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Abstract

The climate crisis is increasingly impacting all aspects of society. This paper seeks to answer how vulnerability to climate change impacts GDP per capita. To do so, an OLS regression is run to measure GDP per capita's sensitivity to the ND-GAIN Vulnerability Index across 178 countries from 1995 to 2018. A time-trend regression is used to determine the sensitivity coefficient. The results show vulnerability to climate change negatively impacts GDP per capita, with sensitivity increasing as years progress. These findings indicate the need for immediate action on a local and international level.

Vulnerability to Climate Change's Impact on GDP Per Capita

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Abstract

The climate crisis is increasingly impacting all aspects of society. This paper seeks to answer how vulnerability to climate change impacts GDP per capita. To do so, an OLS regression is run to measure GDP per capita's sensitivity to the ND-GAIN Vulnerability Index across 178 countries from 1995 to 2018. A time trend regression is used to determine the sensitivity coefficient. The results show vulnerability to climate change negatively impacts GDP per capita, with sensitivity increasing as the years progress. These findings indicate the need for immediate action on a local and international level.

I. Introduction

While climate change may have started as a slow burn issue, its impacts have heightened over the last several years to create increasingly evident effects. The year 2019 was confirmed as the second hottest year and had more tropical cyclones than average (UN News, 2020). Unfortunately, this is expected to be only the beginning of serious climate change effects. The National Aeronautics and Space Administration expects continued negative impacts such as changes in precipitation, sea levels rising one to eight feet by 2100, and hurricanes increasing in intensity and occurrence (NASA, 2020). All of these impacts have — and will continue to have — unfavorable effects on human, ecological, and international life. As research continues to delve deeper into the ways climate change is evolving everyday lives, climate change's impact on the economy is one place that is finally being examined.

The global economy's choices, specifically larger economies like the United States and China, have long been identified as instigators of climate change (Union of Concerned Scientists, 2020). For example, since the industrial revolution began in the mid-1700s, countries have increasingly released carbon dioxide and other greenhouse gases into the atmosphere as they used fossil fuel dependent machines and increased production (History.com Editors, 2019). This trapped heat in the atmosphere and began to warm the planet, raising the global temperature one degree celsius (Hawkins et al., 2017). The warmer atmosphere collects, retains, and drops more water, changing weather patterns and worsening natural disasters, all of which make up climate change (Denchak, 2017).

As countries continue to crave economic growth, climate change is no longer solely an externality, but an impediment. A study by Diffenbaugh and Burke (2019) on climate change

influences on the recent increase in inequality, found a 90% likelihood that per capita GDP is lower today than if climate change had not happened. For countries still looking to grow economically, whether it be to gain power or lift themselves out of debt and poverty, mitigating and adapting to climate change is necessary. International agreements, like the Paris Agreement, are focused on combating climate change effects while creating and investing in a sustainable future (United Nations, 2015). While there is an overall goal of the Paris Agreement, to keep the increase in global temperature below two degrees Celsius of pre-industrial temperatures, each signed country also determines their own goals based on their country's characteristics. To decide the targets to set for a specific country, one necessary aspect to take into account is how vulnerable that nation is to climate change.

Countries have varying levels of vulnerability to climate change due to many reasons. Their economic resources can allow them to focus on preparing for inevitable natural disasters; and further, the geographical characteristics of the land--specifically the distance from the sea and distance from the equator--affects what type and level of intensity of the climate change impacts the country or parts of the country feel (UK Environmental Change Network, 2013). Thus, if a country still desires to have economic growth, it must be aware of its vulnerability to climate change and how its vulnerability impacts its economy. One way to measure a country's vulnerability is through the Notre Dame Adaptation Initiative (ND-GAIN), which calculates a country's ability to deal with climate change in different ways. Using the ND-GAIN, this research paper asks how a country's changing level of vulnerability to climate change affects its gross domestic product per capita. In Section II, I review the literature that has studied climate change and economic growth, describing how my research adds to the conversation. In Section

III, I lay the theoretical groundwork, suggest a new theory, and express three hypotheses. Finally, Section IV lays out the datasets used, and the empirical model utilized to determine how vulnerability to climate change influences GDP per capita.

II. Literature Review

Previous literature has studied the connection between economic growth and vulnerability to climate change. Kanbur et al. (2019) examines 1995 to 2015 to determine the effects of climate change on economic growth. The study finds that climate change slows economic growth. It also finds that the influences of climate change in one climate-sensitive sector can impact sectors that are not directly affected by climate change. The research also states that the NG-GAIN vulnerability and readiness score and GDP per capita are associated with one another in middle and high-income countries globally. Looking at the NG-GAIN score, the most vulnerable African countries are also the poorest, while wealthy countries have low scores, meaning lower vulnerability. Kanbur et al. believes this may indicate that countries can adapt better and reduce vulnerability when they have higher levels of economic growth. Kanbur et al. (2019) also conclude that the impacts discussed can compound and create lasting effects on the economy. My research paper looks at three additional years through the NG-GAIN Vulnerability Index. While it is valuable to look at continent specific data, my research broadens the view to include a greater global perspective. Further, Africa has the lowest GDP per capita as a continent, while North America has the highest (Misachi, 2017). Thus, the countries with the highest greenhouse gas emissions, like the United States, should be compared to African

countries to gain an understanding of possible future global climate change policy decisions, specifically regarding the amount of resources a country should contribute to fight the crisis.

Füssel (2010) conducts a semi-quantitative analysis that looks into how climate change is distributed across countries and various sectors of the economy. Two responsibility indicators, two capability indicators, and 33 sector-specific vulnerability indicators were ranked, correlated, then analyzed to conclude the causes of inequality. Ultimately, the study finds the countries least vulnerable to climate change are those most responsible for it. They also find that the countries most responsible for greenhouse gas emissions are not going to experience the brunt of negative economic growth effects due to climate change because of their economic situations, but those who release few greenhouse gases in comparison will (Füssel, 2010). My research paper attempts to verify Füssel's research findings. When the countries creating greenhouse gases do not experience the main negative climate change impacts, they may not feel the need to rectify their action (DTE Staff, 2015). That could lead to countries following in the U.S.'s footsteps and pulling out of global agreements, specifically, the Paris Agreement, which plans to curtail the adverse effects. My study also looks at overall GDP per capita to get an extended analysis, rather than the economy sector-specifics.

Finally, Dell et al. (2008), looks at the last 50 years of annual variation in temperature and precipitation to determine the effects of climate change on global economic activity. The study finds a one-degree Celsius increase in temperature in a given year decreases economic growth by 1.1 percentage points on average. Additionally, they find that adaptation does not necessarily reverse the adverse effects in the medium term (Dell et al., 2008). My research focuses on the compilation of the effects of climate change rather than measuring the impact of

the individual aspects, like temperature or precipitation, to measure how vulnerable a country is to climate change. Further, by looking at over two decades of data, conclusions may be drawn if the increase in adaptation to climate change has impacted GDP per capita's sensitivity to it, addressing Dell et al.'s (2008) lack of reversal of the adverse effects finding.

III. Theory and Hypotheses

Based on the existing literature, climate change affects the inner workings of a country — specifically, their markets, investment, and human capital (Park, 2017; Al-Amin et. al., 2011). However, it can be said that there are two dueling theories to explain climate change and its impacts— endogenous and exogenous growth theories. The endogenous growth theory believes economic growth comes from technological knowledge developed within an economy, specifically through markets and innovation (Howitt, n.d.). The exogenous growth theory approaches growth in a contrary way. It says economic growth comes from forces outside the economy, like savings rate, production, and diminishing returns of capital (The Business Professor, 2019). Although climate change is an exogenous shock— coming from an outside force— the effects last longer than the initial impact, as seen in Kanbur et al. (2019). Additionally, Dell et al.'s (2008) findings suggest the adaptation measures a country may take after a climatic event does not ensure things will immediately recover from the shock. Instead, the nation must continue to reexamine its economy to adjust to future possible climate change impacts as well as past ones, oftentimes changing their production methods. It should be noted that a country's GDP may increase, or not significantly fall as expected, immediately after a climatic event due to the resources put into the cleanup of the natural disaster. However, in

countries without adequate institutions or government assistance in place to rebuild after a natural disaster, the GDP may only be hurt (Baily, 2011). Further, the endogenous theory helps explain the externality of greenhouse gas production due to manufacturing products. However, the greenhouse gases then spill over to other countries, impacting their environment and economy. Money may be invested into new projects, like raising coastal areas, changing markets to be more green, or developing new sustainable sectors all together to be less vulnerable to the negative consequences of climate change, all suggesting climate change impacts the endogenous workings of a country (Parry & Terton, 2018). Therefore, although exogenous growth theory supports the initial shocks of a natural disaster influenced by climate change, the lingering effects change the economic forces within an economy. Accordingly, the ideal theory to support this research is a combination of endogenous and exogenous growth theories. All this is to stipulate the need for a theory focused on climate change's lasting effects.

However, based on the endogenous effects of climate change, one expected result is that vulnerability to climate change will result in negative losses to GDP per capita; as well as GDP per capita will be increasingly sensitive to changes in vulnerability to climate change over time. These losses will only grow as the years progress because climate change is becoming stronger (Hayhoe et al., 2017). Dell et al. (2008) demonstrates this through their findings that economic growth slowed as a result of higher temperatures due to climate change. Furthermore, as Kanbur et al. (2019) found, the countries most able to adapt because of their high levels of economic growth will be less vulnerable to climate change. Thus, county's with higher income will be less vulnerable to climate change. Finally, Füssel's (2010) findings regarding greenhouse gases

suggest those most responsible for the negative impacts of climate change will not be as susceptible to the climate crisis.

IV. Empirical Model

To determine a country's vulnerability to climate change, the paper uses the Vulnerability Index from Notre Dame-Global Adaptation Index (ND-GAIN) Country Index (2020). The Vulnerability Index measures the "propensity or predisposition of human societies to be negatively impacted by climate" (Chen et al., 2015). Specifically, the index looks at six sectors: food, water, health, ecosystem services, human habitat, and infrastructure. Then, the sectors are evaluated by exposure, sensitivity, and adaptive capacity concerning climate change. Exposure looks at the physical factors outside of the system and determines the possible stress level by changing climate conditions. Sensitivity examines how dependent people are on the sectors that are climate-sensitive and how sensitive the demography of the country is to climate hazards. Finally, the ability to adapt is determined by how well the society and supporting sectors can adjust to decrease possible damage and to react to unfavorable climate change impacts. The Vulnerability Index score is from 0 to 1, with the lower the score, the lower the vulnerability.

As for GDP per capita, the data is retrieved from the World Bank and measured in current US$ (World Development Indicators, 2020). The years used are from 1995 to 2018. In total, 178 countries are used in this research. Both datasets have more than 178 countries included, but since not all the countries overlap, it is necessary to omit the countries that are not counted in both datasets.

To test the low-income country hypothesis, the country divisions between low, middle, and high income based on GNI per capita for the current 2021 fiscal year were also received through the World Bank (2019).

The study utilizes the ND-GAIN and World Bank data by running a cross-sectional regression analysis to predict the effect of the Vulnerability Index on GDP per capita, seen in the equation below. The dependent variable is GDP per capita, and the independent variable is the Vulnerability Index. The cross-sectional regression is run for each of the 24 years, 1995 to 2018, combining all countries and delivering 24 different results. The coefficients measure the sensitivity of GDP per capita to the Vulnerability Index.

$$GDP = \beta_0 + \beta_1 Vulnerability + u$$

Once the twenty four coefficients, the sensitivity coefficients, are estimated, they are run as the dependent variable in a time series regression to determine if there is a trend in the results over the years from 1995 to 2018. The independent variable is years, while the dependent variables are the sensitivity coefficient. Through the results of this regression, it will be determined whether there is a correlation between years and GDP per capita's sensitivity to the Vulnerability Index.

$$Sensitivity = \beta_0 + \beta_1 year + u$$

To address whether countries that release more greenhouse gases are less vulnerable to climate change than those that emit fewer gases, the five least vulnerable countries and the five most vulnerable countries, based on the Vulnerability Index, were pulled from 2017 data. Their

carbon dioxide emissions per capita in tons were then retrieved from Our World in Data (Ritchie & Roser, 2017). The least vulnerable countries include Norway, Switzerland, Luxembourg, Austria, and Germany. The most vulnerable countries include Sudan, Guinea-Bissau, Chad, Niger, and Somalia. The Federated States of Micronesia was among the five most vulnerable countries, however there was no data on their carbon dioxide emissions, so Sudan, the sixth most vulnerable country, took its place.

V. Results

Table 1 shows the results from the regression testing the relationship between GDP per capita and vulnerability. Each coefficient is connected to the corresponding year. The year 1996 was omitted due to the large number of missing observations which therefore gave an insignificant sensitivity coefficient, and a positive one at that.

The 1995 results in table 1 indicate that an increase in vulnerability caused GDP per capita to fall $68,924.68. The absolute value of the sensitivity coefficient slightly falls until 2002, when it begins to increase. The absolute values of the coefficients show that as the years progress, there is an increase in GDP per capita loss due to vulnerability to climate change. Since there are losses, GDP per capita is evidently affected by vulnerability to climate change.

It should be noted that the years 2007, 2008, and 2009 are part of the Great Recession, which impacted GDP per capita globally. Thus, while their sensitivity coefficients could be skewed due to the business cycle during those years, the proceeding years after the recession show similar values as the recession years and therefore support the conclusion that vulnerability

to climate change is responsible for some portion of GDP per capita losses and does not seem to be affected that much by the business cycle.

Table 1: Regression results for 23 Cross Sectional Regressions: Dependent Variable = GDP per Capita, Independent Variable = Vulnerability Index. ***p-value<0.01

Year	Sensitivity Coefficient	Adjusted R Squared	Sample Size
1995	-68,924.68***	0.353	169
1997	-66,318.46***	0.363	169
1998	-64,793.44***	0.354	169
1999	-66,530.63***	0.350	169
2000	-64,568.84***	0.335	173
2001	-64,151.88***	0.347	174
2002	-68,240.03***	0.344	175
2003	-80,557.39***	0.347	175
2004	-92,188.63***	0.349	176
2005	-91,890.07***	0.297	176
2006	-97,647.92***	0.294	176
2007	-121,670.20***	0.353	176
2008	-136,192.40***	0.372	175
2009	-121,249.40***	0.389	175
2010	-124,788.30***	0.377	175
2011	-137,906.00***	0.364	175
2012	-134,201.20***	0.352	174
2013	-138,785.30***	0.358	174
2014	-139,223.20***	0.357	174
2015	-124,454.30***	0.367	173
2016	-125,451.30***	0.369	173
2017	-133,732.20***	0.374	173
2018	-143,641.30***	0.376	172

The time series regression used to demonstrate the correlation between time and the estimated sensitivity coefficient showed a significant negative relationship. The estimated time coefficient is -4179.82 and a significant p-value. This means that with each additional year, the sensitivity coefficient fell by more than four thousand. While the sensitivity may be increasing, the Vulnerability Index itself is not. Due to the way the Vulnerability Index is calculated, there is a set range for each sector of data that is determined for all countries. The data collected for each sector is then scaled 0-1 (University of Notre Dame Global Adaptation Index, 2015). Therefore, it is not helpful to compare the Vulnerability Index by year groupings over time because as seen in table 2, the index falls even though the sensitivity increases. It would be beneficial to look at one country over time, but this is not possible because of the manner that the index is adjusted from year to year.

Table 2: Vulnerability Index summary statistics grouped by years.

	1995-2002	**2003-2010**	**2011-2018**
Minimum	0.2672	0.2489	0.2169
Maximum	0.7044	0.6953	0.6798
Mean	0.4576	0.4379	0.4304
Median	0.4483	0.411	0.4445

To gauge the connection between countries' national income and the Vulnerability Index, summary statistics seen in table 3, are run. The World Bank separates countries into low, middle, and high-income grouping based on their GNI per capita for a given year. Using the 2018 divisions, each country was divided into their respective groupings and assigned their Vulnerability Index for the same year. Based on the summary statistic, the mean Vulnerability

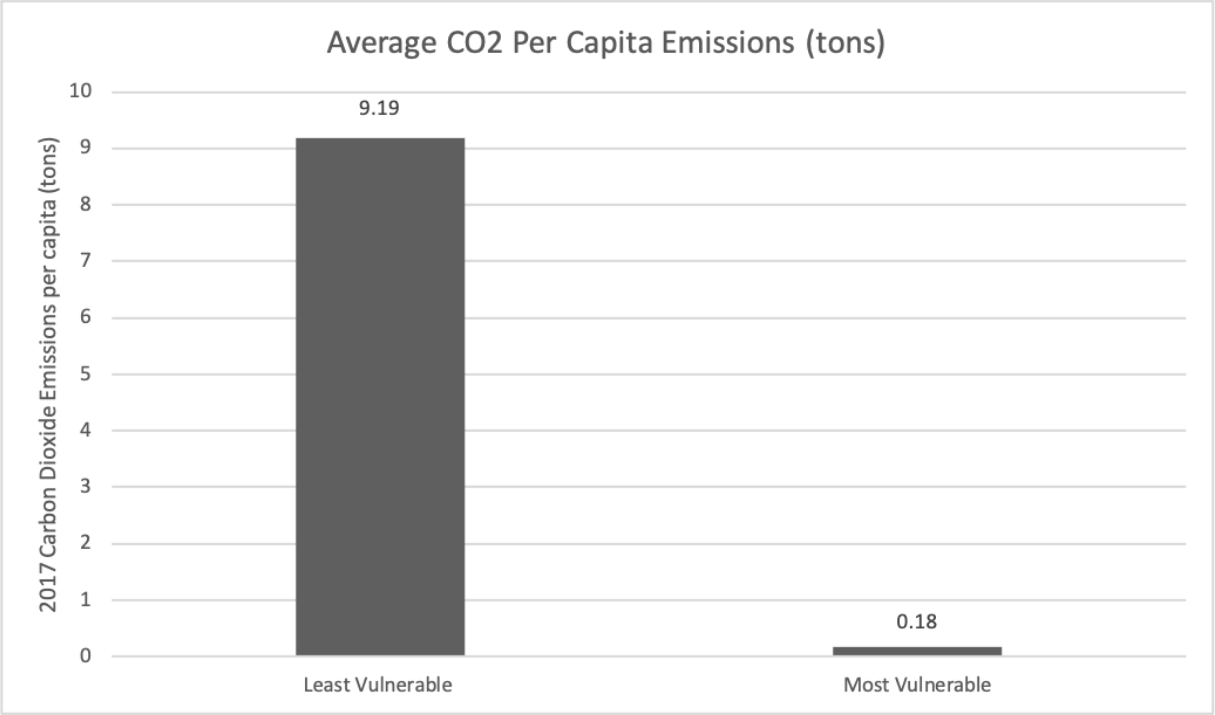
Index values decline as income increases. There are over 0.15 points separating the high income and low-income average Vulnerability Indexes. As the index is only between 0 to 1, small numerical increases represent large vulnerability changes. Therefore, high income countries are less vulnerable to climate change based on the ND-GAIN Vulnerability Index.

Table 3: Vulnerability Index grouped by low, middle, and high income countries.

	Low Income (73)	**Middle Income (53)**	**High Income (57)**
Minimum	0.3806	0.3428	0.2489
Maximum	0.7044	0.6164	0.5068
Mean	0.5306	0.4288	0.3625
Median	0.5372	0.4239	0.3544

Figure 1 shows the 2017 average carbon dioxide (CO2) per capita emissions in tons for the five least vulnerable and five most vulnerable countries, based on the Vulnerability Index. Norway, Switzerland, Luxembourg, Austria, and Germany all have Vulnerability Indexes below 0.30. Norway, Luxembourg, Austria, and Germany have CO2 per capita emissions above seven tons, with Switzerland at 4.51 tons per capita. As for the most vulnerable countries, Sudan, Guinea-Bissau, Chad, Niger, and Somalia have Vulnerability Indexes above 0.60 and CO2 per capita emissions less than 0.50 tons. This is a stark difference in their emissions and vulnerability indexes.

Figure 1: Average 2017 carbon dioxide per capita emissions by tons for the five least vulnerable and five most vulnerable countries, based on the Vulnerability Index.



VI. Discussion and Policy Implications

Based on the results, vulnerability to climate change negatively impacts GDP per capita. All sensitivity coefficients retrieved from the regression testing2 the relationship between GDP per capita and the Vulnerability Index, with the exception of 1996, were negative. Therefore, it appears that a country's economy is hurt by the presence of climate change. One reason this could happen is due to the decline in real output in different sectors that lasts and compounds over time (Kahn, 2019). This result and conclusion follows from the hypothesis that vulnerability to climate change negatively impacts GDP per capita. It further supports the findings of Kanbur et al.'s study that shows climate change impedes economic growth (2019).

Additionally, the second regression testing the relationship between time and the sensitivity coefficients found that as time goes on, vulnerability has a greater impact on GDP per capita. These results combined with the Vulnerability Index summary statistics show that vulnerability's effect on GDP per capita is growing and only expected to grow as temperatures continue to increase (Hsaing, 2017). This is in line with the hypothesis that as climate change becomes stronger, the impacts on GDP per capita will become more severe.

As global losses to GDP per capita intensify, the summary statistics for the low, middle, and high-income countries demonstrate that the more income a country has, the lower their vulnerability to climate change. Losses to GDP per capita for low income countries are going to be more drastic for those countries because the losses will be a larger percentage of their overall income. The losses will also make it difficult for low-income countries to invest in adaptive strategies, which continues the cycle of vulnerability (Fankhauser & McDermott, 2014). Therefore, low income countries are more adversely impacted by climate change compared to middle-and high-income countries, supporting the previously stated hypothesis.

Low-income countries are not only more vulnerable to climate change, but they are experiencing the effects of something they had a minimal hand in developing. Based on the comparison between the five least and five most vulnerable countries and their average CO2 per capita emissions in 2017, the discrepancy between the two averages is over nine tons. Since greenhouse gas emissions, including carbon dioxide, are a major contributor to climate change, the difference in emissions and vulnerability levels demonstrates a disproportionate amount of harm experienced by the five most vulnerable countries. A 2012 study found increased economic activity results in more CO2 emissions; and since wealthier countries have more economic

activity than poorer countries, the countries that are most vulnerable to climate change are not nearly as responsible for climate change as the least vulnerable countries (Granados et al., 2012; Felipe et al., 2010).

The results from this study reveal the importance of adapting and mitigating to climate change because the impacts are substantial and reach into the global economy. As the sensitivity of GDP per capita to climate change increases, it is necessary to take the essential measures to readjust societies to confront the climate crisis. Readjusting society involves acting quickly and altering responses to match the number of people in danger. Additionally, "build the resilience of the world's poorest citizens, and enhance the ecosystem function they depend on," all of which is possible to accomplish (El-Ashry, n.d.).

The fact that global GDP per capita changes due to vulnerability to climate change further supports the need for international agreements. It is not enough for a few countries to reduce emissions and take other actions that fight against climate change; a global agreement is paramount. Additionally, the international agreements on climate change should be supported, especially by high-income countries. Further, unlike the Paris Agreement, an international climate agreement should be legally binding, with consequences for countries who do not meet their goals (Paris Agreement, 2015). The agreements should also focus on equality and justice, while likewise sending a clear signal to decision makers that a carbon free future is necessary (Dagnet & Morgan, 2014). Although high-income countries are not as vulnerable to climate change, the GDP per capita losses from the first regression suggest that low income countries are experiencing greater economic hardships and are already in a more precarious position due to

their economic standing. Thus, the high-income countries can and should contribute money and resources to fighting the climate crisis that is proportionate to their part in creating the disaster.

The same reasoning stands with helping low-income countries adapt and mitigate to climate change. In proportion, the losses the low-income countries are experiencing due to their vulnerability to climate change means they need outside help to fund their fight. Further, since low income countries are more vulnerable to climate change, they will need to do more to adapt to the rising temperatures, sea levels, and natural disasters than the middle-and high-income countries. There are imperative local and national steps all countries should take to fight climate change, but because this study focuses on the global viewpoint, the results support a global solution.

VII. Conclusion

Climate change's effects on the environment have been documented as far back as the 1800s (History.Com Editors, 2017). More recently, however, studies have begun to investigate climate change's impact on local, national, and the global economy. Based on previous literature, these impacts have increased over the years, negatively affecting many sectors of the economy. This study looks at the specific impact vulnerability to climate change has on GDP per capita. The results find that vulnerability to climate change negatively impacts GDP per capita for each year from 1995 to 2018, with the exception of 1996. Additionally, as the years go on, GDP per capita's sensitivity to climate change vulnerability increases, causing larger global GDP per capita losses. Additionally, low-income countries are more vulnerable to climate change than

middle-and high-income countries even though they produce less greenhouse gases than the least vulnerable countries.

All these results suggest a need for immediate action towards climate change. It is the issue of our time and one that is having increasingly greater impacts on society. Adapting and mitigating to climate change is no longer to protect the future because the results from years of polluting and destroying habitats are occurring now and affecting everyone (Cho, 2019). If the destruction to wildlife and sensitive populations was not enough for governments to make serious commitments to fighting the climate crisis, then perhaps the economic losses will ignite the motivation to step up.

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