# How do levels of carbon emissions impact the sustainability and success of a country?

BTMA 431 Fall L01

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## Introduction

*Overview & Background*

Climate change and its impact on sustainability has been a major topic and in recent years it has become one of the most important issues around the world. For study purposes, we focused on carbon dioxide (CO2) emissions since it makes up the vast majority of greenhouse gas emissions from the burning of fossil fuels like coal, oil, and natural gas (EPA, 2021). The gas also has the ability to trap solar energy in a process known as the greenhouse effect which raises average temperature of the atmosphere. (Nunez, 2019). We wanted to explore how the level of CO2 emissions of a country impacts their level of sustainability and success. We selected Gross Domestic Product (GDP) as an economic success measure, and happiness and life expectancy levels as social success measures. For question one, we conducted tests to find if emissions have an impact on GDP. Previous research has expressed that there is a definitive relationship between carbon emissions and GDP, as one analysis by Kasperowicz says "causality runs from energy consumption to CO2 emissions, GDP is responsible for the increase in energy consumption, and there is strong causality between GDP and CO2 emissions over the long run in developed countries" (Kasperowicz, 2015). For the second question, we investigated whether we are able to find a relationship between carbon emission and different factors of social sustainability. We explored life expectancy and happiness levels and formulated hypotheses around statistics we collected about the negative impacts of carbon emission. For question three we asked ourselves if stronger policies regarding emissions and targets (such as net-zero targets) led to a decrease in emissions and used the outcome to measure sustainability. It is not an uncommon notion that governments can be successful when it comes to enacting policy, but then fail when it comes to initiating the change associated with it (Mueller, 2020). The term “posturing” is often associated with this state. We wanted to evaluate if there is posturing taking place with relation to certain countries.

Overall, we wanted to analyze the current situation in regards to how these success measures interact with carbon emissions and if there were any significant or non-existent relationships. Claims have been made that over time the net benefits of reducing emissions will show up in economic prosperity and life expectancy (WHR, 2020). The majority of countries around the world are now committed in their efforts to combat environmental consequences of carbon emission. This intuition led our group to head into the research with the belief that there are significant relationships between carbon emission and exploratory factors like GDP, life expectancy, happiness levels and sustainability.

## Methodology

*Data collection & Sources*

Our overall data collection method includes three different processes to attain the necessary data required to answer our questions. We first came up with hypotheses and focused on which datasets we needed to attain in order to perform tests. After this process, we found six different sources that contained all the tables and datasets we needed. We found a dataset on GitHub containing historical emissions by country, which was the key dataset as it is used to perform our statistical tests for every question. For question one, we found a dataset from The World Bank website containing historical GDP values for every country. We then discovered a table from the Food and Agriculture Organization of the United Nations (FAO) website containing all 195 countries and their corresponding ISO3 codes. For our second question, we needed two data sets to perform our statistical tests. Firstly, we used a dataset from the Our

World in Data website that contained historical life expectancy for each country. Secondly, we found an Excel file from the World Happiness Report website that contained a happiness score out of 10 for each country. For our third question, we found a relevant table in a PDF from the CCPI website. After we had found the six different sources needed to answer our questions, we began our data collection process.

The first step was to scrape a table from the FAO website that contained a list of all 195 countries in the world and their corresponding ISO3 codes. We needed this table in order to filter our other datasets to include only every country, instead of countries and regions. It was necessary to install the “tidyverse” and “rvest” packages and once that was done, we proceeded with our data scrape (*Appendix D*). This resulted in the storage of a data frame called “country_list_table”. We then used two different methods to download the other data sets. To collect our emissions data, we stored the GitHub URL containing the data in a variable and then used the “read.csv()” function to store the data in the global environment. For the gross domestic product data, life expectancy data, and happiness level data we downloaded CSV or XLSX files directly from the source, stored it in the working directory that we set, and loaded it into variables using either the “read.csv()” function or the “read_excel()” function. Then, for our Climate Policy Scores data, we copied the data from the PDF file containing results on the Climate Change Performance Index website into a CSV file, and imported that using “read.csv()” once again. Once we had all of our data loaded in we had to perform some necessary cleaning. As mentioned before, the Emissions data set and the GDP data set both included more than 195 rows, as there were regions in addition to countries. To attain only the 195 rows needed, we filtered each dataset using the ISO3 codes stored in the “country_list_table”. We then removed all NA values in every dataset using the “na.omit()”

function. In addition to that cleaning, we also had to transform the datatables to include only the necessary columns and once this was done, we made use of the “merge()” function to combine data frames by their corresponding ISO3 code columns or country name columns. After all the previous steps mentioned were complete, we had the properly formatted data frames that we needed to perform our statistical tests.

*Question 1: Does the level of carbon emissions that a country emits significantly impact the GDP of that given country?*

We asked this question because GDP is an important measurement that is used to determine a country’s economic output. A country with a higher GDP will also generally have a higher standard of living (Fernando, 2021). We wanted to explore how a country’s level of carbon emission impacts the GDP of that country, and if this impact is significant. Our null hypothesis was that a country’s level of carbon emissions does not significantly impact the GDP of the given country and our alternative hypothesis was that a country’s level of carbon emissions does significantly impact the GDP of the given country. The reasoning behind our alternative hypothesis is that globally, the primary sources of greenhouse gas emissions were electricity and heat (31%), agriculture (11%), transportation (15%), forestry (6%) and manufacturing (12%) according to data from 2013 (World Resources Institute, 2017). Using intuition, we recognized that these sectors have a direct effect on the economic output of a country. If we were to think of a factory, the more goods it manufactures would require the use of more electricity and heat. The factory will also require more materials that come from forestry or agriculture processes and increased levels of transportation to deliver the materials. This process would increase the level of carbon emissions that the factory produces. In turn, the increase of production adds to the increase of GDP for the country where the factory is located. We tested our intuitive alternate hypothesis using a regression model to evaluate the significance emissions may have on GDP. Total emissions in gigatonnes (GT) of a country is the variable we used to see if it has a significant impact on total yearly GDP in USD billions of a country which is the dependent variable, or in this case more accurately the outcome variable. For statistical test purposes, we assumed that emissions acts as a predictor variable rather than an independent variable in the regression model in order to return a p-value, since we cannot confirm that emissions are completely independent. The regression summary gives us the value of 108296330586 for the intercept, and 1854370000 for the coefficient of emissions which was used to create a regression equation for our follow-up question. The p-value was 2.2e-16 which indicated that a country's emissions is a significant predictor for GDP. With the findings we rejected our null hypothesis and accepted the alternative hypothesis, concluding that a country's level of carbon emissions does significantly impact the GDP of the given country.

*Follow up to Question 1: Should we use the level of carbon emissions that a country emits to accurately predict the GDP of that given country?*

With the conclusion from question one that emissions are a significant predictor for GDP, we wanted to explore further to see if there is a direct cause and effect relationship between emissions and GDP. Specifically, we want to rule on if emissions could be an independent variable for GDP. Our null hypothesis is that we should not use the level of carbon emissions that a country emits to accurately predict the GDP of that given country and our alternative hypothesis is that we should use the level of carbon emissions that a country emits to accurately predict the GDP of that given country. The reasoning behind our alternative hypothesis was that the p-value from question one was extremely low at 2.2e-16. This made us wonder if emissions could account for the majority of GDP. In order to test our alternative hypothesis, we used the intercept and coefficient value for emissions from our regression model stated above in order to create an equation that we applied to the year 2019 total emissions (GT) and predicted the same year's total GDP value in USD. Then we ran a t-test between the predicted values for GDP 2019 and actual values for GDP 2019. The t-test itself had the null hypothesis that the means are equal, and the alternative hypothesis that the means are not equal. The result of the t-test was a p-value of 0.9716 which was much higher than 0.05. We failed to reject the null hypothesis of the t-test. This can be interpreted to our own hypothesis to reject the null and conclude that yes, we can use emissions values to predict GDP.

*Question 2: Does the level of emission per country impact its citizens life expectancy?*

The United Nations definition of social sustainability is about identifying and managing a country's business impact, both positive and negative, on its people (United Nations, 2021). This led us to question whether or not the social sustainability of a country, through its impact of carbon emission levels, influences their citizens quality of life. It has been discussed by a number of scholars that human health has been linked to economic growth and air pollution (Manisalidis, 2020). Researching the cause of carbon emissions on the social wellbeing of countries left us questioning how much does it actually impact their citizens and are we able to quantify it ? To compare carbon emission levels to a segment of a citizen's quality of life, we decided to take a look into life expectancies. This posed a question, *do emission levels impact the life expectancy of a country?* Collecting data from Our in World Data, we were able to merge the carbon emission data with the life expectancy values of 2018 in order to create a final table to model with.

To understand the relationship between life expectancy and carbon emission, we created a regression model to indicate if our dependent variable, life expectancy, was impacted by an independent variable (CO2 emission). However, we did not assume that emission levels are the sole predictor of life expectancy, but more of an influence. To build the model, we set our null hypothesis to be no, the emission levels do not impact a citizen's life expectancy. Our alternative was set to be yes, emission levels do impact a citizen's life expectancy. The reasoning behind our alternative hypothesis is based on how life expectancy is calculated. According to Our World in Data, life expectancy is calculated by taking a group of individuals who are born in the same year and averaging out the time they all passed away (World Data, 2017). When we look at studies done in 2017, 1.2 million people died due to air pollution in China alone (E.Wong, 2013). Intuitively, we assumed that the average would be skewed by deaths related to emission levels after understanding how life expectancy is calculated and how many citizens die due to its impact. If emission levels were to increase and environmental consequences worsen, this could decrease the lifespan of citizens.

The regression model calculated a p-value of 0.111, and we failed to reject the null hypothesis as the value is greater than 0.05. The model indicated that CO2 levels do not impact the life expectancy of its citizens. This finding was shocking as we were nearly certain that there would be a significant impact based on our intuition and research that was done prior to the test. The results left us questioning if there are other aspects that may impact the life expectancy of citizens aside from just carbon emission levels.

*Follow up to Question 2: Does carbon emission impact the happiness index of its citzens?*

Since we were not able to conclude that carbon emissions were able to impact life expectancy, we decided to take the analysis one step further to understand if there are other social success factors that are impacted by carbon emission. The World's Happiness Index seemed to be a relevant factor that we decided to select. The World Happiness Index (WHI) report ranks 156 countries by their happiness levels calculated by factors like income, social support, freedom, and trust which are all provided by the country they live in (F. Helliwell, 2018). We wanted to question if the WHI report reflects the negative impact on the happiness of citizens caused by carbon emissions. We extracted the data that was collected from 2018 and  merged the data with the carbon emissions data to create our model.

We set our dependent variable to be happiness level and our independent variable to be CO2 levels. Our null hypothesis was that carbon emission does not impact the happiness index of its citizens. Alternatively our hypothesis is that yes, carbon emission does impact the happiness index of its citizens, The reasoning behind our hypothesis stems from a logical standpoint. The Happiness Index must have multiple factors that influence the values to be higher or lower. Countries with cleaner water, air and social prosperity may be more well off, and in result be happier than other countries without. The regression model is to see how happy citizens are in parallel to the country's carbon emission level and if it is enough of an influence to accurately quantify its impacts on their score.

Prior to setting up our model, we created a plot to visualize whether the relationship between carbon emission and happiness levels was linear and to our surprise, it was not (Appendix A). The regression model also calculated a p-value of 0.3714. We failed to reject the null hypothesis because the p-value is greater than 0.05. The model indicated that carbon emissions do not impact a countrys' happiness levels In conclusion, carbon emissions do not impact the factors that measure the social success of its country. In order to measure the true impact, it would be a good option to add in other factors such as GDP or measures of sustainability for further research.

*Question 3: Does a country's improvement in emission levels correlate to their communicated net-zero targets?*

Given the ongoing climate crisis, we determined that it was necessary to analyze the actual measures implemented to decrease emission. Specifically, we wanted to explore how countries' communicated targets regarding carbon emissions correlate with actual carbon emissions produced by that country. Because targets are announced at different points and it can take time to perceive a meaningful impact, we used a start year of 2002. The significance of this year was that the Kyoto Protocol was ratified by the European Union, meaning many countries had emission reduction targets at this point (Britannica, 2021).

To determine the strength and impact of restrictions put into place, and thus comparing them among countries, we used the Climate Policy Score from the United Nations Climate Change Performance Index. This is a measure of the national and international policy among 60 countries to reduce emissions, where each country is scored (Climate Change Performance Index, n.d.). The better the policy aims to reduce emissions, the higher score a country will receive. We compared this score with the country's observed decrease in $CO_2$ emissions to determine how effective their reduction measures actually were.

Our null hypothesis was that a country's Climate Policy Score does not significantly impact the emissions of that country, and our alternative hypothesis was that a country's Climate Policy Score does significantly impact the country's emissions. The reasoning for our alternative hypothesis was that we wanted to determine if a country's target level regarding emissions is effective and if it leads to a meaningful change in carbon emission. With intuition we assumed that countries with higher scores should see a proportionate decrease in carbon emissions levels. We created a linear regression model with a confidence interval of 95%. Our independent variable for the test was the emission reduction measures of a country. Specifically, their Climate Policy Score. The dependent variable of our test was the percentage difference in emissions between the years 2020 and 2002.

We received a coefficient of -0.02432 for Climate Policy Score and a p-value of 0.04702. Due to a $p\text{-value} < 0.05$, we accepted the alternative hypothesis and concluded that a country's Climate Policy Score does significantly impact its carbon emissions.

*Follow up: Given the rankings of countries based on Climate Policy Rating, do these rankings change when factoring in actual decrease in emissions?*

We have highlighted that the Climate Policy Score is a relative measure of a country's action against climate change. A country's ranking is based on how high their Climate Policy Score is. That being said, it does not account for a country's actual change in its overall emissions levels. Given that we saw a significant impact of Climate Policy Scores on carbon emission levels, we wanted to see if incorporating the actual change in emissions would influence a country's relative ranking. To do so, we conducted a hypothesis test with the null hypothesis that incorporating the actual decrease in emissions will not result in a difference of median between the two rankings. The alternative hypothesis was then that incorporating the actual decrease in emissions will result in a difference of median between the two rankings. We created the measure by subtracting the percentage difference in carbon emissions from 2002 - 2020 from the Climate Policy Score as a percentage. This was to benefit countries that have been able to reduce their emissions and hinder those who have not. We used a Wilcoxon signed-rank test to conduct this test. This test resulted in a p-value of 0.887, thus we failed to reject the null hypothesis and concluded that this change in measure does not significantly change the countries rankings. Regardless, we wanted to analyze the position of the countries moving forward using this measure. We determined that the best country as a result of this process was Denmark and the worst was Vietnam, meaning both the best and worst countries based on Climate Policy Score alone changed when implementing our new measure (they were previously Luxembourg and Australia). Vietnam was also a particularly interesting datapoint given that it dropped 20 spots to land in last place. The largest drop came from India, that fell 34 positions when including the actual change in emissions over those 18 years. Our interpretation of these changes was that although there is a correlation between having strong measures against carbon emissions and actually achieving a change in carbon emissions, this does not tell the full story as some countries will experience a more positive (Denmark) or negative (Vietnam) change than was warranted according to their Climate Policy Score.

The regression performed for our main question did prove that there is a negative correlation between a high Climate Policy Score and the percentage difference in emissions between 2020 and 2002. This speaks to the idea that countries are following up their climate policies with real actions. We did find in our sub question that this was not necessarily the case for all countries. Our method to measure which incorporated the policy score and the reduction in emissions, demonstrated that certain nations are outliers as some outperformed their policy stances in some cases, and largely underperformed in others.

## Conclusion

*Results*

In completing our research we were able to obtain the following results from our questions and sub-questions. First of all for question one, we found that increasing emissions resulted in a net increase in overall economic performance. We followed up this insight with a sub question that evaluated whether emissions levels could be used as a predictor of GDP, and this was true. In our second question we found that there was no connection between emission levels and either life expectancy or happiness level for a country. Finally, our third question evaluated if a country's overall climate policy has led to a change in emissions. We did find that this was the case.

*Discussion*

Aside from making a determination on whether or not emission reductions are truly impacting climate change, our findings on the overall benefits for countries were not as we expected. In relation to GDP and economic advancement, we found that countries who have seen an increase in emissions over time have also seen an increase in GDP. We also found that overall life expectancy and level of happiness are not impacted by changes in emissions.

In analyzing these results, our group formed several insights. The first being that from an economic point of view, sustainability objectives have actually been harmful to development. We believe that there could be multiple reasons for this. First of all, it could be too early to judge whether investments in sustainability today have fully paid off. We would be interested to re-evaluate the data years into the future, and still see if this is the case. Also, much of the investment today is being made in areas that are still unproven. This is especially the case in developed countries which have the means to invest in the future and give up short term development.

As for life expectancy and happiness levels, it did make sense to us that we weren't able to make a connection. Broadly speaking, advancements in medicine and nutrition have led to an increase across the world, regardless of a country's level of emissions. The idea of emission reductions is also something that is hard to actually "see", and therefore may not be a factor in citizens' happiness. As time goes on, emissions may become more of a factor in both these areas, so we see the opportunity to conduct a similar investigation years into the future.

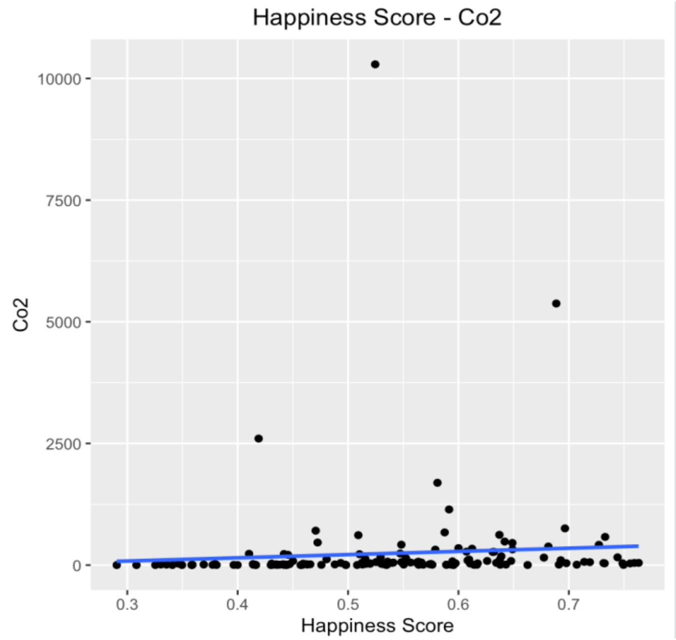
As our final question demonstrated, there is no doubt that countries are not only paying attention to the topic of emissions, but actually acting on the policies they have set forth. Climate policy will continue to be a focus on the international stage going forward.

*Future Research*

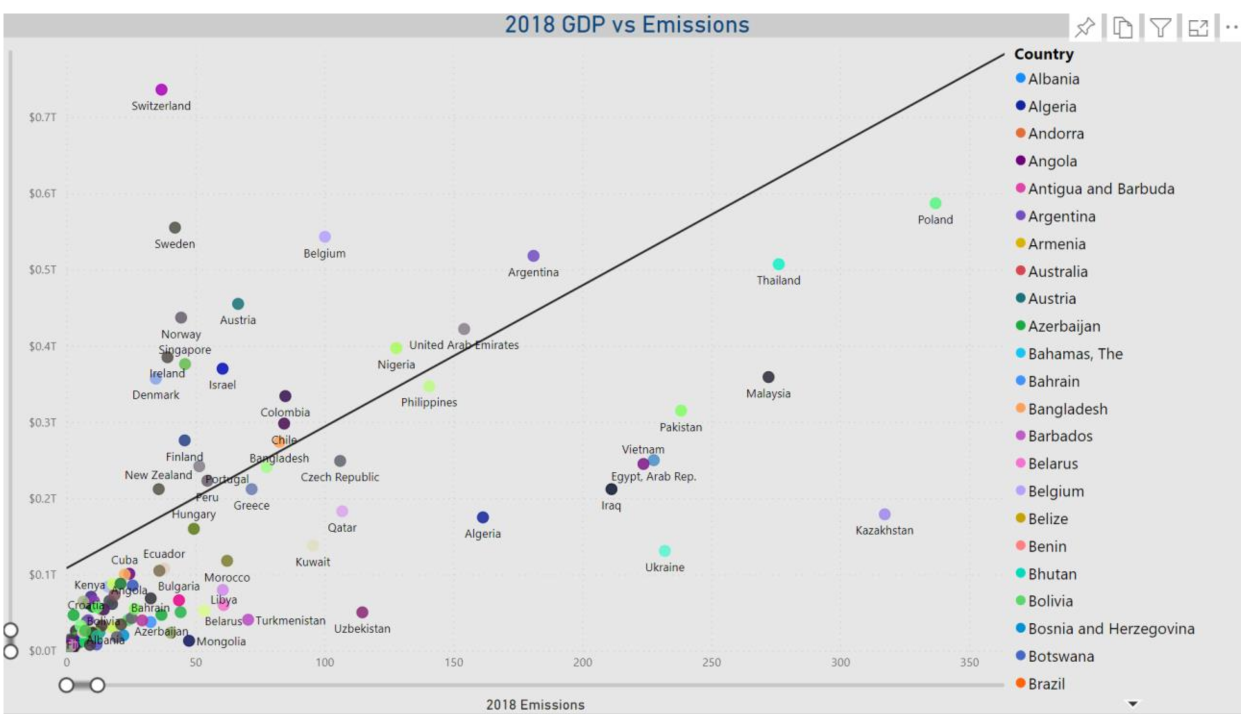
As noted in the discussion section, we identified a number of opportunities for further research going forward. The main opportunity is obviously to conduct a similar research project in the future. This would allow us to identify if there had been any changes in our questions one or two. For instance, economically speaking this additional time may allow some of the current investments in areas of sustainability to pay off. Looking more at the research we completed in this report, there are also opportunities for us to possibly explore the questions in more depth. We used GDP as our indicator of economic success, but we easily could have expanded to include other externalities that measure the success of a nation. Unemployment levels for example would have been an interesting topic. We should also consider that carbon emissions travel by wind and air, and most of the time a country will not produce its own level of carbon emissions.  In looking at these other areas, it could have been the case that emissions reductions aren't necessarily having the negative effects on development that we found in our second question. As a group, we all agreed that the topic of emissions reductions lends itself to multiple paths when it comes to analysis and is something that we will pay attention to going forward.

# Appendices

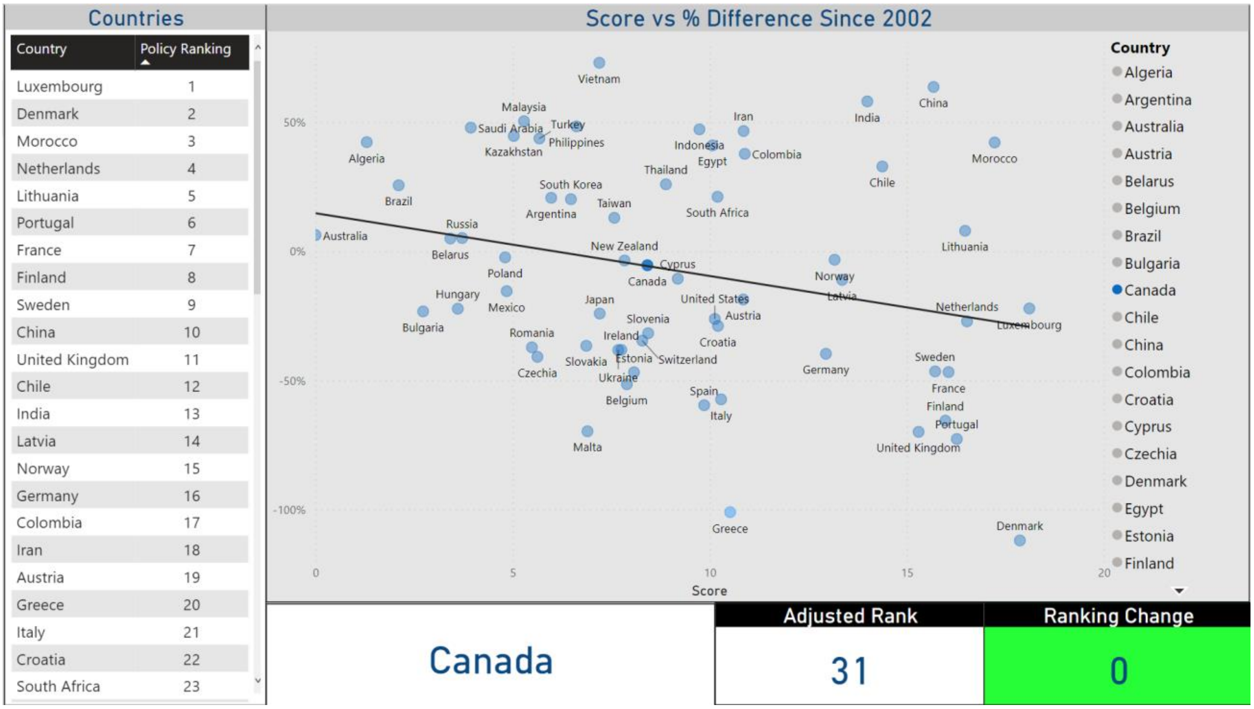
## *Appendix A:*




## *Appendix B:*



*Appendix C:*




*Appendix D:*

```
#Web Scraping a list of all the countries in the world + their ISO3 codes
#We used the following link to structure the web scraping code:
#https://towardsdatascience.com/scraping-data-from-wikipedia-tables-3efa04c6b53f
url = "https://www.fao.org/countryprofiles/iso3list/en/"

country_list_html = read_html(url)
country_list_html %>%
  html_nodes(css = "table")

country_list_table =
  country_list_html %>%
  html_nodes(css = "table") %>%
  nth(1) %>%
  html_table(fill = TRUE)
```

## References

*Data collection*

Emissions: https://github.com/owid/co2-data/blob/master/owid-co2-data.csv

Climate Policy Scores:

https://ccpi.org/wp-content/uploads/CCPI-2022-Results_2021-11-07_A4-1.pdf

List of countries: https://www.fao.org/countryprofiles/iso3list/en/

GDP data: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

Life expectancy : https://ourworldindata.org/grapher/life-expectancy-vs-gdp-per-capita

Happiness Index : https://worldhappiness.report/ed/2018/

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