Technical Report

Introduction

The goal of this paper is to determine whether the Limestone Power Plant in Limestone, Texas should retire in the next five years. Following my data analysis, I recommend that the Limestone Power Plant should, in fact, retire within the next five years. If retiring the plant is not an option, a suggested solution would be to explore more environmentally friendly fuel sources. I came to this conclusion by performing a systems analysis in R of the plant and graphically representing the fuel sources and the air pollutant and greenhouse gas emissions released from the plant over the course of 2 decades. In my analysis, I identified the greenhouse gasses and air pollutants being emitted, how far they traveled, their impacts on water consumption and waterways, their environmental and societal impacts on water sources and wastewater, their impacts on human health and risk and any economic, consumer, and social considerations.

Background

The Limestone Generating Power Plant is an operational power plant in Limestone, Texas. It is located in the unincorporated community of Farrar in Limestone County in Eastern Texas and generates at least 1850 megawatts of energy with multiple units. This is on the higher end for capacity compared to the average 1300-megawatt capacity of other coal plants in Texas [1] even though some units are no longer in operation. The two operating units use lignite and sub-bituminous coal as a fuel source and have a capacity of 893 Megawatts and 957 Megawatts. Limestone Electric Generating Station is a steam turbine power plant, and the aforementioned units use subcritical technology which have been in use since 1985 and 1986 respectively [5]. The boiler in the first unit has been in operation since October 1985, so, the projected retirement date is December 2029 [3]. Subcritical technology is a system that has a constant evaporation endpoint. Being a steam powered generator, it is operated with natural or assisted circulation. The water leaving the generator riser is separated into water and steam. This steam then flows into a superheater and the water is returned to evaporator. These units have efficiencies between 32% and 37% [8]. The third unit, called Limestone 3, was proposed to be built as a 745-Megawatt expansion to the existing Limestone Generating Power Plant; however, it was canceled on December 6, 2012. The Sierra Club stated that the third unit's progress was halted "due to the changing economics of coal plants, the growth of wind energy in the state, and because of legal challenges and grassroots opposition from Sierra Club and allied groups across Texas" [8]. This unit was going to use sub-bituminous coal as a fuel source and was set to use supercritical technology [3]. Supercritical technology is a system with a variable evaporation endpoint and is drum less, so evaporation takes place in a single pass [10]. All three units are owned by the parent company NRG Energy Inc, which is a leading energy supplier headquartered in Houston, Texas. Unit 1 and Unit 2 are owned by NRG Texas Power LLC within NRG Energy Inc [5].

In 2006, emissions data showed that the plant released roughly 13 million tons of carbon dioxide emissions and about 16,000 tons of sulfur dioxide emissions in addition to around 12,000 tons of nitrogen oxides emissions. In 2005, it was recorded that the plant released about 1000 lbs of mercury emissions [5]. After reviewing these numbers, the Sierra Club and the Environment

Integrity Project filed a lawsuit in October 2022 against the US Environmental Protection Agency over the effective exemption of 8 power plants that used coal as their primary source of fuel [8]. Their reasoning was that these plants were in violation of fine particle pollution standards and that the EPA had failed to approve an amendment to the Texas State Implementation Plan regarding National Air Quality Standards. By failing to approve or reject the amendment, the 8 power plants continued to release large amounts of dangerous levels of harmful chemicals in the atmosphere, causing deaths in the surrounding communities [8].

The main demographic of Limestone County, Texas is white, non-Hispanic with a 51.6% male and 49.4% female population of the roughly 22,200 people who live there as of July 1, 2022 [12]. The main industries that employ from the area are healthcare and social assistance, and construction with a smaller but significant amount of people in education, manufacturing, and retail trade. There is a focus in the energy and mining industry because of the existing and neighboring power plants [4]. The electricity generated from the power plant is used to power the houses and businesses in the area including the mining industry, and any remaining electricity is sent to the Texas power grid to be redistributed.

Data

The data used in my analysis is sourced from the United States Energy Information Administration (EIA) website. I used the EIA open data monthly and annual generation and fuel consumption data to be used in my systems analysis. I used the EIA-860 form to identify the type of boiler, firing configurations, and emission control technologies used for lignite and sub-bituminous coal. I found that the Limestone power plant has an operating boiler type code of Da. This code is the standard work performance for fossil-fuel fired steam boilers if their construction started after September 18, 1978 [15]. The firing type for this plant is dry bottom, tangential, concentric, or corner firing. The plant uses a flue gas desulfurization unit as a So2 control process. This plant uses fly ash reinjection. The standard sulfur rate is listed as 0.6, which is used as our So2 emission factor [15]. This value was found using the United States Environmental Protection Agency's (U.S. EPA) AP-42 (air pollutant emissions factors) data [16]. The existing nitrogen oxide control strategy is using a Low NOx burner. The plant uses an activated carbon injection system to control mercury usage and release [9].

Results

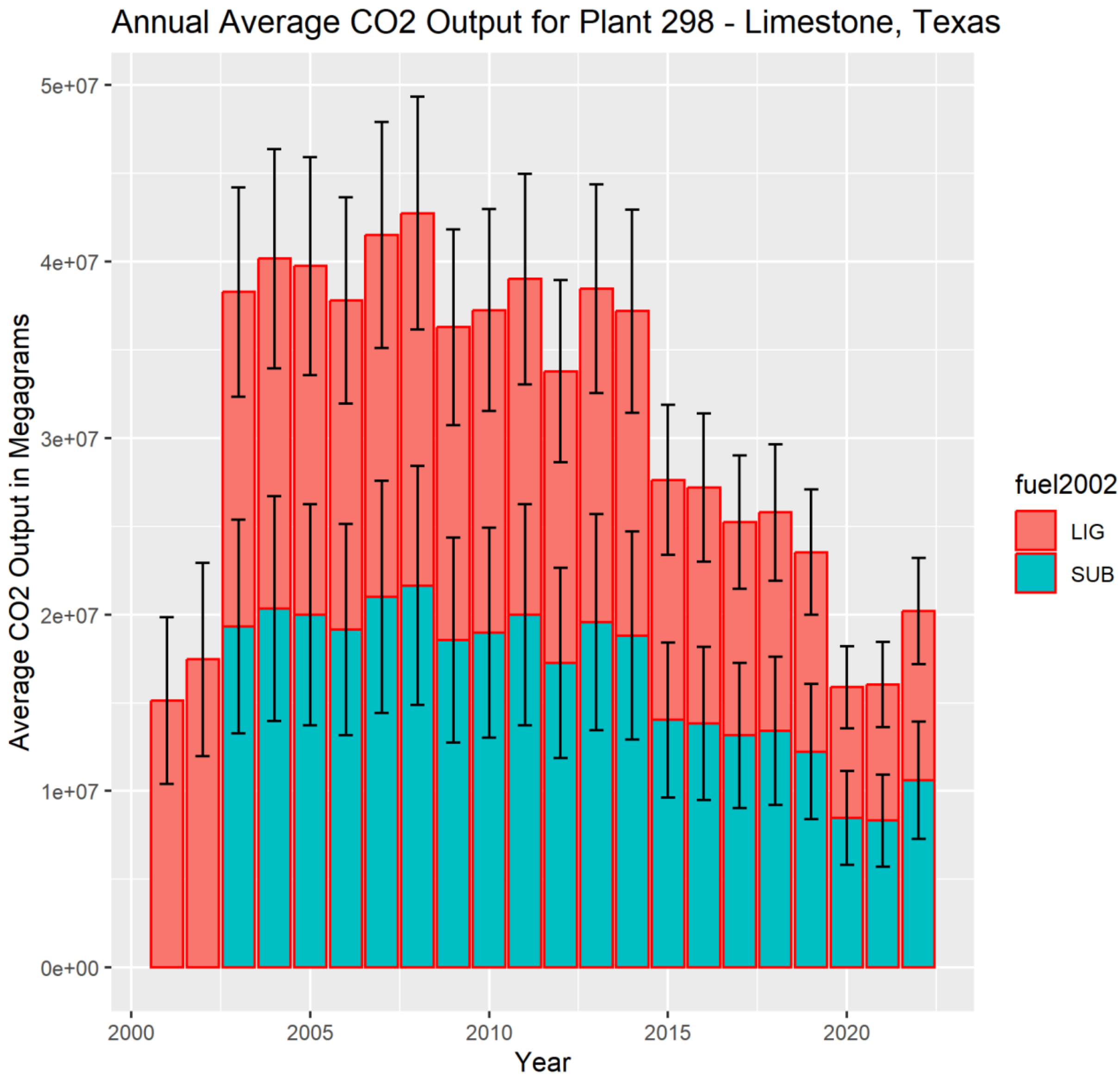

Figure 1: The annual average Carbon Dioxide output including percent error

The graph above shows the annual CO2 emissions released from the Limestone Plant over the course of 2 decades. The bar chart shows the emissions released from lignite coal stacked on top of the sub-bituminous coal. Included are error bars showing the highest and lowest possible emission values from each coal type. The error values were calculated using the 10% standard uncertainty values given for a coal plant.

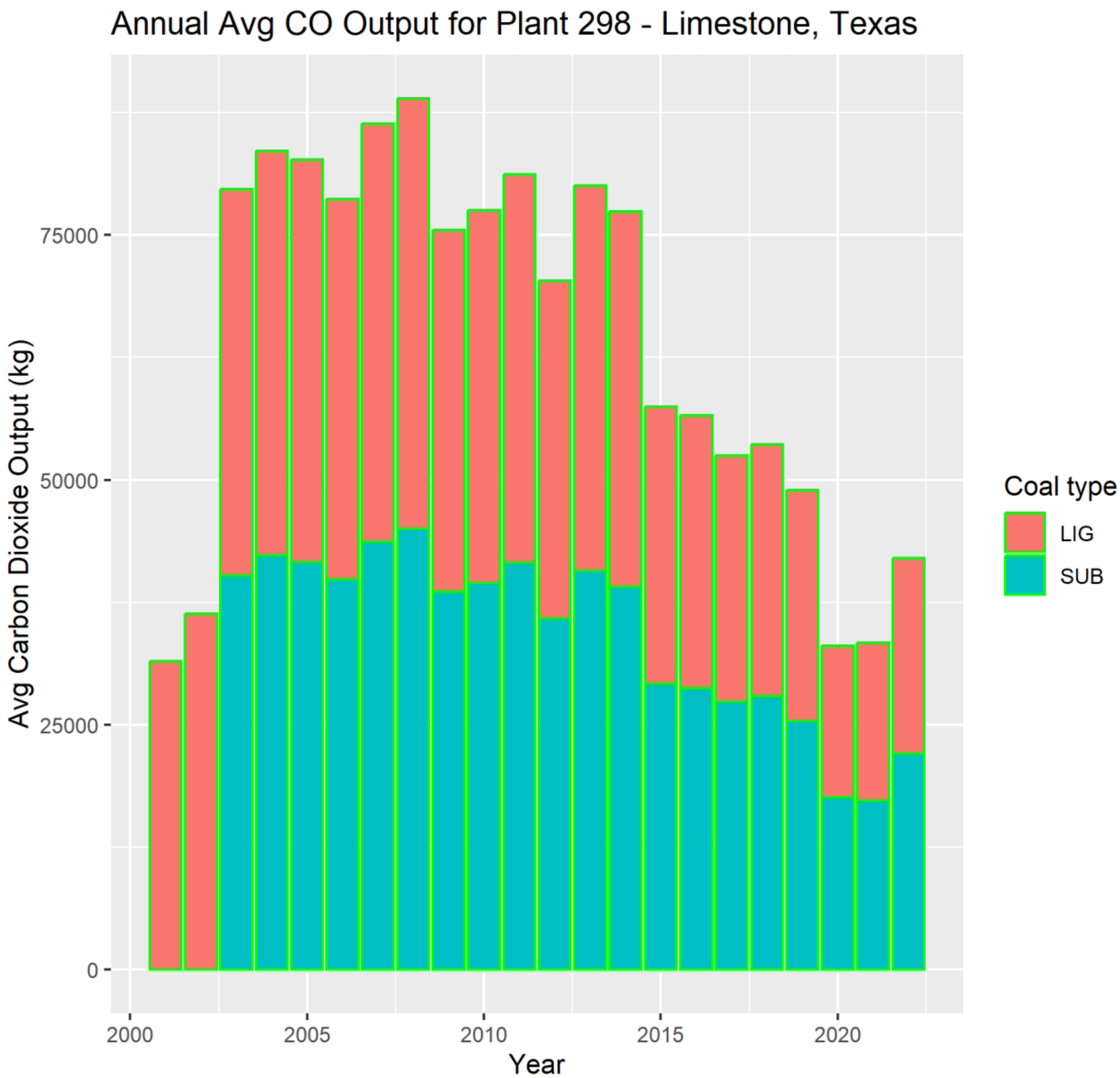

Figure 2: The annual average carbon monoxide output

The figure above shows the annual average output values of carbon monoxide released by the Limestone power plant over the course of two decades. It shows the output values from lignite coal stacked above the output values for sub-bituminous coal.

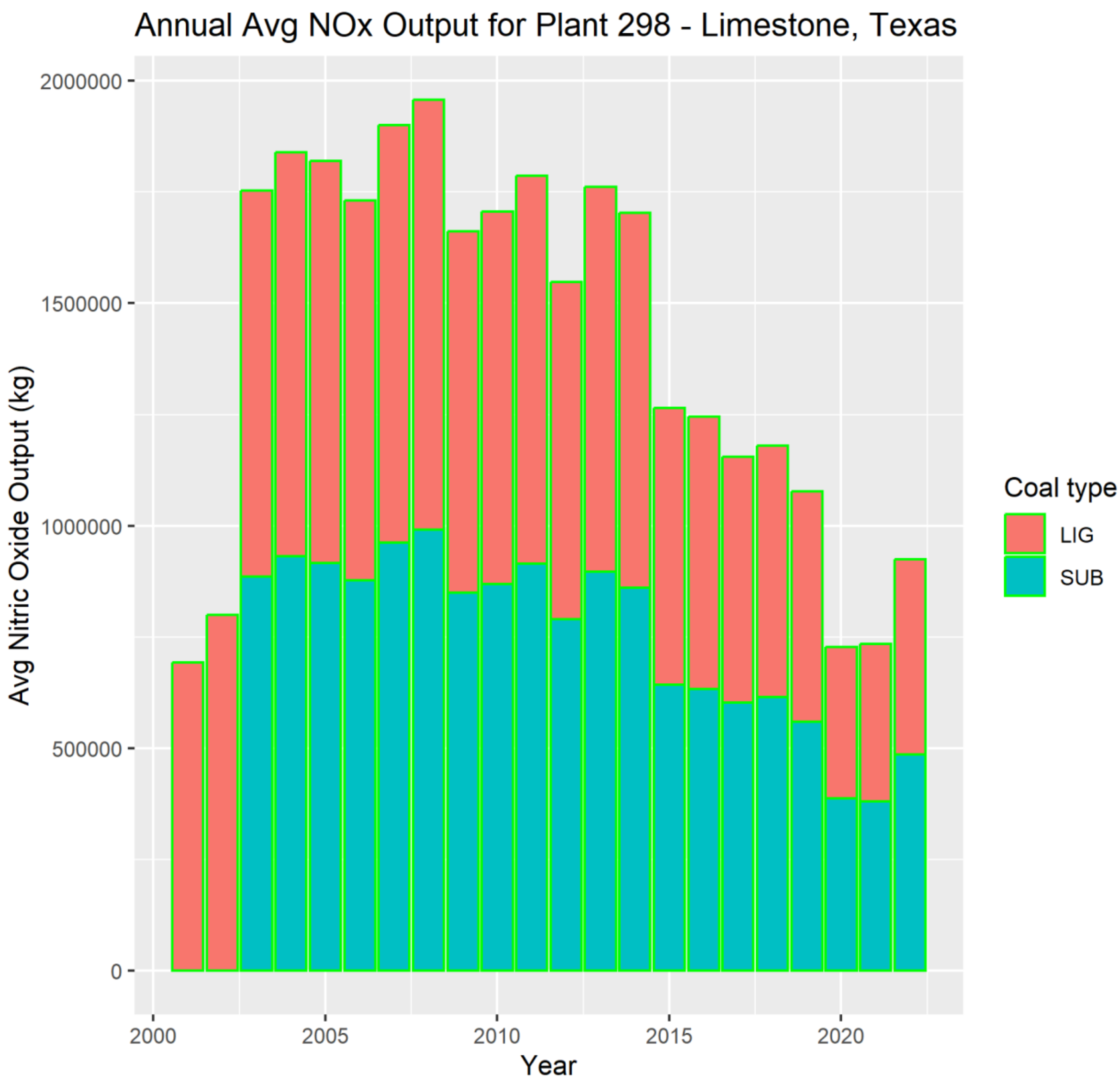

Figure 3: The annual average nitrogen oxide output

The figure above shows the annual average output values of nitrogen oxides released by the Limestone power plant over the course of two decades. It shows the output values from lignite coal stacked above the output values for sub-bituminous coal.

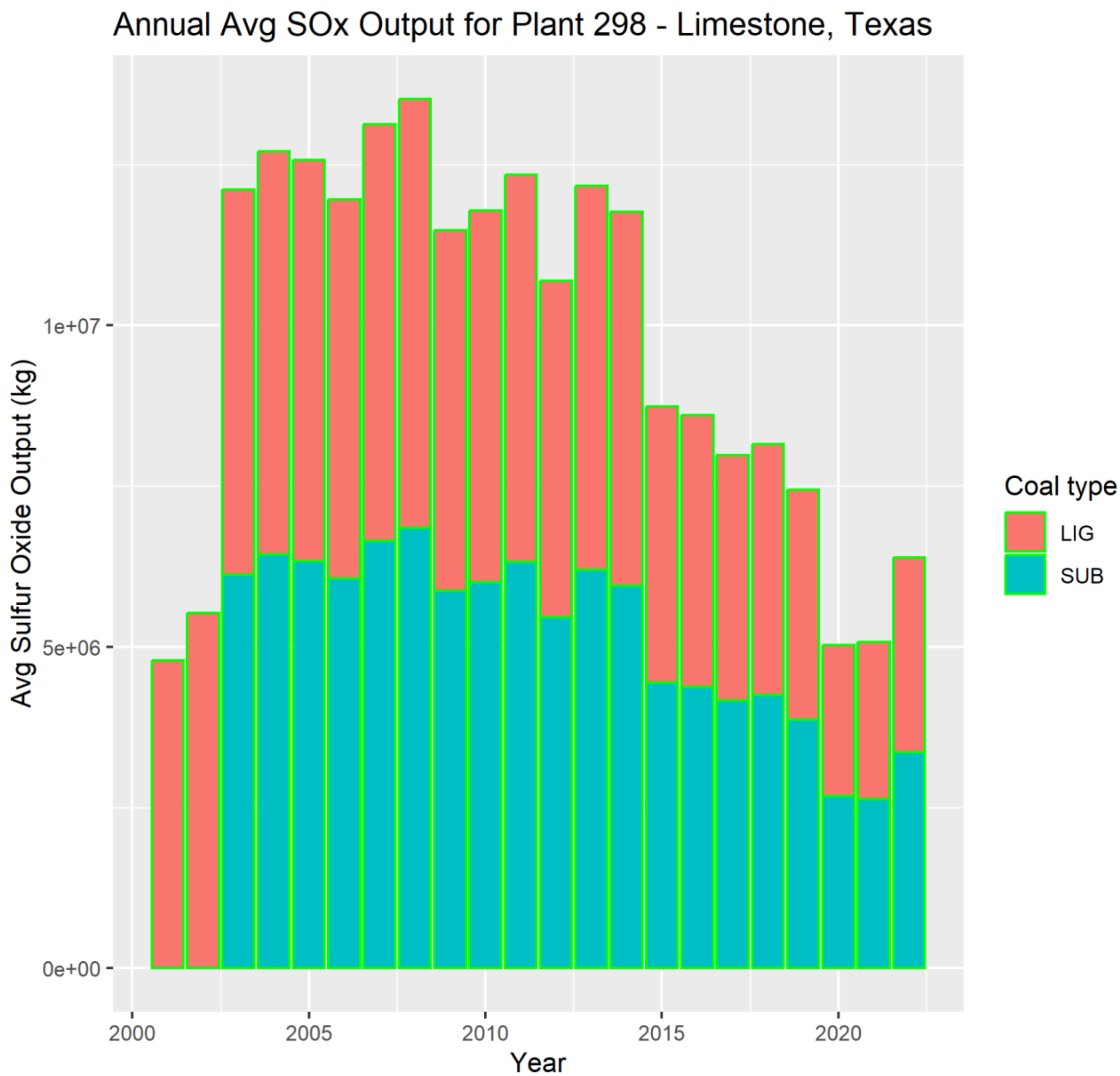

Figure 4: The annual average sulfur oxide output

The figure above shows the annual average output values of sulfur oxides released by the Limestone power plant over the course of two decades. It shows the output values from lignite coal stacked above the output values for sub-bituminous coal.

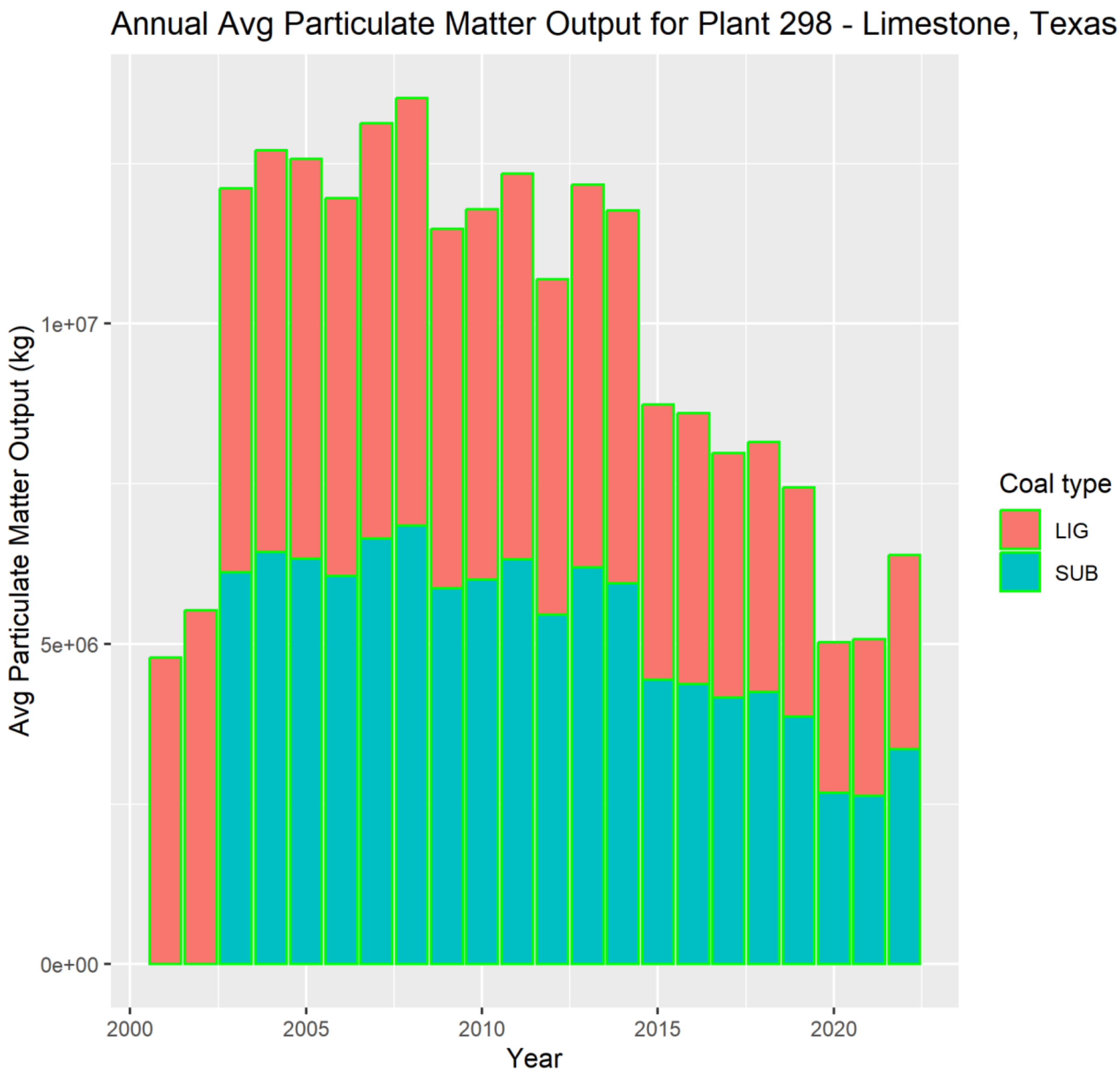

Figure 5: The annual average output values for particulate matter

The figure above shows the annual average output values of particulate matter like flyash released by the Limestone power plant over the course of two decades. It shows the output values from lignite coal stacked above the output values for sub-bituminous coal.

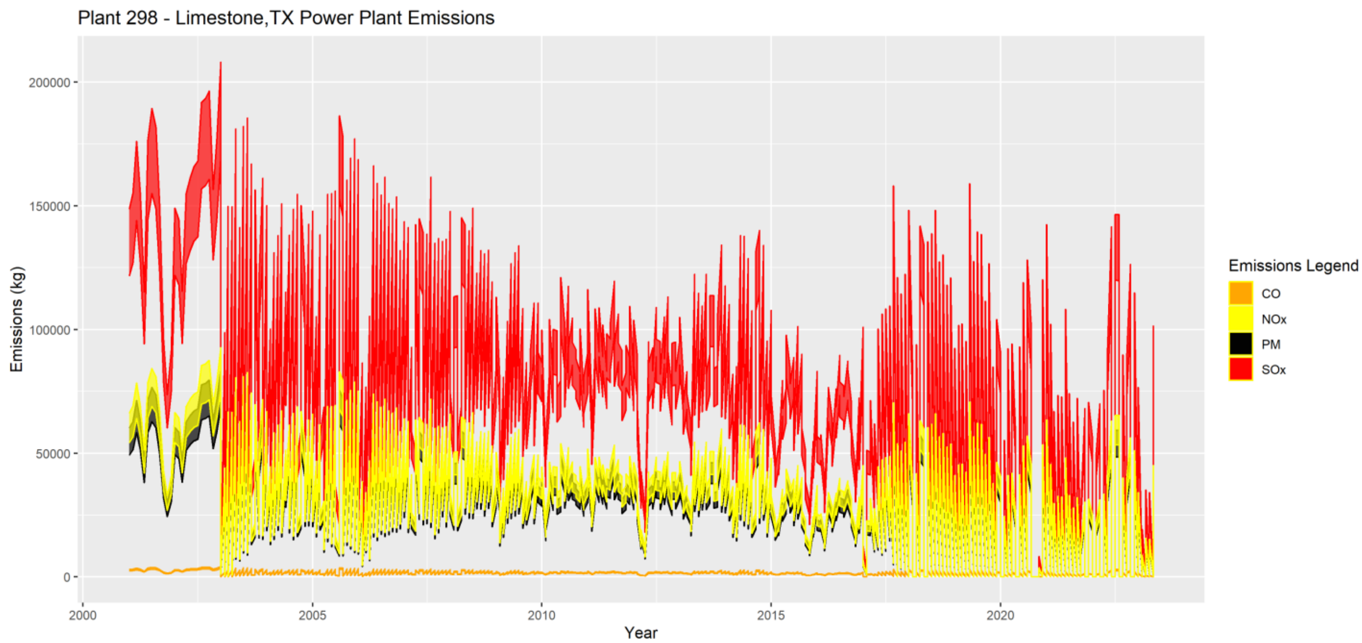

Figure 6: Emissions released by Limestone Plant including ranges of error

The graph above shows the annual average emissions output for the Limestone plant in Limestone, Texas. The emissions include carbon monoxide, nitric oxide or nitrogen dioxide, sulfur dioxide, and particulate matter. Looking at the graph it is apparent that most of the emissions from the Limestone plant are sulfur oxides reaching a high of over 200000 kg/year and the lowest annual average emission is carbon monoxide which lies really close to 0 kg/year. This graph uses a shadow ribbon for each emission to show the range of errors. The lower edge of each ribbon shows the minimum emission values given the 10% error for a functional coal plant. The upper edge of each ribbon shows the maximum emission value. The upper and lower bounds were found by adding and subtracting 10% of our average value for each emission.

Analysis

Following the systems analysis, the results show that the greenhouse gases emitted are carbon dioxide. Carbon dioxide accelerates global warming and contributes to climate change because it traps heat energy and leads to increasing temperatures. Dissolved carbon dioxide in the ocean throws off the equilibrium between the ocean and the atmosphere. The air pollutants emitted are particulate matter, sulfur oxides, carbon monoxide and nitrogen oxides. The distance travelled was calculated using a velocity of 10 m/sec, a trivial remaining value of 5%, and characteristic times for particulate matter, carbon monoxide, sulfur oxide and nitrogen oxide as 1 week, 1-2 weeks, 1 day, and 1-2 hours respectively [7]. The results show that particulate matter travelled 18,000 km, carbon monoxide travelled 18,000 km – 36,000 km, sulfur oxide travelled 2600 km, and nitrogen oxide travelled 110 km – 220 km.

Particulate matter is a mixture of solid particles and liquid droplets found in the air or water. These include dust, dirt, soot, etc. They are released into the atmosphere from the smokestack of a power plant. Some particles are so fine (less than 2.5 micrometers in diameter) that they can enter human lungs and blood streams and cause serious health issues, and in extreme situations, death [14]. These particles also contribute to reduced visibility and haze which increase the risk of accidents on the road and in certain workplace situations. Particulate matter can get into waterways and reduce water quality which negatively affects ecosystems and communities that rely on that water by contaminating it. By reducing air and water quality, the economic, consumer, and societal impacts of particulate matter are that they harm labor and negatively impact labor productivity, workplace safety, increase health expenditures and decrease the quality of life of locals.

Carbon monoxide is an air pollutant that has negative effects on human health when inhaled in large amounts. If large amounts of carbon monoxide are inhaled, they can travel through the bloodstream and reach critical organs like the lungs, brain and heart thereby reducing the availability of oxygenated blood to travel through the body. Some observable effects include headaches, nausea, dizziness etc [13]. The environmental effects of carbon monoxide include dissolving into oceans, therefore trapping heat and increasing ocean temperatures, accelerating global warming and contributing to climate change [2]. Carbon monoxide indirectly contributes to climate change because it participates in chemical reactions that lead to the production of greenhouse gases like ozone. The economic, consumer, and societal impacts include negatively harming the workforce therefore delaying progress on projects, increasing health related expenditures, and reducing the quality of life of those nearby.

Sulfur oxides include sulfur with a combination of multiple oxygen atoms. The sulfur oxide emission of greatest concern is sulfur dioxide. The short-term human health effects of sulfur dioxide include harming the respiratory system. This makes breathing especially difficult for people with asthma and other respiratory diseases. The long-term health effects include increasing the likelihood of developing a respiratory disease. Sulfur oxide emissions can form small particles and contribute to particulate matter pollution which can then enter human Airways and bloodstreams and lead to negative health effects [11]. The environmental impact of sulfur dioxide is that in high concentrations, it can lead to the formation of other sulfur oxides. In high concentrations gaseous sulfur oxides can harm plants by damaging foliage and decreasing growth. Sulfur oxides can also contribute to acid rain which then further damages or causes sensitive ecosystems [11]. The economic, consumer, and societal impact of sulfur oxide emissions are reduced labor productivity, increased health related expenditures, decreased quality of life, decreasing plant cover, and sensitive or weak ecosystems which turns away tourism.

Nitrogen oxide is a group of highly reactive gases that include nitrogen with a combination of oxygen atoms. Nitrogen dioxide as an example of nitrogen oxide [6]. Human health effects of nitrogen oxide include aggravating existing respiratory diseases such as asthma or leading to the development of respiratory diseases if exposed to nitrogen oxide for an extended period of time. Breathing in high concentrations of nitrogen dioxide irritates airways and can lead to coughing, wheezing and general difficulty breathing. Some of the environmental effects of nitrogen oxide include reacting with other chemicals to form air pollutants and greenhouse gases like particulate matter and ozone [6]. These contribute to other human health problems and indirectly accelerate global warming and contribute to climate change. Nitrous oxides interact with water oxygen and other chemicals in the atmosphere to form acid rain which can harm local ecosystems and can lead to reduced visibility and haze [6]. This creates an unsafe work environment for occupations that require people to work outside and can lead to increased roadway accidents. This, in the end, contributes to a decreased quality of life, decrease in tourism and increase in health problems and related expenditures which negatively impacts the economy.

Conclusion and Recommendation

Taking all the data and systems analysis into consideration, I believe that the Limestone generating power plant should retire within the next 5 years. This conclusion was reached by considering the annual average emissions output values including uncertainty as shown in figure 6. Sulfur oxide had a peak of over 200000 kg a year, followed by nitrogen oxide with a peak of just under 100000 kg, closely followed by particulate matter and finally carbon monoxide. Given that these emissions are consistently no less than 30,000 kg annually and are present in the atmosphere for extended periods of time, they have had adverse effects on the surrounding ecosystems and communities and the people that live in them. These effects include accelerating global warming, contributing to climate change, reducing plant cover, weakening ecosystems, causing respiratory and health problems to locals, economic impacts like reducing tourism, decreasing productivity, and overall, negatively affecting the quality of life of individuals in the area and surrounding towns. Since the boiler in the first unit reaches the end of its life in 2029, it may be economically and societally beneficial to retire the entire plant by that time instead of replacing the boiler. If retiring the power plant is not possible, another suggestion would be to divert from coal use and turn to natural gas or another fuel source that has less of a negative impact on the surrounding communities and the environment.

Limitations and Assumptions

The data limitations of this power plant are that live and up to date data is not available. Additionally, there are three units in the limestone power plant, however, one of these units is not in operation so the data encompasses emissions from both boilers combined. Additionally, all numerical values have a standard uncertainty of 10% used for all coal plants.

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