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**DECOMPOSITION ANALYSIS OF CO₂ EMISSIONS: HOW DID THE
2008 CRISIS CONTRIBUTE TO THE "DECARBONIZATION" OF THE
WORLD ECONOMY?**

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Introduction

This work analyses global and regional trends in carbon dioxide (CO₂) emissions from fossil fuel and discusses results obtained from a decomposition process of emissions driving factors (economic growth, energy intensity of GDP and carbon intensity of energy) up to 2013.

In the intensive debate on global warming and climate change, few basic facts can be given for granted. First, since decades, CO₂ emissions have been accelerating at a global scale (IPCC, 2014), and the human influence on them is clear and visible (Oreskes, 2004; Doran, 2009; Anderegg, 2010 and Cook, 2013). Second, emissions from the burning of fossil fuel represent the primary cause of global warming (epa.gov). Third, national and international initiatives have not been effective in curbing global atmospheric concentrations of greenhouse gases.

A recent event brought global attention back to the crucial topic of climate change. At the end of 2015 Paris hosted the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change: the 195 countries involved managed to achieve a new international agreement to keep global warming below 2°C. The shared decision to limit the rising temperature below a certain threshold represents a fundamental milestone and allows us to be less pessimistic about the world's future. However the development and implementation of climate change policies require a specific analysis of past emissions, to detect the risk of deviation from emissions reduction targets and to identify the emission sources to concentrate on as a priority (Janssens-Maenhout, 2013). In this context, it emerges the importance of analysing the driving factors that mostly affected the historical trends in emissions.

Through this work we want to understand how the path of CO₂ emissions evolved during the last four decades and which drivers have affected them most. In order to perform our analysis we adopt standard decomposition techniques, based on the Kaya identity, to break up carbon dioxide emissions into four driving factors (population, GDP per capita, energy intensity of GDP and carbon intensity of energy).

The work is organised as follows. In Chapter 1 we introduce the topics of global warming and climate change, by looking at anthropogenic causes, and we illustrate global and regional trends in greenhouse gases emissions trends. In Chapter 2 we introduce the 'Kaya identity approach', comparing pros and cons, and we perform the decomposition analysis over different countries and regions (China, US, India and OECD Europe) accounting for specific time intervals. In Chapter 3 we concentrate on the period of the global financial crisis, in

order to see whether changes in driving factors have been registered, and if the decarbonization trend that the world have started came to an halt or not. Finally, conclusive remarks summarizes the analysis we went through.

CHAPTER 1

Global warming and CO₂ emissions

On August 2015, President Barack Obama announced a new and ambitious plan to cut off emissions of the gases responsible for the greenhouse effect: the America's Clear Power Plan would force each single State to cut carbon pollution by 32% within 2030 (comparing to the 2005 levels of emissions). This is just one of the facts it is possible to mention in order to show how the topic of global warming and climate change is still crucial and present in the political debate.

1.1 Global warming

1.1.1 Trends in the world temperature and observed climate changes

In the speech, President Obama stated: "2014 was the planet warmest year on record. One year does not make a trend, but fourteen of the fifteen warmest years on record have fallen within the first fifteen years of this century".

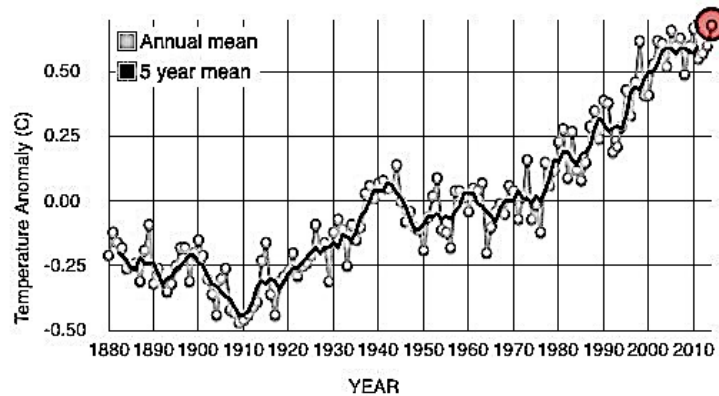
Global warming is defined as the gradual increase of the overall temperature of the earth's atmosphere (Oxford Dictionaries). According to data provided by the National Oceanic and Atmospheric Administration (NOAA), 2014 has been declared as the warmest year on record in their databases because the global temperature was 1.24°F (0.69°C) above the long-term average for the 20th century.

Climatologists, however, prefer to combine short-term weather records into long-term periods when they analyse climate. There is no universal definition of what really earth's average temperature is, and there exist different methods to track it: however, what emerges from these different sources (NOAA National Climatic Centre, NASA Goddard Institute for Space Studies and UK Met Office Hadley Centre) is that trends are remarkably similar, and it is possible to say that almost the entire globe has experienced global warming recently (see [Figure 1.1](#)).

It has been observed that (IPCC, 2014) each of the last three decades have been successively warmer than any preceding decade since 1850, at the earth's surface; in the northern hemisphere, the period from 1983 to 2012 was very likely the warmest 30-years period of the last 800 years.

Averaged over all land and ocean surfaces, temperatures warmed roughly 1.53°F (0.85°C) from 1880 to 2012, as presented by the Intergovernmental Panel on Climate Change (IPCC).¹

Figure 1.1 - Global land-ocean temperature index



Source: <http://climate.nasa.gov/vital-signs/global-temperature/>

A recent research highlighted that global warming proceeds more rapidly than previously anticipated and, if current trends continue, the mean global temperature could increase 1.4 to 5.8°C by 2100 relative to 1990 (Edenhofer, 2009).

Global warming and climate changes are often used as synonyms, meanwhile there is a difference in their meaning: basically the latter is one of the consequence of the former.

Considering the unequivocal warming of the climate system, in recent years the environment has been showing with clear evidence the impact of climate changes on it: not only the atmosphere has warmed, but the oceans too, and the amount of snow and ice has diminished (IPCC, 2014).

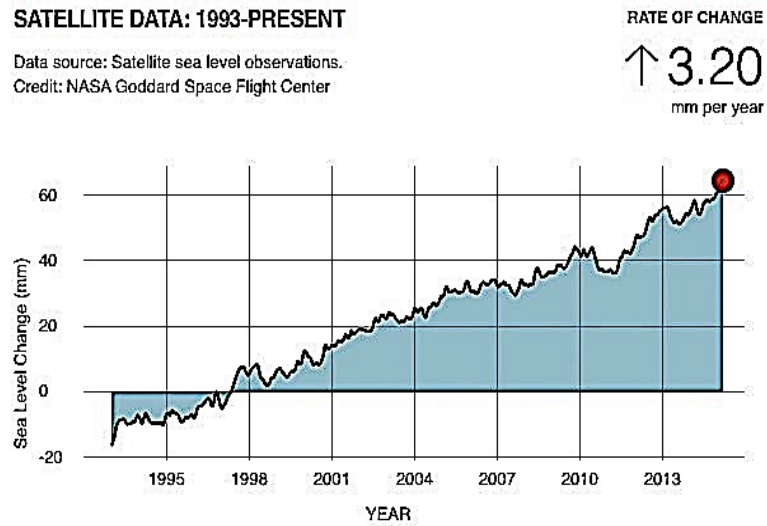
Ocean warming dominates the increase in energy stored in the climate system; on a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11°C per decade over the period 1971-2010. Consequences of the process of global warming can be measured on the cryosphere too: glaciers have continued to shrink almost worldwide, and the Greenland and Antarctic Ice sheets have been losing mass, contributing as a result to the sea level rise. During the last century, global mean sea level rose by 0.19 m (Church, 2006). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia.

Finally, the number of record high temperature events has been increasing, together with increasing intense rainfall events.

¹ Most of the data presented in this section are taken from the IPCC, a leading international scientific body for

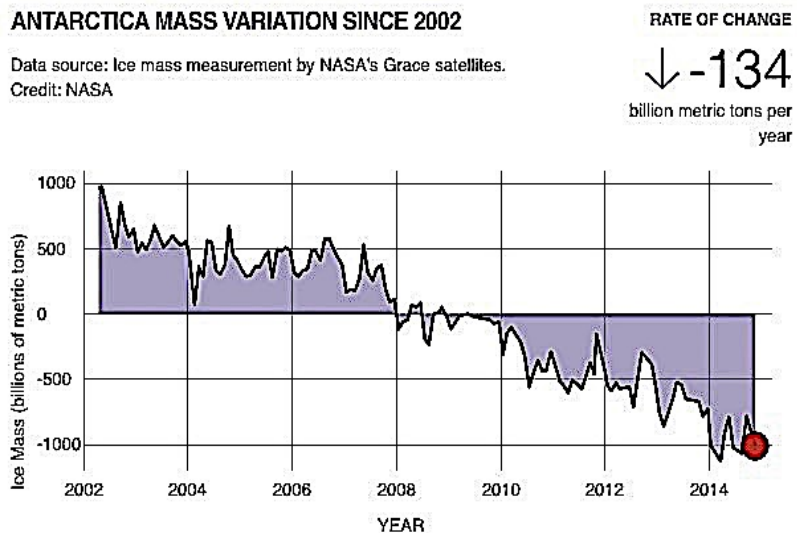
The NASA's Jet Propulsion Laboratory provides some useful graphs (see [Figure 1.2](#) and [Figure 1.3](#)) about the compelling evidence for rapid climate changes: from the first glance everyone is able to understand the magnitude of these climate changes and how much the recent trends are significant.²

Figure 1.2 - Sea level satellite data



Source: <http://climate.nasa.gov/vital-signs/sea-level/>

Figure 1.3 - Antarctica mass variation



Source: <http://climate.nasa.gov/vital-signs/land-ice/>

² See Appendix 1

1.1.2 Potential causes of global warming

Scientists have spent decades trying to figure out what causes global warming.

First, there are causes that cannot be controlled and addressed by humans, and that are not related with human activities: natural cycles (with different intensity and duration), variations in the solar output and brightness, small wobbles in the earth's orbit, volcanic eruptions and others.

Changes within the sun and changes in the earth's orbit affect how much solar energy reaches the earth, provoking warming or cooling periods (NCR, 2010). It already happened in the past, when the solar variability has played a role in climate changes (Jansen, 2007; NCR, 2010): the so-called 'Little Ice Age' between the 17th and 19th centuries may have been partially caused by a low solar activity phase from 1645 to 1715, which coincided with cooler temperatures (Greenland was largely cut off by ice and glaciers advanced in the Alps). However, since 1750, the average amount of energy coming from the sun either remained constant or increased slightly; furthermore, since 1978, a series of satellite instruments have measured the energy output of the sun directly, showing a very slight drop in solar irradiance over this time period (therefore, the sun does not appear to be responsible for the warming trend observed over the past 30 years).

Volcanic activity had also, in the deep past, contributed to episodes of global warming. More recently two major volcanic eruptions happened (El Chichon in 1982 and Pinatubo in 1991), pumping sulphur dioxide gas high into the atmosphere and causing a dipping in the global temperature for the following two/three years (USGS, 2009). Although many volcanoes are still active around the world, and continue to emit carbon dioxide, the amount they release is extremely small compared to human emissions.³

The vast majority of the scientists (Oreskes, 2004; USGCRP, 2009 and IPCC, 2014) agree that the main cause of the rapid warming process is the *greenhouse effect*: basically it is a layer of greenhouse gases - primarily water vapour, and then smaller amounts of carbon dioxide, methane and nitrous oxide - that act as a thermal blanket for the earth, absorbing heat and warming the surface to a life-supporting average of 59°F (15°C). Without the greenhouse effect the earth would be a too cold place considering the normal temperature we are used to. But today "atmospheric concentrations of GHGs are at levels that are unprecedented in at least 800,000 years" (IPCC, 2014).

³ On average, volcanoes emit between 130 and 230 million tonnes of CO₂ per year; by burning fossil fuels, people release in excess of 100 times more into the atmosphere every year.

Some of the previously mentioned GHGs are considered responsible for climate changes because their concentration (especially referring to carbon dioxide) have hugely increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever (IPCC, 2014).

This is why we will later focus on the anthropogenic GHGs emissions: the current warming trend is of particular significance because most of it is very likely human-induced (and proceeding at a rate that is unprecedented in the past 1,300 years). In its Fourth Assessment Report, the IPCC 2007 concluded that there is a more than 90% probability that human activities over the past 250 years have warmed our planet.

The first gas considered responsible for global warming is CO₂: over the last century the burning of fossil fuels, like coal and oil, has increased the concentration of atmospheric carbon dioxide. But it is important to notice that some greenhouse gases trap more heat than others; a molecule of methane trap 20 time more heat than a molecule of CO₂, and one of N₂O (that derive from fertilizers, gases used for refrigeration and industrial processes) is even 300 time more powerful.

1.1.3 Risks and impacts of climate change

We have already pointed out that during the 20th century the earth's average temperature has increased of about 1 Celsius degree (IPCC, 2014); it may look like a relatively small change, but it is an unusual event in our planet's recent history, and even small changes in temperature correspond to enormous changes in the environment. "Temperatures are rising, snow and rainfall patterns are shifting, and more extreme climate events - like heavy rainstorms and record high temperatures - are already taking place" (epa.gov).

Natural and human systems have already been affected by climate changes and, if the current trend continues, risks will be magnified and new ones will be created. However the extent of climate change effects on individual regions will vary over time (and from region to region - effects are unevenly distributed) and with the ability of different societal and environmental systems to mitigate or adapt to change.

The Fifth Assessment Report of the International Panel on Climate Change deeply analyse the future risks and impact of a changing climate:⁴

- The first risk derives from storm surges, sea level rise and coastal flooding, inland flooding in some urban region and finally periods of extreme heat. Climate

⁴ See Appendix 2

changes will have major effects on the world's water system: in mountainous regions, melting glaciers are impacting on freshwater ecosystems causing widespread floods (eventually followed by long-term water shortages and related humanitarian and environmental problems). Oceans, which importance is strategic because of their 'ability' to absorb carbon dioxide, are becoming more acid (since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30% - noaa.gov), because of higher temperatures and huge GHGs concentrations⁵; rising seas threaten to inundate low-lying areas and islands, together with dense coastal populations. Periods of extreme heat will provoke an increase in the number of heat-related deaths⁶, more frequent and severe periods of droughts in certain areas (again, with relative consequences for agriculture, water provision and human health) and finally hot temperatures and dry conditions also increase the likelihood of forest fires.

- Weather extreme events. Climate changes will cause more intense storms, hurricanes and tropical storms, that last longer and unleash stronger winds, causing more damage to coastal ecosystems and communities. Damages to properties and infrastructures impose heavy costs: for example, between 1980 and 2011 floods in Europe affected more than 5.5 million people and caused direct economic losses of more than €90 billion (ec.europa.eu).
- Food and water insecurity and loss of rural livelihoods and income (especially for poorer populations). How will climate change undermine food security? The redistribution of global marine species and the reduction of their biodiversity will impact fisheries productivity; higher projected temperature in the future will negatively affect the level of production for cereals as wheat, rice and maize. Climate changes will reduce groundwater resources and renewable surface water, amplifying the problem of fresh water shortages.
- Loss of ecosystems, biodiversity and ecosystem services. Global warming is likely to be the greatest cause of species extinctions this century: a 1.5°C average rise may put 20-30% of species at risk. If the planet warms by more than 3°C, most ecosystems will struggle (wwf.org). Many plant species, for example, cannot shift their geographical position and adapt in such a short period of time, considering the

⁵ See Appendix 3

⁶ A total of more than 9,000 Americans suffered heat-related deaths from 1979 to 2013. The indicator shows a peak of heat-related deaths in 2006, a year that was associated with widespread heat waves and was the second-hottest year on record in the contiguous 48 states. Dramatic increases in heat-related deaths are closely associated with both the occurrence of hot temperatures and heat waves (epa.gov).

current pace of climate changes; meanwhile marine organisms have to survive the problem of ocean acidification and the rise of ocean temperatures.

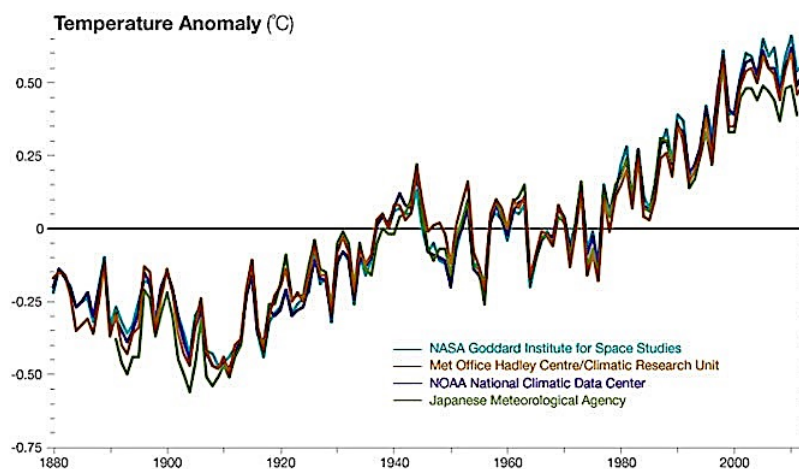
Looking more closely to Europe, it is possible to list the tangible effects of the climate changes impact in this region: southern and central Europe are seeing more frequent heat waves, forest fires and droughts, meanwhile northern Europe is getting significantly wetter (winter floods could become common in the near future); the whole Mediterranean area is becoming drier, so even more vulnerable to drought and wildfires (EEA, 2008).

"Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped" (IPCC, 2014). Probably neither adaptation nor mitigation alone can avoid all future climate change impacts; however, they can integrate each other and together can significantly reduce the disrupting consequences of global warming. But in order to achieve significant results in terms of reduction of risks and mitigation of GHG emissions, international cooperation is required. Without additional efforts global warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts.

1.2 Anthropogenic causes of global warming

From a comparison of different peer-reviewed scientific journals (Oreskes, 2004; Doran, 2009; Anderegg, 2010 and Cook, 2013) it emerges that the large majority of climate scientists (see [Figure 1.4](#)) agree on the fact that global warming and related climate changes are very likely consequences of human activities.

Figure 1.4 - Scientific Consensus on Global Warming



Source: <http://climate.nasa.gov/scientific-consensus>

Climate has been changing throughout history, and for sure changes that took place thousands of years ago cannot be the consequence of human civilization. But, especially over the last century, the dangerous trends can be linked with human-related emissions: the Fourth Assessment Report of the IPCC states that emissions of heat-trapping gases from human activities have caused most of the observed increase in globally averaged temperatures since the mid-20th century, with a 90% certainty.

1.2.1 Atmospheric concentrations of greenhouse gases

The starting point of the analysis is that global atmospheric concentrations of carbon dioxide, methane, nitrous oxide, and certain manufactured greenhouse gases have all risen significantly over the last few hundred years (IPCC, 2013). When GHGs are emitted into the atmosphere, many of them remain there for long periods of time, ranging from a decade to many millennia. Over time, these gases are removed from the atmosphere by chemical reactions or by emissions sinks, such as the oceans (previously mentioned) and vegetation. However, as a result of human activities, these gases are entering the atmosphere more quickly than they are being removed, and thus their concentrations are increasing.⁷

In 2010, worldwide emissions from human activities totaled nearly 46 billion metric tons of greenhouse gases, expressed as carbon dioxide equivalents, a 35% increase compared to 1990 emissions levels (IPCC, 2013).

Gases differ because of variations in their atmospheric lifetime and for their global warming potential. The main responsible gas is carbon dioxide, which concentrations have increased steadily since the beginning of the industrial era (IPCC, 2013). The concentration of methane in the atmosphere has more than doubled from 1950; this increase is predominantly due to agriculture (which affects the level of nitrous dioxide too) and fossil fuel use.

Fluorinated gases ('F-gases') are a family of man-made gases used in a range of industrial applications and processes; they are powerful greenhouse gases, with a global warming effect up to 23,000 times greater than carbon dioxide, and their emissions are rising strongly (ec.europa.eu).

The last considered gas is ozone: overall, the total amount of O₃ in the atmosphere decreased by about 3% between 1979 and 2013. This gas is also a GHG but its effect depends on its altitude, and it naturally exists in the stratosphere (here it has a slight net warming effect on the planet, but it absorbs harmful ultraviolet radiation from the sun, preventing it from

⁷ See Appendix 4

reaching the earth's surface). In the troposphere - the layer of the atmosphere near ground level - ozone is an air pollutant, harmful to breathe: a main ingredient of urban smog. Globally, the amount of ozone in the troposphere increased by about 4% between 1979 and 2013 (IPCC, 2013).

1.2.2 Current concentration of carbon dioxide and the fossil fuel combustion

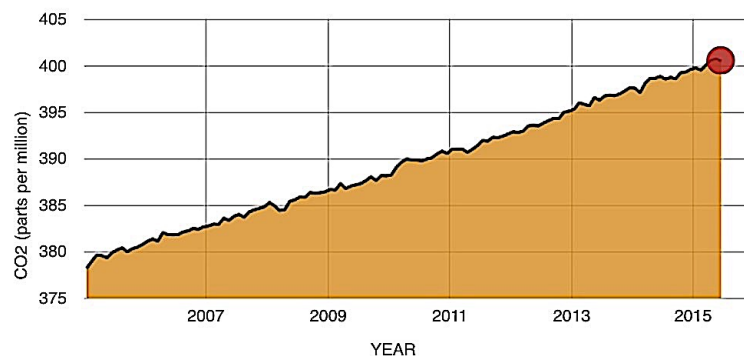
According to the latest data provided by the NASA's Orbiting Carbon Observatory-2, in June 2015 the level of carbon dioxide corresponded to 400.47 ppm (parts per million) (see [Figure 1.5](#)).

Carbon dioxide is the primary GHG emitted through human activities, and it accounts for three-fourths of total GHG emissions (epa.gov).

Figure 1.5 - Carbon dioxide measurements

DIRECT MEASUREMENTS: 2005-PRESENT

Data source: Monthly measurements (corrected for average seasonal cycle). Credit: NOAA



Source: <http://climate.nasa.gov/vital-signs/carbon-dioxide/>

Considering the long lifetime of this heat-trapping gas in the atmosphere, stabilising concentrations of greenhouse gases at any level would require large reductions of global CO₂ emissions from current levels. "The lower the chosen level for stabilisation, the sooner the decline in global CO₂ emissions would need to begin, or the deeper the emission reduction would need to be over time" (IEA, 2014a).

"Fossil fuel combustion accounts for 90% of total CO₂ emissions (excluding deforestation and other changes in land uses). Power generation remains the most important sector in relation to fossil fuel consumption" (Olivier, 2014).

The main factors that determine the previously showed percentage are: energy demand or the level of energy-intensive activity, changes in energy efficiency, shifts in fuel mix (such from coal to gas or from fossil fuels to nuclear/renewable energy).

Many studies conducted by the IEA concluded that changes caused by the oil price shocks in the 70s and consequent energy related policies had more effect on the reduction of carbon dioxide emissions, compared to climate policies implemented 20 years later (IEA, 2008).

Carbon dioxide resulting from the oxidation of carbon in fuels during combustion dominates the total GHG emissions.⁸ Global total primary energy supply more than doubled between 1971 and 2012, mainly - more than 80% - relying on fossil fuels; growing world energy demand plays a key role in the upward trend in carbon dioxide emissions.

Coal combustion is responsible, at a global level, for 43% of CO₂ emissions from fossil fuel combustion, even if oil is the largest energy source (IEA, 2012).⁹ Currently, coal fills much of the growing energy demand of developing countries (as China and India) where energy-intensive industrial production is growing rapidly and large coal reserves exist, meanwhile they have limited reserves of other energy sources (IEA, 2014a).

Shifts from coal to gas are particularly relevant in the overall trend for this gas emissions because the combustion of coal produces 75% more CO₂ compared to natural gas (it is characterized by a heavy carbon content per unit of energy released) and natural-gas-fired combined cycle power plant are even more efficient than the traditional coal-fired ones.

Apart from fossil fuel combustion other relevant carbon dioxide emission sources are (Olivier, 2014):

- oil and gas production: the venting or flaring process that regards the wasted stream of gas, from conventional or unconventional oil production, affects GHG emissions (especially CO₂ and methane);
- cement and steel production (non-combustion): they are both indicators of national construction activity. CO₂ emissions are generated by carbonate oxidation in the cement clinker production process and they derive from blast furnaces used to produce pig iron and from conversion losses in coke manufacturing. Cement production accounts for about 9.5% of global CO₂ emissions.

Looking at emissions by different sectors, from the 2012 CO₂ emissions overview of the International Energy Agency emerges that "two sectors combined, generation of electricity

⁸ CO₂ from energy represents about three quarters of the anthropogenic GHG emissions countries, and almost 70% of global emissions. This percentage varies greatly by country, due to diverse national structures.

⁹ See Appendix 5

and heat and transport, represented nearly two-thirds of global emissions in 2012" (respectively they account for 42% and 23% of world carbon dioxide emissions). Electricity and heat, all around the globe, heavily rely on coal; countries such as Australia, China, and India produce over two-thirds of their electricity and heat through the combustion of this fossil fuel. The industry sector accounts for the 20% and the residential for the 6% of global emissions.

1.2.3 Other anthropogenic causes of global warming

The second most important GHG is methane: globally, "over 60% of total CH₄ emissions comes from human activities" (EPA, 2010).

Methane's lifetime in the atmosphere is much shorter than that of carbon dioxide, but it is far more efficient at trapping radiation, so its impact on climate change is stronger: however its concentration, luckily, is much lower. CH₄ is emitted from industry, because of leakages in the processes of natural gas and petroleum systems, from agriculture (the digestion of ruminants as goats, cows, and similar) and from waste decomposition as landfills.¹⁰

Analysing the anthropic elements in the emissions of the other greenhouse gases, it emerges that NO₂ is heavily produced in the agriculture sector too, specifically in the production and the use of organic fertilizers and it is also produced when burning fossil fuels. Chlorofluorocarbons, man-made compounds very harmful for the environment, were produced for industrial use, mainly in refrigerants and air conditioners: today they are strongly regulated by the Montreal Protocol.

Land-use changes cause alterations in the amount of sunlight reflected from the earth's surface back into space, what is technically called the surface 'albedo'. The magnitude of these changes is estimated to be about one-fifth of the forcing on the global warming due to changes in emissions of greenhouse gases (wmo.int).

Deforestation is the second largest anthropogenic source of carbon dioxide to the atmosphere, after fossil fuel combustion, ranging between 6% and 17% (Wan Der Werf, 2009). Global forest loss between the years 2000 and 2012 was 2.3 million square kilometres, while 800,000 square kilometres regrew during that period; of all countries Indonesia shows the largest increase in forest loss for the accounted years (Hansen, 2103)¹¹. According to the United Nations' Food and Agriculture Organization (FAO), around 18 million acres of forest are lost

¹⁰ Methane is also emitted from a number of natural sources. Wetlands are the largest source, smaller sources include termites, oceans, sediments, volcanoes, and wildfires. (epa.gov)

¹¹ Since the last century, Indonesia has lost at least 15.79 million hectares of forest land.

each year.¹² About half of the world tropical forests have been cleared, and about 36 football fields worth of trees are lost every minute (WWF).

Forests importance is critical, given their ability to absorb carbon dioxide. But carbon is not the only GHG affected by deforestation: in fact the devastation of forests impact the exchange of water vapour between the atmosphere and the ground surface, and even small changes can have a huge effect on climate, modifying natural weather patterns (deforestation has decreased global vapour flows from land by 4%, according to the U.S. National Academy of Science). Other consequences of this harmful practice are the disruption of water cycle, the increase of soil erosion and the reduction of biodiversity.

Atmospheric aerosol is another important element related to climate change. Aerosols are small particles present in the atmosphere with varying size, concentration and chemical composition: some of them are emitted directly into the atmosphere while others are formed from emitted compounds. Aerosols contain both naturally occurring compounds and those emitted as a result of human activities such as surface mining and industrial and agricultural processes (IPCC, 2007).

Aerosol can affect climate in two important ways: they scatter and absorb solar and infrared radiation (which respectively cause a cooling and a warming process in the air), and they may change the microphysical and chemical properties of clouds.

1.3 CO₂ emissions trends and per capita emissions

As CO₂ is recognized as the chief greenhouse gas that results from human activities, in order to see whether adopted measures are being effective enough to face these issues, a powerful indicator is represented by the atmospheric CO₂ concentration.¹³

The concentration levels are increasing at an accelerating rate from decade to decade. The most recent available information, June 2015, set the concentration at 400.47 ppm. To keep the increase of global warming within 1°C (to avoid irreversible ice sheet and species loss), relative to 2000, with nominal climate sensitivity of 3/4°C per W/m² and plausible control of other GHGs, it will be required to maintain the CO₂ concentration level below 450 ppm (Hansen, 2007).

¹² 'State of the World's Forests 2012' is the tenth edition proposed by the FAO Committee of Forestry.

¹³ Data for this indicator can be found within those available from the Mauna Loa Observatory in Hawaii, US, part of the National Oceanic and Atmospheric Administration, Earth System Research Laboratory and Global Monitoring Division.

1.3.1 Global trends (1971 - 2012)

Global emissions of carbon dioxide have been characterized by a positive increasing trend in the period between 1971 and 2012 (see [Figure 1.6](#)).

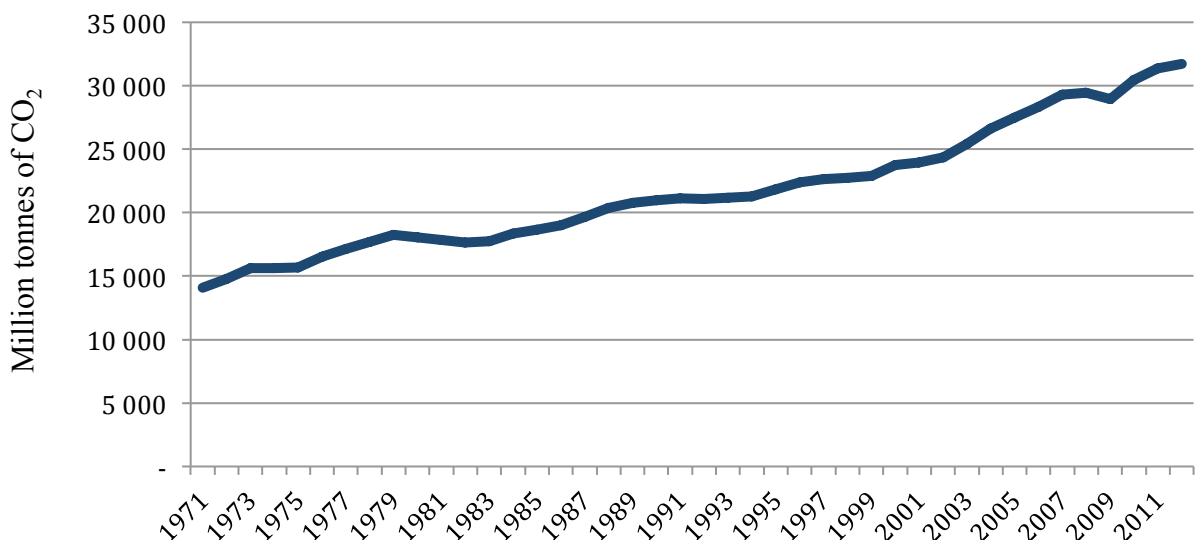
In 1971 the amount of carbon dioxide emissions totaled 14.1 billion tonnes; in 2012 the amount totaled 31.7 billion tonnes, with an increase of 125%.

Tracking the energy-related CO₂ emissions trends back to four decades it is possible to distinguish various periods: 1971-1979 with a global growth rate of 29.5%, 1980-1990 with a much lower growth of 16.1%, then the increase in emissions continued at a slower pace (13.5%) during the years 1991-2002 and finally the last period (2003-2012) characterized by an increased rate of 24.8%.

During those years there have been three times in which emissions have stood still or fallen compared to the previous year, and they all were associated with global economic weakness or crisis:

- the early 1980's, affected by the US recession. In 1980 emissions decreased by 0.9%, and in the two following years by 1.3% and 1.1% respectively;
- 1992, when emissions slightly dropped (-0.3%) after the collapse of the Soviet Union;
- 2009, and the global financial crisis that exploded.

Figure 1.6 - Global carbon dioxide emissions (1971 - 2012)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

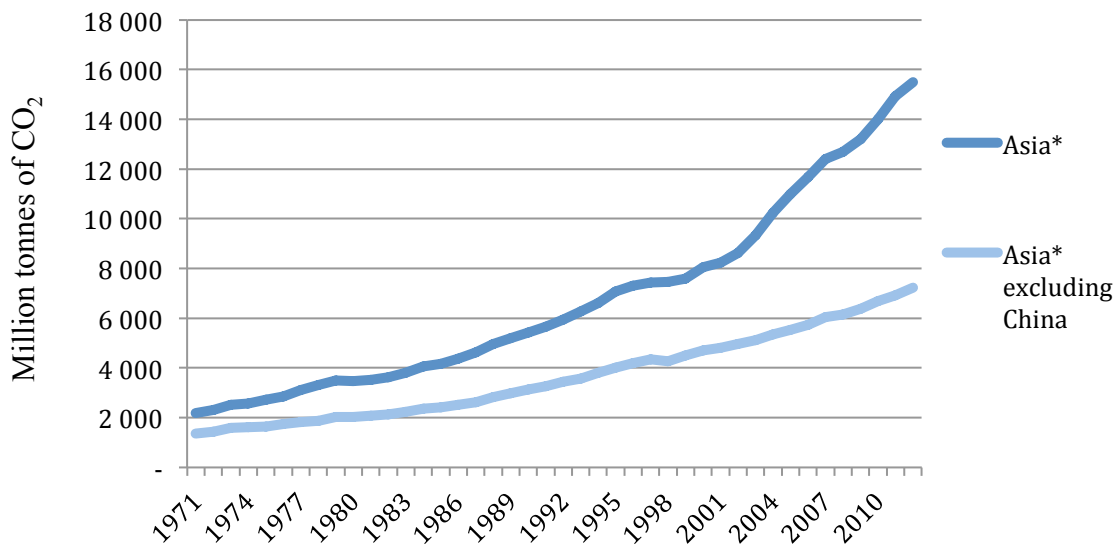
Today the six largest emitting countries/regions are: China, United States, the European Union, India, the Russian Federation and Japan.

Our analysis first focuses on one, among the continents, that is considered the most responsible for the recent increasing trend of CO₂: Asia*.¹⁴ From [Figure 1.7](#) we can look at the trend that characterized the continent from 1971 to 2012.

We can identify three different periods in which emissions grew at very different paces:

- from 1971 to 1988 it was recorded a total increase of more than 127% of carbon dioxide emissions, with an average annual increase of 5%;
- after the collapse of the Soviet Union emissions started to grow at a quite lower pace (approximately 4% every year) compared to the previous period, until 2002 (summing up, a total increase of 66%);
- in the last decade (2003-2012) it is possible to note a highly sloped trend which reflects the renewed boost and growth in carbon dioxide emissions, with a total increase of 66% in less than 10 years (and an average annual increase of almost 6%).

Figure 1.7 - Asia*: CO₂ emission (1971 - 2012)

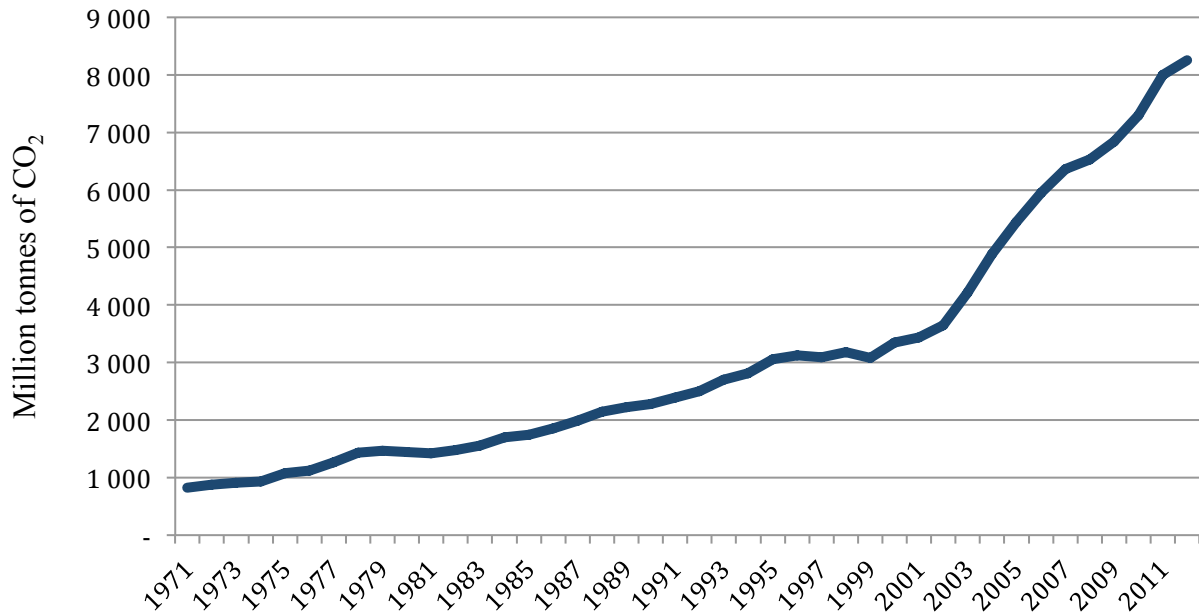


Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

It is worth to look more in detail at China, the major contributor in the Asian continent. In 1971, China was responsible for almost 20% of the total amount of emissions in Asia; 40 years later, 47% of its emissions are attributed to China.

¹⁴ * Analysing data for the continent Asia we excluded those coming from the Former Soviet Union and, after its collapse, data from countries that became independent.

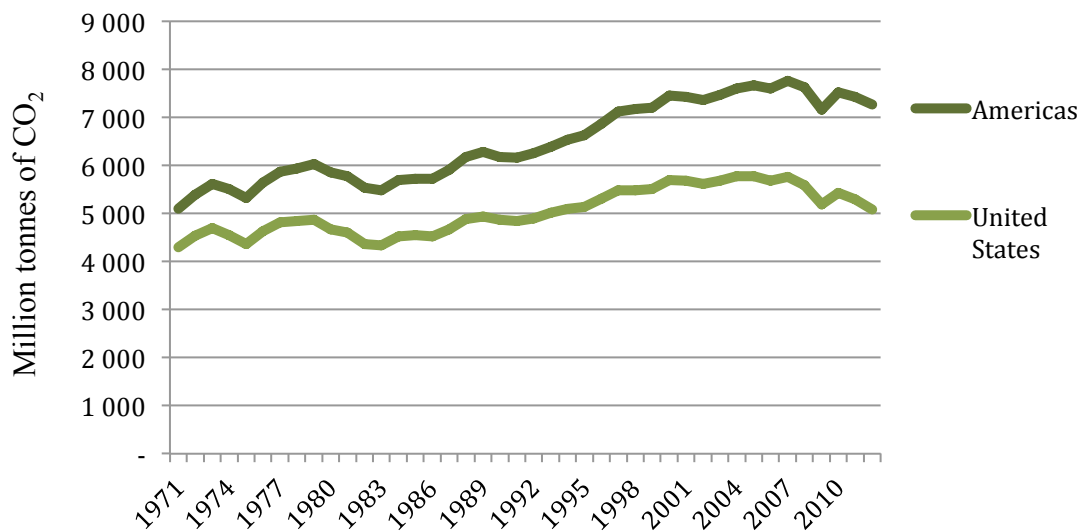
Figure 1.8 - China: CO₂ emissions (1971 - 2012)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

Since 2006 (included) China holds the first position in the ranking of top carbon dioxide emitters from the consumption of energy as measured by the U.S. Energy Information Administration. Today, CO₂ emissions accounts for 28.3% of the global amount of emissions (corresponding to 9.5 billion tonnes). The most impressive trend goes from approximately 2001 to 2012: a total growth rate of 146% (see [Figure 1.8](#)).

Figure 1.9 - Americas: CO₂ emissions (1971 - 2012)

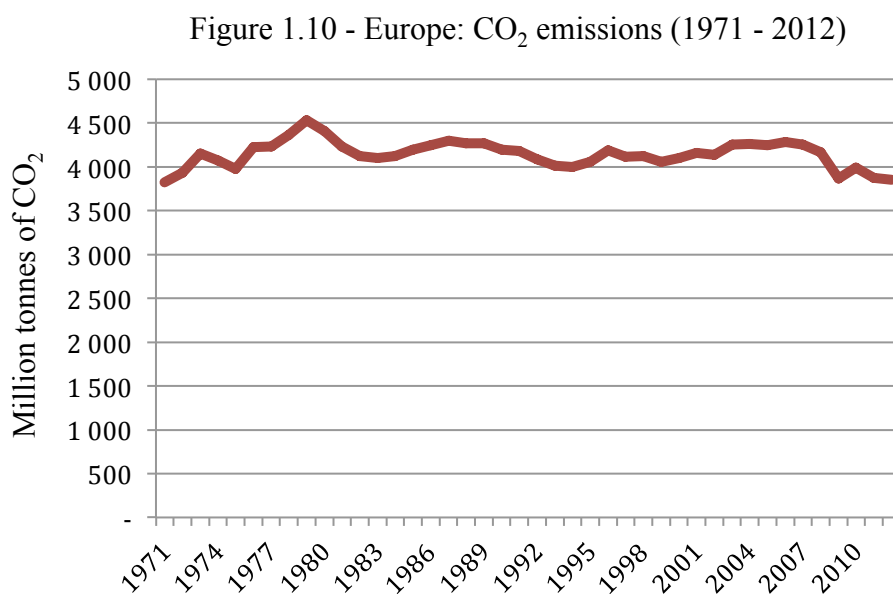


Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

In [Figure 1.9](#) we present the trend for the American continent. Here we have the great influence of the United States (the second country in the ranking of world top emitters), which on average accounts for 80% of the total Americas' emissions. Energy-related carbon dioxide emissions have increased by 43% since 1971, but the growing path is very different from the one we have previously seen for Asia, and strongly affected by the U.S. events.

Even if nowadays US emissions account for 15% of the global emissions of CO₂, since 2007 the U.S. have been able to decrease year after year their carbon dioxide levels, with the only exception of 2010, and since 1990 their total emissions have increased only by 4.2%.

The picture changes again when we move to Europe (see [Figure 1.10](#)).



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

To calculate the total amount of energy-related CO₂ emissions we summed up OECD Europe data and data coming from Albania, Bulgaria, Cyprus, Gibraltar, Malta and Romania.¹⁵ The first trend affects the time span that goes from 1971 until 1979: in only 8 years emissions increased by almost 19%, with the only exception of the two-years period 1974-75, linked probably with the big price increase imposed by oil producing nations. After 1980 it was recorder a progressive reduction in emissions for the following 4 years, and then a period of relatively stable emissions growth until 1989. It is possible to see ([Figure 1.10](#)) a general downward trend for the 1990-99 period (a total reduction of 5% in emissions), followed by a

¹⁵ OECD Europe includes: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Switzerland, Turkey, United Kingdom. We excluded data coming from 'Former Yugoslavia' and countries that became independent after its collapse.

period of relatively unchanged level of CO₂ emission, until 2006. The year 2009 clearly show a sharp drop in emissions caused by the global financial and economic crisis.

1.3.2 Per capita carbon dioxide emissions

The picture changes significantly when moving from absolute emissions of carbon dioxide to indicators such as emissions per capita or per GDP, considering that different regions and countries have contrasting economic and social structures, different resources and energy mix adopted.

Table 1 - Top 20 countries according to total and per capita emissions in 2014

	Highest CO ₂ emissions		Highest CO ₂ per capita emissions	
1°	China	8485,6	Bahrain	73,1
2°	United States of America	5488,3	Qatar	41,9
3°	India	2085,6	Singapore	39,5
4°	Russian Federation	1707,9	Trinidad and Tobago	34,1
5°	Japan	1220,5	Kuwait	28,5
6°	Germany	756,9	United Arab Emirates	25,8
7°	Republic of Korea	681,5	Brunei Darussalam	20,6
8°	Saudi Arabia	622,4	Saudi Arabia	20,2
9°	Canada	593,8	Luxembourg	19,6
10°	Iran (Islamic Republic of)	580,2	Australia	17,3
11°	Brazil	550,1	United States of America	17,2
12°	Indonesia	477,6	Armenia	17
13°	South Africa	474	Canada	16,7
14°	United Kingdom	461	Oman	15,1
15°	Mexico	417,4	Malta	15,1
16°	Australia	406,1	Seychelles	14,7
17°	Italy	334,8	Israel	13,5
18°	France	333,9	Republic of Korea	13,5
19°	Taiwan	309,7	Netherlands	13,4
20°	Turkey	309,4	Kazakhstan	12,7

Source: <http://www.tsp-data-portal.org/>

Using latest available data from the U.S. Energy Information Administration it is possible to get a list of the countries with the highest CO₂ emission in per capita terms, and results are quite interesting: in 2014 the first one is Bahrain, followed closely by Qatar and Singapore.¹⁶ For the country that is taking up the first spot, Bahrain, the level of emissions corresponds to 73.1 million tonnes of CO₂ per million people, and it reaches 41.9 and 39.5 for those occupying the second and the third position. China, which according to the popular opinion is

¹⁶ International data for carbon dioxide emissions from the consumption of energy includes emissions due to the consumption of petroleum, natural gas, coal, and also from natural gas flaring.

one of the main responsible of the current trends related with climate changes, totaled 6.2 million tonnes of CO₂ per million people, and the United States 17.2, occupying today the 11th position in the ranking of top emitters in per capita terms.

If we look at the situation 10 years before, in 2004, the top three emitting countries were Qatar, United Arab Emirates and Kuwait, meanwhile 20 years before the countries with the highest CO₂ emissions in per capita terms were still Qatar and United Arab Emirates followed by Bahrain.

In [Table 1](#) we provide a comparison between the ranking of the top 20 CO₂ emitters and the ranking of the top 20 countries with the highest CO₂ emissions per capita (in both cases we consider emissions resulting from the consumption of energy).

1.4 Consumption-based and production-based accounting

In 2004, "23% of all CO₂ emissions from fossil-fuel burning were emitted during the production of goods that were ultimately consumed in a different country" (Davis, 2010).

Of all these goods, the majority were exported from emerging countries to developed ones, reinforcing the already large global disparity in per-capita emissions. The geographical separation of production and consumption is a fundamental aspect in the analysis of carbon dioxide and other GHG emissions and complicates the question of who is truly responsible and how the burden of mitigation should be shared (Caney, 2009).

Many publications has been written about the vast topic of CO₂ emissions ignoring the benefit delivered to customers through international trade; but some other studies juxtapose consumer and producer emissions of greenhouse gases in order to show the effects of trade on the national emission budget, and some others have estimated emissions embedded in international trade of numerous countries and world regions (Wiedmann, 2009).

1.4.1 Imports, exports and involved CO₂ emissions

The 'responsibility' of producers and consumers emerged in the scientific literature only about 15 years ago (Eder, 1999; Munksgaard, 2001), but in recent studies the adoption of the consumption-based accounting method is becoming more and more preferred. Through this method, all emissions occurring along the chains of production and distribution are allocated to the final consumer of these products, so as to redistribute the CO₂ emissions among countries that are going to actually take advantage from the products themselves.

Various are the benefits provided by the consumption-based accounting. Hereafter some of them will be mentioned (CP/RAC, 2008):

- it includes the driving forces for GHG emissions associated with consumption;
- added information are particularly useful in the adoption of specific climate change policy, for example related with carbon leakage;
- it provides a better understanding of the different responsibilities of countries;
- it could encourage international partnerships and cooperation between developed and developing countries;
- it makes consumers more aware of the GHG emissions caused by their lifestyle choices, and it raises awareness of the indirect emissions in governments and businesses.

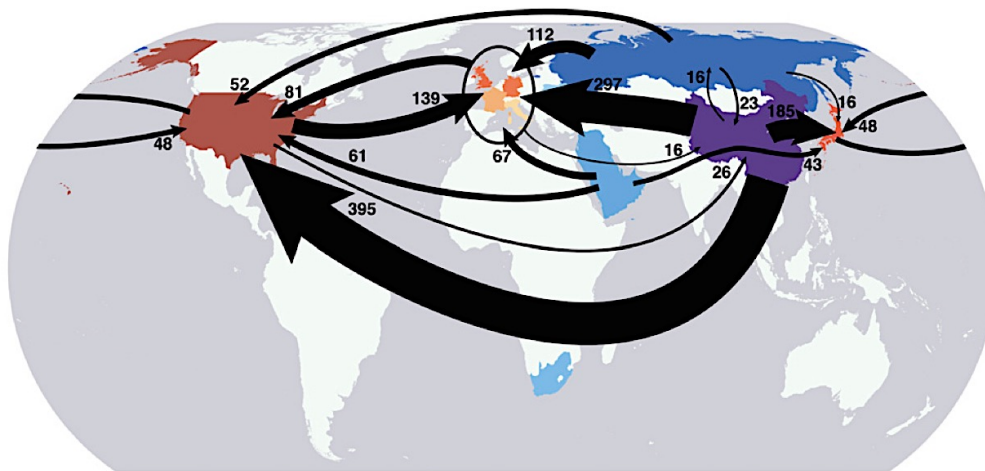
A multi-region input-output (MRIO) analysis is generally used to study trade-related impacts from a consumption perspective (Wiedmann, 2009). The MRIO analysis, in synthesis, "is based on monetary flows between industrial sectors and regions [...], considering the total economic output of each sector in each region, each sector's output produced in one region and consumed in another, and a matrix of intermediate consumption..." (Davis, 2010). Interdependencies between foreign sectors with different production technologies, resource use and pollution intensities can be quantified and the analyses become the more specific the more countries and economic sectors this model is able to distinguish (Wiedmann, 2009).

The difference between production emissions and consumption ones represents the net effect of emissions embodied in trade (or EET) and therefore equals emissions embodied in exports less those embodied in imports (Davis, 2010).

Considered emissions embodied in trade, as we can see in [Figure 1.12](#), the coloured countries in blue represent the largest net exporters, and in red the net importers: in other countries the balance of EET is close to zero. The dominant aspect that emerges from the figure is the export of emissions embodied in goods that come from China and are addressed to consumers in the U.S., Japan and Western Europe. As for the exporters, "China is by far the largest net exporter, followed by Russia, the Middle East, South Africa and Ukraine" (Davis, 2010).

China requires a more detailed analysis considering that it is the world largest former of CO₂ emissions and it has received, and it is still receiving, a lot of international pressure.

Figure 1.12 - Emissions embodied in international trade



Source: www.pnas.org/cgi/doi/10.1073/pnas.0906974107

One of the arguments Chinese policy makers use to legitimize their levels of emissions is that a huge portion of that is due to the production of exports (McGregor, 2007), together with the fact that limits on emissions could hamper their economic development and, however, they have low per-capita emissions (WRI, 2007).

Somehow data support their argument: "in 2005, 33% (1700Mt) of China's domestic CO₂ emissions were in the production of exports and this has steadily increased from 12% (230 Mt) in 1987" (Weber, 2008). In most of the accounted years, the growth rate of the emissions from the production of exports is greater than the growth rate of total emissions, showing the particular importance of exports to China's growth in CO₂ emissions (Weber, 2008).

Going back to the global scenario, countries vary widely in their relative shares of CO₂ related with trade; most European countries have a high share of domestic emissions in the production of exports (it varies between 20 and 50%), the USA has 8%, Japan 15%, India 13%, South Korea 28%, and South Africa 45% (Peters, 2008). Focusing the attention on imports, emissions imported to the United States exceed those of any other country or region¹⁷, followed by Japan and Western Europe (Davis, 2010).

"On a per-capita basis, net imports of emissions to the United States, Japan and countries in Western Union are disproportionately large, with each individual consumer associated with 2.4-10.3 tons of CO₂ emitted elsewhere. Net exports of emissions from China, Russia and the Middle East are also substantial: from 0.9 to 2.0 tons per capita.[...] These figures suggests that individual customers in the most affluent and least populous countries of Western

¹⁷ Primarily embodied in machinery, electronics, motor vehicles and parts, and intermediate goods.

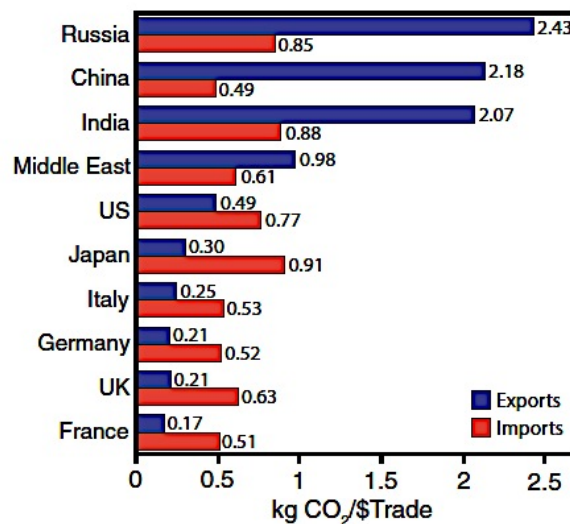
Europe, for example, are importing the same mass of emissions as are exported by 5-10 people in China" (Davis, 2010).

Summing up, consumption-based accounting methods are useful to understand how much carbon dioxide emissions are traded internationally, without being included in traditional production-based methods. It is, as previously said, a useful tool in policy debates and discussions at a global level, when countries have to respond for their degree of responsibility in certain atmospheric emissions of dangerous GHG, most of all CO₂.

1.4.2 Carbon intensity of trade

The carbon intensity of trade (in kg CO₂ per US\$ of imports or exports) is an useful indicator obtained as: CO₂ emissions per unit of energy × energy consumption per US\$ of trade (Davis, 2010). In [Figure 1.13](#) it is reported the mean CO₂ intensity of imports and exports to and from the largest net importing/exporting countries. Considering the export side of trade, countries such as China, Russia and India are characterized by a high carbon intensity of trade, mainly for the export side, that can be explained with the use of carbon-intensive fuels as coal and relatively low value for energy-intensive exports (Davis, 2010).

Figure 1.13 - Mean CO₂ intensity of imports and exports



Source: www.pnas.org/cgi/doi/10.1073/pnas.0906974107

In particular, China and its low cost production does benefit most consumers, but this benefit comes at the detriment of both the local Chinese environment (Streets, 2006) and the global environment due to the effects of climate change.

On the other hand, countries like Japan and some areas in the Western Europe use low-carbon technologies to generate a big proportion of the energy required, and are more highly valued per unit of energy necessary for exports too (Davis, 2010).

Referring to the import side, looking at [Figure 1.13](#) we realize how goods imported in Western Europe and Japan embody much more CO₂ per US\$ compared to their exports (they import energy-intensive products from somewhere else), meanwhile the carbon intensity for China, Russia and India is much lower (Davis, 2010).

1.4.3 The potential for international carbon leakage

The whole topic of carbon leakage would require a specific and detailed analysis. Here we will simply remind that carbon leakage is defined as the possibility that businesses transfer their production to other countries with less emissions constraints, provoking negative consequences in terms of CO₂ and other gases emitted (ec.europa.eu). In other words, it is "the increase in emissions outside a region as a direct result of the policy to cap emission in this region. Carbon leakage means that the domestic climate mitigation policy is less effective and more costly in containing emission levels, a legitimate concern for policy-makers" (IEA, 2008).

In order to solve climate problems, international cooperation and simultaneous national actions are needed: but one of the main risks of imposing limits on emissions is that carbon intensive producers may decide to move the production out of a certain region that impose a carbon cost (IEA, 2008).

The risk related with carbon leakage varies within sectors and industries: those with high emission intensities and high trade ratios more likely will generate substantial leakage (for example primary metal industries, as iron and steel, or petroleum and coal products industries) (CBO, 2013).

In many countries, the implementation of certain emission reduction programs, as policies to shrink carbon dioxide emissions, can affect the potential for carbon leakage. However sometimes it can be difficult to prove that a specific policy directly caused a business to move to another place with less restrictions.

The EU Emission Trading System (ETS) is a fundamental tool to fight climate change and reduce industrial greenhouse gas emissions in a cost-efficient way, and it was launched in 2005. It is based on the so called 'cap and trade' system: a total amount of GHG that can be emitted is set, and then, within the cap, companies receive and buy allowances which can be

traded. It is addressed to factories, power plants and other heavy energy using-installations of the European Union, and the primary object is to reduce emissions (including carbon dioxide, nitrous oxide and perfluorocarbons) by 21% from the covered sector within 2020, compared to 2005 (ec.europa.eu).

According to what is reported in the 'Climate policy and carbon leakage' information paper of the International Energy Agency (2008), since the beginning of the ETS three smelters have been closed in Germany, Hungary and France, which were contributing for 6.5% to the European production in 2006. At this point, a legitimate question is: can this be considered a sign of relocation because of the CO₂ cap? There is the possibility that a relocation occurred outside Europe, but in the paper this is not verified. A revision of the current ETS directive lists several measure aimed to the mitigation of carbon leakage, especially for sectors with a higher risk, but considering the important implications of this aspect, deeper studies are required.

CHAPTER 2

Decomposition analysis of CO₂ emissions (1971 - 2008)

"Developing and implementing climate change policy requires a sound analysis of past GHG emissions. Such an analysis can help to detect a risk of deviation from emissions reduction targets, to identify the emission sources to target in priority, to evaluate the effect of mitigation policies and to improve emissions projections" (Janssens-Maenhout, 2013).

Many researchers have developed various models to conduct analysis on CO₂ emissions, and these models could be extensively used to help countries or regions formulating the corresponding policies in terms of climate and energy (Xiangzhao, 2008). In this Chapter we adopt the Kaya identity, and the Laspeyres index, to decompose the total amount of emissions and provide a comparison between the impact and relative weight of the driving factors in different countries and different time periods. We will stop our analysis in 2008, when the world economy was hit by a global financial crisis: in Chapter 3 we will focus more deeply into the effect of the crisis on carbon dioxide emissions.

2.1 The Kaya identity

2.1.1 Definition and decomposition

The Kaya identity, first proposed by the energy economist Yoichi Kaya (Kaya, 1997) is one of the most extensive models used to analyse CO₂ emissions trends from human activities. It is based upon a simple mathematical formula and it has been widely adopted in numerous studies and publications. As argued by Albrecht (2002), "the historical trends in the Kaya identity components provide a reference point for evaluating current and future climate policy projections of carbon emissions as well as the key economic, demographic and energy intensity factors leading to those emissions".

The Kaya identity is generally expressed in the following form:

$$C = P \times \left(\frac{G}{P}\right) \times \left(\frac{E}{G}\right) \times \left(\frac{C}{E}\right) \quad (1)$$

where C represents CO₂ emissions, P is the population, G is the GDP and E is the primary energy consumption.

Basically it is only a definition that relates the quantity of carbon emissions to different terms that represent the population, gross domestic product in per capita terms (G/P), the energy intensity of GDP (E/G) and the carbon intensity of energy consumption (C/E).

If any term on the r.h.s. of (1) has any tiny change in any period, it will ultimately lead to changes in CO₂ emission, which is approximately equivalent to the sum of the change rate of every term in the corresponding period:

$$\Delta \log(C_t) = \Delta \log(P_t) + \Delta \log\left(\frac{G}{P_t}\right) + \Delta \log\left(\frac{E}{G_t}\right) + \Delta \log\left(\frac{C}{E_t}\right) \quad (2)$$

where $\Delta \log(\dots)_t = \log(\dots)_t - \log(\dots)_{t-1}$.

Giving a closer look at the components of the identity, we can notice that: population is a fundamental driving factor (trivially, more people needs more energy), as well as per capita GDP, considering that bigger and expanding economies use more energy; the third term is "determined largely by the structure of each economy and [it] encapsulates a wide range of driving forces, ranging from domestic resource endowments to the energy policy landscape characterising each economy" (EBRD, 2011) and finally the carbon efficiency of existing fossil fuel sources (C/E) is mainly affected by the fuel mix in the primary energy supply that each country and region adopts (coal and oil, traditionally, are carbon intensive, compared to natural gas, nuclear power and renewable energy sources) (EBRD, 2011). Structural changes, that are shifts toward more or less energy intensive economic activities, as well technological changes (energy efficiency improvements) can affect the E/G. Meanwhile, a switch to renewable energy or other energy sources alters the carbon emitted per unit of energy production (C/E).

Through the adoption of this identity it is possible to decompose the factors that are related with carbon emissions and understand which of the previously mentioned ones can be considered responsible for an increase or decrease in the emission levels for carbon dioxide.

2.1.2 Caveats of the Kaya identity and the Laspeyres Index

There are some drawbacks that can arise using the Kaya identity: one of the main caveats is that the four factors on the right-hand side of the equation should be considered neither as

fundamental driving forces in themselves, nor as generally independent from each other (Janssens-Maenhout, 2012).

In various traditional decomposition methods, a typical shortcoming is represented by the presence of a residual between the real data and the calculated one; for analysis over long periods, the presence of high residuals make it impossible, or very unlikely, to derive reliable conclusions about the decomposition of carbon emissions, and changes that affected them. "With the presence of the residual, we cannot make a good explanation for the changes in CO₂ emissions" (Xiangzhao, 2008). How can we solve this problem? In some published studies the authors simply removed the residuals, which they were not able to explain, to make a better use of the Kaya identity. Otherwise, there is the possibility to choose an index method, according to the availability of specific data, that would allow to solve the problem. "Although a large number of energy decomposition analysis studies have been reported in the last 25 years, there is still a lack of consensus among researchers and analysts as to which is the 'best' decomposition method" (Ang, 2004).

The two most common decomposition approaches are those based on the Laspeyres index and the Divisia index, and then many modified methods have been developed starting from them.

The Laspeyres index method is one of the most popular and conventional decomposition method: it adopts the index number formula as developed by Laspeyres, and it measures the percentage change in some aspect of a group of items over time, using weights based on values in some base year. Its strength is represented by the ease of understanding for the underlying concept, especially to the non-experts; however it does not allow us to solve the problem of the residual term arising from interactions of the factors in the decomposition (Ang 2007).

Other decomposition techniques, based on the Shapley approach, have been used to study CO₂ emissions with a decomposition without 'unexplained' residuals, as demonstrated by Albrecht (2002) and Sun (1998). The Shapley decomposition, for example, refines the Laspeyres index method in order to have very small residuals.

In some cases the residuals are very small, and results can be interpreted without any problem, but in some others they get larger and the Laspeyres index cannot be considered a good choice. A perfect index decomposition method techniques do not give rise to residuals (Janssens-Maenhout, 2012).

Among 'perfect methods', Ang (2007) mentioned:

- Modified Fisher ideal index method, which can be seen as extension of the Laspeyres index method with the interaction terms distributed among the main effects in a specific manner;
- Logarithmic mean Divisia Method I, where the results given by multiplicative decomposition and additive decomposition are related by a simple formula and interchangeable (it is considered the preferred method);
- Logarithmic mean Divisia Method II.

It has been showed that decomposition results given by the application of those 'perfect methods' are very similar, meanwhile "those for the Laspeyres index method could either be very similar to or quite different from these results" (Ang, 2007), leading to problems in interpretation and questions about how useful those results are.

Sun and Ang (2000) proposed three extended decomposition models, mathematically more complex, developed through refining Laspeyres, Paasche and Marshall-Edgeworth basic index models. Results show that these extended models provide the same decomposition output, and moreover they do not leave residuals.

We will proceed with the adoption of the Laspeyres index method. Using the Laspeyres index method, a change over time in emissions ΔC can be expressed as the joint contribution of the four underlying effects (indicated with subscript f)

$$C(t + \Delta t) = \Delta C = P_f + \left(\frac{GDP}{P}\right)_f + \left(\frac{E}{GDP}\right)_f + \left(\frac{C}{E}\right)_f \quad (3)$$

where each effect can be derived from multiplication, as done here for population

$$\begin{aligned} P_f = & \Delta P * \left(\frac{GDP}{P}\right)_t * \left(\frac{E}{GDP}\right)_t * \left(\frac{C}{E}\right)_t + \Delta P * \frac{1}{2} * \left[\Delta \left(\frac{GDP}{P}\right) * \left(\frac{E}{GDP}\right)_t * \left(\frac{C}{E}\right)_t + \left(\frac{GDP}{P}\right)_t * \right. \\ & \left. \Delta \left(\frac{E}{GDP}\right) * \left(\frac{C}{E}\right)_t + \left(\frac{GDP}{P}\right)_t * \left(\frac{E}{GDP}\right)_t * \Delta \left(\frac{C}{E}\right) \right] + \Delta P * \frac{1}{3} * \left[\Delta \left(\frac{GDP}{P}\right) * \Delta \left(\frac{E}{GDP}\right) * \left(\frac{C}{E}\right)_t + \Delta \left(\frac{GDP}{P}\right) * \right. \\ & \left. \left(\frac{E}{GDP}\right)_t * \Delta \left(\frac{C}{E}\right) + \left(\frac{GDP}{P}\right)_t * \Delta \left(\frac{E}{GDP}\right) * \Delta \left(\frac{C}{E}\right) \right] + \Delta P * \frac{1}{4} * \Delta \left(\frac{GDP}{P}\right) * \Delta \left(\frac{E}{GDP}\right) * \Delta \left(\frac{C}{E}\right) \quad (4) \end{aligned}$$

The first part of the equation $\Delta P * \left(\frac{GDP}{P}\right)_t * \left(\frac{E}{GDP}\right)_t * \left(\frac{C}{E}\right)_t$ can be interpreted as the partial effect of the population component on the change of CO₂ emissions between time step t and

the preceding step t-1. The following parts capture interactions between the remaining variables and form the so called residual term.

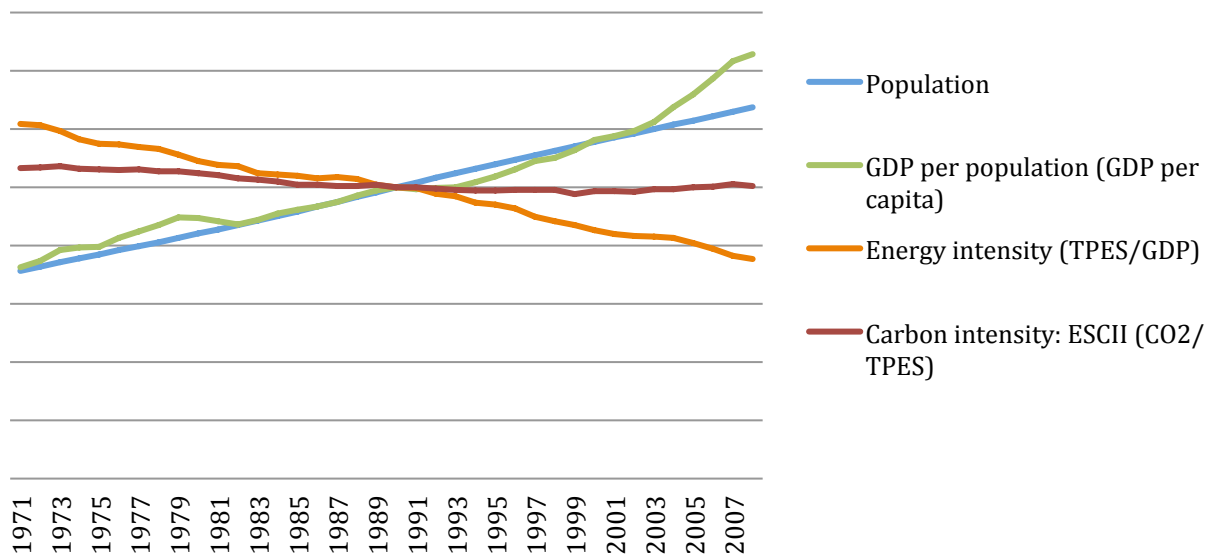
In this Chapter we will choose specific time frames and compare results for different periods and different countries. In order to be able to show the relative contributions of changes in Kaya factors to changes in emissions, all quantities are normalized to 100 in the year 1990 (our reference year), to perform our analysis.

2.2 Global trends (1971 - 2008)

Which are the main driving factors of global CO₂ emissions? If we look closely at the four pillars of the Kaya identity from a global point of view, considering collective results rather than singular country ones, which conclusions can we arrive to?

Figure 2.1 provides a general idea of how the four driving factors evolved over the period 1971-2008.

Figure 2.1 - Evolution of Kaya identity drivers for CO₂ emissions (1971-2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

"One of the main driving forces of the global CO₂ emissions is economic development and population growth since the past few hundred years, but not the only one" (Oberheitmann, 2013).

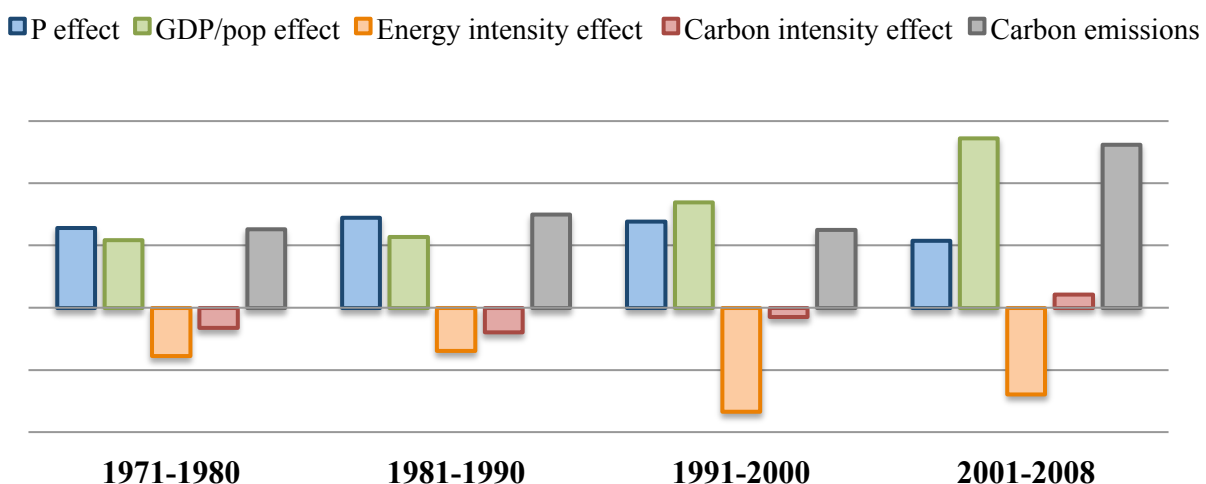
From 1971 to 2008 population increased by 79%. More people, basically, means more carbon emissions: in fact, population has been the second driving factor of the increase in carbon dioxide emissions over this period.

However what captures our attention is the huge importance of GDP per head on the Kaya identity in determining the increase in CO₂ emissions. Many international comparative studies (which used decomposition techniques to perform the analysis of major drivers) agree in considering economic growth as the fundamental driving factor for the current levels of carbon dioxide emissions (Raupach, 2007; Metz, 2007; Kojima, 2009; Mundaca, 2013; Arto, 2014).

"GDP per capita is the most important driver in the Kaya identity for the growth of CO₂ emissions as a growth of disposable income increases the demand for energy directly [...] as well as indirectly through the increase of energy which is needed to produce goods and to provide services being purchased from additional disposable income" (Oberheitmann, 2012).

The author, through a double-logarithmic regression analysis, proved that 1% increase in global per capita income induces a 2.5% increase in global CO₂ emissions worldwide. The rise in world living standards can deeply affect the total amount of emissions and this is the reason why economic development has to be seen as the most influential driving factor for the accounted period. The majority of the studies we have considered are performed over short-time span, but even adopting a long term perspective "findings suggest that the most important determinants of CO₂ emissions [...] are income and population growth" (Teives Henriques, 2014).

Figure 2.2 - Global Kaya identity (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

As we can see from [Figure 2.2](#), talking about countermeasures, the main factor responsible for global emissions reduction is the energy intensity of GDP. Reducing the energy intensity can be one of the most effective solution in order to meet future targets in terms of mitigation,

considering that "the global reduction of energy intensity of GDP can compensate 60% of the worldwide CO₂ emission increase due to the growth of global per capita income" (Oberheitmann, 2013).

A smaller effect on emissions is given by the carbon intensity of the energy consumption. The introduction of modern renewable energy sources strongly affected this factor, causing a reduction of global CO₂ intensity of primary energy supply, at least until 2001, when the importance of coal re-emerged (see [Figure 2.2](#)).

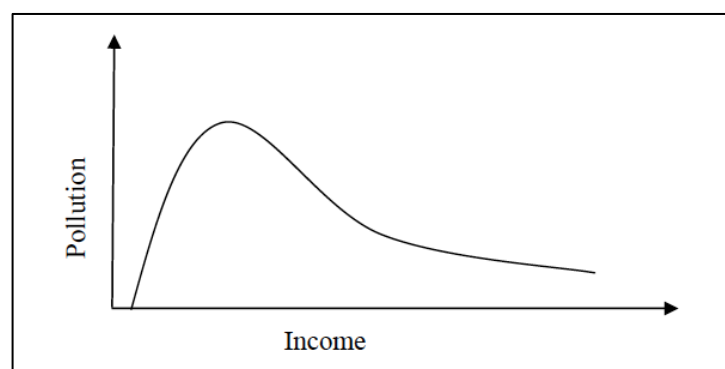
Considering results we have obtained through the global analysis of the Kaya identity, it is right now the proper time to introduce the concepts of coupling and decoupling.

For many years, economic development has been linked with CO₂ emissions (Sheram, 2000) and, as a consequence, a growth in emissions was directly explained with economic growth of a certain area or country.

Sheram (2000) provides a definition of coupling: if CO₂ emissions grow at the same rate as GDP (a widely used measure for economic growth) they are said to be coupled or linked. Basically, an increase in GDP means that a country is getting richer, and we have seen that for the past years it was linked with increase energy demand and consumption, leading obviously (especially for low and middle income countries) to greater CO₂ emissions (Sheram, 2000).

Many studies support the Environmental Kuznets Curve (EKC) hypothesis, which indeed describes the relationship between economic growth in terms of per capita income and environmental degradation. There is a supposed bell-shaped relationship between per capita income and environmental degradation, meaning that with increasing income per capita, environmental degradation first rises and after reaching a maximum level, the turning point, it starts to decline (Grunewald, 2009).

Figure 2.3 - Shape of the Environmental Kuznets Curve



Source: Lieb (2003, p.2)

This would basically mean that economic and income growth of a country will eventually, after the initial period, reduce CO₂ emissions per head, even promoting economic growth as a tool for a more equal distribution of income or a decreasing level of environmental degradation, without applying any redistributive measures.

In support of the EKC's theory, the fall in emissions brought about as income rises is presumed to be caused by: consumers preferring less material intensive sectors, a fall in the demand for the infrastructure, materials being converted and used more efficiently and finally an increase in recycling of energy-intensive materials (Giorgetti, 2007).

But an opposite view is proposed by Azar (2002), according to whom emissions seem to be much harder to decouple from income. "Decoupling is said to occur when CO₂ emissions grow at a slower rate [relative decoupling] or negative rate [absolute decoupling] relative to their economic driving force over a given period" (OECD, 2002).

Stern (2006) sustains this last thesis too: in the global scenario, without specific policy interventions, the long-run positive relationship that exists between income growth and emissions per head is likely to persist.

The main reasons are:

- globalization increases trade between countries, so more transports and more CO₂ emissions;
- manufacturing activities are relocated to developing countries, and emissions get relocated as well;
- demand for carbon-intensive goods and services will continue to grow as income rises and many other reasons.

Relative decoupling has been achieved in many cases: extremely different were the causes that allowed countries to achieve these form of decoupling, as reductions in the energy intensity of GDP, reduction in the carbon intensity of energy or a combination of both. Few countries have been able to achieve absolute decoupling, especially in recent years.

Grunewald (2009) confirms: "We could not confirm an EKC for CO₂ among all countries but for high-income countries there is evidence for future declining emissions. Still, rising GDP represents the main driving force behind rising emissions". However, it has been showed that better technologies has a high potential to outweigh increases in CO₂ emissions driven by GDP.

2.3 Regional trends (1971 - 2008)

We decided to focus on countries which have a strategic importance in the global scenario, as those who are the largest emitters today or have been top emitters for many years. We have considered periods of ten years starting from 1971 until 2008, when the global financial crisis deeply affected various economies, with many consequences in terms of emissions: for this reason, we will more specifically deal with the most recent years in the Chapter 3. Furthermore, we accounted for the fact that the share in CO₂ emissions from middle and low income countries has risen considerably within the examined time-span, and very likely they will continue in the future, considering the stage of industrialization in which they are (Grunewald, 2009).

2.3.1 China

China is today the most emitting country, and the leading primary energy consumer in the world in absolute terms (Lee, 2014). These are some of the reasons why we have chosen to start our analysis from this country, considering even its incredible rise in the global economy and the environmental consequences related with that boom.

Over the past decades, China's rapid transformation from an agriculture-based economy to the world's manufacturing workshop has forced people to move to urban areas, causing the rise of very high-density cities: this changes had significant impact on Chinese natural resources, and, looking specifically at the huge increase in CO₂ emission, we want to understand which of the kaya identity factors can be considered the driving one for them.

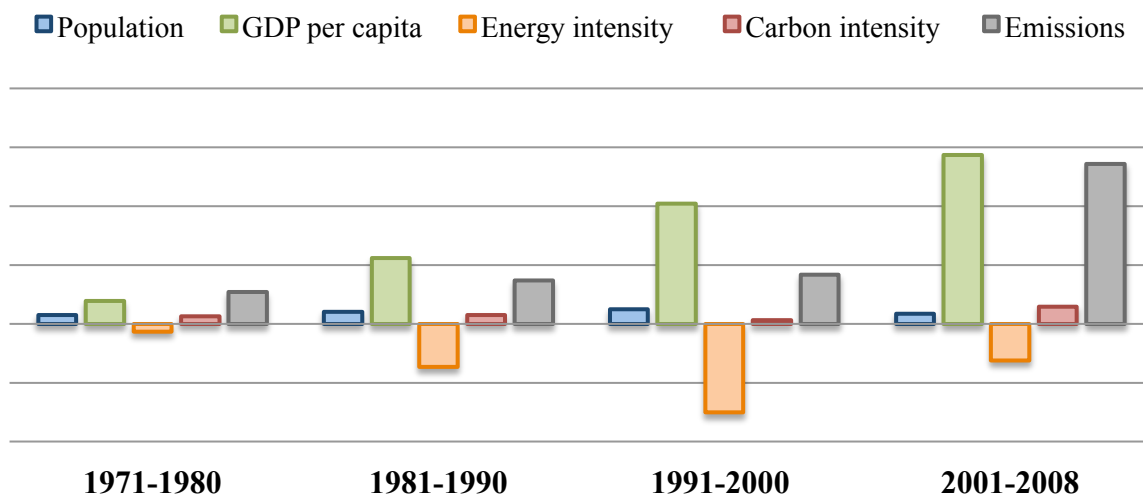
In the first decade we analysed, from 1971 to 1980, population grew at a relatively high speed, considering that the China's family planning policy was introduced only in 1978, together with the Chinese economic reform created to boost the economic system (which, in those years, was not performing at its best). After this last reform, a new era of growing started: in the early 80s economy grew at a really fast pace, stopped only by a rising pressure of inflation at the end of the decade, meanwhile what distinguishes this period from the previous one is a strong decline in the energy intensity of economic activities and the optimization of the primary energy consumption, which will become even larger in the following years. This last two factors positively contributed to a reduction in the levels of carbon dioxide emissions but they have never been huge enough to counterbalance the other factors.

From 1991 the economy started to expand again, accompanied by an increasing energy demand especially for oil: China even became a net importer of petroleum products. On the other side, China was affected by an overproduction of coal caused by the declining share of this primary source in the energy structure which, together with some regulations imposed by the Chinese government about local environment pollution, brought to a great improvement in the carbon intensity of the energy structure and an important optimization in the energy use efficiency. The impact of the financial crisis in the south east Asia (which in 1997, raised fears of a worldwide economic meltdown) was reflected in the diminishing emissions that characterized the last years of this decade.

In the period from 2001 till 2008 the economy grew at higher rates as a consequence of increased fixed capital investments; however the government positively promoted a process toward the decarbonisation of the energy structure mainly through renewable energy and hydropower, but clean energies grew slower than the other fossil fuels.

What immediately can be noticed is that the rapid economic development played a dominant role for the huge Chinese levels of emissions. GDP per person is the factor which increased most. On the other side, the improvement of energy intensity of GDP facilitated the mitigation of CO₂ emissions: in 1980 China had one of the highest energy intensity (Lee, 2014), but in the following years the implementation of activities as energy efficiency improvements in the economic context, the promotion of technical progress, industrial restructuring and energy-saving regulations allowed the country to achieve important results in terms of emission reduction. Especially for the decade 1991-2000 the reduction in the energy intensity of GDP reached its peak (see [Figure 2.4](#)).

Figure 2.4 - China: Kaya identity analysis (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

To a lesser extent, another factor which contributed to the reduction of the total amount of emission for China is the carbon intensity of energy, basically the gradual optimization of the primary energy structure: we mainly refer to the development of clean fuel technologies, spread of renewable energies and related laws and regulations.

Population is always one of the important factors to induce CO₂ emissions: from 1971 to 2008 China's population increased by 58%, bringing obvious consequences in terms of people's needs, even if this factor cannot be considered the most important in evaluating the one mostly responsible for current level of carbon dioxide.

What are the conclusions we can draw for this country, today the world largest emitter?

In these 38 years in China GDP per capita rose rapidly, followed by the increase in population, in the whole period; progressive decoupling of income growth from energy consumption has been achieved until the really first years of the new century, when CO₂ emissions started to grow very rapidly. GDP per capita has been the fundamental driving factor in the rise of CO₂ emissions.

2.3.2 United States

The path of United States CO₂ emissions is quite different from the previous we have seen; however we have to consider that the U.S. were already the top emitter country in 1971 and they have kept the first spot until 2007.

In the two years period 1973-74 the United States were affected by the Arab Oil Embargo, when the Arab members of the Organization of the Petroleum Exporting Countries (OPEC) cut production and stopped oil shipments to the United States: energy demand in the country exceeded supplies, causing gasoline prices to skyrocket. After the initial period of crisis brought by unprecedented fuel costs (the real price of oil had been declining since the end of the World War II), the situation finally showed positively drawbacks, triggering a serious discussion about alternative sources of energy and drastic improvements in energy efficiency. Immediately after the shock, President Nixon announced a package of new energy policies designed to alleviate fuel shortages, and shortly after President Carter pushed for greater reliance on solar energy and 'synthetic' fuels made from coal and shale, and in 1978 the Congress passed the *Energy Tax Act*, to encourage fuel efficiency and renewable energies.

Even if none of the adopted policies or programs was especially designed to reduce CO₂ emissions (which were not considered a problem, as climate change was not an issue yet),

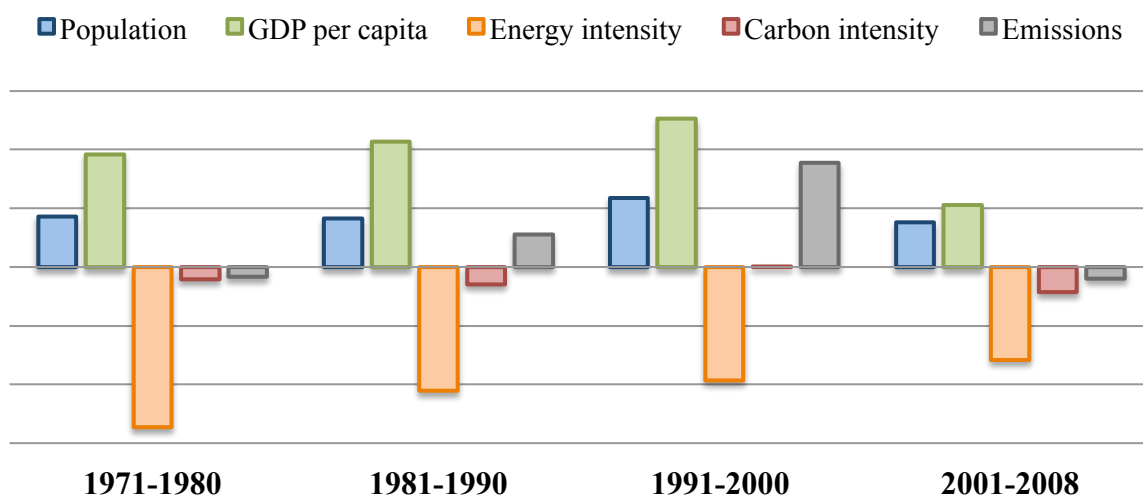
those measures provoked by the oil shock have probably done more to curb carbon emissions than any policy introduced after the embargo.

In fact "since 1973, the energy intensity of the U.S. economy [...] has fallen by more than half; petroleum use per capita has dropped by more than a third. The most important change has been the deceleration of total carbon emissions, which is what matters most for mitigating climate change" (Ross, 2013).

As we can notice (see Figure 2.5), for the decade 1971-80 emissions decreased and the energy intensity reached its maximum efficiency, contributing to the curb in total emissions.

"In the United States, energy intensity has been declining steadily since the early 1970s and continues to decline in EIA's long-term projection" (eia.gov); what mainly had contributed to reduce energy intensity have been structural changes and greater efficiency.

Figure 2.5 - United States: Kaya identity analysis (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

The most important driving factor results to be GDP per capita, as in the previous case, to prove once again how much economy and emissions are related. Especially in the decade 1991-2000, an increasing consumption of goods and services contributed to high CO₂ emissions.

2.3.3 India

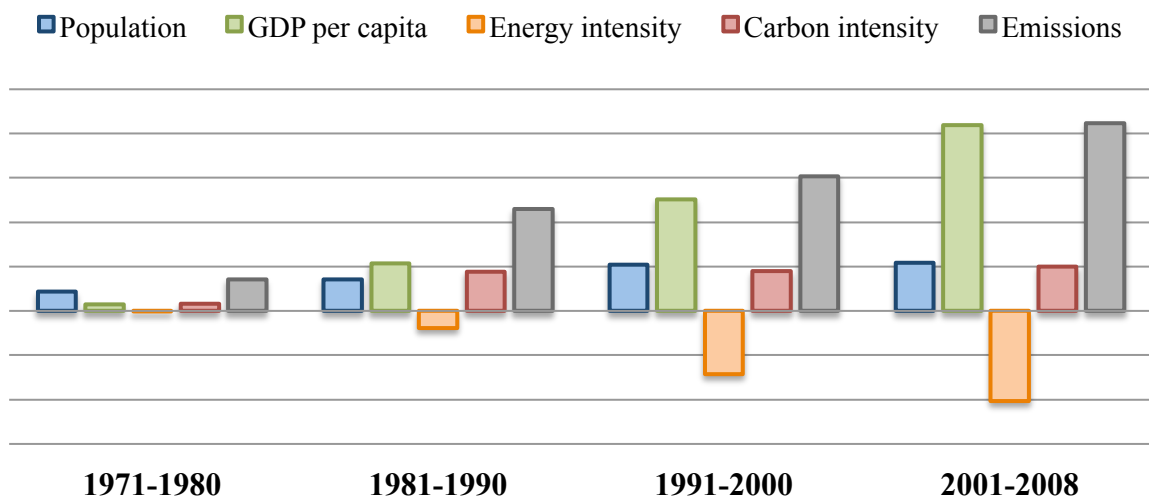
China and India share some common characteristics: they both have a huge population, they are big exporters and their economies experienced a real boom in a very short time frame.

"India shows an almost exponential increase in carbon dioxide emissions over time [...]; growth of population and per capita GDP are the two most important contributors to carbon dioxide emissions" (Ravindranath, 2002).

If we look closer at [Figure 2.6](#), we can notice that in the first decade population appear to be the main driver for CO₂ emissions, but thereafter GDP per capita represented the fundamental driving factor (indiaenergyportal.org).

In fact, after a severe balance of payment crisis, in 1991 an important economic reform was passed in India to quadruple growth and reduce problems of poverty and unemployment; however, Indian regulators' choices were driven purely by economic considerations, ignoring environmental issues (Ahluwalia, 1998). As a drawback, negative consequences in terms of environmental impact have been proven by different studies: especially the trade liberalization that was implemented had for sure fostered the economy but, at the same time, it resulted in a shift in the composition of production, exports and foreign direct investments to more pollution-intensive manufacturing industries (Jha, 2002). After the economic reform, Indian GDP increased on average by 6% each year; carbon dioxide emissions increased by 57% from 1991 to 2000, and in the following 7 years they increased even more, by nearly 50%.

Figure 2.6 - India: Kaya identity analysis (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

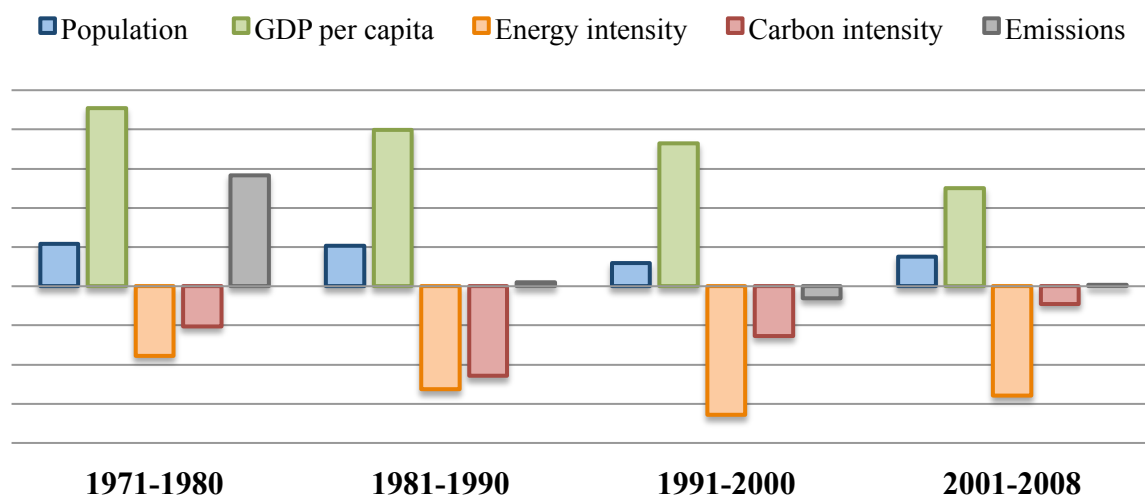
Recent literature (see for example Winters, 2007) shows that economic growth has been, in fact, the most important driver, but in this country there was not the offset given by improvements in energy intensity that we have seen for China, especially for the first three decades we have considered. Anyway "since 1999, India's energy intensity has been decreasing and is expected to continue to decrease" (indiaenergyportal.org); this can be attributed to structural economic changes towards lesser energy intensive industries, impressive growth of services and various general improvements in the efficiency of energy use.

2.3.4 OECD Europe

In 1971, world carbon dioxide emissions amounted to 14084.8 million tonnes, of which about 66.5% belonged to OECD countries. Almost 40 years later, in 2008, global emissions totaled 31734.3 m tonnes, and the percentage attributed to OECD countries dropped to 43.3%. We decided to focus on OECD Europe, to see how the path of CO₂ emissions evolved in the 'Old Continent' too, compared to other top emitters. Countries included are: Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Slovenia Spain, Sweden, Switzerland, Turkey and the United Kingdom.

What we can immediately notice from [Figure 2.7](#) is that the increase in economic output, especially from 1980, has been partly or almost totally offset by the significant decoupling of economic growth from energy consumption and by a mild decline of the carbon intensity coming from the mix of energy sources.

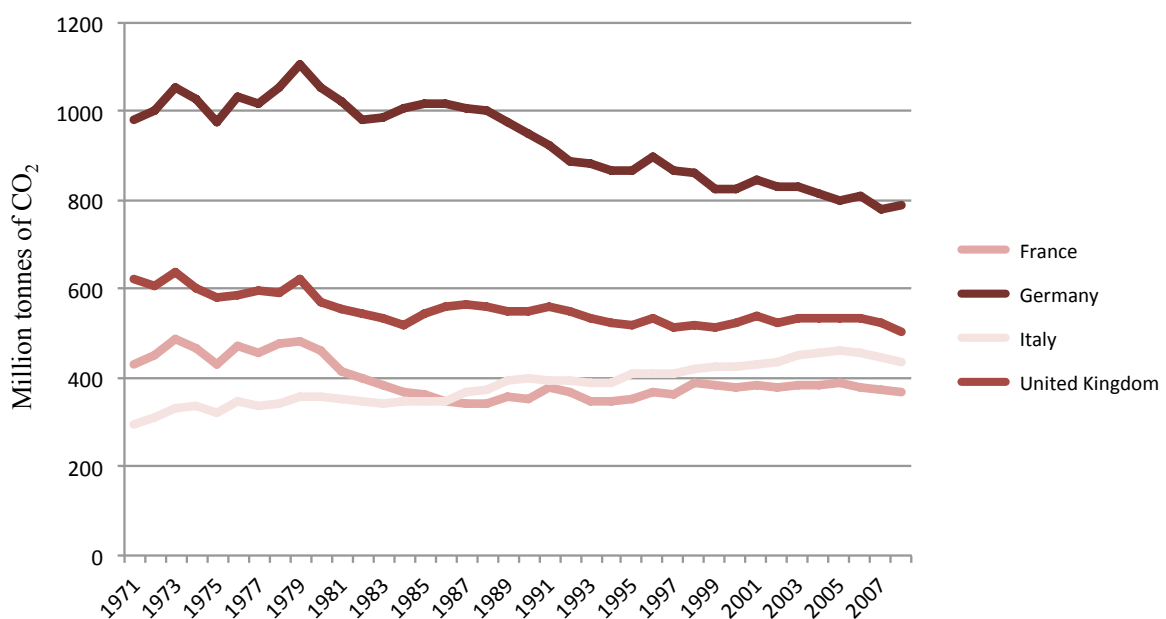
Figure 2.7 - OECD Europe: Kaya identity analysis (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

It is important to say that from 1971 till 2008 carbon dioxide emissions of the considered region increased only by 10%. Countries like Germany, UK, France and Italy have been the biggest contributors for the majority of the years, immediately followed by Poland, Spain and the Netherlands. In 1971 the first four countries accounted for almost 64% of the total amount of emissions, meanwhile in 2008 the same countries (which were still holding the first four spots in the list of top emitters) were responsible for 52% of the carbon dioxide emissions. In the time frame we analysed, their emissions (see [Figure 2.8](#)) have been characterized by small changes up and down and a relatively stable path.

Figure 2.8 - Trends in CO₂ Emissions for the top 4 emitters of OECD Europe (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

- **Germany**

In 2008 Germany was still leader in Europe, however it has been able to reduce CO₂ emissions by nearly 20% and they have set very challenging goals for the future regarding energy efficiency, renewables and climate protection.

From [Figure 2.9](#) we can visually understand the magnitude of German emissions compared to other European countries and how they evolved in the accounted time frame.

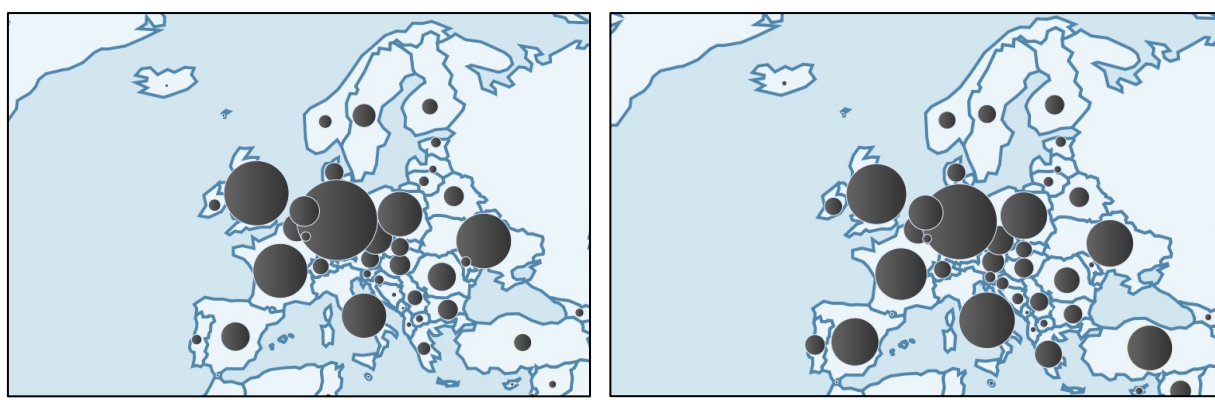
An important change in the path of emissions occurred in 1990: after the fall of the Berlin Wall and the reunification of the country, the decline of the East German industrial and power sectors meant important CO₂ reductions.

In the following years, Germany passed some important acts which allowed the country to

achieve huge greenhouse gas reduction goals, and within the German Energy Law two of them were crucial:

- in 2000 the Renewable Energy Sources Act (frequently amended in the next versions) promoted the generation of electricity using renewable energy sources;
- in 2005 the German Energy Act aimed at ensuring a safe, cost-effective, consumer-friendly, efficient and environmentally-friendly supply of power and gas.

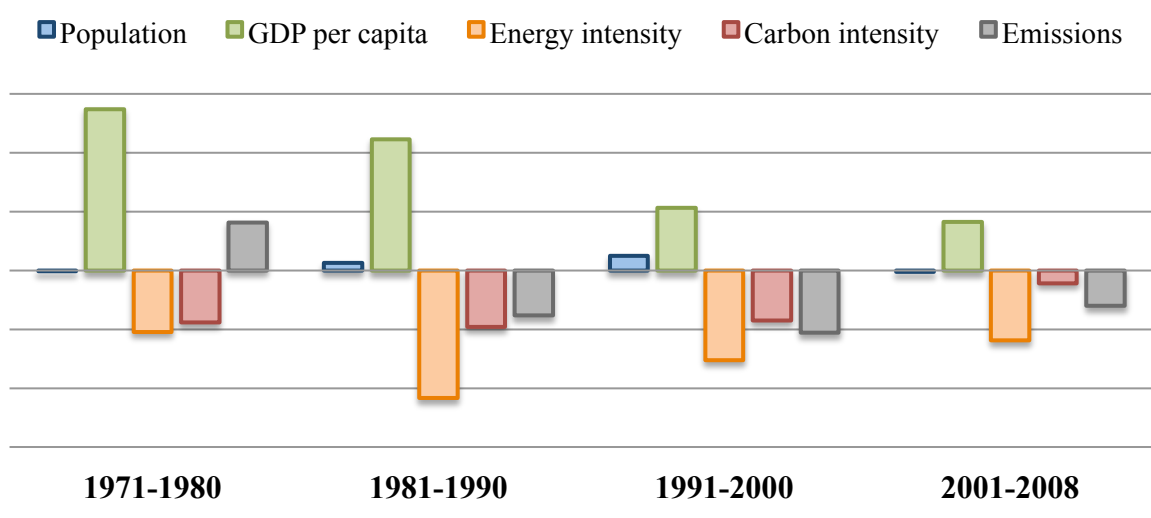
Figure 2.9 - Comparison of fossil fuel emissions in Europe in 1971 and 2008



Source: <http://emissions2015.globalcarbonatlas.org/en#>

As a result, until 2008, emissions were affected by a steady decline, and the driving factors mostly responsible (see Figure 2.10) were energy intensity of GDP and carbon intensity of energy: this last one, in particular, has been decreasing a lot due to the focus on renewable energy sources (especially wind and solar) strongly promoted by the government.

Figure 2.10 - Germany: Kaya identity analysis (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

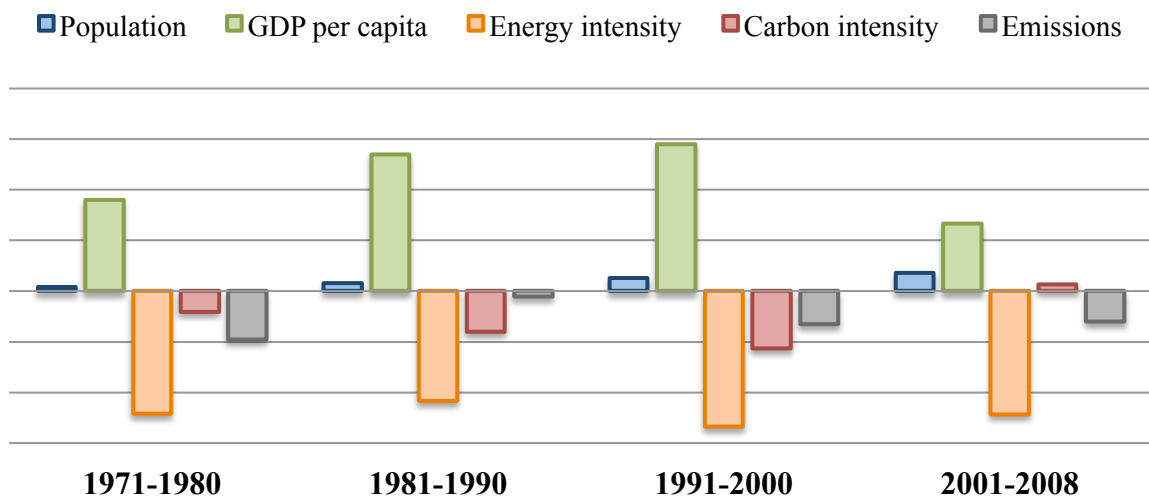
- **United Kingdom**

The United Kingdom has many features in common with the top European emitter that we have just analysed. Similarly to Germany, from 1971 to 2008 the UK was able to decrease its carbon dioxide emissions by nearly 20%, moving from 620 million tonnes of CO₂ to around 500.

Looking at the path of emissions, we can notice the same peak as for Germany, corresponding to 1979, followed by an important reduction in emissions because of the price of oil, which slowed down economic activities in many industrialized countries. From 1990, another decrease in CO₂ emissions was here registered, resulting mainly "from changes in the mix of fuels being used for electricity generation, including fuel switching from coal to gas and the growth of renewables, together with greater efficiency resulting from improvements in technology and a decline in the relative importance of energy intensive industries" (gov.uk).

From [Figure 2.11](#) we can notice that for the periods we have considered combined technological and fuel switching factors (represented by energy and carbon intensity) offset economic development and contributed to the decline of emission.

Figure 2.11 - UK: Kaya identity analysis (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

Emissions decrease in the last period has been achieved even through the adoption of new legislation and acts by the government. In 2000 the United Kingdom Climate Change Programme was launched, to cut GHG emissions, especially those of carbon dioxide (proposing a set of quantitative targets broken down by sector and by measure), to stimulate investments and more efficient solutions for power generation, and to promote energy

efficiency (oecd.org).

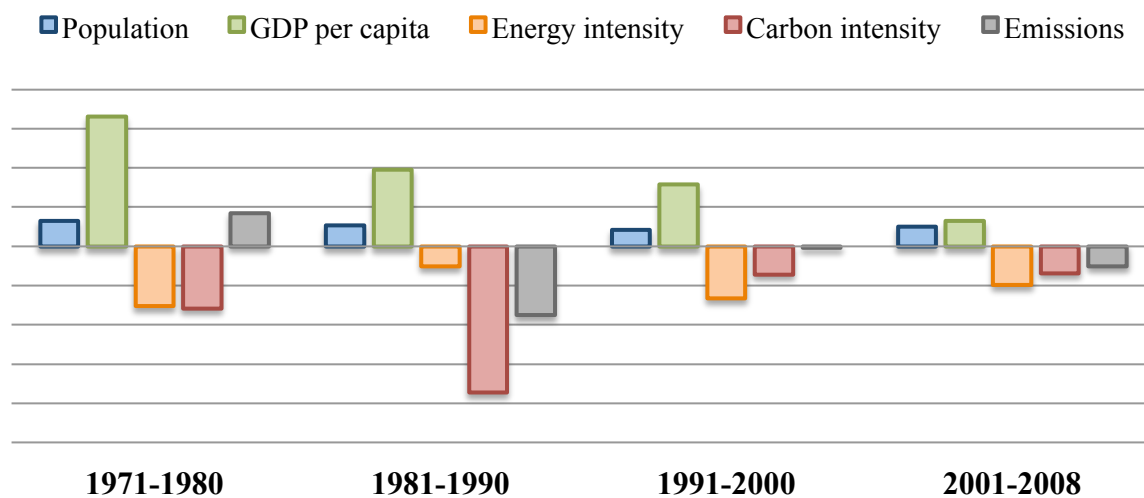
Two years later, in 2002, the UK Emissions Trading Scheme was adopted, a voluntary trading scheme created as a pilot for the following European one: it was particularly important because it represented the first multi-industry carbon trading system in the world.

- **France**

We have seen that the decarbonization of the economy is driven by two forces: change in the energy intensity of the economy and change in the carbon intensity of the energy supply.

France was the only European country, together with Sweden, to realize a strong decarbonization of its energy supply. "The fossil-fuel CO₂ emissions history of France is striking in that emissions have declined since 1979" (cdiac.gov). Since the oil crisis, the country's emissions reflected a modest decline in petroleum use and a bigger reduction in the use of coal. France continued to increase the use of natural gas, but most of all it made a major commitment to nuclear power, allowing the country to become even a net exporter of electricity.

Figure 2.12 - France: Kaya identity analysis (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

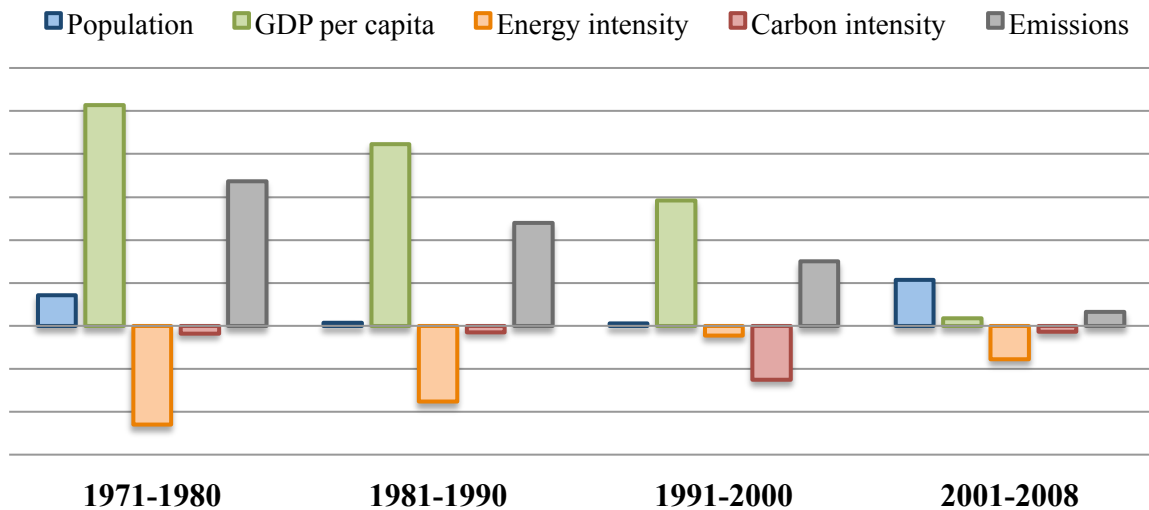
The adoption of this carbon-free technology, a fuel switching effect included within the driving factor of carbon intensity, had a fundamental role in the reduction of CO₂ emissions. The government invested a lot in the research, development and deployment of nuclear power technologies: in 2008, 75% of its electricity supply came from this source. As shown in [Figure 2.12](#), especially for the decade 1981-1990 the carbon intensity effect was able to drive emissions CO₂ downwards. In France, for the whole accounted period, carbon intensity

decreased by nearly 50%, mainly because of its nuclear commitment.

- **Italy**

Among the top four European emitters, Italy is the one whose emissions increased in the period from 1971 to 2008 by 49% (see [Figure 2.13](#)).

Figure 2.13 - Italy: Kaya identity analysis (1971 - 2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

In performing our analysis, it has to be considered that Italy had (and still has) limited domestic energy resources with high dependence on external energy supply, and at the end of the examined period its energy import dependency was more than 80%, against an European average of around 50%.

Let's first see how the Italian economy evolved, to check if CO₂ emissions were coupled with growth. In the early 70's, due to the first oil crisis, the pace of growth slowed down compared to the boost it had in the previous years, causing a significant downturn of the Italian economy, reaching in 1975 a drop in per-capita GDP of 2.7%. In the second half of the 1980s, the Italian economy was again prospering until the recession of the earlier 1990s. In the following years, Italy has been experiencing a prolonged period of slow growth with an average of 0.57% per annum (Annicchiarico, 2014).

Referring instead to emissions, "since 1974, emissions from liquid fuels have vacillated, dropping from 76% to 46% of a static but varying total; significant increases in natural gas consumption have compensated for the drop in oil consumption [...]. Coal usage grow steadily till 1985" (cdiac.gov). From 1986 to 2004 there was a constant growth in the path of emissions, anyway from 2005 we notice a turnaround: CO₂ emissions started to decrease, and

the country witnessed a decoupling from economic growth, energy consumption and GHG emissions.

After the oil crisis, an important reduction in the energy intensity of GDP was registered, due to increased efficiency in the use of energy sources and new energy policies implemented beyond the crisis, to which it followed a drop of the energy intensity in the manufacturing sector (Annicchiarico, 2014).

In the whole accounted period energy intensity decreased by 26%, and it has always been lower than the OECD Europe average (see [Figure 2.14](#)).

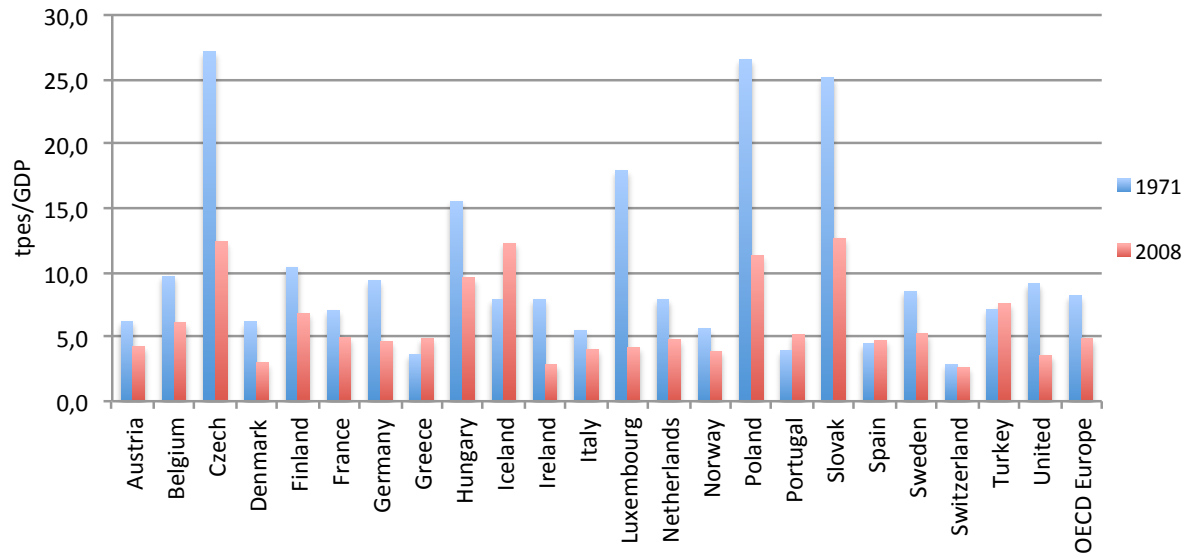
From [Table 2](#) it is possible to compare the energy intensity of GDP of various European OECD countries, among which Italy, in 1971 and in 2008. Many changes occurred in the accounted period, but overall tpes/gdp decreased substantially.

Table 2 - OECD Europe: energy intensity in 1971 and 2008

	Energy intensity in 1971	Energy intensity in 2008
Austria	6,2	4,2
Belgium	9,7	6,1
Czech Republic	27,1	12,4
Denmark	6,2	3,0
Finland	10,4	6,8
France	7,0	5,0
Germany	9,4	4,6
Greece	3,6	4,9
Hungary	15,6	9,6
Iceland	7,9	12,3
Ireland	7,9	2,8
Italy	5,5	4,0
Luxembourg	17,9	4,2
Netherlands	7,9	4,8
Norway	5,6	3,9
Poland	26,5	11,3
Portugal	3,9	5,2
Slovak Republic	25,1	12,6
Spain	4,4	4,7
Sweden	8,5	5,2
Switzerland	2,9	2,6
Turkey	7,1	7,6
United Kingdom	9,1	3,5
OECD Europe	8,2	4,8

Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

Figure 2.14 - OECD Europe: Energy intensity of GDP (1971 -2008)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2014 edition), IEA, 2014

CHAPTER 3

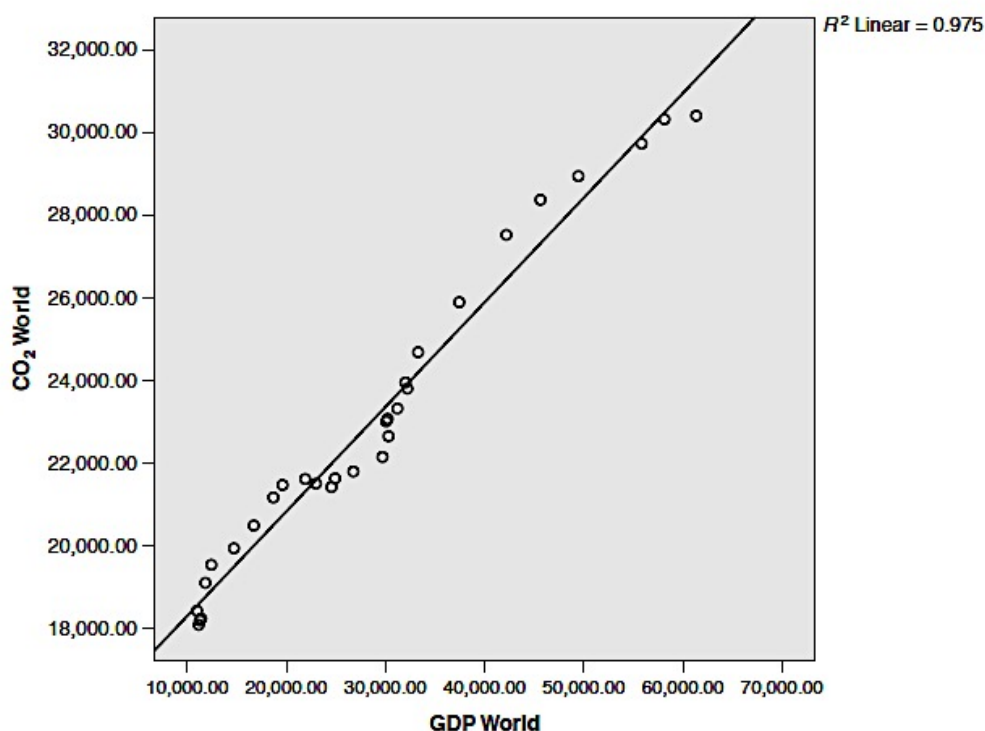
Decomposition analysis of CO₂ emissions after the 2008 global financial crisis

At first glance, an economic downturn is expected to have a positive effect on the environment, as emissions tend to fall because of their correlation with GDP and energy consumption. The question, however, is whether and how economic crisis can affect the carbon intensity of GDP. In particular, we are interested in examining the impact of 2008-2009 global financial crisis (GFC). For instance, if emissions went down, but the decline proved to be modest compared with the GDP fall, we might argue that the 'decarbonization process' came to an halt in these years and in the immediately following period.

3.1 Economic indicators and CO₂ emissions

The link between world economic output and pollution is fundamental to better understand the whole climate change debate and the various policy options related with the trade-off between 'affluence' and environmental quality.

Figure 3.1 - Total emissions 1980 - 2008 against global economic output

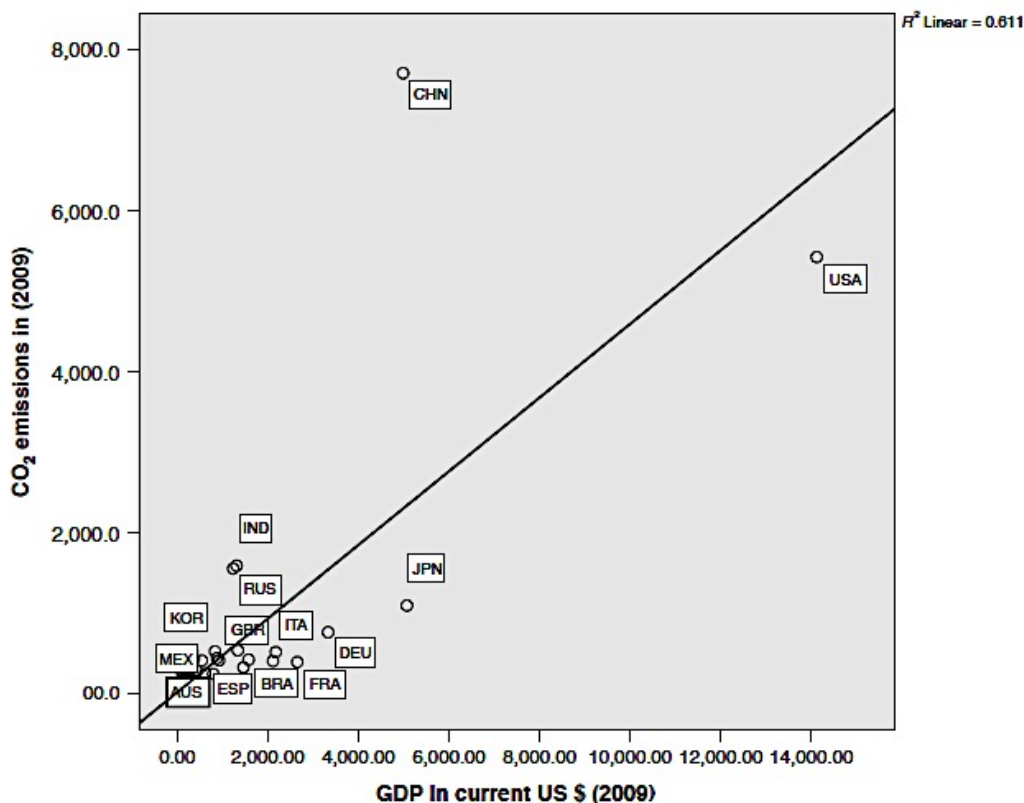


Source: CO₂ emissions + Population: EIA (2010); GDP data: The World Bank (2011)

According to Lacey (2011), there are only two ways to reduce CO₂ emissions: lowering the rates of economic growth and the creation of a completely innovative green economy. These alternatives appear really tough to put in practice; realistically only the second one is 'feasible', that is, reducing the conversion factor between energy-output-emissions.

In Figure 3.1 we can see how much CO₂ emissions equivalent increased from 1980 till 2008, and here yearly totals are plotted against total output. This source of pollution increases as a function of economic activity: the most obvious explanation is that more economic output requires more energy, and today the majority of it comes from the burning of fossil fuels. This leads to great levels of carbon dioxide emissions: as Figure 3.1 shows, the match between these and GDP increase is almost 'perfect'. In general terms, "a country economy delivers more CO₂ emissions the more affluent it is and the larger its transmission factor between output and pollution" (Lacey, 2011). Clearly there are some differences between countries: China can be contemplated as an outlier (see Figure 3.2), considering its current levels of pollution and its GDP, far lower than US ones for example. This transmission factor today stands at 0.45, implying that one unit of economic output results in 0.5 unit of emissions (Lacey, 2011).

Figure 3.2 - Country emissions against country GDP in 2009



Source: CO₂ emissions + Population: EIA (2011); GDP data: The World Bank (2011)

Do we have evidence of a scale effect in the output-emissions space? We have seen that a higher GDP corresponds to more emissions. But it could happen (even if this is not the most common scenario) that the amount of emissions per GDP unit decreases at the same time due to economies of scale in energy production and consumption (Lace, 2011). In the next future, mankind is hardly going to settle down for zero growth: considering that economic expansion is unstoppable, and global population is still expected to rise, is very likely that we will observe increase in CO₂ emissions as well. If new sources of energy will not overcome the strong fossil fuel dependency that affect many countries, the current trends would not be stopped.

Other theories examined the relationship between income and carbon dioxide emissions, explaining us how can they be connected. We have already analysed, in Chapter 2, the Environmental Kutzets Curve hypothesis asserting that after a certain turning point in income emissions will decrease because of more energy-efficient production and the adoption of renewable energy sources. Another crucial and very discussed hypothesis, formulated for the first time by Porter (1991 and 1995), states that properly designed regulations can lead to both economic growth and improvements in environmental quality. He argued that the existing debate about the trade-off between ecology and economy is based on an old, static view of the environmental regulation where technology, processes, products and costumers needs are all fixed; meanwhile, the new paradigm of competitiveness is a dynamic one, based on innovation. Companies competitive on an international scale are those able to improve and innovate continuously; considering this aspect, well-designed environmental policies can trigger innovation such that firms can partially or fully offset costs arising from being compliant with that standards. How is it possible? Accurately crafted regulations can signal companies about resource inefficiencies and potential technological improvements, letting them generate corporate awareness about environmental issues. Furthermore regulations create pressure that motivates innovation and progress (Porter, 1995). An essential feature is innovation: companies not only get smarter about how to deal with pollution and harmful materials generated, but innovation can affect even products and processes (better performing and higher quality products, lower product costs, higher resource productivity, material savings and lower energy consumption during the production process, conversion of waste into valuable forms and many others).

As argued by Porter (1995), "Pollution [...] is a manifestation of economic waste and involves unnecessary, inefficient or incomplete utilization of resources, or resources not used to generate their highest value". If companies and regulators keep their focus on environmental

improvements framed as resource productivity, not only pollution control, this can lead firms to actually raise economic value and growth.

3.2 Historical global crisis and the most recent 'financial' one

As argued by Giedraitis (2010), "There is a strong correlation between CO₂ concentrations in the atmosphere and economic situations which could be seen during recession periods, when industrial activity decreases. During the first significant financial crisis after the beginning of the industrial revolution, *The Panic of 1873*, CO₂ emissions on a global scale reduced".

Another case is represented by the Great Depression of the 1930s, which had a deep impact on the economic activity levels of that time; in that situation, the crisis interrupted the growing trend in CO₂ emissions that was affecting many nations since the industrial revolution and it has been proved that the registered decrease in emission was not due to natural factors (as volcanic eruptions), but only anthropogenic ones (Giedraitis, 2010).

Other more recent economic crisis deeply affected the trajectory of CO₂ emissions. Siddiqi (2000) examined the consequences of the Asian financial crisis, concluding that the growth rate of energy consumption somewhat declined because of the financial situation, leading to a decline in emission growth but not to an absolute decline of CO₂ emissions; anyway the crisis even caused the postponement of measures to improve environmental quality. Pondering benefits and costs for the environment, probably the Asian crisis, in the long term, had more costs and provoked only economic and political changes, not structural ones.

A previous crisis characterized by global consequences started with the Arab Oil embargo (oil crisis happened in 1973 and 1979): however in these circumstances the crisis brought to structural changes in the economy of various countries, stimulated the development and diffusion of more energy-efficient production processes and somehow affected the fuel mix (namely, particularly in Europe, from oil to natural gas).

But a huge recent global crisis, which affected many countries, and whose consequences are still visible in some regions, is far more interesting for us. In September 2008 the collapse of the Lehman Brothers almost brought down the world financial system, and provoked what is referred to the worst recession since the Great Depression in 1930s.

"The pace of global activity had already been softening before the most intense phase of the financial crisis began [...] The large run up in home construction and dwelling prices in the United States had started to turn by mid-2006 and this was dampening the overall growth of the US economy". A similar situation was taking place in the United Kingdom, meanwhile

other parts of the world (as China and some other emerging economies in Asia) continued to look resilient through the first half of 2008, growing at a firm pace (Edey, 2009).

Following the Lehman Brothers' collapse, financial conditions all over the world started to deteriorate and the level of activity in the major economies took a sharp turn for the worse. Business and consumer confidence collapsed, and the major result was an exceptional fall in global industrial production towards the end of 2008, and significant contractions in GDP in most of the major economies. The downturn, in a climate of extreme uncertainty, quickly spread to other parts of the world, including Asia, Latin America and eastern Europe. Later on, together with the deterioration in confidence, unemployment started to rise, households around the world made a rapid re-evaluation of their spending plans, cutting back discretionary expenses: private consumption fell sharply, especially in the industrialized and emerging market economies. The US, the Eurozone and other regions had to face periods of recession; 2009 was characterized by negative growth for the mentioned areas, and a very limited recovery was witnessed in 2010.

Especially in the Eurozone, the speed of the recovery from the global financial crisis has been very slow: countries as Italy and Spain struggled most to overcome the economic recession which affected them, meanwhile Germany, the UK and France have been hurt less severely by the crisis but however it took some years for them to recover.

3.3 Analysis of CO₂ emissions after the global financial crisis

Considering the slow down of economic growth registered in emerging economies and the recession that affected developed ones, a decrease in CO₂ emissions is more than expected.

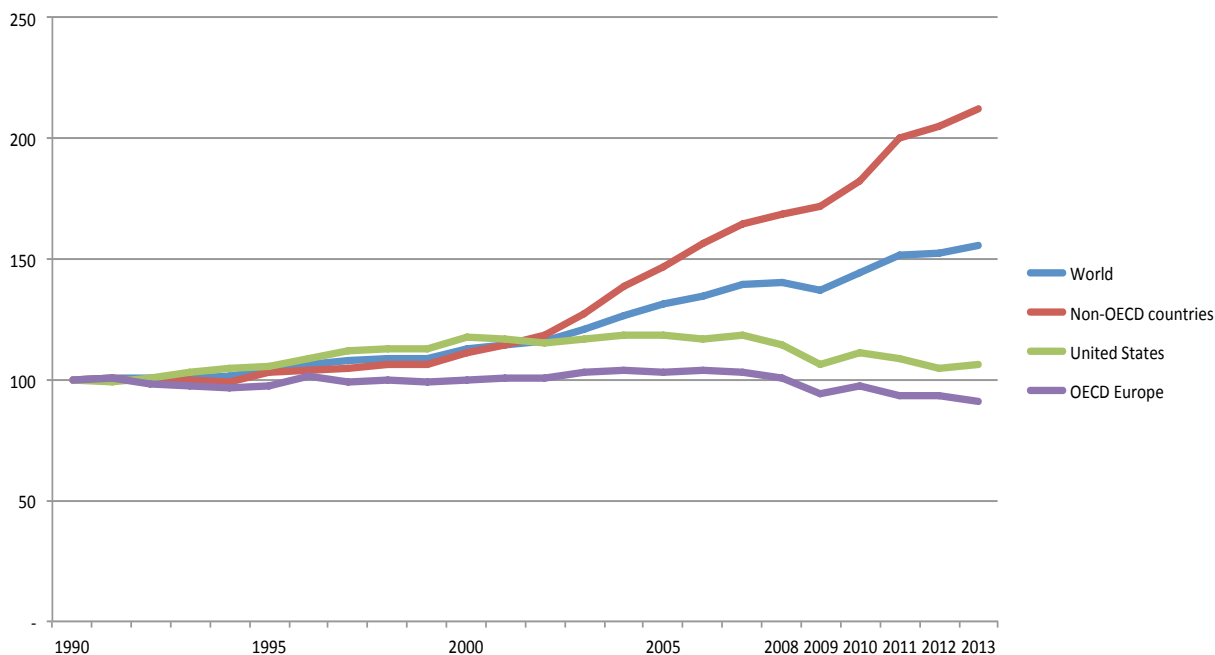
However a decrease cannot be interpreted *per se* as a 'decarbonization' of the economy ('decarbonization' refers to the declining average carbon intensity of GDP over time). Therefore, rather than focusing just on the emissions decrement, if any, we will try to understand the driving factors behind it.

Plausible explanations could be a simple contraction in GDP, an economic slowdown or the combination between these factors and a continuum in the process of decarbonization that started decades before. If CO₂ emissions and economic growth are coupled (i.e. linked), a GDP decrease by 1% would result in a corresponding emissions decrease (1%); but in the recent years, as explained in the previous Chapter, we have seen how a progressive decoupling process have occurred in many countries. If our analysis will prove that emissions have been abated by even a larger quantity, this would imply that the decoupling trend continued, and that the decrease in emissions was even affected by a continuance in the

'decarbonization' way.

First, we look at the CO₂ emissions from 1990 to 2013, focusing on the years of the global crisis and the immediately following period (see [Figure 3.3](#)); all quantities, from this figure on, are normalized to 100 in the year 1990 (our reference year).

Figure 3.3 - CO₂ emissions from 1991 to 2013



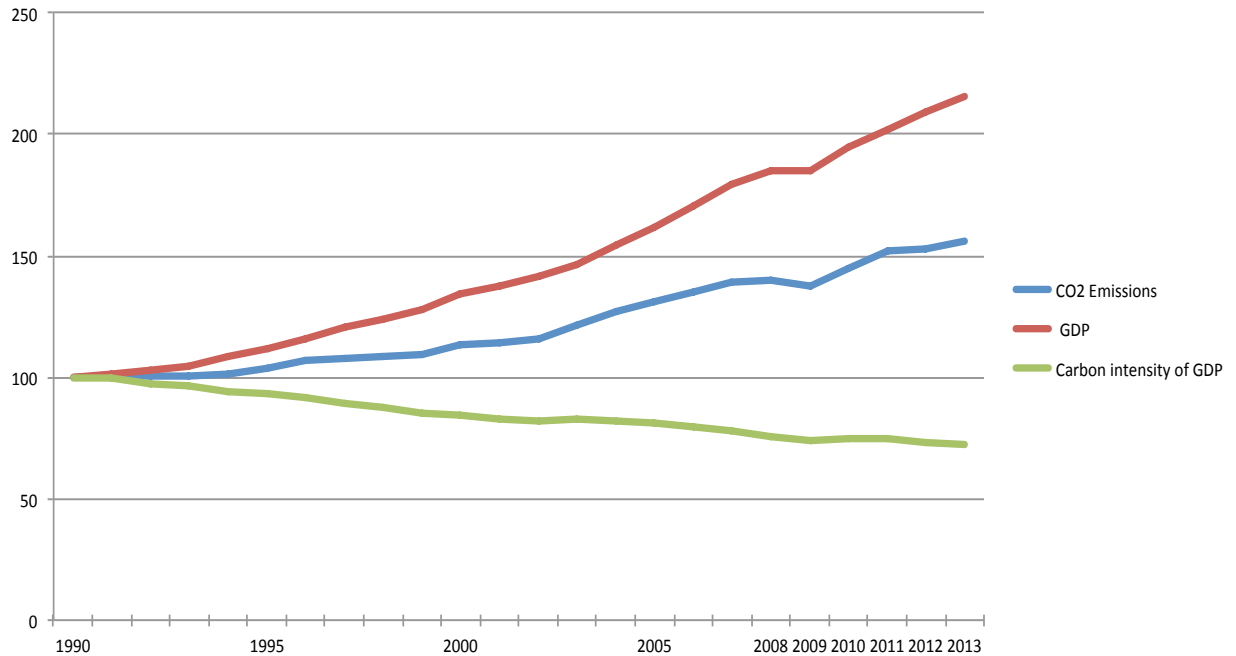
Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2015 edition), IEA, 2015

Clearly, the crisis had an impact on emissions: a drop between the years 2008 and 2009 is distinctly visible for all the accounted areas. Data from the International Energy Agency tells us that 2009 had been characterized by a modest reduction in global emissions by 1.7%, yet the 2010 growth in emissions (for which were mainly responsible few emerging key economies, as China and India) overcame the drop just recorded, putting emissions back on the high-growth trajectory that persisted before the crisis (Peters, 2011). In the United States, where the crisis started, CO₂ emissions dropped by 7.1% in 2009 compared to the previous year; the OECD Europe registered a very similar decrease in emissions (7.0%). Non-OECD countries, a pivotal group that includes giants as China and India, were to a lesser extent impacted by the crisis: emissions reduced their extraordinary growth slowing down the boosting path, however CO₂ emissions increased by 2% in 2009 and by 6% the next year.

Considering the global perspective we can focus now on the other topic, represented by the carbon intensity of GDP: it will allow us to understand if the decarbonization path came to an

halt or not because of the global crisis. From [Figure 3.4](#) we can see how global GDP, emissions and the carbon intensity of GDP evolved from 1990 to 2013.

Figure 3.4 - Emissions, GDP and carbon intensity of GDP from 1990 to 2013

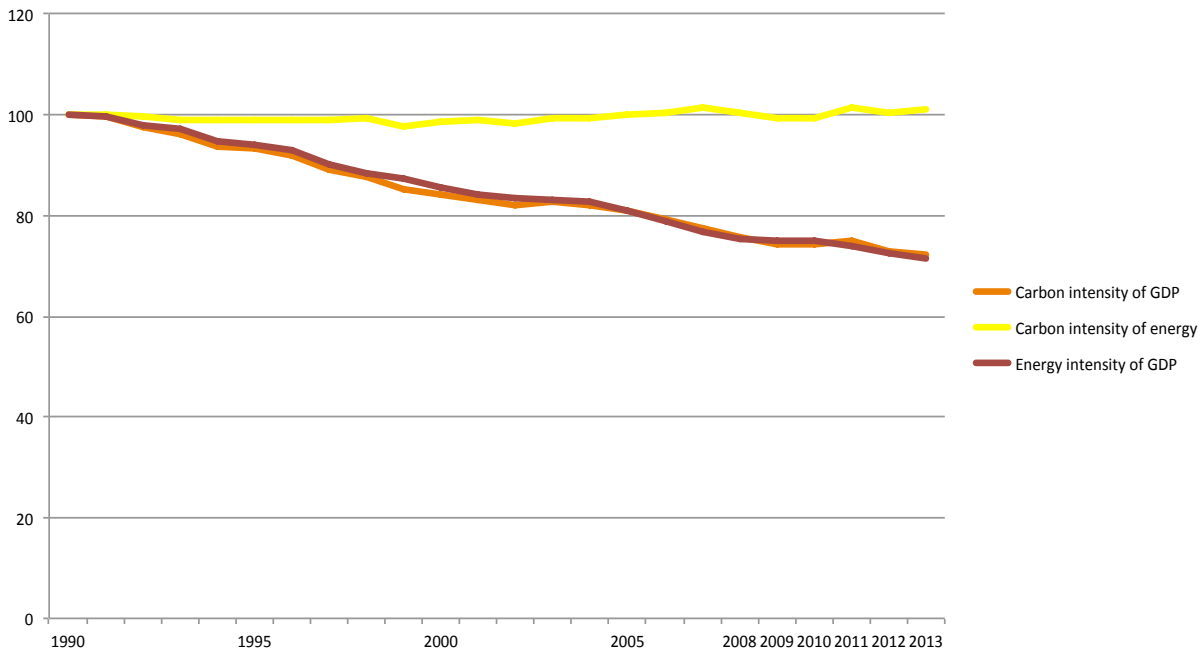


Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2015 edition), IEA, 2015

Again we have clear evidence of the short-term drop in emissions and in GDP because of the global crisis. A more interesting finding is represented by the fact that the slow but constant decreasing path characterizing the carbon intensity of GDP continued during the years of the crisis and in the immediately following period, since we do not have evidence of strong and decisive changes in its trend (differently from the other analysed factors). Anyhow consequences of the recession are yet visible: a small deviation from the mentioned trend is given by an increase of 0.1% from 2009 to 2010 and a more decisive increase 0.9% from 2010 to 2011. In 2009, after the crisis boom, world GDP decreased by 0.12% meanwhile CO₂ emissions registered a much greater drop of 1.9%. Here emerges the evidence of the process of decoupling between emissions and economic growth, and the larger reduction in CO₂ emissions can be explained with a continuation in the decarbonization path.

A deeper analysis would allow us examine what happened specifically to the decarbonization trend, and the driving factor in which we are interested most is the carbon intensity of GDP. For instance, the carbon intensity of GDP can be decomposed in the carbon intensity of energy and the energy intensity of GDP. From [Figure 3.5](#) we can look at which factors were mostly affected by the crisis and compare their trends before and after the GFC.

Figure 3.5 - Decomposition of carbon intensity of GDP (1990 - 2013)



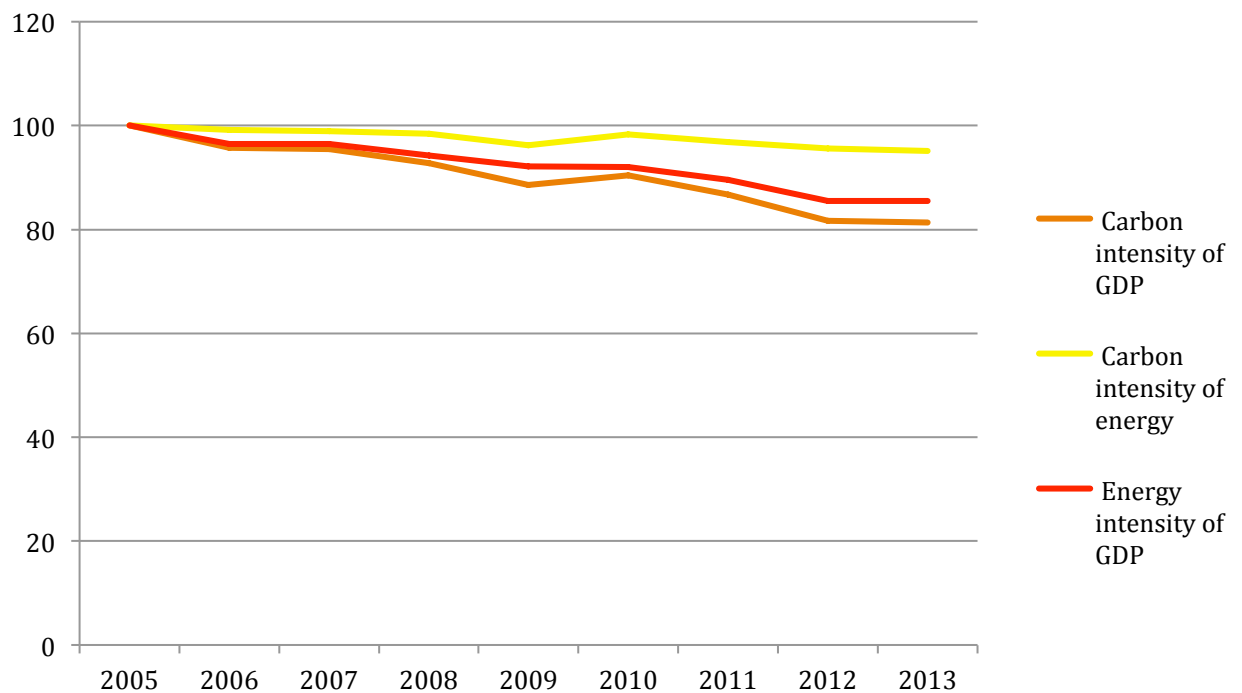
Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2015 edition), IEA, 2015

From the first glance it can be immediately observed that the decreasing path of carbon intensity of GDP can be explained with a non-negligible reduction in energy intensity of GDP. On the other hand, changes in the fuel mix have played a minor role, however moving away from coal and oil helped in the reduction of carbon intensity. Focusing on the decomposition of the carbon intensity of GDP since 2008 on, we can notice a more visible variation in the carbon intensity of energy: probably the reduction in oil prices because of the crisis fostered the use of traditional fossil fuel sources rather than renewable energy sources.

We will here proceed with a wider analysis for specific regions and areas crucial in the global scenario, to better understand how the dynamics for these driving factors of carbon dioxide emissions evolved. Quantities now on will be normalized to 100 in the year 2005, to concentrate on years we are interested on.

First we perform our analysis on the United States (see [Figure 3.6](#)). If we look at the carbon intensity of GDP, we can notice a quite steep decline from 2007 to 2009. But what emerges immediately after is the boost from 2009 to 2010, in great part due to the increase in the carbon intensity of energy (+2%). Anyhow, since 2010 on, CO₂/GDP got back again to their decreasing trend. The energy intensity of GDP suffered less because of the global crisis and continued almost firmly its downward process.

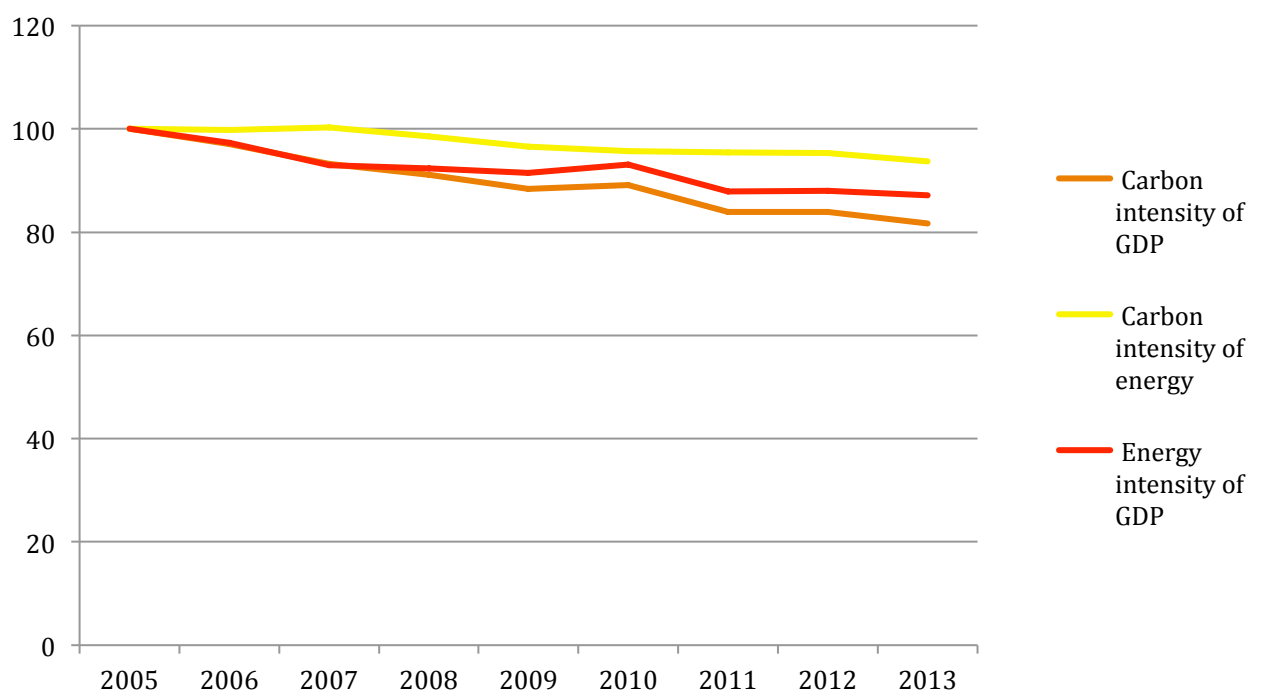
Figure 3.6 - US: decomposition of carbon intensity of GDP (2005 - 2013)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2015 edition), IEA, 2015

We now move the analysis to OECD Europe: a similar path can be observed for the carbon intensity of GDP (see [Figure 3.7](#)), with a strong reduction in correspondence with the years just before the crisis boom, a weak growth in 2010 and a recovery toward the decreasing trend in the most recent period.

Figure 3.7 - OECD Europe: decomposition of carbon intensity of GDP (2005 - 2013)



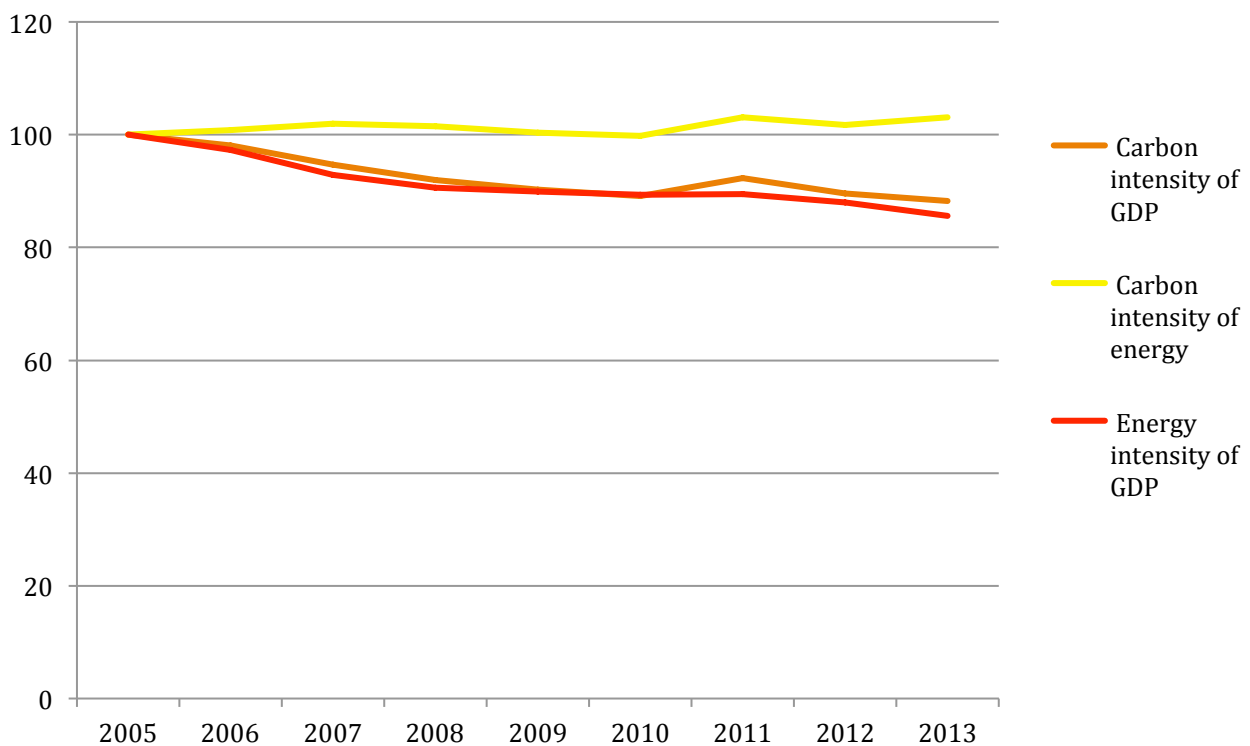
Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2015 edition), IEA, 2015

The interesting difference from the previous case is that here the factor predominantly affected by the crisis is the energy intensity of GDP; considering that structural changes cannot happen in such a short period of time, the other way to interpret this results is through a reduction in the overall energy efficiency of the economy.

A completely different group is represented by non-OECD countries. For many countries among those included (and we are referring especially to giant top CO₂ emitters), the global financial crisis just implied a temporary slowing down in the economic expansion they were performing. Carbon dioxide emissions only showed a smaller growth rate in 2009, but since then on, they continued to skyrocket. Probably the most evident consequence of the GFC, in our analysis (see [Figure 3.8](#)), is the visible increase in carbon intensity of GDP (4% from 2010 to 2011), that can be explained with the corresponding increase in the carbon intensity of energy. One among the plausible reasons could be a still growing reliance on fossil fuels, especially coal.

The biggest top emitter included within non-OECD countries is China: we choose to separately analyse how previously mentioned driving factors evolved from 2005 to 2013.

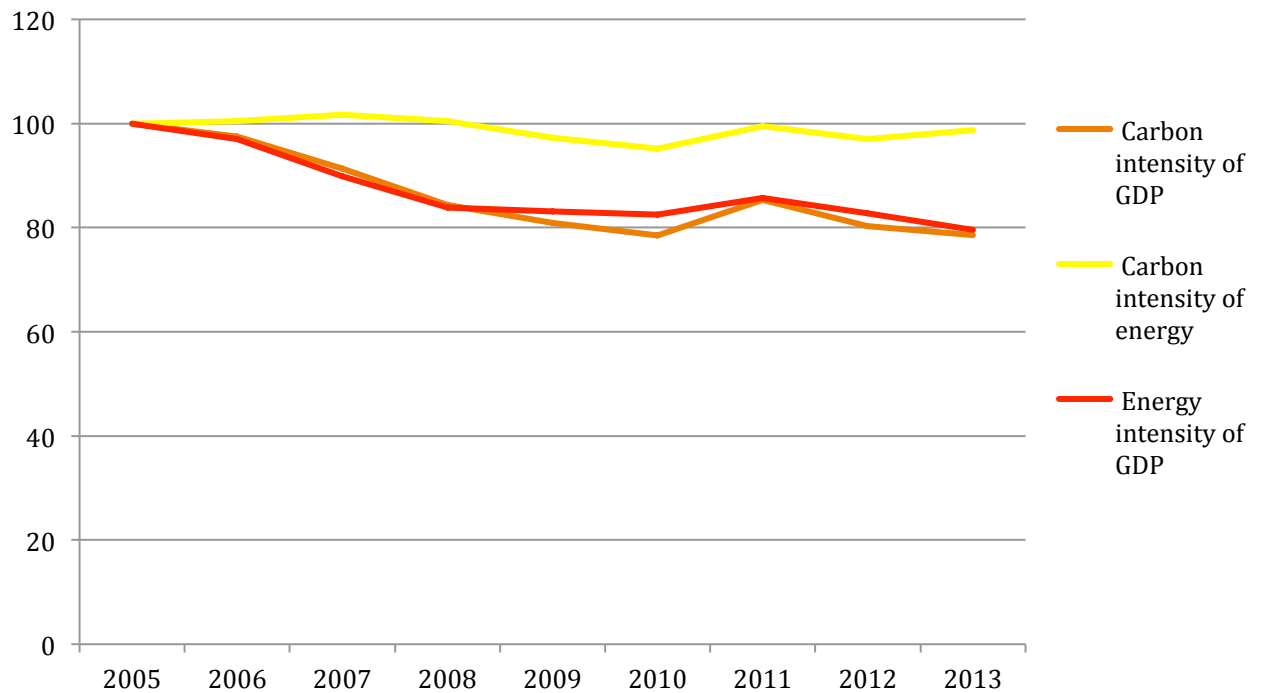
Figure 3.8 - Non OECD countries: Decomposition of carbon intensity of GDP (2005 - 2013)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2015 edition), IEA, 2015

Carbon intensity of GDP, approximately since 2008, reflects changes occurred to carbon intensity of energy, as happened in the previous case. From 2010 to 2011 the Chinese carbon intensity of energy increased by 5%, and the corresponding peak is visible in [Figure 3.9](#).

Figure 3.9 - China: Decomposition of carbon intensity of GDP (2005 - 2013)



Source: Author's calculations based on *CO₂ Emissions from Fuel Combustion* (2015 edition), IEA, 2015

3.4 The short-term impact of the crisis on emissions

The economic crisis had a short-lived impact on CO₂ emissions. In fact, what IEA data shows us is that emissions started to grow again with a stronger boost. According to Peters (2011), there are three main reasons that can explain why it took a short time for emissions to get back to the high growing path that characterized the first years of the 2000s.

First of all, the rapid decrease of energy prices removed pressure from structural changes in energy consumption: during the previous oil crisis, many countries were affected by persistent price shocks forcing them to deeply change the structure of their primary energy sources, but this did not happen during the last global crisis, and countries continued to use traditional sources for their energy production and consumption.

The second reason is that governments decided to put in place huge investments in order to foster a quick economic recovery and bring countries back to a pre-crisis situation, with the

consequence that, as countries GDP started to grow again, the same happened for carbon dioxide emissions.

Finally, the effect of a decade of high economic growth in the developing world, whose countries strongly contributed to a rapid global post-crisis return to high emissions.

In short, the GFC surely helped developed countries to meet their production/territorial-based emission commitments, as promised in the Kyoto Protocol. Yet, the GFC had minimal impact on emissions growth in emerging economies (Peters, 2011) and the quick rebound from the crisis emphasized pre-existing challenges related with reduction targets.

Conclusive remarks

In this work we presented an analysis of CO₂ emissions from fossil-fuel combustion and discussed results obtained from a decomposition process of emissions driving factors from 1971 to 2013. We used data from the International Energy Agency to perform the analysis and we adopted a standard decomposition technique, based on the Kaya identity, to find out which have been the drivers that most affected emissions trends over the last four decades. In particular we were interested in understanding the impact of an expanding economy on CO₂ emissions, and if these two variables presented evidence of being coupled or not.

First we introduced the concept of global warming, showing proof of how much human activities not only contributed, but strongly determined increases in globally averaged temperatures since the mid-20th century (IPCC, 2013). Greenhouse gas emissions are considered big contributors to the global warming process and, among them, CO₂ emissions (which concentrations have increased steadily since the beginning of the industrial era) have been accounted as the main responsible. We presented global and regional trends for CO₂ emissions and we underlined the importance of distinguishing between total and per capita emissions, especially for very densely populated countries. In 2014 China, for example, was globally the largest emitter of CO₂, but moving the analysis in terms of per capita emissions, it ranked 11th.

We then moved the analysis to the decomposition of CO₂ emissions from 1971 to 2008. The Kaya identity, and the adoption of the Laspeyres index, allowed us to decompose emissions into four driving factors: population, GDP per capita, energy intensity of GDP and carbon intensity of energy. Economic development and population growth resulted to be the main drivers of emissions; another important aspect that arose was the decarbonization process that contributed to limit the incredible growth of CO₂ emissions. 'Decarbonization' refers to the declining average carbon intensity of GDP over time; the large part of reduction achieved in recent years was due to a decreasing energy intensity of GDP, because of structural changes (shift towards less energy and carbon-intensive economic activities) and/or reductions in sector-level energy intensities. Instead the worldwide carbon intensity of energy, affected by changes in the fuel-mix, showed a much lower decrease.

In the last Chapter we focused on the consequences of the 2008 global financial crisis, and re-performed the decomposition analysis for the period from 2008 to 2013. In particular we tried to understand how the slowing down experienced by various economies (and the recession that hit some others) affected CO₂ emissions, and if the global crisis somehow interrupted the

decarbonization trend that was taking place before. Undoubtedly the GFC had an impact on emissions: in 2009 a reduction by 1.7% was registered, however the very following year emissions increased again by 5.4%, bringing them back to the high growth trajectory that started with the new century. We found that the carbon intensity of GDP, our measure of the economic decarbonization, was partially affected by the crisis, but we did not see a decisive halt because of the crisis, and after 2011 the carbon intensity started to decrease again.

By decomposing CO_2/GDP into $CO_2/TPES * TPES/GDP$ we wanted to find which variations have occurred to the carbon intensity of GDP during the period of the crisis. We performed the mentioned analysis for United States, OECD Europe, non-OECD countries and China. We noticed that in U.S., non-OECD countries and China, the energy intensity of GDP registered less changes because of the crisis and related consequences, than the carbon intensity of energy. This implies that changes in the fuel mix have been more significant and affected most the carbon intensity of GDP. Differently, in the OECD Europe, the energy intensity of GDP registered much larger variations and, considering that structural changes cannot take place in 5 years, the other plausible explanation is represented by an increase in the sector-level energy intensities.

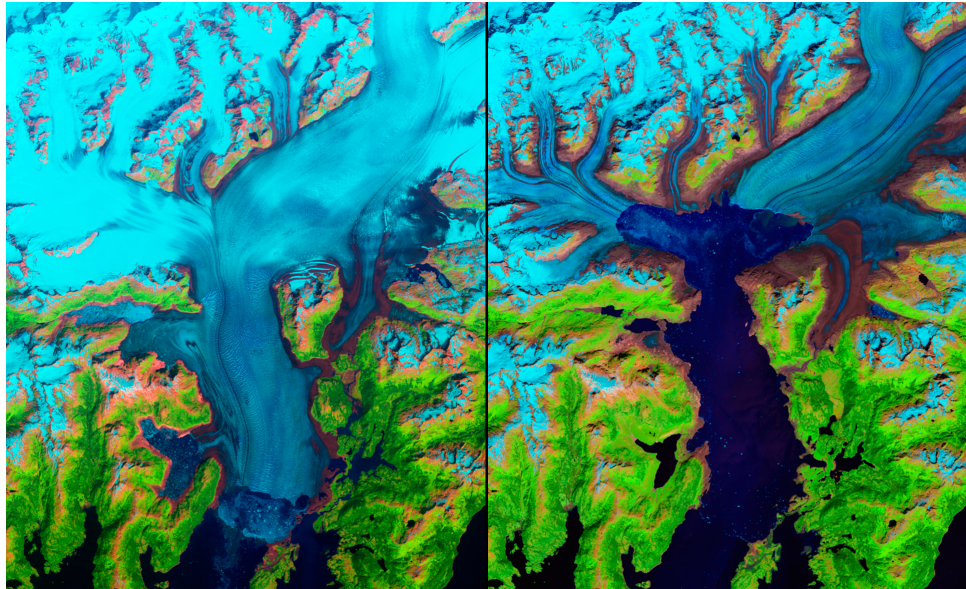
Considering the future scenario for CO_2 emissions and the global path toward decarbonization, it is interesting to notice that "preliminary data from the IEA indicate that global emissions of CO_2 from the energy sector stalled in 2014, marking the first time in 40 years in which there was a halt or reduction in emissions of the greenhouse gas that was not tied to an economic downturn" said Kelly Levin, senior associate of the World Resources Institute.

However many CO_2 emissions peaking will take place in the next few years. If commitments pledged during the Paris talks will be met, by 2030 we expect that many strategic players as China, Brazil, Mexico and South Africa will pass their peak in emission levels (many developed countries have already reached their top level of emissions) and experts are forecasting that global carbon dioxide emissions will not peak before that date, with CO_2 levels that will continue rising at least for the next 15 years. Therefore, in order to avert the worst climate impacts, countries need to update their current mitigation objectives and work together to achieve more ambitious targets.

Appendices

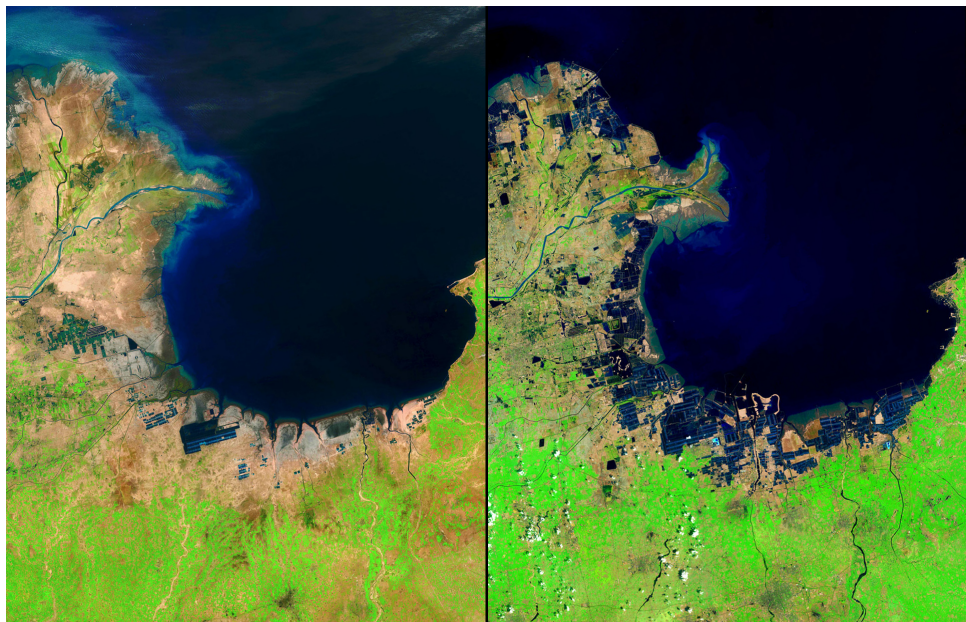
Appendix 1

Figure A - Alaska's Columbia Glaciers (1986 - 2014)



Source: http://climate.nasa.gov/state_of_flux#Columbia_Glacier_930x312.jpg

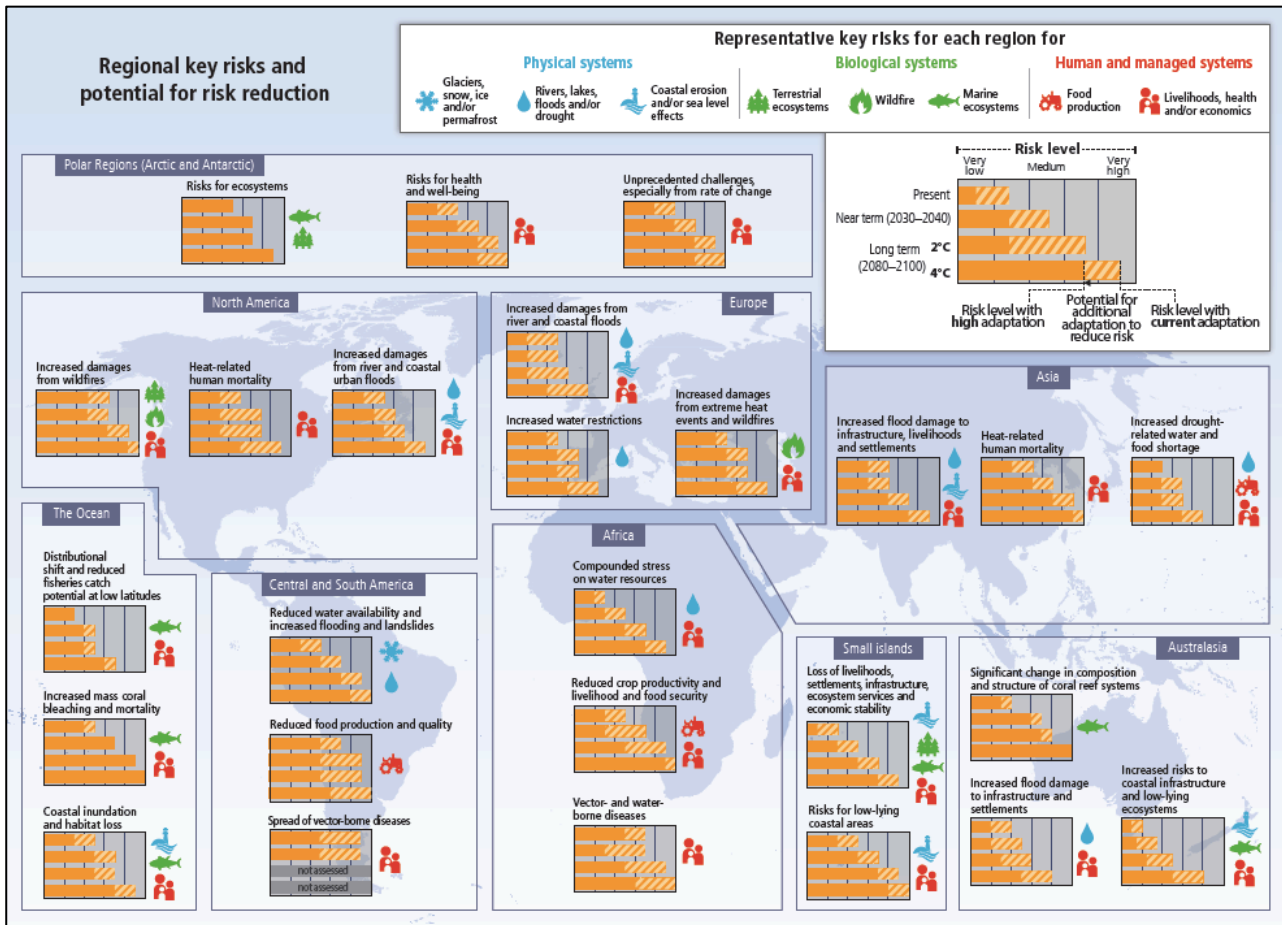
Figure B - China's Huang He (Yellow) River (1985 - 2014)



Source: http://climate.nasa.gov/state_of_flux#Huang_He_Delta_930x430.jpg

Appendix 2

Figure C - Regional key risk and potential for risk reduction



Source: IPCC, 2014: *Climate Change 2014: Synthesis Report*. IPCC, Geneva, Switzerland (p. 65)

In [Figure C](#) we can look at the representative key risks for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation.

Identification of key risks was based on expert judgment using the following criteria: large magnitude, high probability or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation. Risk levels are assessed as very low, low, medium, high or very high for three timeframes: the present, near term (here, for 2030–2040) and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2°C and 4°C global mean temperature increase above pre-industrial levels). For each time frame, risk levels are indicated for a continuation of current adaptation and assuming high levels of current or future adaptation.

Appendix 3

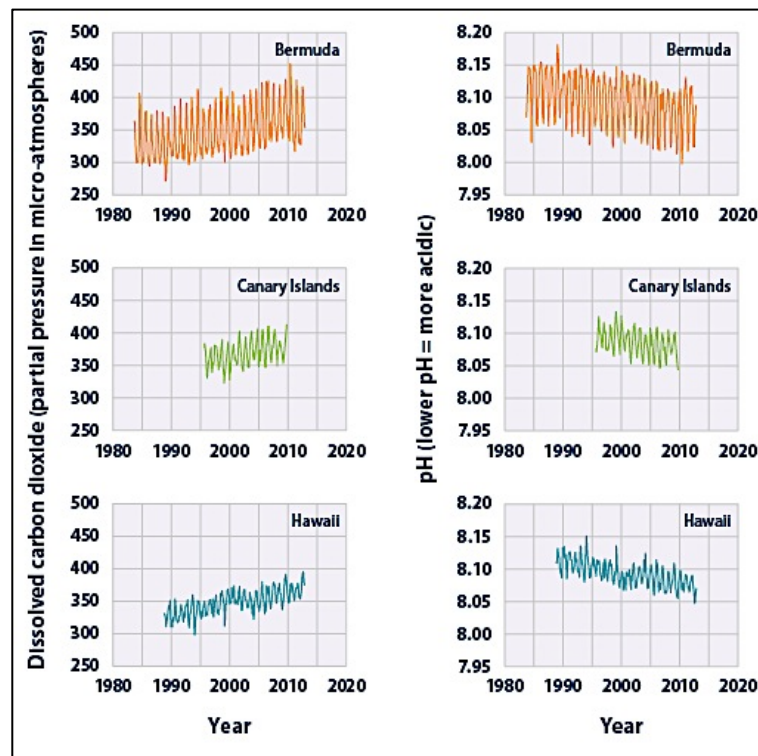
The United States Environmental Protection Agency provide a specific section, within Climate Change indicators in the U.S., dedicated to oceans and ocean acidity.

Ocean acidity is a fundamental indicator that describes changes in the chemistry of the ocean.

"Measurements made over the last few decades have demonstrated that ocean carbon dioxide levels have risen in response to increased carbon dioxide in the atmosphere, leading to an increase in acidity (that is, a decrease in pH)".

The data come from two observation stations in the North Atlantic Ocean (Canary Islands and Bermuda) and one in the Pacific (Hawaii). The observation periods goes from 1983 to 2012. The up-and-down pattern shows the influence of seasonal variations.

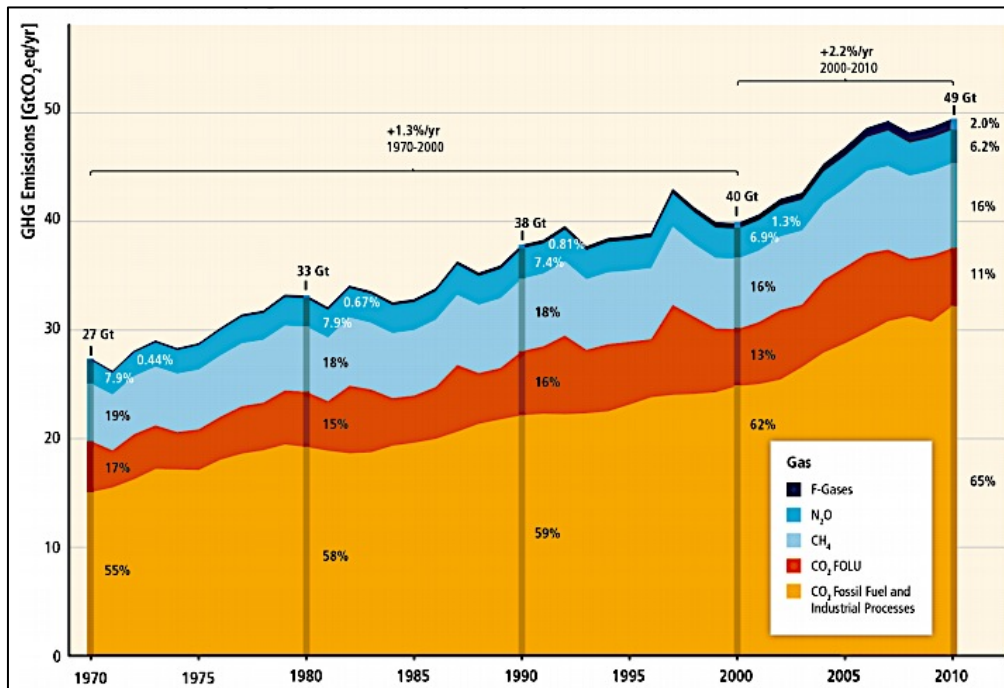
Figure D - Ocean acidity



Sources: Bermuda Institute of Ocean Sciences, 2014; González-Dávila, 2012; Dore, 2014

Appendix 4

Figure E - Total annual anthropogenic GHG emissions (1970 - 2012)

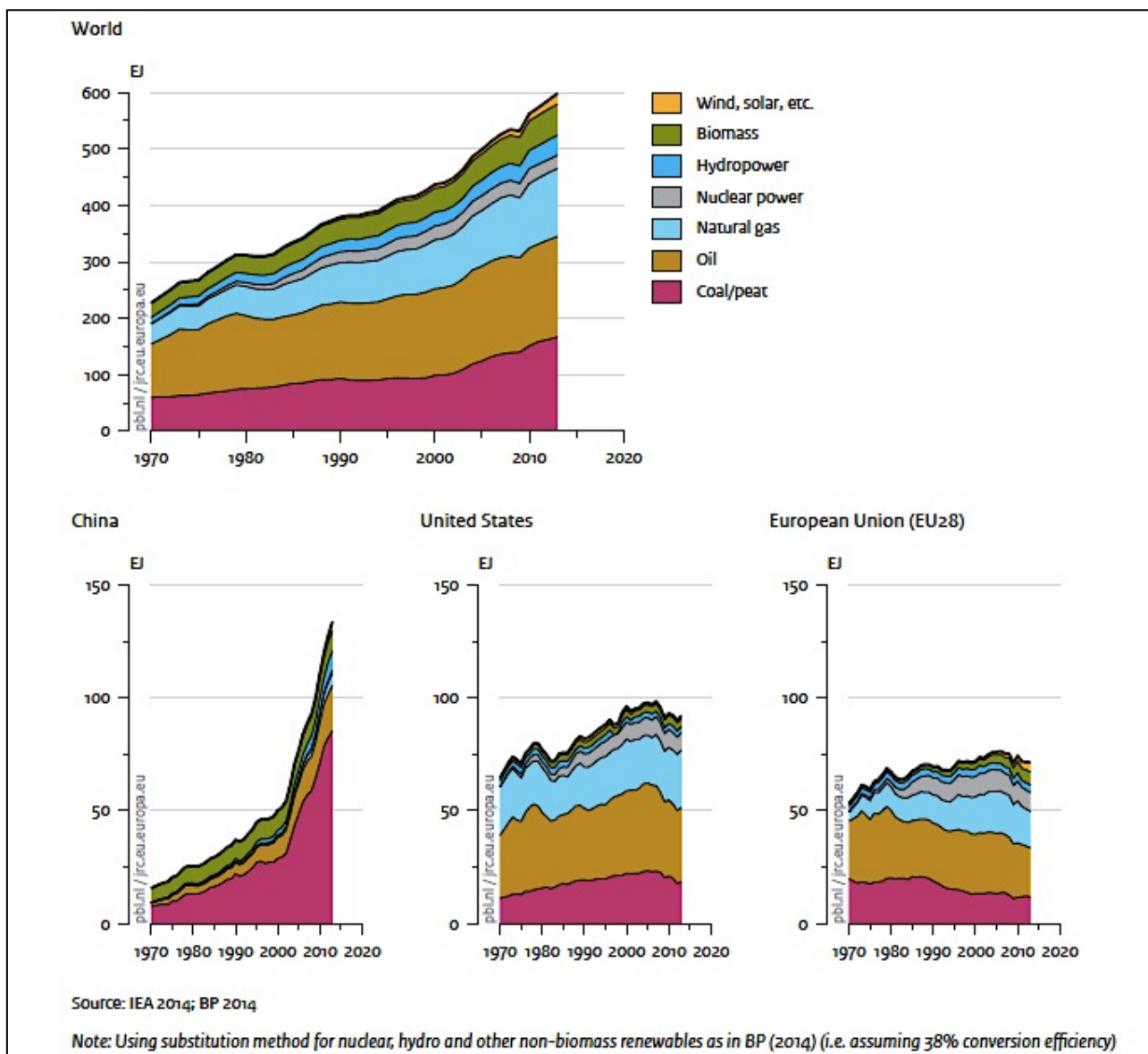


Source: IPCC, 2014: *Climate Change 2014: Synthesis Report*. IPCC, Geneva, Switzerland (p. 21)

Total annual anthropogenic greenhouse gas (GHG) emissions for the period 1970 to 2010 by gases:

- CO₂ from fossil fuel combustion and industrial processes;
- CO₂ from Forestry and Other Land Use (FOLU);
- methane (CH₄);
- nitrous oxide (N₂O);
- fluorinated gases covered under the Kyoto Protocol (F-gases).

Figure F - Historical trend in global energy mix



Source: Olivier, J., Janssen-Maenhout, G., Peters, J., 2014. *Trends in global CO2 emissions; 2014 report.*

Available at: www.pbl.nl/en or edgar.jrc.ec.europa.eu.

Since 2002, the strong increase in coal consumption is mainly caused by the fast developing economy of China (in 2013 it increased over 3.7%).

Bibliography

PAPERS AND BOOKS:

- Ahluwalia, I. J., Little, I. M. D., 1998. *India's Economic Reforms and Development: Essays for Manmohan Singh*. New Delhi: Oxford University Press.
- Albrecht, J., Francois, D., Schoors, K., 2002. A Shapley decomposition of carbon emissions without residuals. *Energy Policy*. Vol 30, pp. 727-736. Available at: www.elsevier.com/locate/enpol
- Anderegg, W. R. L., 2010. Expert Credibility in Climate Change. *Proceedings of the National Academy of Sciences*. Vol. 107, n. 27, pp. 12107-12109.
- Ang, B.W., 2004. Decomposition analysis for policymaking in energy: which is the preferred method? *Energy Economics*. Vol. 32, pp.1131-1139
- Ang, B.W., Liu, N. 2007. Viewpoint: Energy decomposition analysis: IEA model versus other methods. *Energy policy*. Vol. 35, pp. 1426-1432.
- Annicchiarico, B., Bennato, A.R., Zanetti Chini, E., 2014. *150 Years of Italian CO₂ Emissions and Economic Growth*. Center for Research in Economic Analysis of Time Series. Available at: http://pure.au.dk/portal/files/69386900/rp14_02.pdf
- Arto, I.E., Dietzenbacher, E., 2014. Drivers of the growth in global greenhouse gas emissions. *Environmental Science and Technology*. Vol. 48, n. 10, pp. 5388-5394. Available at: <http://pubs.acs.org/doi/abs/10.1021/es5005347>
- Azar, C., Holmberg, J. and Karlson, S., 2002. *Decoupling: past trends and prospects for the future*. University of Göteborg, Department of Environmental Economics, Stockholm.
- Borghesi, S., 1999. *The Environmental Kuznets Curve: a Survey of the Literature*. FEEM Working Paper No. 85-99. FEEM, Fondazione Eni Enrico Mattei, Milan.
- BP (2011-2014). BP Statistical Review of World Energy 2011-2014. Available at: <http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html>.
- Caney, S., 2009. Justice and the distribution of greenhouse gas emissions. *Journal of Global Ethics*. Vol. 5, issue 2, pp. 125-146.
- Church, J. A., White, N. J., 2006. A 20th century acceleration in global sea level rise. *Geophysical Research Letters*. Vol. 33, L01602. Available at: <http://onlinelibrary.wiley.com/store/10.1029/2005GL024826/asset/grl20848.pdf;jsessionid=6272A1B7E0702D73F932D3CF1B070BBB.f01t01?v=1&t=ie1iqlk9&s=8f761f6f4c0ce3d7ed1cd7eee1458f3c890f2b17>
- Congressional Budget Office, 2013. *International Trade and Carbon Leakage*. Congressional Budget Office, Washington, DC. Available at: https://www.cbo.gov/sites/default/files/113th-congress-2013-2014/workingpaper/44970-InternationalTradeCarbonLeakage_1.pdf
- Cook, J., et al, 2013. Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environmental Research Letters*. Vol. 8, n. 2, p. 3. Available at: <http://iopscience.iop.org/article/10.1088/17489326/8/2/024024;jsessionid=2C067279F054ADA9140CF34496629596.c1>
- CP/RAC, 2008. *Methodological challenges and strategic opportunities of the consumption-based approach to greenhouse gas emissions in the Mediterranean*. Workshop on Consumption and Climate Change, 4 November 2008, Barcelona, Spain, Regional Activity Centre for Cleaner Production (CP/RAC), Mediterranean Action Plan, United Nations Environment Programme.

- Davis, S., Cladeira, K., 2010. *Consumption-based accounting of CO₂ emissions*. Harvard University, Cambridge. Available at: www.pnas.org/cgi/doi/10.1073/pnas.0906974107
- Doran, P. T., Zimmerman, M. K., 2009. Examining the Scientific Consensus on Climate Change. *Eos Transactions American Geophysical Union*. Vol. 90, issue 3, p. 22
- EBRD, 2011. *The low carbon transition*. Special Report on Climate Change. European Bank for Reconstruction and Development & the Grantham Research Institute on Climate Change and the Environment, London.
- Economist, 2013. *Renewable energy in Spain. The cost del sol. Sustainable energy meets unsustainable costs*. Available at: <http://www.economist.com/news/business/21582018-sustainable-energy-meets-unsustainable-costs-cost-del-sol>.
- Edenhofer, O. et al, 2009. *The Economics of Decarbonization*. Report of the RECIPE project. Potsdam-Institute for Climate Impact Research: Potsdam.
- Eder, P., Narodoslawsky, M., 1999. What environmental pressures are a region's industries responsible for? A method of analysis with descriptive indices and input-output models. *Ecological Economics*. Vol. 29, pp. 359-374.
- Edey, M., 2009. The Global Financial Crisis and Its Effects. *Economic Papers: A journal of applied economics and policy*. Vol. 28, pp. 186-195. Available at: <http://onlinelibrary.wiley.com/doi/10.1111/j.1759-3441.2009.00032.x/full>
- Energy Information Administration, 2013. *Natural gas generation lower than last year because of differences in relative fuel prices*. U.S. Energy Information Administration. Available at: <http://www.eia.gov/todayinenergy/detail.cfm?id=13111>.
- Environmental protection Agency, 2010. *Methane and Nitrous Oxide Emissions from Natural Sources*. U.S. Environmental Protection Agency, Washington, DC, USA. Available at: <http://www.epa.gov/outreach/pdfs/methane-and-nitrous-oxide-emissions-from-natural-sources.pdf>
- European Bank for Reconstruction and Development and Grantham Research Institute on Climate Change and the Environment, 2011. *The Low Carbon Transition: special report on climate change*.
- European Commission, 2014. *2030 framework for climate and energy policies*. European Commission, Brussels. Available at: http://ec.europa.eu/clima/policies/2030/index_en.htm
- European Environment Agency, 2008. *Impacts of Europe's changing climate: indicator-based assessment*. Joint EEA-JRC-WHO report. Available at: http://www.eea.europa.eu/publications/eea_report_2008_4
- European Union, 2001. Directive 2001/77/EC of the European parliament and of the council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market.
- European Union, 2003. Directive 2003/30/EC of the European parliament and of the council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport.
- European Union, 2009. Decision no 406/2009/EC of the European parliament and of the council of 23 April 2009 on the effort of member states to reduce their greenhouse gas emissions to meet the community's greenhouse gas emission reduction commitments up to 2020.
- Eurostat, 2014. In 2013, CO₂ emissions in the EU28 estimated to have decreased by 2.5% compared with 2012. Early estimates of CO₂ emissions from energy use. *Eurostat Newsrelease*, 7 May. Available at: http://epp.eurostat.ec.europa.eu/cache/ITY_PUBLIC/8-07052014-AP/EN/8-07052014-AP-EN.PDF

- Geels, F. W., 2013. The impact of the financial-economic crisis on sustainability transitions: Financial investment, governance and public discourse. *Environmental Innovation and Societal Transitions*. Vol. 6, pp. 67-95.
- Giedraitis, V., Girdenas, S., Rovas, A., 2010. Challenges of globalization. Feeling the heat: financial crisis and their impact on global climate change. *Perspectives of Innovations, Economics & Business*. Vol. 4, issue 1.
- Gilpin, A., 1997. *Dictionary of Environment and Sustainable Development*. Wiley, Chichester.
- Giorgetti, A., 2007. *A Discussion on Decoupling Economic Growth from the Emissions of Carbon Dioxide*. Environment Waikato Technical Report
- Grunewald, N., Martínez-Zarzoso, I., 2009. *Driving Factors of Carbon Dioxide Emissions and the Impact from Kyoto Protocol*. Cesifo Working Paper n° 2758. Category 10: Energy And Climate Economics. August 2009.
- Guay, J., 2014. Chinese coal consumption just fell for first time this century. *Huffington Post*, 18 August. Available at: http://www.huffingtonpost.com/justin-guay/chinese-coal-consumption_b_5687972.html
- Hansen, et al, 2007. Dangerous human-made interference with climate: a GISS model study. *Atmospheric Chemistry and Physics*. Vol. 7, pp. 2287-2312. Available at: <http://www.atmos-chem-phys.net/7/2287/2007/acp-7-2287-2007.html>
- Hansen, et al, 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science Magazine*, November. Available at: <http://www.sciencemag.org/content/342/6160/850.full>
- International Energy Agency, 2008. *Climate policy and carbon leakage. IEA information paper*. OECD/IEA. Available at: https://www.iea.org/publications/freepublications/publication/Aluminium_EU_ETS.pdf
- International Energy Agency, 2014a. *CO₂ Emissions from Fuel Combustion. Highlights: 2014 edition*. Available at: <https://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2014.pdf>
- International Energy Agency, 2014b. *Tracking Clean Energy Progress 2014*. International Energy Agency, Paris. Available at: http://www.iea.org/publications/freepublications/publication/Tracking_clean_energy_progress_2014.pdf
- International Energy Agency, 2014c. *Energy Statistics of OECD Countries and Non-OECD Countries*. International Energy Agency, Paris.
- International Energy Agency, 2015. *CO₂ Emissions from Fuel Combustion*. International Energy Agency, Paris. Available at: <https://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2015.pdf>
- IPCC, 2007: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

- IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland.
- Jansen, E., et al, 2007. *Paleoclimate. In: Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available at: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch6.html
- Janssens-Maenhout, G., Paruolo, P., Martelli, S., 2013. *Analysis of Greenhouse Gas Emission Trends and Drivers: A Survey of Techniques for Emission Decomposition and Econometric Trend analysis*. Joint Research Centre, European Commission, Luxembourg. Available at: <https://ec.europa.eu/jrc/sites/default/files/lb-na-25814-en-n.pdf>.
- Jha, S., Gamper-Rabindran, S., 2002. *Environmental Impact of India's Trade Liberalization*. Available at: <https://www.gtap.agecon.purdue.edu/resources/download/1690.pdf>
- Kaya, Y., Yokoburi, K., 1997. *Environment, energy, and economy : strategies for sustainability*. Tokyo [u.a.]: United Nations University.
- Kojima, M., Bacon, R., 2009. Changes in CO₂ emissions from energy use: a multicountry decomposition analysis. *Extractive Industries for Development Series*. The World Bank. Vol. 11. Available at: http://siteresources.worldbank.org/EXTOGMC/Resources/co2_emissions1.pdf
- Lane, J., 2011. CO₂ emissions and GDP. *International Journal of Social Economics*. Vol. 38, pp. 911-918. Available at: <http://dx.doi.org/10.1108/03068291111171414>
- Lee, M., Park, D., Saunders, H. D., 2014. *Asia's Energy Challenge: Key issues and policy options*. Asian development Bank and Routledge, New York. Available at: <http://www.adb.org/publications/asias-energy-challenge-key-issues-and-policy-options>.
- Lieb, C.M., 2003. *The Environmental Kuznets Curve – A Survey of the Empirical Evidence and of Possible Causes*. University of Heidelberg. Discussion Paper Series 391. Available at: <http://www.uni-heidelberg.de/md/awi/forschung/dp391.pdf>
- Metz, B., Davidson, O., Bosh, P., Dave, R. and Meyer, L., 2007. *Climate Change 2007: Mitigation of Climate Change*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: https://www.ipcc.ch/publications_and_data/ar4/wg3/en/contents.html
- Moutinho, V., Madaleno, M., Silva, P. M., 2015. Which factors drive CO₂ emissions in EU-15? Decomposition and innovative accounting. *Energy Efficiency*. Available at: <http://crossmark.crossref.org/dialog/?doi=10.1007/s12053-015-9411-x&domain=pdf>
- Mundaca T., L., Markandya, A., Nørgaard, J., 2013. Walking away from a low-carbon economy? Recent and historical trends using a regional decomposition analysis. *Energy Policy*. Vol. 61, pp. 1471-1480. Available at: [http://orbit.dtu.dk/en/publications/walking-away-from-a-lowcarbon-economy\(4aece773-68c7-4a40-bfdd-970f35e2c9a1\).html](http://orbit.dtu.dk/en/publications/walking-away-from-a-lowcarbon-economy(4aece773-68c7-4a40-bfdd-970f35e2c9a1).html)
- Munksgaard, J., Pedersen, K. A., 2001. CO₂ Accounts for Open Economies: Producer or Consumer Responsibility? *Energy Policy*. Vol. 29, pp. 327-335.
- NCR, 2010. *Advancing the Science of Climate Change*. National Research Council. The National Academies Press, Washington, DC, USA. Available at: <http://nas-sites.org/americasclimatechoices/sample-page/panel-reports/87-2/>
- Oberheitmann, A., 2012. CO₂ emission reduction in China's residential building sector and contribution to the national climate change mitigation targets in 2020.

- Mitigation and adaptation strategies for global change*. Springer Netherlands. Vol. 17, issue 7, pp. 769-791. October 2012.
- Oberheitmann, A., 2013. Long-Term Kaya Identity Analysis and Prerequisites of a Sustainable and Green Economic Growth in a 2°C World. *Institute for Strategic, Political, Security and Economic Consultancy Strategy Series: Focus on Defence and International Security*. Vol. 236. July 2013. Available at: http://mercury.ethz.ch/serviceengine/Files/ISN/167156/ipublicationdocument_singledocument/6162c207-2cd4-4128-a59e-2875a204e1fe/en/236_Oberheitmann.pdf.
 - Olivier, J., Janssen-Maenhout, G., Peters, J., 2014. *Trends in global CO2 emissions; 2014 report*. The Hague: PBL Netherlands Environmental Assessment Agency; Ispra: European Commission, Joint Research Centre. Available at: www.pbl.nl/en or edgar.jrc.ec.europa.eu.
 - Oreskes, N., 2004. The Scientific Consensus on Climate Change. *Science Magazine*. Vol. 306, p. 1686. Available at: <http://www.sciencemag.org/content/306/5702/1686.full>
 - Organization for Economic Co-operation and Development (OECD), 2002. *Indicators to Measure Decoupling of Environmental Pressure from Economic Growth*. OECD, Paris.
 - Percebois, J., 1989. Economie de l'énergie. *Energy Policy*. Vol. 17, issue 5, pp. 532-533. Paris: Economica. Available at: http://econpapers.repec.org/article/eeeeenepol/v_3a17_3ay_3a1989_3ai_3a5_3ap_3a532-533.htm
 - Peters, G.P., Hertwich, E.G., 2008. CO₂ embodied in international trade with implications for global climate policy. *Environmental Science and Technology*. Vol. 42, pp. 1401–1407.
 - Porter, M. E., 1991. America's Green Strategy. *Scientific American*. Vol. 264, p. 96. Available at: <http://www.scientificamerican.com/article/essay-1991-04/>
 - Porter, M. E., Van Der Linde, C., 1995. Toward a New Conception of the Environment - Competitiveness Relationship. *Journal of Economic Perspectives*. Vol. 9, n. 4, pp. 97-118.
 - Pöyry, 2013. *Outlook for new coal-fired power stations in Germany, the Netherlands and Spain: a Report to DECC*. P.M. Consulting. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/194335/Poyry_Report_-_Coal_fired_power_generation_in_Germany.pdf
 - Raupach, M.R., G. Marland, P. Ciais, C. Le Quéré, J.G. Canadell, G. Klepper, C.B. Field, 2007. *Global and regional drivers of accelerating CO₂ emissions*. Proceedings of the National Academy of Sciences. Vol. 104, n. 24, pp. 10288-10293. Available at: <http://www.pnas.org/content/104/24/10288.full>
 - Ravindranath, N. H., Sathaye, J. A., 2002. *Climate Change and Developing Countries*. Kluwer Academic Publishers, Netherlands.
 - Ross, M. L., 2013. How the 1973 Oil Embargo Saved the Planet. *Foreign Affairs*, Council of Foreign Relations, U.S., October 2013. Available at: <https://www.foreignaffairs.com/articles/north-america/2013-10-15/how-1973-oil-embargo-saved-planet>.
 - Sheram, K., Soubbotina, T. P., 2000. *Beyond Economic Growth: Meeting the Challenges of Global Development*. World Bank, Washington D.C.
 - Siddiqi, T. A., 2000. The Asian Financial Crisis: is it good for the global environment? *Elsevier Environmental change*. Vol. 10, pp. 1-7.
 - Stern, N., 2006. *The Economics of Climate Change: the Stern Review*. HM Treasury, Cabinet Office, London.
 - Streets, et al, 2006. Modeling study of air pollution due to the manufacture of export

- goods in China's Pearl River Delta. *Environmental Science and Technology*. Vol. 40, pp. 2099-2107.
- Sun, J. W., Ang, B. W., 2000. Some properties of an exact energy decomposition model. *Energy Economics*. Vol. 20, pp. 1177-1188
 - Sun, J.W., 1998. Changes in energy consumption and energy intensity: a complete decomposition model. *Energy Economics*. Vol. 20, pp. 85-100.
 - Teives Henriques, S., Borowiecki, K. J., 2014. The Drivers of Long-run CO₂ Emissions: A Global Perspective since 1800. *EHES Working Papers in Economic History*. European Historical Economics Society. Vol. 62. August 2014. Available at: http://www.ehes.org/EHES_62.pdf
 - Tol, R.S.J., Pacala, S.W., Socolow, R.H., 2009. Understanding long-term energy use and carbon dioxide emissions in the USA. *Journal of Policy Modeling*. Vol. 31. Available at : <http://ageconsearch.umn.edu/bitstream/12043/1/wp060107.pdf>
 - U.S. Geological Survey, 2009. *Volcanic gases and their effects*. Volcano Hazards Program. Available at: <http://volcanoes.usgs.gov/hazards/gas/index.php>
 - United States Global Research Program, 2009. *Global Climate Change Impacts in the United States*. Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press. Available at: <http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf>
 - Van Der Werf, et al., 2009. CO₂ emissions from forest loss. *Nature Geoscience*, November, vol. 2, pp. 737-738. Available at: <http://sites.biology.duke.edu/jackson/ng09.pdf>
 - Winters, L. A., Yusuf, S., 2007. *Dancing with Giants: China, India, and the Global Economy*. The International Bank for Reconstruction and Development and The World Bank, Washington, USA. Available at: http://www.wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2007/01/10/000020953_20070110150325/additional/Front_matter.pdf
 - World Resource Institute, 2007. *Climate Analysis Indicator Tool (CAIT)*. Version 5.0. World Resource Institute, Washington, DC.
 - Xiangzhao, F., Ji, Z., 2008. *Economic Analysis of CO₂ Emission Trends in China*. *Chn Popu Res Envi*. Vol. 18, issue 3, pp. 43-47. Available at: www.sciencedirect.com

WEBSITES:

- <http://2014.newclimateeconomy.report/energy/> (Accessed on January 10th, 2016)
- <http://blog.euromonitor.com/2014/11/the-recovery-from-the-global-financial-crisis-of-2008-missing-in-action.html> (Accessed on February 6th, 2016)
- http://cdiac.ornl.gov/trends/emis/tre_fra.html (Accessed on January 4th, 2016)
- http://cdiac.ornl.gov/trends/emis/tre_ita.html (Accessed on January 5th, 2016)
- <http://climate.nasa.gov/effects/> (Accessed on October 3rd, 2015)
- <http://climate.nasa.gov/vital-signs/global-temperature/> (Accessed on September 15th, 2015)
- <http://earthobservatory.nasa.gov/Features/GlobalWarming/page4.php> (Accessed on September 15th, 2015)
- http://ec.europa.eu/clima/change/consequences/index_en.htm (Accessed on September 16th, 2015)
- http://ec.europa.eu/clima/policies/ets/cap/leakage/index_en.htm (Accessed on September 20th, 2015)
- http://ec.europa.eu/clima/policies/ets/index_en.htm (Accessed on February 6th, 2016)

- <http://environment.nationalgeographic.com/environment/global-warming/gw-causes/> (Accessed on September 10th, 2015)
- <http://epa.gov/climatechange/ghgemissions/gases/ch4.html> (Accessed on September 10th, 2015)
- <http://infographics.pbl.nl/website/globalco2/> (Accessed on September 11th, 2015)
- <http://nas-sites.org/americasclimatechoices/sample-page/panel-reports/87-2/> (Accessed on August 28th, 2015)
- <http://oco.jpl.nasa.gov> (Accessed on September 2nd, 2015)
- http://unfccc.int/essential_background/items/6031.php (Accessed on December 10th, 2015)
- http://unfccc.int/kyoto_protocol/items/2830.php (Accessed on December 10th, 2015)
- <http://www.bbc.com/news/science-environment-29239194> (Accessed on August 29th, 2015)
- <http://www.carbonbrief.org/climate-showdown-has-the-us-uk-or-germany-done-more-to-cut-emissions> (Accessed on December 12th, 2015)
- <http://www.economist.com/news/schoolsbrief/21584534-effects-financial-crisis-are-still-being-felt-five-years-article> (Accessed on February 6th, 2016)
- <http://www.eea.europa.eu/data-and-maps/indicators/atmospheric-greenhouse-gas-concentrations-4/assessment> (Accessed on August 27th, 2015)
- <http://www.epa.gov/climatechange/science/causes.html> (Accessed on September 12th, 2015)
- <http://www.epa.gov/climatechange/science/indicators/ghg/ghg-concentrations.html> (Accessed on September 12th, 2015)
- <http://www.epa.gov/climatechange/science/indicators/health-society/heat-deaths.html> (Accessed on September 12th, 2015)
- <http://www.epa.gov/climatechange/science/indicators/index.html> (Accessed on September 15th, 2015)
- <http://www.fao.org/> (Accessed on September 26th, 2015)
- http://www.germanenergyblog.de/?page_id=283 (Accessed on January 3rd, 2016)
- <http://www.globalissues.org/article/768> (Accessed on February 7th, 2016)
- http://www.iea.org/media/statistics/topics/emissions/CO2_Emissions_Overview.pdf (Accessed on September 26th, 2015)
- <http://www.iea.org/newsroomandevents/news/2015/march/global-energy-related-emissions-of-carbon-dioxide-stalled-in-2014.html> (Accessed on September 26th, 2015)
- http://www.indiaenergyportal.org/overview_detail.php (Accessed on December 28th, 2015)
- <http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=50> (Accessed on September 9th, 2015)
- <http://www.livescience.com/27692-deforestation.html> (Accessed on September 5th, 2015)
- <http://www.ncdc.noaa.gov/extremes/> (Accessed on August 29th, 2015)
- <http://www.nrdc.org/globalwarming/> (Accessed on August 29th, 2015)
- <http://www.oecd.org> (Accessed on September 3rd, 2015)
- <http://www.oecd.org/env/country-reviews/2452198.pdf> (Accessed on September 3rd, 2015)
- <http://www.oxforddictionaries.com/definition/english/global-warming> (Accessed on August 29th, 2015)
- <http://www.populationmatters.org> (Accessed on September 23rd, 2015)

- <http://www.scientificamerican.com/article/population-growth-climate-change/> (Accessed on September 23rd, 2015)
- <http://www.tsp-data-portal.org/TOP-20-CO2-emitters-per-capita#tspQvChart> (Accessed on September 23rd, 2015)
- <http://www.unfpa.org> (Accessed on September 23rd, 2015)
- <http://www.worldwatch.org/global-energy-and-carbon-intensity-continue-decline-0> (Accessed on September 20th, 2015)
- <http://www.worldwildlife.org/threats/deforestation> (Accessed on August 29th, 2015)
- http://www.wwf.org.uk/what_we_do/tackling_climate_change/impacts_of_climate_change/# (Accessed on August 20th, 2015)
- http://www.wwf.org.uk/what_we_do/tackling_climate_change/impacts_of_climate_change/climate_change_and_water/ (Accessed on August 20th, 2015)
- <https://www.cleanenergywire.org/factsheets/germanys-greenhouse-gas-emissions-and-climate-targets> (Accessed on September 13th, 2015)
- <https://www.eia.gov/todayinenergy/detail.cfm?id=10191> (Accessed on October 2nd, 2015)
- <https://www.gov.uk/government/policies/business-and-the-environment> (Accessed on December 29th, 2015)
- https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/416810/2014_stats_release.pdf (Accessed on December 29th, 2015)
- https://www.ipcc.ch/publications_and_data/ar4/syr/en/spms5.html (Accessed on February 3rd, 2016)
- https://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3s3-4-1.html (Accessed on February 3rd, 2016)
- <https://www.ornl.gov/news/carbon-dioxide-emissions-rebound-quickly-after-global-financial-crisis> (Accessed on February 6th, 2016)
- https://www.wmo.int/pages/themes/climate/causes_of_climate_change.php (Accessed on August 29th, 2015)
- <https://www2.ucar.edu/news/what-average-global-temperature-now> (Accessed on August 29th, 2015)
- <http://climateactiontaker.org> (Accessed on August 29th, 2015)