Contributing Factors of Carbon Dioxide Emissions by Sector

Jonathan Perlin
Prof. Anthony Capote
Quantitative Research Methods

Contributing Factors of Carbon Dioxide Emissions by Sector

ABSTRACT

It is no secret that as our global population on the planet increases, the effect technology and industry has on the planet increases with it. Recently, we have entered a new geologic Epoch of time directly corresponding to this development. The National Geographic Society defines the Anthropocene as follows:

> "The Anthropocene Epoch is an unofficial unit of geologic time, used to describe the most recent period in Earth's history when human activity started to have a significant impact on the planet's climate and ecosystems." ("Anthropocene")

The newly introduced effect that humanity has on the planet is believed to have originated with the introduction of the Industrial Revolution in the mid nineteenth century. The invention of the steam engine around this time period introduced humanity's first pollution and emissions into the atmosphere and only continued to do so at an increased rate as time went on. By the mid twentieth century, it was observed that not only was the planet's surface temperature increasing, but also that the polar ice caps were shrinking at an alarming rate. This study aims to determine which sector of infrastructure contributes the most to the receding ice area of Arctic sea ice. By utilizing data sets of carbon dioxide emissions sourced from the Environmental Protection Agency, NASA, NOAA, and other scientific organizations, a data-set will be combined that includes emissions from different sectors of infrastructure on a global scale as well as Arctic Sea Ice extent over a period of roughly thirty years. The results are expected to demonstrate a strong relationship with the decrease in ice extent over time.

Contributing Factors of Carbon Dioxide Emissions by Sector

INTRODUCTION

The sociological consequences of increased emissions of carbon dioxide into our atmosphere are dire and could threaten not only the health of our planet, but also our wellbeing and ultimately our survival on this "little blue marble." As we continue to have an increased and direct effect on the planet and by proxy, the environment in which we survive, we need to continue asking ourselves how we can not only mitigate the consequences of climate change, but also determine the main cause of the condition and reverse the adverse effects and damage already done. This venture will not only require a collective effort of multiple organizations and networks on a global scale, but also cost an unimaginable amount.

For decades, the starling increase of greenhouse gasses pumped into our atmosphere has yielded an almost incomprehensible volume of emissions. Within the scale of time our planet has been around, humanity – as the dominant species on Earth – has been around for a startlingly small amount of time. On the Kardashev scale, we score a pitiful scale of 0.7. On the Kardashev scale of civilization, a Type 1 civilization is able to harness all of the energy provided by the planet upon which the dominant species lives. In our case, the level of energy consumption we utilize is primitive at best on a large scale. Over-reliance on fossil fuels, nuclear energy, and renewable energy not only threaten our lifespan on the planet, but also threaten the health of Earth itself. Each civilization that is plotted on the scale is combating a "great filter." These filters are defined as obstacles that the civilization must overcome in order to continue on to the next level on the Kardashev scale.

Contributing Factors of Carbon Dioxide Emissions by Sector

In the case of humanity, our level of energy consumption renders us below a Type 1 civilization. If we do not overcome this filter, we will find ourselves extinct before we can even consider moving up on the scale. In order to continue our habitation on this planet, we will need to look to increase in technological development and then face the most difficult challenge of working together to resolve the harm we inflict on our planetary home.

Before we can start implementing a plan to surpass our first Great Filter, we first need to gather data and ascertain what aspect of our habitation contributes the most to rendering our global environment inhospitable. We have seen a dramatic increase in technology and innovation within the last few decades. This rate of technological development will aid in attaining our goal of survival. The digital age (following the Age of Information) is our best hope of survival.

With the increase in satellite imagery and other digital methods within the field of Global Information Systems (GIS), we have been able to record and track the effects of our impact on the planet better than ever before. Satellite imagery and data has been invaluable regarding viewing and recording changes to our environment on a global scale. From deforestation, tracking ice extent, and measuring levels of emission in our atmosphere, our technology is the best hope we have for determining and remedying the adverse effect greenhouse gas emissions are having on our planet.

Once the major contributing sector has been pinpointed, we then need to formulate a plan of attack on how to not only counter these adverse effects on our environment, but also plan on how to decisively and accurately utilize all of the energy offered by our planet.

Contributing Factors of Carbon Dioxide Emissions by Sector

LITERATURE REVIEW

The Anthropocene

For millions of years, the Earth has gone through many natural fluctuations of temperature and other elements that affect its environment. That is, until its dominant species that has only been around for a fraction of its time began to disrupt the natural stability of the planet. In a journal titled *The Anthropocene*, researcher William Ruddiman investigates the extent and origin of this impact. Ruddiman begins by positing an origin of this impact:

> "Evidence from Earth's atmosphere…appears to support the notion that the industrial era was the start of the Anthropocene. Atmospheric concentrations of two major greenhouse gases—CO2 and CH4—began to rise exponentially by 1850 (Figure 1). These increases are tied to land-use changes caused by rapid population growth and to the burning of fossil fuels. More than 85% of the global population increase to the current level of 7 billion has occurred since 1850. Together, this wide range of evidence leaves no doubt that the industrial era marks a major inflection point in human influences on the environment." (Ruddiman, 2013)

This data supports this project's research goal of determining the largest contributing factor of carbon emissions by sector. Further research should demonstrate that greenhouse gasses are the largest root cause of the planet's unnatural heating resulting in an unprecedented melting of the polar ice caps. This paper, however, will focus on the Arctic sea ice extent and its faster-than-normal decrease. Ruddiman concludes his journal by stating the following:

Contributing Factors of Carbon Dioxide Emissions by Sector

> "The evidence of unexpectedly large preindustrial anthropogenic effects is clear, but much remains to be done to synthesize and analyze archeological data and, perhaps, to uncover new historical sources." (Ruddiman, 2013)

We are just scratching the surface determining the extent to which we are impacting the environment around us. It is imperative that we dedicate as many resources as possible to mitigate and ultimately cease the harm we inflict to our home.

Carbon Emissions

In 2013 James Hansen contributed to a journal on climate change and rising carbon emissions as well as their impact on our polar ice caps. The journal article also draws on data that humans are the main contributing factor leading to the dramatic increase of carbon based greenhouse gasses in out atmosphere. In the introduction he posits:

> "Humans are now the main cause of changes of Earth's atmospheric composition and thus the drive for future climate change... The principal climate forcing, defined as an imposed change of planetary energy balance…, is increasing carbon dioxide (CO2) from fossil fuel emissions, much of which will remain in the atmosphere for millennia... The climate response to this forcing and society's response to climate change are complicated by the system's inertia, mainly due to the ocean and the ice sheets on Greenland and Antarctica together with the long residence time of fossil fuel carbon in the climate system. The inertia causes climate to appear to respond slowly to this human-made forcing, but further long-lasting responses can be locked in." (Hansen et al, 2013)

Contributing Factors of Carbon Dioxide Emissions by Sector

If this problem is not addressed soon enough, irreversible damage will be done to our environment and quite possibly lead to the Earth being an unsustainable planet to safely harbor human life. Specifically regarding the alarming rate at which the polar ice caps are melting, Hansen states the following:

> "Antarctic and Greenland ice sheets present the danger of change with consequences that are irreversible on time scales important to society. These ice sheets required millennia to grow to their present sizes. If ice sheet disintegration reaches a point such that the dynamics and momentum of the process take over, at that point reducing greenhouse gases may be unable to prevent major ice sheet mass loss, sea level rise of many meters, and worldwide loss of coastal cities – a consequence that is irreversible for practical purposes…Paleoclimate data for sea level change indicate that sea level changed at rates of the order of a meter per century, even at times when the forcings driving climate change were far weaker than the human-made forcing. Thus, because ocean warming is persistent for centuries, there is a danger that large irreversible change could be initiated by excessive ocean warming." (Hansen et al, 2013)

This journal article enforces the hypothesis of the project and drives the investigation into the importance of mitigating the adverse effects we are having on our planet. In the journal, Hansen discusses some of the dangers associated with climate change.

Contributing Factors of Carbon Dioxide Emissions by Sector

The Digital Age and Climate Change

The emergence of the digital age has provided humanity with an opportunity to not only gather more data through methods that were not previously available but also plan and implement solutions with which to solve potentially disastrous problems. Technology is our biggest hope to identify and solve environmental problems. From electric cars to new methods of energy production, there are countless ways to harness the energy offered by our planet. In a journal from 2015, author Nic Lutsey reached the following conclusion:

> "The carbon mitigation would result from more electric vehicles entering the fleet while lower-carbon energy sources become widely available. Electric vehicle technology allows the global fleet to achieve approximately 40% lower carbon emissions than a highly efficient conventional combustion fleet (and 70% lower carbon than a business-as-usual fleet) in 2050. Matching the earlier projected electric vehicle deployment, electric vehicle climate benefits will initially be highest in European nations and in select United States regions. Over the long-term, potential electric vehicle climate benefits are greatest in China and other emerging automobile markets." (Lutsey, 2015)

Since the mid-nineteenth century, primitive methods of energy consumption that are harmful to our environment were employed and remain in use to this day. Although green energy is now being more widely utilized and we are seeing the impacts of climate change decrease, there is still much more work to be done in order to sustainably consume energy on our planet.

Contributing Factors of Carbon Dioxide Emissions by Sector

The Kardashev Scale

As a further note of discussion, I will briefly discuss the Kardashev scale within the context of climate change. In 1964, Soviet astronomer Nikola Kardashev created the *Kardashev Scale* to measure and classify the overall consumption of a civilization (Jiang, 2022). The Kardashev Scale distinctly categorizes three types of civilizations: Planetary, Stellar, and Galactic. For the purposes of this paper, I will refer to only Type 1 civilizations. According to Kardashev, a planetary civilization "has harnessed for its use all major forms of energy available from its home planet (for example human civilization and the Earth). Of course, this also includes the energy received by the home world from its parent star. Planetary energy sources humanity can tap include fossil and bio-derived fuels, nuclear energy, wind, solar, geothermal, and tidal, among others." (Jiang, 2022). Humans are currently at 0.7 on the scale as we have not yet succeeded in harnessing all of the energy our planet has to offer. Within the context of climate change, this means the following:

> The evolution of the universe and the Earth has provided many material prerequisites including energy and global environmental conditions for the emergence of human beings. The development of human beings has transformed the evolution of the Earth. In this process, the development and utilization of energy drives the stepwise upward evolution of human civilization, but the progress of civilization in turn accelerates the evolution of energy utilization types and the development of utilization technologies and brings about the global fossil energy crisis and climate change, thus affecting the upgrade of human civilization (Zou et al, 2022)

Contributing Factors of Carbon Dioxide Emissions by Sector

As humanity still struggles to become a Type 1 civilization, we will have to eliminate our primitive methods of energy consumption. This journal exemplifies the importance and urgency of our current climate crisis. The research conducted in this study will hopefully shed some light on how we can best mitigate the harm we are doing to our environment within the context of identifying which sector is responsible for the most carbon emissions.

Contributing Factors of Carbon Dioxide Emissions by Sector

METHODS

This study will focus on several sectors of industry including emissions originating from buildings, industry, land use and forestry, other sources of fuel combustion, transportation, manufacturing and construction, fugitive emissions, and electricity and heat. In order to determine which sector is responsible for the most Carbon Dioxide emissions, combinations of each sector will be applied as an independent variable to the area of sea ice in order to attempt to see a significant impact on the ice. Here, I will be looking for a strong negative relationship between sea ice area (measured in millions of square kilometers) and each sector's volume of emissions (measured in billions of square tons) over a period of roughly thirty years (1990 - 2018). Once the models have been run, I will look for the pattern of significance for each sector. Here I will be looking for several pieces of information to further my investigation of the mediating relationship between carbon emissions and the reduction of sea ice: 1) Which is the biggest moderating variable in the dataset, 2) Which sector is contributing the largest volume of carbon dioxide emissions, 3) Which sector is emitting the most carbon, 4) what is the solution? That is, which sector from a perspective of policy would we want to target the most in order to reduce the largest amount of carbon emissions?

Contributing Factors of Carbon Dioxide Emissions by Sector

RESULTS

With data sourced from the multiple Scientific organizations as well as the website *ourworldindata.org*, a complete dataset will be generated including the year, ice extent by area, and the annual global emissions of Co2 by sector. The dependent variable will mostly be the ice extent by area as the emissions of each sector (the independent variables) is compared to Ice. Here, I will be searching for the significance of each sectors' emissions over time. First, I described all of the independent variables and analyzed the descriptive statistics of all of the sectors compared to the ice extent. The results of the model indicated that a few of the sectors are more strongly negatively correlated with sea ice extent than others. The sectors less correlated with impact on sea ice extent were excluded in order to continue to pinpoint the sector with the most impact on sea ice extent. The goal here is to separate necessary and unnecessary factors that will lead to a factor analysis that will ultimately lead to a conceptual analysis on why this investigation is important.

Model1 -

model1 = lm(Ice ~ Year + Industry + Transport + Manufacturing.construction + Electricity.heat, data = Complete_Data)

The first model is a question of which more significant sectors have more of an effect on the extent of arctic sea ice. Here, it was observed that none of the factors were significant when compared to the arctic ice extent. In order to try and achieve some significance for the factors, *model2* will combine some factors together.

Model2 -

model2 = lm(Ice ~ Year + necessary + work_commute + Other.fuel.combustion, Complete_Data)

Contributing Factors of Carbon Dioxide Emissions by Sector

The second model groups together a few variables in order to try and achieve some significance between the sectors and change in the arctic ice extent. For example, the variable *work_commute* combines *buildings* and *transportation.* And *necessary* combines factors that we could not survive without including *Industry, Manufacturing and Construction,* and *Electricity and Heat. Forestry and land use* is subtracted here as it is the only factor we see that results in a slightly higher significance and does not contribute to our investigation of which sector contributes the most to decrease in arctic sea ice extent.

<u>*Model3*</u> -

model3 = lm(Ice ~ Year, Complete_Data)

In the third model, we control for *Year* compared to all the factors in the data set in order to try to find some significance of the sectors to arctic ice extent. After running the model, still no significance is recorded and a new model must be created in order to continue to attempt to find some significance.

<u>*Model4*</u> -

model4 = lm(Ice ~ Year + Buildings + Industry + Land.use.Forestry +

Other.fuel.combustion + Transport +

Manufacturing.construction + Fugitive + Electricity.heat, Complete_Data)

In *model4,* we control for *Year* and the individual factors to try and find some significance from the factors contributing the most to Co2 emissions. When run, this model still does not show significance between the factors from the complete dataset.

Contributing Factors of Carbon Dioxide Emissions by Sector

Model5 -

Before running *model5*, I will take the logarithmic values of each variable.

Logged_data <- data.frame(log(Complete_Data$Ice), log(Complete_Data$Buildings),
log(Complete_Data$Industry), log(Complete_Data$Land.use.Forestry),
log(Complete_Data$Transport), log(Complete_Data$Other.fuel.combustion),
log(Complete_Data$Manufacturing.construction),
log(Complete_Data$Fugitive), log(Complete_Data$Electricity.heat))

After the data has been logged, I will create a new dataset that removes the logged variable of year.

Logged_data$Year <- Complete_Data$Year

After creating this new dataframe, I will rename all of the columns to fit their respective variables.

names(Logged_data) <- c("Ice", "Buildings","Industry", "Forrestry", "Transport",
"Other", "Construction", "Fugitive", "Electricity", "Year")

Once the names have been changed, I will create and run the renamed logged dataset with *Ice* as the dependent variable against the total of each of the logged variables.

model5 <- lm(Ice ~ Buildings + Industry + Forrestry + Other + Transport + Construction
+ Fugitive + Electricity + Year, Logged_data)

Model5 still does not show any significance between the variables.

Model6 -

Complete_Data$Total <- with(Complete_Data,
Year + Buildings + Industry + Land.use.Forestry + Other.fuel.combustion +
Transport + Manufacturing.construction + Fugitive + Electricity.heat)

Contributing Factors of Carbon Dioxide Emissions by Sector

model6 <- lm(Ice~Total, Complete_Data)

The sixth model uses *Ice* as the dependent variable and compares just the total values of the columns of variables together from the dataset *Complete_Data.* Here I finally see significance between the intercept and the dataset of total values!

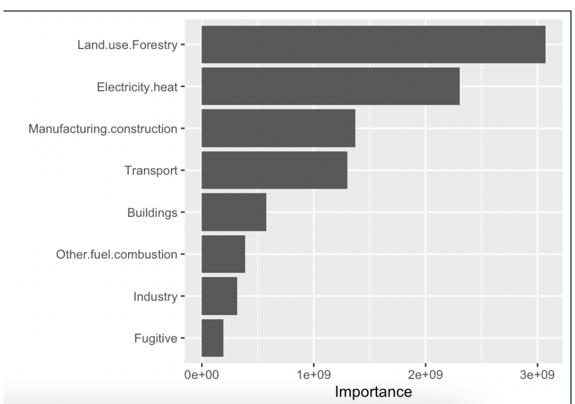
Model7 -

model7 <- lm(Total ~ Buildings + Industry + Land.use.Forestry + Other.fuel.combustion + Transport + Manufacturing.construction + Fugitive + Electricity.heat, Complete_Data)

The seventh and final model uses the data frame *total* as the dependent variable and compares each of the sectors against itself. While excluding *Year*, we finally see significance between all of the variables.

Variable Importance Plot (VIP)

vip(model7)



By utilizing a Variable Importance plot, we can see that Land use and Forestry is the most significant contributor to carbon dioxide emissions. In the following discussion, I will discuss why this makes sense and next steps to continue the project determining greenhouse gasses and their effect on sea ice extent.

Contributing Factors of Carbon Dioxide Emissions by Sector

CONCLUSION

After running the models for the analysis, it makes sense that the final results pointed to forestry and land use as the most significant factor contributing to carbon emissions. Not only does the great effort of clearing land utilize a substantial amount of resources and fuel combustion from construction efforts, but also directly removes a natural filter for carbon dioxide. Trees and other plants are our main natural filter of carbon dioxide through photosynthesis. As we remove large areas of brush and forests for land use and other applications, we are actively increasing the amount of carbon dioxide released into the atmosphere and contributing to the alarming heating effect we are seeing on our planet. In order to mitigate this adverse and potentially disastrous effect we are having on our environment, we will need to plan and implement a solution to reverse these negative anthropogenic impacts.

DISCUSSION

As humanity continues to develop and grow, solutions for how to realistically and safely continue our civilization on the planet must be carefully planned and thought out. In order to achieve the status of Type 1 civilization as referenced by the Kardashev Scale, measures must be taken – both technological and governmental – to confidently assure our survival.

The results of this investigation points to further research. Next steps would include other contributors of greenhouse gasses such as methane and nitrous oxide in order to determine the sector contributing the most to climate change. In addition, further research would include not only the arctic ice extent, but also antarctic ice in order to determine the most impactful greenhouse gas contributing to anthropogenic climate change. Also, time series models would be very helpful in terms of projecting emissions based on current trends. Until we figure out how to successfully mitigate and slow the negative effects we are having on our environment, we are in danger as a species of rendering our planet uninhabitable.

Contributing Factors of Carbon Dioxide Emissions by Sector

References

Global Climate Change Mitigation Potential from a Transition to ... https://www.researchgate.net/profile/Nicholas-Lutsey/publication/286623711_Global_climate_change_mitigation_potential_from_a_transition_to_electric_vehicles/links/566c547708aea0892c4fbc0d/Global-climate-change-mitigation-potential-from-a-transition-to-electric-vehicles.pdf.

Hansen, James, et al. "Assessing 'Dangerous Climate Change': Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature." *PLoS ONE*, vol. 8, no. 12, 2013, https://doi.org/10.1371/journal.pone.0081648.

Jiang, Jonathan H., et al. "Avoiding the Great Filter: Predicting the Timeline for Humanity to Reach Kardashev Type I Civilization." *Galaxies*, vol. 10, no. 3, 2022, p. 68., https://doi.org/10.3390/galaxies10030068.

National Geographic Society. "Anthropocene." *National Geographic Society*, 5 June 2019, https://www.nationalgeographic.org/encyclopedia/anthropocene/.

Ruddiman, William F. "The Anthropocene." *Annual Review of Earth and Planetary Sciences*, vol. 41, no. 1, 2013, pp. 45–68., https://doi.org/10.1146/annurev-earth-050212-123944.

Solomon, Susan, et al. "Irreversible Climate Change Due to Carbon Dioxide Emissions." *Proceedings of the National Academy of Sciences*, vol. 106, no. 6, 2009, pp. 1704–1709., https://doi.org/10.1073/pnas.0812721106.

ZOU, Caineng, et al. "Earth Energy Evolution, Human Development and Carbon Neutral Strategy." *Petroleum Exploration and Development*, vol. 49, no. 2, 2022, pp. 468–488., https://doi.org/10.1016/s1876-3804(22)60040-5.