_{t-4} - 0.287x_{t-5} - 0.126x_{t-6} - 0.021x_{t-7} - 0.465x_{t-8} - 0.387x_{t-9} - 0.064x_{t-10} - 0.151x_{t-11} - 0.295x_{t-12-} - 0.060x_{t-13})(1 + B)x_t = \alpha + w_t$$

Residual autocorrelation

The no-autocorrelation of the errors (Ho: rk=0) was tested using the Ljung-Box test with lag=30. In all cases the null hypothesis was not rejected; therefore, suggesting that the errors are not correlated among them. Table 3 shows the results of the residual autocorrelation tests.

Table 3: Results of Ljung-Box tests for autocorrelation

	X-squared	p-value
Finland	13.433	0.996
Netherlands	13.595	0.9956
*Poland	16.842	0.9744
Belgium	12.574	0.9978
United Kingdom	15.61	0.9858

Denmark	7.9272	1.0000

*Model with two differences

Randomness

The randomness (Ho: the residuals comes from a random sample) was tested using the Runs test with lag=30. In all cases the null hypothesis was not rejected; therefore, suggesting that the residuals come from a random sample which is necessary for the model to be appropriate. Table 4 shows the results of the randomness tests.

Table 4: Results of the Runs tests for randomness

	Z	p-value
Finland	-0.4908	0.6236
Netherlands	-1.4532	0.1462
*Poland	-0.0756	0.9397
Belgium	0.6701	0.5023
United Kingdom	-0.8335	0.4046
Denmark	-0.562	0.5741

*Model with two differences

Residual heteroscedasticity

The homoscedasticity of the residuals (Ho: r1=r2=r3=…=rn=0) was tested using the Ljung-Box test with lag=30. For the model to work, the residuals need to be homoscedastic which means that the variability of the variable is equal across the the rest of the elements. Table 5 shows the results of the homoscedasticity tests. As the residuals show a homoscedastic trend, the ARIMA model is valid.

Table 5: Results of the Ljung-Box test for homoscedasticity

	X-squared	p-value
Finland	25.063	0.722

Netherlands	43.913	0.048
*Poland	20.905	0.891
Belgium	26.415	0.6538
United Kingdom	24.002	0.7719
Denmark	29.699	0.4811

*Model with two differences

Prediction

Using the models mentioned before, an estimated prediction was calculated with tendencies shown in figure 9. According to the suggested models, the Netherlands and Poland will continue with relatively stable emissions as they have been since 1990. The United Kingdom will have also stable emissions although they have been decreasing during the last two decades. Finland seems to keep its tendency of peaks and drops. Belgium on the other hand shows a worrisome tendency of increasing emissions which is a sign of alert. If Belgium were to overpass the boundaries of the Paris Agreement, they could face serious issues within the EU. Denmark shows a tendency to drop its emissions which is positive in order to keep emissions in control and below the threshold established by the agreement. Although these countries have had emissions below those from 1990, it is imperative to keep revising emissions year after year. Any sign of increasing emissions should be an alarm that needs immediate action. Also recognizing what factors contribute the most is important for policy makers to make the right choice when putting penalties in place for exceeding CO_2 emissions.

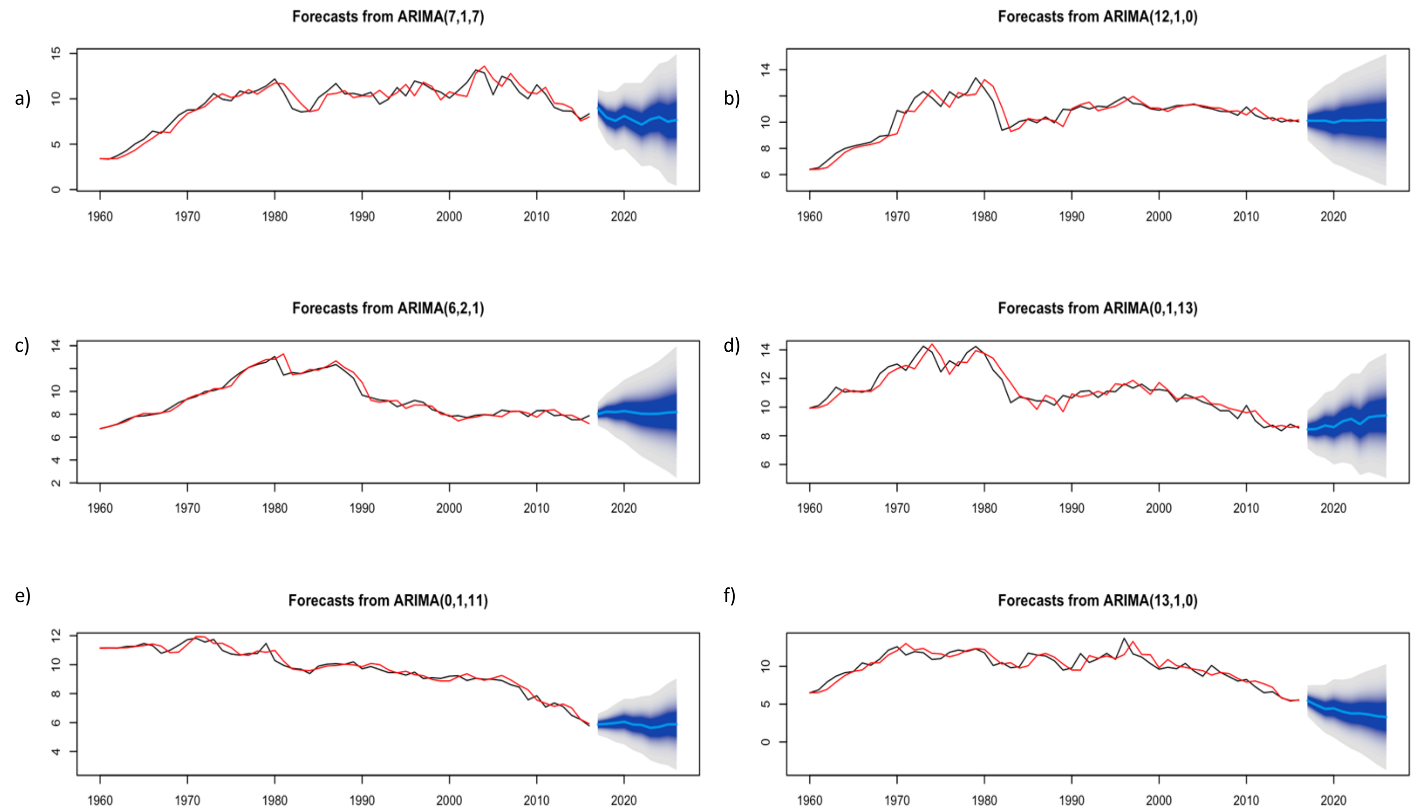

Figure 9: Forecast graphs, h=10, a) Finland b) the Netherlands c) Poland d) Belgium e) the United Kingdom f) Denmark

CONCLUSIONS

The Earth Summit aimed to establish a mechanism to help reducing CO_2 emissions and, therefore, climate change although it did not create legally binding enforcement systems. Although, there was no legal binding to this initial agreement, it did cause an impact in the overall emissions of Europe as a continent. The emissions as whole show a reduction in comparison to the previous trend of past emissions before 1992. As the population and globalization increases, so does the emission of CO_2 in the atmosphere due to the increasing demand of cars, mass production of goods, production of energy, and production of food. The Paris Agreement established clear parameters which are feasible for countries like those in Europe since they have the funding to do so. As it has been seen so far, even the largest emitting countries have managed to stay within the bounds established by the agreement of keeping emissions below the ones in 1999 in addition to the 20/20/20 plan. Countries with low and medium emissions will have no problem staying within the bound but will need to deploy more resources in order to achieve the three main points of the Paris Agreement of emission reduction, renewable energy, and energy efficiency. However, the countries that emit the most, will need not only to deploy more resources but also strengthen the mechanisms to enforce what the agreement demands. It is important to stay below what is mandated to avoid crossing the point of no return. It is clear that a good public transport system is not enough to decrease emissions as cars are not completely responsible for the total CO_2 emissions. In fact, sectors like the industry and energy production are the ones that share a great part of the responsibility as it is seen in countries like Finland, the Netherlands, Belgium, and Denmark. It is up to the policy makers to develop strategies that force these sectors to pay carbon taxes which in turn would provide resources in order to develop new technologies necessary to reduce emissions and increase the use of renewable energy sources. It is important to focus on countries like Belgium which have the potential to increase emissions instead of reducing them in order to develop emergency plans to keep the emissions under control and stay within the bounds of the Paris Agreement. We also suggest an extension of this study to include Russia, China, and the United States, especially the last 2 since those are the ones who hesitated before joining the agreement. In fact, the United States poses a potential threat to worsen global climate change as it has officially withdrawn from the agreement in 2020. This could lead to unmeasurable consequences that could harm the planet in an irreversible way. It is up to the EU to keep their efforts to keep climate change under control in the future.

REFERENCES

Beedlow, P. A., Tingey, D. T., Phillips, D. L., Hogsett, W. E., & Olszyk, D. M. (2004). Rising atmospheric CO2 and carbon sequestration in forests. Frontiers in Ecology and the Environment, 2(6), 315-322.

Brown, T., Schäfer, M., & Greiner, M. (2019). Sectoral interactions as carbon dioxide emissions approach zero in a highly-renewable european energy system. Energies, 12(6), 1032.

Castillo, A. C., & Angelis-Dimakis, A. (2019). Analysis and recommendations for European carbon dioxide utilization policies. Journal of environmental management, 247, 439-448.

European Commission. (2014). Progress towards achieving the Kyoto and EU 2020 objectives. Report from the Commission to the European Parliament and the Council.

Fearnside, P. M., & Laurance, W. F. (2004). Tropical deforestation and greenhouse-gas emissions. Ecological Applications, 14(4), 982-986.

Friedlingstein, P., Solomon, S., Plattner, G. K., Knutti, R., Ciais, P., & Raupach, M. R. (2011). Long-term climate implications of twenty-first century options for carbon dioxide emission mitigation. Nature Climate Change, 1(9), 457-461.

Geden, O., Peters, G. P., & Scott, V. (2019). Targeting carbon dioxide removal in the European Union. Climate Policy, 19(4), 487-494.

Joos, F., & Spahni, R. (2008). Rates of change in natural and anthropogenic radiative forcing over the past 20,000 years. Proceedings of the National Academy of Sciences, 105(5), 1425-1430.

Karmellos, M., Kopidou, D., & Diakoulaki, D. (2016). A decomposition analysis of the driving factors of CO2 (Carbon dioxide) emissions from the power sector in the European Union countries. Energy, 94, 680-692.

Kyoto Protocol to the United Nations Framework Convention on Climate Change, Dec. 10, 1997, 2303 U.N.T.S. 162.

Lauvset, S. K., & Gruber, N. (2014). Long-term trends in surface ocean pH in the North Atlantic. Marine Chemistry, 162, 71-76.

Oberthür, S., & Groen, L. (2017). The European Union and the Paris Agreement: leader, mediator, or bystander?. Wiley Interdisciplinary Reviews: Climate Change, 8(1), e445.

Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015, T.I.A.S. No. 16-1104.

Quéré, C. L., Moriarty, R., Andrew, R. M., Canadell, J. G., Sitch, S., Korsbakken, J. I., ... & Houghton, R. A. (2015). Global carbon budget 2015. Earth System Science Data, 7(2), 349-396.

Schimel, D. S., House, J. I., Hibbard, K. A., Bousquet, P., Ciais, P., Peylin, P., ... & Canadell, J. (2001). Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. Nature, 414(6860), 169-172.

Shaffer, G., Olsen, S. M., & Bjerrum, C. J. (2004). Ocean subsurface warming as a mechanism for coupling Dansgaard-Oeschger climate cycles and ice-rafting events. Geophysical Research Letters, 31(24).

Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M. M., Allen, S. K., Boschung, J., ... & Midgley, P. M. (2014). Climate Change 2013: The physical science basis. contribution of working group I to the fifth assessment report of IPCC the intergovernmental panel on climate change.

Taylor, J. A., & Lloyd, J. (1992). Sources and sinks of atmospheric CO2. Australian Journal of Botany, 40(5), 407-418.

United Nations Framework Convention on Climate Change, May 9, 1992, S. Treaty Doc No. 102-38, 1771 U.N.T.S. 107.

Yakir, D. (2011). The paper trail of the 13C of atmospheric CO2 since the industrial revolution period. Environmental Research Letters, 6(3), 034007.

Zapata Ceballos, H. A., Bustince, H., & Dimuro, G. P. (2020). Funciones t-migrativas t-overlap: una generalización de migratividad en funciones t-overlap. Revista Científica, 38(2), 184-189. https://doi.org/10.14483/23448350.15601

Zeebe, R. E. (2013). Time-dependent climate sensitivity and the legacy of anthropogenic greenhouse gas emissions. Proceedings of the National Academy of Sciences, 110(34), 13739-13744.

Zeebe, R. E., Ridgwell, A., & Zachos, J. C. (2016). Anthropogenic carbon release rate unprecedented during the past 66 million years. Nature Geoscience, 9(4), 325-329.

Zickfeld, K., Solomon, S., & Gilford, D. M. (2017). Centuries of thermal sea-level rise due to anthropogenic emissions of short-lived greenhouse gases. Proceedings of the National Academy of Sciences, 114(4), 657-662.