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Climate Change Economics

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7/06/2019

ABSTRACT

Climate change is threatening the world's future. With oceans filled with plastic, forests degrading, loss of biodiversity, and CO_2 emissions reaching unprecedented levels, humankind still seems not aware of the consequences of its actions. Yet, underdeveloped countries are already suffering the impacts of the so-called human-induced global warming, despite the emissions not being theirs. In this context, there is growing concern as to whether climate change can be breeding conflict, especially in poor economies. Given the relevance of this topic, some of the main findings on the field of economics of climate change are assessed in this essay, followed by a review of the different positions found in the literature regarding the causal link between global warming and conflict. Moreover, an empirical exercise is carried out on a subset of African countries to detect possible associations between droughts and participation in political violence.

CONTENTS

1. INTRODUCTION

The issue of climate change has, unfortunately, become a constant on our day-to-day. However, there's still little understanding of the potential consequences this phenomenon is likely to provoke on our planet and, in the same vein, to each and every living animal on its surface. To begin with, it is important to establish a clear distinction between climate and weather, two terms that are usually mixed up. The first one is defined as the statistical mean and variability of wind, temperature, humidity and other variables over a period of time, and it can have a monthly, yearly or even a broader scope[1]. Thereby, climate change is an alteration on the usual pattern of these statistical measures. Nonetheless, this expression is commonly used when the causes of such disturbances are human-induced. On the other hand, when talking about the weather we are usually referring to the realization of the climatic process for a short period of time[2]. That is, for instance, whether it is sunny or rainy at a certain place.

Despite headlines being dominated by climate change issues over the last years, global warming is, by no means, a new phenomenon. Scientists, through analysing indirect measures of climate change such as tree rings or glacier lengths, have proven that the Earth's climate has suffered from changes even before the dinosaur's extinction. Nevertheless, prior to the Industrial Revolution, the causes of such disturbances had had a natural origin. By that time, atmospheric CO_2 concentrations moved between 180 parts per million (ppm) during ice ages and 280 ppm during interglacial warm periods (NOAA, 2013). After this point, human activities have been the potential driver of global warming, rising CO_2 concentrations by more than a third since the 18th century.

In the last years, humankind has changed its production habits, going from the manual and artisan work to the massive industries where fossil fuel burning is a constant. Moreover, people have moved from the countryside to big cities, a fact that has contributed to an increase in production and income. In addition, consumption patterns have changed since the manufacturing costs have decreased, leading to the possibility of buying at cheaper prices. Regarding mortality, crude death rates have fallen and population, in exception of the residents in the least developed countries, have completed

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1 Nordhaus, William. Climate Casino, page 37.
2 Nordhaus, William. Climate Casino, page 37.

a demographic transition. Overall, developed countries have experienced a radical change of lifestyle which has come along with usage of fossil fuels and its consequent impact on the Earth's system.

Hence, without any doubt, human-induced climate change is one of the biggest challenges that humankind has ever faced. Aiming to reduce Greenhouse Gases' emissions, that is, mitigating climate change, must be a priority on the political agenda of every country. Unlike other environmental problems, global warming must be tackled globally in order to efficiently prevent disastrous consequences. Despite of the uncertainties that surround future global warming estimates, cutting down CO_2 emissions involves a clear trade-off between today's welfare and the welfare of forthcoming generations. That is, there is a price to pay in order to avoid the unforeseeable and disastrous impacts of climate change, and the later humankind stops polluting, the worse the world's prospect will be. Along these lines, the current debate is placed on the value that should be given to the so-called Social Discount Rate, the parameter that has characterized the controversy between Nicholas Stern and William Nordhaus in the last years[3].

On the other hand, consensus on some of the consequences of climate change does not exist, especially in regards of conflict-related issues, a relatively nascent field on economic research. Some authors, such as Edward Miguel, Solomon Hsiang, and Marshall Burke argue that climate variability is the cause of social instability, whilst others, such as Halvard Buhaug, state that there is not enough empirical evidence to support this causal inference.

As an empirical exercise, this essay contains, for a subset of African countries, an analysis on whether political violence and droughts are associated. Note that the findings do not pretend to infer any causal relationship, as they only assess possible correlations between the conflict and the climate variables.

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[3] The Social Discount Rate is a crucial parameter to determine whether it is necessary to delay or to accelerate climate change policies. It measures how population value the future's wellbeing relative to the present's welfare.

2. CLIMATE CHANGE AND THE ENVIRONMENT

2.1. Greenhouse Effect, Global Warming, And Climate Change

Understanding global warming implies understanding that the temperature of our planet lies upon a balance of incoming and outgoing solar energy[4]. In broad terms, if this energy is absorbed by the Earth's system, the planet will warm up. Likewise, if the absorbed energy from the Sun is released back, the Earth will cool down. Thus, the constant increase on temperature registered on our planet is a clear signal of a global-scale disequilibrium, that is, the Earth is receiving more sunlight than it is releasing heat back to space. As a consequence, its surface has been heating up over the last century, a fact that has been translated into an increase of 0.9ºC compared to the temperatures registered a hundred years ago[5]. In addition, each decade since the last thirty years has been warmer than the previous one[6]. Overall, the ongoing global warming is undeniable.

The factors that give rise to climate change can be both natural and human, including variations in the sun's energy, changes in the reflectivity of the Earth's atmosphere and surface, and CO_2 emissions. Those factors, also named forcing mechanisms or radiative forcings, are the causes of the unbalances between incoming and outgoing energy and they can either be positive (if they warm the Earth's surface up) or negative (if they cool the planet down)[7]. Furthermore, radiative forcings are affected by climate change feedbacks which can diminish or amplify the initial forcing. These feedbacks comprise, among others, the heat released by organic matter when it decomposes as a response to the melting of the frozen soil they lie on, the permafrost[8].

Nowadays, what it is believed to be cause for climate change is the human contribution in increasing the so-called Greenhouse Effect, a process by which the atmosphere, a layer of gases that surrounds the Earth, traps solar radiation and, consequently, warms the

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4 Wolfson, R. (2015). Energy Environment and Climate, 2nd ed. New York, U.S.A: Norton, 2012.
5 See, for example, IPCC Climate Change Synthesis Report (2014), page 40.
6 CO2 Earth (2019). Retrieved from: https://www.co2.earth/global-warming-update (visited: 30/04/2019)
7 Ramaswamy, V. (2018). Radiative Forcings of Climate Change, page 353.
8 Stenhouse, K. and Donev, J. (2016). Positive climate feedback. University of Calgary. Retrieved from: https://energyeducation.ca/encyclopedia/Positive_climate_feedback (visited: 20/03/2019)

planet's surface[9]. More specifically, this phenomenon is the result of the clustering of certain gases on the atmosphere, which block heat from escaping and remain there, at least semi-permanently. Those gases, known as Greenhouse Gases (GHGs), keep our planet warm enough to sustain life by sharing the capacity of absorbing solar radiation. Nonetheless, the current global warming is due to the increasing amount of GHGs in the atmosphere. These gases are, mainly[10]:

1. Carbon dioxide (CO_2), the most long-lived gas forcing global warming which, in addition, accounts for over 75% of the global GHGs emissions[11]. It is released to the atmosphere through human activities such as deforestation, degradation of soils and fossil fuels' burning.

2. Methane (CH_4), a hydrocarbon gas emitted through human activities such as natural gas and coal's production and transportation. It comes from natural sources and it is much less abundant than CO_2 on the atmosphere, but it is considered to be far more active than the latter.

3. Nitrous oxide (N_2O). It is a powerful gas produced by agricultural activities such as soil cultivation practices, along with fossil fuel combustion and biomass burning.

4. Chlorofluorocarbons, which are synthetic compounds of industrial origin. Nowadays, the production and release of these gases are highly regulated due to their powerfulness.

5. Water vapor (H_2O vapor). A high concentration of this GHG leads to a large absorption of longwave radiations, which are emitted back to the Earth's surface. This process contributes to increasing global warming.

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[9] Retrieved from the Department of the Environment and Energy of the Australian Government webpage. See: https://www.environment.gov.au/climate-change/climate-science-data/climate-science/greenhouse-effect (visited on 25/01/2019)

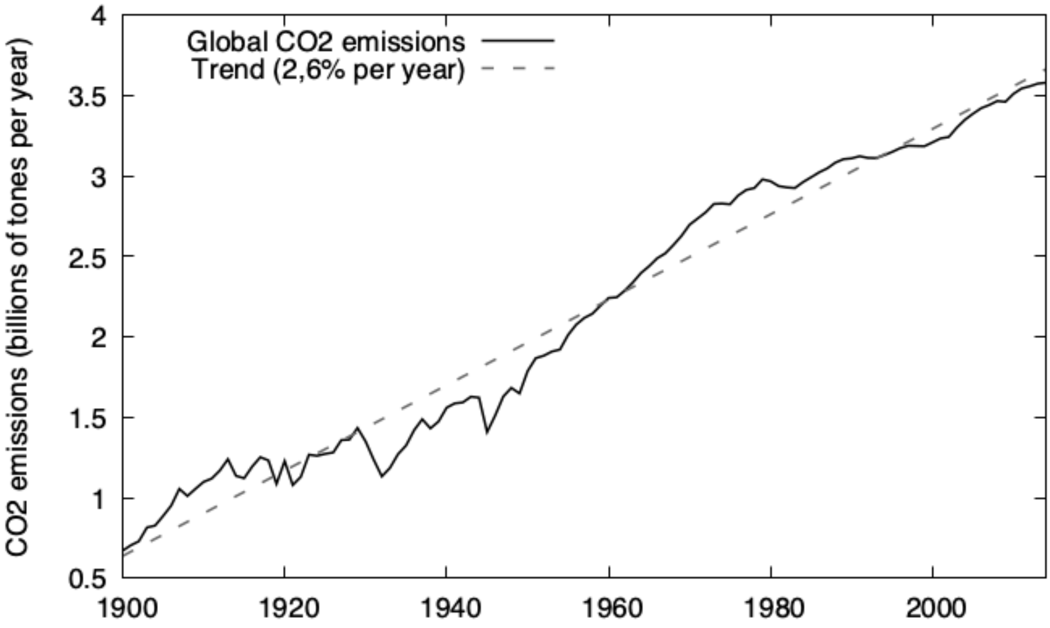
[10] Retrieved from the US Environmental Protection Agency webpage. See: https://www.epa.gov/ghgemissions/overview-greenhouse-gases (visited on 11/12/18).

[11] Retrieved from the US Environmental Protection Agency webpage. See: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data (visited on 24/01/2019).

Evolution of CO_2 emissions

Figure 1 includes the long-term evolution of global CO_2 emissions. In the figure we can appreciate a clear overall positive and significant trend since 1900, even if we see periods of faster and slower growth of emissions.

Figure 1: Global CO_2 emissions (1900-2014)



Source: Author's creation. Data: CDIAC (2019)

The deterministic trend of any time series can be estimated by running a regression of the series with respect to time. In this case, the following regression has been estimated:

$$\ln(CO2\ emissions_t) = \beta_0 + \beta_1 * time + u_t \quad (1)$$

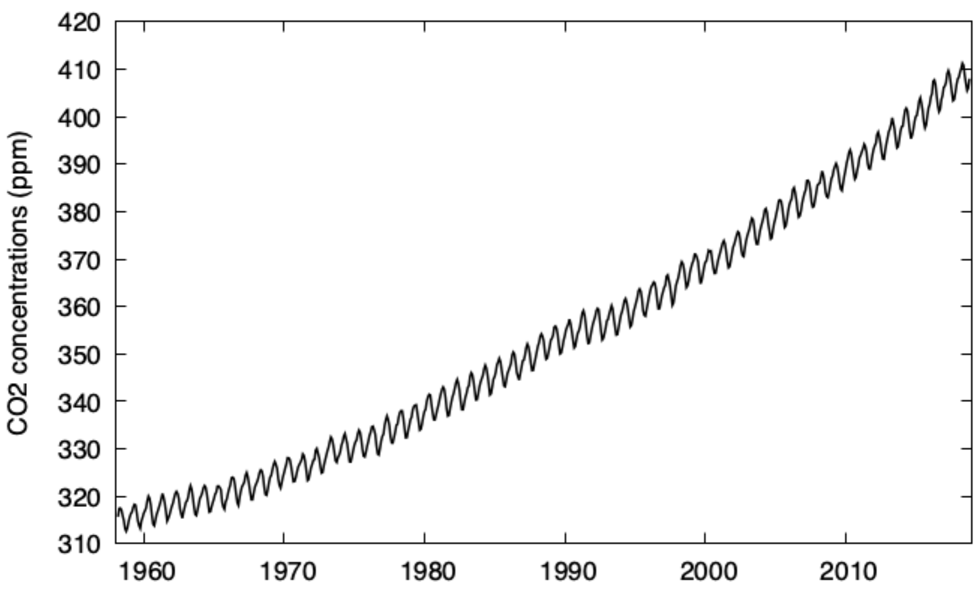
The results of the estimation indicate that we are persistently increasing our CO_2 emissions by 2,6% per year, whilst contributing to enlarge the Greenhouse Effect and the consequent climate change[12].

[12] Appendix-1 includes the regression used to estimate this trend.

Evolution of CO_2 concentrations in the atmosphere

Data on atmospheric CO_2 concentrations have been collected systematically since the late fifties in Mauna Loa, an observatory located on the top of a volcano in the big island of Hawaii[13]. The plot of the Mauna Loa records, represented below in Figure 2, is considered the very first significant evidence of global warming, and it is a symbol of the anthropogenic impact on the planet. The curve plotted in the abovementioned figure is known as the *Keeling Curve,* in honour of Charles David Keeling. Seventy years ago, the notion of climate change did not exist, as it was unclear to what extent the increase on the CO_2 levels could be the result of the burning of fossil fuels which, at their turn, could lead to global warming. Nonetheless, Charles David Keeling, the American geochemist who started monitoring the trends of such concentrations in the above-mentioned volcano, was determined to demonstrate that the CO_2 concentrations were following an overall upward trend, accompanied by the seasonal cycle of growth and decompose of plants.

Figure 2. Evolution of CO_2 concentrations in Mauna Loa, 1958:03 – 2018:11



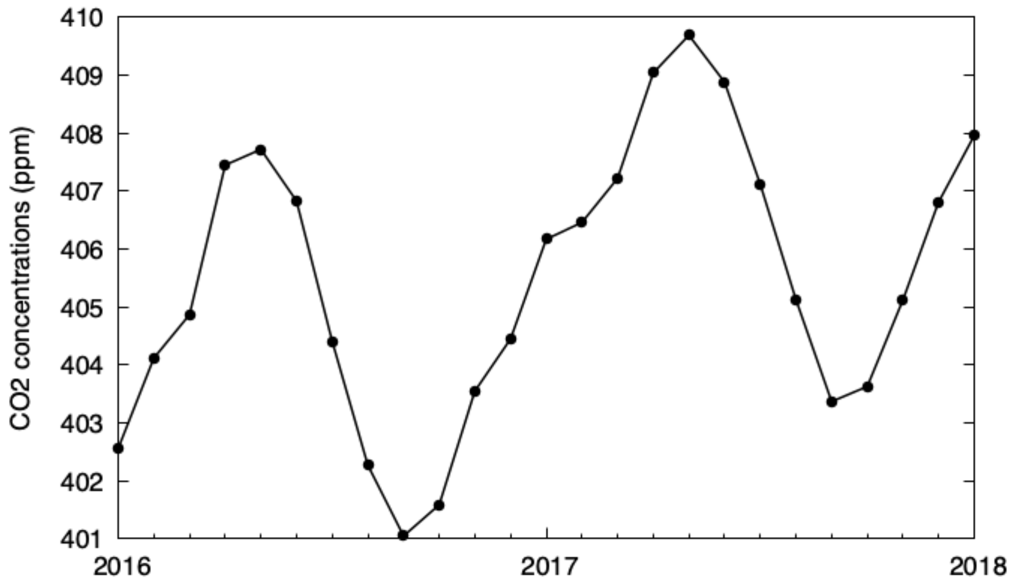
Source: Author's creation. Data: NASA (2019)

[13] See Earth System Research Laboratory, https://www.esrl.noaa.gov/gmd/obop/mlo/ (visited 12/12/18).

Likewise, the trend and the seasonality components of the time series data on CO_2 concentrations in the atmosphere are shown in Figure 2[14].

The seasonal component in the data collected in Mauna Loa is explained by the growth and decay of plants. This behaviour is consistently described by the plants' absorption of CO_2 during summer and spring, when the seasonality reaches its maximum peak, and the respiration and oxidation process during the rest of the year. This phenomenon is clearly illustrated if we plot just the monthly evolution of CO_2 concentrations for a couple of years, as shown in Figure 6.

Figure 3. Seasonality of the CO_2 concentrations, January 2016-January 2018



Source: Author's creation. Data: NASA (2019)

The plot clearly illustrates how the months of April, May and June are the ones with the highest concentrations of CO_2, oppositely to September and October. Nonetheless, the terrestrial biosphere is estimated to absorb only one-fourth of the anthropogenic CO_2

[14] Any time series data, that is the values that a variable takes over time which is chronologically plotted, is composed by the trend (the long-term pattern of the series), the seasonal and/or the cyclical variation (the regular fluctuations over a period of time), and the irregular component. These components can be combined in different ways, but it is usually assumed that they are multiplied or added.

emissions, whilst oceans are estimated to absorb the same percentage. Thus, the remaining 50% of the CO_2 emissions is fostering the Greenhouse Effect[15]. Likewise, recent studies show that, as the Earth warms up, the plants absorb less CO_2[16].

In order to remove the monthly variation from the time series, the following regression is estimated[17,18].

$$CO2_t = \sum_{i=1}^{12} \beta_0^i d_{i,t} + u_t \quad (2)$$

Where *i* represents the months, starting with 1 for January and 12 for December, and the $d_{i,t}$ is an indicator variable that takes value 1 if the observation corresponds to month i and 0 otherwise. Correspondingly, each β_0^i will represent the expected level of CO2 concentrations in the atmosphere for month i[19].

Estimation of regression (2) can be used to remove the seasonal component from the original series. It is important to mention that all the coefficients of the dummy variables are significant in a 95% confidence interval[20]. Notice that the predicted values of the CO_2 concentrations, $\widehat{CO2_t}$, account only for its seasonality. Accordingly, the corresponding residuals will account for the other components of the time series excluding seasonality. That is:

$$CO2_t^* = CO2_t - \widehat{CO2_t} \quad (3)$$

15 National Oceanic and Atmospheric Administration (2019). Ocean-Atmosphere CO2 exchange. Retrieved from: https://sos.noaa.gov/datasets/ocean-atmosphere-co2-exchange/ (visited: 01/06/2019).

16 For further discussion, see: Green et al (2019). Large influence of soil moisture on long-term terrestrial carbon uptake, Nature vol.565: 476-479.

17 Appendix-2.1 includes the estimated coefficients of regression (2).

18 In order to remove the seasonality of a time series, other methods can be used. For example, applying a moving average of length twelve. This would imply that, to calculate the average value for a certain month, an average of the six previous months and an average for six following months has to be computed.

19 Notice that the constant regressor has been removed from the regression in order to avoid perfect collinearity issues.

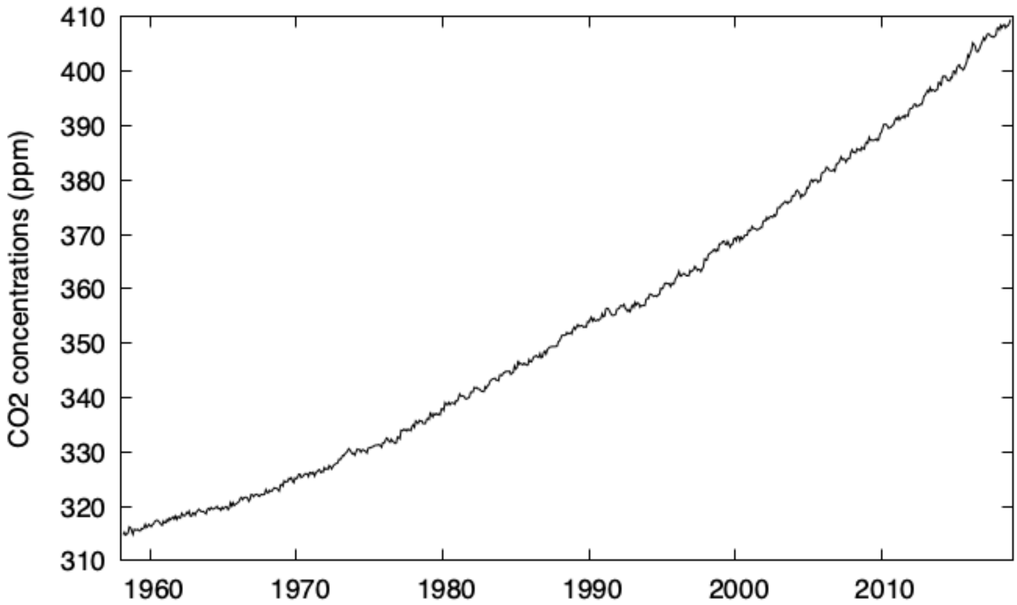
20 See Appendix-2.2. for more information on the confidence intervals.

Notice that the way series $CO2_t^*$ has been constructed the series will have mean 0, as we have removed all the monthly averages[21]. Thus, if we want to properly restore the original mean, we will have to add the overall mean of the CO_2 concentrations. This method is called rebenching. Then, the rebenched series, CO_2^{**}, where monthly seasonality has been removed is:

$$CO2_t^{**} = CO2_t^* + mean(CO2) \quad (4)$$

Figure 4 illustrates the rebenched series of Mauna Loa records from 1958 to 2018.

Figure 4. CO_2 concentrations without seasonality component, March 1958 - November 2018

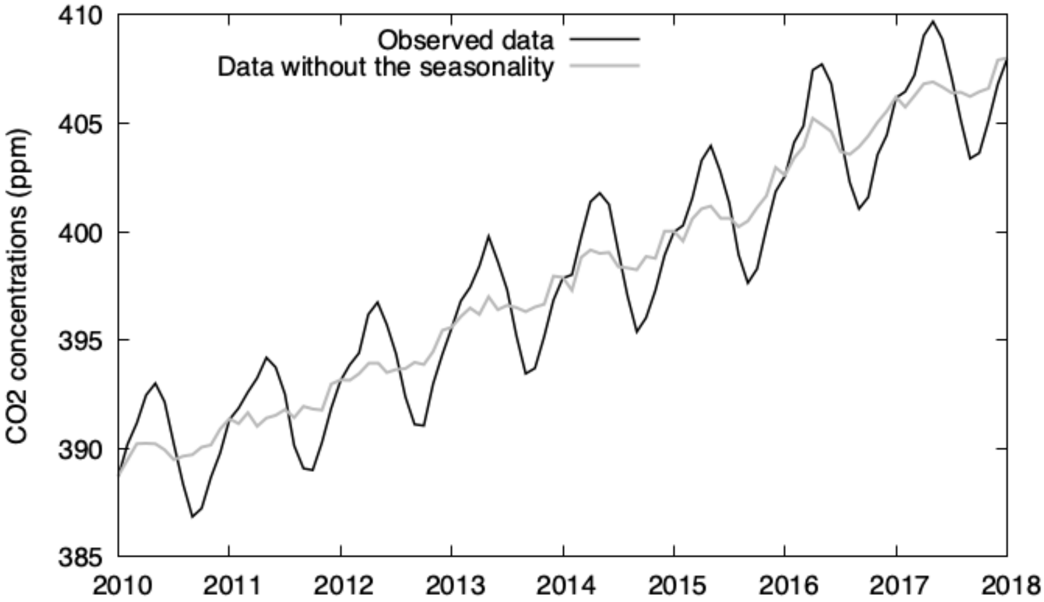


Source: Author's creation. Data: NASA (2019)

To clearly compare the observed time series with the series with the seasonality removed, Figure 5 has been graphed for the years comprised between 2010 and 2018.

[21] Notice that series CO2* is the vector of least squares residuals from regression (1), and by numerical properties of least squares estimation, we know that the sum of all OLS residuals is 0.

Figure 5. CO_2 concentrations versus the series without seasonality, January 2010 - January 2018



Source: Author's creation. Data: NASA (2019)

Regarding the trend, the series shows a global and persistent increase on the CO_2 concentrations in the atmosphere over time. As explained above, a deterministic trend can be estimated using linear regression model. To check whether these concentrations follow a linear or a non-linear trend, the following linear regression was estimated[22]:

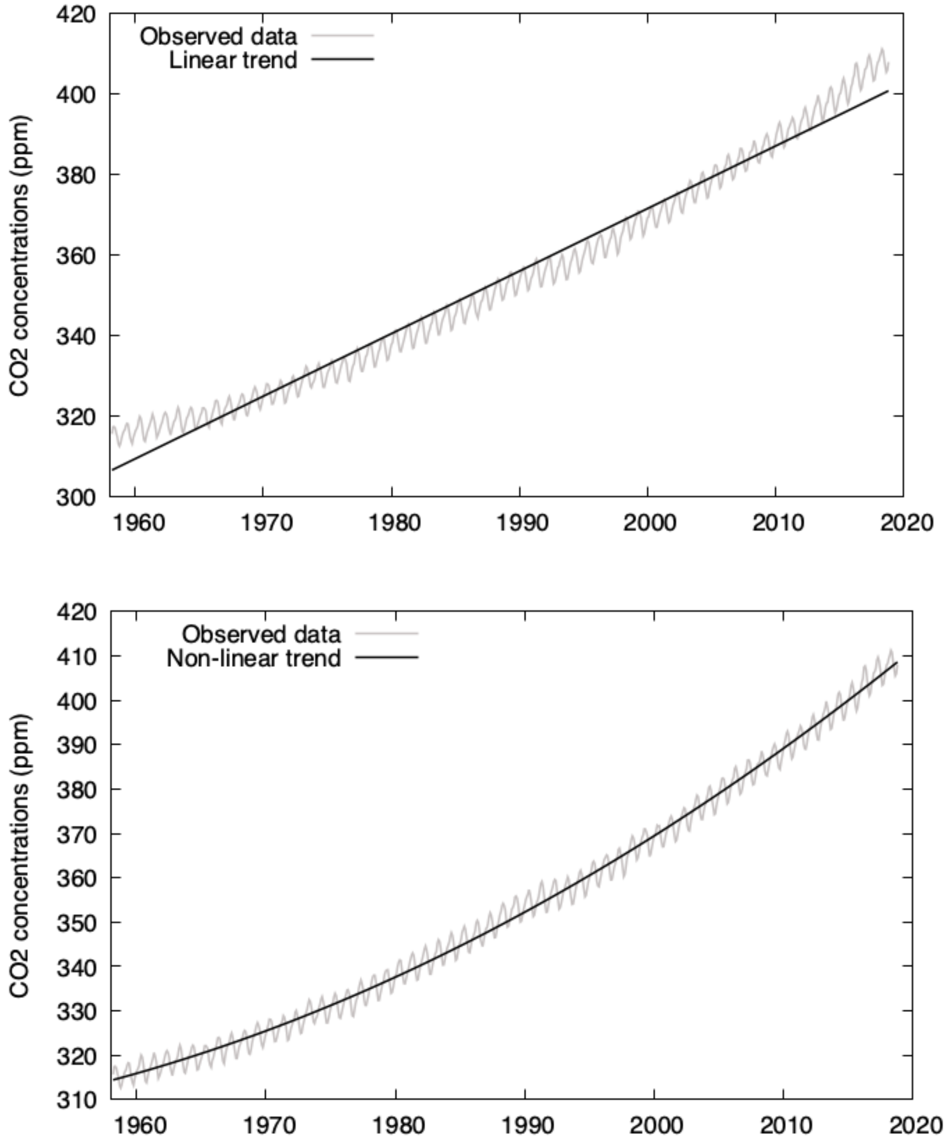
$$CO2_t = \beta_0 + \beta_1 t + \beta_2 t^2 + u_t \qquad (5)$$

The estimation of model (5) indicates the presence of a significant non-linear trend, with a positive estimate for the coefficient of the quadratic time trend, implying that CO_2 concentrations have been increasing at a higher rate, that is, have been increasing exponentially.

Graphically, we can see in Figures 6 (A) and (B) that a non-linear trend fits better to the plotted data from Mauna Loa.

[22] The result of estimating this model is found in Appendix-3.

Figure 6 (A) and (B). Analysis of the trend of the CO_2 concentrations monitored in Mauna Loa.



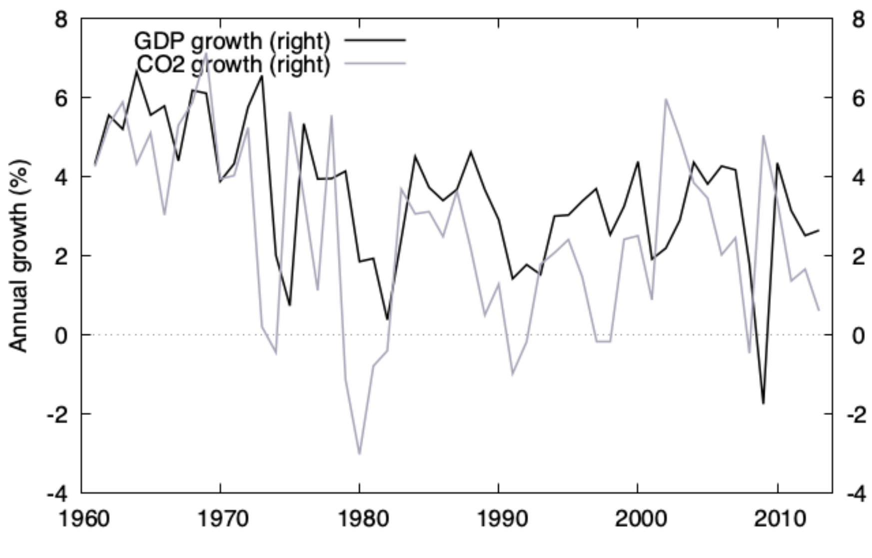
Source: Author’s creation. Data: NASA (2019)

Emissions and economic activity

What is the cause of the rise of greenhouse gases' emissions? If we stop to think for a minute about the consumption decisions that we take on a daily basis, we will realize that most of them involve CO_2 emissions: taking the car, turning the heating on in winter or taking a shower, for instance. Indeed, about 90% of the energy we use comes from fossil fuels which emit CO_2 when they are burnt, whilst enlarging the existent Greenhouse Effect[23]. Thus, the starting point of all these emissions seems to lay nowhere but in humans. Sadly enough, we can't stop using this type of energy from one day to the other, as the renewable sources still require a great investment in order to be fully implemented in our society.

Nonetheless, it is important to underline that growth of global CO_2 emissions has been lower than world's economic growth, as shown in Figure 7. This phenomenon, known as decarbonisation, implies that we progressively need less energy derived from CO_2 to produce the same quantity of output[24]. The reasons hidden behind decarbonisation are diverse and comprise, among others, the ongoing shift from traditional energy sources (such as coal) to renewable or less carbon-intensive sources.

Figure 7. Annual growth of the world's GDP and the world's CO2 emissions

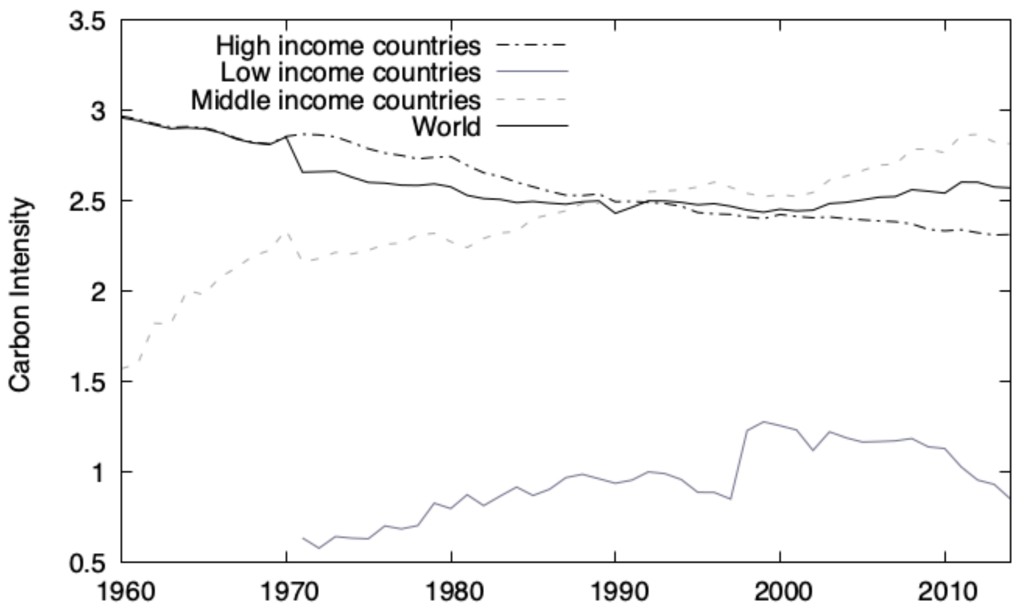


Source: Author's creation. Data: NASA (2019) and World Bank (2019)

[23] Nordhaus, William. Climate Casino, page 20.
[24] Nordhaus, William. Climate Casino, page 22.

When breaking down the emissions of Greenhouse Gases, GHGs, by the economic activities that lead to their creation, we find that the electricity and heat production sector accounts for one-fourth of the total emissions. Alongside, agriculture, forestry, and other land usage activities account for more than 20% of the total emissions[25]. Another sector that largely contributes to global warming is the one composed by the industries which require burnt fossil fuels as an energy source; that is, chemical, metallurgical and mineral transformation activities. Overall and exemplifying, activities such as deforestation, livestock farming, the use of fertilizers and the burning of coal, oil, and gas, are fostering GHGs emissions[26].

Figure 8. Evolution of carbon intensity divided by income levels[27,28], 1960-2014



Source: Author's creation. Data: World Bank (2019)

[25] The United States Environmental Protection Agency. See: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data (visited 30/04/2019)

[26] The United States Environmental Protection Agency. See: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data (visited 30/04/2019)

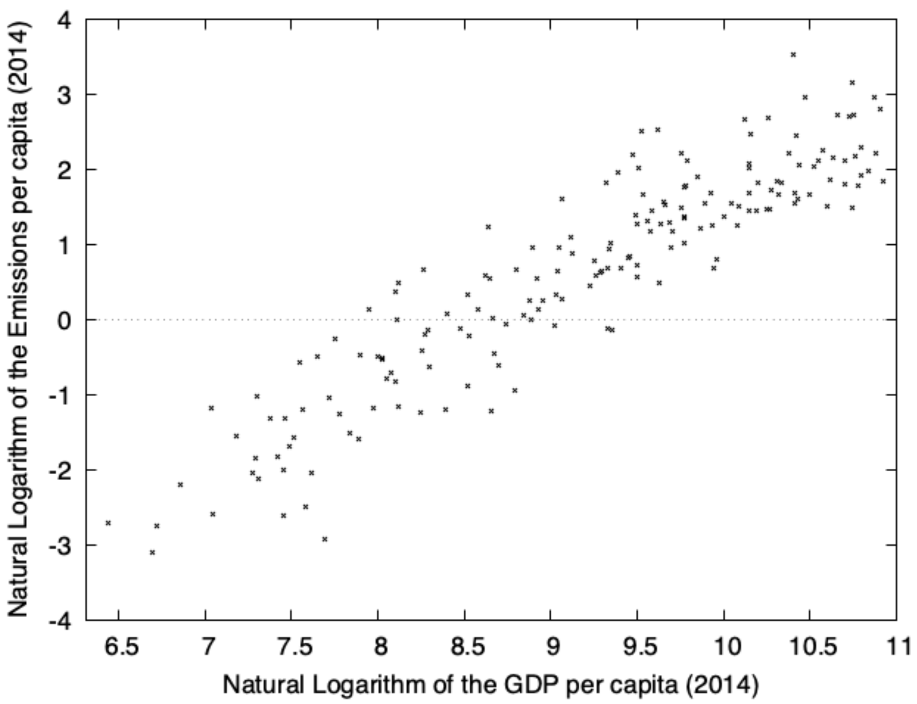
[27] Carbon intensity is measured by the ratio of kilograms of carbon dioxide per kilograms of oil equivalent energy units.

[28] According to the World Bank Atlas method, for the current 2019 fiscal year, low-income countries are those with an annual Gross National Income per capita of 995$ or lower; middle-income countries' GNI per capita ranges from $996 to $12.055 and high-income economies have a GNI per capita of $12.056 or higher.

The ratio of carbon dioxide emissions per unit of energy is called carbon intensity. Its evolution is plotted in Figure 8. Emission intensities are a way to compare environmental impacts of fuels and economic activities. In this graph, we can see that the overall world's carbon intensity use has followed a negative trend, yet when splitting the planet in regions according to their income, a different conclusion is inferred[29]. Concretely, high-income countries have reduced their carbon intensity, while middle-income countries have almost doubled such ratio from 1960 to 2014. Low-income countries, on the other hand, have a carbon intensity use of approximately the half of high-income economies.

At a country-level, China and the United States are the countries with the largest CO_2 emissions. Nonetheless, when taking a look at the emissions per capita, Bahrain (73.1 $MtCO_2$) and Qatar (41.9 $MtCO_2$) were heading the list in 2014. Figure 9 shows, for 188 countries, the positive association between income per capita and emissions per capita.

Figure 9. Relationship between CO_2 emissions and GDP per capita (2014).



Source: Author's creation. Data: World Bank (2019)

29 Appendix-4 includes the regression to estimate this trend.

Concretely, the estimated elasticity indicates that countries with a 1% larger income per capita are expected to generate 1.14% more emissions, on average. Thereby, richest countries are, on average, the ones that emit the most GHGs[30]. To obtain these results, the following regression has been computed:

$$ln(GDP\ per\ capita_{2014}) = \beta_0 + \beta_1 * ln(CO2\ emissions\ per\ capita_{2014}) + u_t \quad (6)$$

2.2. Effects Of Climate Change On The Environment

Regardless of the contribution of each gas behind climate change, it is important to notice that, overall, they all cause severe damages to societies and to the environment. However, the severity of such impacts depends on the system that is affected. That is, whether a managed system, also called human-intervened, is harmed, or whether an unmanaged system results damaged[31]. Thereby, the degree of human intervention placed on each system will potentially determine the extent of the damage caused by global warming.

Naturally, fundamental concerns are placed on unmanaged systems and on the so-called tipping points. The latter are discontinuities in climate behaviour that lead the natural system to a new state, probably resulting in an irreversible bad equilibrium. Often, their behaviour is based on self-reinforcing processes that, at some highly unpredictable point, when such process is tipped, can continue without additional forcing[32]. Hence, tipping points are critical thresholds from which the climate changes from a stable state to a worse one, whilst representing the physical, biological and economic impacts of climate change.

The main causes of the tipping points are nonlinear reactions to stresses, and we are far from understanding these dynamics[33]. Furthermore, and even if we understood those dynamics, the difficulty to assess the impacts and the gravity of the consequences is much larger. Examples of systems that may be subject to tipping points comprise the loss of the

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[30] See the Appendix-5 for the estimated regression.
[31] Nordhaus, William. Climate Casino, page 71.
[32] Postdam Institute for Climate Research. See: https://www.pik-potsdam.de/services/infodesk/tipping-elements (visited 29/03/2019)
[33] Nordhaus, William. Climate Casino, page 136.

Greenland Ice Sheet, which is rapidly melting due to the current temperature increase[34]. Consequently, it is becoming thinner, it is losing height and, as its surface sinks, it is increasingly exposed to warmer air, a fact that accelerates the melting process. Scientifics have indicated that the tipping point leading to a complete loss of the Greenland's ice sheet could be reached if the planet's temperature rises by 2ºC.

On the other hand, unmanaged systems, that largely operate with barely any human intervention, are considered to be the most affected systems by global warming. These comprise, for example, wildlife reserve and the sea-level rise. The latter is the consequence of the melting of glaciers and ice sheets, occurrences derived from the human-induced climate change. The Polar Arctic Circle, for instance, has melted faster in the last 20 years than in the last 10.000, but we are still not noticing the full extent of its consequences in the sea level rise. Nonetheless, in the period comprised between 1900 and 2016, the sea level rose about 16 to 21 cm, and approximately 7 cm of such increase on the sea-level have occurred since 1993[35] .

Thus, regarding the sea-level rise, the major challenge relies on predicting which will be the thermal expansion and whereas the 4% of the population living in coastline areas, such as the Netherlands and Bangladesh, will have to migrate. However, it is important to notice that the barriers of adaptation to such occurrence will be different in both places. Despite of the two countries being partially surrounded by the sea, the Netherlands, a fully developed state that can afford to build dykes in order to avoid, or at least to postpone, catastrophes derived from the sea-level rise, will have an easier adaptation to the sea-level rise than Bangladesh, a country where 20% of the population lives in extreme poverty[36].

In the same vein, the increasingly urbanised coasts of Somalia and Kenya are clearly threatened by floods, which can destroy critical infrastructures, contaminate the few

34 Robinson, A., Calov, R. & Ganopolski, A. Multistability and critical thresholds of the Greenland ice sheet. Nat. Clim. Chang. 2, 1–4 (2012).

35 USGCRP (2017). "Climate Science Special Report. Chapter 12: Sea Level Rise". Retrieved from: https://science2017.globalchange.gov/chapter/12/ (visited: 30/03/2019)

36 Barne, Donna (2016). World Bank. Retrieved from: https://blogs.worldbank.org/es/voices/celebran-notable-descenso-de-la-pobreza-en-bangladesh (visited: 31/03/2019)

existing freshwater supplies and reduce the potentially fertile land[37]. Given the large number of inhabitants in such areas, sea-level rise would result in catastrophic consequences to these countries, probably leading to a large displacement of population which, at the same turn, could conduct to disputes for food and housing. Overall, the more economic difficulties and the higher the political instability, the more difficult it will be for a country to adapt to such event, and the worse will be the consequences for its inhabitants.

Another dimension that should be taken into account when talking about the oceans is their process of carbonization and acidification, as it is impossible, at least by now, for humankind to intervene in this natural cycle. The increase in CO_2 in the sea is likely to result in species extinction, concretely in oysters, plankton, coral and shellfish. However, we do not have a full understanding of the impacts of ocean acidification and it's still difficult to assess the potential consequences it will have on humans. Even so, what's clear is that, through ocean acidification, the global fish stock will migrate to non-contaminated areas and part of it will die on the way. This process will increase the likelihood of international conflicts, especially in those sectors dedicated to fishery, as the scarce fish will move to neighbour waters, thus reducing economic and income opportunities in the local region.

In the same way, hurricanes, or tropical cyclones, are another example of an unmanageable system which is tremendously affected by climate change. For such a phenomenon to take place, warm water (at a temperature of 26.5ºC in the surface, at least) and strong wind are needed. Thus, the conditions for the existence of hurricanes are idyllic under the current global warming. In addition, statistics show that damages derived from tropical cyclones have risen about 2% per year faster than GDP[38]. Moreover, calculations exhibit that an increase in temperature of 4ºC would enlarge the average intensity of hurricanes at about 16 miles per hour. Incentives should be placed, then, in relocation and orderly planning as a way to reduce the vulnerability towards such event.

Yet, even if there is some uncertainty about whether and when the consequences of climate will occur, it is even more difficult to assess the future economic impact they

[37] Werrell, C. and Femia, F. (2018). Climate change raises conflict concerns. The UNESCO Courier.
[38] Nordhaus, William. Climate Casino, page 117.

might have on biodiversity. Indeed, climate change is considered to be the primary cause of the loss of biodiversity (IPBES 2019). The usage of fossil fuels is destroying forests, contaminating seas, and hindering the living of animals. Nowadays, one million species are under threat of extinction, and we are still undermining the place where they, and we, live in. Nonetheless, as animals do not carry a monetary price tag, it is really difficult to value, in economic terms, the potential loss of wildlife.

Although one cannot compare the value of a living animal with cultural heritage or settlements, both are threatened by the current global warming and they do not have a monetary value assigned. Notwithstanding, if population really cares about animals, why are seas filled up with disposable plastic? On the other hand, how valuable is for the humanity that cities such as Venice or London may disappear? The answer to these questions is, at the very least, challenging.

When analysing the impacts of climate change on manageable systems, agriculture and farming must be mentioned as they are the most dependent and sensitive economic sector to climatic processes. Although global warming is likely to decline soil moisture and to reduce the availability of water for irrigation purposes, projections show an increase in agricultural productivity in many regions for "modest warming" (a local increase of 3ºC)[39]. Given the uncertainties that surround the estimates, what's certain is that possible harmful impacts can be mitigated with carbon fertilization, trade, and a decline of the share of agriculture in the economies. As a matter of fact, despite the increase in temperatures, technological change has contributed to the 3% decline per year in food price.

Nonetheless, water and food are largely indispensable for survival. Thus, the resulting water scarcities and the difficulties of accessing to food derived from climate change will contribute to people increasingly questioning their security, their lives and their prosperity. If individuals' basic needs are not covered, that is, if their demand for basic resources such as housing, water and food, is not satisfied, conflict will likely arise. Sadly enough, tensions derived from these situations are already happening in the Middle East and Africa. Overall, a stable institutional framework is needed in order to slow down the risks of conflict and social instability resulting from global warming.

[39] IPCC Fourth Assessment Report (2014), page 54.

Likewise, climate change is also having an impact on health, especially concerning the spread of certain diseases, malnutrition, and diarrheal illnesses. In extreme cases, global warming, through increased heatwaves, is likely to have a direct impact on mortality[40]. Nonetheless, the methods used to estimate the impact that climate change will have on health are highly controversial. However, what can be stated is that, as income is rising, the degree of vulnerability against climate change is decreasing in the health and agriculture sector. In other words, we are progressively isolating our communities from the detrimental impacts of climate change.

Unfortunately, global warming cannot be mitigated from one day to the another. Its direct effects on managed and unmanaged systems, going from floods to heat waves and comprising the consequent decrease on basic resources, are likely to lead to social disruptions. Food and water insecurities can give rise to socio-political issues, whilst the predicted increase of extreme events can call into question the state's resilience against global warming. As a consequence, the risk of internal terrorism is enlarged and, as the government is less able to meet the basic needs of its society, revolutions and conflicts are more likely to appear.

2.3. Climate Change: Evidence And General Consensus

Among the climate science experts, there's a 97% of consensus (NASA, 2019) that anthropogenic emissions are the main cause of global warming, at least since 1950[41]. That is, 9.7 out of 10 scientists agree on the fact that the current climate change is human-induced. Indeed, in a report of 2014 published by the prestigious Intergovernmental Panel on Climate Change (IPPC), an organisation where the pioneer scientists in global warming work, the 100% of the responsibility of climate change was attributed to humans[42]. Nonetheless, sceptics can still be found and especially in America, where only two out of six people support the scientific consensus. Most of the dismissive arguments

[40] Bowles, D. C., Butler, C. D., & Morisetti, N. (2015). Climate change, conflict and health. *Journal of the Royal Society of Medicine*, *108*(10), 390–395.

[41] Nuccitelli, D. Trump thinks scientists are split on climate change. So do most Americans. The Guardian 22/10/2018.

[42] In a 5% confidence level.

placed against the compelling evidence of global warming comprise political ideologies, and the vast majority of such population is completely disengaged from the problem.

Climate change is placed in the political agenda since 2015, when the Paris Agreement was signed. In that conference, the United Nations reached an agreement to tackle climate change, requiring all member countries to work together in key aspects such as limiting the increase of the planet's temperature below 2ºC compared to industrial levels (idyllically aiming for 1.5ºC), pursuing domestic policies to mitigate global warming whilst minimizing its adverse losses and damages, and raising public awareness, among others[43]. Indeed, climate action is in the list of sustainable development goals to be achieved by 2030.

Likewise, the IPCC published a special report in October 2018 concerning the world's temperature target. In their review, they study the impacts of rising emissions to 1.5ºC above preindustrial levels instead of limiting them to 2ºC. Certainly, half a degree of difference can make a large and palpable difference in our ecosystems, whilst slowing down the frequency of extreme events, securing food and ensuring life to threatened biodiversity. In order to avoid possible disastrous and irreversible consequences of climate change, we would have to cut down the emissions of GHGs by 45% by 2030 compared to the levels of 2010, and by 2050 our emissions should be zero.

The evidence that supports the presence of climate change comprises the global temperature rise since the late 19th century, being the temperature of the Earth's surface 0.9ºC higher than one hundred years ago. Nonetheless, global warming differs across the globe[44]. What is even more alarming, if possible, is that the temperature's rise has mostly happened in the last 35 years, being the heat waves registered in this period completely unprecedented[45]. Consequently, oceans have absorbed a part of this warmth, increasing

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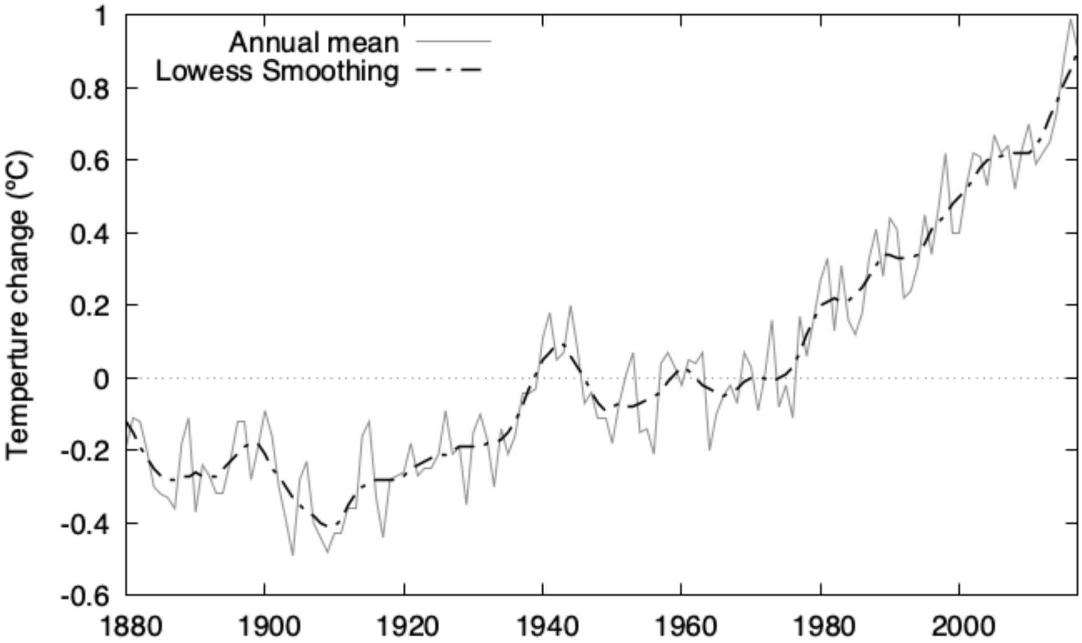
[43] United Nations Framework Convention on Climate Change (2019). Retrieved from: https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement (visited 25/02/2019)

[44] For example, in the case of Spain, the temperature has increased 1.5ºC in the same period of time, believed to be causing desertification in some areas of the territory and, following the UN statistics, 6% of the Spanish surface is irreversibly degraded.

[45] NASA (2019). Climate change: how do we know? Retrieved from: https://climate.nasa.gov/evidence/ (visited 26/02/2019).

the temperature of their surface (approximately 700 meters of depth) by more than 0.4ºC in the last fifty years.

Figure 10. Global Surface's temperature change, 1881-2017



Source: Author's creation. Data: NASA

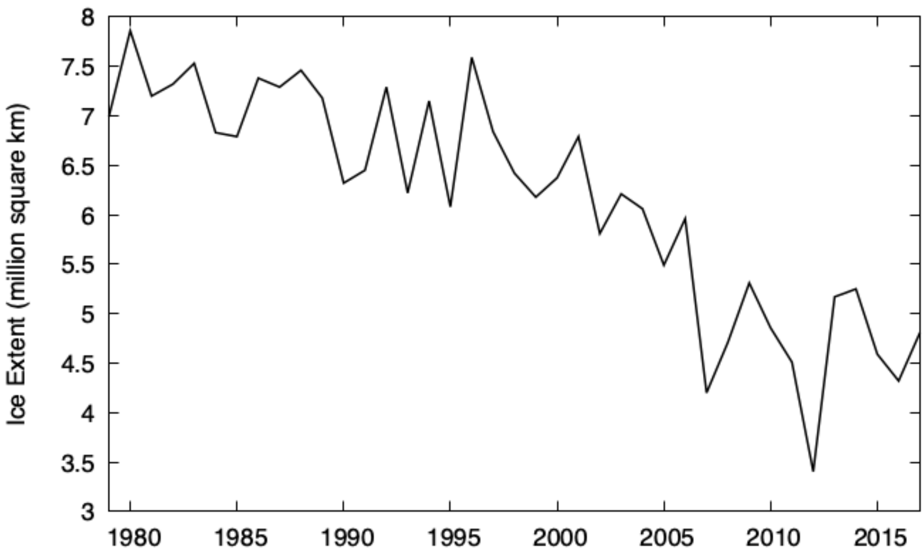
Figure 10 shows the relative change of the Earth's surface temperature with respect to the average temperatures registered between 1951 and 1980. The grey line represents the observed annual data. In this case, a Locally Weighted Scatterplot Smoothing (LOWESS) method of smoothing the series has been used[46]. Despite the movements of the series, it can be stated that since mid-sixties it has had an overall upward trend. Finally, it should be pointed out that eighteen of the nineteen warmest years have taken place since 2001. Hence, global warming seems undeniable.

Another consequence of climate change is the melting of the Arctic and Antarctic's ice sheets and the glacial retreat occurring in places such as the Alps, the Himalaya, and Alaska, for instance. Moreover, studies show that Greenland, for example, has lost an average of 286 billion tons of ice per year in the last 25 years and that the snow cover in the Northern Hemisphere has largely decreased.

[46] The Locally Weighted Scatterplot Smoothing aims to fit simple models to localized subsets of the data.

In Figure 11 we can appreciate the extent to which the Arctic's Ice Sheets are declining. The data is extracted using the months of September, when ice sheets reach its minimum. Overall, the 12,8% decline on their size per decade is alarming[47].

Figure 11. Evolution of the extent of the Arctic Ice Sheet, 1979-2017.



Source: Author's creation. Data: NASA (2019)

One of the consequences of the melting of ice sheets is the rise in the sea level, which has increased about 20 centimetres in the last century. The rate at which oceans rise is accelerating every year, being the one of the last two decades nearly the double that of the last one hundred years. Moreover, oceans are acidifying as a result of CO_2 emissions. For instance, in European urban areas, where 80% of its population lives, the frequency and the exposure to extreme events such as heat waves, rising sea levels, and flooding, has increased with climate change. When breaking down the continent by areas, the Mediterranean regions are becoming drier than ever, and the central and south are now suffering from forest fires and droughts. Furthermore, northern provinces are getting remarkably wetter. However, developing countries are the ones who will suffer the most the effects of climate change[48]. Indeed, their economy largely relies on natural resources, meaning that most of the population residing in such countries work on the primary sector

[47] NASA, 2019.
[48] European Comission (2019). Climate Change consequences. Retrieved from: https://ec.europa.eu/clima/change/consequences_en (visited 26/02/2019).

and live off it. As it has been explained, agriculture and farming are the most sensitive sectors to global warming, and changes in the usual weather patterns can lead to poor harvests and to a subsequent food scarcity. Furthermore, conflict in such places is likely to arise if the access to basic needs is restricted.

There is no doubt that the uncertainty regarding how climate will change makes the study of global warming even more complicated. Actually, we do not know how climate change will evolve because its complex nature makes it difficult for experts to anticipate its behaviour. In addition, the uncertainty regarding future policies' outcomes, the impacts of GHGs emissions and the consequences of the forcing mechanisms, the unknown tipping points, and the climate and social feedbacks make it even more complicated to forecast reliable projections. Nonetheless, it is known how variables such as temperature, precipitation, and extreme events have conducted in the last decades. Thus, scientific models which allow for past behaviour, and which of course take into account future uncertainties, may serve as a tool for understanding how climate may evolve.

3. CLIMATE CHANGE AND CONFLICT: LITERATURE REVIEW

3.1. Linking Climate Change And Conflict

Will the population living in coastal areas become climate refugees due to sea-level rise? Will food and water shortages derived from global warming trigger conflict? Will climate change lead to tensions? Many are the questions that arise when studying the potential consequences of climate change, and little consensus is found in the literature.

Despite an overwhelming scientific agreement regarding human-induced climate change, an accorded resolution on the linkage between global warming and conflict does not exist. Indeed, before 2014 there were few and scattered comments on the security issues derived from climate change in the most prestigious reports on global warming, the ones published by the United Nations Intergovernmental Panel on Climate Change (IPCC). Nonetheless, such issue was present in the public debate before 2014. For instance, the conflict in the region of Darfur, Sudan, had been linked to climate change by Ban Ki-moon, the Secretary-General of the UN, who argued that violence in some African countries could be a consequence of similar environmental problems[49]. In the same vein, Nicholas Stern argued, in the Stern Review (2006), that forced environmental migration could give rise to conflict, however this was not the main focus of his publication. It was not until the release of the IPCC's 5th Assessment Report that the UN's scholars introduced a subchapter on "Water, food and human systems, human health, security and livelihoods" where it was stated that "multiple lines of evidence relate climate variability to some forms of conflict" (IPCC 2014, 73). Thus, the study of the relationship between climate change and conflict is relatively nascent, yet the perspective on the issue has evolved throughout its analysis.

Nowadays, scholars are debating on the existence of a correlation between climate change and conflict and whether or not such relationship follows a causal pathway. Two confronting positions can be found in the literature. The first one is defended by Marshall Burke, Solomon M. Hsiang, and Edward Miguel, a group of economists from the universities of Stanford and Berkeley, in the United States, who argue that global

[49] Nordas, R. and Gleditsch, N. (2007). "Climate change and Conflict". Page: 629

warming does induce human conflict. On the other hand, Halvard Buhaug, a professor at the Norwegian University of Science and Technology, and his workmates, call into doubt such statistical correlation.

Before introducing their arguments, two points must be highlighted. First of all, it is important to understand the difficulty in measuring and testing causal relationships outside the context of an experiment. Most of the economic data is observational, that is, nonexperimental data. In order to properly interpret the results of an analysis that is carried out with such type of data, one must bear in mind that it may have selection bias, that is, observations may not be representative and they are not always randomly selected. In addition, it may contain information bias, that is inaccuracy in reporting the data, and measurement errors. Nonetheless, what truly concerns the study of the relationship between climate change and conflict is confounding. Such a risk factor when studying causation arises when a variable, say X, affects at the same time two other variables, say Y and Z, whose association is being tested. Thus, when trying to infer a causal relationship between these two variables, if X is not taken into account, the estimated relationship between Y and Z is biased.

Thereby, linking climate change and conflict would be simpler if two identical societies existed and could be compared. If it were the case, one of the populations would be "treated" with a variation in the climatic conditions, such as an increase on the frequency of precipitations or a heat wave. Oppositely, the other society would adopt the role of a "control group". That is, as both population groups are assumed to be identical, the divergences in the conflict outcomes across populations would be credited to the only different factor, the climate variability. Unfortunately, such experiment cannot be carried out as no homogeneous societies, nor individuals, exist. Nonetheless, if an experiment is to be made, randomisation of treatment is the best way to prevent confounding issues.

Thereby, to isolate the effect of climate change on conflict, two econometrical approaches are widely used in the literature; these are cross-sectional and panel data studies. The first one consists on comparing how the conflict variable evolves across sites, whilst controlling for the variables that covariate with the observed conflict outcomes, as economic indicators, and adding them to the regression[50]. The two main drawbacks of

[50] Burke, M., Hsiang, S. and Miguel, E. (2014). Climate and Conflict. Page 4.

this method are that population is assumed to be homogeneous and that some drivers of conflict, such as religion, are difficult to measure and, consequently, they are hard to be controlled. In addition, not all the drivers of conflict are known, and the scholar who uses this method is likely to conflate the real effects of climate change with the unknown determinants of the studied social instability.

On the other hand, panel data approaches aim to analyse climate variability across time within the same population, defining the latter as both the "control" and the "treatment" group[51]. That is, the conflict outcomes are measured, for the same population, before a variation in the climate and after that variation Forasmuch as the period of time comprised between the events is small, the effect of the climate variable on conflict can be interpreted as causal. Nonetheless, and as a consequence, only climate variations that are short-run can support this approach.

The other point to be highlighted is that, despite climate change being a world-wide issue, societies living in poor countries are the most vulnerable to the impacts of global warming. In addition, the study of social systems is inherently complex, as it is really difficult, if not impossible, to predict how the population will react to certain stresses. However, the differences between developed and underdeveloped countries, in terms of their access to basic needs and the design of their institutions, can help us explain the divergences on behaviour.

On one hand, survival in poor countries depends on natural resources, as the main economic activity for such population is agriculture. Indeed, more than one out of two people in underdeveloped countries work in the cultivation of soil and in farming, the sector which is the most affected by climate-related variations[52]. Thereby, as the world is becoming warmer, water is increasingly being limited, the harvests are scarcer, and the survival of these societies is progressively more threatened. Consequently, climate change, by shifting weather patterns, rising the sea level and increasing the world's temperature, among others, is turning their lives into a life or death game, whilst rising the likelihood of disputes over basic needs. In addition, climate change is making

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51 Burke, M., Hsiang, S. and Miguel, E. (2014). Climate and Conflict. Page 5.

52 World Bank (2019). Employment in agriculture in underdeveloped countries. See: https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=XL (visited: 30/05/2019).

underdeveloped countries more dependent on wealthy societies as, by themselves, they do not have the resources to cope efficiently with climate change.

On the other hand, institutions, in wealthy societies, aim to promote peace and are composed by democratically chosen politicians. However, poor countries struggle with political instability and corruption, which ends up deriving on fragile situations. Indeed, in the World Bank's Development Report (2011), such situations are defined as time phases when states or institutions lack the ability or the legitimacy to moderate the relations between social groups, consequently leaving the door open for possible conflict.

Thereby, if climate variability hits an economy dependent on agriculture and reduces the availability of natural resources, less food and water will be available for the same population, and society will try to fight for its survival. In addition, if the political institutions are fragile, they won't be able to solve the conflicts that will likely arise from the reduced access to basic needs.

Overall, developed countries have the skills and the resources to cope with climate change impacts in a more peaceful manner than underdeveloped states. That is a reason why conflict is measured differently according to the location that is studied, as it is explained in the following chapter.

Going back to the linkage between climate change and conflict, the group of American economists composed by Hsiang, Burke and Miguel argue that, despite climate variability not being the only causal factor of conflict, it can certainly alter the interactions between individuals, whilst modifying the frequency and the intensity of social instability. To infer the causal relationship between both variables, they use a fixed effects approach jointly with the use of country time trends and binary dummy variables, which enables them to control for the unobserved variables that might affect the conflict outcomes.

They suggest that economic incentives could be a channel through which climate change causes conflict[53]. That is, an alteration on the usual weather patterns may result in worse harvests, which could reduce the opportunity cost attached to conflict, whilst rising civil

[53] Carleton, T., Hsiang, S. and Burke, M. (2016). Conflict in a changing climate. Page: 497.

unrest. Likewise, they state that climate change, through a psychological pathway, could potentially increase the likelihood of conflict. They rely on the fact that serotonin levels, a neurotransmitter negatively associated with aggressive behaviour, do fall when temperature increases. Thus, global warming has been shown to be linked with a decrease on the serotonin levels, which could lead to civil unrest under heat stress.

Buhaug, at his turn, states that the "climate breeds conflict" hypothesis holds only under the benchmark used by Hsiang, Burke and Miguel. He argues that, when using different climate parameters, such as interannual growth of precipitations, and different controls, such as political exclusion, as well as when modifying the dependent variable, for a more "inclusive" indicator, that is, that encompasses all conflict years instead of limiting it to an amount of deaths in battle, causality disappears[54].

Nonetheless, he states that climate change may have an indirect and conditional effect on social security, and that climate variability may influence the dynamics of interaction between individuals, although he finds little evidence to support this linkage in the short-term[55,56]. His approach is based on the fact that extreme weather conditions or adverse changes in the usual patterns of temperature or precipitations, for example, may lead to a decline on agricultural productivity and/or to crop failure. The economic impacts that could arise from this occurrence are diverse, but they can be categorized within four events. First of all, if agricultural productivity slows down, access to food can be reduced, leading to an increase in the price of the basic commodities. Secondly, farmers could experience a loss on their income derived from a decline in their sales. Moreover, if the state rose money from agriculture by means of taxation or exports, it would also experience a loss of its revenues. Last but not least, if the demand for basic needs is not covered by the supply-side, the population can decide to move into other places where they can have a better prospect. As a consequence of such events, Buhaug states that conflict could arise.

Nonetheless, Buhaug argues that the negative effects of climate variability can be compensated by technological innovation, and those adverse changes may not lead to a

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54 Halvard, B. (2019). Climate not to blame for African civil wars. Pages 16478, 16479.
55 Halvard, B. (2016). Climate Change and Conflict: Taking Stock. Page 334.
56 Thiesen, O., Gleditsch, N and Buhaug, H. (2013). Is Climate Change a Driver of Armed Conflict? Page 4.

decline in agricultural productivity. Thus, the vicious poverty cycle in which some countries are involved, especially in the Sub-Saharan region, would disappear. Moreover, he argues that for the Middle East and North Africa region (the MENA), the impacts of climate variability are different, as these economies do not rely as much upon agriculture as poorer economies. The possible effects on these countries comprise the decline in the petroleum demand as a result of the progressive shift towards renewable energies, an occurrence derived from the burning of fossil fuels and its negative impacts on the atmosphere. Moreover, if temperatures increase above a certain threshold, tourism and freshwater resources could decline. Likewise, Buhaug states that the MENA context is challenging, as the population is growing rapidly, they have high unemployment rates and extreme environmental conditions.

3.2. Empirical Evidence

When scholars talk about conflict, they are usually comprising different types of social instability. One of them is the interpersonal conflict, which accounts for violent crime, domestic violence, property crime, violent retaliation, and murder, among others. Another one is the intergroup conflict, which makes reference to an armed conflict between the state's government and an organized rebel movement, or between two social groups. That are, political instability, civil wars, and civil conflict, for example. Other types of conflict range from institutional breakdown to population collapse.

It is important to notice that scholars differ on the choice of the variable that accounts for the climate variability. Most of the studies use data on precipitations and on temperature, although the time and the spatial unit can differ. That is, whether it is annual or monthly, and whether it is measured at a country-level or at a city-level, for example.

In addition, most of the studies examine the effect of climate variability on conflict in underdeveloped countries, especially in the Sub-Saharan region. This territory is particularly affected by global warming for many reasons. First, these countries are among the ones with the slowest economic growth in the world. Furthermore, they rely extensively on agriculture and on rainfall, as they have scarce irrigation mechanisms. Thus, as they do not have the resources to cope efficiently with the consequences of climate variability, they will be the ones who suffer the most. Overall, due to their geographical location, their extreme weather conditions and their level of underdevelopment, this region will most likely bear the burden of climate change, although it is, by no means, their fault.

In their papers, the group of economists composed by Hsiang, Burke and Miguel, find a strong causal relationship between climate variability and social instability across different regions, different time periods and different climatic events[57] That is, changes in the usual climatic pattern towards more extreme weather directly lead to an increase in conflict. In other words, as climate changes, the world becomes more violent. Concretely, their findings suggest that the magnitude of the effect of climate on conflict is considerable: for each one standard deviation change in climate towards hotter temperatures or more intense rainfall, interpersonal conflict rises 4% and intergroup violence goes up by 14%, on average[58]. Nonetheless, these authors do not conclude that climate is, and has been, the only driver of human conflict, but that when large climate variations occur, human conflict is exacerbated. Likewise, they argue that the existing research is still unable to explain the mechanisms through which climate leads to conflict, although the evidence consistently points towards a clear causal pathway.

In 2004, Miguel et al., in order to estimate the effect of economic growth on civil conflict, used an instrumental variables approach where exogenous rainfall variation was the IV for income growth. In addition, they used country fixed effects and coded the dependent variable with 1 if at least 1.000 deaths were reported in a specific country. For the period comprised between 1979 and 1999, they found that when there was a decrease in rainfall, the likelihood of conflict arose on the following year in the region of Sub-Saharan Africa. One year later, Miguel (2005), used local variation on rainfall to assess the effect of income shocks on murder. He found that in the countryside of Tanzania, when there were periods of extreme rainfall variability, that is droughts or floods, the murder of "witches" -elderly women- doubled relative to other years. Moreover, such extreme rainfall was related to a decline in agricultural production and a consequent increase in famine.

Burke et al (2009) adjusted the study of Miguel et al. (2004) to control simultaneously for temperature and rainfall changes from 1981 to 2002, as both variables are correlated

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57 Hsiang, S. and Burke, M. (2013) Climate, Conflict, and Social Stability: What Does the Evidence Say?

58 Hsiang, S., Burke, M. and Miguel, E. (2013). Quantifying the Influence of Climate on Human Conflict. Science (341), 1235367.

over time. They corroborated the finding from Miguel et al., plus they found that when temperature increased, civil war incidence was more likely to happen. Nonetheless, this study was criticized by Buhaug (2010), who argued that the definition of civil war used by Burke et al. was the cause of the positive correlation between civil war and temperature. In addition, Buhaug added a lagged conflict incidence indicator, as he argued that recent conflict could influence the probability of new social unrest, and he used a logit regression as well as possible interactions between temperature and poverty and political exclusion. With these modifications in Burke et al (2009) model, he found no casual implications of climate variations on civil war.

Likewise, Hendrix and Glaser (2007) used data on interannual rainfall, land degradation and freshwater resources in Sub-Saharan Africa to estimate the impact of short and long-term climatic variations on social instability, measured as state-based internal armed conflict at a national level. As control variables, they used GDP per capita, whether the country was an oil producer and the percentage of the country's mountainous terrain. In their article, they studied the effects of climate change as long-term trends that may increase the probability of conflict, and as short-term triggers that can also lead to the same prospect. They found that an increase in rainfall was followed by a decrease in the likelihood of conflict in the next year, and their findings suggest that it was a more significant determinant on civil conflict than long-term trends such as land degradation and freshwater resources. Nonetheless, no causal relationship was inferred between rainfall and armed conflict.

Dell et al. (2012) studied the effects of temperature on economic growth for poor countries. They found that a negative correlation between temperature and economic growth, and they noticed that higher temperatures also had a negative effect on agricultural and industrial production, whilst increasing political instability in poor countries. Along similar lines, Sarsons (2011), also arrived at the conclusion that climate variability, in his study defined by positive precipitation shocks, lowered the probability of riot violence between Hindus and Muslims by 8% on the following year in India. He controlled for agricultural wages and his study included district fixed effects. Nonetheless, he found no relationship between such shocks and income variability.

Rowhani et al (2011), studied the effect of interannual variability in ecosystems on armed conflict and malnutrition in the Republic of Sudan, Somalia and Ethiopia. They used a nutrition indicator and controlled for the economic activity per regions, whilst finding a positive correlation between ecosystem productivity and armed conflict. However, no causality was inferred.

Overall, there seems to be a relationship between climate variability and conflict. In addition, despite most of the studies being set in Africa, this relationship seems to hold in the rest of the world. Nonetheless, there is less evidence on the path that leads from climate change to conflict. Some studies find significant associations between climate change and economic growth and conflict, respectively, whilst not being able to infer a pure causal relationship. Others, as Burke (2009), find a robust causal relationship between climate variability and conflict.

4. DROUGHTS AND POLITICAL VIOLENCE: AN EXERCISE

The previous chapter has illustrated once more how challenging is to measure and test causal relationships in the context of nonexperimental data. Usually, we need to just settle in measuring and testing implications of causal links between variables. That is, if a given theory argues that, say variable Z has a positive effect on variable Y, it might be very difficult to use observational data to measure and test such theory. However, we can try to measure a testable implication on such theory, which is that there is a positive association between Z and Y. This is the type of exercise carried on in this section.

Thereby, an implication of the climate change breeds conflict hypothesis will be tested in this chapter. That is, whether or not conflict variables are correlated with climate variables. To do so, a data set from Vestby (2019) has been used, which consists on data extracted from the Afrobarometer (2016), a survey that is estimated to represent 76% of the African population, and from the Standardised Precipitation-Evapotranspiration Index (SPEI). The first one is a random study carried out in different districts of 37 African countries, which reports participation in political violence. To do so, over 73.000 randomly chosen citizens had to respond whether they had used force or violence for a political cause during the previous year. Notice that the question embraces a broad scope of activities, certainly implying illegal acts. The possible answers they could report were "No, would never do this", "No, but would do if had the chance", "Yes, once or twice", "Yes, several times", "Yes, often", "Don't know" or "Refuse to answer".

To facilitate the interpretations, such answers have been compiled into a binary variable named Political Violence, which takes value 1 if they did use force for a political cause, regardless of the frequency, and 0 if they did not. In addition, when participants responded, they were reported their age, their gender, which has been computed as a binary variable taking value 1 if the respondent was male and 0 if female, and whether they lived in urban or rural areas, a variable that has also been computed as binary, taking the value 1 if they lived in rural areas and 0 if they lived in urban settlements.

In regards of the climatic variable, data from the SPEI (2016) has been used. Such institution facilitates data of precipitations in geo-localized spots, which allows us to know the exact climatic conditions that the respondents faced when they were involved, or not, in political violence. Such data has been compiled into two binary variables, which account for the presence of droughts and floods. The first one takes value 1 if drought was present during the growing season, and 0 otherwise; the latter, at its turn, takes value 1 if there were presence of floods, and 0 if not.

Notice that, as we are dealing with binary variables, we cannot estimate the correlation between the two them using the usual Pearson correlation coefficient. Instead, Pearson's Chi-square statistic has to be applied.

Association between Conflict Variable and Climatic Variables

First, in order to infer an association between political violence and drought, two contingency tables must be computed, that is, two tables that display the frequency distribution of both indicator variables. Table 1 disposes the conditional observed frequencies and their marginal value. On the other hand, In Table 2, the conditional expected frequencies and their respective marginal values are shown.

Table 1. Contingency table of the observed frequencies of political violence and drought

	Drought		
Political Violence	**[0]**	**[1]**	**Row Marginal**
[0]	55.112	16.399	71.511
[1]	1.729	728	2.457
Column Marginal	56.841	17.127	73.968

Source: Author's creation. Data: Vestby (2019)

Table 2. Contingency table of expected frequencies of political violence and drought

	Drought		
Political Violence	**[0]**	**[1]**	**Row Marginal**
[0]	54.952,9	16.558,1	71.511
[1]	1.888,1	568,9	2.457
Column Marginal	56.841	17.127	73.968

Source: Author's creation. Data: Vestby (2019)

Once the tables are computed, we carry out a hypothesis test to assess whether or not political violence and droughts are associated. Our null hypothesis (H_0) states that there is no association between the variables, and the alternative hypothesis states the opposite. That is:

$$\begin{cases} H_0\text{: } no\ association\ \ between\ Political\ Violence\ and\ Droughts \\ H_1\text{: } not\ H_0 \end{cases}$$

Under the null hypothesis of no association between political violence and presence of droughts, the statistic of contrast follows a Chi-square distribution with one degree of freedom. To compute the value of the test-statistic, the formula defined in (7) must be used, where f_o stands for the observed conditional frequency and f_e accounts for the expected conditional frequency. That is:

$$X^2 = \sum_{i=1}^{4} \frac{(fo_i - fe_i)^2}{fe_i} \sim X^2(1) \qquad (7)$$

Once we compute the Pearson's Chi-square statistic with the values from the contingency tables, we obtain:

$$X^2 = \frac{(55.112 - 54.952{,}9)^2}{54.952{,}9} + \frac{(16.399 - 16.558{,}1)^2}{16.558} + \frac{(1.729 - 1.888{,}1)^2}{1.888{,}1} + \frac{(728 - 568{,}9)^2}{568{,}9} = 59.883$$

Moreover, we know that under a Chi-square distribution with 1 degree of freedom and a right-tail probability of 0.01, that is, at a significance level of 1%, the critical value is 6.6349. Any value which is smaller than the critical value will lay on the acceptance area, that is, the null hypothesis will not be rejected.

Nonetheless, notice that when we compute the Pearson's Chi-square statistic, we obtain a value of 59.883, which is way larger than 6.6349. Thus, we must reject the null hypothesis of no association between participation in political violence and the presence of droughts. In addition, the p-value equals 1.00668e-14, a value that is way smaller than the significance level of 1%.

Hence, an association between participation in political violence and the presence of droughts has been found. This means that, on average, when droughts were present during growing season in the 37 selected African countries, respondents participated in political violence. Notice that we cannot estimate the magnitude of such event, that is, the extent to which political violence increased when droughts were present. Nonetheless, we do know that such association has very likely existed, as the correlation appears to be significant at a 1% of confidence level.

Conflict Variable and Climate Variables: Logit model

In addition, a regression analysis has been used in order to measure the association between political violence the presence of droughts and floods, controlling for other variables available in the data set and that might also be related to political violence. These are: the age, the gender and the geographical living area of the respondents.

Given the binary nature of our conflict variable, a logit model has been used. The dependent variable of our model, political violence, embraces a broad scope of activities implying illegal acts, and only takes two values, zero and one. Thus, p is defined in a way that it will only range within this interval. That is:

$$p = Prob\{Political\ Violence = 1\} = \frac{e^{\beta_0 + \beta_1 * Drought + \beta_2 * Flood + \beta_3 * Age + \beta_4 * Gender + \beta_5 * Urban + u}}{e^{\beta_0 + \beta_1 * Drought + \beta_2 * Flood + \beta_3 * Age + \beta_4 * Gender + \beta_5 * Urban + u} + 1} \quad (7)$$

Expression (7) can be written, by applying natural logarithms, in terms of the natural logarithm of the odds ratio.

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 * Drought + \beta_2 * Flood + \beta_3 * Age + \beta_4 * Gender + \beta_5 * Urban + u \quad (8)$$

The climate change breeds conflict hypothesis implies the parameter β_1 to be positive, as if the binary variable Drought takes value 1, we would expect the probability of participating in violent activities to increase. In addition, the same reasoning can be applied to the variable drought. That is, climate change breeds conflict hypothesis suggests that the parameter β_2 is to be positive, as if the binary variable Flood takes value 1, we would expect the probability of participating in political violence to increase.

In Table 3, the estimates of the Logit model are shown. The parameters of this model are estimated using the maximum likelihood estimator.

Table 3. Estimates of the Logit model, where the dependent variable is Political Violence

Model 1: Logit, using observations 1-73968

Dependent variable: Political Violence
Standard errors based on Hessian

	Coefficient	*Std. Error*	*z*	*Slope**
Constant	−3.61075	0.0517136	−69.82	
Drought	0.346438	0.0452633	7.654	0.0118025
Flood	−0.171053	0.168502	−1.015	−0.00493187
Age	−0.00712996	0.00135585	−5.259	−0.000221837
Gender	0.361012	0.0417542	8.646	0.0112764
Urban	0.192534	0.0430710	4.470	0.00588202

*Evaluated at the mean
Number of cases 'correctly predicted' = 71511 (96.7%)
f(beta'x) at mean of independent vars = 0.179
Likelihood ratio test: Chi-square(5) = 172.857 [0.0000]

Mean dependent var	0.033217	*S.D. dependent var*	0.179204
McFadden R-squared	0.008017	*Adjusted R-squared*	0.007460
Log-likelihood	−10694.63	*Akaike criterion*	21401.26
Schwarz criterion	21456.53	*Hannan-Quinn*	21418.27

Source: Author's creation. Data: Vestby (2019)

We know that, under the null hypothesis of an asymptotic z-test, z is normally distributed with mean 0 and variance 1. Also, under the null hypothesis, with a two-tailed probability of 0.01, that is, at a significance level of 1%, the critical values are -2.575 and 2.575. Thus, when contrasting this value to the z-value of Table 3, we can see that the variable Drought is statistically significant (7.65>2.57). Under the same reasoning, the variable Flood is not significant (-2.57<-1.015<2.57).

Hence, from Table 3 we can infer that the estimate of parameter β_1 is positive and significant, thus indicating that the presence of drought in a region is positively associated with the probability of participating in political violence

Furthermore, the estimates show that the fact of being a male and of living in rural areas is positively associated to political violence. That is, a man is more likely to be involved in an act of force or violence for political issues than a woman. At the same time, people living in rural areas are positively correlated with political violence. Probably, this fact is due to the difference of opportunities and resources between urban and rural areas, and to the presence of a weak institutional framework in the later.

On the other hand, the age seems to be negatively associated with the participation in violent activities. That is, as the respondent is older, he is less likely to be involved in an illegal act of violence.

5. CONCLUDING REMARKS

Undoubtably, climate change will be a major challenge for humanity in the following decades. Its effects on unmanageable systems, as well as its inherently complex behaviour, make it difficult for economic analysis to properly estimate its costs and benefits. Nonetheless, despite the uncertainty surrounding the issue and the difficulty on predicting human behaviour, it is nearly undisputed among the scientific community that humankind has created this problem by itself.

While it is true that climate change affects, in a larger or a shorter extent, each and every region on Earth, not all countries are able to cope efficiently with such impacts. Developing countries, that largely rely on natural resources and that are characterised by a low and steady economic growth which comes along with a weak institutional framework, do not possess the means nor the knowledge to tackle such a problem. In addition, as their economies are agriculture-based, if climate change results in a lower frequency of precipitations or in heat waves, harvests will be resented. In addition, as economic productivity declines, the nations' output will contract, as well as the availability of basic needs, such as food and water.

Notwithstanding, complexity lies on predicting how societies will react to such global warming stresses, fundamentally in developing countries, as they are not as immune to climate change impacts as wealthy societies. On one hand, Neo-Malthusian theories suggest that, as the availability of basic needs is reduced, population will start to fight over the remaining resources. Thereby, conflict, by means of civil war, rebel movements or crimes, for example, will arise. However, such approach is not fully supported by the empirical evidence, which does not stand on a consensual answer regarding the relationship between climate variability and conflict outcomes.

Indeed, the difficulty of causally relating climate change to conflict relies on confounding issues. Thus, the differences in scientific findings on such relationship derive from the assumptions behind the econometrical method used. Notwithstanding, what is easier to test are the implications of causation. That is, whether there is or there is not an association between conflict outcomes and climate variables.

Likewise, the empirical exercise has proven that, for a sample of over 73.000 respondents of 37 African countries, the presence of droughts seems to be associated with political violence. Moreover, being a male and living in the countryside are also related to this type of conflict. Nonetheless, it seems that, as population gets older, they are less likely to participate in illegal acts.

6. APPENDICES

Appendix-1: Estimating the linear trend of CO_2 emissions, 1900-2014

Model 1: OLS, using observations 1900-2014 (T = 115)

Dependent variable: Logarithm of CO_2 emissions
HAC standard errors[59], bandwidth 3 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	−49.8072	1.25795	−39.59	<0.0001	***
time	0.0265506	0.000638106	41.61	<0.0001	***

Mean dependent var	2.152349	S.D. dependent var	0.897883
Sum squared resid	2.569626	S.E. of regression	0.150798
R-squared	0.972041	Adjusted R-squared	0.971793
F(1, 113)	1731.262	P-value(F)	2.33e-70
Log-likelihood	55.38945	Akaike criterion	−106.7789
Schwarz criterion	−101.2890	Hannan-Quinn	−104.5506
rho	0.935452	Durbin-Watson	0.131062

* indicates significance at the 10 percent level

** indicates significance at the 5 percent level

*** indicates significance at the 1 percent level

Confidence interval of the estimates

t(113, 0.025) = 1.981

Variable	Coefficient	95 confidence interval
constant	-49.8072	(-52.2994, -47.3150)
time	0.0265506	(0.0252864, 0.0278148)

[59] Robust standard errors are used to account for the presence of autocorrelation. Given that we are analyzing a time series data, it is likely to find a strong presence of autocorrelation of the disturbances. Hence, we need to correct the original calculation of the standard errors.

Appendix-2.1: Estimating the seasonality of Mauna Loa records with dummy variables

Model 2: OLS, using observations 1958:03-2018:11 (T = 729)

Dependent variable: Average Interpolated CO_2 Concentrations [60,61]
HAC standard errors[62], bandwidth 6 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
dm1	353.746	3.51859	100.5	<0.0001	***
dm2	354.503	3.51972	100.7	<0.0001	***
dm3	354.740	3.52674	100.6	<0.0001	***
dm4	356.013	3.53790	100.6	<0.0001	***
dm5	356.573	3.54131	100.7	<0.0001	***
dm6	355.998	3.52975	100.9	<0.0001	***
dm7	354.507	3.50939	101.0	<0.0001	***
dm8	352.492	3.50144	100.7	<0.0001	***
dm9	350.926	3.50955	99.99	<0.0001	***
dm10	350.966	3.53274	99.35	<0.0001	***
dm11	352.297	3.55196	99.18	<0.0001	***
dm12	352.679	3.50610	100.6	<0.0001	***

Mean dependent var	353.7872	S.D. dependent var	27.54750
Sum squared resid	549966.0	S.E. of regression	27.69544
R-squared	0.004503	Adjusted R-squared	-0.010770
F(11, 717)	1455.595	P-value(F)	0.000000
Log-likelihood	−3449.561	Akaike criterion	6923.121
Schwarz criterion	6978.221	Hannan-Quinn	6944.381
rho	0.999870	Durbin-Watson	0.000283

* indicates significance at the 10 percent level

** indicates significance at the 5 percent level

*** indicates significance at the 1 percent level

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60 The data is averaged because it is computed with the monthly mean CO_2 mole fraction determined from daily averages. When values are missing, they have been interpolated. That is, they are the result of the sum of the average seasonal cycle value and the trend value for the missing month.

61 Dm accounts for "dummy variable" and the following number represents the month in a chronological order, that is: 1 for January, 2 for February, and so on.

62 Robust standard errors have been used to account for the presence of autocorrelation.

Appendix-2.2: Confidence interval of the dummy variables

Confidence interval of the estimates

t(717, 0.025) = 1.963

Variable	Coefficient	95% confidence interval
Dummy variable for January	353.746	(346.838, 360.654)
Dummy variable for February	354.503	(347.593, 361.413)
Dummy variable for March	354.740	(347.816, 361.664)
Dummy variable for April	356.013	(349.067, 362.959)
Dummy variable for May	356.573	(349.621, 363.526)
Dummy variable for June	355.998	(349.068, 362.928)
Dummy variable for July	354.507	(347.617, 361.396)
Dummy variable for August	352.492	(345.618, 359.367)
Dummy variable for September	350.926	(344.036, 357.816)
Dummy variable for October	350.966	(344.031, 357.902)
Dummy variable for November	352.297	(345.323, 359.270)
Dummy variable for December	352.679	(345.796, 359.563)

Appendix-3: Estimating non-linear trend of emissions 1900-2014

Model 3: OLS, using observations 1958:03-2018:11 (T = 729)

Dependent variable: Average Interpolated CO_2 emissions
HAC standard errors[63], bandwidth 6 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	314.394	0.341117	921.7	<0.0001	***
time	0.0651917	0.00238171	27.37	<0.0001	***
time squared	8.78692e-05	3.25005e-06	27.04	<0.0001	***

Mean dependent var	353.7872	S.D. dependent var	27.54750
Sum squared resid	3563.720	S.E. of regression	2.215560
R-squared	0.993549	Adjusted R-squared	0.993532
F(2, 726)	26505.41	P-value(F)	0.000000
Log-likelihood	−1612.826	Akaike criterion	3231.653
Schwarz criterion	3245.428	Hannan-Quinn	3236.967
rho	0.845831	Durbin-Watson	0.307969

* indicates significance at the 10 percent level

** indicates significance at the 5 percent level

*** indicates significance at the 1 percent level

63 Robust standard errors have been used to account for the presence of autocorrelation.

Appendix-4: Estimating the trend of the World's carbon intensity indicator

<u>Model 4: OLS, using observations 1960-2014 (T = 55)</u>

Dependent variable: World's carbon intensity indicator
HAC standard errors[64], bandwidth 2 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	2.80415	0.0532305	52.68	<0.0001	***
time	−0.00724532	0.00169522	−4.274	<0.0001	***

Mean dependent var	2.601282	S.D. dependent var	0.155995
Sum squared resid	0.586491	S.E. of regression	0.105194
R-squared	0.553682	Adjusted R-squared	0.545261
F(1, 53)	18.26673	P-value(F)	0.000080
Log-likelihood	46.83398	Akaike criterion	−89.66796
Schwarz criterion	−85.65330	Hannan-Quinn	−88.11546
rho	0.944902	Durbin-Watson	0.106730

* indicates significance at the 10 percent level

** indicates significance at the 5 percent level

*** indicates significance at the 1 percent level

64 Robust standard errors have been used to account for the presence of autocorrelation.

Appendix-5: Estimating the effect of the GDP per capita on the CO_2 emissions per capita, 2014

Model 1: OLS, using observations 1-217 (n = 188)

Missing or incomplete observations dropped: 29
Dependent variable: Logarithm of Emissions per capita (2014)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−9.90233	0.354540	−27.93	<0.0001	***
ln(GDP per capita)	1.14391	0.0378987	30.18	<0.0001	***

Mean dependent var	0.712530	S.D. dependent var	1.492389
Sum squared resid	70.61564	S.E. of regression	0.616161
R-squared	0.830451	Adjusted R-squared	0.829540
F(1, 186)	911.0287	P-value(F)	1.35e-73
Log-likelihood	−174.7165	Akaike criterion	353.4331
Schwarz criterion	359.9060	Hannan-Quinn	356.0557

* indicates significance at the 10 percent level

** indicates significance at the 5 percent level

*** indicates significance at the 1 percent level

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