INTRODUCTION

Scientists have stated that the tipping point into ecological and environmental devastation is a 2°C increase in the average global temperature compared to the pre-industrial baseline. They have also strongly urged that we try to avoid even the 1.5°C threshold, as its effects may take centuries to recover from. To stay below the 1.5°C limit, countries would have to reduce the amount of greenhouse gases (GHGs) they emit each year, working to avoid a global concentration limit set by scientists. This is the basis for the Paris Agreement, a treaty adopted in December 2015 by 197 United Nations countries pledging to fight climate change. Each party submitted emission reduction goals in Intended Nationally Determined Contributions (INDCs) before and Nationally Determined Contributions (NDCs) after its adoption.

The data for this project contains historical GHG emissions from all countries and the benchmarks laid out in their INDCs and NDCs. The trajectory of the historical data was extrapolated forward to 2030 to provide projections of GHG emissions to compare to the goals of the Paris Agreement. The difference will be measured as the emissions gap. The analysis conducted with this data focused on historical global greenhouse gas emissions and identifying the largest contributors to greenhouse gas emissions, both historically and currently. The countries of focus were identified based on their behavior as top emitters in 2015. The top 10 emitters in 2015 will be a primary focus of this analysis.

BACKGROUND & THEORY

The Paris Agreement signatories had to submit plans for how and by how much they would lower their GHG emissions through 2020, 2030, and 2050. Such plans, or Intended Nationally Determined Contributions (INDCs) and Nationally Determined Contributions (NDCs) for pre- and post-Agreement plans, respectively, would be reviewed and revised at each benchmark based on the nations' achievements toward their GHG target. In a ramp-up style, the Agreement requires countries to recommit to more aggressive plans with each consecutive iteration. While NDCs include more than just GHG emission reduction targets, they will be the focus of this project.

It is understood that annual GHG emissions have accelerated exponentially across the globe since the pre-industrial period (often considered by scientists to be 1850 – 1900). In 1992, the United Nations drafted its Framework Convention on Climate Change (UNFCCC) to devise an agreement to limit the increase in GHGs in the atmosphere. This was built upon by the Kyoto Protocol, adopted in 1997 and later superseded by the Paris Agreement in 2015. Each successive treaty was more aggressive and urgent in its goals. However, we continued to see rising atmospheric GHG concentrations and greater yearly emissions during that time. We also saw accelerated effects of climate change. So far, no treaty has had much success in its attempt to curb the impacts of climate change.

This project aimed to examine how well the parties that signed the Paris Agreement are meeting their goals. Based on what they need to reduce to by a particular year and where they are now, are they on track to limit warming? Which countries have the greatest impacts – whether they achieve or fail – on the global limit goal?

HYPOTHESIS

Despite having lower emissions than those on their pre-2016 business-as-usual (BAU) trajectories, I expect most nations will fall short of their reduction goals. Their predicted emissions for 2030 will exceed the pledged emissions cap. Larger countries, such as the United States, will significantly impact global emissions. I suspect many of these larger nations will not meet their goals. I predict that the gap between actual and pledged emissions for 2030 will be lower than it would have been without the adoption of the Paris Agreement for industrialized nations, but this may not be the case for developing nations that are still industrializing. I expect the actual global emissions gap for 2020 to be significant, as will the

estimated gap for 2030. I believe that the top emitters will include the United States, China, and India based on population and economic activity.

DATA

The primary dataset of historical emissions was the PIK PRIMAP historical emissions dataset,[1] which was chosen for its thoroughness. It includes all Kyoto Protocol GHGs, used by the Intergovernmental Panel on Climate Change (IPCC) and UNFCCC for their global-standard reports. While country-reported data was prioritized, third-party data was collected to fill in where nationally reported data was unavailable. The list of emissions sectors and categories used is also comprehensive.

An additional dataset was created containing the NDCs of the countries investigated and the global benchmarks established by scientists necessary to stay under the 1.5 and 2°C thresholds.[2][3] The data was collected from various sources and underwent any transformations needed to get the required metrics.

ANALYSIS

It should be noted that the emissions data used excluded calculations for Land Use, Land Use Change, and Forestry (LULUCF). This sector covers GHG emissions and removals from human-induced land use, including deforestation, reforestation, and afforestation; cropland, grazing land, and forest management; and revegetation. This is important for affecting the amount of carbon dioxide in the atmosphere, but there is no common framework for LULUCF accounting. Many INDCs and NDCs, along with the data provided by governments, lack mention of the necessary assumptions and methods applied to collecting LULUCF data, presenting an issue in consistently tracking international LULUCF data. Even when mentioned, many different methods are used to collect this data, adding to the inconsistency. For this reason, the totals used for analysis exclude LULUCF in this project. The effect of this exclusion was evaluated, and it was found that after 2000, there is not a pronounced effect on the data. Therefore, this author feels confident that it has no significant impact on the underlying assumptions and analysis.
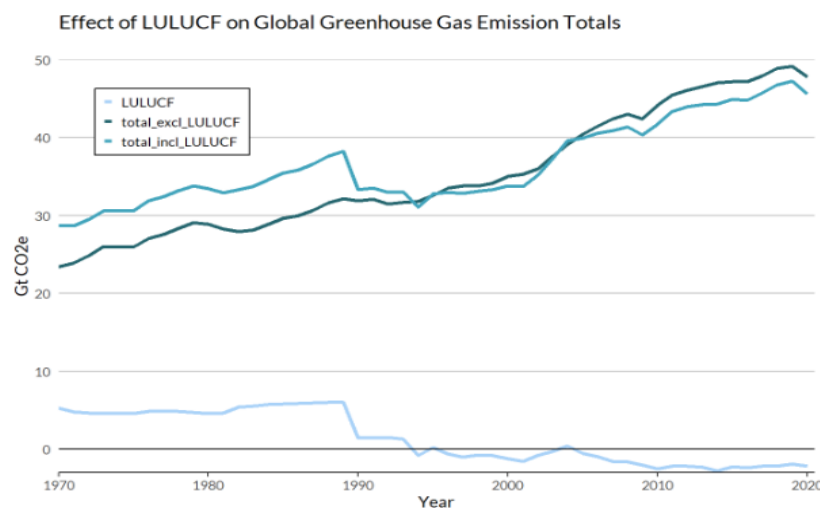

Figure 1

[1]Link to & information about the dataset: Gütschow, J.; Pflüger, M. (2021): The PRIMAP-hist national historical emissions time series v2.3.1 (1750-2019). zenodo. doi:10.5281/zenodo.5494497.

[2] Sources for NDCs: Climate Watch NCD Tracker Custom Comparison, Climate Watch Explore NDCs,

[3] Sources for pathways: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

When attempting to lower global GHG emissions, it is important to know which countries have the greatest impact. A few patterns are noticeable when evaluating cumulative historical emissions from 1850 to 2020. Ten countries have the greatest cumulative emissions over the period (in descending order): the United States, China, Russia, India, Germany, the United Kingdom, Japan, France, Ukraine, and Brazil. Figure 2 shows the share of global emissions each of these ten countries make up each year, with all other countries grouped as "All Others", from 1950 – 2020. These ten countries accounted for roughly 50% or more of yearly global emissions in this period. The widening or narrowing of each country's area on the graph reflects increases or decreases in yearly emissions over time.
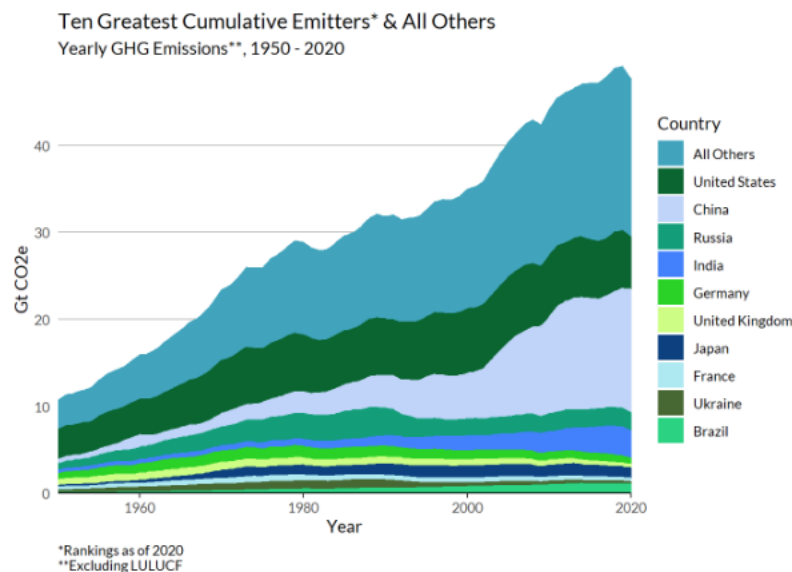

Ten Greatest Cumulative Emitters* & All Others
Yearly GHG Emissions**, 1950 - 2020

*Rankings as of 2020
**Excluding LULUCF

Figure 2

The United States saw its most significant changes from the 1870s to the early 1970s. As one of the first countries to industrialize and liberalize its economy, the composition of the United States's economic activity has not seen major change in the last half-century. This lack of change is reflected in the graph: Over the last 40 years, the United States' yearly emissions have increased slightly but have remained relatively consistent. Fellow early-industrializers that made the list include France, Germany, and the United Kingdom. These three countries have made visible decreases in the last few years. By contrast, China – and India, to a lesser extent – show increases over the same period, rising significantly around the turn of the 21st century. These emission increases reflect the countries' efforts to rapidly industrialize in recent decades and open their economies to global markets.

Population plays an essential role as well. If this data were represented in emissions per capita, it could significantly change the composition of these rankings. The United States, China, and India occupy large, densely populated territories. The United States has a large, relatively stable population. While China and India also have large populations, they saw theirs boom in the latter half of the twentieth century. A large share of these countries' emissions is likely, in part, due to their large populations.

The combination of early industrialization, a large economy, and a large population provide the foundation for the United States being the largest single contributor to Earth's greenhouse gas concentrations since 1850. Countries like the United States, France, Germany, and the United Kingdom with high historical emissions must play a large leadership role in the global effort to reduce GHG emissions.

Table 1. Top 10 Cumulative Emitters, 1850 – 2020

Country	Total excl. LULUCF summed	Total incl. LULUCF summed	LULUCF summed
United States	557.11072	592.42232	35.3115949
China	363.94993	426.09615	62.1462261
Russia	175.72992	186.76164	11.0317199
India	119.18615	149.72161	30.5354622
Germany	115.40118	114.588	-0.8131868
United Kingdom	99.21004	102.51547	3.3054277
Japan	76.41112	75.42995	-0.9811712
France	59.74854	56.53729	-3.2112424
Ukraine	51.47677	57.26918	5.7924091
Brazil	49.02884	130.26351	81.2346635

The nations of focus for the projections were determined by the highest emitters when the Paris Agreement was signed and NDCs were being crafted. Comparing the largest cumulative emitters since 1850 to the largest emitters of 2015, we see some countries appear on both lists. In 2015, the ten countries that emitted the most GHGs were, in descending order: China, the United States, India, Russia, Japan, Brazil, Iran, Germany, Indonesia, and Saudi Arabia. Together, these "Top Contributors" made up nearly 2/3 (64.5%) of global emissions that year (Figure 3). This effect is noticeable in the data – aggregated historical emissions of those ten mirrors the global emissions data nearly perfectly since 1900. Since 1980, this group of countries has constituted roughly the same percentage of global emissions each year, reflecting the massive effect these countries have on the aggregate.

Table 2. 2015 Top Emitters

Country	Total excl. LULUCF summed	Total incl. LULUCF summed	LULUCF summed
China	12.7866	11.9384	-0.84823
United States	6.78486	6.04640	-0.73846
India	2.91943	2.62143	-0.29800
Russia	2.06200	1.45604	-0.60596
Japan	1.32334	1.26709	-0.05624
Brazil	1.16606	1.38636	0.22031
Iran	0.92902	0.94871	0.01969
Germany	0.89913	0.88146	-0.01768
Indonesia	0.82857	1.47743	0.64886
Saudi Arabia	0.75156	0.74232	-0.00924

Ten Greatest Emitters* vs Global Emissions
Aggregated Annual GHG Emissions**, 1920 - 2020

*In 2015
**Excluding LULUCF
Top Contributors: China, United States, India, Russia, Japan, Brazil, Iran, Germany, Indonesia, and Saudi Arabia
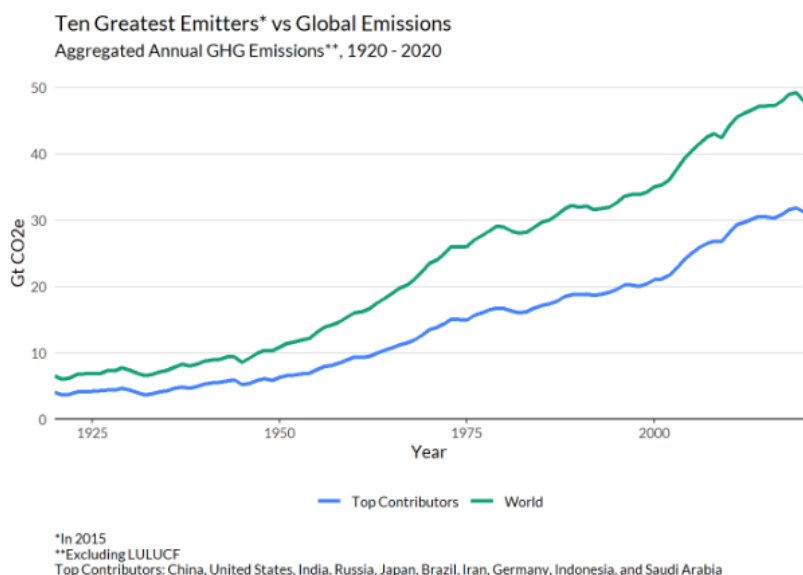
Figure 3

The countries on this list share several characteristics. Many of these countries highly depend on fossil fuels for energy needs. Germany, China, India, Russia, the United States, and Indonesia rely heavily on coal for most of their power generation or fuel. In 2016, each of these six countries was also in the top ten of global coal producers.[4] Saudi Arabia, and Brazil also rely heavily on fossil fuels, mostly on oil. Transitioning from fossil fuels to renewable energy sources for economic activities and away from fossil fuel production is a key approach to combatting emissions.

Energy-intensive sectors, such as manufacturing and transportation, are large emissions components for Germany, Japan, Saudi Arabia, the United States, and China. Several countries have made massive advancements in transportation. Germany is one of the few major European Union countries to not institute an energy-efficient transportation system, and the United States is incredibly reliant on passenger vehicles for almost all its transportation. A transition to high-speed rail powered by renewable, clean energy would eliminate many of the need for trucks and combustion-engine trains for industrial transportation. A wide-coverage system would allow commuters in urban and suburban areas to help lower emissions. The United States has a long way to go. It currently lacks traditional public transportation infrastructure in most of the country. Advancements in any form of public transportation would be helpful. However, we must push for the most climate-friendly options as well.

Renewable energy as the primary input source for manufacturing activities, away from coal, oil, and gas, can help reduce emissions. Technologies and infrastructures like carbon capture and storage and direct air capture solutions can help combat byproduct emissions from manufacturing. Additionally, using materials that promote circular economies can reduce energy needs. The responsibility for these actions currently falls largely on corporations as strong government policies are mostly lacking.

The largest source of Iran's emissions is urbanization – particularly buildings.[5] Other nations, such as Germany, the United States, and Saudi Arabia, also produce significant emissions from powering buildings. Decarbonization strategies, as well as efficiency and weatherization measures, would substantially lower emissions in this sector. The largest source of building emissions is from heating and cooling systems and lighting. Electrifying heating and cooling away from natural gas and oil, upgrading energy-efficient appliances, and other building utility optimization methods are all potential partial solutions. Changing the construction of new buildings and weatherizing existing buildings to increase the efficiency of heating and cooling can significantly reduce electricity needs.

Major emissions sources for China and India come from the size of their economies and rapid economic growth. The influence of India and China's massive shift toward rapid industrialization at the turn of the 21st century is reflected in the sharp increase in emissions around the year 2000. Rapid economic growth over the last 30 years also greatly contributes to Iran's emissions. Analysis of emissions as a percentage of GDP reveals that Iran's rate is approximately 5 times higher than the global average of 0.5 tons of GHG per $1000 GDP. However, while it makes the top 10 list of emitters, it was ranked 26th in terms of GDP in 2015; Saudi Arabia was 20th, Indonesia 17th, and Russia 12th, while the rest of our Top Contributors were in the top 10th by GDP.[6]

As mentioned before, large populations and economies in China, India, the United States, Russia, and Germany contribute to having a large share of global emissions. These countries must make massive

[4] Rob Smith, "These are the world's biggest coal producers." World Economic Forum, 11 January 2018, https://www.weforum.org/stories/2018/01/these-are-the-worlds-biggest-coal-producers/
[5] Claudio Providas, "Iran tackles its cities' carbon emissions." UNDP, 21 October 2021, https://www.undp.org/blog/iran-tackles-its-cities-carbon-emissions
[6] World Bank Data, "GDP (current US$)." World Bank Group, 2015, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

changes in other areas, like inputs and systems of economic activity, to counteract population-related emissions.

While not part of this project's measurements, deforestation has been the largest component of Brazil's emissions.[7] Brazil has, therefore, made emissions reduction efforts in other parts of its NDC less of a focus than combating deforestation. Despite this focus, government policy has rolled back on its commitment to lowering legal deforestation and is struggling to combat illegal deforestation. Changes in the national government and the power of domestic voting blocs have largely been the source. Similarly, the United States saw a drastic change in climate policy after the 2016 election. Most significantly, the president pulled out of the Paris Agreement, and like Brazil, also advocated for rollbacks in environmental protections to benefit a particular industry. These countries are meant to hold themselves accountable for an international agreement but have gone back on those promises to satisfy particular domestic economic sectors. These examples show how greatly domestic political issues can affect foreign policy. To an extent, national policy can be mitigated by state and local policy, but to ensure a country will work towards its NDC, a commitment to fighting climate change must become a key issue for voters.

The Top Contributors submitted INDCs in the fall of 2015 as part of their intention to sign the Paris Agreement at the UNFCCC's twenty-first session of the Conference of the Parties (COP 21) that November. These INDCs and their later NDCs were aggregated to evaluate their combined proposed trajectory (with immediate implementation) (Figure 4). Historical data for the sum of the Top Contributors and the global total were used to predict each grouping's yearly emission trajectory for 2021 through 2030. First, a BAU line, reflecting behavior before 2016, was predicted to estimate emissions if pre-INDC policies were maintained. Next, 2015 to 2020 served as each group's post-INDC and NDC policy behavior period. That data was extrapolated to predict what emission levels are expected to be in the 2020 - 2030 period if the post-Paris Agreement behavior remains unchanged.
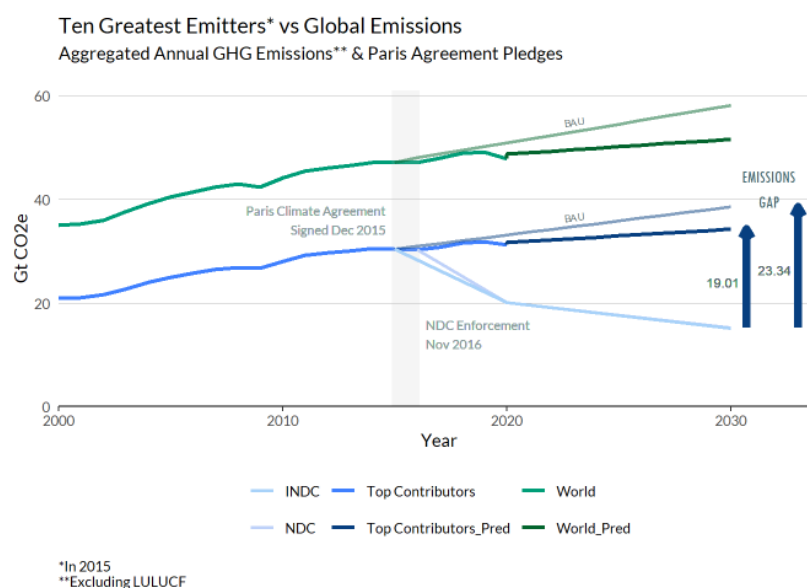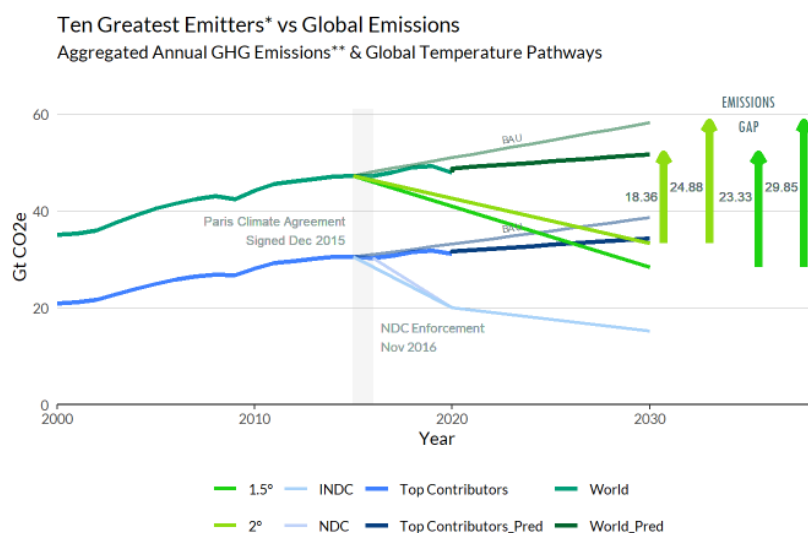

Figure 4

2021 is a unique year to investigate these actions. Global data through 2020 has been collected and calculated, and reflection can be done on pre-2020 pledges (e.g. Cancun Pledges, Doha Amendment) before entering the 2021-2030 interval of the Paris Agreement. In Figure 4, the collective pre-2020 goals for the Top Contributors can be seen on the INDC and NDC lines at the year 2020. This connection links

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[7] Jocelyn Timperley, "The Carbon Brief Profile: Brazil." Carbon Brief, 3 July 2018 https://www.carbonbrief.org/the-carbon-brief-profile-brazil/

their behavior when making their post-2020 pledges to their shortcomings in meeting their pre-2020 pledges. The line's steepness reflects the degree of change they would need to make to be on track. This year is also significant because we have reached the first step in the 5-year ambition-raising cycle of the Paris Agreement. Before COP 26 this fall, parties were requested to submit new or updated NDCs representing a progression in intention and actions compared to their first NDCs.

For the years 2016 to 2020, global emissions, and those of the Top Contributors, were lower than their BAU predictions were estimated to be. However, the decrease in yearly emissions came nowhere close to as low as needed to reach 2020 pledges or be on track to reach 2030 pledges. When aggregating the pledges for the period ending in 2020, their yearly emissions were meant to be lowered to 20.06 Gt of CO_2 equivalent by 2020. The collected data from that year shows that the actual aggregate was 31.18 Gt of CO_2 equivalent – more than 10 Gt more than the goal.

The INDC and NDCs these countries submitted were significantly more ambitious than their pre-2020 targets: 15.15 and 15.25 Gt CO2e before 2030, respectively.[8] However, estimates show that emissions will continue to increase from 2020 to 2030. Additionally, the gap between actual emissions and the pledges will be even larger in 2030 than that for 2020. Compared to the aggregated NDCs for the Top Contributors, estimates put emissions for the year 2030 at 19.01 Gt CO_2 equivalent higher than pledged (34.26 against 15.25). This gap is, however, smaller than the gap between pledged emissions and BAU emissions for the year 2030 (23.34). As noted above, our Top Contributors collectively failed to meet their pre-2020 pledges and are on track to fail to meet the pledges of their current NDCs. Plans will need to be considerably more aggressive in the next round of NDCs, and actions must be more urgent throughout the decade if members hope to close the gap.

Figure 5

As previously stated, the main goal of the Paris Agreement is to limit global warming to 2°C while making best efforts to stay below 1.5°C compared with pre-industrial levels. In its Fifth Assessment Report[9], the IPCC predicts that the paths with a more than 50% chance of occurring require 72% and

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[8] Russia is the only country that submitted an NDC with a less aggressive goal than its INDC, from a maximum effort of 75 Gt CO2e to 70 Gt CO2e.

[9] This report was the basis for the Paris Agreements; the Sixth Assessment Report was released this year and will be the basis for the next round of NDCs.

49.5% (42-57%) reductions in global GHG concentrations by 2050 as compared to 2010 levels, for 1.5 degrees and 2 degrees, respectively. That means that global emissions in 2030 would need to be 28.28 and 33.26 to be along the 1.5 least-cost and 2°C mean-cost pathways, respectively (Figure 5). Like with the NDCs, there is a large gap between the pathways and predicted global emissions in the year 2030 (23.34 and 18.36 Gt CO2e more in predicted emissions for 1.5 and 2 degrees, respectively). However, like the Top Contributors data, the predicted emissions through 2030 are lower than those predicted for the BAU trajectory (51.61 and 58.14 Gt in 2030). Like the others, the emissions gap here is significant (29.85 for 1.5°C, 24.88 for 2°C).

Table 3. Goal Emissions, Predicted Emissions, and Predicted Emissions Gaps in 2030

Group	Pathway	Emissons (Gt)	Surplus from Goal (Gt)
World	1.5°	28.28	
World	2°	33.26	
Top Contributors	NDC	15.25	
World	Predicted	51.61	18.35, 23.33
Top Contributors	Predicted	34.26	19.01
World	BAU	58.14	24.88, 29.86
Top Contributors	BAU	38.59	23.34

The data reflects that, on the aggregate, countries that have signed onto the Paris Agreement are not doing enough so far to limit warming below 2°C. The largest emitters have not enacted policy changes that put them on track to meet the goals of their NDCs. These nations are also not expected to reach peak emissions before 2030. One goal of the Paris Agreement is to peak as soon as possible; the goal in 2015 was for peak emissions by 2025. The longer it takes for emissions to peak, the more difficult it will be to reach net zero goals and stay on track to limit warming.

CONCLUSION

The Montreal Protocol was created in 1987 to reverse the depletion of the ozone layer in the atmosphere by phasing out substances that cause ozone depletion. In 2016, scientists confirmed that the ozone layer was recovering, with the possibility of a full return by 2066. The international cooperation in this treaty is an example of a successful collective, multilateral response to a global climate issue. These countries can make these GHG emission changes happen.

Those already disadvantaged, both inter- and intra-nationally, will face the brunt of global warming's effects. Those countries and communities that currently lack, or have been systemically blocked from accessing, the infrastructure, technology, and financial resources to mitigate these changes will all need particular focus and investment to ensure an equitable approach to climate adaptation and emission reduction efforts. On an international scale, industrialized and wealthy nations, particularly those that are the greatest emitters, should lead the way in investing in developing nations and the Global South. As one of the leaders in both, this is particularly true for the United States. On the national front, domestic policy must reflect this approach.

Climate change is an imminent global crisis that we are already facing the costly effects of: increasingly frequent and destructive natural disasters and "100-year storms," unprecedented heat waves and heat-related deaths, massive flooding, and more. Scientists state that if we cannot keep global warming below 1.5°C, we will see catastrophic environmental consequences, including uninhabitable regions resulting in climate refugees, crop failure, and biodiversity decline.

Governments and corporations must address and combat climate change through policies curbing GHG emissions. These policies require innovative technologies, changing the status quo, and massive investments in both. Transitions to renewable energy away from fossil fuel combustion is a great first

step. However, there must be a multi-pronged approach across industries, sectors, and levels of government. As stated previously, many developing nations will require international financial support to make these transitions. Governments often step in to fill gaps where corporations see no benefit to an action. This is where strong pro-environmental policies and regulations come in. Still, corporations must see the benefit of moving to green, sustainable actions and technologies. Voters in the former case and consumers in the latter hold power to encourage those changes. We must fight for those who will be hurt first and greatest, and time is running out.