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THE GAME OF DECARBONIZATION: A DATASET FROM THE WORLD BANK

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INDEX

Introduction

Industrialization, emissions, climate change. Three concepts that are strictly correlated between each other, and that can provide an exhaustive framework of the situation we find ourselves in these days. We are talking about a phenomenon that timidly started during the First Industrial Revolution (XVIII – XIV Century) with primitive attempts of mechanized factory systems that worked through simple steps: burn a coal pile to bring water to a boil, produce steam, and use it as an energy source for machines, which used steam energy to propel pistons back and forth (steam power). With the exceptions of breathing and making a fire, that was the first-time humanity released CO_2 into the atmosphere as a waste product.

From that moment through the next centuries, technology and progress relied more on producing energy from non-renewable resources – such as earth minerals and metal ores, and fossil fuels (coal, petroleum, natural gas, etc.) – resulting in massive CO_2 emissions that soon reached unsustainable levels.

This has led to one of the major challenges facing humanity in modern times, the Greenhouse Effect, caused by an increase in the percentage of some gasses in the atmosphere, otherwise known as the Greenhouse gasses (GHG). This phenomenon causes, as a consequence, a progressive thickening of the atmosphere around the planet, allowing sunlight to reach the Earth in the first place, but making it harder to return to space once they have bounced on the surface. In other words, it is the main cause for climate change, rising temperatures around the world, and all the related consequences – ice melting, sea level rising, ecosystems changing, etc.

As it turns out, CO_2 (brute formula for carbon dioxide) emissions keep increasing, because of countries and firms that won't step back from polluting or, in many cases, won't even try to be more sustainable. Now, we have to draw a line between two of the concepts that will pop up more frequently in the elaborate: the concepts of decarbonization (which is opposed to total emissions), and per capita emissions. Total emissions are the mere sum of some countries or economic system's overall emissions of CO_2 and – in general – other GHG gasses, and they are usually computed on a yearly basis (we will find data coming from every year since 1990 until 2018). As a matter of fact, we could never be allowed to just compare – for instance – China's huge GHG emissions with Cyprus ones, because other than a difference in the surface and dimension of these two countries, there is also a fundamental inequality in population, meaning that the more populated a country is, the more likely it will be for it to produce more waste than a smaller one. At the basis of this reasoning lies the definition of per capita emissions, defined as the ratio of total GHG emissions to the population – both quantities must, obviously, refer to the same country or economic system.

World Bank recently published a dataset showing, year after year, from 1990 until 2018, CO_2 emissions' levels from different countries in the world, outlining an overall trend in the past thirty years, both at State level and global level (there are also data clustered into macro-regions and economic systems, such as South Asia, EU, and OECD members, to draw some examples). The first thing coming at the eye when we look at the dataset, is that some countries performed better than others if compared in the 1990-2018 period. Starting from our point of view, the European Union as a whole system experienced an exceptional reduction in the emissions level, going from 2,62 million kt in 1990 to an all-time low (considering those 30 years) 2,09 million kt in 2018[1], while Italy was able to bring down its emissions level, too, but not in the same measure as the EU, meaning some countries were able to perform way better than us at "the game of decarbonization".

The aim of this study is to provide an overall look at the countries' emission levels through the years, analyzing which performed "better" or "worse" than the others, emissions-wise. Once these patterns are established, it would be convenient to prosecute the study by comparing the results with the GDP trend of the selected countries, in order to compare them and, possibly, find a relationship that ties them together.

In the first chapter, the elaborate opens with an overview about the main protagonist of the elaborate, CO_2, providing general insights into scientific and social effects of GHG emissions on our planet. Chapter 1 will also cover specifics from the data coming from the World Bank.

[1] Data from World Bank emissions dataset, available at https://data.worldbank.org/

Within chapter 2, the focus falls upon the dataset itself, concerning its overall structure, origin, utility, and way of data collecting. In the third chapter there will be the main analysis, with creation of graphics, analytics, and proper indexes that could explain trends, with a proper focus on the trends of the six continents, macro-regions, and economic systems. Also, in chapter 3 there will be a section dealing the theme of carbon intensity. Chapter 4 will, in part, deal with the results found out in the previous chapters, especially the ones of Chapter 3, since there will be an analysis conducted to find out about possible relationships between the emission levels of the countries, and their degree of GDP, all from a per-capita perspective.

Chapter 1. A Road to Decarbonization

1.1 Carbon Dioxide, a general overview

Carbon dioxide (CO_2) is naturally occurring gas fixed by photosynthesis into organic matter. As a byproduct of fossil fuel combustion and biomass burning, it is also emitted from land use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured, thus having a Global Warming Potential of 1.

Burning of carbon-based fuels since the industrial revolution has rapidly increased concentrations of atmospheric carbon dioxide, increasing the rate of global warming and causing anthropogenic climate change. It is also a major source of ocean acidification since it dissolves in water to form carbonic acid.

The addition of man-made greenhouse gases to the Atmosphere disturbs the earth's radiative balance. This is leading to an increase in the earth's surface temperature and to related effects on climate, sea level rise and world agriculture.

Emissions of CO_2 are from burning oil, coal, and gas for energy use, burning wood and waste materials, and from industrial processes such as cement production. We call emission intensity the average emission rate of a given pollutant from a given source relative to the intensity of a specific activity. Emission intensities are also used to compare the environmental impact of different fuels or activities.

The carbon dioxide emissions of a country are only an indicator of one greenhouse gas. For a more complete idea of how a country influences climate change, gases such as methane and nitrous oxide should be considered, too (we will refer to them as GHG equivalents, because their emission levels can be considered as multiple of a single CO_2 emission). This is particularly important in agricultural economies. The environmental effects of carbon dioxide are of significant interest.

Carbon dioxide (CO_2) makes up the largest share of the greenhouse gases contributing to global warming and climate change. Converting all other greenhouse gases (methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6)) to carbon dioxide (or CO_2) equivalents makes it possible to compare them and to determine their individual and total contributions to global warming.

When we talk about CO_2-equivalents, we refer to the fact that GHG fall in different categories (there is not just carbon dioxide); in fact, we also consider to be greenhouse gasses: methane, nitrous oxide, Sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons. Emissions of each of these gasses can be somehow converted into CO_2 emissions by weighting their global warming potential (GWP) in relation to that of carbon dioxide. In specific we have:

- CO_2 = 1 (CO_2 emissions represent the unit of measure in this system)
- methane = 25

- nitrous oxide = 298
- sulfur hexafluoride = 22.800
- hydrofluorocarbons and perfluorocarbons comprise under the same category many different gasses having different GWPs.

Before going further with the elaborate, it is important to point out some of the limitations and exceptions to the estimates, that are provided by the U.S. Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) calculates annual anthropogenic emissions from data on fossil fuel consumption (from the United Nations Statistics Division's World Energy Data Set) and world cement manufacturing (from the U.S. Department of Interior's Geological Survey, USGS 2011). Although estimates of global carbon dioxide emissions are probably accurate within 10% (as calculated from global average fuel chemistry and use), country estimates may have larger error bounds. Obviously, trends estimated from a consistent time series tend to be more accurate than individual values: each year the CDIAC recalculates the entire time series since 1949, incorporating recent findings and corrections. Estimates exclude fuels supplied to ships and aircraft in international transport because of the difficulty of apportioning the fuels among benefiting countries.

Carbon dioxide emissions, largely by-products of energy production and use, account for the largest share of greenhouse gases, which are associated with global warming. Anthropogenic carbon dioxide emissions result primarily from fossil fuel combustion and cement manufacturing. In combustion, different fossil fuels release different amounts of carbon dioxide for the same level of energy use: oil releases about 50 percent more carbon dioxide than natural gas, and coal releases about twice as much. Data for carbon dioxide emissions include gases from the burning of fossil fuels and cement manufacture and excludes emissions from land use, such as deforestation.

The unit of measurement is kt (kiloton); carbon dioxide emissions are often calculated and reported as elemental carbon, meaning they are converted to actual carbon dioxide mass by multiplying them by 3.667 (the ratio of the mass of carbon to that of carbon dioxide).

According to M. Fay, S. et al (2015), cities offer some of the best opportunities for decarbonization, and a few sectors – such as buildings, transport, water, and waste – have the greatest potential for high impact decarbonization investments: creating an enabling environment for cities to invest heavily to achieve systemic transformations in these sectors is essential for meeting the less than 2 °C target of the Paris Agreement, considering also an urban population growing – on a weekly basis – by approximately 1.4 million. Unfortunately, significant barriers exist for these investments to grow at the required pace. The good news is that there are many initiatives such as the alliance of cities that have committed to achieving 80 percent reductions of GHG emissions by 2050, networks such as the C 40 network of city mayors from around the world that connect leaders and undertake research and programs to help cities implement low carbon and climate resilience strategies, and those of major private and institutional investors committed to ramp up their low carbon investments.

→ Granoff, Hogarth and Miller (2016) state that many of the barriers to low carbon investments in cities are nested within those that are common to all infrastructure investment. These fall into several categories – says Kahn (2013) in his 2013 article – ranging from the political-economy related such as the frequent failure of local authorities to appropriate sufficient resources for needed investments and to allocate spending to those activities that maximize benefits; to the multilevel-governance related constraints that come with local decision makers having to depend on higher political levels or other actors of society, and to the diffused nature of public spending benefits which often makes them difficult to translate into a price, thus making it less attractive to private investment.

1.2 Technological Innovation and Key Policies

Based on the data of BP Statistical Review of World Energy, KOF Globalization Index, and the World Development Indicators, this paper explores the impact of technological innovation on CO_2 emissions in a panel of 96 countries over the period 1996–2018 with spatial econometric models. First, both CO_2 emissions and R&D intensity show significant spatial correlation across countries, and thus spatial econometric models are more suitable for research. Second, technological innovation has no significant mitigation effect on CO_2 emissions globally. However, group-based studies show that technological innovation in high-income, high-technology, and high-CO_2 emission countries can significantly reduce CO_2 emissions in neighboring countries, while R&D intensity in other countries even increase CO_2 emissions. Third, the higher the level of globalization is in a country, the more obvious the effect technological innovation has on reducing CO_2 emissions. Among them, the moderating effect of political globalization is the most obvious and even low-income, low-technology, and low-CO_2 emission countries can benefit from it; the "pollution haven" in economic globalization and the guidance of environmental protection awareness in social globalization deserve more attention. Therefore, countries should pay attention to the spillover effects of technological innovation, improve the corresponding level of globalization according to their own characteristics, and ultimately enhance environmental quality through international cooperation.

- Pricing policies and targeted investments – that bring clean technologies below the threshold of cost-parity with fossil fuel technologies can trigger reinforcing feedbacks that cascade up scales to propel disproportionately rapid decarbonization.
- Traditional approaches to climate policy based on welfare economics principles of minimizing marginal abatement costs, and pricing externalities,

are likely to miss these opportunities. Systems thinking can help identify ways for policy to drive effective change.

- Positive-sum cooperation between small groups of countries can accelerate the activation of tipping points in the global economy, facilitating decarbonization in all countries.
- Early opportunities for this are in the power and light road transport sectors, where clean technologies are increasingly competitive with fossil fuels.
- The value of decarbonization policies should be judged not just on their immediate effects on emissions within the implementing jurisdiction, but also for their potential to contribute to upward-scaling tipping cascades in the global economy.

Many economists have long held that carbon pricing (either through a carbon tax or cap-and-trade) is the most cost-effective way to decarbonize energy systems, along with subsidies for basic research and development. Meanwhile, green innovation and industrial policies aimed at fostering low-carbon energy technologies have proliferated widely, and most of these predate direct carbon pricing.

Low-carbon leaders such as California and the European Union (EU) have followed a distinct policy sequence – helping overcome some of the political challenges facing low-carbon policy by building economic interest groups – in support of decarbonization and reducing the cost of technologies required for emissions reductions. Representatives from EU and California met in 2017, in light of the global momentum generated by the Paris Agreement (even though the US eventually withdrew from the Agreement in 2020 under Trump administration), and in order to step up cooperation on emissions trading and zero-carbon transportation.

However, while politically effective, this policy pathway faced and still faces significant challenges to environmental and cost effectiveness, including excess rent capture and lock-in. As countries move toward deeper emissions cuts, combining and sequencing policies will prove critical to avoid environmental, economic, and political dead-ends in decarbonizing energy systems.

1.3 What about the Paris Agreement?

It is a legally binding international treaty on climate change. It was adopted by 196 Parties at COP 21 in Paris, on 12 December 2015 and entered into force on 4 November 2016. Its goal is to limit global warming to well below 2, preferably to 1.5°C, compared to pre-industrial levels. In order to achieve this long-term temperature goal, countries aim to reach global peaking of greenhouse gas emissions as soon as possible to achieve a climate neutral world by 2050.

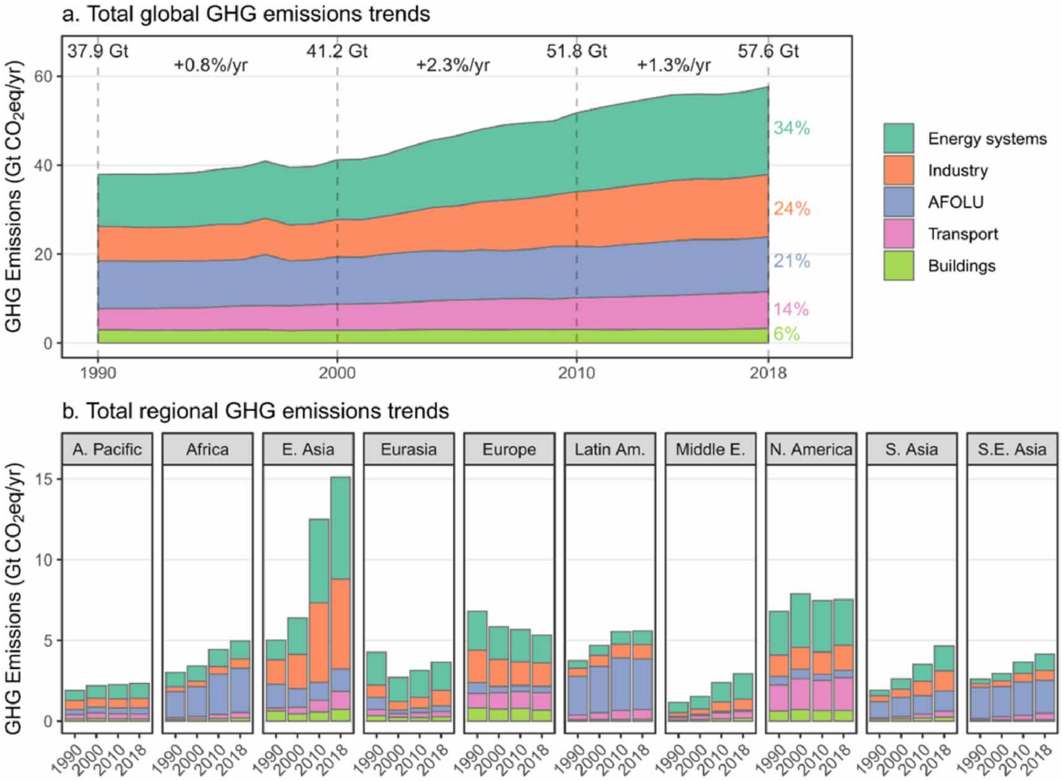
The Paris Agreement is a landmark in the multilateral climate change process because, for the first time, a binding agreement brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects: it provides a framework for financial, technical, and capacity building support to those countries who need it, in terms of finance, technology, and capacity building[2].

But things aren't always as easy and immediate as someone might imagine, even if projects – such as the Paris Agreement itself – point at the long period.

According to a study conducted by Professor William F. Lamb et al. (2021), Global GHG emissions continued to rise between 2010 and 2018, although the rate of emissions growth has slowed since 2014 (Figure 1). GHG emissions were the highest in human history in 2018, reaching 58 GtCO_2eq. The largest share of emissions in 2018 came from the energy systems sector (34%; 20 GtCO_2eq), followed by industry (24%; 14 GtCO_2eq), AFOLU (21%; 12 GtCO_2eq), transport (14%; 8.3 GtCO_2eq) and the operation of buildings (6%; 3.3 Gt CO_2eq). Estimates based on direct emissions produced in each sector. Industry and buildings sectors further contributed to emission growth indirectly, by drawing on electricity and heat production in the energy systems sector.

[2] Data coming from UNFCCC Sites and Platforms, available at https://unfccc.int/

Figure 1. Global and regional GHG emissions trends for all sectors. Panel (a) shows total global GHG emissions divided into major sectors. Panel (b) shows regional emission trends in the years 1990, 2000, 2010, and 2018.



Source: A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018 (2021).

In terms of regions, East Asia and North America together accounted for 40% of global GHG emissions in 2018, within which emissions are dominated by China and the United States - the highest absolute increase between 2010 and 2018 was in Eastern Asia (2.6 $GtCO_2eq$).

Four regions – the Middle East, Africa, Eurasia, and South-East Asia – accounted for the rest of the global emissions increase with approximately 0.5 $GtCO_2eq$ each. The most rapid relative growth in emissions since 2010 occurred in Southern Asia at 3.6% per year, followed by the Middle East (2.6%/year), Eastern Asia (2.4%/year) and Eurasia (1.9%/year). The only region with a decline in emissions since 2010 has been Europe (−0.3 $GtCO_2eq$, −0.8%/year). North America, Latin America, and developed countries in the Asia Pacific saw only minimal growth over this period (+0.1%/yr, +0.1%/year and +0.4%/year, respectively).

It is interesting (and in a way, predictable) to underline the fact that trends by sector differ widely across regions. Developed countries in Asia Pacific, Europe and North America tend to have higher shares of emissions from energy systems, industry and transport, and lower shares from AFOLU (agriculture, forest, and other land uses). Overall emissions in these regions are relatively stable, apart from the energy systems sector in Europe and North America, which have seen gradual reductions since 2010 (−1.8%/year and −1.5%/year, respectively). This general pattern is reversed in the case of Africa, Latin America, and South-East Asia. In these regions AFOLU is the largest emitting sector (specifically: CO_2 emissions from deforestation). The main counteracting, yet insufficient, factor that led to emissions reductions was decreased energy use per unit of GDP in almost all regions (−2.1% globally).

These reductions in energy intensity are a result of technological innovation, regulation, structural change and increased economic efficiency. But there are also counters to these emissions-reducing effects coming from the energy rebound effect, which has been found in several studies to significantly offset some energy savings. The energy rebound effect is the phenomenon that an increase in energy efficiency may lead to less energy savings than would be expected by simply multiplying the change in energy efficiency by the energy use prior to the change (for example, when you buy a more fuel-efficient car, you will drive more, therefore keeping your emissions constant or even increasing them).

In the next chapters – in the third one in particular – it will be necessary to go through several issues concerning emissions, such as carbon intensity, defined as the ratio between total emissions and GDP referring to the same economic system or region. This index gives us an idea of the measure CO_2 emissions are connected to a certain country wealth and production, and that, if decreased, it would mean that less pollution is created per unit of GDP.

Then main part of this study is to analyze the per capita emissions, and, only eventually, compare them with the total ones. Per capita emissions can be computed easily by dividing each year GHG emission level with the associated population level of that year.

It is also important to distinguish between decarbonization in actual terms, and in relative terms (or per-capita decarbonization): the first is the mere reduction of

GHG emissions, and, in a nutshell, what really matters for the planet, while the second one gives us a hint on the relationship between emissions and population in a given country/economic system/region. On one hand, it is fundamental to reduce the relative emissions, for instance, by producing the same amount of goods and services – in other words, the GDP – with fewer emissions, or enabling the population to turn down our emissions (with changes in technology and lifestyle). It goes without saying that per-capita decarbonization does not guarantee "absolute decarbonization", since the former may have been altered because of changes in the population or GDP, and not because of an actual decrease in pollution (*scale problem*). As a consequence, it is important to point out that the per-capita decarbonization necessary to guarantee the absolute one must increase, or there won't be any improvement.

Chapter 2. Dataset Presentation

2.1 World Bank Dataset

The World Bank is an international organization made up of 189 member countries. These member countries, or shareholders, are represented by a Board of Governors, who are the ultimate policymakers at the World Bank. Generally, the governors are member countries' ministers of finance or ministers of development. They meet once a year at the Annual Meetings of the Boards of Governors of the World Bank Group and the International Monetary Fund to discuss issues of various topic.

This organism is also called World Bank Group, since it consists of 5 bodies:

- The International Bank for Reconstruction and Development (IBRD) – lends to governments of middle-income and creditworthy low-income countries.
- The International Development Association (IDA) – provides interest-free loans (called credits) and grants to governments of the poorest countries. Together, IBRD and IDA make up the World Bank.
- The International Finance Corporation (IFC) – it is the largest global development institution focused exclusively on the private sector. We help developing countries achieve sustainable growth by financing investment, mobilizing capital in international financial markets, and providing advisory services to businesses and governments.

- The Multilateral Investment Guarantee Agency (MIGA) – it was created in 1988 to promote foreign direct investment into developing countries to support economic growth, reduce poverty, and improve people's lives. MIGA fulfills this mandate by offering political risk insurance (guarantees) to investors and lenders.
- The International Centre for Settlement of Investment Disputes (ICSID) – provides international facilities for conciliation and arbitration of investment disputes.

In particular, our data have been collected by Climate Watch, an online platform designed to empower policymakers, researchers, media and other stakeholders with the open climate data, visualizations, and resources they need to gather insights on national and global progress on climate change[3].

Climate Watch represents an institutional, since it is based on data sources that are officially reported by national governments under the United Nations Framework Convention on Climate Change or gathered by reputable institutions (e.g., World Bank, United Nations Development Programme) and research organizations (e.g., Potsdam Institute for Climate Impact Research, World Resources Institute). Furthermore, data are publicly available for most of the countries and updated on a regular basis.

The dataset contains historical data contains sector-level greenhouse gas (GHG) emissions data for 194 countries and the European Union (EU) for the period

[3] https://www.climatewatchdata.org/about/description

1990-2018, including emissions of the six major GHGs from most major sources and sinks. For example, we will have emissions levels for the variable *Italy* for every year, starting from 1990, and until 2018.

Aside of regular countries, as we already said, we can consult data for macro-areas, and this will come up in handy for later, when we will need to collect countries into clusters in the case, they will present similar emissions' trends. These macro-areas are: World, Arab World, Caribbean small states, Central Europe and the Baltics, East Asia and Pacific (with or without high incomes), Euro area, Europe and Central Asia (with or without high incomes), EU, fragile and conflict afflicted situations, heavily indebted poor countries (HIPC), Latin America and Caribbean (excluding high incomes), least developed countries (UN classification), Middle East and North Africa (with or without high incomes), North America, OECD members, other small states, Pacific island small states, small states, South Asia, Sub-Saharan Africa (with or without high incomes), high income, low income, middle income, upper middle income.

These further classifications help the reader to understand the main differences and analogies between systems and economies that present heterogeneous characteristics, income-wise, territory-wise, and climate-wise.

Emissions are measured in kt, and in order to ease the analyses up, we will maintain this measure unit, and change other ones; for example, in Chapter 3, the study will include GDP data about all the countries of the dataset, and they will be listed in billions of dollars, instead of dollars only.

Before starting the analysis, some countries (variables) have been deleted because of lack of information in the period 1990-2018 about GDP or population. These countries are: Eritrea, Ghana, Armenia, Afghanistan, American Samoa, Bosnia and Herzegovina, Channel Islands, Curacao, Channel Islands, Estonia, Faroe Islands, Gibraltar, Guam, Croatia, Isle of Man, Israel, Cambodia, Liberia, Lithuania, St. Martin (both FR and ND), Latvia, Moldova, Montenegro, Northern Mariana Islands, Nauru, Palau, Korea, St. Marino, Somalia, Serbia, South Sudan, Sao Tome and Principe, Slovenia, Turks and Caicos Islands, Timor-Este, Virgin Islands (both UK and US), Belize, Bermuda and Kosovo. This skimming leaves us down to 159 variables (countries) to work with.

2.2 Macro-regions and Economic Systems

There are pronounced differences, both in recent changes in the absolute levels and drivers of GHG emissions, when differentiating countries by income levels or by regions. In general, in high-income countries, significant improvements in energy intensity led to declining CO_2 emissions between 2010 and 2015, despite increasing income levels and populations. In upper middle-income and lower middle-income countries, rising income more than offset any energy structural or intensity gains, leading to increased emissions. And CO_2 emissions increased the most in low-income countries, due to significant increases in carbon intensities, income levels and population. Importantly, some of these trends are partially related to shifts in global supply chains, where some production emissions could also be allocated to final consumers under a so-called consumption-based perspective, mostly in high- and middle-income countries.

In this elaborate, emissions trends will be analyzed from a "countries" perspective and from a "macro-areas" perspective, in order to obtain a more general idea of the emissions patterns of countries that are similar to each other from a social and economic point of view. In particular, we will be conducting analyses for the following macro-areas:

- European Union – EU aggregate.
- Fragile and conflicted situations – countries here are distinguished based on the nature and severity of issues they face. The classification uses the following categories:

  - Countries with high levels of institutional and social fragility, identified based on publicly available indicators that measure the quality of policy and institutions and manifestations of fragility.

  - Countries affected by violent conflict, identified based on a threshold number of conflict-related deaths relative to the population. This category includes two sub-categories based on the intensity of violence: countries in high-intensity conflict and countries in medium-intensity conflict[4].

- High income - economies in which 2020 GNI per capita was $12,696 or more. Most of the countries here are from the "developed" world, so Europe, North America, Australia and some Pacific Islands, and even some well-being realities in East Asia and Latin America.
- Middle income – economies in which 2020 GNI per capita was between $1,046 and $12,695. This cluster includes many countries from Latin America, Middle East and North Africa, East Asia, and Eastern Europe.
- Lower income – economies are those in which 2020 GNI per capita was $1,045 or less. These include most countries from Africa, and many from South Asia, Middle East, East Asia, and Pacific.
- Heavily indebted poor countries (HIPC) – countries that participated in the HIPC Initiative, launched in 1996 by the IMF and World Bank to reduce external debt burdens of the most heavily indebted poor countries at that time to sustainable levels. To date, most of the countries completed the program, receiving 76 billion in debt-service relief over time[5].

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[4] Available at https://www.worldbank.org/en/topic/fragilityconflictviolence/brief/harmonized-list-of-fragile-situations

[5] Available at https://www.imf.org/en/About/Factsheets/Sheets/2016/08/01/16/11/Debt-Relief-Under-the-Heavily-Indebted-Poor-Countries-Initiative

- Least developed countries – countries classified as under-developed on social, economic, environmental, and institutional basis by the UN. Many of them are African and Asian countries[6].
- OECD members – 38 member states from all over the world, representing 2/3 of the world's production of goods and services and 3/5 of world's exports (as it may seem, it is a "club" of rich countries). It is an economic, rather than political organization (unlike the EU), and its aim is to promote the expansion of the economies of its MS, in order to reduce the obstacles to the international trade.
- World – world aggregate.

[6] Available at https://data.worldbank.org/country/XL

Chapter 3. A Descriptive Analysis

The content of this chapter will be about the elaboration of our dataset, with the creation of graphs and indexes, in order to discover trends, analogies, and differences in between data. The main analysis instruments will be Excel functions and tools.

The first step for the analysis includes the creation – and collection – of different measurements; to get this over with, I needed information about per-capita emissions (our dataset), population levels, and GDP. These other kinds of data have been downloaded the same way as we did with the emissions one, from the online platform of World Bank. The following step was to compute total emissions – by multiplying per-capita emissions and population levels – and carbon intensity – that is, the ratio between total emissions on GDP level. Obviously, total emissions and carbon intensity have been computed for every country and every year, according to previous dataset's schemes.

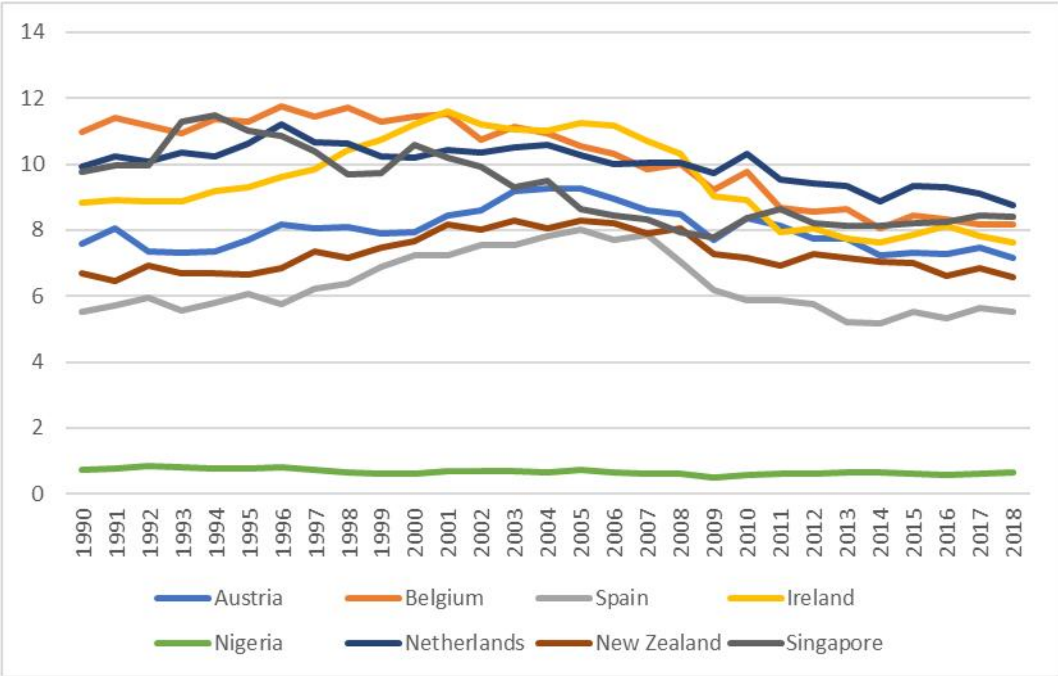
Once these five datasets are ready, it is possible to compute average, median, and standard deviation, both at year level (columns) and country level (rows), and then decide, for every country, whether there had been a downward or upward trend between 1990 and 2018, by comparing the starting and finishing number in every row (1990 levels versus 2018 levels).

3.1 Per-Capita Emissions and Total Emissions

As we already said, it is clear that a reduction in the per-capita emissions, does not guarantee a reduction in the total amount of GHG emissions of a system, because the variables in play might be of different nature. As a matter of fact, per-capita emissions may as well fall because of an increase in the population of a country-region (population functions as denominator in the ratio), while the "absolute" emissions will not change, or worse, they will increase, even if a little – if the increase in the emissions is smaller than the increase in population, the result will still be a decrease in per-capita emissions. It is easily stateable that, the final goal, is to reduce the absolute CO_2 emissions.

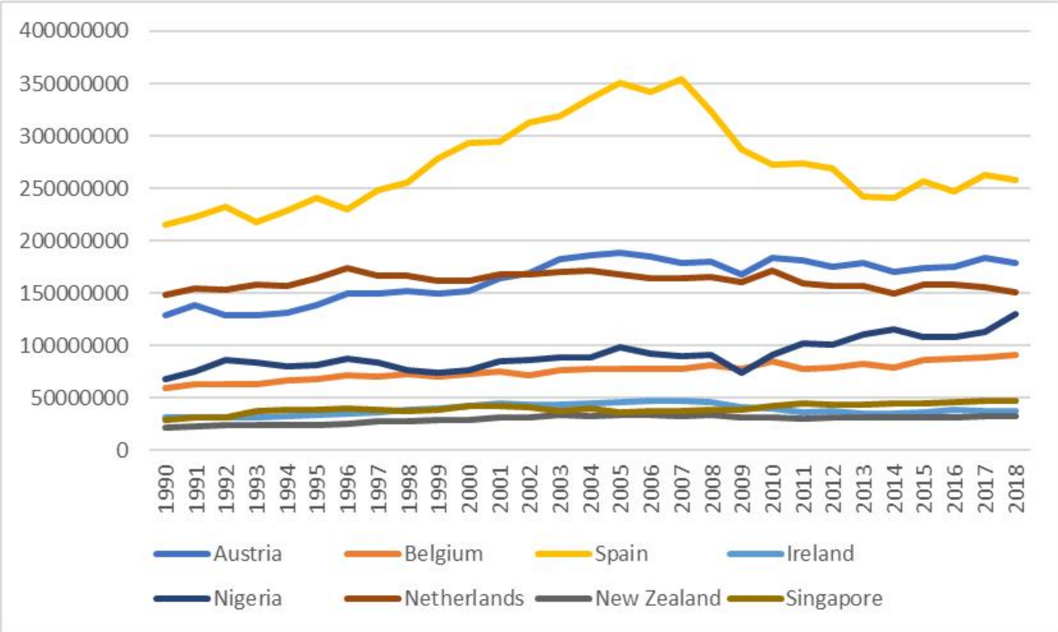
Coming down to the analysis itself, we can notice that some countries registered in 2018, CO_2 levels that are higher than 1990's, even though they could achieve a reduction in the per-capita emissions. It is the case of several countries from Europe, starting from Belgium and Austria, but also Bulgaria, Ireland, the Netherlands, and Spain, too; same thing happened in many other countries around the world, such as Japan, Singapore, the United States, Nigeria, and New Zealand. The following graphs show the trends in the above countries, with the exception of the USA, Japan, and Bulgaria – data pertaining these countries have been omitted due to a problem of scale in representation, as reporting higher volumes than for other countries would compromise the overall picture.

Figure 2. Per-capita GHG (in metric tons) of countries that well-performed from a per-capita point of view but didn't from an absolute point of view.



Source: own elaboration, data from World Bank.

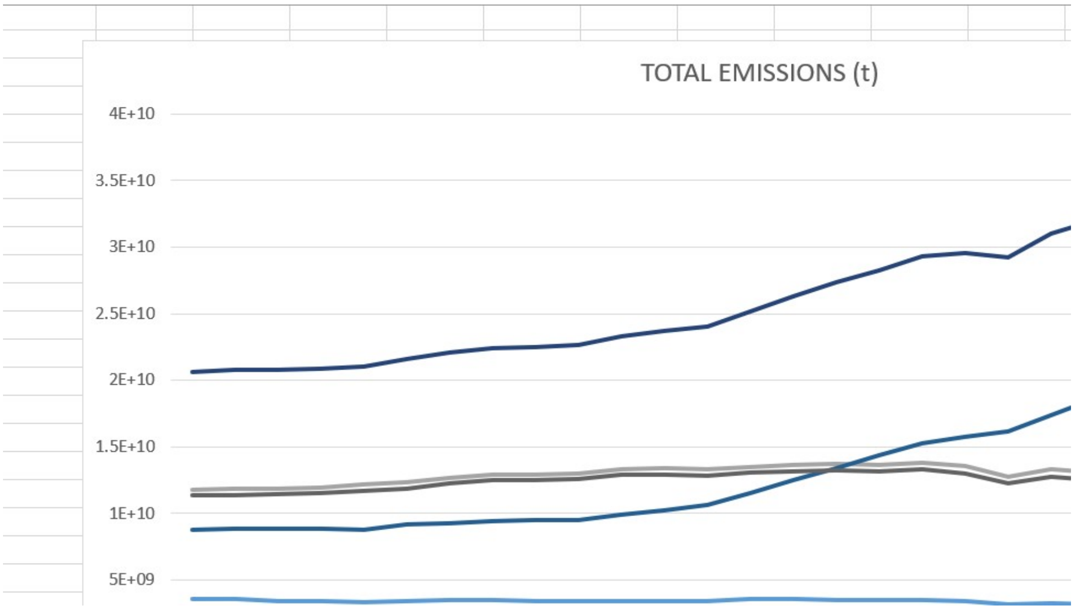
Figure 3. Total GHG emissions (in tons) of countries that well-performed from a per-capita point of view but didn't from an absolute point of view.



Source: own elaboration, data from World Bank.

Another relevant piece of information – from a descriptive point of view – is the average amount of emissions that is produced every year; we can now consider the macro-region "world", and notice that the overall trend in the period 1990-2018 is a growing function, as represented in the graph.

Figure 4. Aggregate levels of GHG emissions (in tons).

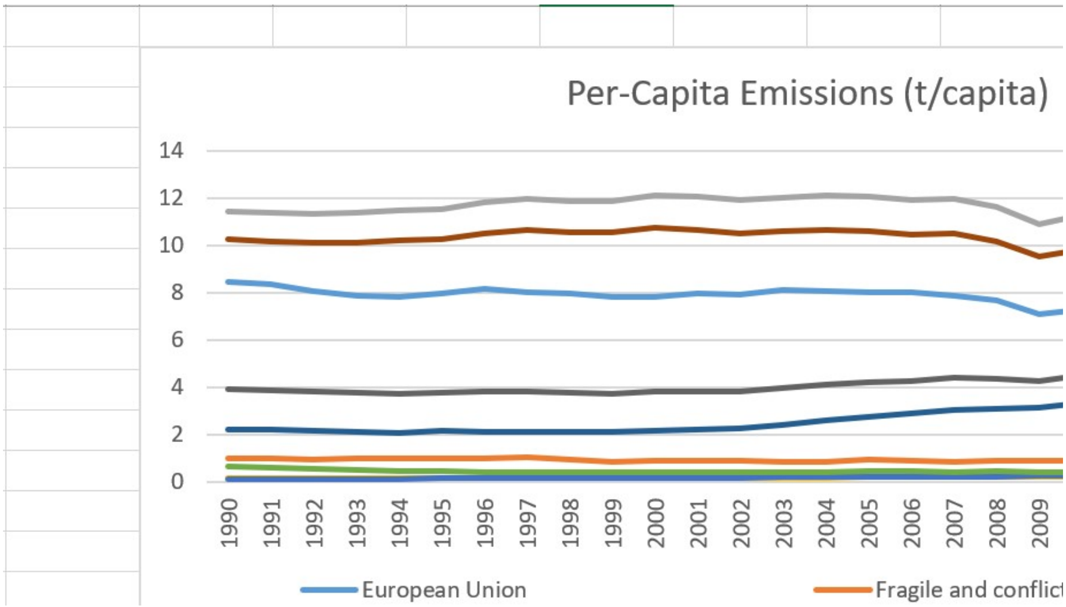


Source: own elaboration, data from World Bank.

This result is undeniable proof that the environmental emergence is real, and that in the last thirty years, the world – as an aggregate – only worsened this situation to a critical point and an all time maximum.

Interestingly, the only two macro-regions that reduced their absolute levels of GHG emissions were the European Union and the Low-Income aggregate: the former variable may be explainable through all the efforts made by the community and all the organizations to reduce the emissions (one among them, the Paris Agreement, to which most European countries were signatories from the beginning). And what about the Low Income aggregate? This outcome may depend on a progressive worsening of the living conditions of the inhabitants of these regions, and consequently, in their consumptions habits (stated that higher consumption levels determine higher emissions for a country).

Figure 5. Per-capita emissions of the aggregates.

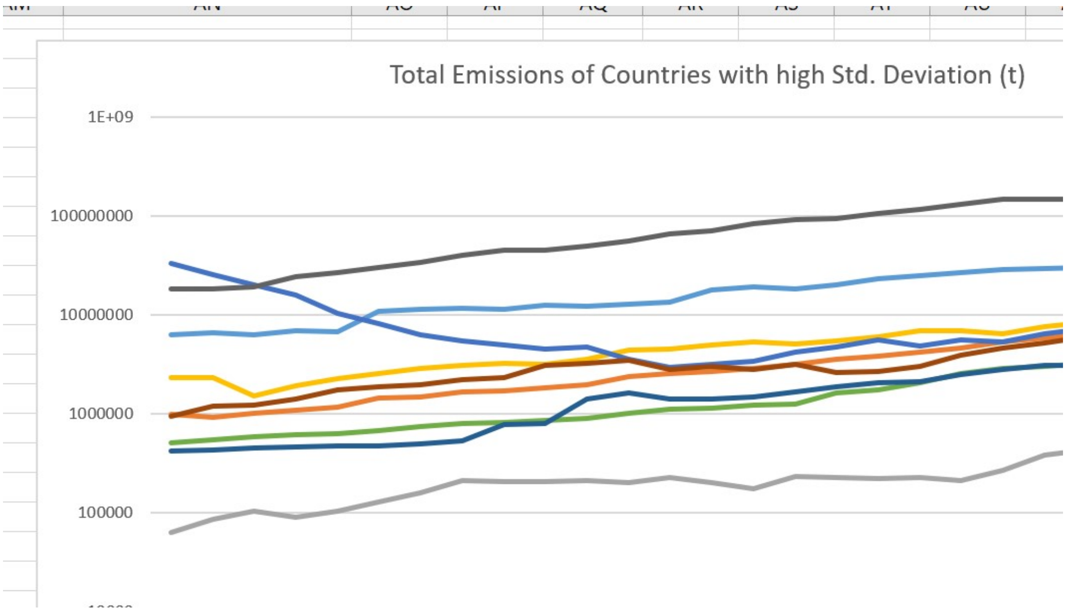


Source: own elaboration, data from World Bank.

Figure 5 demonstrates once again that, even though many other macro-regions – other than the European Union and Low Income – were able to bring down their per-capita emissions, that is not enough to reduce the overall emitted amount of GHG, since the magnitude of the "emissions/population" ratio may decrease as a result of an increase in the latter, too.

Another subject of relevance in this study is the analysis of the standard deviation – representing the average deviation of a set of measures from the mean – from a "country" perspective and from a "yearly" perspective. In particular, that country perspective represents the average deviation of a country emission levels from the mean, while "yearly" stands for the average deviation of the emissions of all the countries in the world, but in a fixed year (for example, in 1990 the computed yearly standard deviation was 446'588'187.1 Tons, meaning that, on average, other countries GHG levels diverge by 446'588'187.1 Tons from a mean of 114'230'268.9 Tons). For this study's sake, we will consider the standard deviation from a relative point of view, by easily dividing the standard deviation for the mean, and obtaining. This will allow us to know measure of deviation of a set of emission levels around the mean, in percentage, and it is a tool that comes in handy to know which countries, on average, reported the most diverging values. For example, let's take Italy: Italy – from a country perspective – shows a standard deviation equal to 45'623'736.35 Tons and a mean equal to 406'035'172.4 Tons; as a consequence, the relative standard deviation will be around 11.24%, meaning that Italy, in the period 1990-2018, registered emission levels that deviated from the mean on average by 11,24%. But there are countries whose standard deviation is way higher, or way lower. I decided to make a distinction between countries with a high std. deviation (relative std. dev. > 50%), and countries with a low one (relative std. dev. < 10%). Results show that many countries from the *Low* and *Middle-Income* macro-regions belong to the variables that reported high standard deviation, meaning that in the last 30 years, they could have developed and brought their emissions (and possibly, their production and consumption levels) to the next stage. To give an impression, some of these countries are Angola, Bhutan, Bangladesh, Ethiopia, Georgia, Nepal, Mali, Vietnam, and LAO PDR.

Figure 6. Total Emissions of some countries that reported high Std. Deviation



Source: own elaboration, data from World Bank.

In the realization of Figure 6, it was necessary to apply a logarithmic scale for the y axis, in order to best emphasize the differences between the trends.

As we can imagine, a high standard deviation might be explainable in different ways, and the countries that are represented in Figure 6 demonstrate it very well. For instance, LAO PDR reported an outstanding value, equal to almost 150%, explainable by the gap between 1990's GHG level of 510'000, and the 2018 GHG level equal to 18'790'000; it is well known, in fact, that in LAO PDR, the growth of industries and industrial sector – and the resulting rise in air pollution – has caused considerable environmental damage, and to remedy this, the ministry's Deputy Minister Phouvong Luangxaysana planned to increase green spaces to 70% of the country's land area, so that more trees will be available to absorb the carbon dioxide emitted by industry and other processes[7].

3.2 A Regional Analysis

Analyzing emissions on a country-by-country basis is important, but our dataset also allows for regional and continental clustering of countries so that additional spatial – rather than economic – information can be contributed to the study.

The purpose of this section is, precisely, to present a general trend of emissions for each continent, in order to outline the main differences and analogies between them.

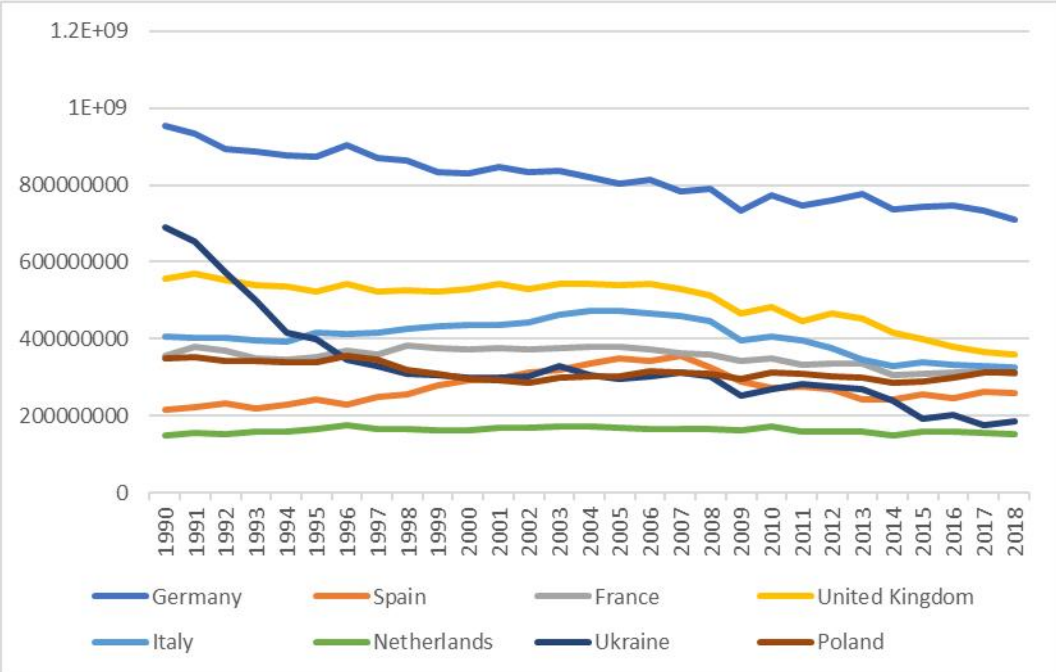
[7] Huaxia, www.news.cn Asia and Pacific (12th September 2022), available at https://english.news.cn/asiapacific/20220214/c863d08cc6de493a9030e2fde995a195/c.html

3.2.1 EUROPE

Aside from the World Bank dataset, we can refer to an article published by Eurostat about EU GHG emissions in the period from 1990 to 2020 (basically the exact same period we needed for our analysis). The data are recorded in GHG emission inventories and submitted to the United Nation Framework Convention on Climate Change (better known as UNFCCC), and they serve as official data for international policies. In addition, Eurostat classified GHG emissions according to the emitting economic activities (AFOLU, manufacturing, energy, etc) by using air emission accounts (AEA), one of the modules in the European environmental economic accounts that are suited for integrated analyses (environmental and economic together). The article includes emissions from international aviation, too, and it does exclude emissions or removals from land use, land change, and forestry (LULUCF).

The main take from these statistics is the (overall) downward trend, since, in 2020, greenhouse gas emissions in the EU were down by 33% if compared with 1990 levels, representing an absolute reduction of 1.563 million tons of CO_2-equivalents. More in specific, during the '90s the Union experimented an initial reduction in emissions (aside from a relative peak in 1996, when a cold winter led households to an increase in heating requirements), while, after that, emissions levels remained steady until 2008. Then, in 2009, as a consequence of the global financial and economic crisis, GHG emissions saw a sharp drop (one of the main reasons was the rapid decline in industrial activities). In the following years, EU experimented a general up and down GHG emissions-wise, and the most notable point is the sudden fall in 2020 caused by Covid19 pandemic (even if that is not covered by the World Bank dataset).

Figure 7. Main European Countries' GHG Emissions Trend (tons).



Source: own elaboration, data from World Bank.

At first glance, by just looking at the graphs, the outcome is easily predictable: in the period 1990-2018 we have on one hand the total emissions that went down, and on the other hand, a population that, on overall, has grown (even if after 2010, the mortality rate officially surpassed the birth rate, and outperforming it later, during Covid19 Pandemic). EU greenhouse gas emissions declined steadily from 2010 until 2014, rose slightly in the period 2015-2017 and dropped again in 2018. In 2019 emissions fell by nearly 4 % compared to 2018, the sharpest drop since 2009. In 2019, EU GHG (greenhouse gas) emissions were over 1 billion tons of CO_2 equivalent lower than in 1990. This corresponds to a 24 % reduction compared with 1990 levels, which is more than the EU reduction target of 20 % by 2020. The new target for 2030 is a 55 % reduction of GHG emissions compared to 1990. GHG emissions were below 1990 levels in 22 Member States, and the largest reductions (over 50%, too), were recorded in Estonia, Romania, Lithuania, and Latvia[8].

In Figure 9 it is possible to outline even better the contribution of each of the previously cited countries concerning GHG emissions. It is clear that Germany (in light blue) is the leading polluter in Europe, as many of the continent's largest industries and manufacturing plants are based in Germany. This high productivity – and consequently, high emissions – is also justified by the value of Germany's GDP, one of the highest in Europe throughout the period 1990-2018, bringing out the topic of carbon intensity, but this is an issue that will be discussed later.

[8] Eurostat, Greenhouse gas emission statistics - emission inventories, data from June 2022. Next update planned for June 2023. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Greenhouse_gas_emission_statistics_-_emission_inventories

France and Poland display two interesting cases: France, despite being as big and populated as other European countries, present lower GHG levels, thanks to alternative energy sources (according to BP and Ember, 2021, 69,3% of French electric energy is produced in nuclear plants nowadays[9]); on the other hand, while not among the top three European emitters, Poland is home to the company that for much of the 2010s reported the highest level of CO_2 equivalent emissions.

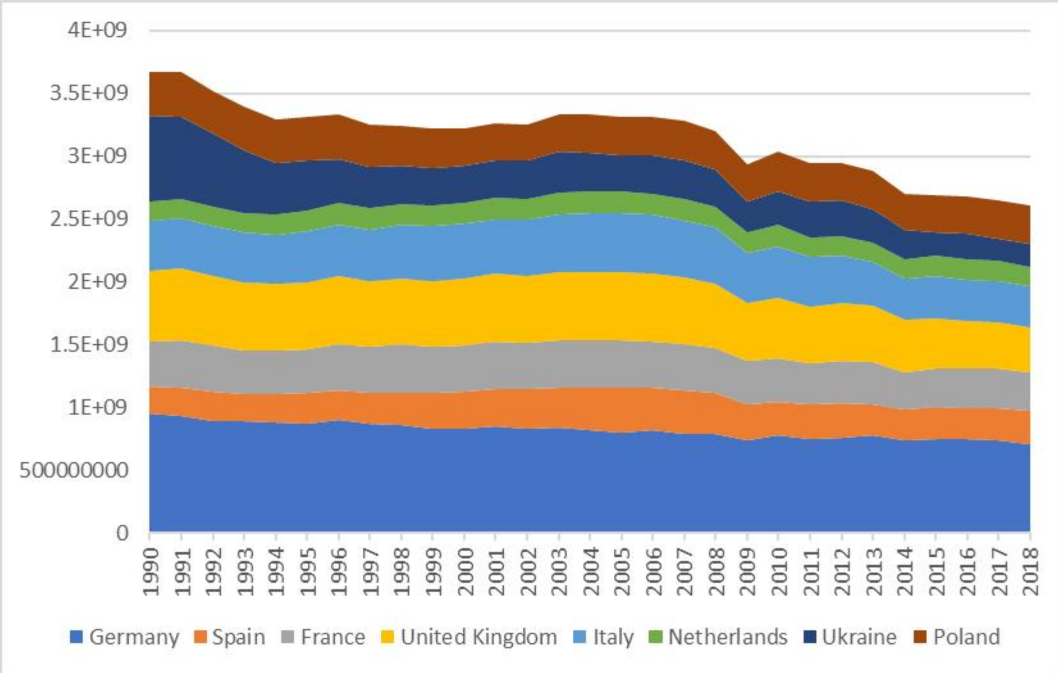
Figure 8. Most polluting companies in Europe (tons of CO_2)

Source: Renewable and Sustainable Energy Reviews (2021), Fekete.

Anyways, even if not at first place in the ranking, German companies took all the positions from place 2nd to 8th for being the most emitting plants in Europe, also due to the use of coal as the main source of energy for its thermal power plants (despite of that, Germany planned to eliminate coal-fired power supply by 2038).

[9] Available at https://ember-climate.org/countries-and-regions/countries/france/

Figure 9. Main European Countries' GHG Emissions Aggregate (tons).

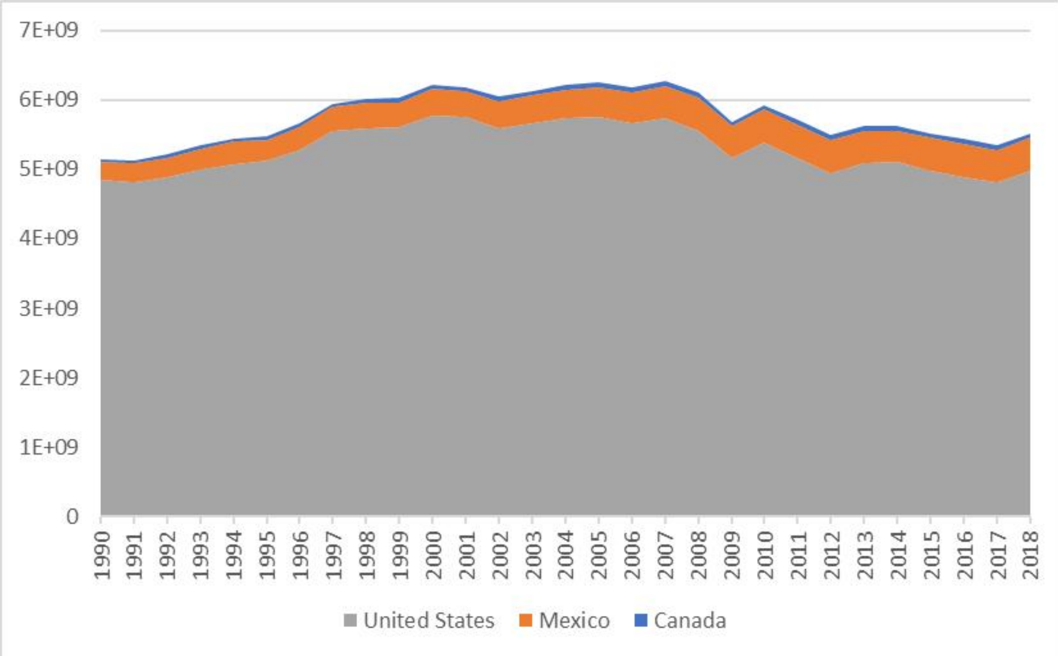


Source: own elaboration, data from World Bank.

3.2.2 NORTH AMERICA

As you might imagine, talk of North America usually means considering only the United States, as Mexico, Canada, and other insular countries report extremely lower levels of emissions, to the point of being considered omissible. In 2018, U.S. greenhouse gas emissions totaled 6,558 million metric tons (14.5 trillion pounds) of carbon dioxide equivalents. This total represents a 2% increase since 1990 but a 12% decrease since 2005.

Figure 10. United States of America, Canadian, and Mexican GHG Emissions.



Source: own elaboration, data from World Bank.

According to EPA – Environmental Protection Agency – (2021), emissions of carbon dioxide, the primary greenhouse gas emitted by human activities, increased by 3%, while Methane emissions decreased by 15%, as reduced emissions from landfills, coal mines, and natural gas systems more than offset increases in emissions from activities such as livestock production. Nitrous oxide emissions, predominantly from agricultural soil management practices such as the use of nitrogen as a fertilizer, increased by 1%.

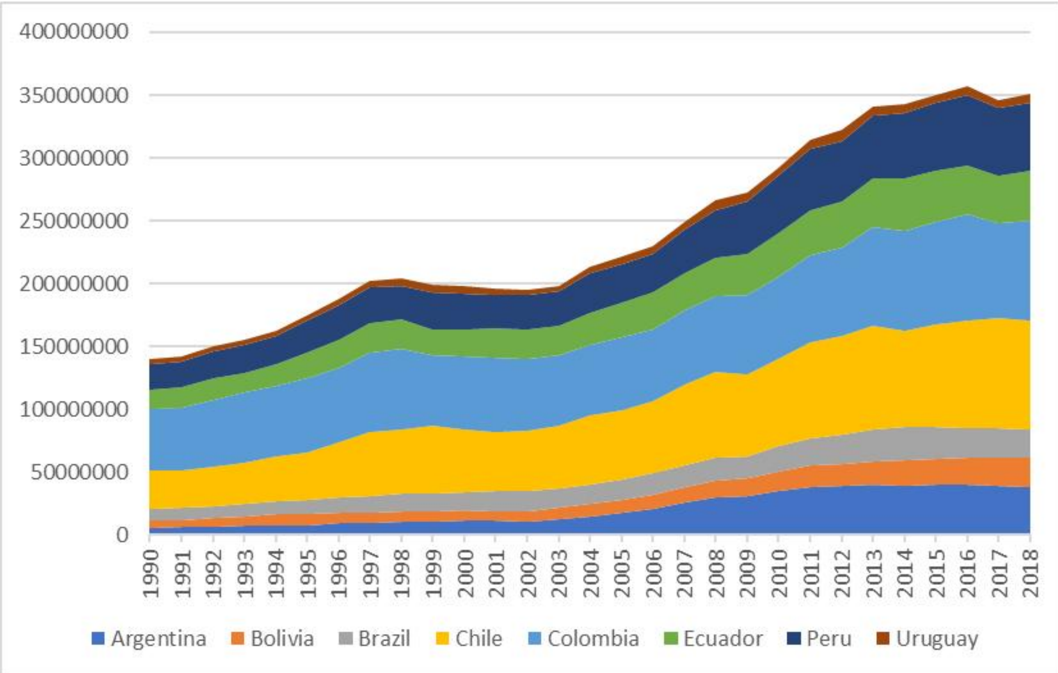
3.2.3 SOUTH AMERICA

Latin America have seen only modest growth at or below 1% per year emissions-wise, presenting patterns similar to other developing regions, such as Africa and Pacific Asia. According to Seri and Fernandez (March 2022), AFOLU is the largest emitting sector (specifically: CO_2 emissions from deforestation), yet much of the recent growth comes from the energy systems, industry and transportation sectors. Latin America is also notable for its high transport emissions, since in all other sectors apart from AFOLU it tends to be one of the lowest regional contributors. Land-use and management emissions here is associated with the expansion of agriculture into carbon-dense tropical forest areas, where vast quantities of CO_2 emissions are released due to the removal and burning of biomass and draining of carbon rich soils.

Land-use and management CO_2 emissions grew from 1990 to 2010 due to high continuous Amazon deforestation rates until the mid-2000s alongside accumulating legacy emissions (INPE 2020). However, deforestation rates subsequently decreased until 2018 following government initiatives and international moratoria (Nepstad et al 2014). This trend in emissions is likely to reverse past our time period of analysis, as the 2019 and 2020 seasons saw the highest Amazon deforestation rates since 2008 (Silva Junior et al 2021).

If we consider the larger countries from Latin America, we can easily outline the main differences and analogies between them in Figure 11: this graph puts in evidence the main trend followed by the continent concerning emissions, that is mainly upward, with a slight decrease before the beginning of the 21^{st} Century, a steady phase that lasted for 3 to 5 years, and then a considerable increase. The major emitters are Chile, Colombia, and Peru: these three countries alone constitute almost the 50% amount of South America emissions.

Figure 11. Aggregated GHG Emissions from Latin Countries (tons)



Source: own elaboration, data from World Bank.

Another important insight is that none of the major countries from Latin America has "improved" nor their absolute emission level nor their per-capita emissions.

3.2.4 ASIA and OCEANIA

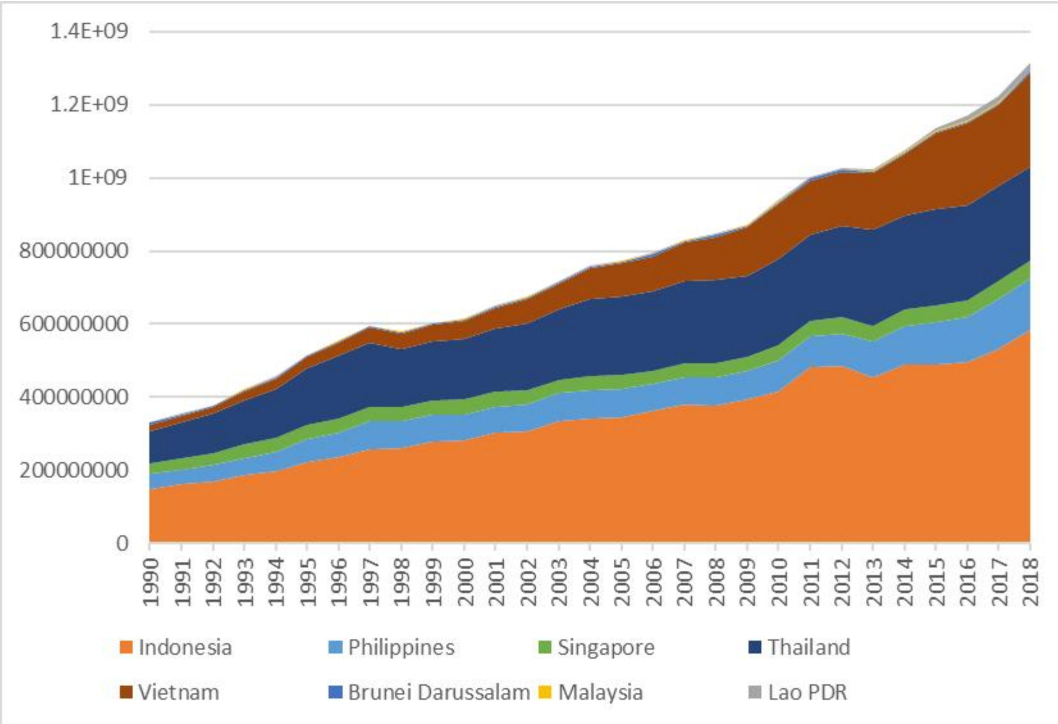
It goes without saying that Asia contributed on a large scale to the emissions during the last decades, since most of the developing countries (and more polluting ones) come from the continent. It is interesting to outline the fact that growth rates of emissions were relatively large for CO_2 because the major sources of these gasses are power plants, industries, and road transport, for which fuel consumption increased significantly along with economic development (same thing goes for other pollutants, such as SO_2 or NOx).

According to Lau et al. (2022), CO_2 emissions increased keenly in the early 2000s, along with rapid growth of emissions of these species in China. A change in China's production structure and consumption patterns (i.e., the type of goods and services consumed) have become the main moderating factors of emissions after 2010, while economic growth, consumption levels and investment remain the dominating factors driving up emissions.

On a regional basis, East Asia stands out as the largest contributor to energy systems emissions in 2018 (6.3 $GtCO_2eq$), and with the largest absolute growth from 2010 to 2018 (+1.2 $GtCO_2eq$), averaging 2.6% per year. Southern Asia, South-East Asia, and the Middle East are not amongst the largest absolute contributors, but they exhibit the largest annual growth rates of 4.9%, 4.3% and 3.3% respectively between 2010 and 2018.

ASEAN (Indonesia, Malaysia, Thailand, Philippines, Vietnam, Singapore, Laos, Cambodia, and Brunei) – as a whole system – increased its CO2 emissions since 1990 due to increased population, urbanization, and economic prosperity (probably total and per capita emission went up). In Figure 12 it is possible to outline the contribution to GHG emissions for each ASEAN member state, and in part, their trends in the period 1990-2018.

Figure 12. GHG emissions from ASEAN countries (tons of CO_2 equivalents).



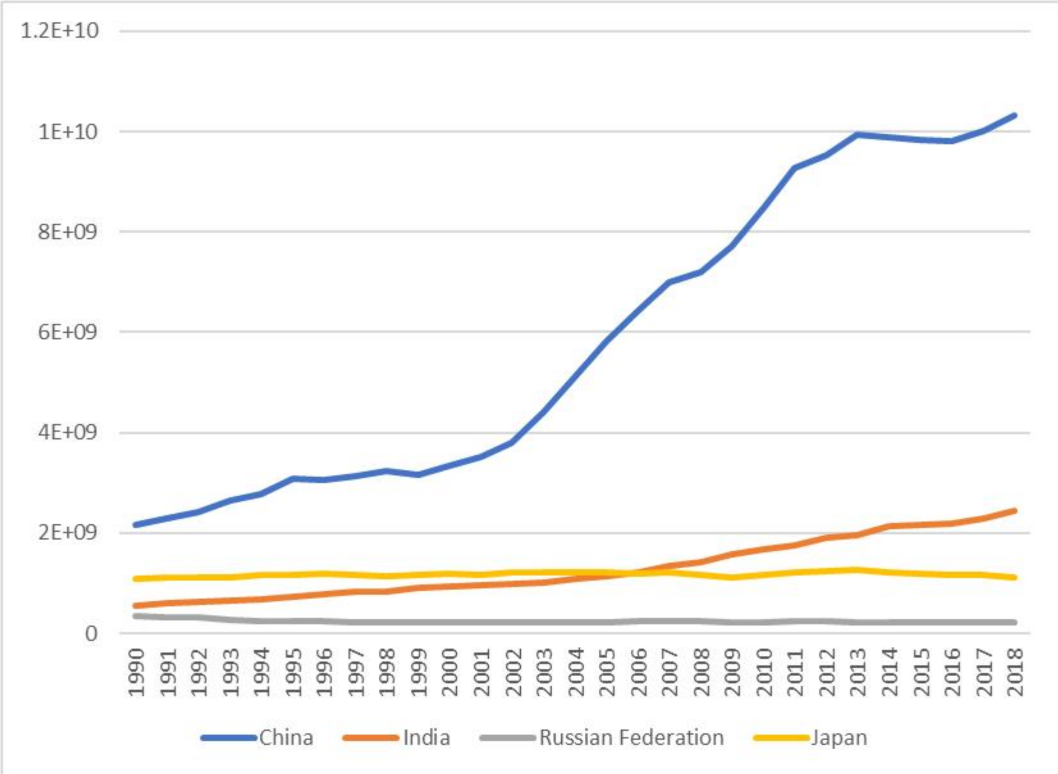
Source: own elaboration, data from World Bank.

It is clear that the major contributor is Indonesia, with an all-time-high of 6 million tons of CO_2 in 2018; in 2nd place, there's Thailand, followed by Vietnam, while smaller countries like LAO PDR and Malaysia are barely noticeable. Despite of that, all the member states are signatories to the Paris Agreement (December 2015), whose objective is to limit the rise of the world's temperature to less than 2°C above pre-industrial times. In ASEAN, renewable energies are mostly used for power generation, even though, as of 2018–2019, renewable electricity generation was only 25% of total electricity generation and renewable energy contributed only to 20% of TPES (= Total Primary Energy Supply).

Japan may be the only exception to this list, since it achieved the status of productive and developed country way before the others, and if compared to rest of Asia, emissions of all species in Japan – except for CO_2 – were reduced significantly after reaching peak values. This emissions' maximum has been reached before the interested period of this study (around the 60s), and after that, emissions have generally continued to increase, but with a less steep trend.

In India low emission efficiency and expansion of production and trade caused the growth of emissions: this became clearer and clearer after the 2000s, mainly due to an increasing consumption of fossil fuels coming from both power plants and road transport (tendencies were comparable to China's). In Figure 13, we can see emissions trends for these countries, and outline the remarkable – and alarming – levels reached by them, especially China and India.

Figure 13. Emissions of CO_2 equivalents from the main Asian countries, with the exception of ASEAN member states, in Tons of CO_2 equivalents.



Source: own elaboration, data from World Bank.

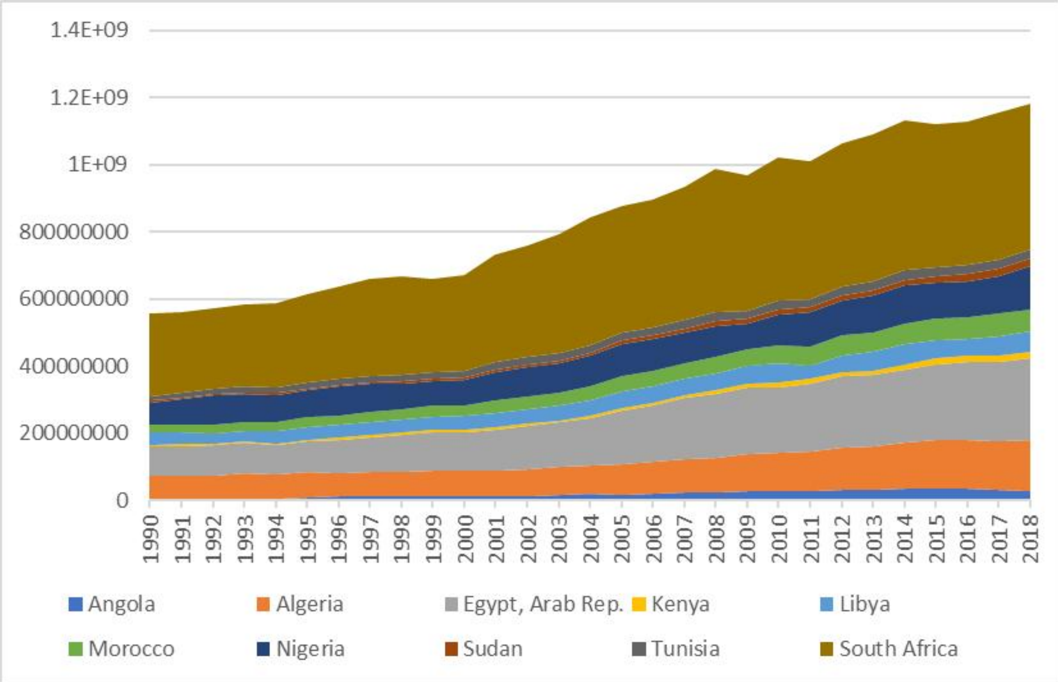
On the other hand, there is not much to say about Oceania, since many of these countries are latecomers to development, and many of them rely on low GHG emissions. Most of the countries are signatories of the Paris Agreement, and this defines the main inflection of the emissions' trend (mostly increasing until 2015, and after that, steady and decreasing).

3.2.5 AFRICA

In order to analyze African emission levels, I relied on a study published by Lacour M. Ayompe et al., called Trends and drivers of African fossil fuel CO_2 emissions 1990–2017. The authors utilized the Kaya identity as a mean to analyze patterns and trends in CO_2 emissions from the combustion of fossil fuels in Africa between 1990 and 2017 – Kaya identity is a mathematical identity stating that the total emission level of the greenhouse gas carbon dioxide can be expressed as the product of four factors: human population, GDP per capita, energy intensity (per unit of GDP), and carbon intensity (emissions per unit of energy consumed).

In this article, data show increasing trend in Africa's CO_2 emissions between 1990 and 2017, except in 2015. During this time, South Africa was the highest CO_2 emitter followed by Egypt, Algeria, and Nigeria. With about 1185 $MtCO_2$ emitted in 2017 Africa contributed to 4% of global CO_2 emissions with the lowest CO_2 emissions intensity of 34.9 tCO_2/TJ and CO_2 emissions per population of 0.9 tCO_2/capita compared to all regions of the world. However, Africa's CO_2 emissions/GDP of 0.5 $kgCO_2$/\$ was higher than that of all regions, except Asia with 0.6 $kgCO_2$/\$ (Canton, H. International Energy Agency, 2019).

Figure 14. Major African GHG emitters (1990-2018)



Source: own elaboration, data from World Bank.

Our results show that energy intensity in Africa decreased by about 15% between 1990 and 2017. During the same period, population, carbon intensity and GDP per capita increased by 97%, 47%, and 71% respectively. These resulted in a net increase in total emissions by 120% between 1990 and 2018. Mozambique had the highest increase in CO2 emissions (700%) in Africa between 1990 and 2018. This is not surprising as Mozambique also experienced increases in population (121%), GDP per capita (172%) and carbon intensity (300%) while energy intensity reduced by −73% during the same period.

Overall, CO_2 emissions increased in all countries between 1990 and 2017 except in DR Congo and Zimbabwe where emissions decreased by −33% and −38% respectively. During this period, all countries also experienced an increase in population with the highest increase occurring in Niger (169%), Angola (152%) and Congo (135%). Nevertheless, GDP per capita change over the same period varied widely from 172% in Mozambique to −42% in Congo.

Although emissions are decreasing elsewhere (e.g., Europe and the Americas) Africa's CO_2 emissions are poised to grow in the coming decades: the growth rate in energy related CO_2 emissions in Africa between 1990 and 2017 (123%) is considerably greater than the world average of 60%. Our results show that about 89% of African countries included in this study have increasing emissions ranging from 0.1%–42.9% yr−1 as recently as 2010–2017. Similar results have been found in developing countries such as China: one factor that influences CO_2 emissions is population growth since it consequently brings a higher need for energy for daily use.

3.3 Economic Clustering

The aim of this section is to talk about – and analyze – macro-regions and bundles of countries, which, like it was said previously, are grouped together due to social and economic reasons. The reason of this step – and desired output of the section – is to outline and bring out the main differences and analogies between the variables at stake like we did before, but instead of territorial clustering, we will consider social-economic characteristics (like income levels, social issues, and belonging to organizations).

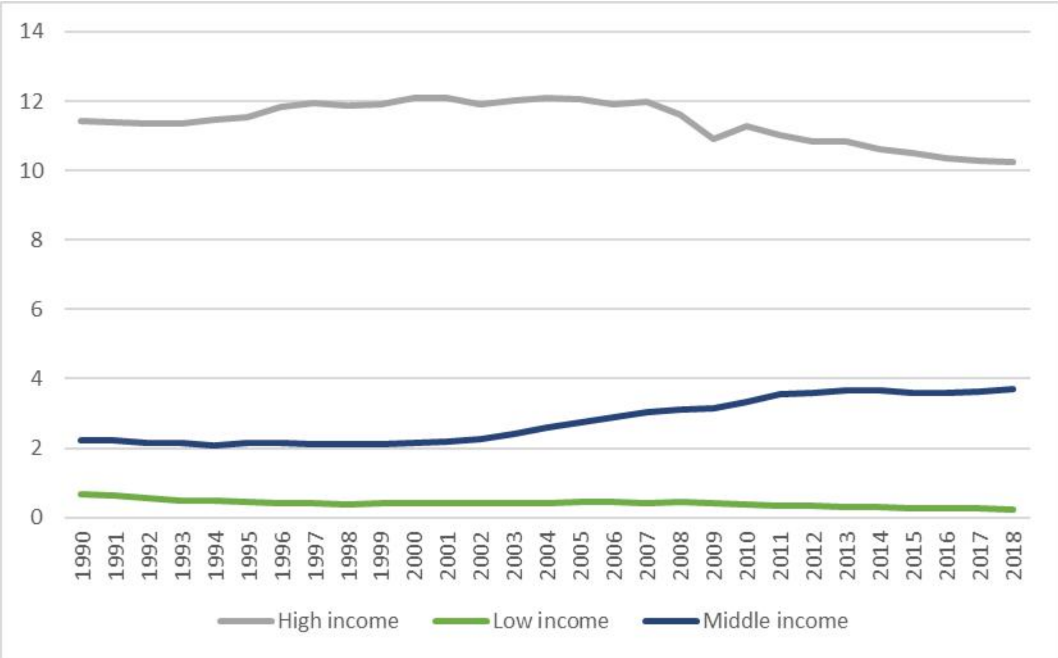
To sum up, the macro-regions that have been selected in the second chapter were: the European Union, fragile and conflict affected situations (FCAS), high-income, middle-income, and low-income, least developed countries, heavily indebted poor countries (HIPC), OECD members, and at last, the World as aggregate. In order to slender the paper, the only comparison that will be made are:

- High-Income vs Middle-Income vs Low-Income.
- Low-Income vs Least Developed Countries.
- Least Developed Countries vs FCAS vs HIPC.

In the first part of this section, it would be good to conduct a comparison between the three income ranges (look at section 2.1 for the characteristics of the ranges) in total emissions and per-capita emissions, analyzing trends and insights.

Figure 15 shows the per-capita trends of these income brackets, and, as it was easily predictable, high-income region reported the higher values, followed by middle and low-income. The main take from this representation is the difference in tendencies: the only one that increased its per-capita emissions in the period 1990-2018 is the middle bracket, and this might be explainable by the fact that most of the developing countries in the world – also considerable as the major emitters – are clustered into that group. Plus, it is iconic to notice how high incomes took the hit of 2008 - 2009 crisis, while on the other hand, the other two did barely flinched.

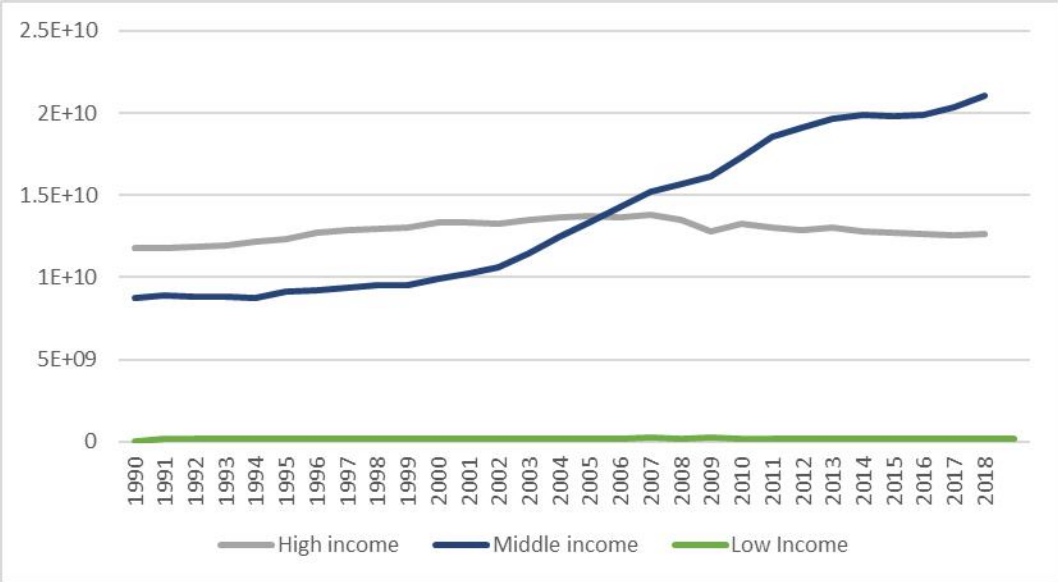
Figure 15. Per-capita GHG Emissions divided by Income Ranges (tons/capita).



Source: own elaboration, data from World Bank.

By looking at the comparison with Figure 16, it is remarkable how, from one day to another, the absolute emissions of the countries in the middle-income group took off and outperformed the high-income ones. This result "justifies" the modern polluting trends of the countries that are still developing – or the ones which recently developed.

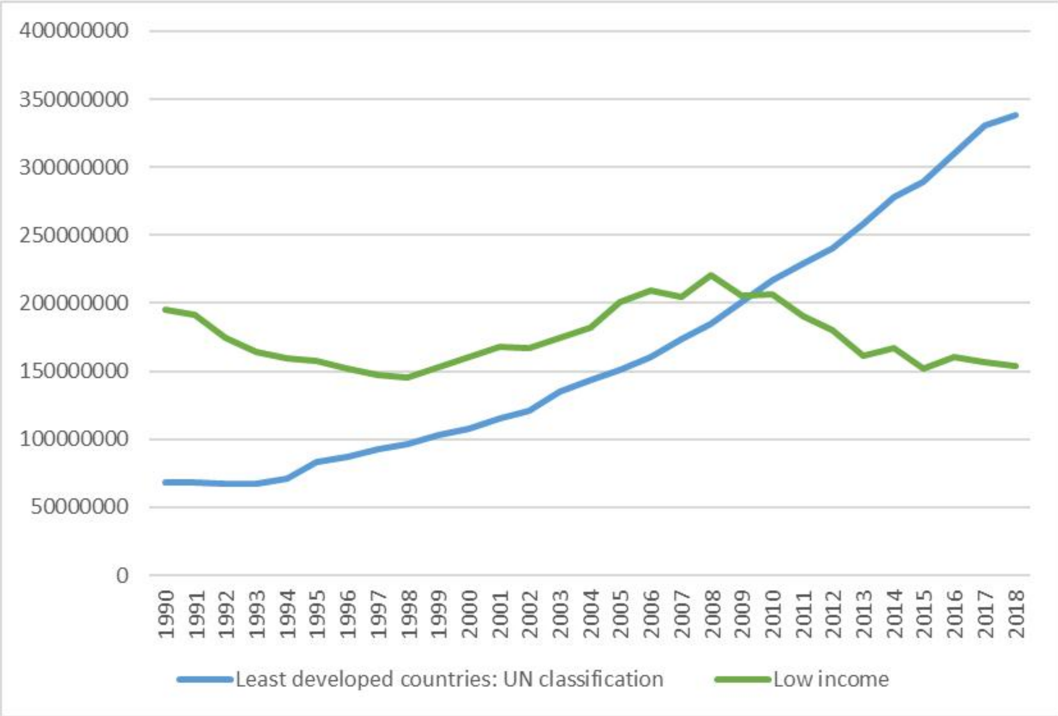
Figure 16. Total GHG Emissions divided by Income Ranges (tons).



Source: own elaboration, data from World Bank.

The second comparison will be betweeen Low-Income countries aggregate and Least Developed Countries. The decision behind this comparison lies in the question: "are the least developed countries the same as the ones clustered into the Low-Income group?" But the answer seems to be tricky, and, at first, not so easy. Through the help of figure 17, we can spot some differences since the beginning, with the low incomes having consistently higher emissions than the least developed, then they follow a similar path until 2009, when something cracks: in post-financial chrisis years, the Least Developed Countries start producing higher amounts of GHG, outperforming the others.

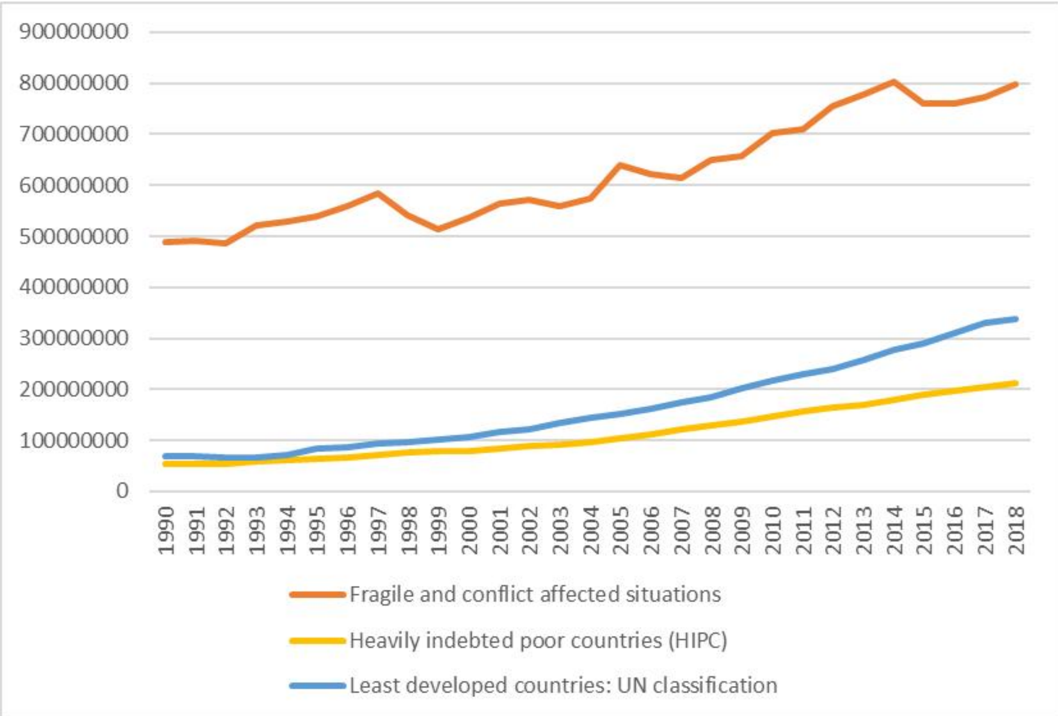
Figure 17. Low-Income vs Least Developed Countries Total Emissions (t)



Source: own elaboration, data from World Bank.

The third and last comparison will be made between the Least Developed Countries, Fragile and Conflict Afflicted Situations, and Highly Indebted Poor Countries. Two things are immediately clear: FCAS have nothing to do with the other two, while on the other hand, HIPC and Least Developed are basically the same countries, with some adjustments, since they follow very similar trends and the emission levels are close to each other. The thing with FCAS could be that, despite of the socio-economic situation these countries find themselves in, they are still able to keep a steady production (and emission levels), even if with relative lows and peaks. These countries are not comparable with the other two categories because many of them are "developed" countries – or in any case, countries that are not from the poorest areas of the world – such as Ukraine and Venezuela. On the other hand, Least Developed and HIPC share basically the same countries, with some exceptions, thus they are very similar.

Figure 18. Least Developed Countries vs FCAS vs HIPC Total Emissions (t)



Source: own elaboration, data from World Bank.

3.4 The Problem with Carbon Intensity

Let's begin this section with a simple definition: carbon intensity is basically the ratio of the emission of a pollutant from a given emission source, to the indicator unit of that source. In our case, we talk about carbon intensity within the ratio "*tons of CO_2 on thousands of $*". It was necessary to use the unit "thousands of $" because of the quality of the results, since using the dollar (USD) as unit of measure of the GDP would compromise the precision of the data (all data concerning carbon intensity would appear in the order of the 3rd or 4th decimal place).

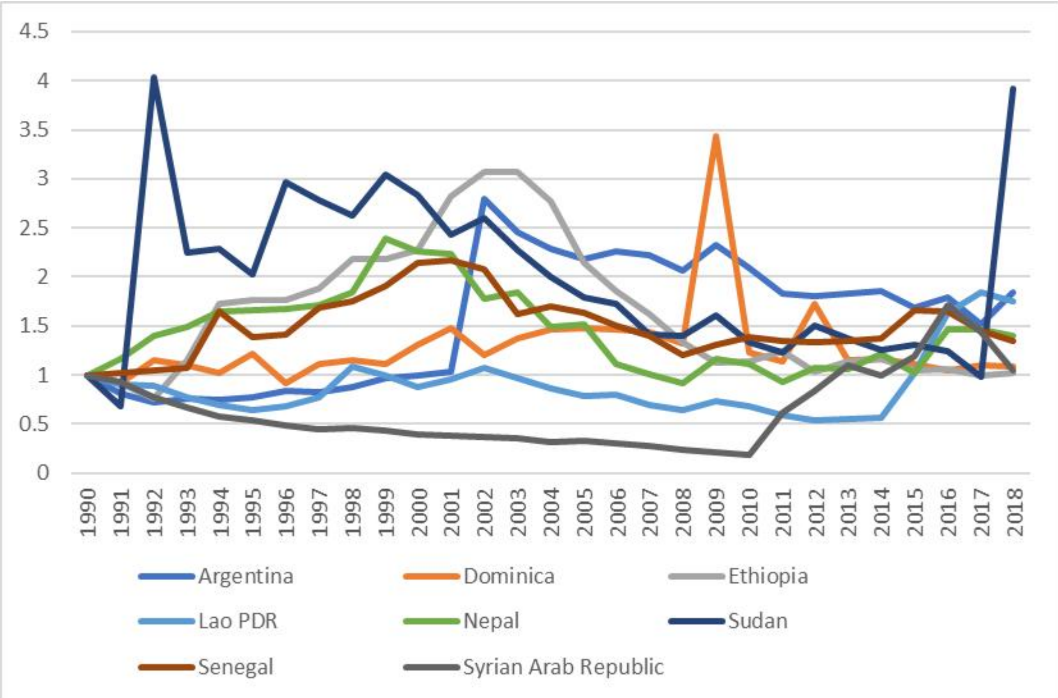
The main take from this topic is that – similarly to what we have seen with per-capita emissions – if we want to reduce emissions, we must reduce the GHG emissions produced by spending a dollar (or euro, etc.). Once again, this condition is necessary, but not enough to reduce the total pollution caused by GHG, because changes in GDP might compensate in the ratio (if emissions are steady, but GDP increases, the effect will be a decreasing carbon intensity).

In this study, the majority of the countries present encouraging improvements, when comparing the values of carbon intensity of 1990 vs 2018, but still, there are some countries in which this measure got worse during the years. In particular, these countries belong to specific regions in which there might be problems concerning GDP, such as South America (Argentina, Dominica), Sub-Saharan

Africa (Ethiopia, Mozambique, Senegal, Sudan, etc.), and Asia-Pacific (Burkina Faso, Bangladesh, LAO PDR, Syria, etc.).

Of course, it is not possible to say that low GDP is always the main problem, since, as we already said before, the balance of carbon intensity lies in the variation of both absolute CO2 emissions (in tons) and GDP (in thousands of $).

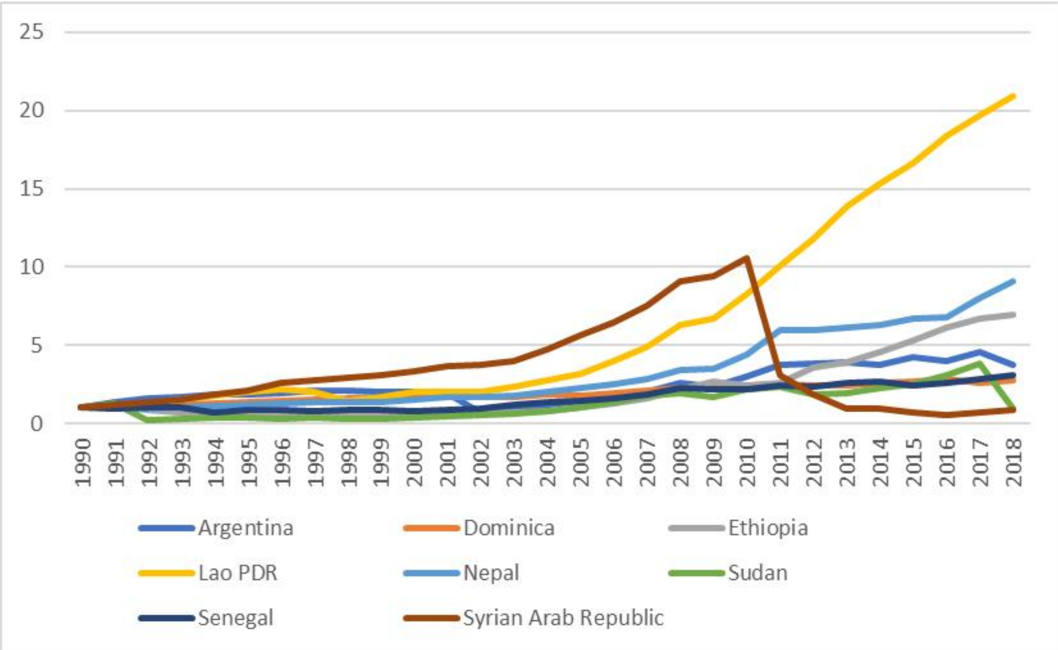
Figure 19. Carbon Intensity trends of countries whose Carbon Intensity index got worse in the period 1990-2018 (indicized scale).



Source: own elaboration, data from World Bank.

But, on the other hand, as demonstrated by Figure 20, we can notice that the only countries (in the previous list) which experimented a decreasing GDP during the period 1990-2018 are Sudan and Syrian Arab Republic (respectively, green and brown lines).

Figure 20. GDP trends of countries whose Carbon Intensity index got worse in the period 1990-2018 (indicized scale).



Source: own elaboration, data from World Bank.

With that being said, we can state that all the other countries – other than Sudan and Syrian Arab republic – whose Carbon Intensity increased, are "guilty" of major GHG emission. Of course, in contrast to the previous situation concerning per capita emissions, it is difficult to point out one of them as the "worse phenomenon" – between the increase in emissions and the decrease in GDP – since they harm different aspects of a country and/or society.

The main take from this section is that most of the countries that the paper included in the study reported a reduction of their carbon intensity in the period 1990-2018, with the few exceptions that we have seen a while ago, but – and this has to be repeated with the risk of sounding redundant – that is not enough. It's not enough because the thing that counts the most is absolute decarbonization, otherwise seen as the overall reduction of the absolute emissions of GHG. In particular, there are countries that, even though they presented a reduction in carbon intensity, they could not reduce their absolute emissions.

At this point, it is possible to create a list of the countries that were able to achieve – in the period 1990-2018 – all three of the goals set by this study, that are:

- Reduce their per-capita emissions (depending on total emissions and pop.)
- Reduce their carbon intensity (depending on total emissions and GDP)
- Reduce their total emissions.

Basically, the countries that could achieve decarbonization on an absolute level (reduction of total emissions of CO_2) also reduced their per-capita emissions and carbon intensity. This means that, even though there could have been variations in their population level or GDP, their effort in emission reduction alone was enough to balance the ratio (since, as we have seen, good results on per-capita emissions and carbon intensity are achievable through population or GDP increases, too). So yes, there are countries who can play at "The Game of Decarbonization", and Table 1 summarizes them in a nuthsell.

Tab 1. Countries that reduced their Total Emissions in the period 1990-2018.

United Arab Emirates	France	Malta
Andorra	United Kingdom	Poland
Azerbaijan	Georgia	Russian Federation
Bahrain	Greece	Slovak Republic
Belarus	Italy	Sweden
Switzerland	Kazakhstan	Syrian Arab Republic*
Congo, Dem. Rep.	Kyrgyz Republic	Tajikistan
Czech Republic	Liechtenstein	Ukraine
Germany	Luxembourg	Uzbekistan

Source: own elaboration, data from World Bank.

There is one particular situation – Syrian Arab Republic – in which total emissions were reduced at the end of the period, but its carbon intensity did not improve the same way. We can state that this happened because of the other driver – GDP – and, as a matter of fact, Syrian GDP registered a 10,29% (more or less $ 2’458’724’000) loss in the period 1990-2018.

Furthermore, we can state that many of the countries that resulted to be the best at reducing the emissions come from Europe (and some of them from Mid-East, too). All this is indicative of the fact that European countries, over the past three decades, have paid more attention than others to the issue of CO_2 emissions reduction. It is worth specifying, that these (European) countries are in the upper-middle range of GDP per-capita, a factor that can lead greater shares of investment by governments towards sustainable energy production technologies.

Chapter 4. Emissions and Growth

In the third chapter, we had the chance to outline the differences in emissions of greenhouse gasses between the countries of the study, putting a focus on some aspects, such as population (in order to find out about per-capita emissions) and GDP (in order to get information about carbon intensity). As obvious as it is, the connection between population and emissions is immediate: as a consequence of an increased population of a country (or macro-region), that very country will also experience an increase in emissions, stated the fact that everyone will keep their emissions rate still (nobody tries to reduce their emissions to face the more popolous situation). The question here is simple: is there such a relationship that ties together CO_2 emissions and GDP growth, too?

To answer this, it is necessary to compare – ideally for every country – the national level of CO_2 emissions per-capita and the per-capita GDP. The result of comparing these two measures, once placed in a scatter plot, should be the ones expected by the Kuznets curve. The Kuznets curve is the inverted U-shaped relationship between economic development (growth) and economic inequality, studied by this economist mainly in the '50s. This model is able to explain the relationship between economic development (GDP growth) and environmental degradation (in our case, CO_2 emissions). As a matter of fact, since the early '90s (being, coincidentally, the virtual beginning of our study), this relationship has been observed empirically for a number of phenomena, mainly involving air pollution.

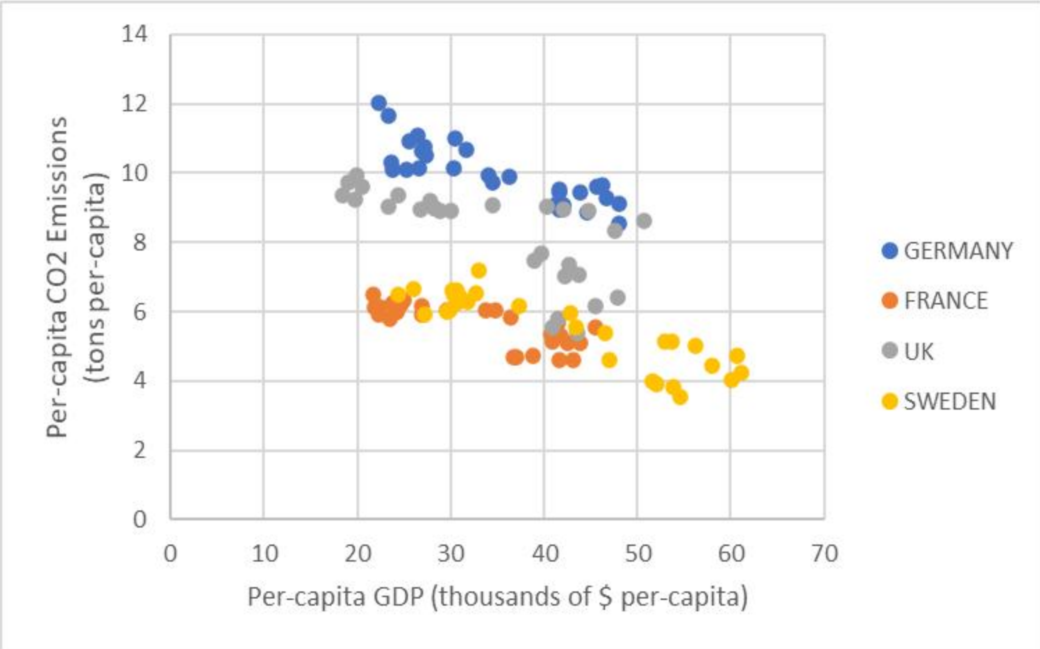
This type of analysis provides results that may vary depending on the cases considered, in terms of shape of the finale curve: the previously-cited “inverted U-shaped” relationship represents a situation in which:

1. GDP per-capita increasing over-time, meaning that there is an actual growt (this gives the curve a progression along the x-axis).
2. Per-capita emissions increase at first, and then decrease in the second part of the graph, thus defining the inverted U-shape, also recalling a bell shape.

For the sake of the study, the next representations will provide information about groups of countries that presented similar traits in the study, emissions-wise, in order to catch the results obtained analysing different trends.

In Figure 21, we can see some of the European countries that could achieve – according also to Table 1 – decarbonization on an absolute and relative level, and a decreasing trend for carbon intensity, too. The following countries respected the criteria of increasing GDP per-capita and emissions, but due to the temporal constraints of the data in this study, it is not possible to denote the initial ascent of the various trends (if our data started fifteen or twenty years before, it would have been possible to draw the bell-shape). Despite of that, it is clear that the scatter plot defines a decreasing pattern for all these countries, compatible with the final part of the Kuznets Curve.

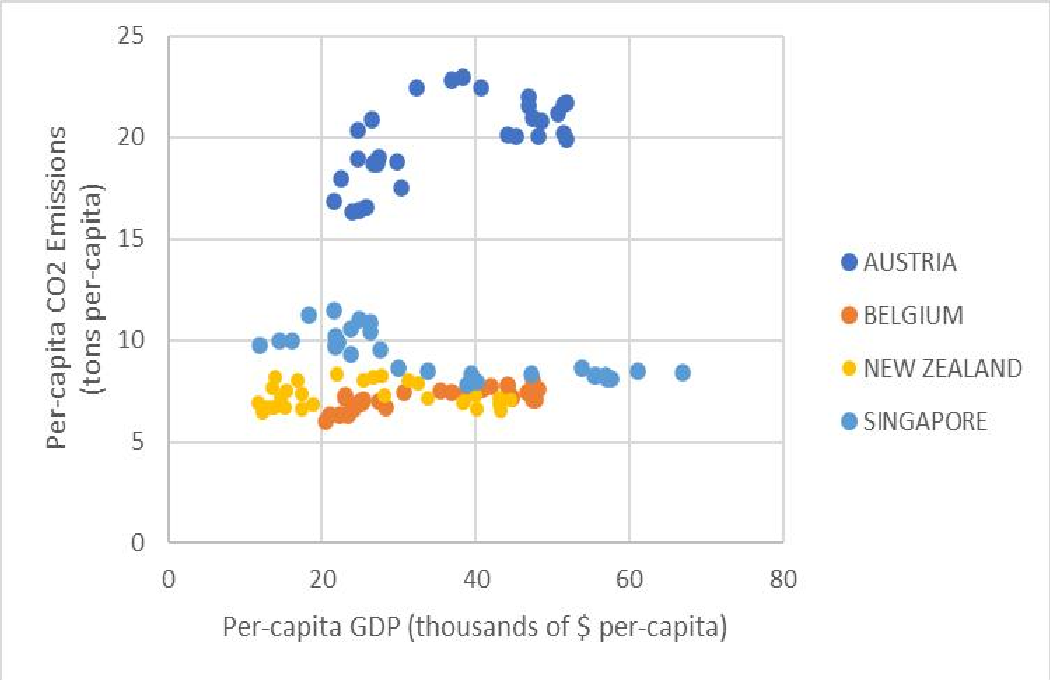
Figure 21. European countries that reduced their GHG emissions (absolute and relative) and carbon intensity.



Source: own elaboration, data from World Bank.

In the following graph (Figure 22) it is possbile to make the same analysis, but this time for countries that could not achieve decarbonization on an absolute level, even though the per-capita decarbonization is promising (as shown previously in Figures 2 and 3). The thing to say here – and it is really clear in Austria's scatter plot – is that the relationship between per-capita emissions and GDP shows an intermediate stage of the Kuznets Curve. Coming back to Austria, even though the final per-capita emissions could not fall underneath 1990's level, it is clear that the graph plotted a inverted U-shape, meaning that, in the next few years, the result will be that of a neat reduction of the GHG emissions.

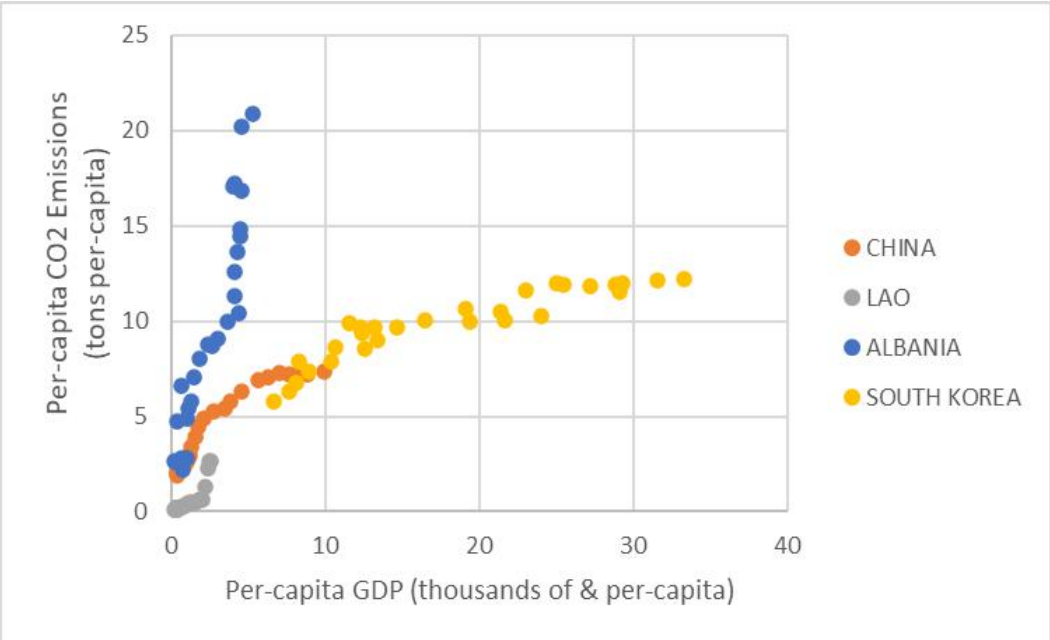
Figure 22. Countries that poorly performed on absolute decarbonization, but achieved per-capita decarbonization.



Source: own elaboration, data from World Bank.

In the final section of this chapter, we will see the relationship between per-capita GDP and emissions in the case of countries that significantly increased their emissions (Figure 23), both at an absolute and relative level. Similarly to the previous two situations, it is possible to outline a pattern that is common to these trends: if in Figure 21 we plotted graphs resembling the final part of the Kuznets curve, and in Figure 22 the trends resembled the intermediate stage of the model, we expect here to reproduce something that could look like the initial part of the EKC (Environmental Kuznets Curve). And, as it can be noticed in the figure, the represented trend is an increasing function with downward concavity.

Figure 23. Countries that increased their emissions and per-capita emissions.



Source: own elaboration, data from World Bank.

Even though it was not possible to plot a complete EKC, it turned out that the selected countries reported something resembling the different stages of the model. This might explain the fact that there is a cycle every country is going through, but they find themselves at different steps of it, according to their degree of development, too. In particular, we've seen:

1. Starting stage (increasing function with downward concavity) – found in the countries that reported increases in emissions, both at absolute and relative level.
2. Intermediate stage (characteristic U-shaped turning point) – noticed in the countries that reported promising reductions in per-capita emissions, but still far away from absolute decarbonization.
3. Final stage (decreasing function) – reported by the countries that achieved decarbonization in the period 1990-2018, both at absolute and per-capita level.

Conclusions

The aim of this study was to bring out information and insights about how countries around the world behave when it comes down to emissions and air pollution, and, once at this point, we could say that some of the question we had at the beginning have been answered.

The main take is that few countries in the world are actually serious about decarbonization, and they are often "grouped" in macro-regions: to draw an example, most of them are in Europe. Does this mean that European countries are more invested in reducing the CO_2 concentration in the atmosphere? That is not so unlikely, since 18 out of the 27 countries that resulted to have reduced emissions are from Europe (see Table 1), but also countries from the Middle East seem to have taken this issue seriously (see Bahrain, United Arab Emirates, and Syria), even though they might be fossil fuels exporter (thus, encouraging GHG emissions among their buyers). It is a vicious circle.

On the other hand, many of the countries that resulted to be furthest away from the decarbonization targets, happened to belong to the same areas, such as Latin America, North America, and East Asia (according to the results, the top 5 ranked emitting countries are: China, USA, India, Russia and Japan, with Canada ranked 7^{th}). Furthermore, there are countries belonging to middle-lower income brackets that report very high values about emissions per-capita and carbon intensity, probably because they are unable to produce sustainable energy with their limited resources (many of them have GDP or society-related issues to deal with, introducing once again the scale problem).

The results found in Chapter 4 have been kind of encouraging from an environmental point of view, since it explained that, with the current policies and sensitivity with regards of the environment, countries all around the world will come to a point where they will reduce their emissions of greenhouse gasses. Obviously, this is not an automatic and immediate process, and it can take years for Governments (especially the ones that are less developed or in particular situations) to implement the tools and infrastructure to address these problems. And back to the Kuznet Curve (EKC model), there are still disputes around the topic, since the model does not automatically apply for all the countries:

- In the case of certain phenomena – such as strong pollution – empirical data becomes way more complex than in standard scenarios (L-shaped and N-shaped curves, etc.).
- Even if we could apply the model to all the countries, the big economies that are still within the transition process might trigger serious consequences that could preclude the downward phase, thus impeding the reduction of emissions and terminal part of the EKC.

Furthermore, changes in better do not happen magically or out of the blue, they should be the result of consciousness-raising by political and environmental authorities, implementation of efficient and effective policies, and perserverance in the application of those policies. Countries that reported encouraging numbers are not allowed to take breaks, and the economies that turned out to be over-polluting should revise their behaviours. The main take from all this is that – as they say – the sooner the better, when it comes to our emissions habits. The planet we call home is one, and one only (for now).

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