Investigating the Coupling of Emissions and GDP

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***Abstract*— This paper aims to prove the correlation between the yearly GDP of a country and their carbon emissions. The research has been conducted using data from the World Bank and the Global Carbon Project [1] [2]. The experiment results suggest that there is a strong correlation between emissions and GDP. This correlation was stronger with countries that are rapidly developing, as opposed to countries that developed over a longer period. To predict future emissions and GDP, a polynomial model to the 3rd degree was used. Accuracy was found by comparing the Mean Squared Error of each model.**

Keywords—gross domestic product, emissions, predictions, correlation.

I. Introduction and Contributions

A. Motivation and Importantance

Emissions are rapidly increasing and are detrimental to the environment and human health. Climate health has become an international crisis. This research paper investigates if there is a correlation or causation between a country's rapidly increasing GDP and emissions caused by industrialization. As noted by McDowall et. al, environmental challenges are recognized as being created by rapid growth and industrialization [1, p. 651]. Three countries' emissions and GDP were used to investigate and attempt to find a correlation. The countries chosen were the USA as a standard to compare to, China as an example of the data following our hypothesis, and India as an opportunity to prove or disprove our hypothesis.

B. Background

As countries rapidly industrialize, such as China in 1960, their GDP increases dramatically, and so does their emissions. China and other countries will be investigated to see if a push to rapidly industrialize to compete economically causes higher emissions, as they may tend to use dirty energy to power their growth. As dirty energy is cheaper for a country to use when they have little infrastructure, this is a factor to investigate.

C. Data Sources

The data sources used are sourced from The World Bank and The Global Carbon Project and contain data from each country's yearly GDP and emissions respectively (The World Bank, 2021) (Robbie & Peters, 2022). The GDP features values both as originally taken and adjusted for inflation. The emissions data records total emissions, as well as emissions from coal, oil, gas, or flaring. All emissions data used will be the total emissions, unless otherwise specified.

D. Types of Models Used

The following research is conducted using linear models, exponential models, and polynomial models to various degrees. These are used to determine the most accurate prediction model to predict the future emissions and GDP of notable countries. A polynomial model to the 3rd degree was used for predictions after it was determined to be the best fit in terms of accuracy to the original data sets used.

E. Overview of Upcoming Sections

In the following sections, this research paper will examine emissions and GDP change over time, correlation findings, projections of developing countries' data and compare these findings to other accredited research papers and articles. The article will then outline the conclusions drawn from the research followed by future research opportunities.

F. Upcoming Sections

- Methodology and Experimental Results
    - Historical Introduction
    - Environmental Concerns
    - Initial Data Introduction
- Correlation Findings: GDP and Emissions
- Compare Statistical Models
    - Linear
    - Exponential (nonlinear)
    - Polynomial (nonlinear)
- Predict and Analyze Future Trends
- Discuss Contributions and Solution
- Future Research Opportunities
- Conclusion
- Acknowledgement
- References

II. Methodology and Experimental results

A. Historical Introduction

The Great Leap Forward was a government led campaign from 1958 to 1962 that intended to compete with the United States and the USSR resulted in massive economic growth in the following decades (The Long-term Health Effects of Fetal Malnutrition: Evidence from the 1959–1961 China Great Leap Forward Famine, pp. 1265-1266). During this period, the CCP (Chinese Communist Party) decided to change the country from an agrarian economy into a communist, collectivist society (Mao's Road to Serfdom: Mao Zedong's ambition to outshine Stalin led to waves of starvation, a grotesque and unworkable economy, and war against his own people. Hoover fellow Frank Dikotter on the Great Leap Forward, which was neither great nor forward, p. 110). The CCP viewed grain and steel production as best way to developer China's economy. People's communes were developed, wages were replaced with work points, and these communes aimed to maximize economic outputs by producing steel and grain to support factories, schools, and cities.

After their industrialization in the 1960s, China built the platform to economically explode, becoming the world's largest exporter of goods in the early 2000s. The Economist explores this growth (The Economist, 1995) and in 1979, Southern China's coastal provinces' GDP have grown by 15% each year, leading to these provinces rivaling the rich southern Europe.

The following sections will examine large polluters to discover if rapid growth in emissions is followed quickly by rapid growth in GDP, at an offset of one to two decades. Rapid industrialization requires large amounts of energy. However, if a country is economically weak, they may not have the existing infrastructure to produce clean and inexpensive energy. This may cause these countries to resort to coal to fuel their industrialization and growth, as China did and India is doing.

B. *Environmental Concerns*

Figure 2, 3, and 4, on page 2, show the annual emissions from the three countries that were chosen for this report. In Figure 2 and 3 it is seen that China's emissions spike during the period of the Great Leap Forward and continue to ever climb upward. China has a disproportionate number of emissions from coal, compared to the other top emitters in the world, as of 2020 (Robbie & Peters, 2022). China's continued dependence on coal greatly hurts the environment. Despite having the funds to invest in clean energy, China still is powered largely by coal, at a rough estimate of 66% of their emissions coming from coal (Robbie & Peters, 2022).

India's coal emissions are currently increasing at an alarming rate, as their GDP steadily grows alongside. As seen in Australia's Mining Monthly (Australia's Mining Monthly, 2010) in 2010, Thiess, a contract mining company, developed coal processing infrastructure in a 5.5-billion-dollar mining project intended to aid India's industrialization (Engineering and Mining Journal, 2010). Like China during the Great Leap Forward, India is prioritizing steelmaking and is using coal to do so (Engineering and Mining Journal, 2010). This has led to high emissions from India as they seek to modernize. As seen in Figure 4, India's emissions and GDP appear to grow in tandem with each other, at a slight delay of 10 to 20 years. It is suspected that India's emission and GDP growth is beginning to reflect China's GDP and emissions growth during their industrialization.

C. *Initial Data Introduction*

Initially viewing the USA's yearly emissions and GDP, as shown in Figure 3, there appears to be a weak correlation between rising emissions and GDP. However, looking at China's yearly emissions and GDP in Figure 2, there appears to be a much stronger correlation. The growth of both emissions and GDP seem to follow a similar rate of growth, at a slight offset. This offset could be caused by the delay of investing into industrial growth and waiting for the investment to return profits. Finally, looking at India's yearly emissions and GDP in Figure 4, we see that the emissions and GDP follow each other well, except between 1990 and 2010. In the following sections, we will view quantitative methods that prove correlation between each country's emissions and GDP. The United States, China, and India will be primarily examined to find cause and effect. Other countries will be analyzed as well to find the best fitting method to predict emissions or GDP for developing and developed countries.

For the reader's information, the three countries chosen and their important base values, are shown below, in Figure 1. This shows us the numerical equivalents of Figures 2, 3, and 4. It also shows the mean change in percent each year for both emissions and GDP. One thing to notice is that the USA's emissions increase minimally year over year, while still having an increasing GDP. However, both India and China's emissions increase in percent is near or over fifty percent of their GDP growth. Their GDP growth is tied to emissions.

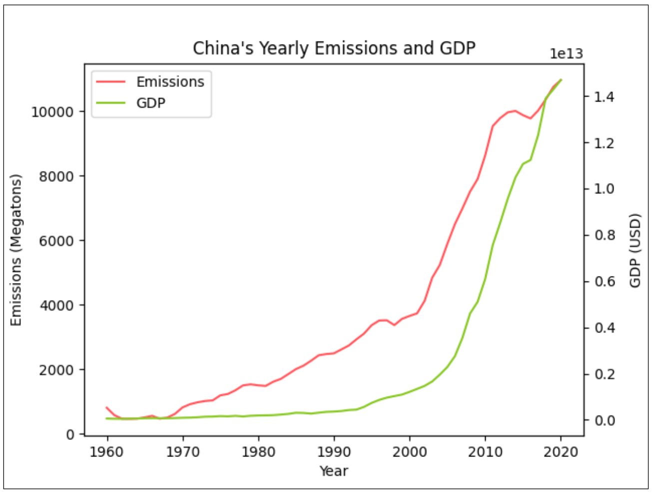

Fig. 2. China's Yearly Emissions and GDP, 1960-2020. Data sourced from The World Bank and the Global Carbon Project (The World Bank, 2021) (Robbie & Peters, 2022).

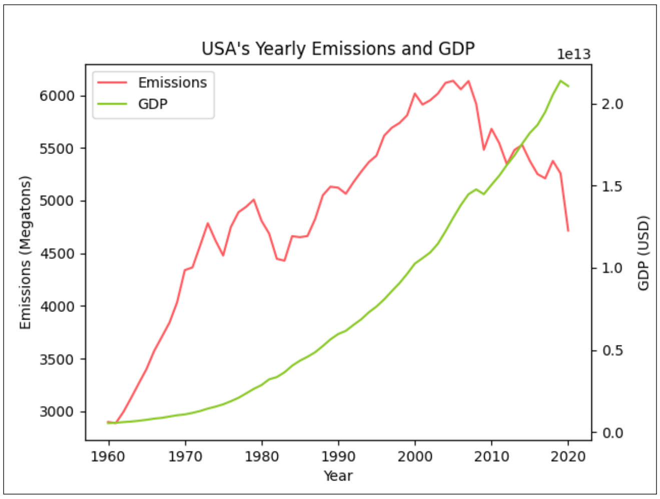

Fig. 3. USA's Yearly Emissions and GDP, 1960-2020. Data sourced from The World Bank and the Global Carbon Project (The World Bank, 2021) (Robbie & Peters, 2022).

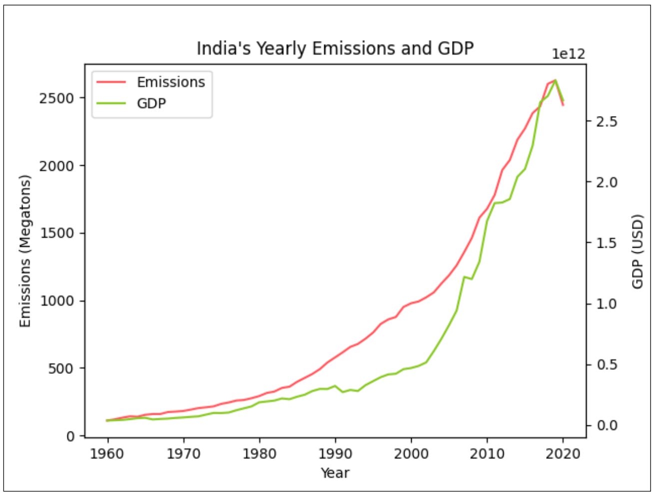

Fig. 4. India's Yearly Emissions and GDP, 1960-2020. Data sourced from The World Bank and the Global Carbon Project (The World Bank, 2021) (Robbie & Peters, 2022).

Fig. 1. USA, China, and India – Initial Data, 1960-2020. Data sourced from The World Bank and the Global Carbon Project (The World Bank, 2021) (Robbie & Peters, 2022).

Country	United States		China		India	
Measurement	GDP (USD)	Emissions (Megatons)	GDP (USD)	Emissions (Megatons)	GDP (USD)	Emissions (Megatons)
Mean	$7,683,465,133,508.20	4962.31	$2,576,101,445,494.81	3822.58	$658,472,481,996.15	847.13
Median	$5,963,144,000,000.00	5093.74	$360,857,912,565.97	2484.85	$288,208,430,383.96	578
Mean Change Year over Year	6.2143%	0.8518%	9.8923%	4.7552%	7.6241%	5.2463%

III. Correlation Findings: GDP and Emissions

In Figure 4, the correlations between emissions and GDP are presented for six countries. A value close to 1.00 indicates a strong correlation, and a value close to -1.00 indicates a weak correlation. The countries chosen were our original three countries, China, India, and the USA, as well as Brazil, the UK, and Canada. These additional three countries were chosen as we wished to sample an additional developing country and more well-developed countries.

Two notable correlations are India, and the United Kingdom. The correlation that India's emissions and GDP shows is the strongest of all the countries sampled. This further aids in supporting our hypotheses that a country quickly industrializing and increasing their emissions, will experience high GDP growth at a slightly delay. Considering both the double line graph in Figure 1.3 and the correlation plot in Figure 2, India displays a high level of cause and effect between yearly emissions and GDP. However, looking at the United Kingdom's correlation between emissions and GDP we notice the exact opposite of India's correlation. The UK has an extremely weak correlation between emissions and GDP and may further support the idea that a country industializing quickly will cause their GDP to closely mirror it.

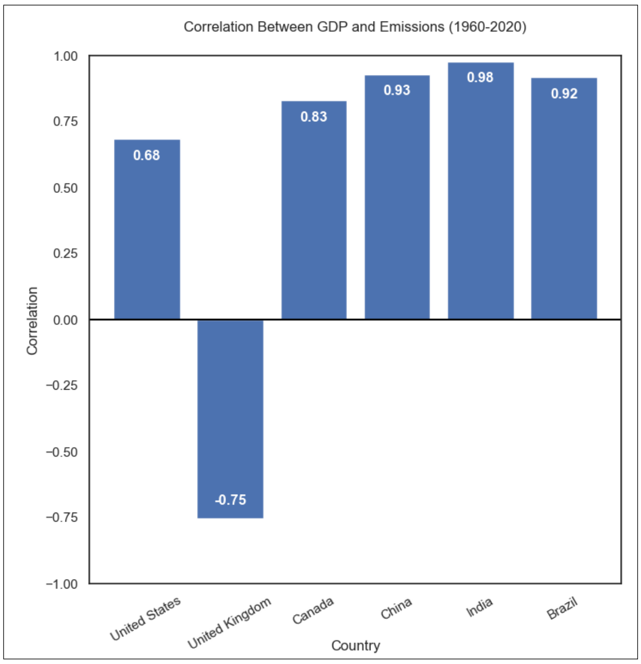

Fig. 5. Correlation Between GDP and Emissions (1960-2020). Data sourced from The World Bank and the Global Carbon Project [1] [2].

Comparing India and the UK historically may also further support the hypothesis that industrializing quickly will yield a higher correlation between emissions and GDP. Europe's industrialization began in the 1780s and was one of the first regions in the world to develop at this scale, which Britain led (Britannica, n.d.). During Britain's reign of India from the 1750s to 1950s, Britain found that it did not make fiscal sense to invest industrializing India. Thus, India's industrialization and modernization did not start till the end of Britain's rule in the 1950s (Sharma, n.d.). It is likely that the roughly 170-year gap between the two's industrialization is responsible for the differences in strength of correlation. The UK's additional 170 years it took to slowly grow may give it the characteristic of having uncoupled emissions and GDP, unlike India. Finally, it is seen that Brazil also shows a high correlation which is used as an additional reference for future predictions further in the paper.

IV. Comparing Statistical Models

In academic research, statistical models are used to define the behaviour of a data sample. They are frequently used to analyze data and project future values. Statistical models are especially popular in the fields of climate research and economics. A 2007 study on Taiwanese energy consumption and economic growth supported this method, by comparing the data to linear and nonlinear statistical models (Lee & Change, 2007, p. 2282). Comparing multiple models gave the researchers a higher chance of finding a model that accurately and precisely represented the sample data.

This section will compare the yearly emission and GDP data with various statistical models. The model which best fits the data will be used to project future GDP and emissions for Canada, China, Brazil, India, the UK, and the US. The models which will be used are linear, exponential, and polynomial models. These statistical models were chosen because of their frequent use in research.

Model selection is a controversial topic within the research community. There are many different metrics and formulas to consider while analyzing statistical models. This research has been conducted using the methodologies outlined in the textbook, which are Occam's Razor and the Principle of Parsimony. Occam's Razor is a scientific principle which Navidi states that "The best scientific model is the simplest model that explains the observed facts." (Navidi, 2011, p. 619) and that the principle of parsimony states "A model should contain the smallest number of variables necessary to fit the data" (Navidi, 2011, p. 619). We have defined the best statistical model as the simplest model which accurately follows the spread of data in the sample. Analysis of the three outlined statistical models were done with these principles in mind.

A. *Linear Model*

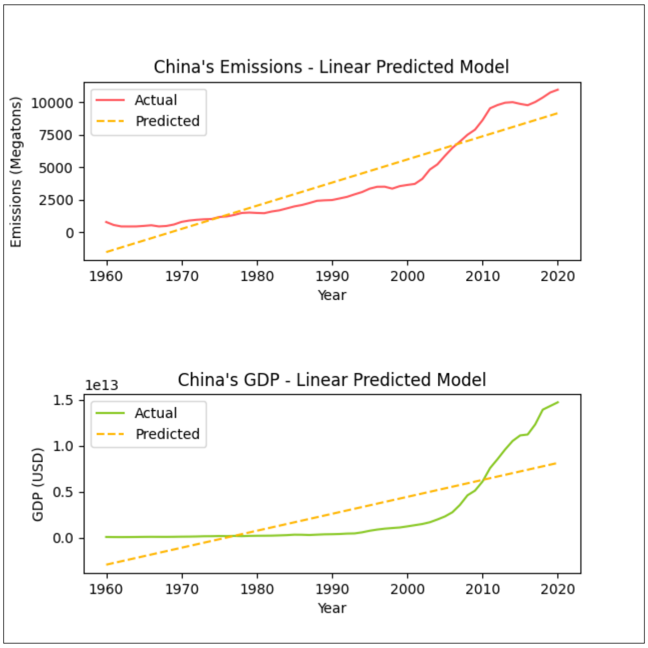

Fig. 6. Linear Predicted Models – China GDP and Emissions (1960-2020). Data sourced from The World Bank and the Global Carbon Project [1] [2].

Figure 6 is one example of a country's linear predicted model that does not track well with the actual data. Both emissions and GDP were largely off. While emissions were predicted slightly better, it is still below the standard chosen for this paper. A linear model does well when there is a strong linear relationship between the x (emissions) and y (GDP) (Navidi, 2011, p. 531). However, there is not a strong linear relationship between emissions and GDP. Next, an exponential model will be used to find an improvement.

B. *Exponential Model (nonlinear)*

Exponential models are best used when modeling data that changes over time, such as GDP, interest, population, or emissions. At first glance this appears to be a better fit than a linear model for the chosen data. As the name suggests, the exponential model will grow exponentially when used to predict data. For example, in Figure 7, we can see the same base data as Figure 6 but predicted using an exponential model instead of a linear model.

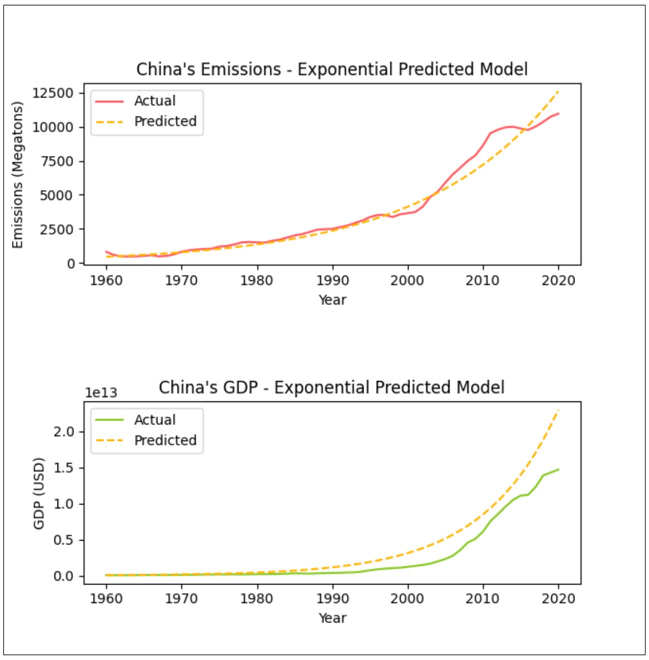

Fig. 7. Exponential Predicted Models – China GDP and Emissions (1960-2020). Data sourced from The World Bank and the Global Carbon Project [1] [2].

As seen in Figure 7, the predicted growth of GDP and emissions are a much better fit to the actual data in the chosen years. The emissions prediction is near perfect, only straying off the actual data when the actual data begins to vary more greatly than previously. However, the predicted GDP is still off course. While the rates of change appear to follow each other closely, the predicted GDP deviates wildly after the year 2010. While this is improved from the linear model, the exponential model is still imperfect. Next, a polynomial model will be used to predict both emissions and GDP again, to help select the best model to use to predict India's and other third world country's future emissions and GDP.

C. *Polynomial Model (nonlinear)*

A polynomial model is best used when the x-axis variable, the year, is not linearly related to the outcome of the y-axis variable, the emissions or GDP. Therefore, the relationship between the data is best predicted using a curve. This could be done using the exponential model; however, it was seen previously that this does not consider any trends downward in our data. To better consider any downward trends in emissions or GDP, a 3rd degree polynomial was used to predict the data.

Polynomial models can use an R^2 value to determine how much of the variance is covered in the predicted model. The R^2 value is a decimal between 0 and 1 and represents the percentage of which the variance is taken into consideration. An R^2 of 0.75 means that the model accounts for 75% of the variance in the outcome.

As seen in Figure 8, a polynomial model to the 3rd degree used to predict emissions and GDP is a near perfect fit. While there is a slight variance in the final values in 2020 for both data sets, it is very close to the original. After predicting the same data with all three methods, the polynomial is clearly the best fit. Using this discovery and the knowledge that emissions and GDP are strongly correlated, a polynomial model will be used to predict India's and other developing countries' upcoming emissions.

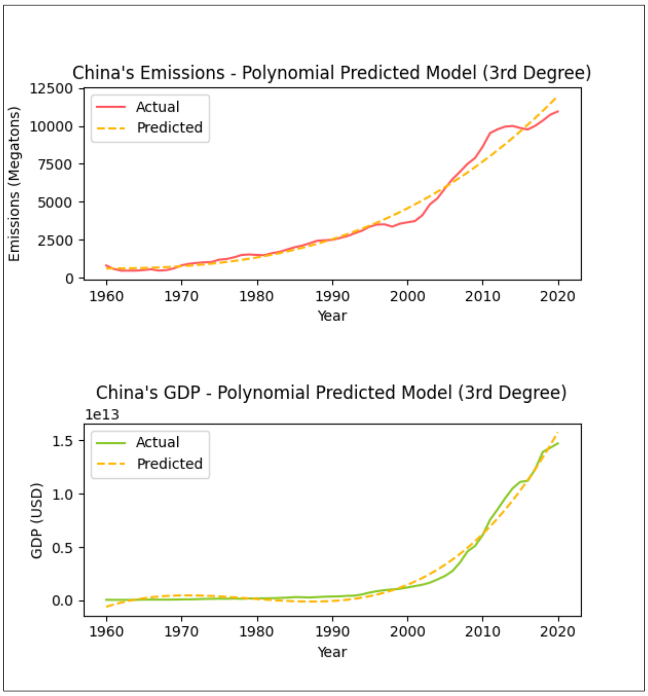

Fig. 8. Polynomial Predicted Models (3rd Degree) – China GDP and Emissions (1960-2020). Data sourced from The World Bank and the Global Carbon Project [1] [2].

V. PREDICT AND ANALYZE FUTURE TRENDS

Figures 9 and 10 show India's and Brazil's predicted GDP and emissions from 2020 to 2040, using the previously analyzed Polynomial Model to the 3rd degree. It is seen that the predicted values vary greatly between India and Brazil. While India's GDP and emissions steadily grow at what appears to be a similar rate, Brazil's GDP and emissions decline drastically. The following section will examine potential causes for Brazil's drastic decrease in GDP, as well as India's growth potential.

By analyzing the projection model for emissions in Figures 9 and 10, India's predicted emissions increase by 13.03% in 2025, 27.23% in 2030, and 59.36% in 2040 from last recorded values in 2020. However, Brazil's emissions predicted emissions decreased by 14.73% in 2025, 34.61% in 2030, and 91.81% in 2040. Brazil's emissions are decreasing drastically at nearly double the rate of India's by 2040.

As noted previously in Section II, Heading B, India is quickly modernizing and fueling their growth with coal. However, Brazil's decrease in emissions may be due to their significant protection of the Amazon rainforest, whose logging industry is a large contributor of emissions [12]. It is unlikely that Brazil's emissions or GDP will turn negative as seen in Figure 10, but it is likely that their actual emissions in the coming years will trend downward significantly. The Brazilian government also pledged to reduce their emissions "by 37% by 2025 from their 2005 emissions levels" [12]. Due to the reduction in deforestation and logging in Brazil, this may also contribute to Brazil's drastic decrease in GDP, that is shown in Figure 10.

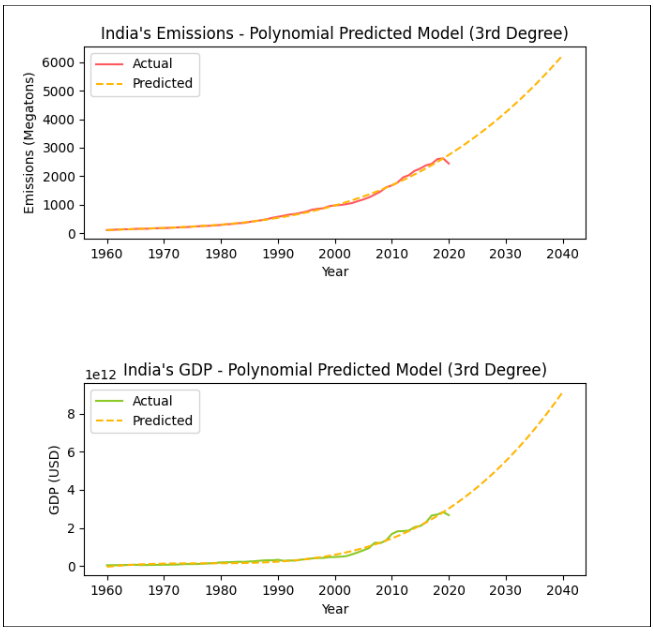

Fig. 9. Polynomial Predicted Models (3rd Degree) – India's GDP and Emissions (1960-2040). Data sourced from The World Bank and the Global Carbon Project [1] [2].

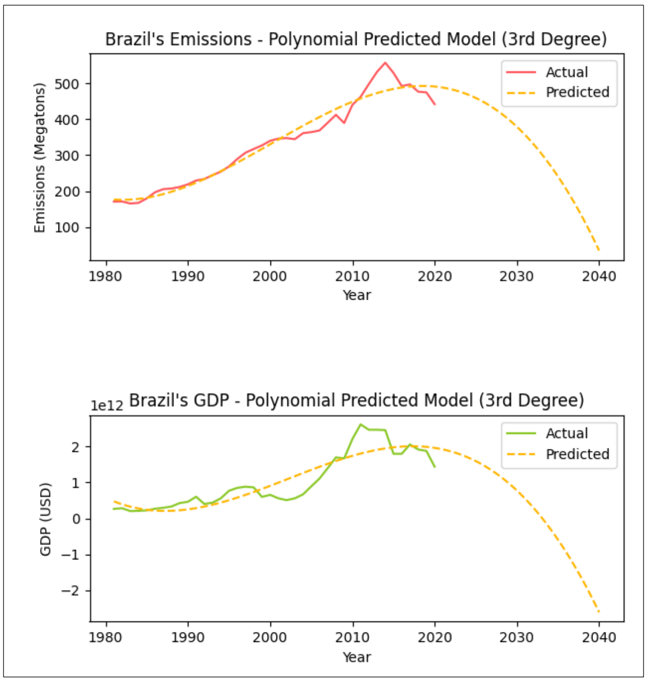

Fig. 10. Polynomial Predicted Models (3rd Degree) – Brazil's GDP and Emissions (1980-2040). Data sourced from The World Bank and the Global Carbon Project [1] [2].

VI. Discuss Contributions and Solution

It has been shown that developing countries with rapidly increasing GDP are likely to also have rapidly increasing emissions (see Figure 5). Countries that are developing rapidly need to convert to renewable and sustainable forms of energy quickly. A proposed solution would be to have developed countries help fund renewable programs in developing countries via loans. Potential renewable programs could include building solar, wind, and turbine infrastructure. Another proposed solution would be to sign international accords, where multiple countries pledge to keep emissions under a certain level. International leadership keeping each other accountable would incentivize countries to prioritize renewable energy projects. A perfect example of this solution would include the Paris Agreement.

VII. Future Research Opportunities

The findings analyzed show that additional research about the relationship between CO2 emissions and GDP is necessary. One major area of research which should be examined further is the specific economic effects of renewable energy investment in developing countries. Using the following solution and the previous predicted future trends, future emissions could be limited when countries begin to modernize. Also, as countries begin to modernize further and develop electrical vehicles, artificial intelligence, or further technology, it is unknown how this boost will affect the assumed GDP growth and emissions.

VIII. Conclusion

This paper has examined the relationship between yearly GDP and yearly CO2 emissions. The research results demonstrate that there is a correlation between GDP and emissions. This is especially true for rapidly developing countries like India. This research has provided a statistical model for projecting GDP and emissions. The statistical model which follows the data most accurately is the polynomial model to the 3rd degree. The paper proposed two solutions to alleviate emissions in rapidly developing countries. They include encouraging developed countries to fund developing countries renewable energy programs via loans and signing international accords to reduce emission levels.

Acknowledgment

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