NTU – Department of Oceanography

Effects of economic growth on CO_2 emissions

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Abstract:

This study investigates the relationship between economic growth and CO2 emissions, challenging the historical assumption that increased prosperity directly leads to higher carbon emissions. Analyzing global CO2 per capita data for 2021, we observe diverse emission patterns across countries, revealing a nuanced interplay between wealth and environmental responsibility. Employing k-means clustering and principal component analysis, we identify distinct economic profiles and outlier nations such as Ireland, Luxembourg, Turkey, and Colombia. Pearson correlation coefficients further highlight varying impacts of economic indicators on CO2 emissions for selected countries. Notably, some nations demonstrate a decoupling of economic growth and carbon emissions, emphasizing the importance of sustainable development strategies.

Keywords: GDP per Capita, CO2 per Capita, CO_2 emissions, economic growth,

1. Introduction

In recent centuries, it was widely accepted that a country's economic growth was inextricably linked to the increase in its carbon dioxide (CO2) emissions. A direct relationship was established: the more prosperous a country became, the more its CO2 emissions increased, mainly due to the dependence on burning fossil fuels for energy production. However, since the 1990s, with the advent of nuclear and other alternative energy sources, many countries have managed to reduce their greenhouse gas emissions while maintaining sustained economic growth. This transition has accelerated over time, marked by the shift from carbon-intensive industries to the service sector, as well as the gradual substitution of fossil fuels for more sustainable and economically viable alternatives. This reflects a significant transformation in how countries reconcile economic growth and environmental responsibility.

We represented carbon emissions per capita globally in 2021, using data from the International Energy Agency. CO2 figures are expressed in tonnes per capita and refer to direct gross emissions from energy combustion only. Thus, carbon emissions from imports are not considered. We can make a first observation on a possible influence of the wealth of the population on CO2 emissions, indeed most of the countries of Africa which are among the least rich countries of the world emit less than 1 ton of CO2 per capita. At the extreme opposite of the Middle East countries can individually group more emissions than the whole of those from Africa. Among them are Kuwait, United Arab Emirates

and Qatar, which holds the record with 31.69 tons of CO2 per capita in 2021. Conversely, other nations manage to keep emissions levels relatively low, sometimes around the global average of around 4 tonnes per person. These countries often adopt policies focused on renewable energy, reducing dependence on fossil fuels, and promoting energy efficiency. This is particularly the case in some European countries such as France, Switzerland, Denmark, or the United Kingdom.

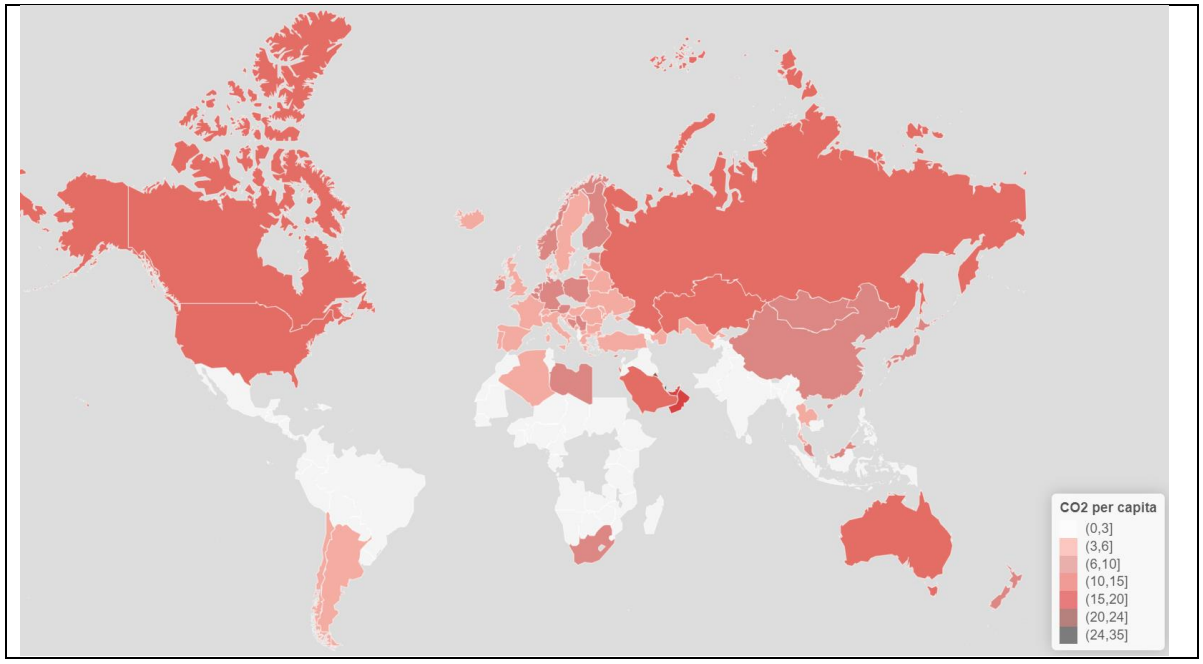


Fig.1 CO2 par habitant dans la monde

To best illustrate the influence of a country's wealth on these emissions we have plotted the GDP per Capita according to CO2 emissions per capita using a log scale. Countries are represented by points whose size increases in proportion to the country's GDP. There are a significant number of countries with low economies that emit very little CO2, represented by the mass of blue dots. Moreover, we can observe that most countries in the world emit less than 10 tons of CO2 per capita, while 4 countries emit more than 20 tons.

Finally, the most interesting observation is that many countries have a very large GDP per capita while maintaining a very low CO2 emission per capita < 5 tonnes/capita. If we draw a line at the level of Qatar, we can count 8 countries with GDP per capita higher than 66,838 dollars per capita at emissions < 15 tons per capita. These include Switzerland, Denmark and Iceland which have emissions below 5 t/hab, Ireland emits 6.71 t/hab, Norway 6.69 t/hab, and finally Luxembourg and the USA which emit more than 10 t/hab.

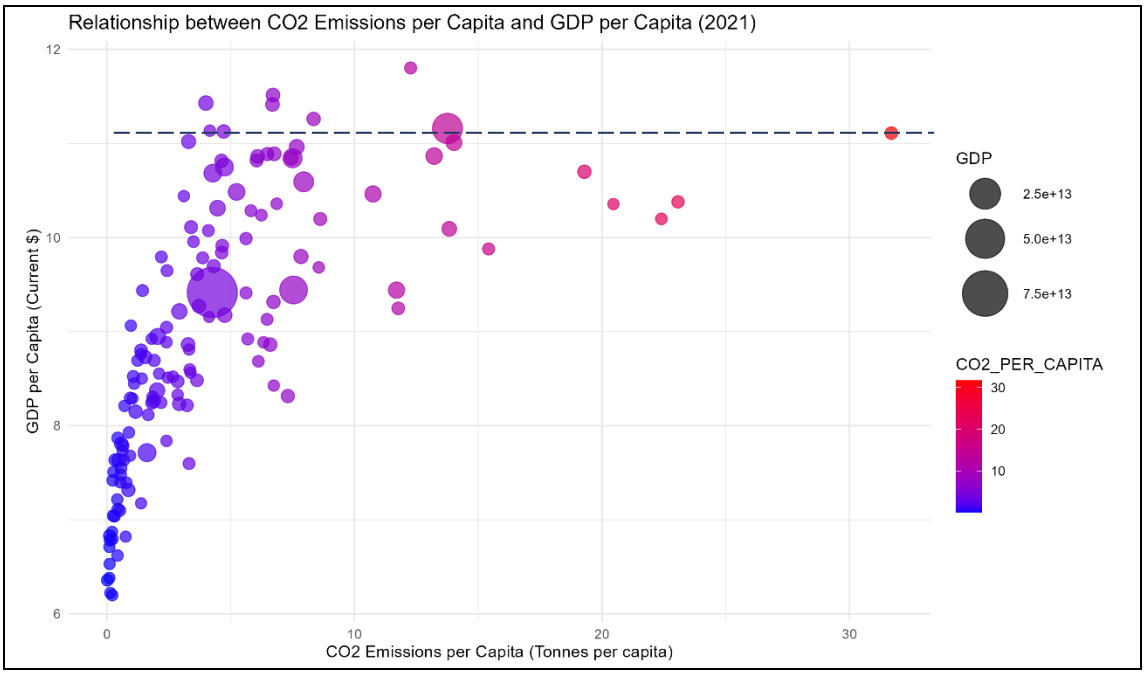
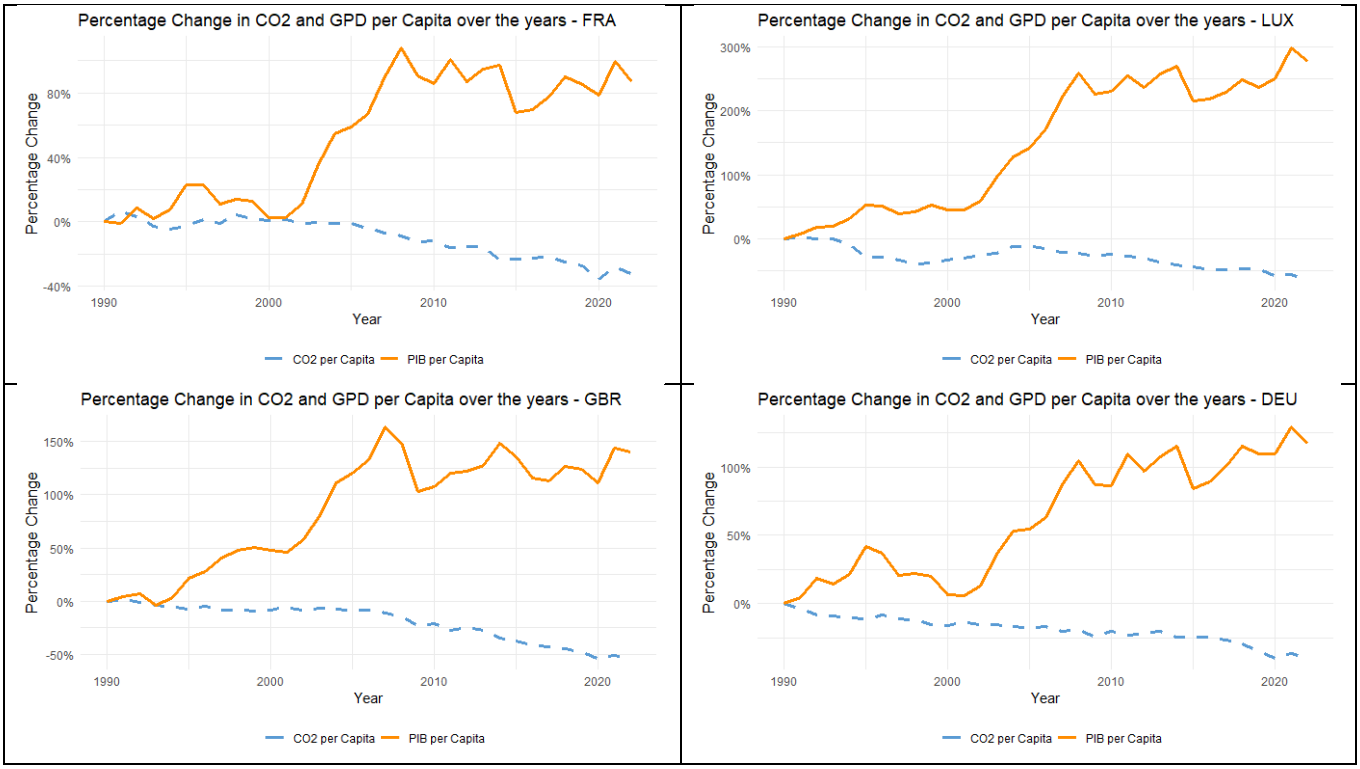


Fig.2 PIB et PIB par habitant en fonction des emissions de CO2 par habitant (échelle log)

Finally, we can illustrate over a longer period of time the evolution of GDP per capita and CO2 per capita for some countries and report the trend in the early 2000s of economic growth in some countries. The graphs show the percentage change over 1990. In the early 2000s, countries such as France, the United Kingdom and Germany experienced a very significant increase in GDP per capita, almost doubling the initial value in 1990, or even multiplying by 4 for Luxembourg. Countries such as Turkey and Saudi Arabia, which are also experiencing this boom, are unable to reconcile it with lower carbon emissions.



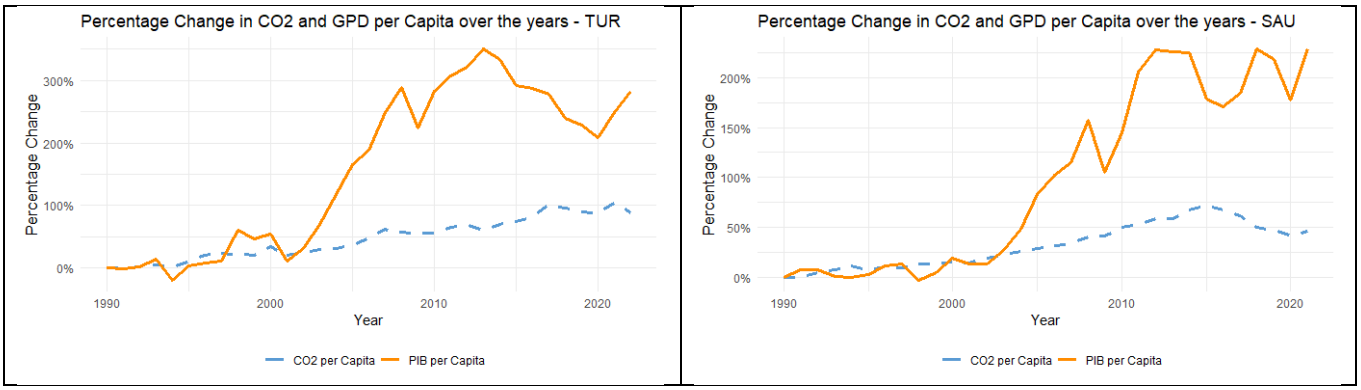


Fig.3 Evolution du CO2 par habitant et PIB par habitant de 1990 à 2021

2. Materials and Methods

In this study we will use several indicators of economic development to explain a potential link with CO2 emissions.

- CO2 PER CAPITA: CO2 refers to gross direct emissions from fuel combustion only, expressed in tonnes per Capita.

The goal is for these indicators to be relevant enough to explain a country's economic growth. The list of economic factors used are:

- GDP PER CAPITA (GDP_PER_CAPITA): GDP per capita in current dollar.
- IMPORTS (IMP) & EXPORTS (EXP): Import and export of goods and services between residents and non-residents expressed as % of GDP.
- HDI (HDI): Human development index expressed by a score between 0 and 1.
- FOOD (FOOD) & ENERGY (ENRG) INFLATION: Food and energy inflation as measured by the Consumer Price Index (CPI) expressed as an index.
- INDUSTRIAL PRODUCTION (INDUSTRY_GROWTH): Production of industrial entities and covers sectors such as mining, manufacturing, electricity, gas and water and air conditioning. Expressed as "an index that expresses changes in production volume over a reference period."
- PRICE LEVEL INDEX (PRICE_LEVEL): Ratios of purchasing power parities to market exchange rates.

The selection of these indices resulted in a significant reduction in the number of countries in which the study was conducted, due to the unavailability of data for the missing countries. The first stage of the analysis was therefore carried out on a total of 35 countries.

The first part of our analysis is to assess the similarity of countries' economic profiles in 2021. To this end, we applied the k-means algorithm to cluster countries according to several economic indicators. To do so, we standardized these indicators to ensure comparable scales, then used a Bartlett test to see if our data are suitable for a technical data reduction like PCA that we used. Finally, the Average Silhouette method allowed us to determine the optimal number of clusters.

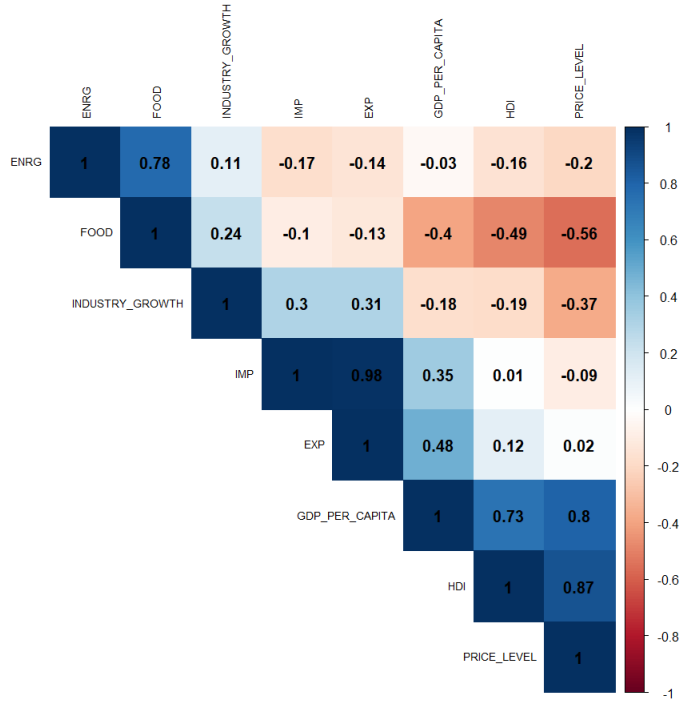
Then we chose countries belonging to the same cluster and analyzed for each of them the importance or not of these economic indicators on CO2 emissions per capita. We have chosen to study the influence over the widest possible period from 2021, which may vary from country to country. We looked at the correlations between the different indicators and finally concluded on the impact of economic growth on CO2 emissions for the selected countries. We also conduct a case study on a selected country to assess the linear relationship between the CO2 emissions and his economic growth

3. Results

The correlation matrix of standardized indicators shows a strong positive correlation (> 80%) between the price level index and the human development index as well as per capita GDP. The result is not surprising since the HDI is an indicator obtained by considering the purchasing power of the inhabitants. Thus, for the 35 countries studied, it seems that the financial capacity of their inhabitants is strongly linked to market exchange rates.

Inflation in energy and food prices seems to be proportional from one country to another, the same for the share of imports and exports in relation to the country's GDP.

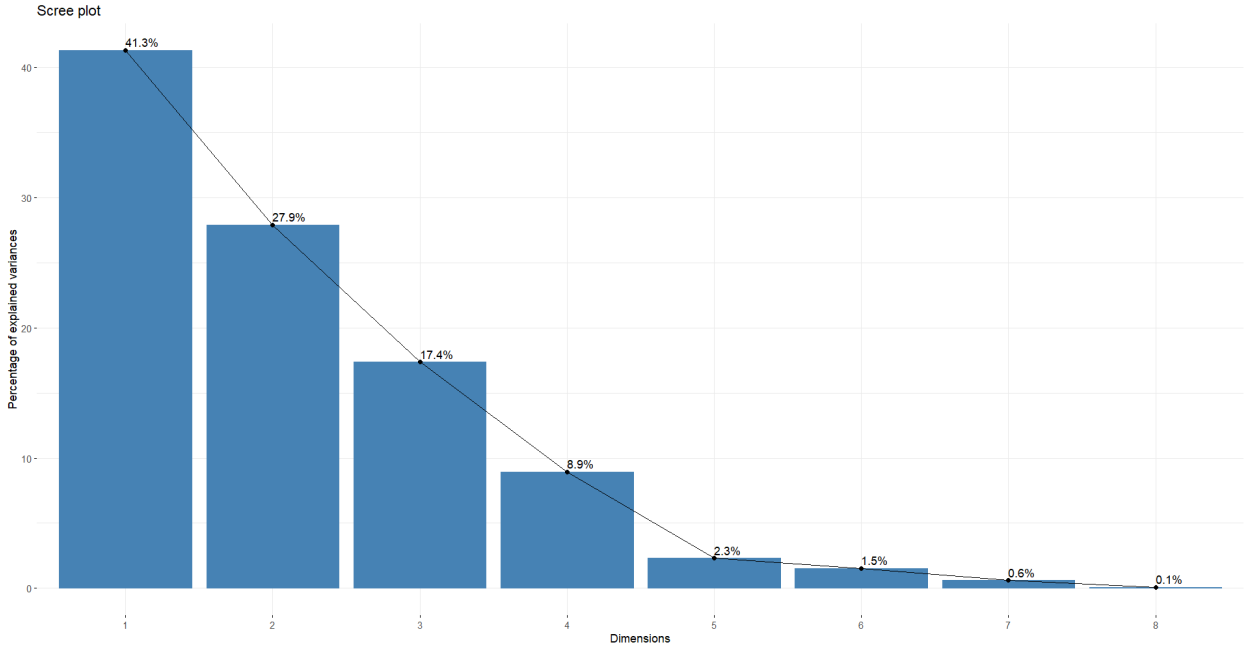
Finally, if the level of food inflation in a country is high, the price level index seems to decrease.



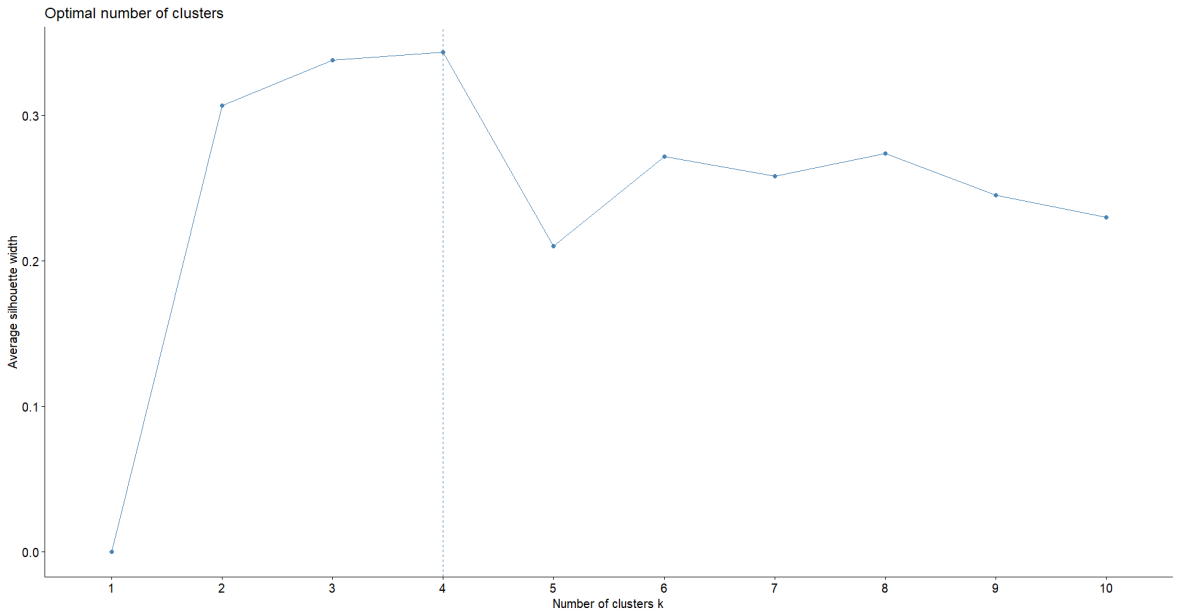
The Bartlett test on the matrix gives a p-value of 9.31886e-49, we can then reject the null hypothesis that it is like an identity matrix, i.e the variables are not correlated. So, the eight indicators in our dataset are fairly correlated so a PCA would not have a hard time compressing these variables into linear combinations that are able to capture significant variance present in the data.

The eigenvalues of the matrix and their respective proportion indicate that the first two main components would explain 69.2% of the variance of our data, it is considered to be a significant part

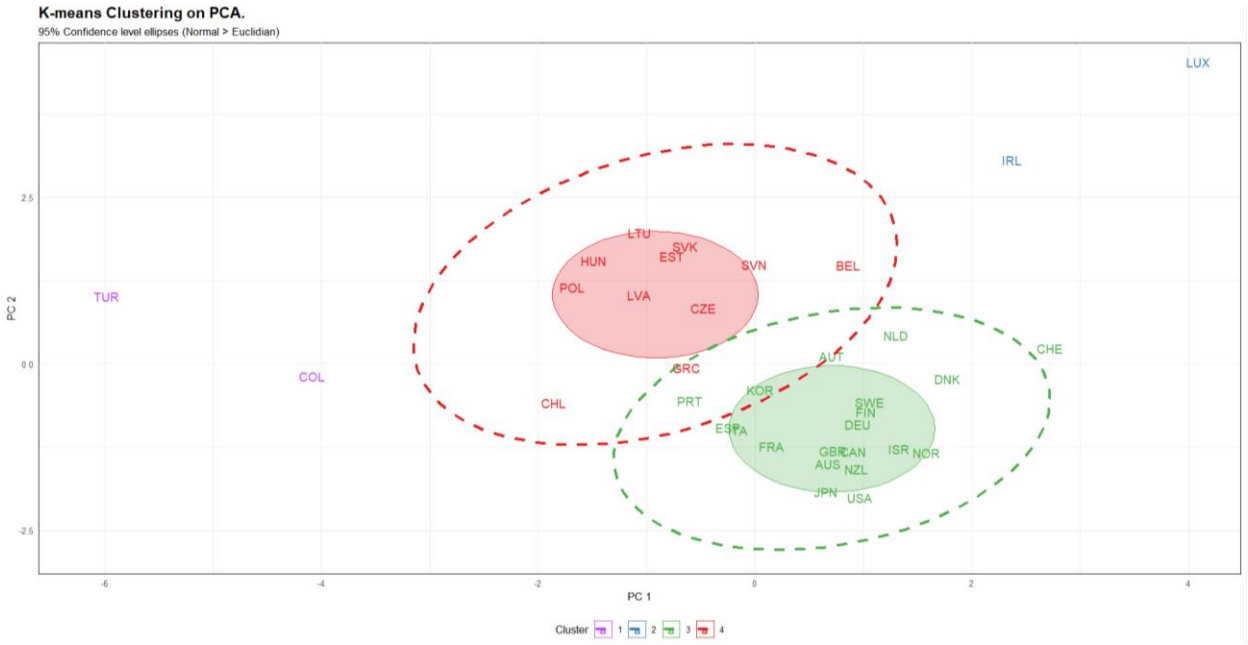
to represent most of the variability of economic indicators across countries.



Then we need to determine the optimal cluster number for our data. Here the average silhouette method indicates that the appropriate choice would be 4 clusters.



We then applied principal component analysis (PCA) to reduce the dimensionality of our data and visualize the clustering structure using the Kmeans algorithm. The ellipses surrounding the points represent 95% confidence intervals for each cluster, with filled ones based on Euclidean distance, and dotted contours based on a multivariate normal distribution.



Among the 35 countries studied, 4 countries differ drastically from the rest: Ireland, Luxembourg, Turkey and Colombia. The latter two have a pronounced negative value for the first main component. Using the table of scores for each variable for PC1 and PC2, it is observed that HDI, GDP per Capita and the Price Level Index contribute significantly positively to PC1. Thus, one can think that Turkey and Colombia are countries where the wealth of the inhabitants is extremely less compared to those of Ireland and Luxembourg.

Luxembourg and Ireland have a high PC1 and PC 2 value, indicating that the inhabitants of these countries have a very high purchasing power, and that a lot of money grows through the exchange of goods and services with other countries, between residents and non-residents. The significance of the value of international trade as a percentage of GDP between residents and non-residents is very complex and is not detailed in this work.

The first red cluster is composed of Latvia, Poland, Hungary, Czech Republic, Estonia, Lithuania, Slovenia, and Slovakia in an Euclidean distance, Belgium, Chile and Greece still following a normal distribution with the countries within. Apart from Chile, all these countries belong to Europe and share a certain geographical proximity, especially for the countries in the Euclidean ellipse.

For the second green cluster, we observe that Switzerland stands out significantly from the group to the point of almost belonging to the blue cluster. The result indicates that Switzerland seems to be a country where the population is in a comfortable economic situation, as may be the inhabitants of Ireland or Luxembourg. But its limited attachment to the green cluster shows that trade with other countries is not a significant part of its GDP. The countries of the green cluster generally seem to have a more prosperous economic profile, where international trade in goods and services is less important than that of the green cluster. Finally, we observe that countries like Canada, Australia and United Kingdom have a significant proximity despite a lesser geographical proximity compared to the Scandinavian countries of the red cluster.

	PC1	PC2
ENERGY INFLATION	**-0.6626**	**-0.02112**
FOOD INFLATION	**-1.0872**	**0.18900**
EXPORTATION	**0.5552**	**1.29941**
IMPORTATION	**0.4202**	**1.32767**
HDI	**1.2037**	**-0.29810**
INDUSTRY GROWTH	**-0.4111**	**0.85594**
PRICE LEVEL INDEX	**1.2552**	**-0.50044**
GDP PER CAPITA	**1.2307**	**0.20400**

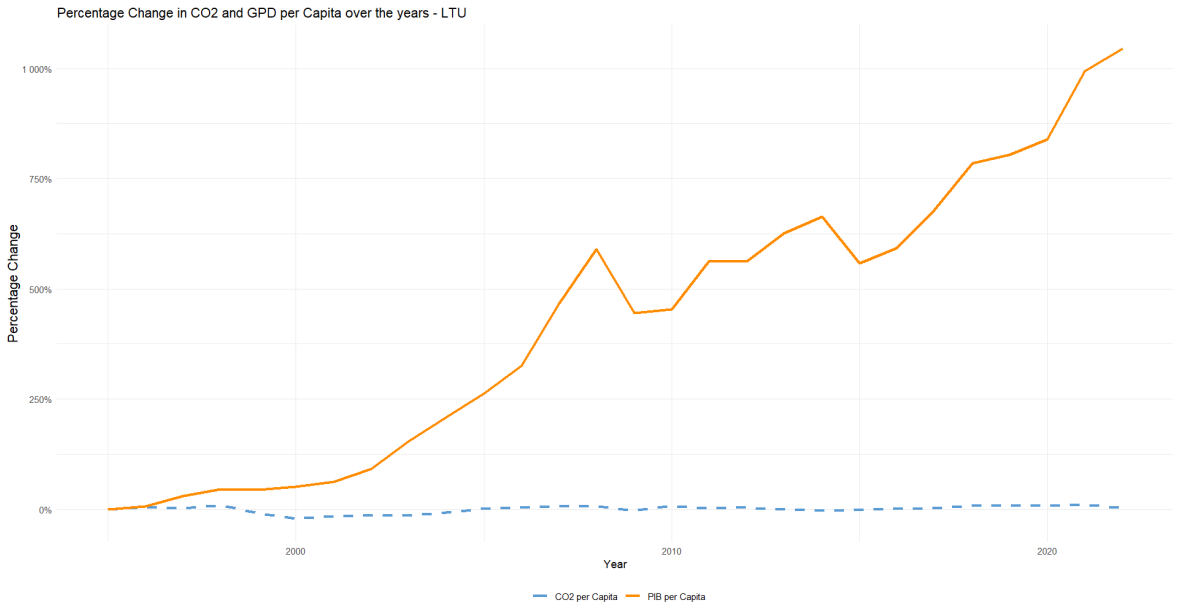
For the rest of the study, we select some countries close to the red and green cluster. The countries selected for each cluster are close enough to consider a similar economic profile, the groups are composed of Slovenia, Estonia and Lithuania for the red cluster, Australia, Canada, and United Kingdom for the green cluster. In addition, we will look at France, which is one of the countries mentioned in the introduction, which has been able to reduce their emissions while maintaining strong GDP growth. Now we look at the Pearson correlation coefficient between the evolution of CO2 per capita with that of the chosen economic indicators, between 1990 and 2021. A rating is given for countries according to whether their economic growth has a positive impact on reducing CO2 emissions.

COUNTRY	**IMP**	**EXP**	**HDI**	**GDP PER CAPITA**	**FOOD**	**ENRG**	**INDUSTRY GROWTH**	**NOTE**
AUSTRALIA	**0.65**	-0.1	-0.01	-0.1	-0.09	-0.29	-0.2	**
CANADA	**0.46**	**0.65**	-0.15	-0.15	-0.36	-0.15	0.21	**
UK	-0.82	-0.86	-0.84	-0.67	-0.94	-0.92	-0.46	***
SLOVAKIA	-0.83	-0.87	-0.93	-0.88	-0.96	-0.88	-0.92	***
ESTONIA	0.22	0.14	-0.13	-0.26	0.3	-0.18	-0.31	**
LITHUANIA	**0.69**	**0.62**	**0.61**	**0.7**	**0.64**	**0.54**	**0.72**	*
FRANCE	-0.8	-0.68	-0.85	-0.77	-0.91	-0.92	0.05	***
TÜRKIYE	**0.91**	**0.76**	**0.96**	**0.83**	**0.91**	**0.94**	**0.97**	*
LUXEMBOURG	-0.76	-0.76	-0.74	-0.6	-0.74	-0.55	-0.27	***

Fig.Pearson correlation coefficient between CO2 per Capita and the economics indicators

The bold coefficients, above 0.5, indicate a high correlation between CO2 emissions and indicators. It is observed that although some share a similar current economic model, some have managed to reduce their emissions while increasing all their economic indicators such as Slovakia and United Kingdom.

Countries like Lithuania and Turkey have known the exact opposite, these less developed countries than those mentioned above have used CO2 consumption to succeed in significantly increasing their GDP per capita, as observed for Turkey in introduction. Yet Lithuania has not seen the same evolution as Turkey. It has multiplied its GDP per capita by more than 10x while maintaining a rather stable CO2 level per capita not exceeding 10%. Thus, despite a strong positive correlation, economic growth is not necessarily synonymous with an increase in CO2 emissions.



Finally, we are interested in the possible linear relationship between economic growth and CO2 emissions for Turkey. We create a multivariable linear regression model, by evaluating the multicollinearities by the Variance Inflation Factors (VIFs). We adopted a tolerance of VIF < 10 for the model.

	ESTIMATE	**STD. ERROR**	**P VALUE**
(INTERCEPT)	2.073e-16	5.170e-02	1.000
EXP	9.866e-02	1.001e-01	0.334
HDI	7.726e-0.1	1.628e-01	7.94e-05
GDP_PER_CAPITA	1.375e-01	1.157e-01	0.246

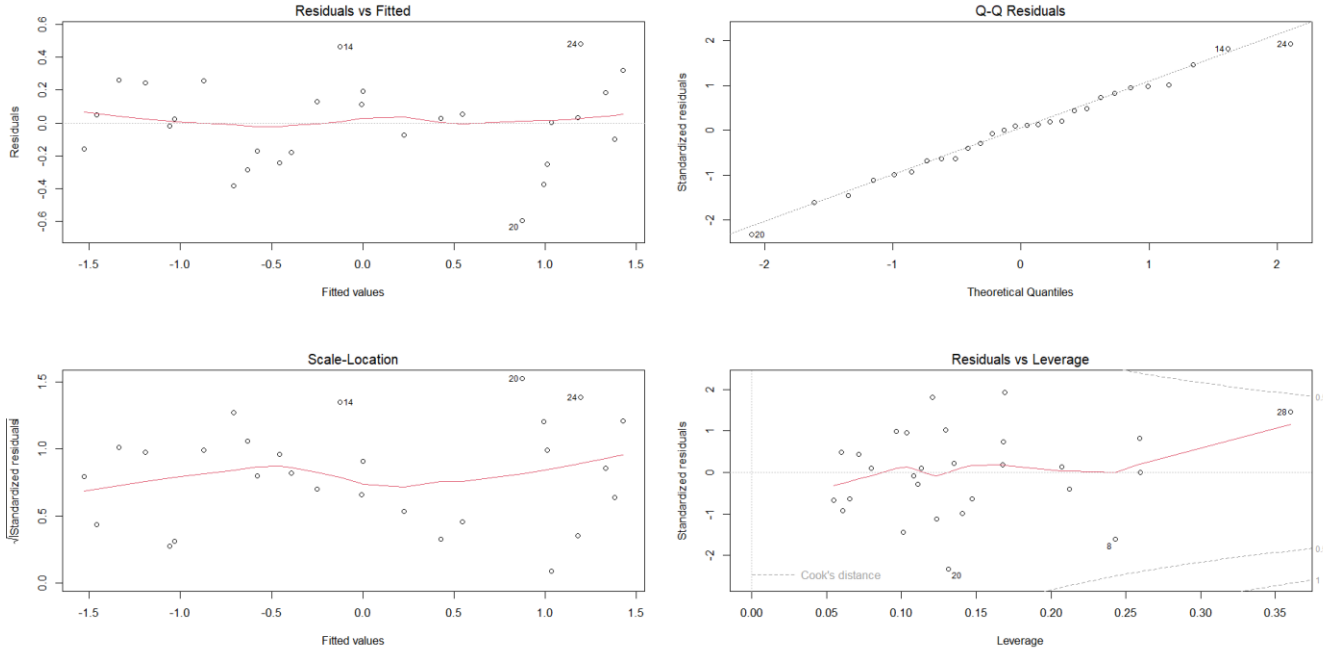
By removing indicators with VIFs values above 10, we end up with a model where CO2 per capita is predicted by the value of exports in % of GDP, the human development index, and GDP per capita in current dollars.

The Multiple R-Squared value is 0.9335 which is a good score for our model, 93.35% of the CO2 variance is explained by the independent variables. The F-statistic is 112.3, with a p-value of 2.932e-14, indicating the overall significance of the model.

For variables, each increase of one unit in the HDI is associated with an increase of about 0.773 units in the CO2 dependent variable. This coefficient is statistically significant with a very low p-value (7.94e-05), indicating a significant relationship between HDI and CO2.

TESTS	P-VALUE
SHAPIRO-WILK	0.9678
BREUSCH-PAGAN	0.5828

According to the Shapiro-Wilk test, the residuals of our model seem to have a normal distribution. The Breush-Pagan test indicates that one can accept the null hypothese homoscedasticity, the residuals are distributed with an equal variance.



The Residuals vs Leverage chart indicates that observations #28, #8 and #20 to some extents are close to the Cook line but remain below 0.5. This suggests a moderate influence of these observations on the model, but they are not necessarily major influence points.

For the left-side plots, the residuals seem to "bounce randomly" around the 0 line. This suggests that the assumption that the relationship is linear is reasonable. The residuals roughly form a "horizontal band" around the 0 line. This suggests that the variances of the error terms are equal.

Finally residuals #14 and #24 "stand out" from the basic random pattern of residuals, and residuals #14 #20 and #24 for the squared standardized residuals. High squared residuals values may indicate outlier points or outliers that have a significant influence on our model.

The model seems to perform well in explaining the variance of the CO2 variable in Turkey using the chosen explanatory variables: EXP, HDI & GDP per Capita. However, the presence of influential observations suggests that it may be useful to examine these points more closely to determine whether they represent specific cases that require special attention.

4. Conclusion

In conclusion, our study challenges the traditional correlation between economic growth and CO2 emissions by revealing nuanced patterns and divergent trajectories among nations. The identified outlier countries, including Ireland, Luxembourg, Turkey, and Colombia, emphasize the need for nuanced policy approaches. While some countries exhibit a positive correlation between economic indicators and carbon emissions, others, notably the United Kingdom and Slovakia, demonstrate successful decoupling. This highlights the potential for sustainable development strategies to mitigate environmental impact while fostering economic growth. The findings underscore the importance of tailored policies that consider the unique economic and environmental contexts of individual nations in the pursuit of a greener, more sustainable future.

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