How close are we to extinction?

How will global CO_2 emissions change in the future?

Mateusz Kazimierczak

S5ES, European school of Alicante

Contents

Abstract

The purpose of this project is to research the most important factors contributing to CO_2 emissions and develop an intuitive online tool, to analyze the effects of these factors. The toolkit may be used by policymakers to develop adequate policies to tackle the impact of climate change.

To develop the NetLogo tool, we chose an array of factors to see how they affect the global emissions, such as population growth, emissions from personal transport, emissions from energy production and artificial CO_2 captures. These factors appear to be the most important sources of CO_2, while also having a considerable amount of data available. In the second step, we analyzed the historical trends in those variables. Then we developed the tool in NetLogo[1]. The next step consisted of validating the model. The results showed that the data from our simulation matched the general trend of the real data. Finally, with the help of the tool, after publishing the program online we conducted research to predict how will the CO_2 emissions change in the future based on the changes in the factors stated above. It enabled us to analyze what steps should we take to fight climate change as efficiently as possible.

After completing our research, we found that we would reach a 2 degrees C threshold, which is the temperature limit discussed in the Paris agreement in 2036 in the best scenario, and 2029 in the worst scenario.

[1] NetLogo is a programmable multi-agent modeling software

Introduction:

Global warming is a very controversial topic today, with evidence showing that we will soon reach a point of no return. Many argue that we should do everything in our hands to tackle this problem, while others do not see much of a threat. In the present report, we will focus on CO_2 emissions as a factor mostly contributing to global warming. CO_2 is the most emitted greenhouse gas in the world (Our World in Data. 2017). Even though this gas does not have a very big global warming potential (Greenhouse Gas Protocol), the emissions of this gas are rising considerably faster than the other gases. Overall, CO_2 has caused more warming than any other gas, and this gas stays in the atmosphere considerably longer than other gases (Union of Concerned Scientists. 2017).

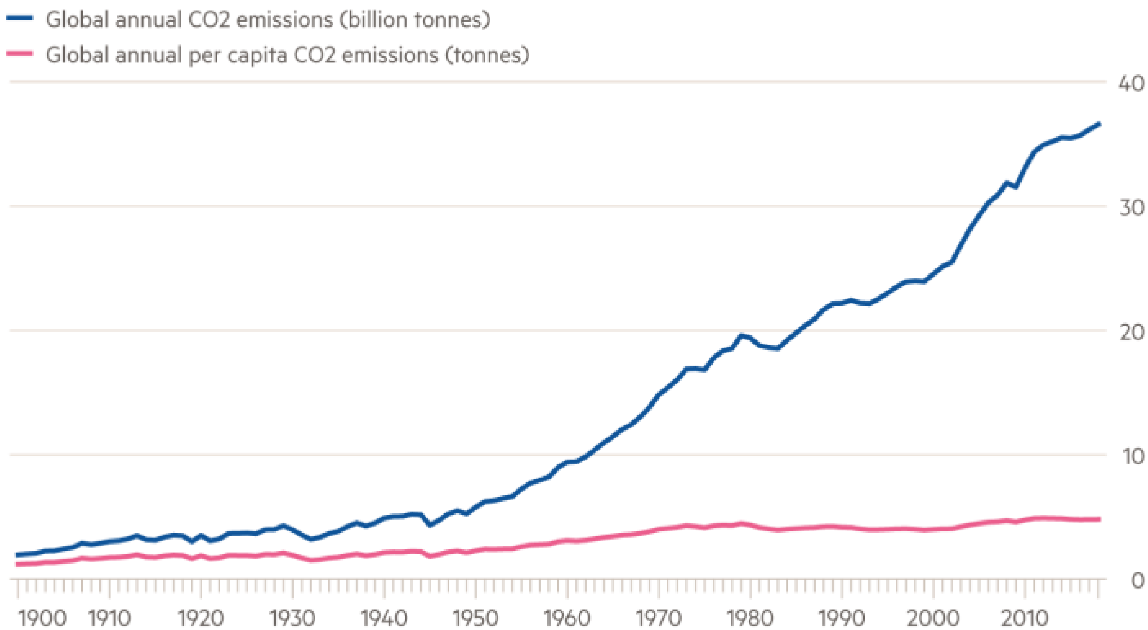
Aim of our project

The main aim of this project is to predict how CO_2 emissions will evolve in the future and investigate what factors most affect the emissions. These predictions can help governments decide what steps are the most efficient to take in order to fight climate change. As we will see later, some policy changes do not make a big difference in the emission levels, while other are much more significant. We have developed an original and easy to use NetLogo tool available online. This tool will help to analyze the different scenarios, and at the same time, it will help raise concern and knowledge about global warming among the wider public.

Outlook on the current situation

As we can see in Figure 1 below. The CO_2 emissions have risen exponentially since the industrial era, and the trend does not appear to change in the near future. This high growth in CO_2 emissions has contributed to a rise in temperature. On the other hand, CO_2 emissions per capita did not appear to change a lot during the century, which suggests the population growth is most likely associated with the global temperature increase and CO_2 emissions, resulting in abnormal rise in CO_2 emissions.

FIGURE 1, THE EVOLUTION OF CO_2 EMISSIONS SINCE 1900 (FINANCIAL TIMES. 18 FEBRUARY 2020. © THE FINANCIAL TIMES LTD.)



We are seeing an increasing number of pieces of evidence from many reliable sources, that climate change is a big challenge for today's society, and if we do not act fast, the Earth will change forever. For example, NASA scientists claim, that if we do not stop climate change, among other things we will have more droughts and heatwaves, hurricanes will become stronger and more intense, sea level will rise 1-4 feet (0.3 – 1.2 meters) by 2100 and the Arctic is likely to become ice-free. Despite this evidence, not all decision-makers are supporting the need to act. Some politicians do not want to give up economic growth for a more environmentally friendly society. However, there are other people like Greta Thunberg who inspire change and raise a concern about climate change.

> ***Taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time.***
> Intergovernmental Panel on Climate Change

Actions taken so far

The international community has tried to mitigate climate change for many decades now. The first international conference with climate change as the main topic was held in Geneva in 1979.

Since then other international agreements have been adopted to tackle this acute problem, here are some of the most substantial:

Montreal Protocol:

The 1987 Montreal Protocol encouraged 196 countries to reduce the emission of ozone-damaging gases. This is relevant to climate change because ozone-damaging gases also contribute to global warming. The Montreal Protocol is seen as an example of the effectiveness of coordinated international efforts to mitigate important threats to the environment. As a result of those accords, the ozone hole has been reduced almost entirely by today.

Kyoto Protocol:

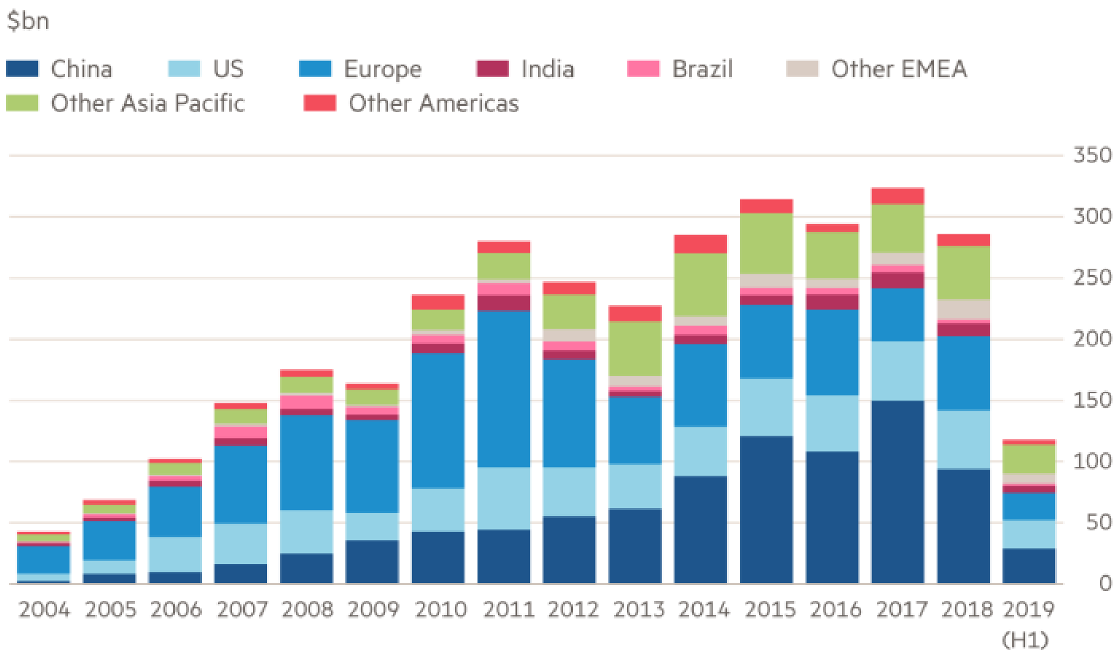
Encourages 192 parties to reduce their greenhouse gas emissions. Meetings are held every year, and the parties discuss how to further reduce the GHG (greenhouse gases) emission. This agreement entered into force in 2005

Paris agreement:

The Paris Agreement was agreed in 2015 by 175 parties. The agreement aims to keep global warming to 'well below' 2 °C and try to limit the temperature increase to 1.5 °C. Meetings are held every 5 years to assess international progress and set further goals. The United States under the presidency of Donald Trump is withdrawing from this agreement.

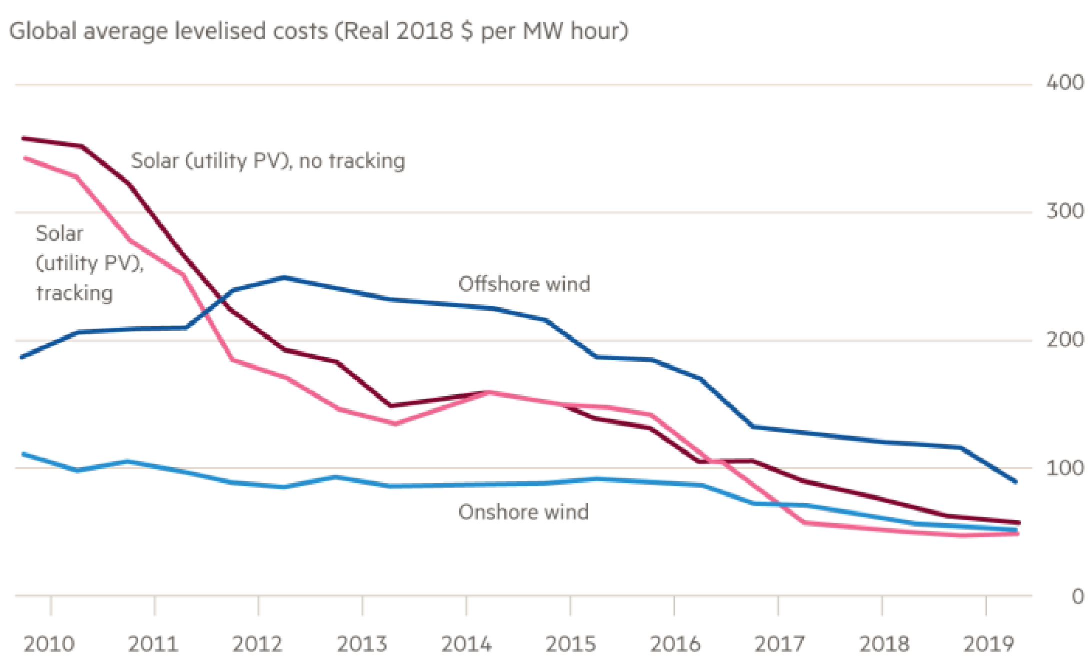
Despite all these international efforts, the interest of governments in clean and sustainable energy sources is falling. This can be seen in Figure 2 below. After a sustainable increase in investment over the first decade of the 21st century, we have seen a severe fall in this type of investments last year. During our investigation, we will assess whether investment in clean energy should be on the rise, or if it is not worth investing money in.

FIGURE 2, DECLINE OF INVESTMENT IN CLEAN ENERGY (FINANCIAL TIMES. 25 NOVEMBER 2019. © THE FINANCIAL TIMES LTD.)



It is also worth noting, that the price of renewable energy is falling considerably, which makes it easier than ever before to implement it, this can be seen in Figure 3 below.

FIGURE 3, THE FALLING COSTS OF RENEWABLE ENERGY (FINANCIAL TIMES. 18 FEBRUARY 2020. © THE FINANCIAL TIMES LTD.)



This said, our investigation will not focus on the political, social nor economic aspects of climate change, but will rather look at the effectiveness of various measures of mitigation of CO_2 emissions for reducing the global warming trend.

What has been found so far concerning this topic

As we have already seen, climate change is a serious topic today. Because of this fact, there is plenty of predictions and investigation about it. Among all the things that have been done concerning this topic, we can find numerous reports making predictions for the future evolution of CO_2 emissions, and even proposing policies, which could help halt the effect of climate change. For example, OECD makes projections and discusses possible political solutions in the document "OECD Environmental Outlook to 2050" (OECD. 2011). A good example of what has been done so far in terms of interactive prediction concerning the future of climate change is the "En-ROADS" simulator (Climate Interactive), which similarly to our project predicts CO_2 emissions and temperature increases.

Method

Introduction to NetLogo and our model

We have developed a NetLogo tool. As the official NetLogo website describes: "NetLogo is a multi-agent programmable modelling environment. It is used by many tens of thousands of students, teachers and researchers worldwide" (NetLogo. 1999). In our case, we will be using this tool to simulate the evolution of different variables which affect the total CO_2 emissions, We have also allowed the user to change the parameters of the model manually and therefore enabled him to see the effect of those changes on future CO_2 concentrations and emissions. The model automatically displays changes in CO_2 atmospheric concentration, CO_2 emissions, population, and many other variables in each cycle, which makes data visualization easy.

Variables in use in our simulation

To develop the NetLogo tool, we have selected various variables which predict future CO_2 emissions.

Dependent variables:

- CO_2 atmospheric concentration in ppm
- CO_2 emissions

Independent variables:

- Emissions from personal transport
- CO_2 captures
- Scenario (affecting the population growth, and growth in CO_2 per capita)
- Population growth
- Emissions from energy production.

We chose these variables because they have a significant impact on total CO_2 emissions, additionally, these variables have plenty of data publicly available (Hannah Ritchie and Max Roser. Our World in Data. 2017).

FIGURE 4, DIAGRAM OF THE MODEL

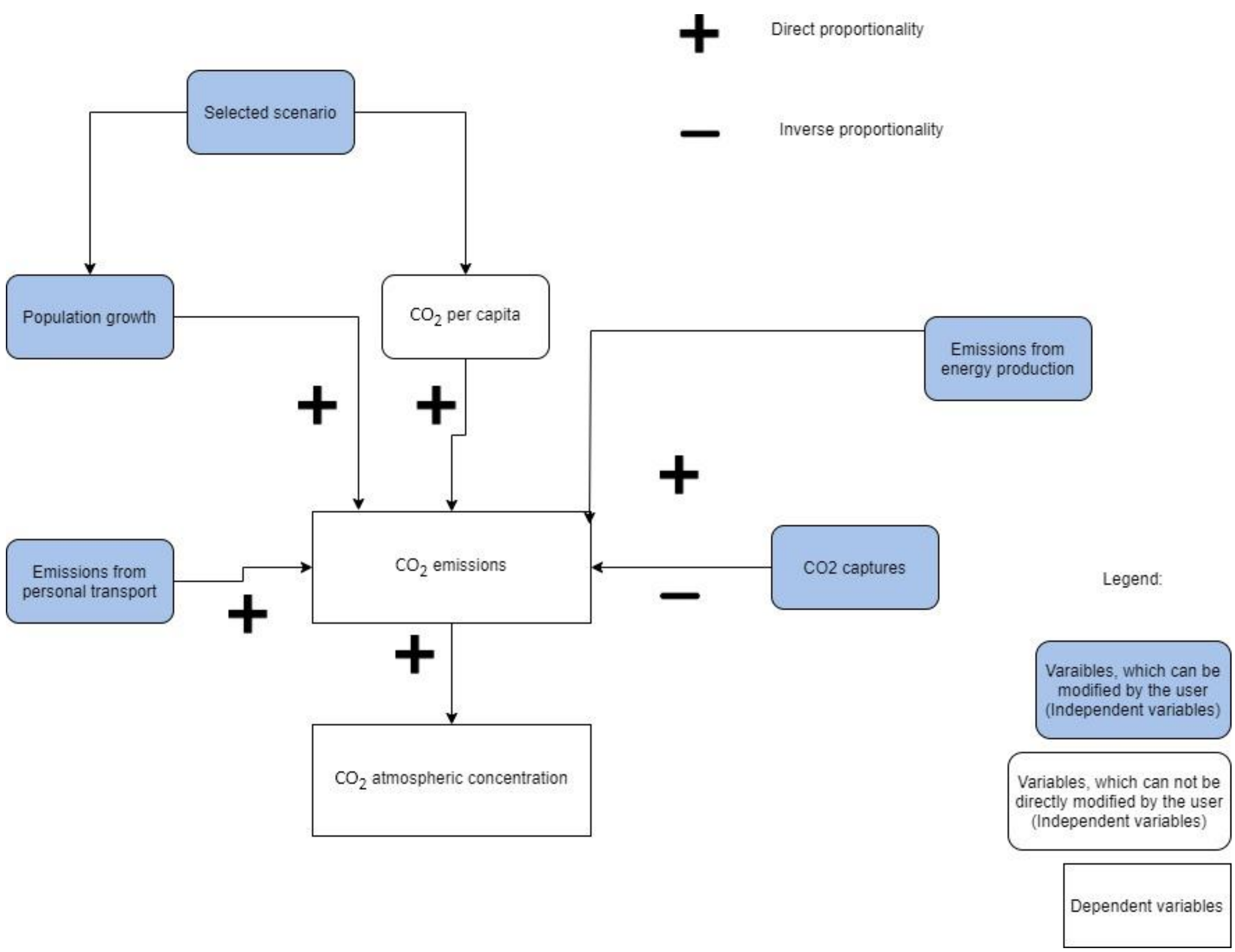


Figure 4 above shows the variables, which affect the final CO_2 atmospheric concentration. These are the variables that the user of the tool will be able to easily modify, to see how the dependent variables will be affected by changes in the independent variables. In the present report, we will analyze the effects of some changes in the independent variables. The diagram also shows what relations each independent variable has with the dependent variables, and which variables can be modified by the user directly from the interface.

Scenarios:

They reflect the changes in population growth rate and CO_2 per capita. Depending on the Scenario chosen by the user, the annual changes in the population growth and CO_2 emissions may be lower or higher.

TABLE 1, THE DIFFERENT SCENARIOS IMPLEMENTED IN OUR MODEL

	CO_2 per capita equation	Population growth rate equation	Base year
Best scenario	polynomial	lineal	2000
Good scenario	lineal	lineal	2012
Average scenario	lineal	exponential	1996
Worst scenario	polynomial	exponential	1990

The 2 sets of graphs below show the evolution of the CO_2 emissions per capita, and the Population growth depending on the scenario selected. On the graphs below, we can see the equation, which is present in the model, to predict the future values of these variables. The blue dots represent the real data in each year, which is taken into account when calculating the equation which best fits the trend.

these scenarios are classified as best, good, average and worst according to their output in the short term on the CO_2 atmospheric concentration. In order to classify them we have looked in how much time does each scenario reach the 450-ppm threshold.

Different scenarios in CO_2 per capita

Figure 5, Trend of CO_2 per capita in the good scenario

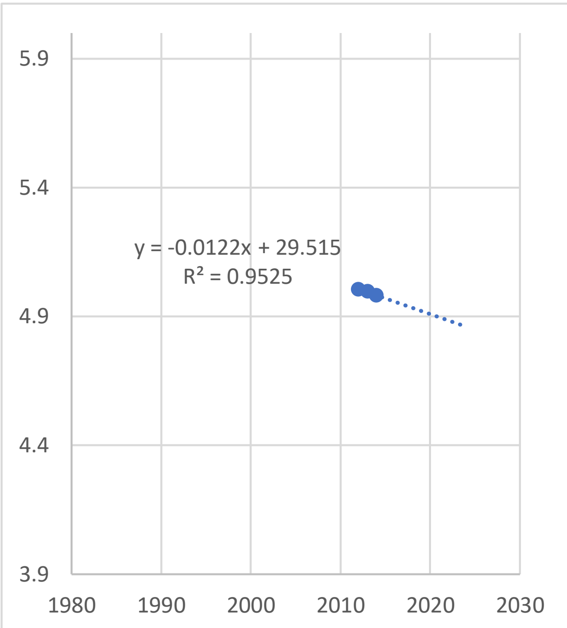


Figure 6, Trend of CO_2 per capita in the best scenario

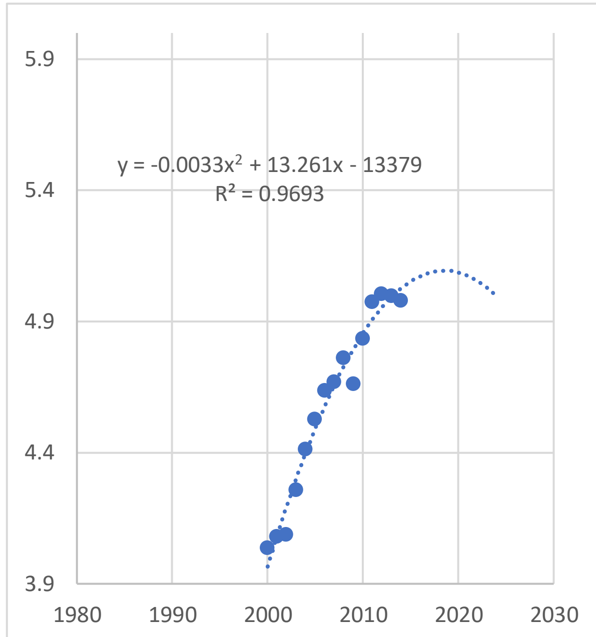


Figure 7, Trend of CO_2 per capita in the average scenario

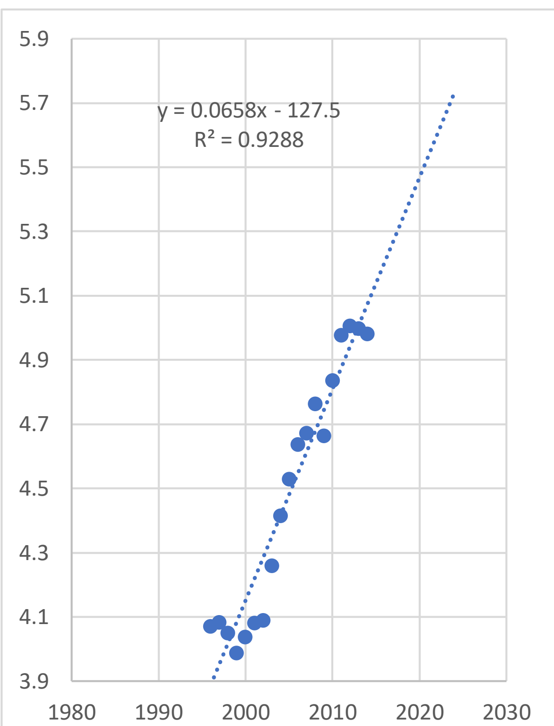
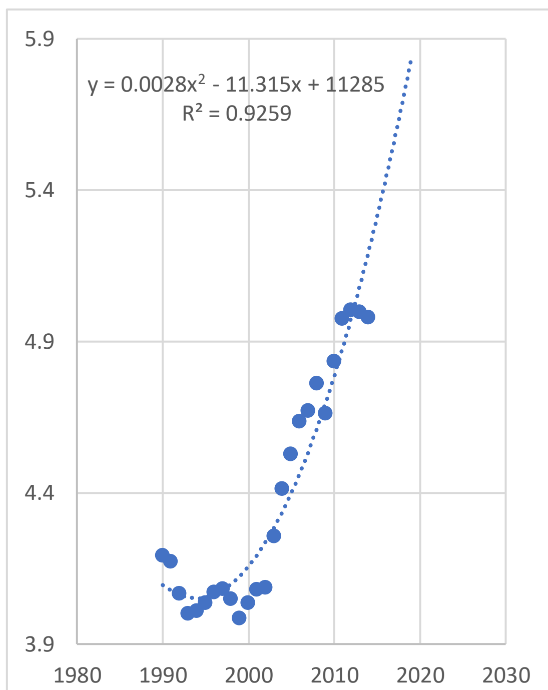


Figure 8, Trend of CO_2 per capita in the worst scenario



Different scenarios in the population growth rate

FIGURE 9, TREND OF POPULATION GROWTH RATE IN THE GOOD SCENARIO

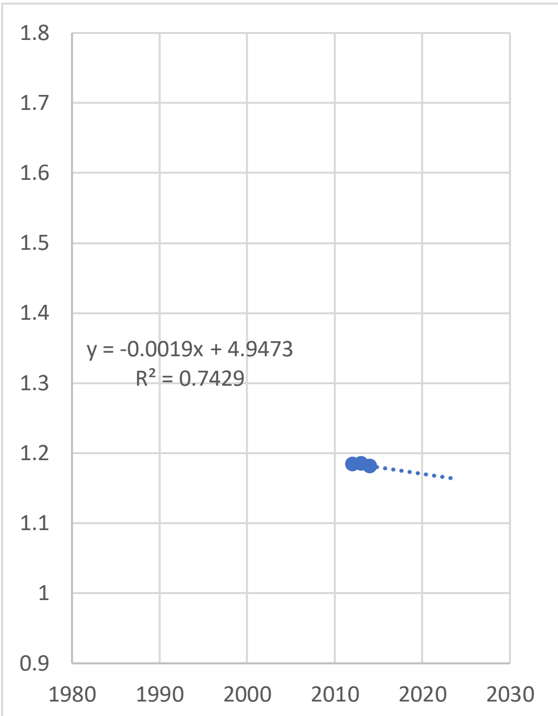


FIGURE 10, TREND OF POPULATION GROWTH RATE IN THE BEST SCENARIO

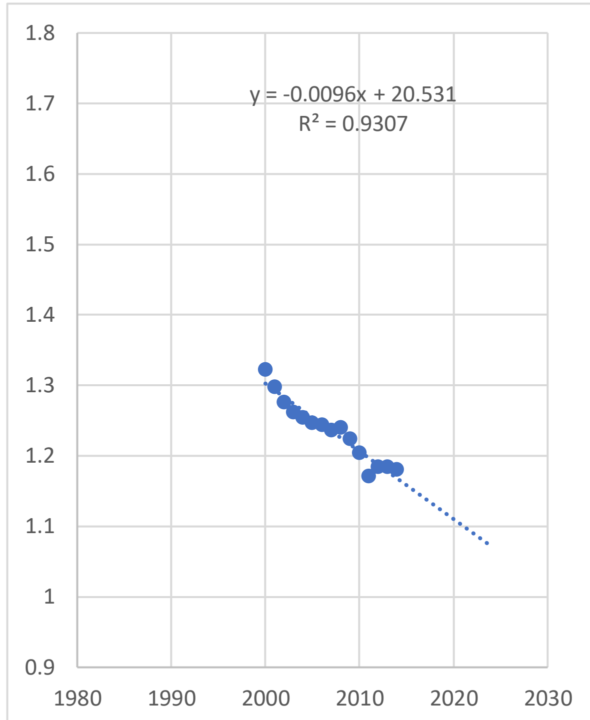


FIGURE 11, TREND OF CO_2 PER CAPITA IN THE AVERAGE SCENARIO

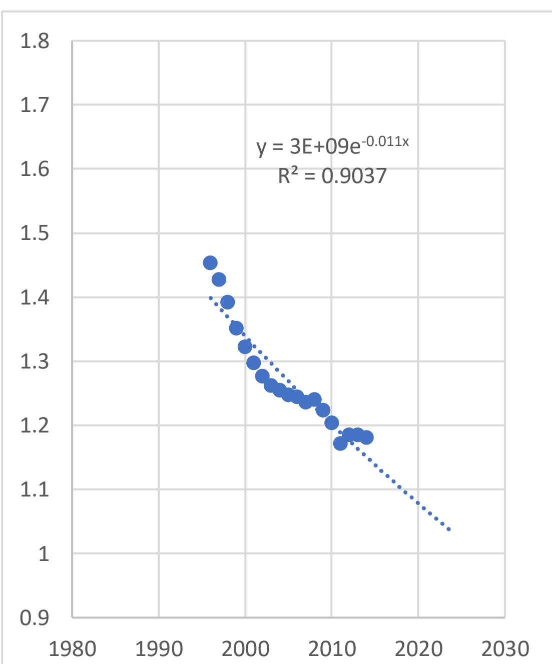


FIGURE 12, TREND OF CO_2 PER CAPITA IN THE WORST SCENARIO

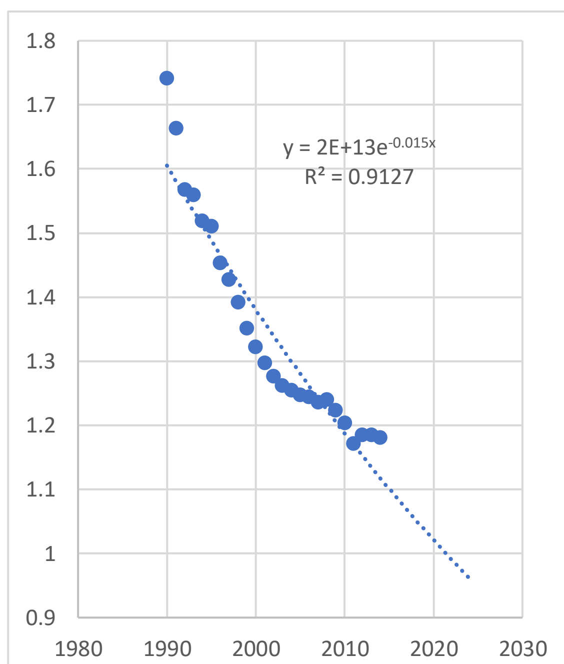


FIGURE 13, THE GENERAL TREND IN POPULATION GROWTH RATE

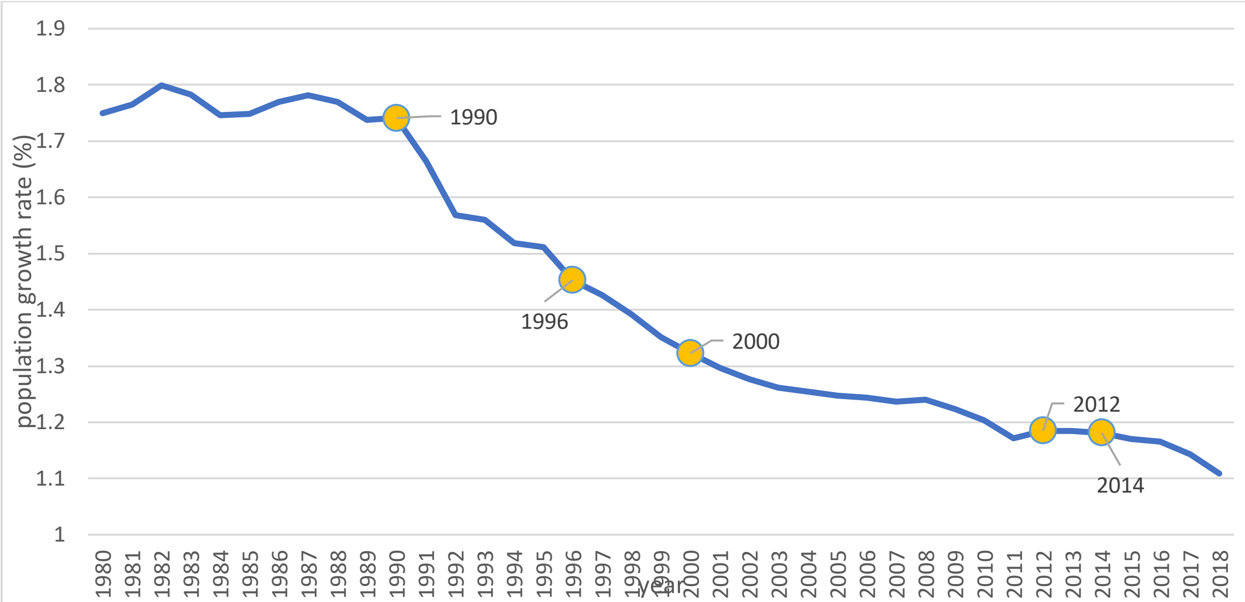


FIGURE 14, THE GENERAL TREND IN CO2 PER CAPITA EMISSIONS

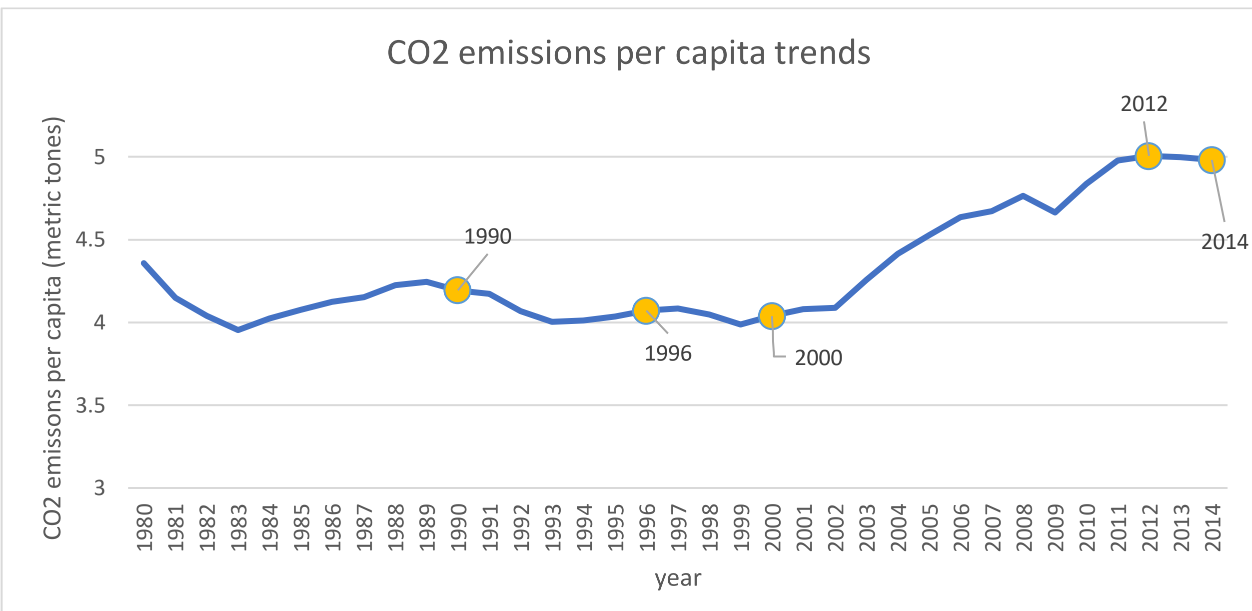


Figure 13 and Figure 14 show the general trends in CO_2 emissions per capital, and population growth rates. Additionally, we can see highlighted years, which have certain importance in our model (2014 is the year, in which the simulation starts, and all the other years are the base years for some of the scenario calculations).

If the user rather prefers to set his own rates of population growth and CO_2 emissions per capita growth, he can also do so in the custom growth rates section in the interface, where he may enter a fixed percentage growth for both CO_2 per capita and population growth rate.

The initial values in the model are based on values of various factors as of 2014, as this year was the latest point in time, for which we have found sufficient data on all the variables being used:

- Population growth rate: the percentage growth of population in the current cycle, Set at 1.17% (Worldometer).
- CO_2-per-capita: the average amount of CO_2 emitted per person in the Earth, set at 4.981 tones per person per year (The World Bank Data).
- Population: population in the current year, base year with value of 7256000000 (The World Bank Data).
- Year: indication to the current year, set at 2014.
- Constants:
  - tones-per-ppm-in-atmosphere: 7800000000 (Skeptical Science). The calculation to get this number and the sources are explained later in more detail.

CO_2 per capita consists of the following components:

- CO_2 emissions from personal transport per capita: 8.18% of the total CO_2 per capita emissions (Own calculations based on data from Our World in Data, and the International Energy Agency).
- CO_2 emissions from energy production per capita: 49.04% of the total CO_2 emissions per capita (Our World in Data).
- other sources of CO_2 emissions per capita: 42.78% of the total CO_2 emissions per capita, this is the reminder of total CO_2 emissions per capita after deducting CO_2 emissions per capita from personal transport and CO_2 emissions per capita from energy production. The CO_2 emissions per capita are divided into 3 components in order to facilitate the functionality of sliders.

Model parameters set by the user:

Population growth rates multiplier (slider): By setting the slider the user can modify the values associated with built-in scenarios. Population growth rate and CO_2 per capita are adjusted using the following equation:

$$y_t = f(t) * m$$

Where y_t is the population growth rate or CO_2 emissions per capita in the year t, f(t) is the function used to predict the value of y, taking the year as a parameter (this is the function which is displayed in each graph representing the calculation of the scenarios, starting on page11), m is a multiplier set by the user through the slider (only for population growth).

Emissions from personal transport multiplier (slider): This value multiplies the CO_2 emissions from personal transport per capita. Total CO_2 emissions per capita from personal transport are calculated in the following way:

$$y_t = e_t * 0.0818 * m$$

Where y_t is the CO_2 emissions from personal transport per capita in year t, e_t is the total CO_2 emissions per capita, m is the value of the multiplying slider. The value 0.0818 is the proportion of emission from transport relative to the total emissions multiplied by the proportion of personal transport relative to the emissions from transport.

Emissions from energy production per capita (slider): This value multiplies the CO_2 emissions from energy production per capita. Total CO_2 emissions per capita from energy production are calculated in the following way:

$$y_t = e_t * 0.4904 * m$$

Where y_t is the CO_2 emissions from energy production per capita in year t, e_t is the total CO_2 emissions per capita, m is the value of the multiplying slider. The value 0.4904 is the proportion of emission from energy production relative to the total emissions.

CO_2 captures (slider): This slider is used to calculate the atmospheric CO_2 in each year (the tones of CO_2 which are present in the atmosphere. Atmospheric CO_2 (tones of CO2 present in the atmosphere in a certain year) is calculated in the following way:

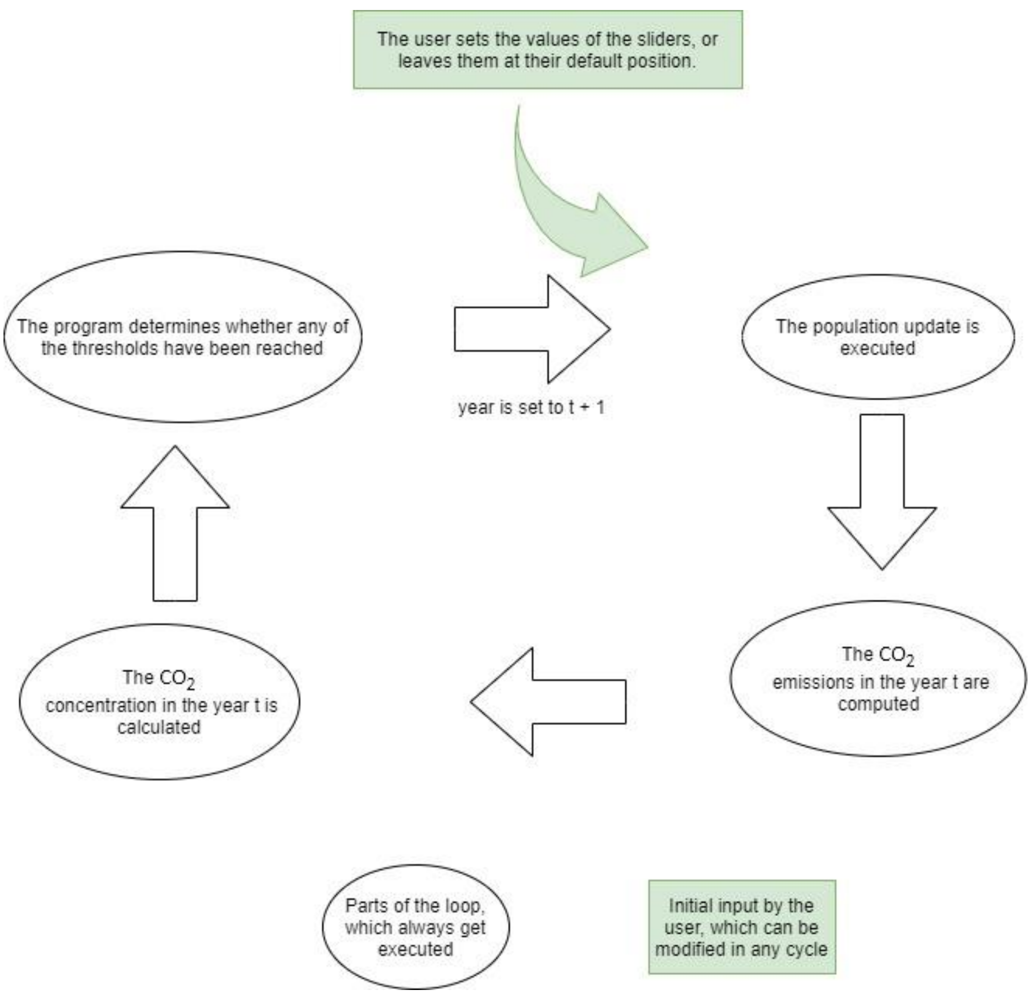
$$y_t = y_{t-1} + e - b * 0.55 - e * c/100$$

Where y_t is the atmospheric CO_2 in the current year, y_{t-1} is the atmospheric CO_2 in the previous year, e is the total CO_2 emissions from the current year, b is the total CO_2 emissions in the base year, in our case 2014 (this value is multiplied by 0.55, and subtracted from the current year emissions, because roughly 55% of CO_2 emissions get absorbed by the Earth, through natural sinks) (Skeptical Science), c is the percentage value of CO_2 captures. After this step, the CO_2 concentration in year t is calculated by the following formula:

$$y_t = \frac{a}{7800000000}$$

Where y_t is the atmospheric concentration of CO_2 in ppm, a is the total CO_2 atmospheric mass (as calculated in the step above).

FIGURE 15, SCHEMA OF THE MODEL



In Figure 15 above we can see what processes are run within each cycle of the model. The user can change the values of the sliders and other inputs whenever he pleases. The new values will be considered automatically. First, the population is computed, as we need the value of the population in year t to calculate CO_2 emissions, next we calculate the emissions in year t, as we will be using this value to calculate the CO_2 concentration, and finally, the CO_2 atmospheric concentration is calculated. The model updates the value of the year to y + 1, and the loop is started again.

Cycles of our model

As seen in Figure 15 above the simulation runs in cycles, each cycle representing a year. As part of each cycle, the following actions are executed in the following order:

- Model setup (this action is only run once, at the start of the model):
    - In this step, the critical constants are given a value, and the year is adjusted to 2014.
- Population-update
    - This step updates the population growth rate based on the selected scenario and the slider and applies it to the total population.
- CO_2 emissions calculation
    - Emissions from different sources are calculated, and total CO_2 emissions are computed based on the CO_2 per capita level, and the total population in year t
- CO_2 concentration calculation
    - The CO_2 atmospheric concentration is calculated based on CO_2 emissions.
- Threshold update
    - In this step, the program checks, whether the CO_2 concentration has reached a certain critical level, and if so, it displays the relevant message.

Values of variables implemented in the model

When calculating the Scenario functions, we considered a certain period of real data: [t, 2014]. When choosing year t for each trend we also made sure that those years have political, social, or scientific importance. The following years are the base years for the scenarios in our model (New Scientist. 2006):

- 2012: This year is the hottest year on record in the US. This event could have shown, that action must be taken to halt the increase in temperature.
- 2000: The Intergovernmental Panel on Climate Change reassess the climate change situation and warns that the world could warm up to 6 degrees C within a century.

- 1996: In this year the second meeting of the Climate Change Convention, where the US agrees for the first time to meet emissions targets.
- 1990: The first report of the IPCC finds that the planet atmosphere temperature increased by 0.5°C in the past century. It also warned, that only strong measures would be able to halt climate change.

FIGURE 16, EFFECT OF SELECTING DIFFERENT SCENARIOS ON CO_2 ATMOSPHERIC CONCENTRATION

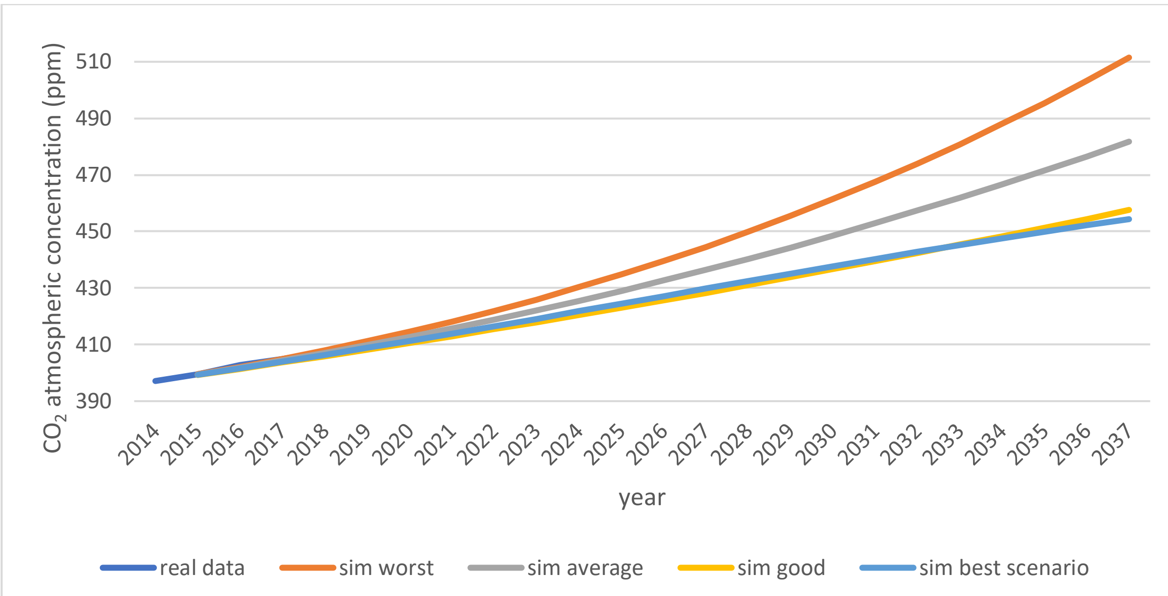


Figure 16 above shows how the different scenarios which can be chosen inside the model affecting the ppm concentration of CO_2.

As we have discussed before these scenarios are classified as best, good, average and worst according to their output in the short term on the CO_2 atmospheric concentration, as presented in Figure 16

When conducting our research, apart from focusing how do changes in different variables affect the CO_2 concentrations, we also look at how much time it would take us to reach a certain critical CO_2 atmospheric concentration levels depending on model configuration. Here are the CO_2 concentration thresholds we considered important in our Model:

- 450 ppm: this level of CO_2 in the atmosphere would lead to an increase in temperature of 2 degrees Celsius according to scientific American (Scientific American. 2011). The main aim of the

Paris agreement was to keep temperature increase due to climate change below 2 degrees Celsius.

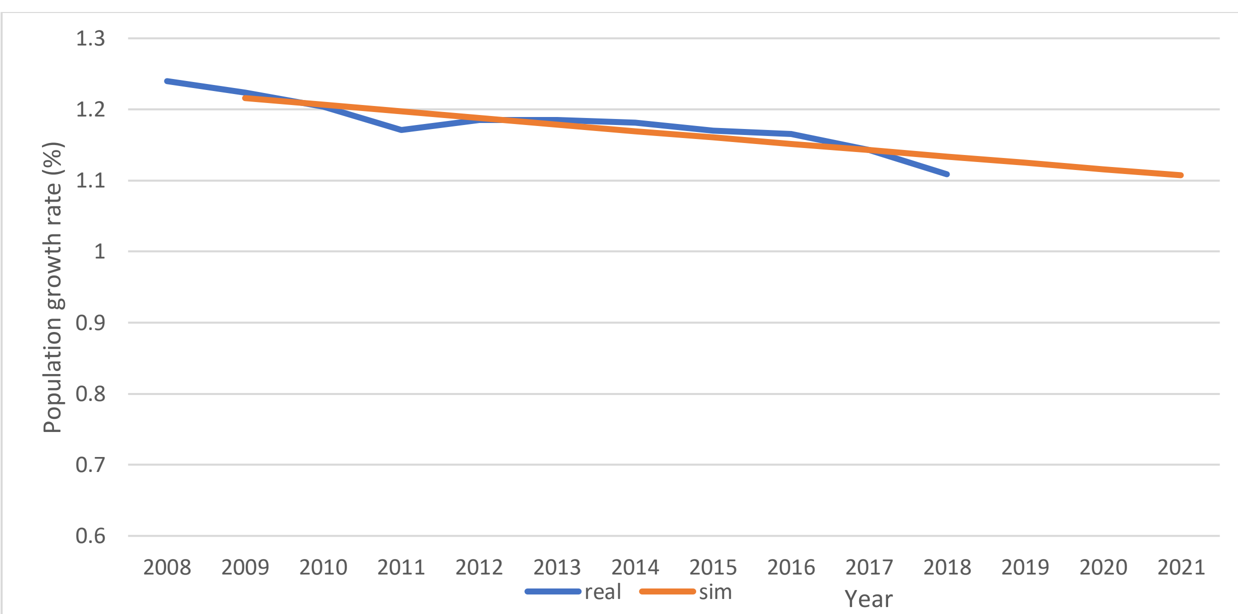
- 800 ppm: According to CO_2 Earth (CO_2 Earth), this level of CO_2 would lead to an increase in temperature of 4 degrees Celsius. With this rise in temperature, it would become significantly more difficult for the world to grow food (Brad Plumer. 2015).
- 40000ppm: According to the FSIS Environmental Safety and Health Group (FSIS Environmental Safety and Health Group), this CO_2 concentration is Immediately Dangerous to Life or Health.

Verification of the model:

To verify that the model can successfully predict CO_2 emissions changes in the future, we developed a verification instance of the model. The only variables we changed in this verification model is the average yearly change in growth rate and the average yearly change in CO_2 emissions per capita. This model's base year is 2008, this gives us a period from 2009 to present for comparing the data produced by the simulation, and real data.

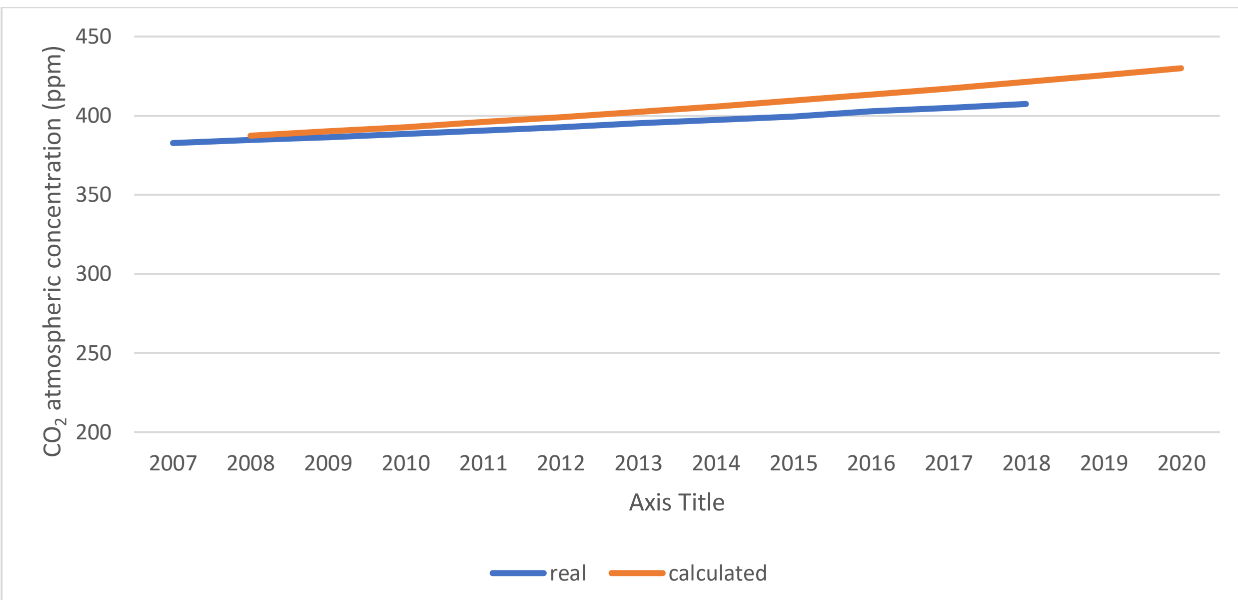
In Figure 17 below we can see a graph showing the real and model generated growth rate. We can see that the model produces a slightly different outcome to the real data, but generally, it achieves to match the real trend. The blue line shows the real population growth rate, which was calculated from the absolute population. The orange line shows the population growth rate generated by the model following the average scenario.

FIGURE 17, REAL AND MODEL GENERATED GROWTH RATE



In Figure 18 below we can see the parts per million of atmospheric concentration. This is a more refined piece of data, where many variables come into play. Despite its complexity, we can see that the simulation was accurate in predicting the general trend of the ppm levels in the past. The blue line once again shows the real data, which was collected from NOAA (National Oceanic and Atmospheric Administration), the data shows globally averaged marine surface annual mean ppm concentration. The orange line shows the data generated by the simulation with an average scenario. We also see that the simulation is accurate while predicting the future ppm levels (notice that the scale is adjusted, so the difference is more noticeable). The small difference between the real data and the predicted data could cause by the fact that during the 2008 to 2018 period the yearly increase in CO_2 emissions per capita is slowing down, but we can see that the simulation achieves to predict the overall trend of the real data.

FIGURE 18, REAL AND SIM PPM ATMOSPHERIC CONCENTRATION LEVELS OF CO_2



Results:

Web Model:

The final NetLogo model can be found under the following link: https://mateusz-alicante.github.io/CO2-Web/

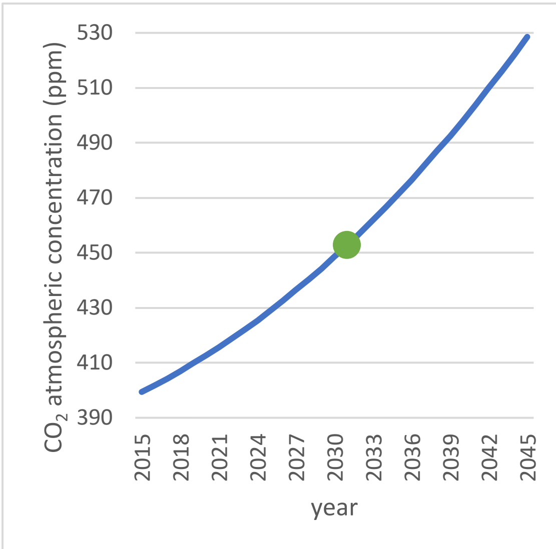
Results of the investigation based on the model:

SET 1, MODEL RESULTS WITH 450 PPM AS A THRESHOLD

In this set of results, we were comparing different scenarios of CO_2 concentration, with the 450ppm threshold, which would mean a 2 degrees C increase in Temperatures, discussed in the Paris agreement. Below each graph the year in which each series of data reaches the threshold, in this case 450 ppm, is presented.

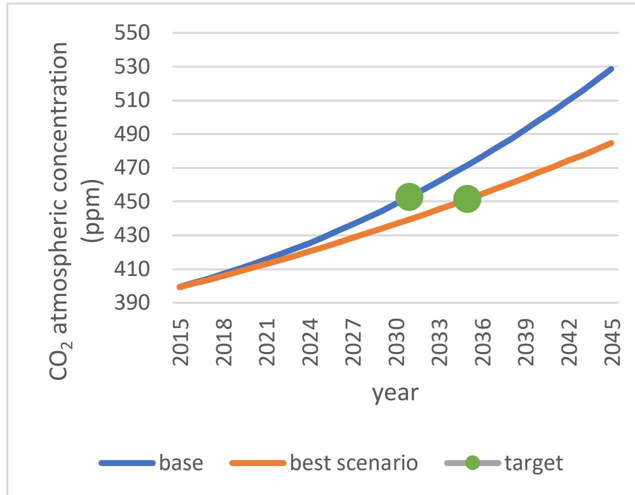
- In Figure 19 we simply look at the base scenario, with the following configuration: the scenario is set to average and there is no modification to the multipliers (sliders).
- In Figure 20 we can see the effect the best scenario has on the CO_2 concentrations relative to the base scenario.
- In Figure 21 we can see the effect the worst scenario has on the CO_2 concentrations relative to the base scenario.
- In Figure 22 we can see the effect of a complete shift to electric cars on CO_2 atmospheric concentration (this takes into account the entire lifetime of both types of cars, including production).
- In Figure 23 we can see how would a 50% fewer emissions from energy production scenario affect the CO_2 concentration.
- In Figure 24 we can see the effect of a 50% less population growth on CO_2 atmospheric concentration.
- In Figure 25 we can see the effect of a 25% CO_2 captures scenario.
- In Figure 26 we can see the effect a good scenario in the model has on CO_2 atmospheric concentration.
- In Figure 27 we can see the effect of a combination of various crucial modifications to different variables on the CO_2 atmospheric concentration following the best possible scenario: 50% lower emissions from energy production. 50% lower emissions from personal transport, which would be mean an absolute shift to electric cars.
- In Figure 28 we see various scenarios in the same graph.

FIGURE 19, BASE SCENARIO CO_2 ATMOSPHERIC CONCENTRATION



Base series target: 2031

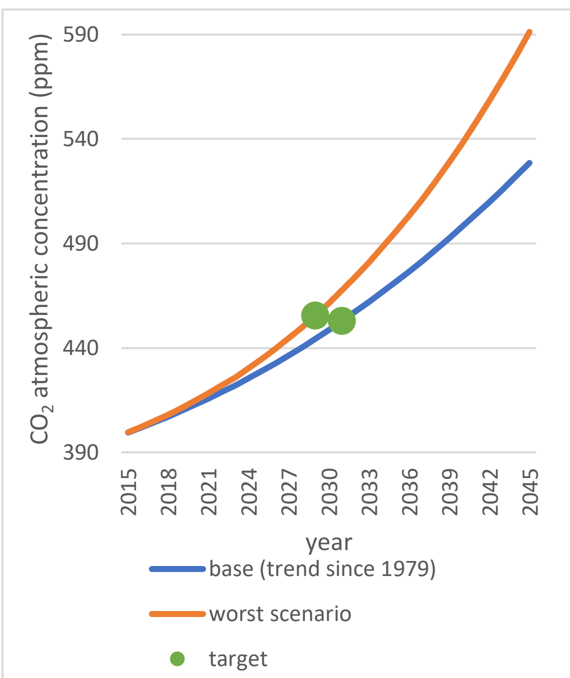
FIGURE 20, EFFECT OF THE BEST SCENARIO IN CO_2 ATMOSPHERIC CONCENTRATION



Base series target: 2031

Good scenario target: 2035

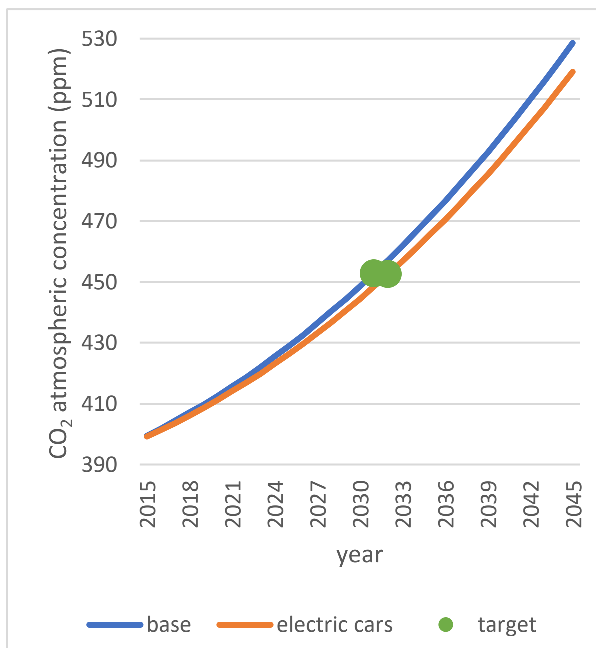
FIGURE 21, EFFECT OF THE WORST SCENARIO ON CO_2 ATMOSPHERIC CONCENTRATIONS



Base series target: 2031

Worst scenario series target: 2029

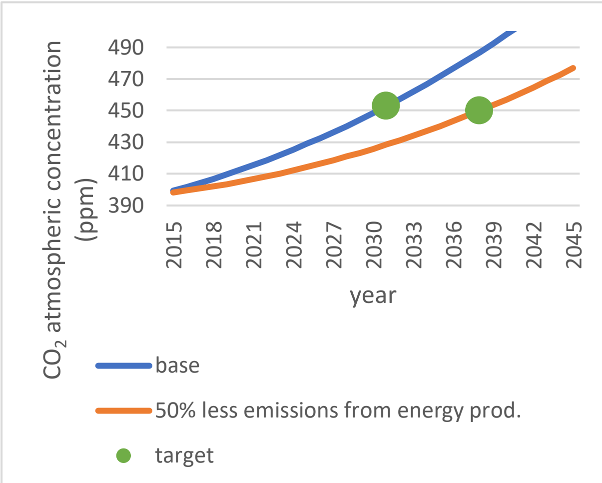
FIGURE 22, EFFECT OF A SHIFT TO ELECTRIC CARS ON CO_2 ATMOSPHERIC CONCENTRATION



Base series target: 2031

Electric cars series target: 2032

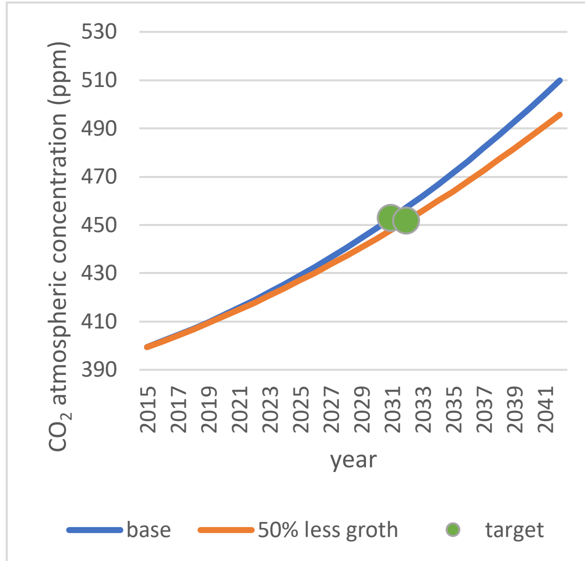
FIGURE 23, THE EFFECT OF A DECREASE IN EMISSIONS FROM ENERGY PRODUCTION IN CO_2 ATMOSPHERIC CONCENTRATION



Base series target: 2031

50% less emissions from energy prod. series target: 2038

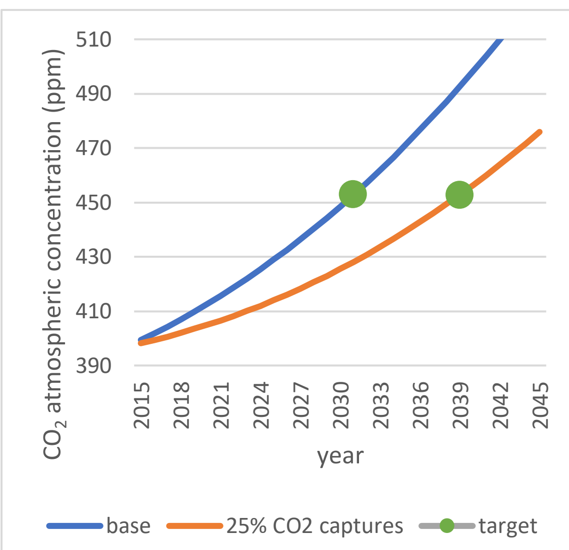
FIGURE 24, THE EFFECT OF A DECREASE IN POPULATION GROWTH IN CO_2 ATMOSPHERIC CONCENTRATION



Base series target: 2031

50% less growth series target: 2032

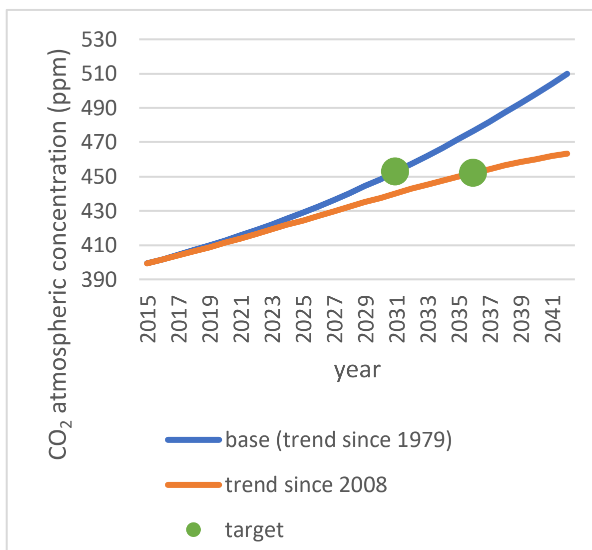
FIGURE 25, THE EFFECT OF 25% CO_2 CAPTURE IN CO_2 ATMOSPHERIC CONCENTRATION



Base series target: 2031

25% CO_2 captures series target: 2039

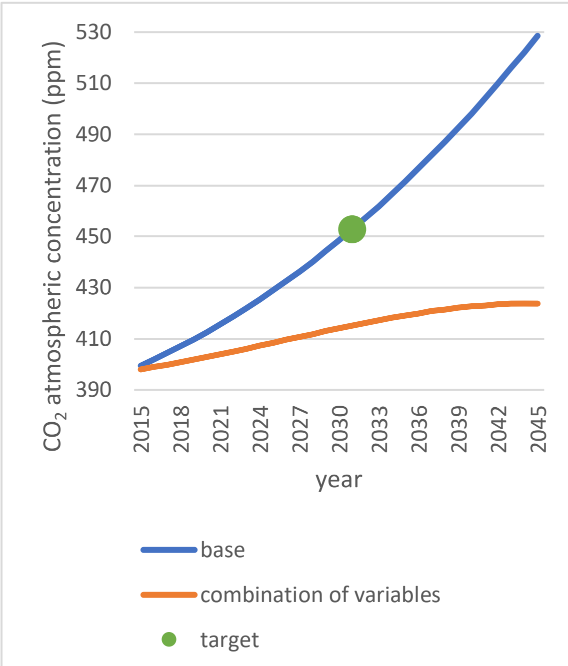
FIGURE 26, THE EFFECT OF THE BEST SCENARIO FOR CO_2 ATMOSPHERIC CONCENTRATION



Base series target: 2031

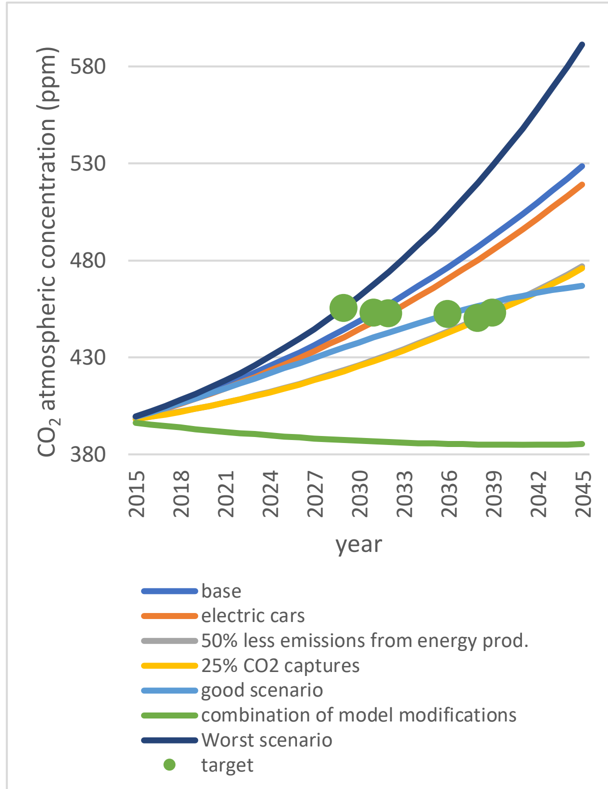
Best scenario series target: 2036

FIGURE 27, THE EFFECT OF A MODIFICATION IN A COMBINATION OF VARIABLES IN CO_2 ATMOSPHERIC CONCENTRATION



Base series target: 2031

FIGURE 28, ALL THE INSTANCES OF THE 450 PPM THRESHOLD SET

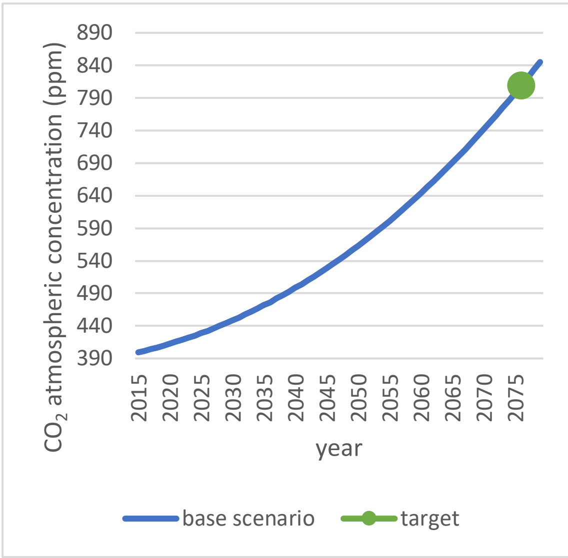


SET 2, MODEL RESULTS WITH 800 PPM AS A THRESHOLD

In this set we look at the time it would take to reach 800-ppm.

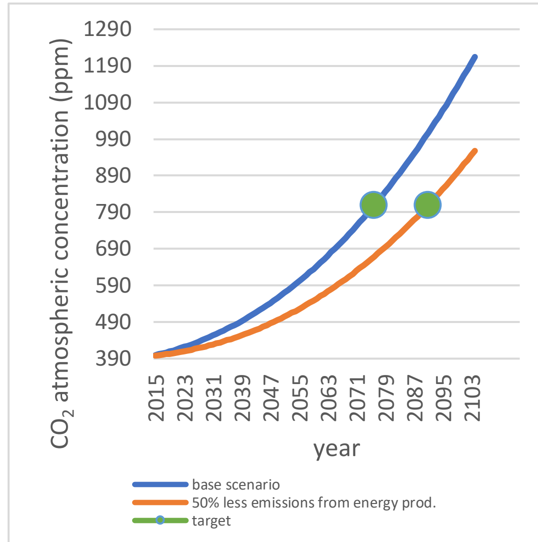
- In Figure 29 we can see the base scenario, with no modification to the multipliers (sliders), and the average scenario set in the model.
- In Figure 30 we see the effect of a 50% reduction in emissions from energy production, with no further changes.
- In Figure 31 we can see the effect of a 50% decrease in the population growth rate.
- In Figure 32 we can see the effect of an absolute shift to electric cars.

Figure 29, Base scenario for the 800-ppm threshold SER



Base scenario target: 2076

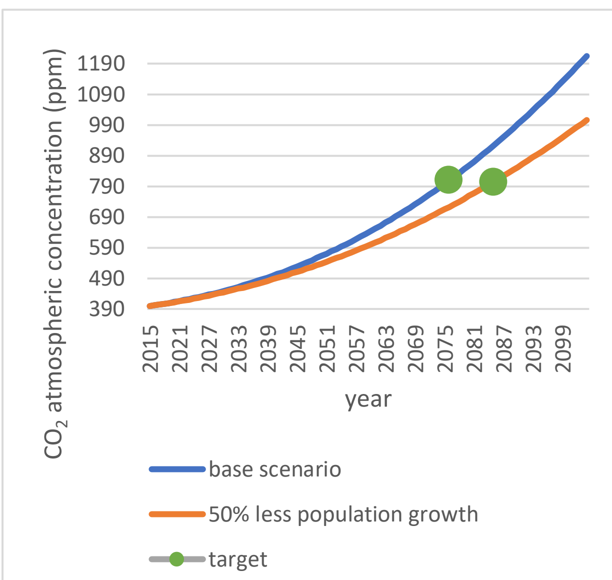
Figure 30, Effect of a 50% reduction in emissions from energy production in the 800-ppm scenario



Base scenario target: 2076

Orange series target: 2091

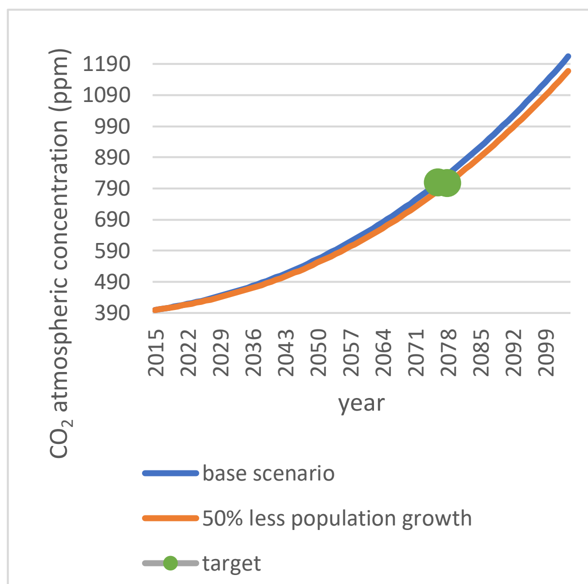
Figure 31, Effect of a 50% decrease in population growth on CO_2 atmospheric concentrations



Base scenario target: 2076

Orange series target: 2085

Figure 32, Effect of a 50% decrease in emissions from personal transport



Base scenario target: 2076

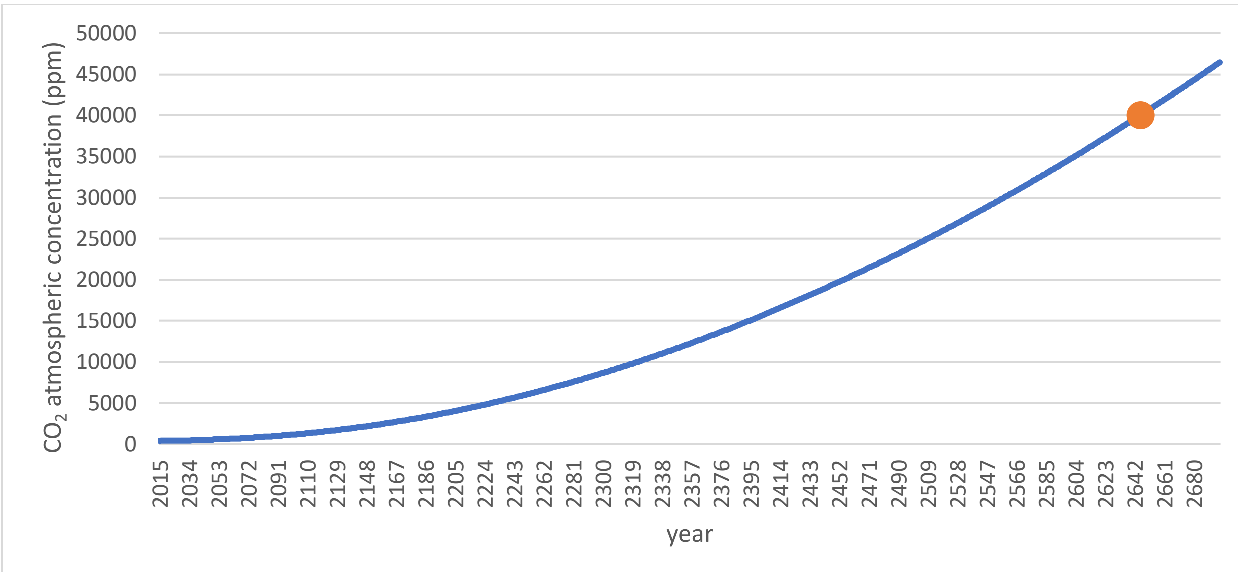
Orange series target: 2078

SET 3, MODEL RESULTS WITH 40000 PPM AS A THRESHOLD

In this set, we used the default model configuration, with the average scenario and no modification to emissions multipliers (sliders).

a)

FIGURE 33, CO_2 CONCENTRATION TO REACH 40,000PPM



Base series target: 2646

Discussion:

Set 1

SET 1, MODEL RESULTS WITH 450 PPM AS A THRESHOLD:

Set 1 (starting on page 22) of results shows the years it will take to reach the 450 ppm CO_2 concentration level, which has been described in the 'Method' section of the report. The first thing we notice when looking at the results of this section is that the critical values of CO_2 concentration are likely to be reached very soon. if the current trends in the most critical variables are continued, we will reach the critical concentration in just 11 years. This reassures us, that if the goal of preventing the rise of temperature by 2 degrees C above the pre-industrial level proposed by the Paris agreement is to be achieved, drastic measures must be taken very soon.

The next thing, which is easy to notice, is that individual modification of the variables does not make that much change. In Figure 22, we show how the CO_2 concentration level would change if we only switched to electric cars[2] (Matt Allan. 2019). With this modification, the time to reach the milestones is only delayed by 1 year. In Figure 25 we can see that even a 25% capture of CO_2 does have a considerable impact in the CO_2 concentration, contributing much more to emission reduction than a radical switch to electric cars. Together with reducing emission from energy production (this factor also seems to have a big impact in the concentration, as can be seen in Figure 23, CO_2 captures may be the way to go to seriously reducing our emissions.

The modifications in emissions from energy production and CO_2 captures (Figure 23 and Figure 25) reduce the growth in the CO_2 concentration considerably but by themselves are not able to prevent the rise of the temperature to a critical point. In Figure 27 we can see a combination of modifications which would not only halt the increase in CO_2 concentration, but it would make it start falling. This combination includes cutting emissions from energy production by 50% and reducing emissions from personal transport to 50%.

As we see in Figure 24, a 50% decrease in population growth rate, has only a minor effect on the atmospheric concentration. This shows that reducing population growth, apart from being difficult to achieve and controversial does not have such a big effect of the CO_2 atmospheric concentration.

[2] this includes the entire lifetime emissions of the electric car, compared to a conventional car

According to the “En-Rods” simulator discussed in the introduction, we will reach the 2 Degrees C increase in temperatures by around 2040, this is a significant difference to our model in the average scenario, although with the best scenario, our model predicts we will reach this threshold by 2039. Different sources have different information about the time when we will reach this threshold. For example, According to another article (Eric Holthaus. 2016), this threshold could be reached by 2030, this is a very close year to the one our model is predicting in the base scenario (2031). This shows us, that predicting the future of climate change is very complex, and the outputs will vary vastly depending on the main variables considered while developing the models.

Set 2

SET 2, MODEL RESULTS WITH 800 PPM AS A THRESHOLD

In this part, we look at how much time it would take to reach the 800-ppm threshold described in the introduction. We can see that in the base scenario if we follow the current trend and do not modify any variables, we would reach this point by 2076 (Figure 29), this period is longer than the one we discussed in point 1, but it is still close, only 56 years from now. It is also worth mentioning how bad would the effects of this atmospheric concentration of CO_2 be for humans. This would lead to an increase in temperature of 4 degrees Celsius. Among other things, this temperature increase would lead to massive extinctions of species, food insecurity in many regions and the risk of irreversibly destabilizing Greenland’s massive ice sheet. According to Bob Watson[3], a 4-degree rise in temperature may mean the start of human extinction (Oliver Tickell, 2008) along with many other extreme threats to the environment, like a long-term 70-80-meter increase in the sea level, and extreme and unpredictable weather. These events would also trigger a chain effect which would contribute to our extinction even further. If we reduced our emissions from energy production to half (Figure 30) this time would extend up to 2091, which is a 15-year extension compared to the base scenario.

Set 3

SET 3, MODEL RESULTS WITH 40000 PPM AS A THRESHOLD

[3] Sir Robert Watson is chair of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, and former chair of the Intergovernmental Panel on Climate Change.

In Set 3(starting at page 28), we can see how much time it would take to reach 40000 ppm of CO_2 concentration. This concentration of CO_2 is Immediately Dangerous to Life or Health according to The FSIS Environmental Safety and Health Group. This would mean that the CO_2 concentration level would directly lead to the extinction of humans. It must be emphasized that the length of the period, and the fact, that CO_2 concentrations will not likely continue to follow the same trend with such a rapid increase in the future makes this prediction less valid. However, this instance is helpful to understand the direct effects of CO_2 on humans, and reassures us, that if an increase in CO_2 concentration causes our extinction, it is likely to do so indirectly, by for example causing natural disasters, and destroy habitats of certain species that are critical to human survival, rather than directly affecting our health as has been mentioned in the previous point.

General discussion:

In the introduction, we have seen the prices of different renewable energy costs. We see that some of them have been slashed to less than half compared to their level in 2010, This data suggests that reducing unnecessary emissions from energy production may be a better solution than for instance reducing population growth, which is very controversial and very hard to achieve, especially in developing and emerging countries.

Previously we have discussed that population growth rate may be one of the most important factors affecting the growth in CO_2 concentrations. In Figure 24 we have seen, that in the short term, a reduction in population growth does not have much impact. However, when we looked at a longer-term goal, the 800-ppm scenario, in Figure 20 we have seen that the population growth does affect CO_2 atmospheric concentrations more than it did in the short-term.

In today's public debate, the switch to electric cars is a very important topic related to CO_2 emissions. However, our research indicates that both in the short and long term (Figure 22 and Figure 32), a reduction from emissions from personal transport does not have a significant impact on the CO_2 atmospheric concentration.

Capturing CO_2 from the atmosphere may be a challenge, as it is relatively new technology. We already see emerging technologies of CO_2capture directly from the atmosphere, which is a more costly solution but may be implemented in all regions. Other technologies (developed mainly by oil companies) allow for upgrading the oil extraction installations to capture CO_2 from gas waste-product, where the gas is more concentrated. This solution is cheaper and more effective and may be used in combination with more efficient energy sources (in cases where green energy cannot be used) to maximize the reduction in CO_2 emissions. The side products of such CO_2 captures have many possible uses, ranging from construction material to animal feed (David Roberts. 2019). An example of a company that is capturing CO_2 directly from the air and producing a useful product is Climeworks (Climeworks). This company produces fertilizer from the CO_2 capture from air. The company has set its goal to capture 1% of total world CO_2 emissions by 2025 (Bobby Magill. 2017). Capturing CO_2 may seem difficult to achieve on large scale, but as technology advances, and more and more firms are becoming involved in this kind of activity, CO_2 captures are possibly one of the best ways we can fight climate change. Governments could help to speed up the time, in which CO_2 capture plants will be profitable by further subsidizing this sector and investing more capital in research.

As we have seen in the introduction, the investment in clean energy is falling, and our research shows, that among the factors we have studied these technologically advanced sources of energy are the best way to reduce CO_2 emissions. To improve the situation, we should pressure governments to move away from polluting energy sources like coal and invest in the research and implementation of high-tech renewable energy sources. Even though the effect of a transition to electric cars (Figure 22) is not as significant as clean energy production, it still has a bigger impact than for instance a 50% decrease in growth of population (Figure 24) in the short term, and is one of the most significant changes individuals can make. We should not forget about the importance of individual behavior in the transition to a more environmentally friendly society as carbon emissions may be effectively reduced by changing lifestyles. Much is still to do in this respect as many people, despite the huge amount of evidence from different sources, are still skeptical about climate change (Financial Times. 2019).

Conclusion

- We have developed an intuitive tool to predict future CO_2 atmospheric concentrations.
- In the best scenario, the 450-ppm threshold would be reached in 2029, and in 2036 in the worst scenario.
- A complete shift to electric cars does not have a significant impact on CO_2 atmospheric concentrations both in the short and long term.

- A decrease in population growth is not significant in the short term but has a bigger impact on CO_2 atmospheric concentrations in the long-term.
- Technological advances in the environmental field, like more modern ways to reduce emissions from energy production, and technologies to capture CO_2 have the best efficiency when reducing CO_2 atmospheric concentration among the factors we have studied.
- In an average scenario, we will reach the 4 degrees C increase in temperature threshold in 2076.

Acknowledgements

I would like to thank my father, for helping me in search of a topic for this report and pointing me to some of the data sources.

I would also like to thank my chemistry teacher Jesús Santamaria for assessing my NetLogo model and orientating me on my first symposium.

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Table of figures:

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Annex 1, NetLogo code

```
globals
[

  growth-rate

  co2-per-capita
  co2-emitted

  co2-from-personal-transport-per-capita
  other-co2-sources-per-capita
  co2-from-energy-produccion-per-capita


  previous-year-atmospheric-co2
  current-year-atmospheric-co2
  ppm

  tonnes-per-ppm-in-atmosphere
  base-year-co2-emissions
  base-year-co2-per-capita
  base-year-population-growth-rate

  pop
  year

  ;; variables, which indicate whether the threshold have been reahced, and in which year
  reached-450-ppm-threshold
  reached-40000-ppm-threshold
  reached-800-ppm-threshold
  reached-custom-threshold
]

to setup
  clear-all
```

```
  reset-ticks
  set growth-rate 1.17 ;;https://www.worldometers.info/world-population/
  set co2-per-capita 4.981 ;; data from 2014 https://data.worldbank.org/indicator/en.atm.co2e.pc

  set tonnes-per-ppm-in-atmosphere 7800000000
  ;;https://skepticalscience.com/CO2-emissions-correlation-with-CO2-concentration.htm

  set ppm 397.12
  ;;https://datahub.io/core/co2-ppm#resource-co2-annmean-gl
  set previous-year-atmospheric-co2 (ppm * tonnes-per-ppm-in-atmosphere)

  set pop 7256000000
  ;;population
  ;;https://data.worldbank.org/indicator/SP.POP.TOTL

  set year 2014

  set base-year-co2-emissions 36140000000
  ;; https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions
  set base-year-co2-per-capita 4.981
  set base-year-population-growth-rate 1.17

  ;; set the threshold indicators to default value
  set reached-450-ppm-threshold "Not yet reached"
  set reached-40000-ppm-threshold "Not yet reached"
  set reached-800-ppm-threshold "Not yet reached"
  set reached-custom-threshold "Not yet reached"
end

to go
  ;; main loop of the model
  set year year + 1
  population-update
  compute-co2
  compute-ppm
```

```
 threshold-indicators-update
 tick
end

to compute-co2

 ;;https://data.worldbank.org/indicator/EN.ATM.CO2E.PC
 ifelse custom-growth-values-insted-of-trend [
   set co2-per-capita co2-per-capita + (co2-per-capita * custom-yearly-increase-in-co2-per-capita / 100)
 ][

 if scenario = "Worst" [set co2-per-capita 0.002837432466820 * year ^ 2 - 11.315217577607400 * year + 11284.861501851500000]
 if scenario = "Average" [set co2-per-capita 0.065823868439909 * year - 127.496844872433000]
 if scenario = "Good" [set co2-per-capita -0.012180996758010 * year + 29.514804710944500]
 if scenario = "Best" [set co2-per-capita -0.003284896405974 * year ^ 2 + 13.261347829620500 * year - 13379.144672174800000]
 ]

 ;; now we split the total emissions in different sectors and categories in order to have more control over the emissions of each type
 ;; first we reset all the variables
 set co2-from-energy-produccion-per-capita 0
 set co2-from-personal-transport-per-capita 0
 set other-co2-sources-per-capita 0
 ;; now we proceed to distributing the value over the variables
 ;; the authors conclude that BEVs generate only half the greenhouse gas emissions of ICEVs
  set co2-from-personal-transport-per-capita ((co2-per-capita * 0.2045 * 0.44) * (personal-transport-emissions-%-slider ))
  set co2-from-energy-produccion-per-capita ((co2-per-capita * 0.4904) * (energy-production-emissions-%-slider))

 set other-co2-sources-per-capita co2-per-capita - ((co2-per-capita * 0.2045 * 0.44) + (co2-per-capita * 0.4904))
```

```
  set co2-emitted (co2-from-personal-transport-per-capita + other-co2-sources-per-capita + co2-from-energy-produccion-per-capita)  * pop

end

to population-update

  ;; adjust population to current growth rate
  ;;https://data.worldbank.org/indicator/SP.POP.TOTL
  ifelse custom-growth-values-insted-of-trend [

    set growth-rate growth-rate + (growth-rate * custom-yearly-increase-in-population-growth-rate / 100 )

  ][



  if scenario = "Worst" [set growth-rate 17205169833699.200000000000000 * e ^ (-0.015076842249428 * year)]
  if scenario = "Average" [set growth-rate 3486890565.294190000000000 * e ^ (-0.010840057577979 * year)]
  if scenario = "Good" [set growth-rate -0.001869740665522 * year + 4.947336745758850]
  if scenario = "Best" [set growth-rate -0.009614179703418 * year + 20.530955752418200]

  ]

 set pop pop + pop * ((growth-rate / 100) * (growth-slider))

end

to compute-ppm

  ifelse ppm <= 0 [

    set ppm 0

  ][
```

```
 set current-year-atmospheric-co2 previous-year-atmospheric-co2 + co2-emitted - ((base-year-co2-emissions) * 0.55 + co2-emitted * (co2-captures / 100))

 ;;https://skepticalscience.com/CO2-emissions-correlation-with-CO2-concentration.htm

 set ppm (current-year-atmospheric-co2 / tonnes-per-ppm-in-atmosphere)

 set previous-year-atmospheric-co2 current-year-atmospheric-co2


 ]


end


to calculate-variables


 set year year + 1

end


to threshold-indicators-update

 if ppm >= 450 and reached-450-ppm-threshold = "Not yet reached" [set reached-450-ppm-threshold year]

 if ppm >= 800 and reached-800-ppm-threshold = "Not yet reached" [set reached-800-ppm-threshold year]

 if ppm >= 40000 and reached-40000-ppm-threshold = "Not yet reached" [set reached-40000-ppm-threshold year]

 if ppm >= ppm-level-for-custom-threshold and reached-custom-threshold = "Not yet reached" [set reached-custom-threshold year]

end
```

Annex 2, Screenshot of the NetLogo tool

FIGURE 34, SCREENSHOT OF THE NETLOGO TOOL