Can Cities Save Us?

Vanshika Jain [1], Nitya Parthasarathy [2*]

December 10, 2019

1. MIT (Course 18) 2. MIT (Course 6) *corresponding author(s): Mark Coletti, Joseph Kennedy, Melissa Allen, Amy Rose

Abstract

With global temperatures slowly climbing and a lack of international efforts to mitigate these issues, it is clear climate change demands attention. Often times, effects are felt at a local level, so we began to ask ourselves, would it be possible for cities to bear the weight and lead the charge against climate change? Further, what would this look like: would it be the top 10 cities reducing emissions drastically or the top 50 cities doing small amounts? We developed a program to intersect city locations with CMIP6 data on future emissions to find how much of global pollution cities will be responsible for. From there, we were able to analyze what levels of reduction would keep us under the two degrees Celsius cutoff. We found that cities can play an instrumental role in helping reduce carbon emissions in situations where we were near the border of the two degree cutoff, but cannot themselves bear the entire weight of the world. However, we do believe that cities will play a critical role in defining what the future of our globe looks like and that it is imperative that local policymakers begin to look at what efforts they can contribute to making their cities more sustainable and eco-friendly.

1 Climate Background

Earth's climate has always been changing, and for most of the past, this has been due to small perturbations in the distribution of sunlight caused by changes in rotation and orbit [3]. In fact, in the last three million years, we have had both periods of mild states with a climate similar to the one we are facing now and periods of ice sheets that covered much of the land [3]. Given that there periods have been roughly cyclical, the regularity at which Earth has seen these phases is surprising.

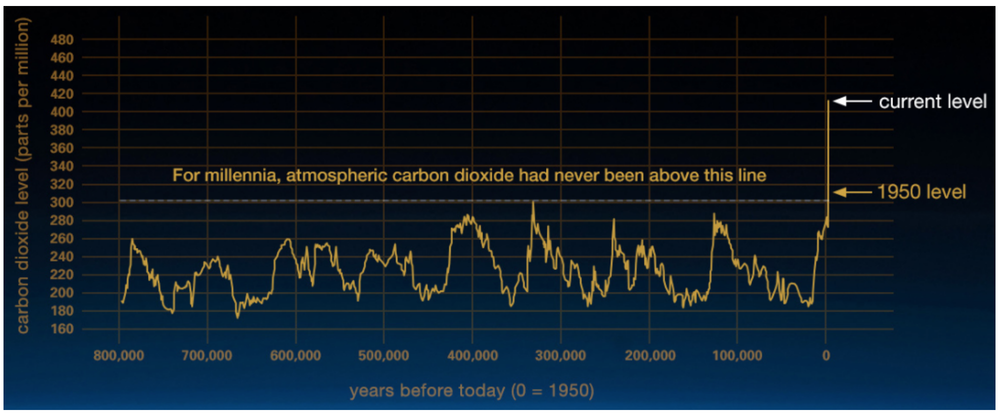

Figure 1: CO2 levels for the past 800,000 years [13]

We note that all types of organisms have been altering Earth's climate for millions of years and humans are just one of such species [3]. What makes human contribution so significant, however, is both the *magnitude* of the impact and the *rate* at which humans make this change. Carbon dioxide, a greenhouse gas, warms the planet by interacting with radiation. Humans have increased the amount of carbon dioxide by half, mostly in the past fifty years, a change of unprecedented magnitude and speed. In fact, there are records of atmospheric carbon dioxide levels for the past 800 thousand years (Figure 1), and the concentration of carbon dioxide in the atmosphere has never been above 300 parts per million (ppm) until the last century [13]. We are now at a concentration of over 400 ppm [13]. Such a change in carbon dioxide has led to changes in atmospheric temperature (Figure 2) where there is a clear warming trend in the Earth's average surface temperature to an increase of 1.5 degrees

Celcius [4].

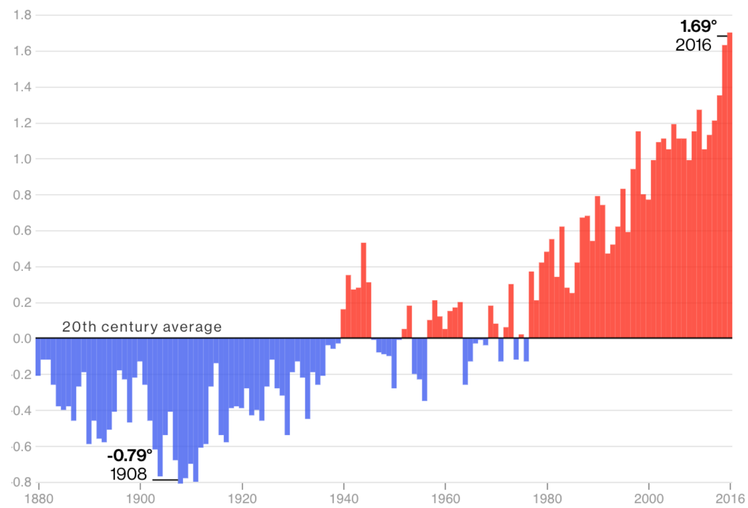

Figure 2: Global average temperature over the past century in Fahrenheit [4]

There is much evidence to show humans are the cause of this change. This is made clear from running simulations; without human influence, we cannot account for the average temperature on Earth [3]. In fact, the Intergovernmental Panel on Climate Change claims with more than 95% probability that the variability in the global mean temperature has been caused by humans. The impact of this change is seen in various ways: an increase in sea levels, a decrease in arctic ice, an increase in ocean acidity, an increase in extreme weather occurrences, and rainfall will occur in more concentrated areas in heavier but less frequent events [3]. Emmanuel Kerry describes in his book:

> "Civilization [has] developed during a period of exceptional climatic stability over the last 7,000 years. While our distant ancestors had to cope with a sea-level rise of about 400 feet over a mere 8,000 years or so leading up to the development of civilization, human society has since become finely adapted to the current climate, so much so that a mere three-foot increase in sea level... would displace around 100 million people" (38).

Given the dependence on a stable climate, the current pace of change is stressing infrastructure, something humans depend so heavily on. Thus, changing temperatures impacts everyone on

Earth, making this a global problem. It is not surprising, therefore, that a lot of solutions have been considered on a global scale.

1.1 Global Solutions

On an international level, there has been a push for change from the Kyoto Protocol to the Paris Agreement. In 1979, there was the First World Climate Conference, which was held in Geneva and sponsored by the World Meteorological Association. This was a meeting to discuss global warming, climate research, and forecasting, which helped frame the problem on an international scale [7]. In 1995, the United Nations began the United Nations Climate Change Conferences, a yearly conference to discuss climate change and create policies to deal with the problem. Two years after being created, at the third conference, the Kyoto Protocol was established outlining legally binding reduction obligations for Annex 1 countries [7]. While this did seem to have a positive impact in terms of the first international protocol for climate change, it is clear that this was not enough. Since then, this conference has led to the Paris Agreement, which created a plan towards climate action to stay below the two degrees Celsius cutoff.

1.2 Problems with Global Solutions

Climate change is a difficult problem because of the lack of aligned incentives, the free-rider problem, and disproportionate damage. There is a lack of clear, immediate benefits to most people, leading to a lack of desire and initiative to take precautionary steps to prevent further damage. While we need large groups of people to bear the weight of reducing carbon emissions, there is no reason one singular person must work to aid the cause. Therefore, many people are able to freeload off the efforts of others while also profiting because polluting can be extremely lucrative. This issue exhibits itself on a larger scale as well where certain countries don't do their share. According to the University of Maryland economist Peter Cramton, freeloading leads to an "unraveling of cooperation" [2]. He believes this dynamic doomed a previous treaty, the Kyoto Protocol where Japan and Canada opted out, encouraging others to free-ride [2]. Furthermore, since much of economic development occurs when there is access to cheap energy, instead of clean energy, there is a lack of aligned incentives, tying back into the free-loader problem. States which mitigate sometimes lose out on short term benefits, while states, which do not mitigate, still get the benefit from those who do, while also benefiting in the short run by producing cheap energy. Actors, as a result, do not always commit to these international plans. A clear example of this was when the United States pulled out of the Paris agreement. Further, climate change is so hard to visualize in places of privilege when it disproportionately affects the poor. According to a study by the World Bank, a warming world will send an additional 100 million people into extreme poverty and nearly half of those people will live in India [8]. These are only some of the reasons why climate change has been so difficult to manage. Since then, there have been many questions as to whether other actors could take the place of states.

2 Cities as Actors

We wonder whether cities could act on this problem, by reducing emissions and taking charge.

2.1 Cities as the Problem

We begin by observing that cities account for more than seventy percent of global fossil fuel emissions and consume around eighty percent of energy production [11]. Cities have been seen as sources of environmental damage, immense carbon emissions, and a burden on the natural world. In a 2013 study by Li Jiang of Renmin University of China's school of economics, he states that "in rapidly urbanizing areas, agriculture intensifies on remaining undeveloped land and is likely to expand to new areas, putting pressure on land resources" [12]. In another study, author Seto states that the "direct loss in vegetation biomass from areas with a high probability of urban expansion is predicted to contribute about 5% of total emissions from tropical deforestation and land-use change" [15]. The World Bank explains that as growth and development continue, energy services like lighting, heating, cooling, will drive more greenhouse gas emissions than industrial activities [10]. Moreover, as cities grow, the global built-up area is expected to triple [10]. This area will increase energy requirements and require additional infrastructure. If this build-up is poorly managed, the energy problem will only be aggravated. We note that the environmental impact of cities is impacted by their affluence, their density, and their energy sources [10].

2.2 Cities as the Solution

While cities put pressure on the environment, they can also be seen as places for large positive changes. In particular, because of the high density of people, cities can be places that allocate and manage resources efficiently. As nations become richer, people expect an increase in their quality of life. Cities give us the most efficient way to increase the quality of life for the most number of people, especially dense cities. This can be demonstrated through an example. Glaeser compared New York City to its surrounding suburbs to see if on a by-household perspective if cities were more efficient. In fact, a household in Manhattan generates 6.4 tCO2 less than a suburban neighborhood [6]. According to the World Bank, "Sustainable cities are the best option to provide a quality of life while reducing net pollution such as greenhouse gas emissions" [10].

As climate change is a global issue, it is reasonable to ask, why should we focus on city-wide change and regulation? There are three primary reasons [10]. First, cities can offer solutions to global problems on a more local level, making the issue more tangible. They are more equipped to restrict infrastructure emissions and control the amount of carbon produced by a single household. Second, there is a faster feedback loop: communication between policymakers and the public can happen more rapidly. As true with most other law, local government more directly represents the voices of the people in that city, so the actions will be more reflective of their desires and far more effective because the changes made will be ones that the people in the city believe they can sustain, guaranteeing more success than nationwide or global policy. Finally, the World Bank report states, "Cobenefits of climate change mitigation and adaption are largest in cities" [10]. With the large potential for improvement in all aspects of city structure, it seems ideal to have the cities implement these changes for the betterment of its people. Furthermore, it is easier for cities to implement policy as to when implementing nationwide or global change because cities are not homogeneous, so effective policies for reducing urban greenhouse gas emissions will likely differ for all cities.

The three issues named earlier still persist, so it is still unclear as to why we believe cities will act, although it may be true that people in urban populations tend to have more of a focus on environmental issues. We also observe that the longer cities wait to mitigate and adapt the harder and more expensive it will be to be ready for climate change [10]. We can see this in California: the energy sector was not prepared for the dryness, specifically the gusty offshore winds, low humidity, and dry fuels created a critical fire weather condition [14]. People had their power off for many days. Drought and heat exacerbate wildfires and with these wildfires claiming more than 94,000 acres of land, 129 million trees and displacing 200,000 people to date in the San Francisco Bay Area, it is evident that cities need to become more prepared. The effects of climate change only get worse over time, so this is an urgent issue for cities, not just countries, particularly because the effects are felt on a local scale.

2.3 Research Question

Given this background, the question proposed was if cities led the charge against climate change, would that be enough? If they act and make reasonable reductions, what does that mean for global emissions? We can approach this not only from a general reduction of emissions from all the top cities but also looking at eliminating all emissions from the top 3,5, or 10 cities. If eliminating all of the emissions from only a few cities makes a significant difference, then examining city-by-city mitigation strategies might make a difference as well.

The idea was that different cities use different amounts of energy and in different proportions. Getting emissions down to each city's minimum might require different measures for each city depending on their infrastructure, culture, geographic location, etc., but if eliminating all of the emissions from a few cities does not make a difference globally, maybe it is a waste of time to try to develop city-level plans for emissions reduction.

3 Project Data

3.1 Overview

For the project, we worked with Oak Ridge National Laboratory that had come up with a baseline implementation parse the CMIP data and to calculate emissions for a city. Their implementation used a KD tree, which is a data structure that organizes points in k dimensions and takes the form of a binary search tree. This structure is an efficient way to get find nearest neighbors; the goal was to get grid boxes in the CMIP data that intersected the city. Therefore, they took a longitude and latitude value, and using the KD tree, took the nearest neighbors of this point, resulting in the corresponding grid cells.

3.2 CMIP6 Data

On the data front, we needed projections for future emissions, so we had to update the data being used in the project. The data we used to calculate emissions is the CMIP6 future anthropological emissions pollution dataset. CMIP is the Coupled Model Intercomparison Project, which began in 1995 under the World Climate Research Programme (WCRP). It is now in its sixth phase. The benefit of using data from the project is that it helps to coordinate independent model comparison activities since all the data has a common infrastructure. The data that was being used prior to this was the CMIP6 historical data ranging from 1750 to 2014 at 1/2 degree resolution giving us cells of approximately 50 km. This was good to use for calibration, but in order to see how much cities should or could do, we needed future data. Moreover, it would also be beneficial to use a finer grid cell to get more accurate emissions for the city. Thus, our goal was to find data with a higher resolution; the finest resolution that was possible to get was a cell with 1/10 degree data. It was a surprise to find that this data was not publicly available, so the ORNL team helped us contact those that had the data, and we eventually received it.

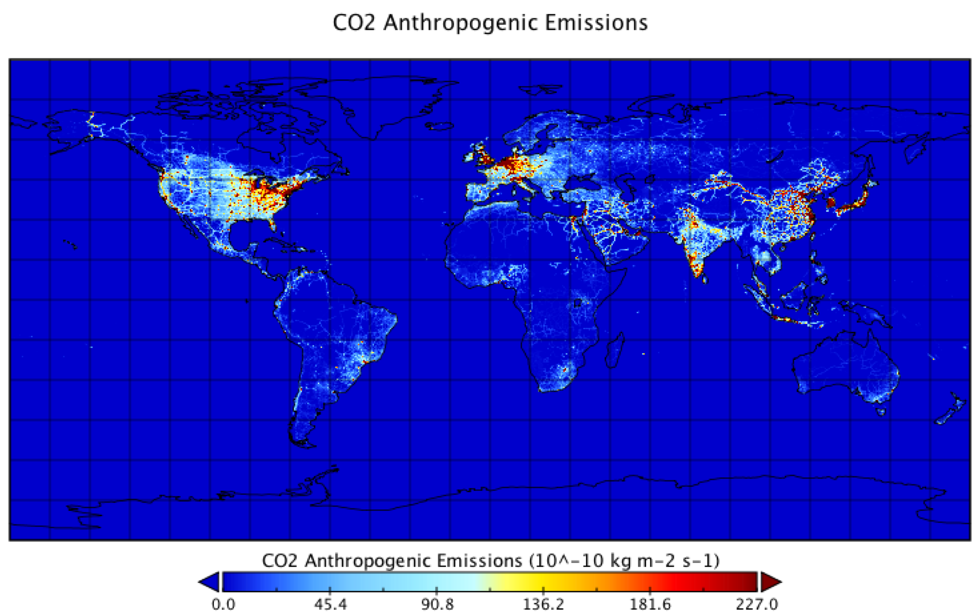

Figure 3: Energy production emissions (sector 4) CO2 emissions for scenario ssp585 during April 2030

The data we received came in a set of eight possible futures, starting in 2015, and continuing until 2100, with 10-year increments. This meant we had estimates for anthropogenic carbon dioxide emissions for each year from 2020 to 2100 which was a multiple of 10, and for that year we got monthly emissions. Thus, in total, we had 120 frames of data to look at. Additionally, the emissions were dived up into different sectors to tell us about what activity was causing the emission. We had nine such sectors, and examples of sectors are shipping (sector 8) and the energy sector (sector 4).

The data came in eight files, each one corresponding to a different socio-economic scenario. Each dataset was labeled with a term SSP[number], where the number ranged from one through five. Among these subdivisions, there was a further subdivision summarized in

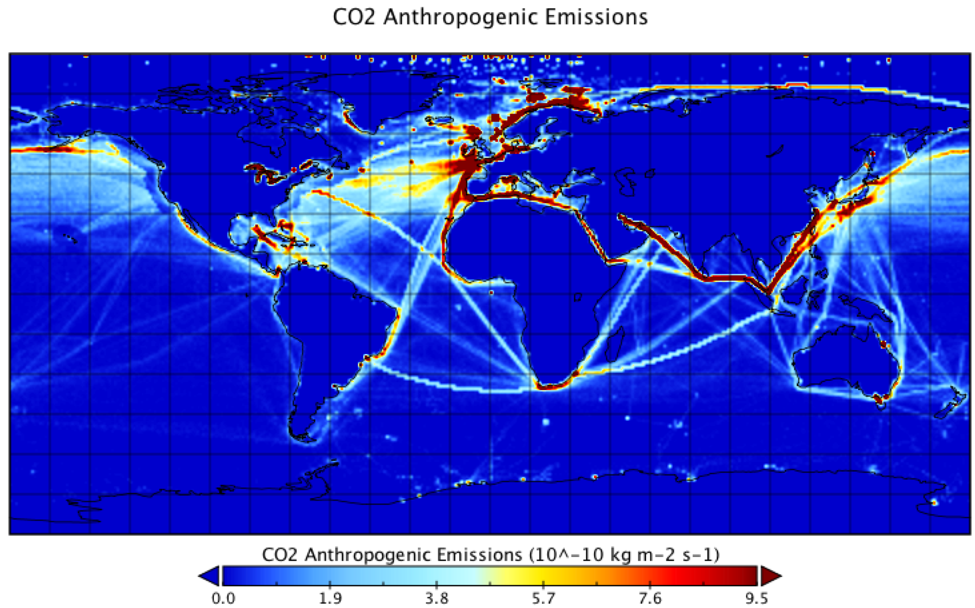

Figure 4: Shipping emissions (sector 8) CO2 emissions for scenario ssp585 during April 2030

Scenario name	SSP	Target forcing level ($W\,m^{-2}$)	Scenario type	Tier	IAM	Contributing to other MIPs
SSP1-1.9	1	1.9	Mitigation	2	IMAGE	ScenarioMIP
SSP1-2.6	1	2.6	Mitigation	1	IMAGE	ScenarioMIP
SSP2-4.5	2	4.5	Mitigation	1	MESSAGE-GLOBIOM	ScenarioMIP, VIACS AB, CORDEX, GeoMIP, DAMIP, DCPP
SSP3-7.0	3	7	Baseline	1	AIM/CGE	ScenarioMIP, AerChemMIP, LUMIP
SSP3-LowNTCF	3	6.3	Mitigation	2	AIM/CGE	ScenarioMIP, AerChemMIP, LUMIP
SSP4-3.4	4	3.4	Mitigation	2	GCAM4	ScenarioMIP
SSP4-6.0	4	6	Mitigation	2	GCAM4	ScenarioMIP, GeoMIP
SSP5-3.4-OS	5	3.4	Mitigation	2	REMIND-MAGPIE	ScenarioMIP
SSP5-8.5	5	8.5	Baseline	1	REMIND-MAGPIE	ScenarioMIP, C4MIP, GeoMIP, ISMIP6, RFMIP

Figure 5: Summary of the different scenarios [5]

Figure 7. SSP1 and SSP5 describe worlds where there is strong economic growth. SSP1 achieves this growth via sustainable pathways while SSP5 achieves growth through fossil fuel pathways. In both of these scenarios, incomes increase and inequality between countries decreases [5]. In SSP1, there is a decrease in the demand for resource-intensive agricultural products because behaviors change. In SSP2, there is moderate population growth, and while there is a convergence of income levels, it is slower than SSP1 and SSP5. Food consumption and demand for energy-intensive agricultural products is expected to increase, and reliance on energy generated by fossil fuels is expected to stay the same. Higher-income countries

are expected to lead the curbing efforts of air pollution and developing countries eventually catch up [5]. The last two groups of scenarios are SSP3 and SSP4, which correspond to high inequality between countries and within countries. GDP is concentrated among current high-income nations and population increase mostly occurs in low and middle-income countries. SSP3 sees a resurgence of coal as a source of energy while SSP4 sees high-tech energy solutions [5]. These scenarios allow policy-makers better understand the best policy option given different scenarios. For us, this meant we would run our code on each of these scenarios to see the impact of cities in all cases.

3.3 Natural Earth Data

While we were hoping to use shape files for each city, due to the lack of such data sets for global cities, we resorted to using city centers as indication of We wanted longitude and latitude data to reflect population centers instead of just the city hall. This way we could get a more accurate emissions profile for each city. We used the Natural Earth dataset which gave us the wanted points.

3.4 Testing Accuracy

Moreover, we needed to find a more accurate way of measuring city emissions as the calculated data was not producing accurate enough results. To determine accuracy, the ORNL team used from a report made by Daniel Hoornweg on climate emissions. The Hoornweg data indicates how much the top 50 cities were emitting in 2005. Then, they compared the emissions estimates they calculated to this data. We use the data provided by Hoornweg because it allows us to compare our time series analysis with the spot analysis conducted by them. If the data matches the overlapping time ranges then it suggests our data will likely be accurate for future years as well.

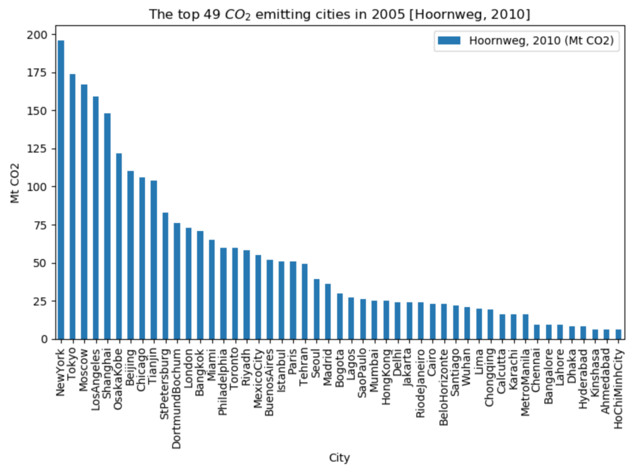

Figure 6: City emissions for the top 49 emitting cities in 2005

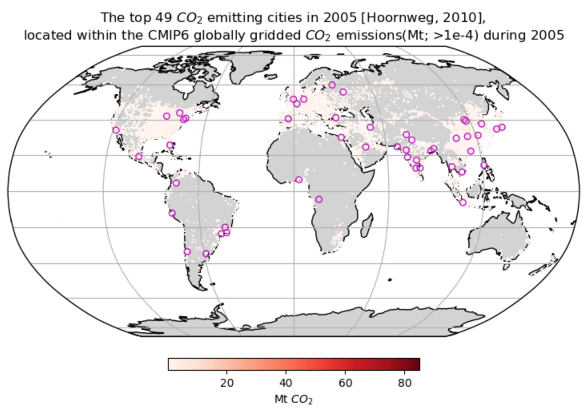

Figure 7: The location of the top 49 emitting cities in 2005

4 Project Code

We began the project by collecting the CMIP data as previously planned and then proceeded to gather the city-data. Our plan was to take the city shapes from LandScan data and intersect them with the emissions. We would be able to calculate this according to a grid, based on the 1/10 degree because that was the quality of the CMIP6 data and match the emissions amount with the percentage of that grid location that the city takes up. This would allow us to account for the emissions at the border of the cities most accurately as we would not be generalizing emissions to a larger area than what the city is producing. Landscan data was used because local and regional administrative boundaries often do not reflect the contributing anthropogenic footprint, so we used the city boundaries derived from the LandScan population distribution.

Our goal was to get a more accurate account of city emissions. One idea we had was to intersect the actual city area with the corresponding CMIP grid cell. We would take the outline of a city as a shapefile, get the midpoint using a simple algorithm we wrote, intersect the city with each grid, and get the area of each intersection. This area would tell us the proportion of emissions we should use for each grid cell because we know the emissions for each grid cell and the area of each grid cell. Much of this relied on the methods of Shapely, making shapefiles necessary to use our methods. After writing this code, we realized we could only find the shapefiles for US cities.

Since we wanted to look at this globally, we had to find another way to calculate emissions. We note that we were able to successfully implement this measure for the US cities but put a pause in this idea. We decided to instead look at the longitude and latitude of each city and then took the k-nearest neighbors. This will still allow us to look at the bounds of the city, so we can perform the same research. We obtained the longitude and latitude from a natural earth shapefile and then created a similar emission grid that matched with the point for each city and found the emissions for the 3 nearest neighbors. In pattern recognition, the k-nearest neighbors algorithm (k-NN) is a non-parametric method used for classification and regression. We used a KD tree as a way to quickly find such nearest-neighbors. The algorithm used is one described in a paper by Maneewongvatana and Mount 1999. A Kd-tree is a binary tree where each node is an axis-aligned hyperrectangle and each node specifies such axis and splits based on whether the coordinate is greater or lesser along that axis. From here we summed up the total emissions for each city and globally so we could calculate the percentage of global pollution each city takes up. Our goal is to find shapefiles for these global cities so we can more accurately measure the city emissions but as later evidenced by our results, they are not so far off from the Hoornweg data so this method does work decently. We were able to find the emission predictions of each city for the future in increments of ten years. We used the various CMIP6 data which details many possible scenarios of future emissions. From here we can look at how the cites will do under all the different circumstances and apply reduction principles to see if cities could actually reduce to be this effective.

5 Results

We began by trying to re-create the classic graph of world emissions and then estimate total global emissions until the end of the century using this. What we did was we sum up the total anthropogenic CO2 emissions among all the nine sectors around the globe for each year given to us in the CMIP6 data for each scenario. Then, we plotted the total emissions per year as seen in Figure 8 and compared this to the graph produced by other research groups.

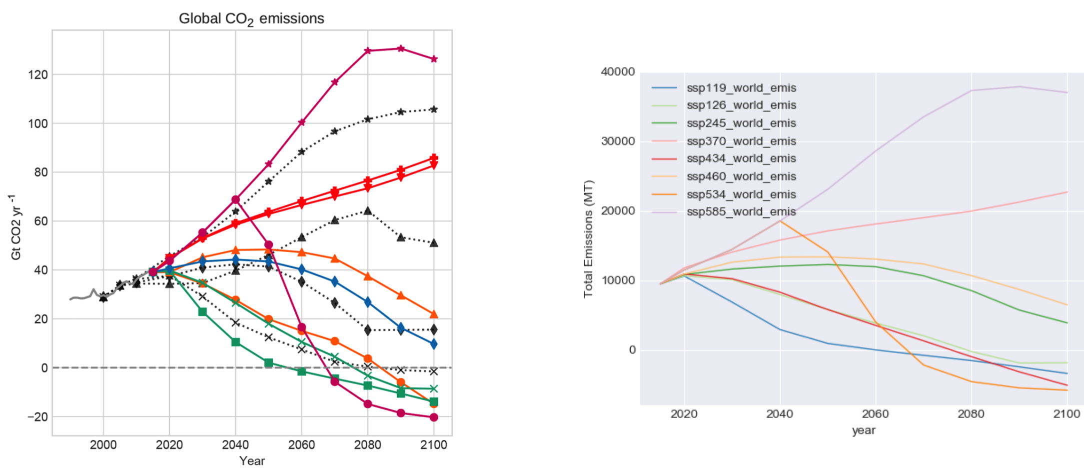

Figure 8: World emissions used to verify calculations [5]

Once we were able to reproduce these results, we wanted to estimate the total global emissions until the end of the century. For every year not given to us by the CMIP6 data, we estimated the total emissions for that year using linear interpolation. After calculating the total global emissions until the end of this century, we looked to which scenarios led to what outcomes in terms of temperature rise. Because we did not have access to like models, we compared our summed amount to the total carbon budget. This at least gave us the proxy to see what impact each pathway had. We compared this calculated temperature impact of each scenario (Figure 5).

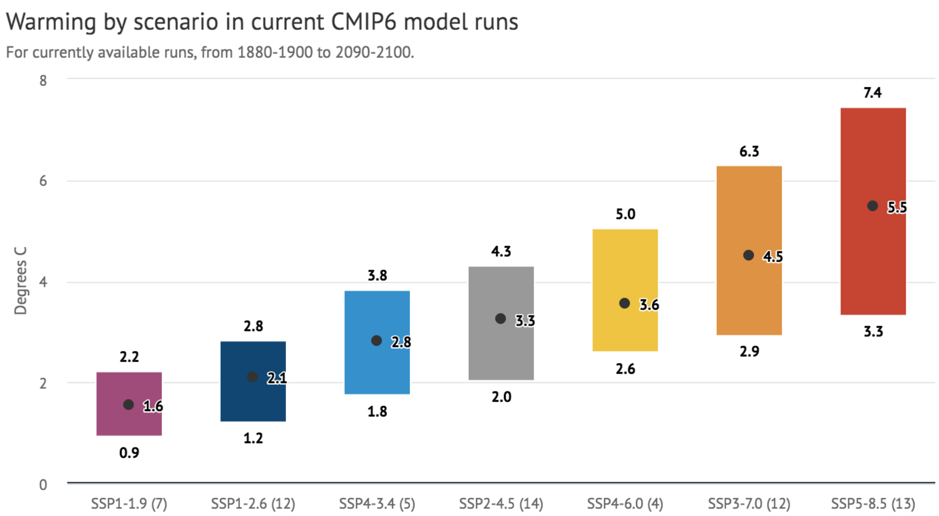

Figure 9: Shows the increase in mean global temperature by the end of the century for each scenario [9]

After calculating global emissions, we looked at calculating city emissions. To calculate city emissions we looked at the top 49 emitting cities from 2005 because this is what was given in the Hoornweg data. Examining these cities and calculating their emissions for each of the different scenarios, we get the graph given in Figure 5. We first note that none of these cities are expected to have negative emissions even if global emissions are expected to be negative. Second, in some scenarios, total city emissions approach zero, but usually far later in the century than we expected. Not looking to SSP119, for all the cities that are approaching zero emissions, they have a timeline for which they do not get close to zero until 2080. Finally, the cities mostly reflect the global trends as seen by comparing Figure 8 and Figure 5.

After calculating the total city emissions, we looked at their percent of total global emissions. What figures 11 and 12 show is how much these forty-nine cities make of total emissions. Immediately, we see that outlier SSP119. The reason the percent of global emissions is so high is because the global emissions are approaching zero much faster than

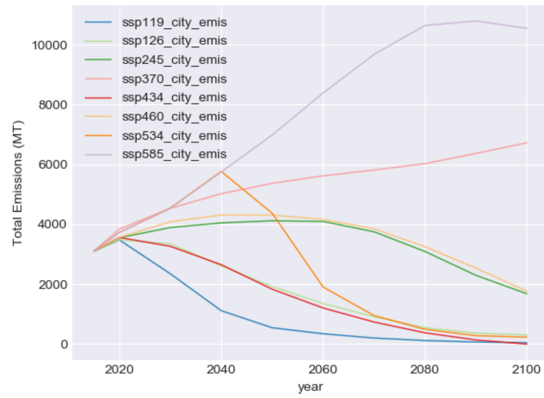

Figure 10: Total city emissions for each scenario

the emissions of these cities. In Figure 12, we note that some of the percentages are negative because the global emissions have become negative, but the city emissions have not. In most of the scenarios, cities are expected to make up at least thirty percent of global emissions, if not more. This presents an interesting opportunity for these cities because if they can become far more efficient, then they could impact global emissions.

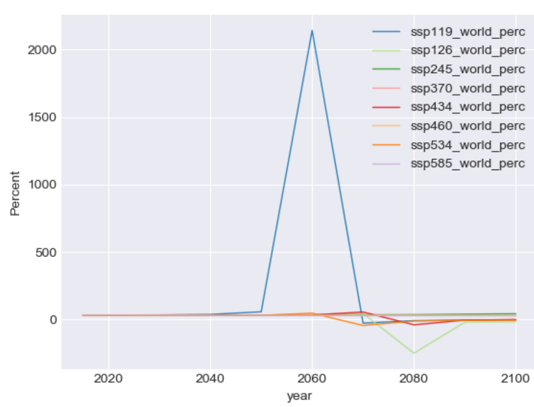

Figure 11: City emissions as a percent of global emissions

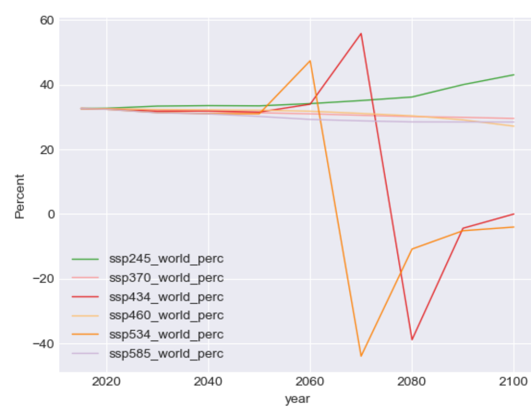

Figure 12: Figure 11 without the 119 and 126 scenarios

We consider two plans. First, we imagine setting all the emissions for these forty-nine cities to zero, beginning in 2020. Clearly, this is not a feasible plan, but it is interesting to see what type of impact this could have on global emissions. Doing this, we get the result in Figure 5. We observe two things. First, this mostly has a translational effect of the projections for global emissions. Therefore, total global emissions, for the pathways where emissions tend to zero, become zero or negative earlier. Therefore, cities do impact total emissions. The second plan we consider is by 2030 cities decrease emissions by 30% compared to estimates, by 2040 cities decrease their emissions by 60% compared to estimates, by 2050 decrease emissions to 90% compared to estimates, and by 2060 onwards make emissions close to 0. To compare the three scenarios, we look to the table.

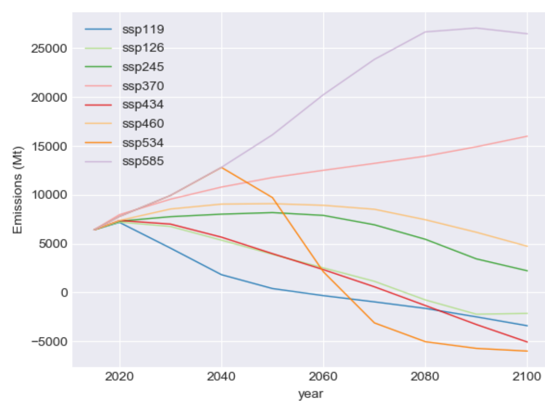

Figure 13: Global emissions when setting city emissions to zero

To quantify to what extent cities, make an impact, we compare estimates for total global emissions until the end of century in the three cases. To put the gigatons of carbon dioxide into context, we note that according to the IPCC, the carbon budget to stay below 1.5 degrees Celsius with 67% probability is 570 Gt, and the carbon budget to stay below 2 degrees with 67% probability is 1320 Gt. This helps explain what the estimates mean. The table below shows us that the more cities can do in the short run, the better for global emissions. Second, the impact cities can have is influenced by the context. If the global emissions are close to zero or negative, it is likely that these cities are also decently efficient, so they do not have that much room to improve and those improvements do not play a major role in total Gt emissions. On the other extreme, if the globe is growing a lot and emitting prodigious amounts of carbon dioxide, cities cannot do enough. However, their impact can still be large. The times that cities play an influential role is in the 'middle-of-the-road' scenarios. Thus, these preliminary experiments suggest that action by cities can save us depending on the context.

Table 1: Global carbon dioxide emissions until the end of century in Gt for predictions made by scenarios, setting city emissions to zero, and the third plan

	ssp119	ssp126	ssp245	ssp370	ssp434	ssp460	ssp534	ssp585
Case 1	133.6	365.8	876.9	1599.7	309.8	1016.5	447.1	2420.5
Case 2	51.0	217.3	571.6	1106.4	172.2	698.1	224.4	1710.0
Case 3	85.9	257.7	616.1	1156.5	212.9	743.8	274.5	1760.0

6 Takeaways

Incorporating highly-resolved temporal and spatial decisions by humans into the Earth system will give planners and policymakers the ability to evaluate spatially-explicit impacts of different policy implementations by city. When asking ourselves the question, can cities save us, our research has definitely shown promising results. However, there is still variability in the fact there is a lot to still consider and that to a large degree, our research has shown that there is still a lot we do not know. For example, we had to use a proxy by looking at the carbon budget and taking the sum for the impact of cities. We still do not know the exact impact city reduction has on the globe. Further, as we alluded to earlier, our research suggests that cities help push us towards our global goals. If we as the world are extremely sustainable, then cities themselves simply add to this reduction in greenhouse emissions and if they are far from our emission goals, then cities will not be able to bear all the weight. However, with decent progress made as a global economy, cities can push us past the barrier into a safer global temperature.

7 Actions Cities Can Take

As for determining whether or not these are reasonable standards to meet, we look to see what cities can actually do to reduce emissions. We begin with transportation where many cities have tremendous room for improvement. Immediate actions include having “regulated tailpipe emissions, limited idling, and created car-free zones. Longer-term actions could be an optimization of transit and transportation systems with an understanding of future technology trends" [1]. It is more important to build these systems in cities like Los Angeles with a lack of public transportation, and less so in cities like Boston and New York that have better public transportation.

Immediate steps by cities to make themselves more sustainable and resilient are possible, and many are already acting: committing to renewable energy, setting emissions targets, and pledging to stick to the Paris climate agreement goals. Some other actions cities can take is to mandate clean energy use for some percent of their energy consumption or require buildings to be carbon neutral.

While the exact actions city should take depends on their profile, there are a multitude of ways cities can act. Moreover, there are many actors, like Bloomberg Philanthropies that will invest in local actors. They have already invested in Tokyo creating a greener real estate market by requiring new buildings to be rated on environmental performance. The goal is to create a market where people also value sustainability. Thus, given the general lack of action, there are many actions local actors can take to reduce their city’s carbon footprint.

8 Further Steps

There is still plenty of work to be done in this area. In terms of our code, the most immediate course of action would be to find the shapefiles for the global cities. We can then proceed to find the emissions intersections. This could also be interesting because it will allow us to look at the suburbs and surrounding areas more to see where the concentration of emissions are and if expanding to the suburbs can get us to where we want to be in terms of climate action and global temperatures. There is still a lot of uncertainty when we look at how these cities are built. For example, driving from the suburbs to the city does account for a lot of transportation emissions. Further, electricity grids stored in other locations may be how cities obtain energy so it is important to continue to understand how cities function and what areas we should be looking at. Another option we have is to look at trying to improve the nearest neighbor formula to develop a better algorithm to find our nearest neighbors. We could also possibly look at trying to quantitatively find the rate of reduction each city needed to maximize climate change control. Whether this be the top 3 cities reducing emissions completely or the top 50 reducing it by half, we would basically be treating it as an emission as an optimization problem. The easiest way to do this make a duplicate dataset with the grids reduced by the amount we calculate (subtracted) and then integrate the global emissions. However, with more time we could also come up with better metrics for reduction so this is something we hope to look more into as we go along.

We also would want to do case studies to compare what cities are doing right now with what they can be doing and what they should be doing. Since each city is different, it is important to understand what parts of their economies will need to adapt in order to allow for climate change mitigation. This will allow us to better understand what measures are practical and what percent of their emissions cities can actually reduce. We would want data like the administrative units to determine where "political capital" should be spent (who all needs to work with who when implementing carbon policies) and a breakdown of emissions by sector for each city (may be hard to find for non-US cities). From here we will be able to potentially either publish or write an op-ed with our research and recommendations such that policymakers can actually understand the changes we need to make to deal with climate change. Ultimately, however, it goes back to the three issues we mentioned in the background of our paper: how are we to implement such changes, despite the science, when people have no immediate desire to react. While not directly the subject of the paper, we do believe this relates to its goal: help people recognize the dangers of climate change and motivate them to act by showing the impact they could have.

9 Acknowledgements

The authors would like to thank the staff of 6.S898, specifically Henri Drake Professor Rivest, Professor Edelman, Professor Fernandez, for creating the class and giving us the platform to conduct this research. The authors would also like to thank the Oak Ridge National Laboratory team for suggesting the problem, providing guidance, and supporting the project.

References

[1] Citylab. What local climate actions would have the greatest impact. https://www.citylab.com/environment/2018/10/local-climate-actions-biggest-impact/572608/, October 2018.

[2] Peter Cramton, Axel Ockenfels, and Steven Stoft. Symposium on international climate negotiations. *Economics of Energy & Environmental Policy*, 4(2):1–4, 2015.

[3] Kerry Emanuel. *What we know about climate change*. MIT Press, 2018.

[4] National Geographic. Seven things to know about climate change. https://www.nationalgeographic.com/magazine/2017/04/seven-things-to-know-about-climate-change/, Oct 2017.

[5] M Gidden, Keywan Riahi, S Smith, Shinichiro Fujimori, Gunnar Luderer, Elmar Kriegler, Detlef P van Vuuren, Maarten van den Berg, Leyang Feng, David Klein, et al. Global emissions pathways under different socioeconomic scenarios for use in cmip6: a dataset of harmonized emissions trajectories through the end of the century. *Geoscientific Model Development Discussions*, 12(4):1443–1475, 2019.

[6] Edward L Glaeser. Green cities, brown suburbs. *City Journal*, 19(1):50–55, 2009.

[7] Joyeeta Gupta. A history of international climate change policy. *Wiley Interdisciplinary Reviews: Climate Change*, 1(5):636–653, 2010.

[8] Stephane Hallegatte, Mook Bangalore, Laura Bonzanigo, Marianne Fay, Tamaro Kane, Ulf Narloch, Julie Rozenberg, David Treguer, and Adrien Vogt-Schilb. *Shock waves: managing the impacts of climate change on poverty*. The World Bank, 2015.

[9] Zeke Hausfather. Cmip6: the next generation of climate models explained. https://www.carbonbrief.org/cmip6-the-next-generation-of-climate-models-explained, December 2019.

[10] Dan Hoornweg. Cities and climate change: An urgent agenda. *Sustainable low-carbon city development in China*, 3, 2012.

[11] Daniel Hoornweg, Lorraine Sugar, and Claudia Lorena Trejos Gómez. Cities and greenhouse gas emissions: moving forward. *Environment and Urbanization*, 23(1):207–227, 2011.

[12] Li Jiang, Xiangzheng Deng, and Karen C Seto. The impact of urban expansion on agricultural land use intensity in china. *Land Use Policy*, 35:33–39, 2013.

[13] NASA. Climate change evidence: How do we know? `https://climate.nasa.gov/evidence/`, Sep 2019.

[14] Ivan Penn. Pg&e warns it could cut power to california users again. *New York Times*, Oct 2019.

[15] Karen C Seto, Burak Güneralp, and Lucy R Hutyra. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences*, 109(40):16083–16088, 2012.