Decision Analytics:
CO_2 Emissions in the United States
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Abstract

        With the industrial revolution bringing change to the environment, the global temperature has always been on the rise. But in recent years, with more technological advances, the global temperature has increased even more. Concerns of lack of resources, rise in sea level, melting of glaciers, and more have emerged. However, scientists have learned that if each country does its share in lowering its CO_2 emissions, then the global temperature can decrease by 2 degrees Fahrenheit, bringing it back to what it was hundreds of years ago. This report will focus on how the United States can help to do their part by increasing solar energy, use of electric cars, reduction of gas cars, reducing of cutting trees and population. It will also focus on the real issue at hand, the amount of carbon emissions in the atmosphere.

        The methodology behind this optimization problem is a linear programming model with variables being the number of gas cars, factories, electric cars, solar power plants, hydropower plants, population, and trees. Population and gas cars are constants with factories being a variable that can change. All of this data was taken from government websites. The objective function formulation is to reduce the amount of carbon emissions created by tons of fossil fuels and more. The outcome of the findings was in one year, the temperature decreased by 0.22 degrees after lowering gas, population, cutting of trees variables, and increasing variables such as electric cars, solar power, and hydropower.

Key Words

C02 emissions, population, electric cars, hydropower, global temperature

Introduction

When Facebook, Apple, Google, and Amazon all get behind an idea, it must be important. In 2017, all of the mentioned companies backed the Paris Agreement, which is an agreement between many nations to slow the production of pollution and its impact on the environment (Shaban, 2017). This agreement abandons the previous, and even more restrictive Kyoto Protocol that also sought to limit the release of pollutants by nations (Bodansky, 2016). Different social and political realities limit the achievements that have been made under either climate change agreement. For instance, India has the challenge of providing electricity to 300 million people who currently have none, and in the US, one of the two major political parties outright rejects the science of climate change (Bodansky, 2016). Perhaps the most important thing to note is that the Paris deal is not legally binding (Mahapatra & Ratha, 2017). This has led to suggest that "the deal is worthless words" (Wente, 2015). In this article, we spend little time discussing the social and political issues with climate change. Instead, the goal here is to think about how nations could help support the slowing of climate change as a result of pollution. Specifically, we discuss how the US can make changes to its economy and lifestyle and what impact these changes can have on CO$_2$ levels.

As the largest economy in the world and the second-most producer of CO$_2$, behind China, it is fitting to focus on the US for pollution mitigating solutions (Wang, Jiang, Dong, Mubarik, & Dong, 2020) From 2007 to 2013, the US CO$_2$ emissions fell about 11% (Hubacek, Feng, Davis, & Sun, 2015). This was largely due to a move away from coal and towards natural gas, and the recession that hit after 2007 (Hubacek et al., 2015). Other studies also show that the US CO$_2$ emissions have dropped since 2007 (Sanchez, 2020; Wang et al., 2020). While this was mostly due to the decline in the economy (Wang et al., 2020), it is possible to better design cities with more vegetation that helps reduce CO$_2$ (Wai, Tan, Morakinyo, Chan, & Lai, 2020).

The top three industries that emit the most CO$_2$ are power generation, the transportation sector, and industries (EPA, 2018). Collectively, these top three groups make up 80% of all CO$_2$ produced by the US. Most US carbon emissions come from the fossil fuels that power our homes (EPA, 2018). And inside that utility sector, almost 63% of electricity generation comes from fossil fuels, 20% is nuclear, and 17% is renewable energy (EIA, 2020). From 2007 to 2019, natural gas has seen the biggest increase in electricity generation (EIA, 2020). American industries also contribute about 22% of the total CO$_2$ made per year (EPA, 2018). This comes from the energy it takes to power factories, as well as the chemical pollutants that are produced as the consequence of converting raw materials.

Literature Review

The most impactful way to reduce CO$_2$, other than planting more trees, is to address how power is made and used. At the state level, it is already recognized that the highest returns will come from addressing electricity demand (Hodgkins, 2008). There has been some progress in the effort to limit CO$_2$ emissions from utility companies. First, the American utility industry has come to recognize that fossil-fuel emissions have played a role in raising the Earth's temperatures (Ball, 2007). Second, the utility industry is in support of some sort of cap-and-trade policy to limit the pollutants it puts out (Ball, 2007). Similarly, one EU study writes that fossil

fuel burning is one of the leading contributors to the production of CO$_2$ and that it is a politically sensitive issue (Achtnicht, 2012). With these two things in mind, the study found that German buyers are willing to pay more for transportation in exchange for a reduction in CO$_2$ (Achtnicht, 2012). Anecdotally, we can see a similar phenomenon in the US. It seems that the American auto-buying population is also willing to pay more for electric vehicles based on the most popular electric car sales. The top three best-selling electric cars from January through June 2020 were all Tesla models (McCarthy, 2020). Tesla is considered a luxury automaker that sells electric vehicles at a much higher cost than the next best-selling electric car, the Chevy Bolt (McCarthy, 2020).

While answers on how to reduce CO$_2$ might seem extreme, there are other options out there to allow CO$_2$-producing sectors to offload some of their burdens. Companies can pay the government or other institutions to help reduce CO$_2$ through carbon taxes. It might even make more fiscal sense for companies to pay the taxes and fees for a lack of carbon reduction than to pay to restructure their entire business model (Hodgkins, 2008). Economics will no doubt play a factor in the way climate change is addressed. The 2007 recession and subsequent decline in income and population was the main cause of CO$_2$ decline in the late 2000s (Wang et al., 2020). Other than hoping for a declining economy, there must change in policy and how people choose to commute.

To address the pollution caused by fossil fuel burning automobiles, research shows that shifting to electric vehicles and plug-in hybrids has serious potential to reduce CO$_2$ (Doucette & McCulloch, 2011). What is unique about the Doucette & McCulloch (2011) study is that they show that plug-in hybrids, that use batteries to more efficiently burn fossil fuels, might be a better solution over the long term, than electric-powered vehicles. Dependence on hybrids, rather than fully electric vehicles is a possible solution at a time when the energy to charge a battery still likely comes from the burning of fossil fuels.

The most proactive step to take to reduce the CO$_2$ in the atmosphere is to plant more trees. Trees are powerful tools that fight global warming because they capture CO$_2$ emitted from power companies and cars. There is research underway to find what trees and under what environments eliminate the most CO$_2$ from the environment ("Which Trees Best Offset Global Warming? Some Trees Are Better than Others at Absorbing Carbon Dioxide," 2020). Environmental engineering in addition to greening the power plants and removing fossil fuel burning cars is the most holistic way to address CO$_2$ and climate change. For instance, 100 Aleppo Pine trees can absorb CO$_2$ from almost 103,730 vehicles (McInerney, n.d.). Proper urban planning with the right number of trees in the right areas can help create micro-climate cooling (MCC) (Wai et al., 2020). If it is possible to plan for each urban center, this model could potentially be expanded to the entire planet. Other studies in Southern California have shown that planting more trees can reduce ozone levels and decrease overall temperatures (Nowak et al., 2000).

Methodology

Exploring the necessary data used to explore our problem caused us some hiccups. We found that certain constants contributed to the addition of carbon emissions in the United States. These constants were the population and the number of gas vehicles currently in use. It would be implausible as a rapid solution (in the next five years) to get rid of a substantial number of either, the first being unethical. Thus, we considered these numbers as a constant factor and looked only to reduce carbon emissions by maximizing variables that reduce carbon emissions. During the exploratory phase of data gathering we came across the fact that a significant percentage of carbon emissions is due to factories, 22% actually (EPA, 2018).

This was heavily debated on whether or not to include it as a variable in the model. We found that it wasn't a constant as these factories could implement changes in how they produce emissions and thus reduce their output. Thus, we decided not to include it in the model as it was not a constant. This explains why we did not add factories as a data parameter. Another data parameter we did not add was the number of hydroelectric plants.

During the exploratory phase, we found inconsistent findings on whether or not these contributed or reduced overall carbon emissions in the US. Some reports said it reduced carbon emissions while others said it slightly increased it. Thus, due to inconsistent results, we decided not to include it in our model. Our obvious choices for data parameters to include in the model were electric vehicles due to their sole purpose of using electricity instead of gas. We also decided to include trees as an obvious data parameter as they absorb carbon dioxide. An interesting find was the use of solar energy systems which replace countless other systems that produce CO2. We checked against multiple sources for all the data parameters we incorporated in the model and then rechecked.

Computational Experiment and Results

The very basic goal of minimizing the overall average temperature in the United States comes down to minimizing certain variables while maximizing others. The result of this combination of forces will inadvertently lead to the reduction of the overall average temperature. We will be taking a look into each variable and explain why we have chosen these and why we didn't include others.

Our first variable is the temperature (TEMP) and is self-explanatory, it represents the average temperature in the United States. Next is total carbon emissions in pounds, donated by TCE. Two things that highly influence the amount of carbon emissions are the current population of the United States and the number of gas vehicles in use. Let P be the current population in the US and VG be the total number of gas vehicles. We then have variables that will help reduce carbon emissions in the US. Let VE be the number of electric vehicles, T be the number of trees, and SES by the number of solar energy systems with an average output of five-kilowatt. It would be feasible to try to reduce the population or the number of gas vehicles as the first is immoral and the latter is unreasonable. A plan would be needed to swap out current gas vehicles with

electric ones, France has such a plan in which they wish to have all-electric and/or hybrid cars by the year 2050; they set this goal sometime in the early 2000s.

We are looking for a more general solution where we can apply linear programming too. Thus, we will introduce the variable CCE which is the total constant carbon emissions and consists of the combination of the current population (P) and the number of gas vehicles (VG). We will then introduce the variable TRED which represents the total reduction of carbon emissions; it consists of the number of trees (T), the number of electric vehicles (VE), and the number of solar energy systems (SES). Thus, the combination of the constant carbon emissions minus the total reductions of carbon emissions will give us our final variable, TCE; total carbon emission.

Our goal is to maximize TRED as the reduction of the population and the number of gas vehicles is infeasible, we are looking for solutions soon, not fifty years from now. Our objective function (1) is determined by having the average temperature of the united states right now, which is 54.4 degrees Fahrenheit and according to a study done by *Nature Climate Change* found that the temperature increased by 34.7 degrees Fahrenheit per trillion tons of carbon emissions (Staff, 2016).

In other words, for every increase of a trillion tons of carbon emission, it goes up by 34.7 degrees Fahrenheit. A trillion tons of carbon is a lot of carbon. To date, the entire world has produced six hundred billion tons of carbon. This year alone the US produced five billion tons of carbon. To put things in perspective since we are terrible at comparing big numbers, I would like to compare these numbers on a more intuitive scale. As the thought of a temperature increase of 34.7 degrees is a huge number but we're neglecting the fact that a trillion is a massive number. For example, a million seconds is twelve days, a billion seconds is 31 years and a trillion seconds is 31,688 years. So clearly when we increase CO2 levels it is a mere fraction of a fraction due to the ridiculously large number to increase it. This is somewhat intuitive as temperatures have continued to rise but at a snail's pace.

Results

According to Palmer, each person in the US contributes 562 lbs. of C02 per year, this is grossly huge to what an average tree absorbs, which is a mere 48 lbs. per year (Palmer, 2009). We will go into why planting trees is so important, but it comes to what other factors come into play as trees take a long time to develop into maturity, and the number of trees to just counteract a person is twelve. So, if we have twelve trees for every human being on earth we're only negating our carbon footprint of just existing. That's a lot of trees regardless. Gas vehicles produce around ten thousand pounds of CO2 per year according to a study done by the US government (Epa, 2018). There is a lot we can do as a population to reduce our carbon emissions, those being through the use of electric vehicles which reduce carbon emissions by 4,000 pounds every year according to "Emissions from hybrid and plug-in electric vehicles" (2021). Also adding to the total reduction in carbon emissions is the number of solar energy systems, which according to Solar (2020) is 15,000 pounds per year. We used Excel and Analytical Solver to compute the below as a linear programming problem. What we found was that we needed to plant 2.3x10^11 trees, install two million solar energy systems, and have 1.4

million electric vehicles on the road. By doing this it reduces the overall temperature to 54.26 degrees Fahrenheit. All of that reduction and we didn't even reduce the temperature by one degree.

This problem is not really about reducing the overall temperature, that's a metric to determine how much CO2 is in the atmosphere. Which is the main goal. We left out the number of factories that contribute to the overall pounds of carbon emissions because we could not find a reliable source of information that had an accurate number. This, and the number of factories, from what was read contributed around twenty-two percent of the total CO2 emissions, which add that to the combined pounds per year from each person and gas vehicle made the solution infeasible. So, in essence, we have looked at a subsection of the overall problem and found that by adding more electrically sustained solutions as well as planting a lot of trees we can indeed lower the overall temperature. Below is a breakdown of the linear programming solution and its variables.

Results

	T	SES	VE		
Decision Variables	2E+11	2000000	1E+06		
Subject To:					
Reduction of C02	48	1500	4000	>=	2.80E+12
Trees	1	0	0	<=	2.28E+11
Solar Energy Systems	0	1	0	<=	2.00E+06
Electric vehicles	0	0	1	<=	1.40E+06

Objective Function	TEMP = 54.4 + 34.7*(TCE/2E15)
TRED (Total reduction)	48T + 15,000SES + 4,000VE
CCE	562P + 10,000VG
TCE	CCE - TRED

TRED=	1.09526E+13
TCE=	-8.15E+12
TEMP=	54.26

Population*562	1.84448E+11
Gas Vehicles*10K	2.62E+12
CCE:	2.80445E+12

Variables:

TEMP- Average temperature of US
TCE - Total carbon emissions in pounds
TRED - Total reduction in carbon emissions
CCE - Total constant carbon emissions
VE - Number of electric vehicles
VG - Number of gas vehicles
P - Population of US
SES - Number of solar energy systems (average five-kilowatt residential system)

T - Number of trees in the US
(each P contributes 562lbs of C02)
(each T will reduced 48 lbs. of C02)
(each SES reduces 15,00 lbs. of C02)
(each VE reduces 4,000 lbs. of C02)
(each VG contributes 10,000 lbs. of C02)

Objective function: TEMP = 54.4 + 34.7*(TCE/2E15)	(1)

Minimize: TEMP

Subject To:
VE <= 1.4 E6
T <= 2.28 E11
SES <= 2 E6
VG == 262 E6
P == 328.2 E6
48T + 15,00SES + 4,000VE = TRED
562P + 10,000VG = CCE
TCE = CCE - TRED

Discussions and Conclusion

Based on the results, we obtained a feasible solution, a reduction of 0.22 degrees in one year. This means that even after reducing gas cars, cutting of trees, population, and increasing use of electric cars, solar power, and hydropower, one year we were only able to bring the temperature down by a small margin. One point to keep in mind is that this result is just for the United States. If we were to create this model for each country, then we most likely will see a greater reduction point. Even if it's a small margin of reduction, 0.22 degrees is still considered to be significant because we were able to obtain a feasible data point. However, the issue with this number, as significant as it may be, is we will have to continue this for about ten years if we want to hit the goal of 2 degrees that scientists have set. To go further than 2 degrees, each country would have to follow this optimization model for essential life long to get the global temperature to what it used to be before the Industrial Revolution. Factories were taken out of the model because it was not a constant variable. Depending on the company, factories can change their output of C02 emissions, so it is not an optimal variable for our model.

As stated previously, this model's purpose is to not only minimize global temperature but to also show how much C02 is in the atmosphere and the amount of damage it is doing to the planet. This model is only the beginning of what countries need to use to reduce the global temperature. It is not just reducing and increasing the variables we used, it is about politics and education as well. Politics is a major issue when it comes to climate change. Unfortunately, politicians see climate change as either a hoax or a party issue more so than an actual issue. This optimization model is a perfect scenario situation, where politics isn't involved. If politics were to be involved then in this lifetime, climate change will never be solved. This is why politicians need to put aside party politics and educate themselves in the seriousness of this issue. Scientists state that this world is heading towards essentially an apocalyptic future, with a lack of resources. If we do not start now, then future generations will not have any resources left to survive.
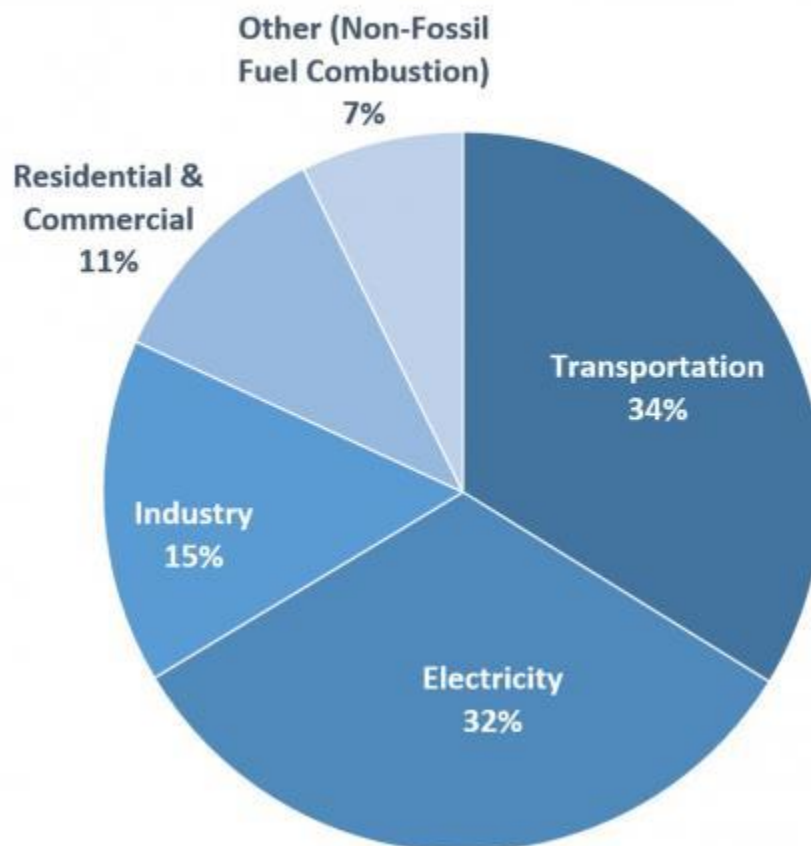
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Appendix

https://www.epa.gov/ghgemissions/overview-greenhouse-gases