Reducing Methane Emissions through Municipal Waste Management

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Introduction

Overview and Descriptive Model

The following study investigates the connection between methane emissions, municipal waste, and country population to predict future trends in methane emissions as the result of municipal waste. As a principal greenhouse gas, methane significantly affects Earth's temperature and is one of the main compounds responsible for global warming. By establishing a connection between methane emissions, municipal waste, and population, areas whose population indicate large amounts of municipal waste can be targeted and taught to more properly manage their municipal waste, reducing greenhouse gas emissions. In the context of this report, methane emissions refer to the amount of methane, measured in metric tons of carbon dioxide equivalent (MTCO2e), produced in a given year; municipal waste refers to the municipal solid waste (MSW), measured in metric tons (tonnes), produced in a given year, and population refers to the number of people in a country. Throughout our study, we use these variables in the prediction of methane trends, and we then prescribe applicable strategies to diminish the release of methane based on our observed correlations.

Methods

To approach this analysis, we broke our efforts up between the members of the team. Ethan, our team leader, was assigned to research methane, waste, and population trends in China, as well to develop the formal report for the study; Andrew was assigned to research trends in the United States and develop the PowerPoint; Nate, our team scribe, was assigned to research trends in Indonesia; Jacob was assigned to research trends in Germany. With our team divided into their respective areas of focus, we downloaded a methane, waste, and population dataset from Climate Watch, the United Nations, and the World Bank, respectively. We primarily used Excel to investigate our datasets, performing time series analysis to visualize the change of methane, waste, and population in each country from 1990 – 2020. Once these visualizations were created, we noted areas of interest and anomalies and researched potential causes for these deviations from our expectations, compiling our findings into a set of observations on the trends of methane, waste, and emissions within each researched country. With our visualizations and corresponding observations completed, we entered the information into the PowerPoint and moved on to our predictions of methane emissions. To predict future levels of methane production in each of our countries, we used our observations of the correlation between methane, waste, and population to make an educated projection of future methane levels. Based on these projected levels of methane, we prescribed methane reduction actions to each country.

Results

Our initial hypothesis was that there would be a positive correlation between methane emissions, waste, and population in each country. This hypothesis was largely proven false by our data. Out of the four countries we analyzed, only one, China, exhibited a positive correlation between population, waste, and methane. Germany, Indonesia, and the United States all demonstrated some positive correlations between population and waste, as we had expected, but shared little correlation between waste and methane emissions, and a sometimes-negative correlation between population and emissions. These results surprised us, as we had expected that increased waste levels would result in more methane emissions through the decomposition of such waste. We discovered that the data's deviation from our expectations was due to the presence of other methane producing activities in each country that served as extraneous variables to the correlation between waste and methane or to government intervention. For instance, car emissions in the US also produce methane, and the Clinton-Gore administration "adopted the toughest standards on soot and smog" to reduce smog-causing pollutants from new vehicles, one of which is methane, by 77 to 95 percent (United States Government, 2001). In the US, the decrease in methane emissions during the Clinton-Gore administration can be attributed to these standards, which explain why, even as waste increased during this period, methane emissions decreased. The manipulation of other extraneous variables across the countries of our sample explains why waste was not as correlated with methane emissions as we had initially expected.

Data Analysis

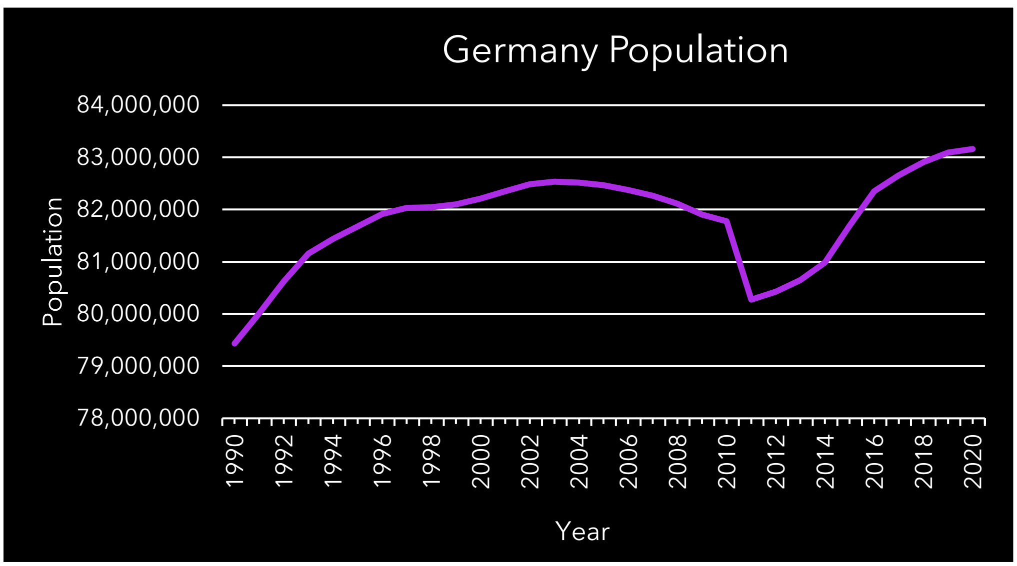
For each of the countries in our sample: Germany, Indonesia, China, and the United States, we created three visualizations, one for population, one for waste, and one for methane emissions. We investigated anomalies within each visualization to gain insight into the deviations of the data away from our expectations.

Germany

The first country analyzed, Germany, depicted surprising trends in its population graph. A large dip in 2011 indicated a potential anomaly that was not expected by our team.

Figure 1

Germany Population



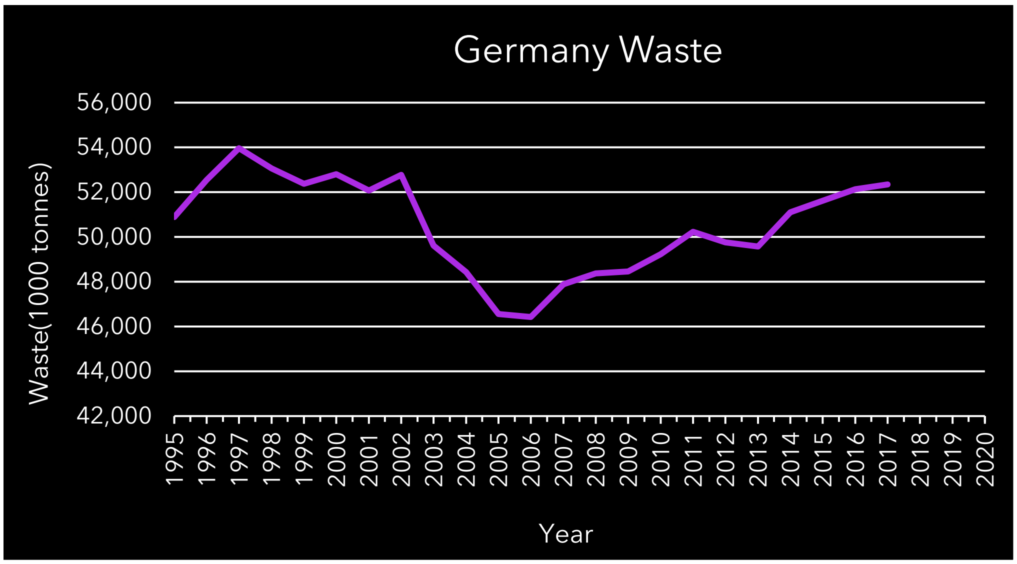
Note. This figure demonstrates the non-linear increase in Germany's population from 1990 – 2020.

From 2010 to 2011, Germany appears to lose 1.5 million people. This anomaly was due to a census miscalculation from before Germany's reunification that was corrected in the 2011 census (BBC, 2013). This misreporting of data made our team aware of the possibility that the data we were analyzing could not be entirely accurate, potentially skewing the results of our analysis.

Germany's waste data displayed equally confusing trends. A massive reduction in waste production in the early 2000's demonstrated that Germany's waste was not exactly correlated with their population, as population continued to increase during this time while waste decreased.

Figure 2

Germany Waste



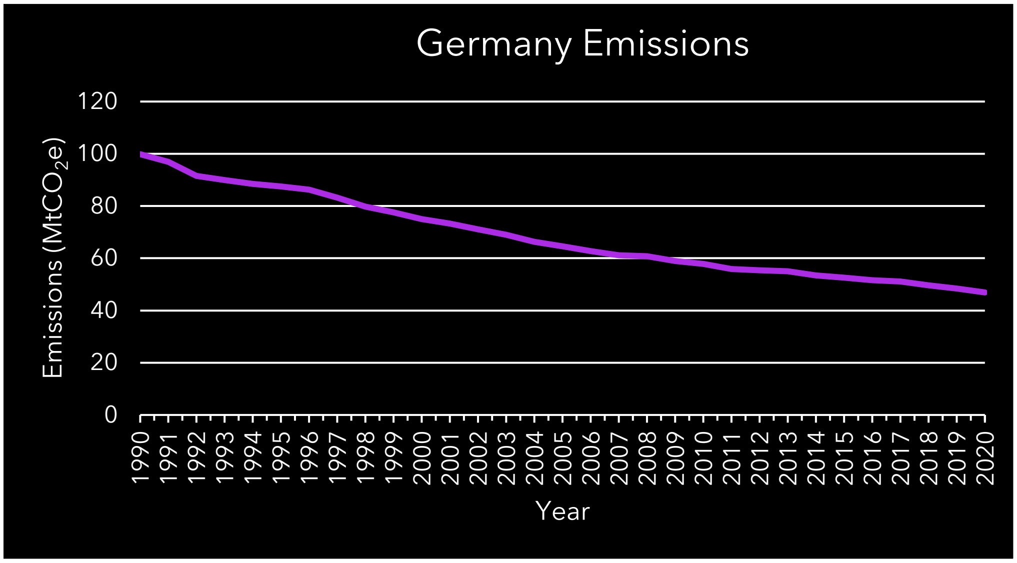
Note. This figure demonstrates the massive decrease in waste production in Germany in the early 2000's

As illustrated by Figure 2, Germany's waste production decreased dramatically from 2002 until 2006. This decrease was most likely precipitated by the installation of the European Union's target of 50% recycling for 2020, which caused Germany's recycling of MSW to increase from 48% in 2001 to 62% in 2010 (Fischer & Scp, 2013). As for the increase in waste beginning in 2006, a major contributor was the construction industry in Germany, which was on the rise and contributing significantly to waste generation (Wilke, 2017). Additionally, increased packaging waste in Germany also contributed to the rise in waste production (Welle, 2019) Our findings in relation to this data demonstrated to us that governmental policy as well as industry activity influenced waste production, meaning that there existed extraneous variables outside of population that effect waste levels.

While Germany's population and waste both demonstrated periods of increase, Germany's emissions did not.

Figure 3

Germany Emissions



Note. This graph demonstrates the consistently decreasing trend in Germany's emissions.

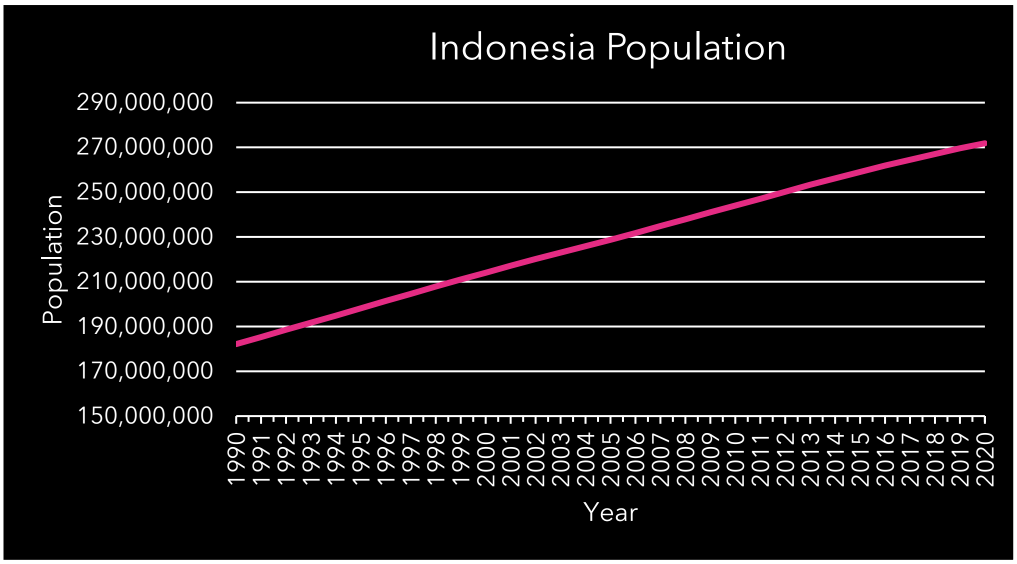
Our team proposed several reasons for methane emissions in Germany not mirroring waste and population trends, as predicted by our hypothesis: the European Union's emission goal to reduce greenhouse gas emission in the European Union (EU) by 55% by 2030 (European Council, 2022) and the Germany's plans to cut greenhouse gas pollutants by 65% of their 1990 levels by 2030 (Appunn et al., 2023). As of 2020, Germany had reduced their methane emissions by 53%. This demonstrated the effectiveness of these initiatives and portrayed the impact of the extraneous variable of government intervention in methane emissions. We learned from our observations of Germany that population, waste, and emissions were not all positively correlated as we had expected, and that this deviation from expectation was largely due to unconsidered variable of government intervention in our results.

Indonesia

The second country analyzed, Indonesia, demonstrated no anomalies in its population, but displayed interesting patterns in its waste and emission data. Indonesia's population increased at a linear rate as depicted in Figure 4.

Figure 4

Indonesia Population

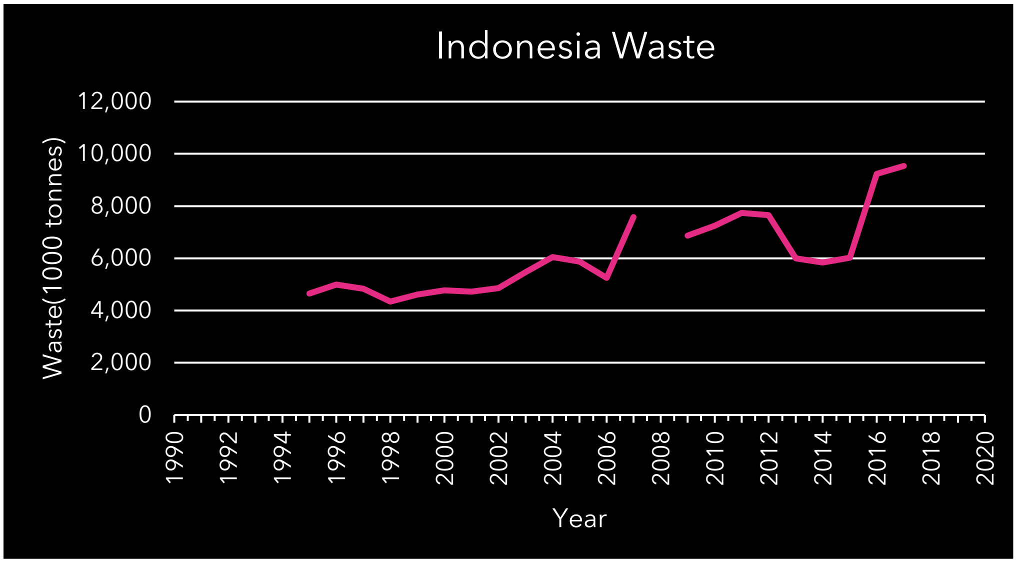


Note. A visualization showing Indonesia's linear rate of population growth.

Indonesia's waste, on the other hand, did not follow such a linear rate of growth.

Figure 5

Indonesia Waste



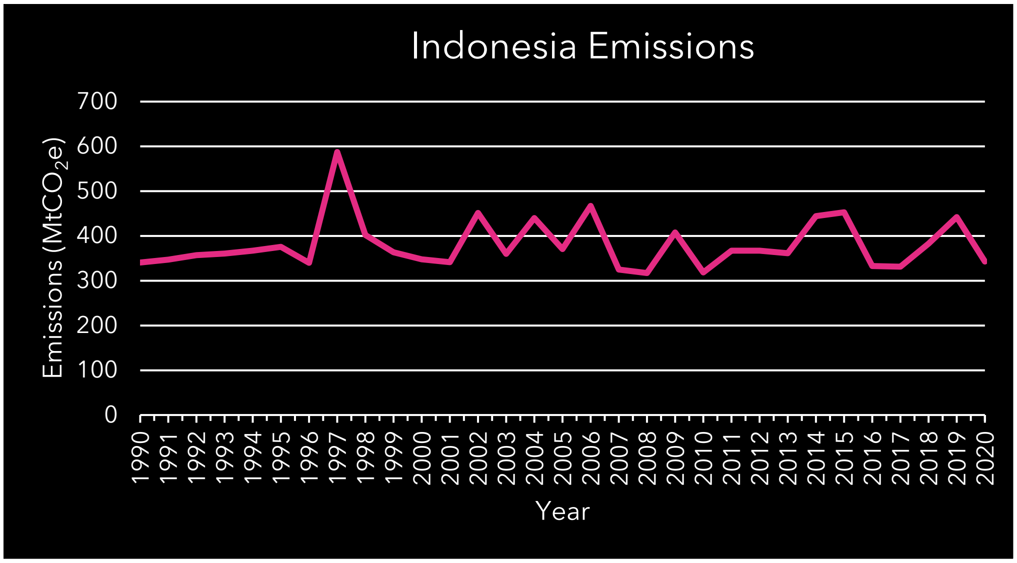
Note. This graph shows the incomplete recoding of waste levels in Indonesia as well as its sharp increases and decreases.

Our team noticed two important observations when studying Indonesia's Waste data. First, there were multiple missing values of waste from 1990 to 2020. Second, the recorded level of waste production in Indonesia was incredibly small considering that in 2017, Indonesia's waste generation was 65.8 million tonnes as recorded by the United Nations Environmental Programme (UNEP) (United Nations, 2023a). Both of these factors led our team to believe that there had been misreporting of Indonesia's waste statistics by either Indonesia or the United Nations. This conclusion added to our teams understanding that extraneous variables other than population, waste, and methane emissions could interfere with our results. In this case it was the government intervention of either Indonesia or the United Nations that caused our data to deviate from what was expected.

Our team next investigated Indonesia's emissions, finding many anomalies within the data as depicted in Figure 6.

Figure 6

Indonesia Emissions



Note. This visualization illustrates Indonesia's sporadic spikes in emissions.

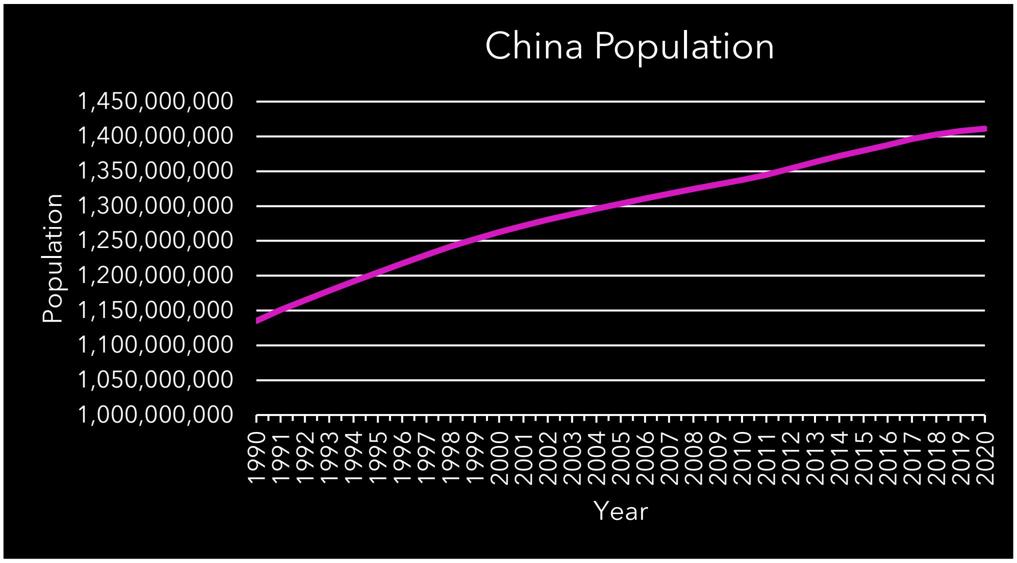
Again, our team's expectations of data were usurped. Instead of sharing a positive correlation with waste and population as we had hypothesized, Indonesia's methane emissions contained many relative extrema and did not gradually increase over time. Through research, we found that these extrema were likely due to forest fires in Indonesia that released methane into the atmosphere through the burning of vegetation. For instance, the Indonesian forest fires of 1997 burned 4.2 million acres of land, most likely resulting in the extrema seen in 1997 in Indonesia's methane emissions (Mongabay, 2020). Through the analysis of Indonesia's population, waste, and emission data, our team gained an understanding of the impact of the extraneous variables of government intervention and natural events as extraneous variables in the comparison of population, waste, and methane emissions.

China

The third country our team analyzed, China, was the only country from our sample that fit our hypothesis. China's population depicted no anomalies, as illustrated in Figure 7.

Figure 7

China Population

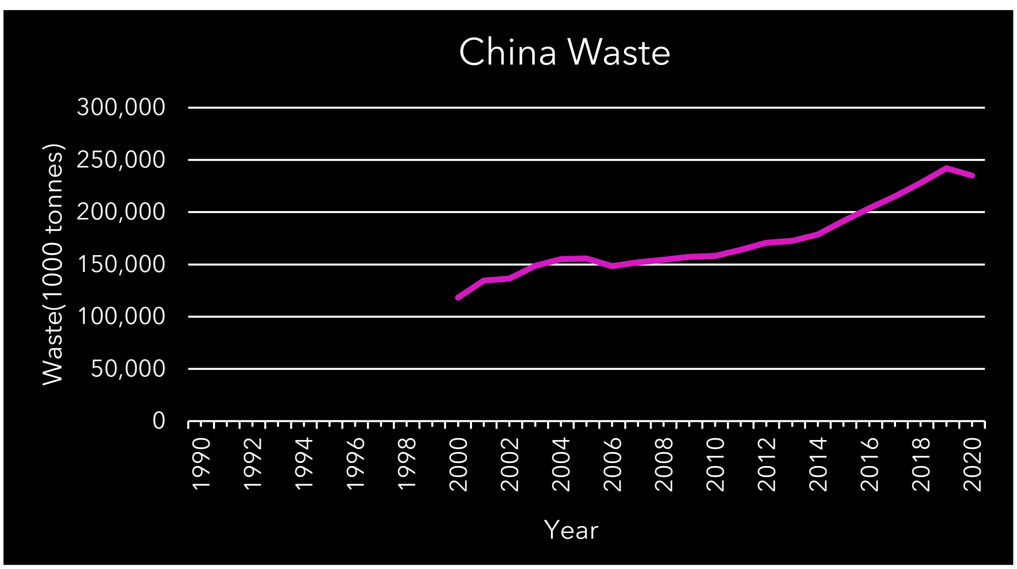


Note. This graph shows China's linear rate of population growth.

China's waste also shared a positive correlation with China's population, as predicted by our hypothesis. Figure 8 illustrates the steady increase of waste in China.

Figure 8

China Waste



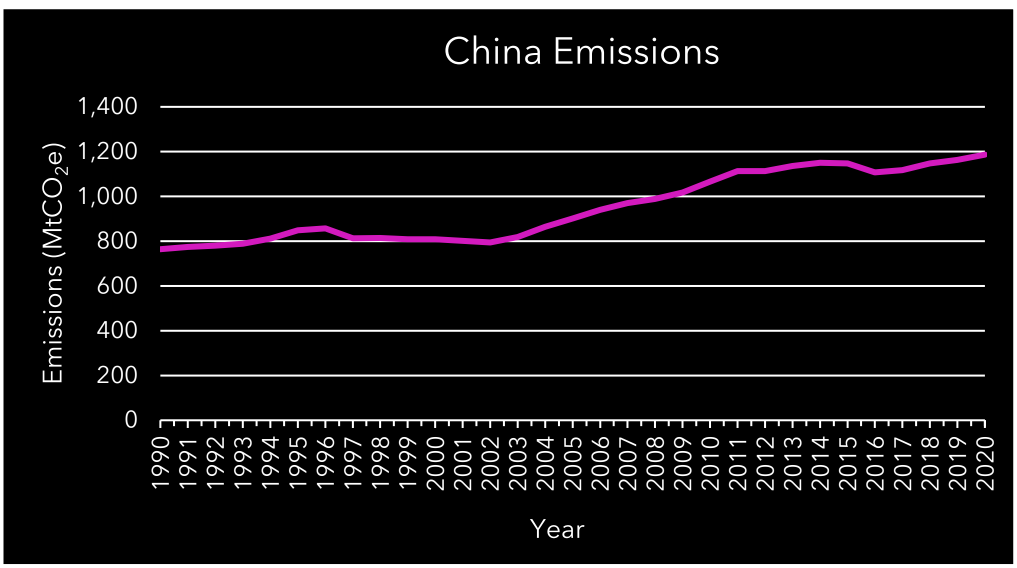
Note. This graph displays the steady increase of waste in China.

Like China's population, China's waste steadily increases for most of the timespan. There are two anomalies within China's waste data. China's waste decreased for the first time from 2005 to 2006. This decrease is potentially due to China's efforts to reduce its waste beginning in 2004 with improved landfill management and an increased budget for municipal waste management (Hoornweg et al., 2005). While these efforts had an impact, the increase resumed in 2006 and continued until 2019. The second decrease in 2019 is likely due to China's compulsory waste sorting law, which eased the burden on landfills by increasing the amount of municipal waste recycled (You, 2019). Both of these deviations from our hypothesis were caused by the extraneous variable of government intervention, which our team identified in our analysis of Germany and Indonesia, as well.

China's emissions followed the same growth seen in population and waste, as show in figure 9.

Figure 10

China Emissions



Note. The graph shows the consistent increase in China's methane emissions.

China's methane emissions data included multiple years in which methane emissions decreased despite increases in population and waste. Our team determined that these anomalies were due to the extraneous variable of other methane producing activities in China that were decreasing. In China, "Coal mining, rice cultivation, ruminant livestock, and waste management are thought to account for about

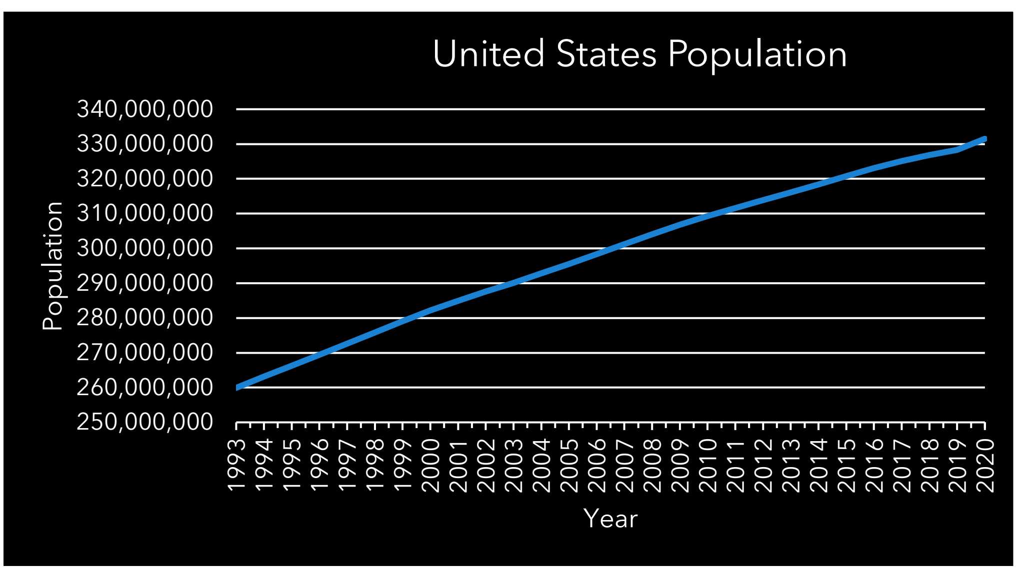
90% of the country's total methane emissions", and China has been decreasing coal mining specifically and shifting to more renewable sources of energy (Sheng et al., 2021). The decrease in the extraneous variable of coal mining, as well as other methane producing industries, could explain the deviation of methane emissions from our team's expectations. This trend of extraneous variables causing shifts in data away from our expectations solidified our team's understanding that methane emissions are not just the result of population and waste as we hypothesized; there are many variables that can affect methane levels and skew the correlation of methane away from population and waste. Overall, however, China did mostly exhibit the positive correlation between population, waste, and methane emissions that we expected, with only a few deviations.

United States

The United States was the last country we analyzed, and it did not fit our hypothesis as China had. The United States population, however, did increase at a positive linear rate with no anomalies, as shown in Figure 10.

Figure 10

United States Population



Note. This graph of United States population follows a positive linear growth.

Waste in the United States also steadily increases, but contains several anomalies, as depicted in Figure 11.

Figure 11

United States Waste

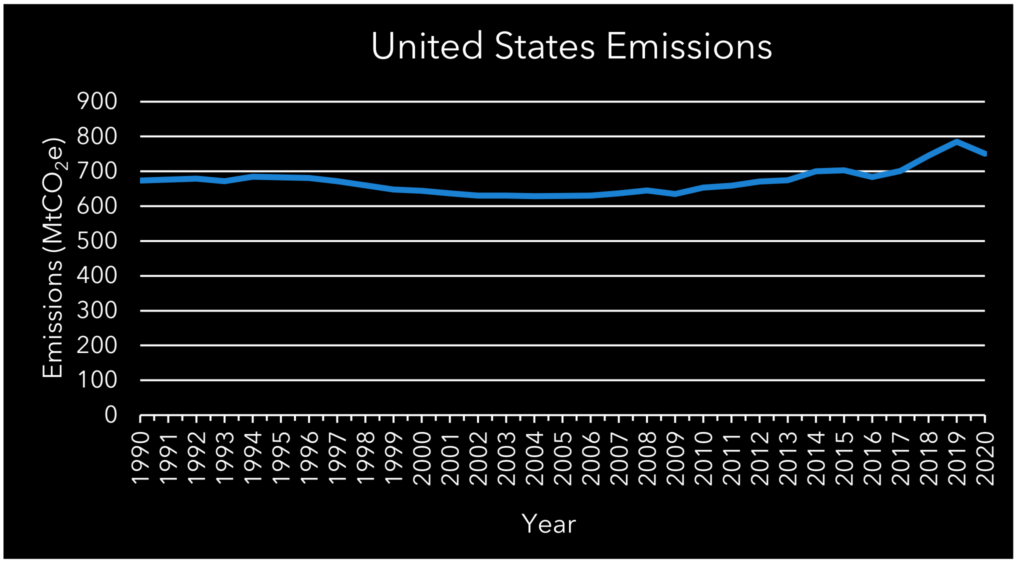
Note. This graph displays the increase in United States waste.

As illustrated by the graph, United States waste increases over the timespan, just as population does, but there are several areas of decreases in waste that are not mirrored by decreases in population. Our team, through research of United States government policies, concluded that these decreases are in part due to government intervention, such as in the Clinton-Gore Administration, when the nations worst toxic waste sites were cleaned, reducing the amount of municipal waste ending up in landfills (United States Government, 2001). With each government intervention, however, waste production in the United States outpaced the effects of the intervention, resulting in an overall trend of growth.

United States emissions, contrary to our expectations, did not experience significant increases or decreases. Over the timespan, United States emissions remained relatively constant, as demonstrated in Figure 12.

Figure 12

United States Emissions



Note. This graph visualizes the constant level of methane emissions in the United States.

Our team, through our research of several presidencies, discovered potential explanations for the gradual decrease of emissions in the early 2000's and the gradual increase in emissions in later years. During the Clinton administration (1993-2001), there were a lot of policies and standards put into play to lower emissions, reflected by the decrease over that period in the graph (United States Government, 2001). On the other hand, during the Bush administration (2001-2009), a more passive route to emission reduction was taken, resulting in the gradual increase in emissions following Bush's tenure. While both presidencies did influence the methane levels slightly, methane emissions stayed constant overall, signifying that either methane producing activities have been regulated extensively by legislation pre-dating the Clinton and Bush administrations or that methane producing activities besides waste were manipulated in such a way by government intervention or other outside source to nullify the net change in methane production from year to year. Comparing the methane emissions in the United States to its population and waste trends, our team observed that methane was not strongly correlated with either, meaning that methane emissions, most likely due to the extraneous variable of government intervention, did not fit our hypothesis of positive correlation between, population, waste, and emissions.

Predictions and Prescriptions

Based on our observed correlations, our team predicted future trends in methane emissions and prescribed actions to limit emissions in the future. This section first details the predictions of trends, followed by the prescription of actions.

Predictions

Germany:

We predict that greenhouse gas reduction plans put into national law will most likely result in a 12% decrease in emissions by 2030. After 2030, we predict that emissions will stay steady. As population nor waste was strongly correlated with emissions, our team asserts that the best predictions of future methane trends can be made based on its current directory and the not the behavior of Germany's population and waste levels.

Indonesia:

We predict that the amount of waste in Indonesia should continue to increase due to the strong positive correlation with population; however, the emissions are expected to remain around roughly the same value due the absence of a strong correlation between Indonesia's population and waste levels.

China:

We predict that the positive correlation between population, waste, and methane emissions in China indicate that as China's population and waste production increase, methane emissions are likely to continue their increase.

United States:

We predict that since the population is still expected to grow in the U.S., waste will continue to increase, but lowering concerns for methane emissions reflected by current U.S. policies will cause methane emissions to increase. As population and waste are not the sole influencers of methane emissions in the United States, we based our prediction on the type of government intervention methane producing activities are likely to undergo.

Prescriptions

Germany:

We believe that Germany should continue with their greenhouse gas reduction plans as they have already decreased emissions by over 50% in the past three decades. Germany's waste production on the other hand has begun to increase, revisiting their strategy in the 2000s centered around recycling could begin to reduce their waste again, potentially affecting methane emissions on a small scale.

Indonesia:

We believe that Indonesia should continue with the changes brought by Law No 41 of 1999 and Law No 32 of 2009, which aim to increase the resilience of Indonesia's forests to fires (Forest Legality Initiative, 2018). This will assist in lowering Indonesia's methane emissions by preventing future methane-releasing fires.

China:

We believe that China has already made great strides towards reducing the amount of municipal waste being directed towards landfills with required trash sorting. We believe additionally legislation enforcing this sorting will help to decrease methane emissions by reducing the amount of waste decomposing in landfills.

United States:

We believe that one big stride the United States has made is the increase in more renewable energy sources and more effective use of energy. Programs like Energy Star and other federal and state initiatives have helped continue to lower the amount of methane emissions produced, thus they should be continued.

Conclusion

Through our analysis of population, waste, and methane emissions data in Germany, Indonesia, China, and the United States, we have concluded that methane emissions are sometimes influenced by waste and population, but more often, there exist extraneous variables that play a larger role in methane emissions than waste does. Methane emissions can be controlled through the regulation of those extraneous variables, as we defined in our prescriptions. Overall, methane is rarely correlated with just waste levels, and is more often influenced by not only waste but also government intervention, methane producing activities, and natural events.

Reflections:

We felt that our team worked efficiently together and performed quality data exploration over the course of this project. As a team, we also had to work through the challenge of sorting through incomplete datasets and discovering our hypothesis was mostly incorrect. Given the opportunity to redo the project, we would dedicate more time to considering the effect of extraneous variables on methane emissions, as this was a consistent influencer of our results.

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